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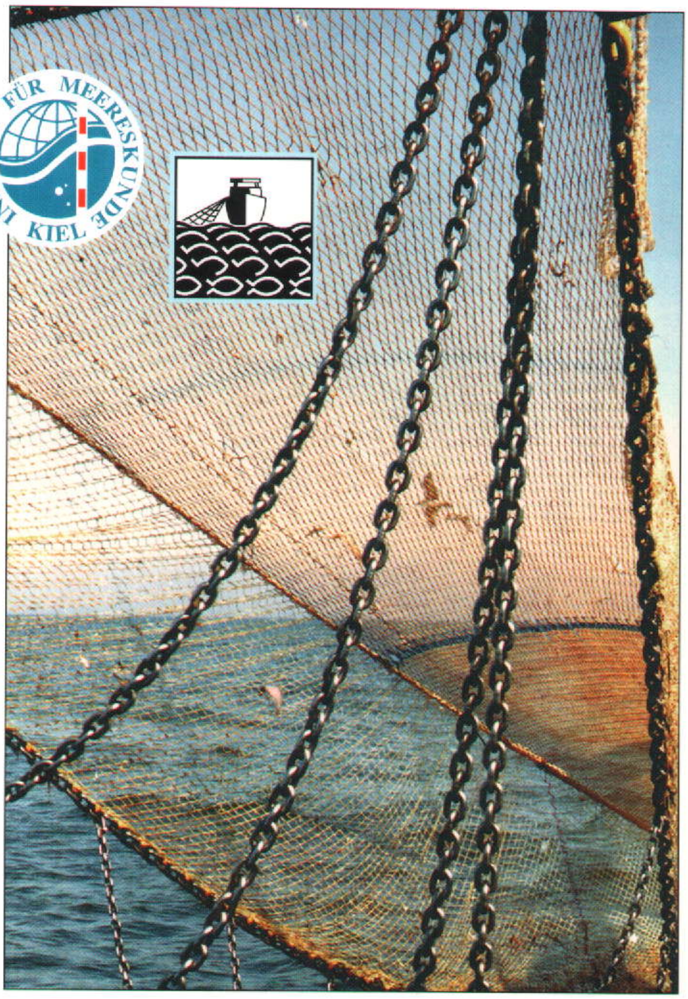
IMPACT-II

THE EFFECTS OF DIFFERENT TYPES OF FISHERIES ON THE NORTH SEA AND IRISH SEA BENTHIC ECOSYSTEMS

Editors: H.J. Lindeboom, S.J. de Groot



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Netherlands Institute for Sea Research (NIOZ)
P.O. Box 59, 1790 AB Den Burg, Texel
The Netherlands

Netherlands Institute for Fisheries Research (RIVO-DLO)
P.O. Box 68, 1970 AB IJmuiden
The Netherlands

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Contractors: **RIVO-DLO, NIOZ, IfM, AWI, RSZV, RWS-DNZ, NIOO-CEMO, FRS-MLA, CEFAS, BFA-ISH, MRI**
Associates: **UWB, FRC**

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NETHERLANDS INSTITUTE FOR SEA RESEARCH

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Editors: H.J. Lindeboom (NIOZ)
S.J. de Groot (RIVO-DLO)

Authors[1]):

B. Ball (MRI-UCG)
C. Bijleveld (RWS-DNZ)
J. Buys (NIOO-CEMO)
U. Damm (BFA-ISH)
M. Fonds (NIOZ)
S. Groenewold (NIOZ)
M.J. Kaiser (CEFAS)
T. Kujawski (IfM)
C.J.M. Philippart (NIOZ)
K. Ramsay (CEFAS/UWB)
J.W. van Santbrink (NIOZ)
I. Tuck (FRS-MLA)
M.J.N. Bergman (NIOZ)
W. Blom (RIVO-DLO)
J.A. Craeymeersch (NIOO-CEMO)
S. Ehrich (BFA-ISH)
R. Fonteyne (RSZV)
I. Hoppe (AWI)
R. Knust (AWI)
B.W. Munday (MRI-UCG)
H. Polet (RSZV)
H. Rumohr (IfM)
A. Schroeder (AWI)
W. Zevenboom (RWS-DNZ)

Authors responsible for:

Size of bottom trawling fleets:
H. Polet & W. Blom

Fishing gears used by different fishing fleets:
H. Polet, B. Ball, W. Blom, S. Ehrich, K. Ramsay & I. Tuck

Physical impact:
R. Fonteyne, B. Ball, T. Kujawski, B.W. Munday, H. Rumohr & I. Tuck

Catch efficiency of commercial trawls:
J.A. Craeymeersch, B. Ball, M.J.N. Bergman, U. Damm, M. Fonds, B.W. Munday & J.W. van Santbrink

Direct mortality due to trawling:
M.J.N. Bergman, B. Ball, C. Bijleveld, J.A. Craeymeersch, B.W. Munday, H. Rumohr & J.W. van Santbrink

Scavenger responses to trawling:
M. Fonds, S. Groenewold, I. Hoppe, M.J. Kaiser, B.W. Munday & K. Ramsay

Comparison of undisturbed and disturbed areas:
I. Tuck, B. Ball & A. Schroeder

Long term trends in demersal fish and benthic invertebrates:
H. Rumohr, S. Ehrich, R. Knust, T. Kujawski, C.J.M. Philippart & A. Schroeder

Fishing mortality in invertebrate populations due to different types of trawl fisheries in the Dutch sector of the North Sea in 1994:
M.J.N. Bergman, J.A. Craeymeersch, H. Polet & J.W. van Santbrink

All authors contributed to the other chapters.

[1] Complete addresses of the participating institutes can be found on page 368.

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PREFACE

This IMPACT II report is the result of an international research project supported by the Commission of the European Communities. Thirteen institutes of five EU-member states worked together. Sometime waves were running high but always a calm followed.

The good cooperation resulted in a really integrated report with all the results combined. Due to the size of the project, it has become a rather large report. However, by using a rather consistent numbering in chapters 2 and 3 we hope that all those interested can find their way.

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 contributions.

Den Burg - IJmuiden
H.J. Lindeboom - S.J. de Groot
Project coordinators IMPACT II

1. INTRODUCTION

1.1. GENERAL

The origin of trawling is vested in obscurity, but trawls were certainly known in northwestern Europe in the thirteenth century. As early as the fourteenth century, fishermen in the United Kingdom were concerned that fishing gear altered seafloor habitats (Anon. 1921). At the end of the sixteenth century Dutch fishermen asked Prince William of Orange to place restrictions on the use of trawls, as they were concerned about the state of the seabed after the passage of trawls, claiming that the grounds would become rough and would probably lower future catches (de Groot 1984).

The fisheries in the North Sea increased considerably with the industrialization of the fleet at the beginning of this century. By 1930, sailing vessels and steam trawlers in the south-eastern North Sea had been largely replaced by motor trawlers. The first Dutch otter trawlers began fishing in 1910 and their numbers increased to a maximum of over 500 vessels in 1940. Otter trawls were designed to catch flatfish (plaice and sole) and roundfish (e.g. cod) and were the standard gears before the beam trawls came in common use in the North Sea sole fisheries in the mid-sixties. Otter trawlers are equipped with one single trawl. Horizontal spread of the otter trawl is attained by the 'otter boards' or 'doors' which are attached to the wings of the net. Fish are guided along the bridles from the doors into the net.

The development of beam trawling for flatfish started just after the second world war, but beam trawler effort remained insignificant until the beginning of the 1960s. Beam trawls are efficient gears designed to catch flatfish (plaice, sole) and are rigged with a set of tickler chains in front of the ground rope in order to start the flatfish from the seabed. Beam trawlers are equipped with two beam trawls. In offshore areas in the North Sea, mainly 12 m wide beam trawls are applied. Vessels with engine power > 221 kW are not allowed in the 12 mile zone and - since 1989 in certain seasons and since 1995 totally - in the "Plaice box" along the Dutch, German and Danish coast. In these coastal areas trawling is carried out mainly with 4 m wide beam trawls, towed by cutters with engine powers < 221 kW. On stony grounds beam trawls equipped with chain matrices are employed to avoid large stones entering the net. The maximum number of beam trawlers in the North Sea fleet occurred around 1970, but the maximum effort occurred in 1988 as a result of an increase of effort per vessel (Rijnsdorp & van Leeuwen 1994).

International concern about the increasing trawling effort was voiced for the first time at the 58th Council Meeting in Copenhagen in 1970, at the International Council for the Exploration of the Sea (ICES). ICES requested information about the effects of trawls and dredges on the seabed and benthic fauna. After a few years of investigation several members states reported on these effects (Anon. 1973). For various reasons ICES deemed it better to leave the conclusions as stated, and for more than ten years hardly any attention was paid to the effects of bottom trawling on the seabed. In 1988 a study group of ICES was initiated to reexamine the ecological effects of bottom trawling (Anon. 1988). Their main conclusion was that the heavier gears now in use might have a greater effect on benthic communities, and new observations on the effects of these gears on the seabed were required.

Several countries began research into the effects of physical disturbance on benthic communities. Rees & Eleftheriou (1989) reviewed field investigations of the biological effects of human activities in the North Sea. Redant (1987) compiled a bibliography on the effects of bottom fishing gear and harvesting techniques on benthic biota.

In the Netherlands, studies on trawling effects were taken up by to the Netherlands Institute for Fisheries Research (RIVO-DLO), the Netherlands Institute for Sea Research (NIOZ) and the North Sea Directorate of the Ministry of Transport and Public Works (RWS-DNZ), within the newly founded interministerial cooperation framework "Policy Linked Ecological Research North Sea and Wadden Sea (BEON). As a result, three years (1989-1991) of combined research was carried out to study the effects of the beamtrawl on the seabed. Studies were carried out to establish the penetration depth of the fishing gear into the sediment, and the direct mortality of the benthic fauna (Anon. 1990, 1991a, 1992b; Bergman & Hup 1992). Gradually, other Dutch institutes joined the research project, i.e. the Geological Survey of the Netherlands - marine Geology Division (RGD) and the Netherlands Institute of Ecology (NIOO-CEMO).

In England and Wales, a study of the effects of 4m beam trawls on benthic communities was begun in 1991 by the Ministry of Agriculture, Fisheries and Food, CEFAS Conwy Laboratory. The same organisation funded a project of examine the effects of scallop dredging on benthic communities around the Isle of Man in 1994.

1.2. IMPACT-I

In 1991 a contract from the European Commission was granted to study the effects of trawling in more detail. The project title was "Environmental impact of bottom gears on benthic fauna in relation to natural resources management and protection of the North Sea (IMPACT-I) (EC-FAR Contract MA.2.549). This project was undertaken from January 1992 till 31 December 1993, by the following research institutes: Netherlands Institute for Fisheries Research (RIVO-DLO), Netherlands Institute for Sea Research (NIOZ), Netherlands Institute of Ecology (NIOO-CEMO), in the Netherlands, Rijksstation voor Zeevisserij (RSZV) in Belgium, Institut für Meereskunde (IfM) and Alfred Wegener Institut für Polar- und Meeresforschung (AWI) in Germany. In an assisting role the North Sea Directorate (RWS-DNZ) in the Netherlands and the MAFF-CEFAS[1] Conwy Laboratory (UK) also joined the project.

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

Within these areas, the effects of 4m and 12m beam trawls on benthic communities were studied. Before and after experimental fishing, both in- and epifauna were sampled using a variety of equipment including: box corers, Van Veen grabs, Day grabs, 3m beam trawls, 1 m dredges attached to a 7m beam trawl, a specially developed benthos dredge (Triple-D) and video techniques. 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. Direct mortality of invertebrates in the trawl path was determined. 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 and sediment profiling photography (REMOTS). 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 4m beam trawl. An inventory of the Belgian, Dutch and German bottom trawling fleet and the different gears used was collated.

The main conclusions obtained were (de Groot & Lindeboom 1994):

1. Flatfish beam trawl fisheries form the most important part of the Belgium and the Netherlands fisheries producing about 81 and 66%, respectively, of the national catches.
2. Studies on the physical impact of the 4m 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 remain visible for up to 52 hours after fishing.
3. Discard composition of the catch of offshore 12m beam trawlers differs from that of the inshore 4m trawlers. Every kg of marketable fish may yield 1 to 2 kg of discarded fish and 1 to 4 kg of dead invertebrates.
4. Fishing with commercial beam trawls causes a range in mortalities of benthic species caught in the nets due to capture and handling of the catch: high mortalities (70-100%) for undersized fish, up to 50% mortality for most crabs and molluscs and very low mortality (<10%) for starfish. Many species, not caught by the nets, show a high mortality caused by the passage of the tickler chains over the seabed: up to 85% of the numbers initially present in several mollusc and crustacean species, up to 60% in some annelids and up to 45% in some echinoderm species.

[1] Formerly known as the Directorate of Fisheries Research.

5. 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.
6. Benthic animals damaged, dislodged or discarded by beam trawls may contribute significantly to the diet of scavengers whose populations may thus become enhanced.

1.3. IMPACT-II

In 1994 a "renewal" contract was agreed with the European Commission, the project title "The effects of different types of fisheries on the North Sea and Irish Sea benthic ecosystem" (EU-AIR 2 94 1664). New partners joined those of the IMPACT-I project. For the Netherlands: North Sea Directorate (RWS-DNZ) became a full partner, as well as the MAFF-CEFAS Conwy Laboratory (UK). Other joining institutes were: FRS Marine Laboratory Aberdeen (Scotland), the University College of North Wales and School of Biological Sciences (both in the UK), the Institut für Seefischerei (BFA-Hamburg) in Germany and in Ireland the Martin Ryan Marine Science Institute Galway (MRI) and the Fisheries Research Centre Dublin (FRC). When awarding the contract the EU-DG XIV stressed that the report of the IMPACT-I study[2] would be integrated in the final report of IMPACT-II.

The working hypothesis of IMPACT-II is: Demersal fishing activities and increased trawling intensity has a direct effect and induces long term effects on the seabed and benthic communities. To test this hypothesis the objectives of the IMPACT-II study were to estimate in space and time the direct and indirect effects of different types of bottom fisheries on the ecosystems of the North Sea and the Irish Sea. This was achieved by undertaking field research and by collecting data from the literature. The information derived from these studies is essential for the future management of marine fisheries, if a balanced choice between nature conservation and fisheries economic issues is to be made. The project provides essential back-ground information to support the policy of 'sustainable development' for both fisheries and natural marine ecosystems.

The IMPACT-II study consisted of five complementary subprojects. However, in the course of the project it was decided, in close consultation with the EU, to report the results in eight subchapters, each encompassing a clearly different aspect of the research.

<u>Subproject 1A</u>. Collection and analyses of historical and present-day data.
Historical and present-day data on catch and discard composition was collected; published and unpublished data sets both on fisheries and on the species composition of demersal fish and benthic invertebrates were identified, collected and analysed. The aim was to reconstruct possible trends in catch and discard composition of different types of benthic fisheries and to estimate the effects of fisheries on non-target species. Methods and results are reported in 2.8 and 3.8 respectively.

<u>Subproject 1B</u>. Collection and analysis of data on bottom trawling gears.
Data on the composition of the different bottom trawling gears in use by the fisheries of Germany, The Netherlands, Belgium and Ireland was collected. The data was taken from available records, augmented by information collected by visiting bottom trawling vessels when in harbour. Detailed information on the gear type, net parameters, a rough indication of the area of preference of individual fishing vessels was also collected. This data provided essential background information for the IMPACT-II program and was required for the overall assessment of the effects of fisheries on the ecosystem. Methods and results are reported in 2.1, 2.2, 3.1 and 3.2.

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2 All IMPACT-I results were made available in the report series of NIOZ and RIVO-DLO (de Groot & Lindeboom 1994).

Subproject 2. Comparative field research to document the direct effects of different types of trawl fisheries.

The aim was to quantify and compare the direct effects of different types of trawl fisheries on the benthic communities of the southern and central North Sea by estimating the species composition of various benthic ecosystems and the total annual production of dead organic material (fish and benthos) derived from trawl fisheries. In 4 selected areas different gear types were compared simultaneously.

The following field data were collected:

- physical impact of trawling on the seabed: pressure executed by beam trawls on the seabed, penetration depth and changes in structure and texture of the upper sediments.
- catch-efficiency of different commercial trawl gears for demersal fish and benthos species on typical types of North Sea sediments.
- catch composition of different gears, divided into the following categories: marketable fish, discard (dead/live) fish, benthos (dead/live), and long-dead (old-discard) organisms (Fig. 1).
- direct mortality of trawl fishery on the abundance's of the smaller-sized benthos, normally not caught by the large-meshed commercial trawl.
- production of discarded (dead) fish and benthos by different types of trawl fisheries.

The methods and results of this subproject are reported in 2.3, 2.4, 2.5, 3.3, 3.4 and 3.5.

Subproject 3. An analysis of fishing effects in fished and unfished areas.

This project consists of three parts:

3A) Scottish Sea Loch:
To follow changes in benthic community structure during a 16 month controlled fishing experiment and for 18 months thereafter. This experiment took place in the Loch Gareloch, Inverclyde, W. Scotland where a ban on fishing has been in place for almost 30 years, owing to the presence of a military base.

3B) German Bight:
To measure the mid- and short-term changes in the benthos communities within the area of the wreck "West Gamma" and within an adjacent control area open to fishing.

3C) The Irish Sea:
To study the effects of the prawn trawl fishing for Nephrops (*Nephrops norvegicus*) on four experimental areas/boxes. These boxes included a wreck and fished site in a heavily fished area (test and control), and a wreck and fished site in a lightly fished area (test and control). New data were compared with existing ecosystem and historical fisheries data.

The methods and results of this subproject are reported in 2.7 and 3.7.

Subproject 4. The consequences of discard material on the benthic ecosystem.

The aim was to study the impact on the benthic ecosystem of dead fish and by-catch discarded by different types of demersal fisheries. In each of 4 selected areas the exploitation of discard materials and disturbed benthic animals by predators and scavengers were compared. The study focused on:

- The distribution of different kinds of dead discard materials (such as dead molluscs, crustaceans or fish) over different scavenger groups (fish, starfish, crabs etc.) The availability of benthos disturbed and discarded by trawl fishery to different groups of scavengers, e.g. competition for discarded food items between fast moving fish (dab and whiting) and slow moving starfish and crabs, etc.
- The importance of "discard food" from trawl fishery for different groups of scavenging predators, in comparison with their normal (maximum) daily food consumption and the normal pattern of food production (availability) and consumption in the ecosystem.
- The rate of decomposition of discard materials not consumed by scavengers.

The methods and results of this subproject are reported in 2.6 and 3.6 respectively.

In discussion chapter 4 an assessment of the relative impacts of the different trawling fleets is compiled. An overview of the results of both IMPACT projects is also given in this chapter, as well as remarks on the working hypotheses. Chapter 5 gives summary, conclusions and recommendations. An extensive glossary is provided in chapter 6.

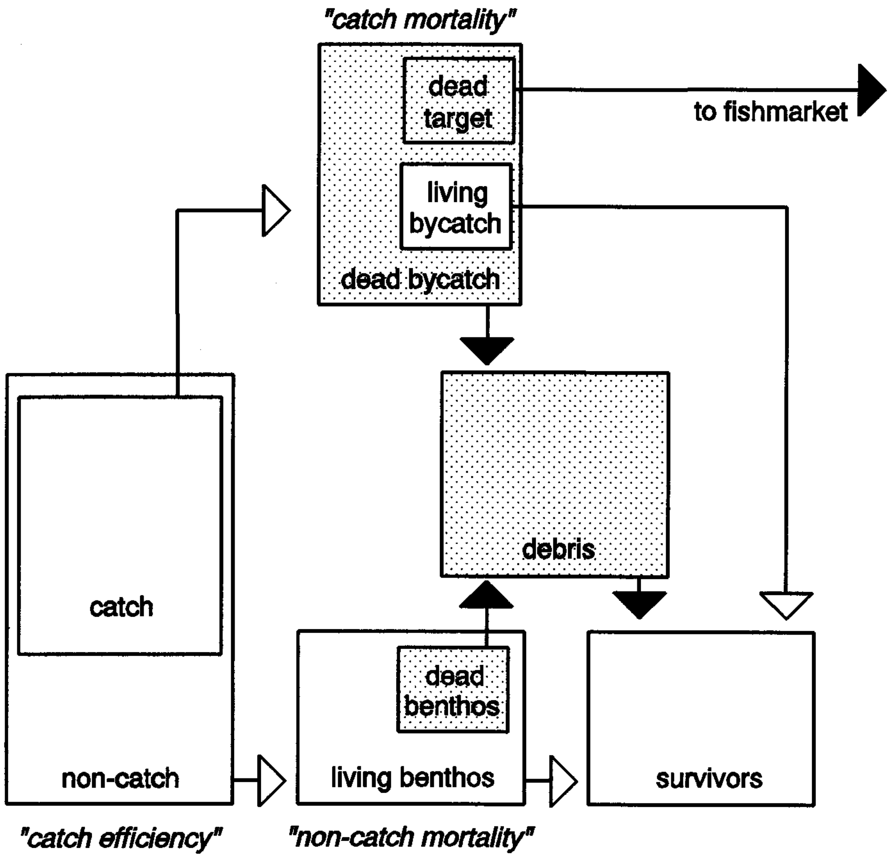


Fig. 1. Direct effect of beam trawling on demersal fish and benthic invertebrates as related to (1) the catch efficiency (i.e. the number of fish and invertebrates that is caught in the nets devided by the total number of animals in the trawl track before fishing), (2) the catch mortality (i.e. the number of dead fish and invertebrates in the catch devided by the total number of animals in the catch), and (3) the non-catch mortality (i.e. the number of dead fish and invertebrates in the trawl track divided by the total number of animals in the trawl track after fishing). The black arrows represent the fluxes of dead animals, whilst the white arrows indicate the fluxes of (initially) living animals.

1.4. AN OVERVIEW OF THE EFFECTS OF BOTTOM TRAWLING ON MARINE COMMUNITIES: STATE OF THE ART[3]

Physical impact of gears on the substratum

Systematic research on the physical effects of trawling on seabed substrata dates from 1970, when the International Council for the Exploration of the Sea requested information on the effects of trawls and dredges on the seabed (ICES 1971: Council Resolution 1970/S/1). Most of the experiments carried out in the early 1970's examined the effects of light beam trawl gears. Almost all beam trawls in the experiments were equipped with tickler chains and only in one case was the beam trawl equipped with a chain matrix (de Clerck & Hovart 1972).

Due to the pressure of the gear on the seabed, certain parts penetrate to a varying extent into the sea bottom. The penetration depth largely depends on the nature of the seabed (Margetts & Bridger 1971; Bridger 1972; de Groot 1972; Anon. 1973). Direct observations have been made using divers (Bridger 1970; Margetts & Bridger 1971), underwater television cameras (Margetts & Bridger 1971; Sydow 1990) and side-scan sonar (Caddy 1968, 1973; de Groot 1972; Sydow 1990).

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 relatively distinct track, which is estimated to persist for up to 16 hours in sandy sediments (Margetts & Bridger 1971; de Groot 1972; Bergman *et al.* 1990). The detectable disturbance is most distinct on muddy or soft sandy grounds. On hard sandy ground, the tracks are difficult to detect, and resemble a smoothed path. On very soft sandy 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 did not appear to be in firm contact with the bottom and will exert a limited pressure on the seabed. Successive layers of sediment are resuspensed but will settle again after the gear passed. This is unlikely to cause a problem in areas where natural sediment movement due to the effect of tidal action and gales occurs frequently (de Groot 1984; Anon. 1973; Anon. 1988; Kaiser & Spencer 1996a). Based on measurements made using markers buried in the seabed, Bridger (1972) concluded that only the surface of the sediment will be disturbed by a tickler chain. Even with an array of 15 tickler chains weighing 1478 kg operating on mud at a low speed of 2.2 knots the penetration depth did not exceed 30 mm.

Direct effects of mobile gears

It is clear that all mobile bottom gears scrape the surface of, or dig into, the seabed to varying degrees. Hence it is not surprising that non-target fish and benthic invertebrate species comprise a large proportion of the catch in some fisheries (Andrew & Pepperell 1992; Anon. 1995; de Groot & Lindeboom 1994; Messieh *et al.* 1991; Raloff 1996; Robin 1992). While gear modifications such as the addition of extra tickler chains increase the catch of target species, there is an unavoidable concomitant increase in the catch of non-target species (Creutzberg *et al.* 1987; Kaiser *et al.* 1994). Whereas nets have been refined to reduce the by-catch of non-target and undersized commercial species (Briggs 1992), few attempts have been made to reduce by-catch or the damage of fishing gears on invertebrate benthic species.

To date, most studies have investigated the effects of fishing on benthic communities in shallow seas on the continental shelf at depths < 100 m. This is not surprising as the majority of demersal fishing activity occurs in this depth range, and quantitative ecological studies become logistically complex at greater depths. Benthic communities in these environments experience continual disturbance at various scales (Hall 1994). Large-scale natural disturbances, such as seasonal storms, strong tidal currents and severe winters (Posey *et al.* 1996; Rees *et al.* 1977; Warwick &

[3] The majority of this text has been modified from - Jennings & Kaiser (accepted). The effects of fishing on marine ecosystems. Advances in Marine Biology.

Uncles 1980), form a background against which other smaller disturbances occur, such as those induced by predator feeding activities (Hall *et al.* 1993b; Oliver & Slattery 1985; von Blaricom 1982). Hall *et al.* (1993b) argued that, while very localised, frequent small-scale predator disturbances could have a considerable additive effect on benthic communities, creating a long-term mosaic of patches in various states of climax or recolonization (Connell 1978; Grassle & Saunders 1973). However, their experimental study concluded that while it was possible to detect short-term effects of predator disturbance, large-scale effects could not be inferred. This implies that small-scale disturbance events, even when frequent, are either masked by the background of large-scale disturbances, or that the scale of disturbance is small enough to allow rapid recolonisation such that large-scale effects never become apparent. However, presumably there exists a threshold scale and frequency of disturbance events at which lasting ecological effects may occur, even against a background of natural disturbance. The additive effects of an entire fishing fleet may reach this threshold. Moreover, fishing effort in shelf seas is not homogeneously distributed. Fishermen concentrate their effort in grounds that yield the best catches of commercial species and generally avoid areas with obstructions and rough ground that would damage their gear. In addition, fishing is restricted in some areas, such as shipping lanes and around oil rigs. Consequently, early estimates of area swept by bottom gears are unintentionally misleading as they imply that physical disturbance is spread homogeneously across large (> 100 km^2) areas (Welleman 1989). More recently, 'black box' recorders have been fitted to a proportion of the Dutch beam trawl fleet which has allowed the tracking of fishing operations. The Dutch fleet accounts for 50-70% of the total beam trawling effort in the North Sea (Rijnsdorp *et al.* 1996). These records indicate that beam trawling effort is very patchily distributed in the North Sea. It is estimated that some 3 x 3 nautical mile areas are visited > 400 times per year, while others are never fished (Rijnsdorp *et al.* 1996). The distribution of bottom trawling disturbance can also be ascertained from the occurrence of physical damage in populations of animals that are able to withstand such injuries. Up to 55% of the starfish, *Astropecten irregularis*, sampled in a heavily beam trawled area of the Irish Sea were found to have missing arms, compared with only 7% in a less intensively fished area (Kaiser 1996). Within intensively fished areas, the background levels of natural disturbance may have been exceeded leading to long-term changes in the local benthic community. However, as pointed out by many previous authors, the communities observed presently may be the product of decades of continuous fishing disturbance (Bergman & Hup 1992; Dayton *et al.* 1995; de Groot & Lindeboom 1994).

Detecting long-term changes in benthic fauna attributable to fishing activities has been problematic for all but the most obvious cases (Riesen & Reise 1982; Sainsbury 1987). Even in these cases, it is problematic to attribute these changes to fishing alone, as the southern North Sea has been influenced by eutrophication events leading to increases in the abundance of polychaete species and echinoderms such as *A. filiformis* (Pearson *et al.* 1985). Furthermore, recent studies suggest that oceanic influences may have had more important effects in the North Sea than eutrophication and fishing disturbance (Lindeboom *et al.* 1995). This emphasises the value of time-series data, especially when trying to determine which factors have had most influence on changes in community stucture.

Infauna

By-catches of non-target infaunal species indicate the extent to which benthic communities are perturbed by a particular gear. For example, Houghton *et al.* (1971) suggested that the quantities of *Acanthocardia* sp. and *Echinocardium cordatum* caught by a 9.5m beam trawl fitted with 17 tickler chains indicated that the gear disturbed the seabed to a depth of 10 to 20 cm. Similarly, the occurrence of the infaunal bivalve, *Arctica islandica* (L.), and the heart urchin, *Echinocardium cordatum* (L.), in a 12m beam trawl catch indicated that the tickler chains had penetrated hard sandy substrata to a depth of at least 6 cm (Bergman & Hup 1992). Smaller size-classes of heart urchins were found closer to the sediment surface and hence were most vulnerable to physical damage by the trawl. It is important to note that it is the position of small urchins within the sediment column, and not their size, that made them vulnerable. Bergman & Hup (1992) emphasised the importance of considering the vulnerability of animals at different stages of their life history. In the same study, it was estimated that 90% of the *A. islandica* in the catch had broken shells, however this provided no information on the number that were damaged but remained in the sediment. The prevalence of *A. islandica* in the stomach contents of cod, *Gadus morhua* at times of intensive otter trawling in Kiel Bay, indicated that large numbers of these bivalves are damaged by trawling (Arntz & Weber 1970). Rumohr & Krost (1991) found large number of damaged *A. islandica* in a dredge towed directly behind an otter board compared with similar samples collected in the centre of the net. Furthermore, damaged *A. islandica* have been observed by divers while surveying areas of the seabed disturbed by beam trawls (Kaiser & Spencer 1996b). Although *A. islandica* are vulnerable to damage by trawls, those that are slightly damaged are able to repair cracks in their shell matrix. Sand grains become lodged between the mantle and the growing edge of the shell as a consequence of physical damage and eventually become incorporated into the shell matrix (Witbaard & Klein 1994). Witbaard & Klein (1994) studied annual growth rings in the shells of *A. islandica,* and were able to back-calculate the years in which they had been damaged by noting the occurrence of sand grains in the shell matrix. The incidence of shell damage correlated with increasing beam trawling activity between 1972 and 1991 at a study site in the southern North Sea (Witbaard & Klein 1994). They concluded that the study site had been disturbed by demersal fishing gear at least once per year during this period (Witbaard & Klein 1994).

While it has been relatively simple to detect significant changes in the abundance of large macroinfauna as a result of fishing disturbance, smaller invertebrates (< 10 mm) show conflicting responses. Bergman & Hup (1992) found both decreases and increases in the abundance of small invertebrates after fishing an area of the seabed with a beam trawl. A species by species analysis of responses to fishing gear disturbance (Bergman & Hup 1992; Eleftheriou & Robertson 1992) is probably of less use than the multivariate approaches adopted in more recent studies (Currie & Parry 1996; Kaiser & Spencer 1996a; Thrush *et al.* 1995). Furthermore, studies undertaken in the southern North Sea have been hampered by the inescapable fact that fishing disturbance has occurred for at least the past 100 years. Kaiser & Spencer (1996a) studied the effects of beam trawl disturbance at a site 27-40 m deep in the Irish Sea that experiences little fishing activity (Kaiser *et al.* 1997). Their experimental area encompassed two distinct habitats; stable sediments composed of coarse sand, gravel and shell debris, which supported a rich epifaunal filter-feeding community of soft corals and hydroids, and mobile sediments characterised by ribbons of megaripples with few sessile epifaunal species. Despite a robust experimental design with paired treatment and control areas, the effects of beam trawl disturbance were undetectable in the mobile sediments. Shepherd (1983) gives the levels of natural variability found in megaripple habitats. Furthermore, De Wolf & Mulder (1985) was unable to estimate accurately the abundance of benthic species in megaripple habitats because of their inherent spatial variability. In addition, animals living in the troughs of megaripples are less likely to be disturbed as the fishing gear rides over the crest of each sand wave. Similarly, Brylinsky *et al.* (1994) were unable to detect any adverse effects of otter trawling over intertidal mud flats which are regularly exposed to large-scale disturbances such as ice-scour. Conversely, in stable sediments the effects of fishing are more noticable. Kaiser & Spencer (1996a) found that the number of species and individuals in infaunal samples collected in the relatively undisturbed sediment community was reduced by a half and a third respectively. Their analysis also revealed that less common species were most severely depleted by beam trawling. In a similar study, Thrush *et al.* (1995) studied the effects of scallop dredging on a coarse sand community at a depth of 27 m. They were able to detect changes in the populations of individuals and compositional differences in the community that lasted for at least 3 months after initial disturbance. Thrush *et al.* (1995) emphasised that their study was conservative as they were unable to simulate the effects of an entire fishing fleet, implying that at larger scales of disturbance recolonisation may take longer. Infauna that live within a few cm of the sediment surface at water depths < 30 m to include small opportunistic species (e.g. spionid and capitellid polychaetes and amphipods) that rapidly recolonise areas after disturbance. Hence, the effects of trawling on this component of the infaunal community are unlikely to last more than 6 to 12 months. However, a recent study by Posey *et al.* (1996) suggested that deeper burrowing fauna were not affected by severe episodic storms. Their study site was at a depth of 13 m, and samples were collected down to 15 cm within the sediment. "Deeper burrowing" was not defined, but it implies fauna living at a depth of 7-15 cm which is well within the depth-range disturbed by trawls and dredges (Bergman & Hup 1992; Krost *et al.* 1990).

Hall & Harding's (1997) studied the effects of mechanical and suction dredging and the scale of disturbance on intertidal benthic communities in the Solway Firth, Scotland. The immediate effects of cockle harvesting were obvious with a drastic reduction in the abundance of individuals, however the community in disturbed areas was comparable to that in similar undisturbed areas after only 8 weeks. This rapid recolonisation was attributed to the immigration of adult fauna against a background of seasonal recruitment (Hall & Harding 1997). This study contrasts with an investigation of the effects of suction dredging for manganese nodules on the abyssal plain of the Pacific Ocean (Theil & Schriever 1990). Trenches created by the suction dredge head persisted for at least 2 years in this stable environment. However, while the persistence of disturbance effects may be approximately correlated to the level of natural disturbance experienced in a particular habitat, there are some exceptions. This is well illustrated in a recent study in which the effects of scale of defaunation were studied in an intertidal sandflat in New Zealand (Thrush *et al.* 1996). In contrast to Hall & Harding's (1997) findings, recolonisation rate was reduced at larger scales of disturbance. The main difference between these two studies was the presence of dense mats of tube building spionid worms in the New Zealand study which stabilised the sandflat sediments. Removal of these animals destabilised the sediment and exacerbated the effects of disturbance. Furthermore, while the changes associated with disturbance are relatively short-lived for the majority of small species, longer-lived organisms recolonise more slowly. For example, Beukema (1995) reported that the biomass of gaper clams, *Mya arenaria* (L.), took 2 years to recover after commercial lugworm dredging in areas of the Wadden Sea, whereas small polychaetes and bivalves had recolonised the dredged areas within 12 months. Many long-lived epifaunal organisms perform a structural role within benthic communities, providing a microhabitat for a large number of species (see epifauna below) (Nalesso *et al.* 1995). Calcareous algae of the genus *Lithothamnion* are amongst the oldest marine plants in Europe and provide a substratum that takes hundreds of years to accumulate. The branching structure of each thallus provides a unique habitat for a diverse community of animals including commercial species such as scallops, *Pecten maximus*. Not surprisingly, scallop dredging in this habitat causes destruction of the interstices between the thalli and causes long-term changes to the composition of the associated benthic fauna (Hall & Spencer 1995).

Van Dolah *et al.* (1991) studied changes in infaunal communities over a period of five months within areas closed to fishing and in adjacent areas fished by shrimp trawlers. They concluded that seasonal reductions in the abundance and number of species sampled had a much greater effect than fishing disturbance. However, in a power analysis of their sampling strategy, only changes in the abundance individuals and the number of species were considered. This assumes that the response of the infauna to trawling disturbance was unidirectional, whereas consideration of changes in partial dominance might have been more sensitive to subtle changes in the fauna. Hence caution is needed in the interpretation of these results, although it seems plausible that light shrimp trawls do not cause significant disturbance to communities in poorly sorted sediments in shallow water (van Dolah *et al.* 1991). In addition, van Dolah *et al.* (1991) sampled fauna from fished areas located between shoals which indicates that the local sediments were probably mobile and inhabited by fauna adapted to frequent natural disturbances (de Wolf & Mulder 1985; Kaiser & Spencer 1996a; Shepherd 1983).

So far we have only considered the effects of bottom fishing on infaunal communities living in coarse substrata. Most animals are found within the top 10 cm of these sediment habitats. However, in soft mud communities a large proportion of the macrofauna live in burrows up to 2 m deep (Atkinson & Nash 1990). Consequently few of these deep burrowers, such as thalassinid shrimps, are likely to be affected by passing trawls. However the energetic costs of repeated burrow reconstruction may have long-term implications for the survivorship or fecundity of individuals. In addition, diel variation in behaviour may periodically increase the vulnerability of some species to fishing activities. For example, the burrowing shrimp *Jaxea nocturna* Nardo moves to the entrance of its burrow to feed at night (Nickell & Atkinson 1995). These animals, along with other bioturbators, have an important role in maintaining the structure and oxygenation of muddy sediment habitats (Fenchel 1996; Fenchel & Finlay 1995; Reise 1982; Rowden & Jones 1993). Consequently, any adverse effects of fishing on these organisms would presumably lead to substantial changes in habitat complexity and community structure.

Epifauna

Intuitively, sessile epibenthic species are vulnerable to the passage of bottom gears. Observations that epifaunal communities had altered in heavily fished areas have provided some of the first indications of the potential long-term effects of fishing on benthic communities. The disappearance of reefs of the calcareous tube building worm, *Sabellaria spinulosa*, and their replacement by small polychaete communities, indicated that dredging activity had caused measurable changes in the Wadden Sea benthic community (Riesen & Reise 1982). Similarly, Sainsbury (1987) reported a measurable decrease in the biomass of the sponge by-catch in the Australian North West Shelf pair-trawl fishery between 1967 to 1985. Loss of the sponge community and associated fauna such as alcyonarians and gorgonians led to a reduction in the catches of porgies, *Lethrinus* spp., and snappers, *Lutjanus* spp. which sheltered and fed among the emergent fauna (Sainsbury 1988). Langton & Robinson (1990) observed about 26% reduction in the mean density of the sabellid worm, *Myxicola infundibulum* and the cerianthid anemone, *Cerianthus borealis*, after one season of intense commercial scallop dredging on the Fippenies Ledges, Gulf of Maine. In addition, the significant negative association between these species became random after intensive fishing (Langton & Robinson 1990). Langton & Robinson (1990) hypothesised that cerianthid predation of scallop and sabellid worm larvae was an important factor controlling the spatial distribution of these species, thus the species association was broken down by dredging disturbance. Using a combination of fishing effort data and direct observations from side-scan sonar surveys, Collie *et al.* (1997) were able to identify comparable substrata that experienced different intensities of scallop dredging on the Georges Bank, northwest Atlantic. Areas that were less frequently fished were characterised by abundant bryozoans, hydroids and worm tubes which increased the three-dimensional complexity of the habitat. Furthermore, examination of evenness within the community suggested dominance by these structural organisms, which indicated that this environment was relatively undisturbed. In contrast, the more intensively dredged areas had lower species diversity, biomass of fauna, and were dominated by hard-shelled bivalves (e.g. *Astarte* spp.), echinoderms and scavenging decapods. The higher diversity indices observed at the less intensively dredged sites were attributable to the large number of organisms, such as polychaetes, shrimp, brittle stars, mussels and small fishes, that were associated with the biogenic fauna (Collie *et al.* 1997). Many of these associated species were also important prey for commercial fish species such as cod, *Gadus morhua* (Bowman & Michaels 1984). Similarly, Auster *et al.* (1996) reported a reduction in habitat complexity as a result of trawling and scallop dredging activity at three sites in the Gulf of Maine. Video obeservations made with an Remote Operated Vehicle (ROV) revealed cleared swaths in the epifaunal cover on the border of the Swans Island conservation area which has been closed to fishing with mobile gears since 1983. As in other studies (Bradstock & Gordon 1983; Collie *et al.* 1997; Sainsbury 1987), hydroids, bryozoans, sponges and serpulid worm matrices were greatly reduced in the fished areas. In addition, there was a reduction in the habitat features produced by some of the target species, e.g. pits created by scallops and crabs (Auster *et al.* 1996). The Jeffreys Bank site was surveyed by submersible in 1987 and again in 1993. Boulders, 2 m wide, were a prominent feature of the site, which had excluded the use of towed fishing gear until 1987. However, when the site was resurveyed, the percentage cover of sponges was greatly reduced, the thin mud veneer that previously covered the underlying gravel was no longer evident, and boulders appeared to have been moved across the seabed. The Stellwagen Bank area ranged in depth from 20 to 50 m, with a mixture of sand, gravel and shell debris habitats formed by large storm waves. These storm events are intermittent compared with the daily scallop dredging activity in the area. ROV surveys revealed that the area was characterised by dense aggregations of the hydrozoan *Corymorpha pendula* which provided shelter for shrimp, *Dichelopandalus leptoceros*. Wide linear swathes through benthic microalgal cover indicated the occurrence of recent trawling and scallop dredging activity. The hydrozoans and associated shrimps were absent from these fished areas (Auster *et al.* 1996).

Where fishing occurs in shallow clear waters, marine plant communities are likely to be severely affected. In particular, seagrass meadows are vulnerable to physical disturbance as dredges and trawls reduce plant biomass and abundance by shearing off fronds and digging shoots from the substratum (Fonseca *et al.* 1984). Seagrass meadows are highly productive, support complex trophic food webs and provide sediment and nutrient filtration, enhance sediment stabilization and act as breeding and nursery areas for species of commercial importance (Short & Wyllie-Echeverria 1996).

These studies illustrate the two main effects of mobile gears on epifaunal communities *i)* modification of substrata (shell debris, boulders, mud veneers) and *ii)* removal of biogenic taxa and a decline in the abundance of species and communities associated with them. The loss of biogenic species not only reduces the supply of important prey species, but also increases predation risk for juvenile commercial species thereby lowering subsequent recruitment (Walters & Juanes 1993). Bradstock & Gordon (1983) reported the removal of extensive beds of bryozoans as a result of trawling activity and advocated the protection of these communities, noting that they provided an important habitat for juvenile commercial fish species. Moreover, Dayton *et al.* (1995) discuss the importance of diffferent functional groups in maintaining community structure. Communities dominated by long-lived suspension feeders are most likely to be replaced by a community of opportunistic deposit feeding species and mobile epifauna when subjected to large-scale and intense fishing disturbance. In particular, biogenic structures that increase the complexity of the epibenthic habitat (e.g. corals, bryozoans, worm tubes) create specialised environmental conditions by altering local hydrographic conditions that encourage the development of a specialised associated community. Loss of such structures will also affect the survivorship of any associated species and prolong the recolonization process.

Scavengers

Here, we discuss the effects of fisheries associated carrion on populations of marine scavengers. For an extensive review of marine scavenger biology and ecology see Britton & Morton (1994). Fishing activities result in the death of both target species and non-target biota, especially in multispecies fisheries. Animals that are not retained by fishers are termed discards and by-catch. A practice known as 'slipping' also occurs in fisheries for pelagic species such as herring, when the catch is too large to be landed, leading to mass mortality of the catch. This situation occurs when the size of the school of fish or the tow length is misjudged.

Discards are species that are returned to the sea because *i)* they are undersized, *ii)* the quota for that species has been used up, *iii)* the vessel has no quota for that species or *iv)* they have no commercial value. High-grading also occurs when fishers reject fish above the minimum legal landing size in favour of larger, more valuable, specimens. Pauly & Christensen (1995) estimated that 27 million tonnes of by-catch are generated by global fishing activities each year. It is estimated that 475 000 t of fish, offal and benthic invertebrates are discarded in the North Sea annually (Camphuysen *et al.* 1993). Camphuysen *et al.* (1993) undertook field experiments to calculate the percentage of each component of discards eaten by seabirds. They estimated that seabirds consumed approximately 90% of offal, 80% of roundfish, 20% of flatfish and 10% of the invertebrates discarded annually in the North Sea. This was estimated to be enough food to maintain about 2.2 million seabirds, which is more than the entire estimated population of scavenging seabirds in the North Sea. The effects of this additional supply of food, which would otherwise have been unavailable under natural conditions, have provided a clear signal of population changes of breeding seabirds form 1900-1990 (Furness 1996; Lloyd *et al.* 1991). Field studies have demonstrated that there is intense competition for offal and discards between scavenging species (Camphuysen *et al.* 1993; Furness *et al.* 1992; Garthe *et al.* 1996; Hudson & Furness 1988). Some species are more adept than others at utilizing certain components of the discards. Fulmars, *Fulmarus glacialis,* and gulls are the main consumers of offal in the northern and southern North Sea respectively, their feeding success is positively correlated with their numerical dominance at

2. MATERIALS AND METHODS

2.1. SIZE OF BOTTOM TRAWLING FLEETS

Introduction

The results of the Impact-projects provide information on the effects of bottom trawling on the benthic ecosystems in the North Sea and the Irish Sea. In order not to restrict the conclusion to the present day situation it was decided to make the link with the past and provide data on fishing activities, fishing fleets and fishing gears, for the past 100 years.

2.1.1. HISTORICAL REVIEW OF FISHING FLEETS AND GEARS

The review of fishing fleets and gears for the past century was based on a large amount of historical data from a wide variety of historical sources. These were national fleet statistics and landings statistics (Anon. 1912-26, 1927-29, 1931, 1934-38, 1950-57, 1959, 1976, 1991b, 1992a, 1992c; Welvaert 1991, 1993) and historical books (de Boer 1984; Tesch & de Veen 1933; Timmerman 1962; Toet & Ouwehand 1967) completed with data provided by the national fishery services from Belgium, Germany and the Netherlands. In order to make this review a tool easy to use, most of the data were gathered in graphs and figures accompanied by explanatory text.
Following data were investigated:

- Numbers of vessels: Numbers of vessels were given according to the vessel type. The vessel types were sailing vessels, steamtrawlers, motorised drifters, motorised otter trawlers and motorised beam trawlers. For the Netherlands the group of sailing vessels were split up into trawling and non-trawling vessels.
- For Belgium and the Netherlands numbers of trawling vessels were grouped into engine power classes in order to show the evolution of the engine power installed on board of the fishing vessels.
- Landings: Data on landings were, where possible, split up into the different species groups, *Nephrops* and shrimp – pelagic – demersal for Belgium, shrimp – herring – roundfish – flatfish for the Netherlands. For Germany only total landings could be given.
- A summation of the total engine power of the fishing fleet has been made for Belgium, since 1936, and the Netherlands, since 1950.
- For Belgium the total tonnage of the fishing fleet was investigated. The tonnage of a vessel can be given in two units, BRT and GT. In the statistics these figures occur mixed and it was not possible to split the data according to the two units used.

No freezing/factory trawlers, and for the Netherlands no shellfish trawlers, were included in the review.

2.1.2. SIZE OF THE BOTTOM TRAWL FLEET - PRESENT SITUATION

Data on fleet sizes and total landings were collected from the national databases for the year 1994 for the three participating countries in sub-project 1-B and also for England and Wales, Scotland and the main fishing ports on the east coast of Ireland. A sub-division was made for the fleet sizes based on fleet engine power classes as defined in section 3.1.2. In addition the landings data were divided into groups according to the fishing gear they were caught with.

These data gave an idea of the importance of the different fishing gears and the several sections of the fishing fleets active in he North Sea and the Irish Sea.

2.2. FISHING GEARS USED BY DIFFERENT FISHING FLEETS

Introduction

The effects of bottom trawling were studied in this project with a selection of the most typical fishing gears used in the North Sea and Irish Sea bottom trawling. In order to make the link with the real situation in the fishing industry it was necessary to make an inventory of the fishing gears used, together with all necessary technical details and operational parameters. An inquiry among netting and fishing gear companies and skippers and vessel owners seemed the best way to obtain this information.

For impact studies it is not enough to know details on the fishing gears used. It is also necessary to know the geographical distribution of the use of the different types of fishing gear in order to be able to link the effect of a gear to the sensitivity of a specific area. Therefore data on fishing effort were collected for all participating countries.

2.2.1. FISHING GEAR INVENTORY

In order to gather detailed information on vessels, fishing gears, netting and operational parameters an inquiry has been carried out. Most of the vessel characteristics were available in the national databases. Basic data on fishing gear and netting have been collected from fishing gear and netting manufacturers. Detailed information on vessels, gears, netting and operational parameters have been gathered by interviewing skippers and vessel owners in situ, i.e. the fishing vessel.

For the inquiry a wide range of information is collected but special attention is given to items which relate to the impact of fishing gears, like the weight of the gear and its components, numbers of tickler chains, dimensions of chain matrices, factors affecting selectivity, operational parameters like towing speed and warp length / depth ratios etc.

The minimum set of vessel and gear data to be included in the inquiry, which was agreed upon in the early stages of the project, is shown in Table 2.2.1. Depending on specific local situations extra information have been added to this list.

These data led to a definition of a "typical fishing gear" for each sub-fleet.

2.2.2. DISTRIBUTION OF FLEET ACTIVITIES

In order to obtain an idea about the geographical distribution of the activities of the fishing fleet, landings and effort data were extracted from the official statistics in the national databases for each ICES statistical rectangle. These data have been divided according to the previously defined sub-fleets and fishing gears and have been plotted as dots on a North Sea map per ICES statistical rectangle. This will give an idea about the geographical distribution of the disturbance of the sea floor by different bottom trawling activities.

TABLE 2.2.1
Parameters included in the standard inquiry forms

Beam trawlers
Vessel data: Homeport, registrationnumber, name, engine power (kW and hp)(nominal or fishing), LOA (m), breadth (m), BRT, Kort nozzle (y, n) and diameter, propeller diameter (m), propeller with controllable pitch (y, n), average towing speed relative to the bottom (kn), min and max, positioning system (gps, decca, ...), warp depth ratio (depth keel of the vessel included, warp length from the top of the outrigger boom to the top of the bridles.
Fishing gear: beam length (m), trawl-head-height (cm)(up to the centre of the beam), type of groundrope and diameter of the roller or bobbins and chains, length of groundrope (m), weight of the groundrope (kg), use of flip-up rope (y, n), weight of the gear (kg)(weighed or estimated), netting material of upper and lower panel, different mesh sizes in upper and lower panel (mm), length of the net (m), netting material of codend, dimensions of codend (numbers of meshes round and deep), target species, alterations to the net depending on the target species, numbers of hours transit and fishing per day, week or trip.
For chainmat gear: dimensions of the quadrants (no's of shackles), diameter of the shackles (mm), weight of the chain-matrix (kg), what type of bottom. *For tickler chain gear*: numbers of tickler and net tickler chains, diameters of the shackles (mm) and weights (kg), what type of bottom.
Are other gears used, if yes what period + details.
Otter trawlers
Vessel data: homeport, registration number, name, engine power (kW and hp) (nominal or fishing), LOA (m), breadth (m), BRT, Kort nozzle (y, n) and diameter, propeller diameter (m), propeller with controllable pitch (y, n), average towing speed relative to the bottom (kn), min and max, positioning system (gps, decca, ...), warp depth ratio (depth keel of the vessel included).
Fishing gear: Type of net, length of the headline, type of groundrope and diameter of the roller or bobbins and chains, length of groundrope (m), weight of the groundrope (kg), netting material and different mesh sizes in the different panels, netting material of codend, dimensions of codend (numbers of meshes round and deep), target species, alterations to the net depending on the target species, numbers of hours transit and fishing per day, week or trip.
Otter boards and rig: type, dimensions, material and weight of the otter boards, length of the bridles and other comment.

2.3. PHYSICAL IMPACT

Introduction

In this sub-project, the physical effects of different types of commercial beam trawls and otter trawls were investigated. Experimental fishing took place between 1992 and 1995. The fishing areas were located in the southern North Sea for the beam trawls, in the western Irish Sea for a *Nephrops* trawl and in a Scottish loch for an otter trawl, and covered shallow sandy areas as well as offshore silty areas (Fig. 2.3.1; Table 2.3.1). The physical effects of trawling on the sea-bed include pressure exerted by the trawls on and penetration depth into the sea-bed, and changes in structure and texture of the upper sediment layers.

2.3.1. PRESSURE EXERTED BY A BEAM TRAWL

2.3.1.1. PRESSURE MEASUREMENTS

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. 2.3.2. 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 F1 and F2. 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. The time interval between the two recordings can be choosen as 1, 2 or 4 seconds. In the present experiments, readings were made at 1 sec time intervals.

The pressure exerted by the 4m beam trawl rigged with a chain matrix was studied whenever possible when fishing with this gear. The pressure exerted by the sole plates was measured by the instrumented trawl head. Simultaneous measurement of the warp load enabled the later calculation of the whole gear pressure. The warp load was measured by an underwater load cell inserted between the bridles and the warp. The range of the load cell was 200 kN. Two series of measurements were made: (i) with a constant warp length /depth ratio to assess the influence of towing speed on the pressure exerted by the gear (ii) at constant towing speed to assess the influence of the warp length / depth ratio on the pressure exerted. Towing speed was measured by the vessel's Doppler log and speed through the water by a SCANMAR speed log attached to the bridles.

2.3.1.2. RELATION BETWEEN GEAR PRESSURE AND ENGINE POWER

The pressure measurements described above were made on a beam trawl with a beam length of 4 m as used by many beam trawlers of the Eurocutter type (221 kW) when fishing within the 12 miles limits. In order to obtain an insight in the variation of gear pressure with vessel and gear characteristics, data from a former series of gear performance measurements and from a detailed inquiry on vessel and gear characterics (especially weight of the different gear components and actually measured on a number of vessels) were analysed to model the gear pressure against vessel hp and gear weight. The data collected during the inquiry are given in Table 1 of section 2.2. - Fishing gears used.

2.3.2. SEA FLOOR DISTURBANCE

The sea-bed disturbance was studied for 12m and 4m beam trawls rigged with tickler chains, for a 4m beam trawl rigged with a chain matrix, for an otter trawl and for a *Nephrops* trawl. These gear types are fully described in section 2.2. The characteristics of the gears used in the experiments are given in Table 2.4.2. The gears were mainly operated from research vessels. Their characteristics are given in the Glossary. The fishing areas are given in Table 2.3.1 and Fig. 2.3.1.

2.3.2.1. BEAM TRAWLS

Immediate effects

REMOTS observations

The REMOTS camera was lowered from the drifting observation vessel and 5-10 consequent pictures of the structures on the sea-bed were taken on the trawl tracks, before and after fishing. The REMOTS camera was guided with a b/w pilot video camera. However the pilot camera was unuseable in extremly turbid waters. The REMOTS pictures were analysed under normal projection following a protocol developed for this case. Both the penetration depth of the prism and the sediment surface roughness were tested with a non-parametric median test. Precise navigation was an indispensable prerequisite for such an integrated approach.

Video observations

In the North Sea studies the underwater video-sled was used according to routines developed for the HELCOM monitoring of the Baltic (Rumohr 1993). The sled was towed at a speed of approx. 0.5-1.0 kn over the sea-bed with the camera mounted 30-50 cm above the bottom. In North Sea waters it was sometimes necessary to go as close as possible to the bottom to get images, because of the considerable turbidity of the water. This was particularly the case after the passage of the towed gear. 1-2 transects on each of these lines were investigated with the video-sled, crossing the trawl tracks two or more times.

Longer term effects

Side-scan sonar

At the request of RVZ, side-scan sonar observations of the sea-bed disturbance caused by a 4m beam trawl rigged with a chain mat, were made by the Research Unit Marine and Coastal Geomorphology of the University of Gent in April 1992 and March 1993 (De Moor *et al.* 1992) and by "Marine Geological Assistance" in June 1996 (Anon. 1996a). Prior to the fishing operations, side-scan sonar recordings were made along a number of lines parallel to the predetermined fishing tracks to check for possible earlier trawling activities. Then the reference track was fished for a number of times. After fishing, sonographs of the fished area were obtained at regular time intervals. A first series of surveys was made on the Flemish Banks (Table 2.3.1 - 1992, 1993, 1996) and a second series on the Scheveningen area (Table 2.3.1 - 1996).

RoxAnn

The RoxAnn system was used by RVZ to evaluate sediment disturbance by the same 4m beam trawl as mentioned above. Calibration and ground truthing of the system was accomplished during several earlier cruises with RV BELGICA. Additionally Van Veen samples were taken on the test sites during the RoxAnn survey for later analysis ashore. The survey methodology was the same as for the side-scan sonar observations. A blank recording was obtained of the reference track and on lines 20, 40 and 50 m on either side of the track. After fishing these lines were surveyed again at regular time intervals.

2.3.2.2. OTTER TRAWLS

Immediate effects

REMOTS and SPI

In the Irish Sea *Nephrops* grounds, a SPI I 3731 Sediment-Profile camera (supplied by Aqua-Fact International Services, Galway, Ireland) was deployed to investigate the direct physical impact of the *Nephrops* trawl on the sea floor. Three replicate SPI photographic images were taken at each of 14 stations before and after trawling. These images were taken back to the laboratory and imported into the computer using a frame grabbing package and analysed using an image analysis system.

Video and stills

In the Irish Sea *Nephrops* grounds following trawling, video footage of the sediment surface was recorded at both inshore and offshore stations using the HYBALL remote operated vehicle (ROV). The trawl tracks were located using the research vessels DGPS. The research vessel was then anchored upstream of the tracks, the ROV was deployed and then the ship was allowed to drift back across the tracks.

Longer term effects

Side-scan sonar

Experimental trawling disturbance was studied using a modified rockhopper groundgear with no net attached in Loch Gareloch, Inverclyde, Scotland, a sheltered muddy sealoch closed to commercial fishing for almost 30 years. Disturbance effects were monitored in this and a reference area prior to, during a 16 month disturbance and 18 month recovery period by FRS-MLA. Trawling disturbance commenced in January 1994 and continued on a one day per month basis until April 1995. Each disturbance event consisted of ten tows over the treatment area, with each trawl tow disturbing a track 35-40 m wide (measured between the trawl doors using SCANMAR distance sensors). Surveys of treatment and reference areas were carried out employing side-scan sonar to visually examine the sea-bed topography.

RoxAnn surveys

In the same disturbance experiment in Loch Gareloch (see above) surveys of treatment and reference areas were carried out employing the RoxAnn system to measure roughness and hardness parameters. Equipment changes and calibration difficulties between surveys mean that comparison can only validly be made between areas on the same survey, and not between surveys.

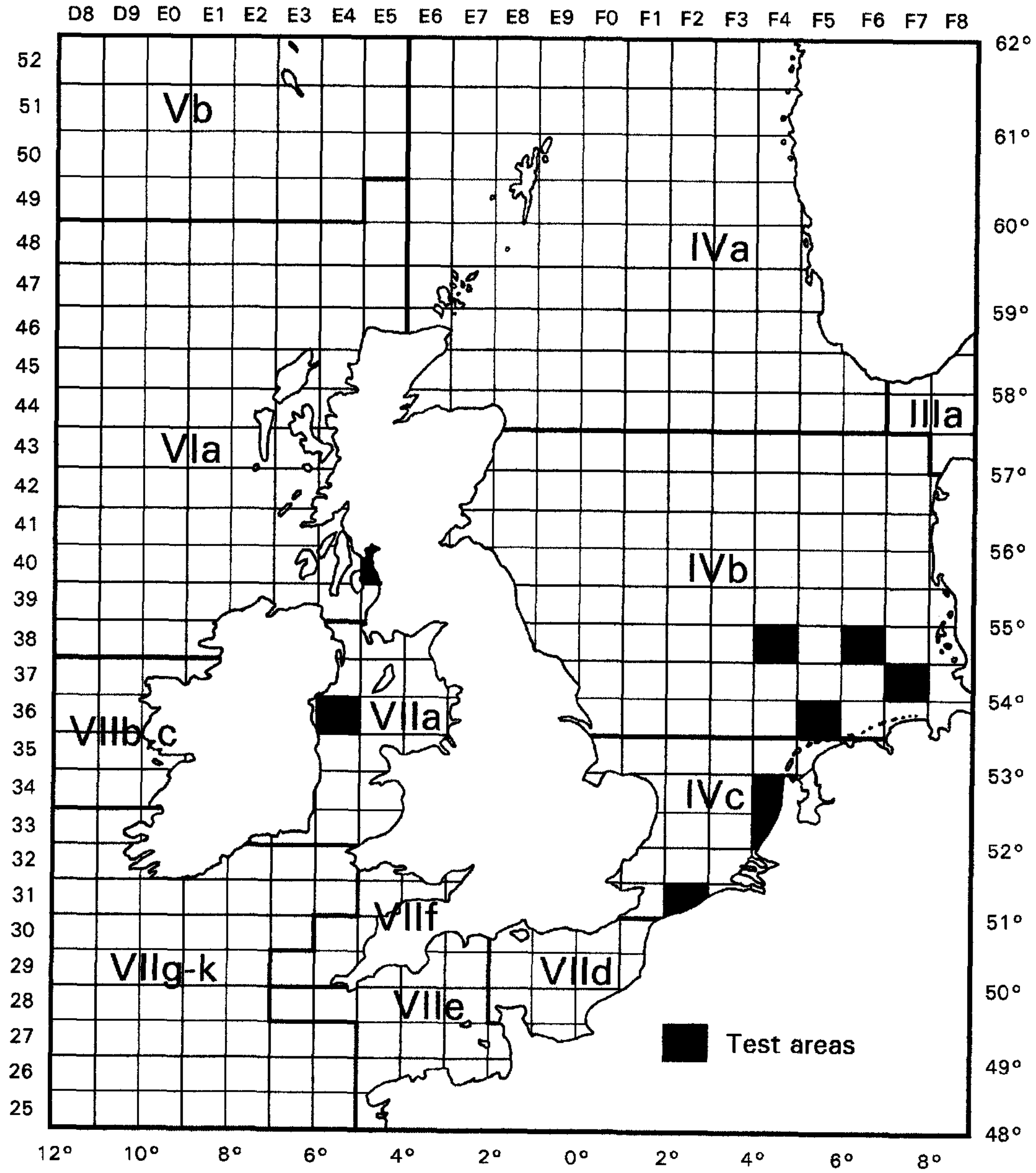


Fig. 2.3.1. Fishing areas physical impact studies.

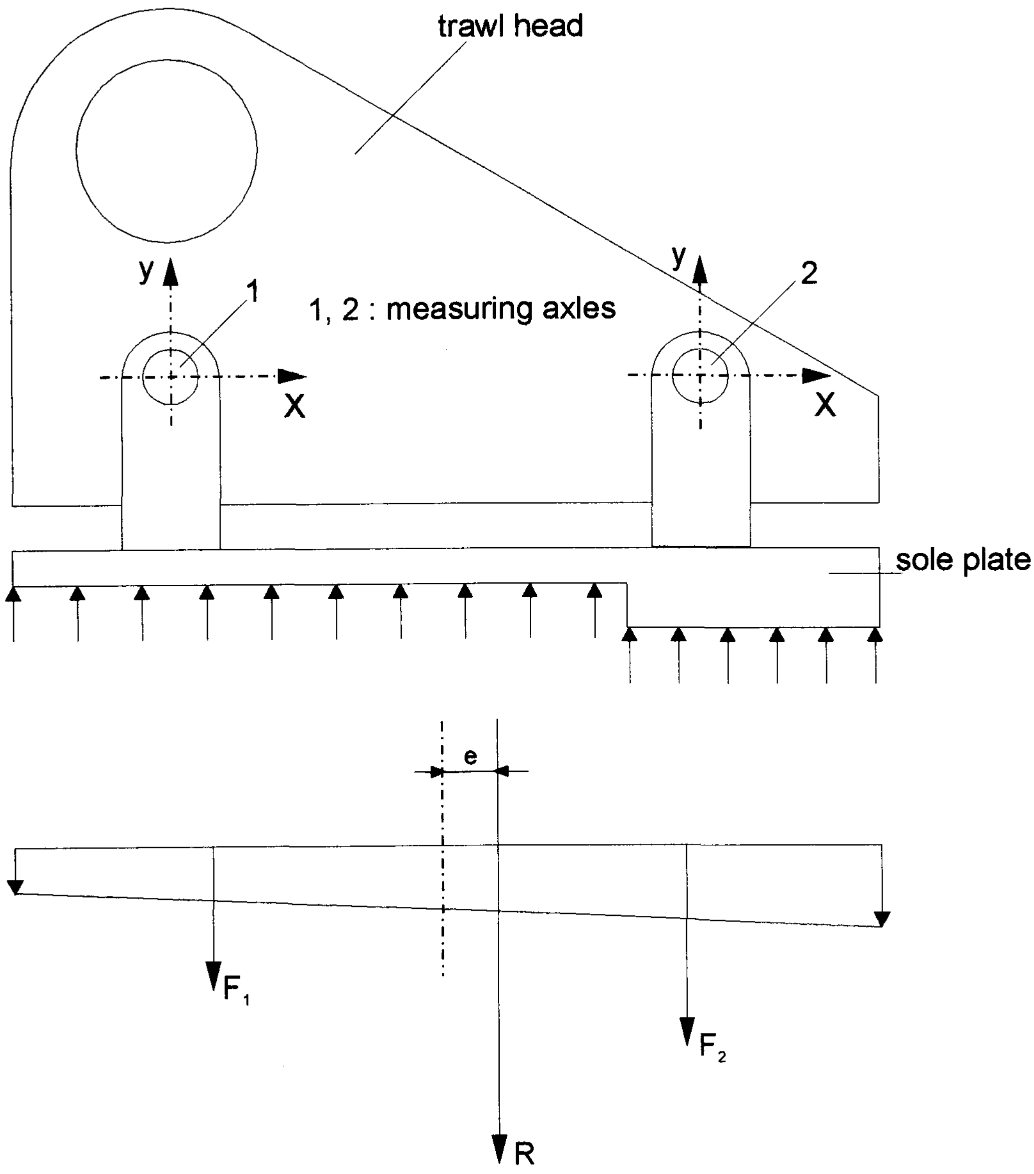


Fig. 2.3.2. Instrumented trawl head - principle.

TABLE 2.3.1
Areas visited in the physical impact studies.

ICES rectangle	area name	water depth m	grain size µm	silt %	year	month	commercial gear	study item
NORTH SEA (sandy)								
31F2	Flemish Banks	25	370-880	1-21	1992	April	4BTM	pr, dss
					1992	November	4BTM	pr
					1993	March	4BTM	pr, dss
					1994	May/June	4BTM	pr
					1995	Aug./Sept.	4BTM	pr, dRO
					1996	June	4BTM	pr,dRO,dss
33F4	Dutch coast south	20	370	1	1994	June	4BT,4BTM	tm, pr, dss
					1995	September	4BT,12BT,4BTM	tm, pr, dRO, dvi, dss
					1996	June	4BTM	pr, dRO , dss
34F4	Dutch coast north	20	100-200	~5	1993	April	4BT	tm, dss
36F5	Dutch Wadden coast	24	205-280	1-8	1992	June/July	4BT	tm, dss
					1994	June	4BT,12BT,4BTM	tm, pr, dss
					1995	September	4BTM	pr, dRO ,dss
NORTH SEA (silty)								
37F7	German Bight	25	225	8	1994	September	4BT,12BT,OT	tm, dss, dvi, dRE
38F4	Oystergrounds	43	155-170	0.6-9	1992	March/April	12BT	tm, dss
					1993	September	12BT	tm, dss
					1994	September	4BT,12BT,OT	tm, dss
38F6	Weisse Bank	45	fine?	5-10	1995	May	4BT, 12BT,OT	tm, dvi, dRE, dss
	Loch Gareloch	40	110	>90	1993	November	OT	dss, dRO
					1994	May	OT	dss, dRO
					1994	October	OT	dss, dRO
					1995	November	OT	dss, dRO
					1996	December	OT	dss, dRO
IRISH SEA								
36 E4 inshore	western Irish Sea	35	10-100	45-55	1995	May	NOT	dRE
					1996	April, May	NOT	dRE
36E4 offshore	western Irish Sea	75	10-100	45-55	1995	May	NOT	dRE
					1996	April, May	NOT	dRE
					1994	May, June	NOT	dRE

4BT = 4 m beam tr.
7BT = 7 m beam tr.
12BT = 12 m beam tr.
4BTM = 4 m beam tr.+mat
OT = otter trawl
NOT = Nephrops otter trawl

pr = pressure on seabed
dRO = disturbance /Roxann
dss = disturbance/sidescan
dvi = disturbance/video
dRE = disturbance/REMOTS

2.4. CATCH EFFICIENCY OF COMMERCIAL TRAWLS

Introduction

The catch composition of commercial demersal gears depends both on the faunal composition in the fishing ground and the type of trawl involved. In field studies in the southern North Sea, the catch composition of different types of commercial beam trawls (12m-, 4m-, 4m with chain matrix) and otter trawls was measured and compared. The catch composition of the *Nephrops* trawl was studied in the western Irish Sea. In addition, the efficiency of the different types of commercial trawls in catching invertebrates and fish was estimated.

The field studies were performed in several locations in the southern North Sea (Belgium, Dutch and German sector) and the western Irish Sea, in the years 1992 to 1996, in both spring and autumn. Substrates covered included both (coastal) sandy areas as well as offshore silty areas (Fig. 2.4.1; Table 2.4.1).

2.4.1. CATCH COMPOSITION

In the North Sea, the relative catch composition was measured of 12m and 4m beam trawls rigged with tickler chains, 4m beam trawls rigged with a chain matrix, and otter trawls. The characteristics of the different types of commercial trawls used in the field studies are given in Table 2.4.2. (for general information on trawl types: see glossary). In general, gears were used that were representative of commercial trawling in that particular area and season. The towing speed of the trawls was within the range used in commercial trawling. All flatfish trawls were rigged with a codend with a mesh opening of 8 cm, except in the studies S19 and S21 (Table 2.4.1) where a codend with a mesh opening of 10 cm was used in the otter trawls.

The studies were grouped into four study areas (Fig. 2.4.1; Table 2.4.1). Some of the trawl types involved in the experimental studies are not used commercially in all of the selected areas. To keep the studies as realistic as possible, an otter trawl was not used in the southern study areas, whereas a 4m beam trawl with chain matrix was not used in the northern study areas. The entire catch, or a subsample, was analyzed and the numbers and/or weight of the different species caught were recorded. Fish species were separated into marketable and undersized. The following were considered below marketable size: sole < 24 cm, plaice, dab and flounder < 27 cm, turbot and brill < 30 cm, gurnard and whiting < 30 cm, cod < 35 cm and all herring. The weight was either measured aboard or calculated using length-weight relationships. Both the caught and the discarded weights were calculated, per hectare trawling and per hour fishing. In case of the otter trawls, fishes in the path of the gear are herded by the otter boards, the bridles and the legs into the mouth of the net. Therefore, to calculate the amount of fish caught per hectare, the width of the trawl path was defined as the distance between the otter boards.

If trawling with more than one gear was performed in a particular area, and during a single study, differences in catch composition between trawl types were tested using one-way analyses of variance: June 1994 (4m rigged with tickler chains, 4m rigged with a chain matrix, 12m beam trawls, area: Dutch coast south), September 1994 (12m and otter trawl, area: German Bight), May 1995 (4 m, 12m and otter trawl, area: German Bight) and September 1995 (4m rigged with tickler chains, 4m rigged with a chain matrix, 12m beam trawls, area: Dutch coast south). The data were log-transformed prior to the analyses.

Nephrops trawling was undertaken using a modified otter trawl in in the north western Irish Sea during Spring and Autumn 1994 and 1995, and in Spring 1996 (Fig. 2.4.1; Table 2.4.1; Table 2.4.2). In the *Nephrops* trawl the mesh size in the codend was 70 mm diamond size (streched mesh). The haul returns were first weighted and a sub-sample of about 50 kg was sorted on deck to provide estimates of weights of *Nephrops*, whiting, poor cod, other round fish, flatfish and invertebrate species to be discarded. *Nephrops* were divided into the marketable fraction (ie. the tails of specimens larger than about 2.5 cm) and discards (i.e heads and specimens less than 2.5 cm carapace length). The retained and the discarded weight was calculated per hectare trawled and per hour fishing. The width of the trawl path was defined as follows: the door spread for fish species, the net spread for invertebrates.

Differences in the catch compostion between season and year were tested using two-way analyses of variance. The data were log-transformed prior to the analysis.

2.4.2. CATCH EFFICIENCY FOR SMALL SIZED FISH AND INVERTEBRATES

The catch efficiency was measured of 12m and 4m beam trawls rigged with tickler chains, 4m beam trawls rigged with a chain matrix and otter trawls in the North Sea, and of *Nephrops* trawls in the Irish Sea (the characteristics of the different types of commercial trawls used in the field studies are indicated in Table 2.4.2). The catch efficiency of commercial trawls was calculated by expressing the catch in one haul per swept area as a percentage of the initial density of benthic fauna in the seabed.

In the North Sea, initial densities of invertebrates, mainly consisting of - at least partially - burrowing species, were estimated in the studies on total direct mortality (see chapter 2.5), involving 4m and 12m beam trawls and otter trawls, on sandy and silty bottoms (Table 2.4.1). The initial densities were estimated with the Triple-D (for larger sized, less abundant in- and epifauna; mesh opening 14 mm, sampling depth 10 cm, sample size 30 m^2) or with a Reineck boxcorer (for small in- and epifauna; sampling depth 15-20 cm, sample size 0.06 m^2). In species that showed a large size range the catch efficiency was estimated for different size classes. Each study yielded one result per commercial gear used in that study, except in the studies carried out in 1995, when replicate-strips were trawled. For the large and sedentary bivalves *Arctica islandica* and *Acanthocardia echinata*, an estimate of the initial density could be obtained from the studies in which a strip was repeatedly trawled (see chapter 2.6). The initial density of these species is estimated from the sum of all catches of the subsequent hauls with the 12m beam trawls, assuming that most of the specimens present on the strip were caught during this intensive trawling.

An estimate of the catch efficiency of the *Nephrops* trawl for invertebrates in the Irish Sea was made in one study (Study S27 in Table 2.4.1), in which a 3m beam trawl was used to estimate the initial density. Contrary to the Triple-D or grab sampler, a 3m beam trawl is not suited to quantitatively sample infauna. Therefore, the catch efficiency of a *Nephrops* trawl could be estimated only for a limited number of strictly epifaunal invertebrate species. In the calculations of the catch efficiency for invertebrates of otter- and *Nephrops* trawls, the width of the trawl path is defined as the distance between the wings of the net.

For small sized demersal fish, the catch efficiency for 12m beam trawls was calculated based on studies in which initial densities were sampled with a 3m beam trawl (see chapter 2.6). For large fish species, it was not possible to estimate catch efficiency in a quantitatively reliable way, as the 3m beam trawl appeared unsuitable to sample these fish, which are too swift and avoid the nets.

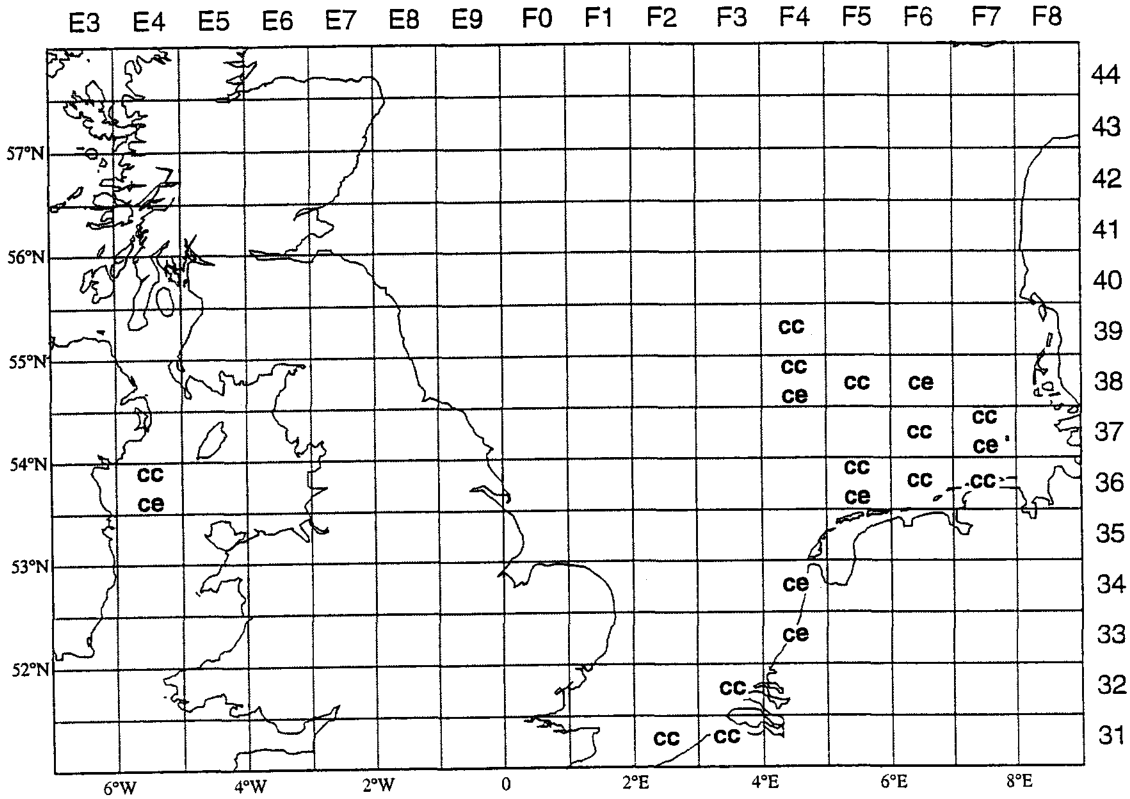


Fig. 2.4.1. Locations of field studies on relative catch composition (cc) and catch efficiency (ce).

TABLE 2.4.1

Field studies on catch composition of commercial trawls and catch efficiency for invertebrates and small sized fish. 4 TBB = 4m beam trawl; 12 TBB = 12m beam trawl; 4 TBBm = 4m beam trawl with chain matrix; OTB = otter trawl; OTBn = *Nephrops* otter trawl; cc = catch composition; ce = catch efficiency.

Area	ICES quadrant	Water depth m	Grain size µm	Silt %	Year	Month	Commercial gear	Study item	Study nr
NORTH SEA (sandy)									
Dutch coast south	33F4	20	370	1	1994	June	4TBB,4TBBm	ce	S1
					1995	September	4TBB,12TBB,4TBBm	ce	S2
Dutch coast north	34F4	20	100-200	~5	1993	April	4TBB	ce	S3
Dutch Wadden coast	36F5	24	205-280	1-8	1992	June/July	4TBB	ce	S4
					1994	June	4TBB,12TBB,4TBBm	ce	S5
German Bight	37F7	25	225	8	1994	September	4TBB,12TBB,OTB	ce	S6
Dutch coast south	31F2, 31F3; 32F3, 32F4	10-25	175->350	< 2	1992	Spring	4TBBm	cc	S7
					1993	Spring	4TBB,12TBB	cc	S8
					1994	Spring	12TBB, 4TBB, 4TBBm	cc	S9
					1995	Autumn	12TBB, 4TBB, 4TBBm	cc	S10
Dutch Wadden coast	36F5	20-35	<175-250	2-10	1992	Spring	4TBB	cc	S11
					1994	June	12TBB, 4TBB	cc	S12
					1995	May	12TBB,4TBB	cc	S13
NORTH SEA (silty)									
Oystergrounds	38F4	43	155-170	6-9	1993	September	12TBB	ce	S14
					1994	September	4TBB,12TBB,OTB	ce	S15
Weisse Bank	38F6	45	~150	5-10	1995	May	4TBB, 12TBB,OTB	ce	S16
Oystergrounds	38F4, 39F4, 38F5	45	<175	10-15	1992	Spring	12TBB	cc	S17
					1993	Autumn	12TBB	cc	S18
					1994	Autumn	12TBB, 4TBB, OTB	cc	S19
German Bight	36F6, 37F6, 36F7, 37F7	20-30	<175-250	2-15	1993	Autumn	12TBB	cc	S20
					1994	September	12TBB,OTB	cc	S21
					1995	May	12TBB, 4TBB, OTB	cc	S22
IRISH SEA (muddy)									
western Irish Sea	36E4 offshore	75	10-100	45-55	1995	May	OTBn	cc	S23
					1996	April, May	OTBn	cc	S24
					1994	May, June	OTBn	cc	S25
					1994	October	OTBn	cc	S26
					1995	August	OTBn	cc, ce	S27

TABLE 2.4.2

Characteristics of commercial gears used in this study. For general descriptions, see glossary. *S-numbers refer to study numbers in Table 2.4.1 or Table 2.5.1; n.d. stands for not-determined.

Type of trawl	Width			Total weight	Tickler chains (**matrix)		Net Roller ticklers		Mesh size streched		Towing speed
	bottom contact net (+bridles) m	between wings m	between doors m	kg*10^3	number	weight kg*10^3	number	diameter cm	front mm	codend mm	nm/h
12m beam +ticklers	12	-	-	5.9-7.8	9-10	1.1-2.2	8-10	25	260	80	5-7
4m beam +ticklers	4	-	-	1.4-1.5	5	0.1-0.3	5-6	15	170	80	3.5-5.5
4m beam +matrix	4	-	-	2.7	-	0.95**	-	25	120	80	3.5
otter	20*-32	15*-20	35*-55	1	-	-	-	-*/20	120	80*/100	3.5-4
Nephrops	n.d.	18	41	0.5	-	-	1	-	70	70	2-3
	*S15,19,41	*S15,19,41	*S15,19,41					*S6,21,38	*S16,22,43		

2.5. DIRECT MORTALITY DUE TO TRAWLING

Introduction

Trawling causes mortality in target and non-target species. A certain percentage of the non-target specimens that are caught in the trawl will not survive after their return (as discards) into the sea. In field studies in the southern North Sea, the mortality of discarded species was measured and compared for different types of commercial beam trawls (12m-, 4m-, 4m with chain matrix) and for otter trawls.

Direct mortality due to trawling occurs not only among caught and subsequently discarded animals (i.e. mortality of discards) but in the trawl path as well, among animals that are damaged or exposed due to the passage of the trawl. The occurrence of such damaged specimens was studied qualitatively by means of two of dredges attached to a beam trawl in North Sea field studies. In subsequent, more detailed studies, the total direct mortality of invertebrates was estimated: in the North Sea, the mortality due to trawling with commercial beam (12m-, 4m-, 4m with chain matrix) and otter trawls, and in the Irish Sea due to *Nephrops* trawls. The design of these fieldstudies, in which the total direct mortality was measured by comparing initial densities with remaining densities two days after trawling, made the results reliable only for sedentarian invertebrate species or species with a very limited migration behaviour. Mortality of fish and high mobile epibenthic invertebrate species could therefore not be estimated, as migration into or even out off the trawled area might not be excluded in this 48 hours interval and dead fish might be swept away by the tidal currents from the rather narrow strips.

During the years 1992-1996, field studies were undertaken in both Spring and Autumn, covering shallow (coastal) sandy areas and offshore silty sites. Investigations centred on several locations in the southern North Sea (Dutch and German sectors) and the western Irish Sea (Fig. 2.5.1; Table 2.5.1).

2.5.1. MORTALITY OF DISCARDS

The mortality was estimated of non-target epibenthic invertebrates and undersized flatfishes that were frequently caught in the North Sea fisheries. In experiments on board the research vessel, this mortality was determined of species caught in 12m and 4m beam trawls with tickler chains, 4m beam trawls with chain matrix and otter trawls. The characteristics of the different types of commercial trawls used in the field studies are given in the previous chapter (Table 2.4.2; for general information on trawl types see Glossary). In general, gears were used that were representative for commercial trawling in that particular area and season.

The percentage mortality of animals brought dead aboard (immediate discard mortality), and the percentage of animals that died over the next few hours or after three days (secondary discard mortality) was estimated. For the latter experiment, animals that were caught alive were placed in survival tanks designed by Van Beek, van Leeuwen & Rijnsdorp (1990). The system consists of plastic holding tanks of 40 by 60 cm and 12 cm high. Two stacks of ten holding tanks were placed in a wooden frame and supplied with a continuous flow of fresh sea water. Water wass pumped into the top tanks, flowing vertically from one tank into the next through vertical overflow pipes. The tanks were checked regularly, and dead animals recorded and removed. At the end of the experiment the surviving animals were counted.

2.5.2. DAMAGE OF INVERTEBRATES

One meter wide dredges ("Kieler Kinderwagen"; mesh opening 10 mm; sampling depth 1-5 cm) attached to a 7m beam trawl (without net) were used to determine the damage to benthic invertebrates due to the contact with the tickler chains. Two dredges were attached to the beam: one was towed behind the tickler chains, and one - as a reference - in front of the tickler chains. The length of the hauls was about 1000 meters; several replicates were made. Catches of the dredges were sorted and specimens were checked for damage. Studies were carried out in sandy sediments in the North Sea.

2.5.3. TOTAL DIRECT MORTALITY OF INVERTEBRATES

The total direct mortality, both in caught animals and in those that were damaged in the trawl path, is determined by the difference in densities of benthic fauna, before and after trawling. In the North Sea, total mortalities were determined due to four types of commercial trawls, all rigged for sole fishery, in the Irish Sea due to *Nephrops* trawling. The towing speed of the trawls was within the range used in commercial trawling.A number of replicate studies were carried out in different locations (Table 2.5.1). The characteristics of the different types of commercial trawls used in the field studies are given in Table 2.5.2. (for general information on trawl types: see Glossary). As the set up of the studies in the Irish Sea differed from the North Sea studies, they are described separately.

North Sea

Effects of trawling were studied in a single strip (IMPACT-I) or in a number of parallel strips (IMPACT-II). The length of a strip was about 2000 m, the width about 60 m; the distance between parallel strips was about 300 m. Each of the strips was trawled with one of the trawl types involved: 12m beam trawls, 4m beam trawls, 4m beam trawls with chain matrix, or otter trawl. In 1995, replicate strips were trawled with each type of trawl in each study. This was done to reduce the possible influence of uncontrollable variables (e.g. patchiness and gradients in sediment type and benthos densities) on the direct mortality and to increase the statistical power of the tests. A standard sampling and trawling procedure was applied in all studies (for main characteristics of sampling gears, see Table 2.5.2):

(1) In each strip ten samples were taken with the Triple-D dredge to estimate the initial densites of invertebrate macrobenthic species (t_0-sampling). This Triple-D was specially designed to sample larger-sized, often low abundant invertebrate species (Bergman & van Santbrink 1994a). After sorting the catches, the numbers (per size class) per species were counted and the densities of the species in each strip were calculated. In some studies, additional sampling was carried out with a Reineck box corer (20 samples, which were sieved on a 1 mm mesh) or a Van Veen grab (12-18 samples, which were sieved on a 5 mm mesh).

(2) Within 24 to 48 hours after the t_0-sampling, each of the strips was trawled with a different type of commercial gear, in such a way that the total surface of the strips was trawled on average 1 to 1.5 times. The number of hauls varied from 4 to 10, depending on the width of the trawls used. In some studies, an extra heavily trawled (on average 3 times) strip was created with 12m beam trawls. The catches in the commercial trawls were sorted, analysed and discarded some miles away from the study location.

(3) At least 24 (1995: 48) hours after the commercial trawling, the remaining fauna in the strips was sampled with the Triple-D. Ten samples were taken in each strip (t_1-sampling). After sorting the catches and counting the numbers of specimens, the densities of the remaining invertebrate macrobenthos species in each strip were calculated. In those studies where a t_0-sampling had taken place with a box corer or Van Veen grab sampler, a t_1-sampling was carried out in a similar way.

During the experiments, side-scan sonar (see chapter 2.3) was used intensively. Before t_0-sampling the study strips were checked with side scan sonar to detect obstacles at the seabed and to get an impression of recent trawling activities in the area. Immediately after sampling or trawling, the positions of the t_0- and t_1-sampling with the Triple-D as well as the tracks of the commercial trawls, were checked. The actual length and the width of the trawled strips were determined: the mean trawling intensities in the strips appeared to range from 100 to 200% (about 300% in the heavily trawled strips). Fig. 2.5.2 shows side scan sonar recordings of tracks of different types of commercial gears as well as of the Triple-D. The t_1-samples that appeared to be situated in sections of the strip that were not trawled, were excluded from the calculations of mortality.

The total direct mortality (M_{dir}) is calculated using the difference between the initial density of the species in the trawl track and the density of the remaining, surviving animals. The density of surviving animals is the sum of the t_1-density recorded in the strip and the number of (larger-sized) animals that survived being caught and discarded by the commercial trawler some miles outside the strip.

$$M_{dir}(\%) = 100 * \frac{D_{t0} - [D_{t1} + C * (1 - 0{,}01 * M_{dis})]}{D_{t0}}$$

D_{t0} = density in the strip before trawling (t_0-sampling; n/m^2)
D_{t1} = density in the strip after trawling (t_1-sampling; n/m^2)
C = number of animals caught in the commercial trawling (n/m^2 swept area)
M_{dis} = mortality among animals caught in the commercial trawling of the strip (% of catch; see 2.5.1).

The differences in the geometric mean initial and remaining densities were statistically tested (t-test on log-transformed data) and the 95% confidence intervals of the differences were calculated.

Total direct mortality could be calculated in this way under the assumption that all mortally damaged or exposed animals in the strip were consumed by predators in the 24-48 hours interval between trawling and t_1-sampling. Because migration of highly mobile epibenthic species in this interval can be expected, mortality could not be determined reliably for such species, like *Pagurus bernhardus, Asterias rubens, Liocarcinus holsatus, Psammechinus miliaris, Cirolana borealis* and shrimp species. For the heart urchin *Echinocardium cordatum*, the measured mortality was corrected for the proportion of the population actually in reach of the Triple-D, under the assumption that no mortality due to trawling occurs in the specimens living too deep to be caught in the Triple-D. Based on literature data (Bergman & Hup 1992) and additional unpublished NIOZ-data, the mean depth frequency distribution of the heart urchin was estimated. This provided an estimate of the proportion of the population in reach of the Triple-D: about 25% of the population in sandy areas and about 60% in silty areas. In the reproductive season, however, the urchins will migrate to the surface layers of the sediment and the majority of the population will be in reach of the dredge. Because the Triple-D itself damages the majority of the heart urchins caught and full numbers in the catch cannot be counted, the t_0-density could not be estimated with this sampling gear.

For each species, total direct mortality was calculated per trawl type and sediment type (coastal sandy sediments and offshore silty sediments). Replicate results, i.e. strips in which the same trawl type was studied in the same type of sediment, were averaged after a weighing based on the 95% confidence intervals. Mortality was not calculated, when the initial density of a species was less than 5 per 100 m^2 (Triple-D sampling) or less than 10 per m^2 (boxcore sampling). Mortalities in the heavily trawled (about 300%) strip could be compared to those in the normally trawled (about 200%) 12m beam trawl strips only in a few studies in which both treatments were applied. To compare the mortalities due to two different types of commercial trawls, the only studies used were those in which parallel strips were trawled with both types of gears.

To determine the relative vulnerability of invertebrate species, the species have, in each study and for each trawl type, been ranked according to the mortality estimates. The species have been sorted according to their mean ranking. The species with the highest mean rank number is the most vulnerable.

Irish Sea

Total direct mortality due to a Nephrops otter trawl was studied in two study sites, on one or two parallel strips with a length of about 1500 m and a width of about 40 m. The offshore site (depth 75 m) was very heavily trawled by commercial *Nephrops* trawlers, the inshore site (depth 35 m) was fished less frequently, primarily at dawn and dusk. Initial positioning and later repositioning of the transect strips was achieved by means of a differential global positioning system (DGPS). ROV video was used as confirmation when relocating the trawl strips. The standard procedure for the Day grab sampling at both the offshore and inshore stations was:

(1) 10-20 samples were each taken in one or two strips, with the Day grab to estimate the initial density of invertebrate macrobenthic species (t_0-sampling). Grab samples were sieved on a 1 mm mesh and fixed in 10% phosphate-buffered formalin. In the laboratory grab samples were sorted for their macrofauna and identified to species level, where possible.

(2) Within 24 to 48 hours after the t_0-sampling, commercial trawling of the strips took place with the *Nephrops* otter trawl. In general, the strips were trawled with a mean trawling intensity of 200%.

(3) At least 24 hours after the commercial trawling, the remaining fauna in the strips was sampled with the Day grab. Between ten and twenty samples were taken in the strips (t_1-sampling). These samples were also sieved on a 1 mm mesh and fixed in 10% phosphate-buffered formalin. In the laboratory grab samples were sorted for their macrofauna and identified to species level, where possible.

An attempt was made to calculate the direct mortality of invertebrate species based on the densities in the strips, before and after trawling. Direct mortality is equal to the difference between the initial density and the density of the remaining, surviving animals. Because migration of highly mobile epibenthic species cannot be excluded, the mortality could not be determined reliably for such species. For the prawns *Nephrops norvegicus,* the proportion of the population actually in reach of the sampling gear is not known, so estimates of direct mortality were not possible.

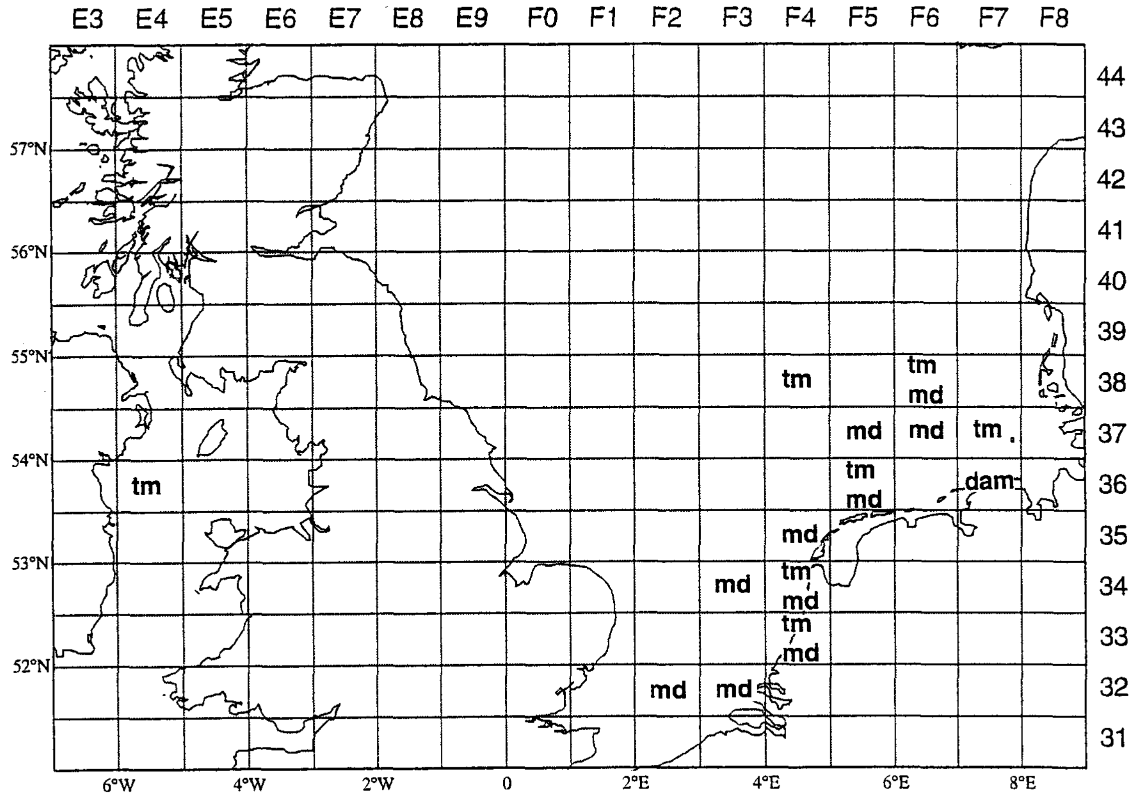


Fig. 2.5.1. Locations of field studies on mortality of discards, damage to invertebrates and total direct mortality. tm = total direct mortality of invertebrates; md = mortality of discards; dam = damage to invertebrates.

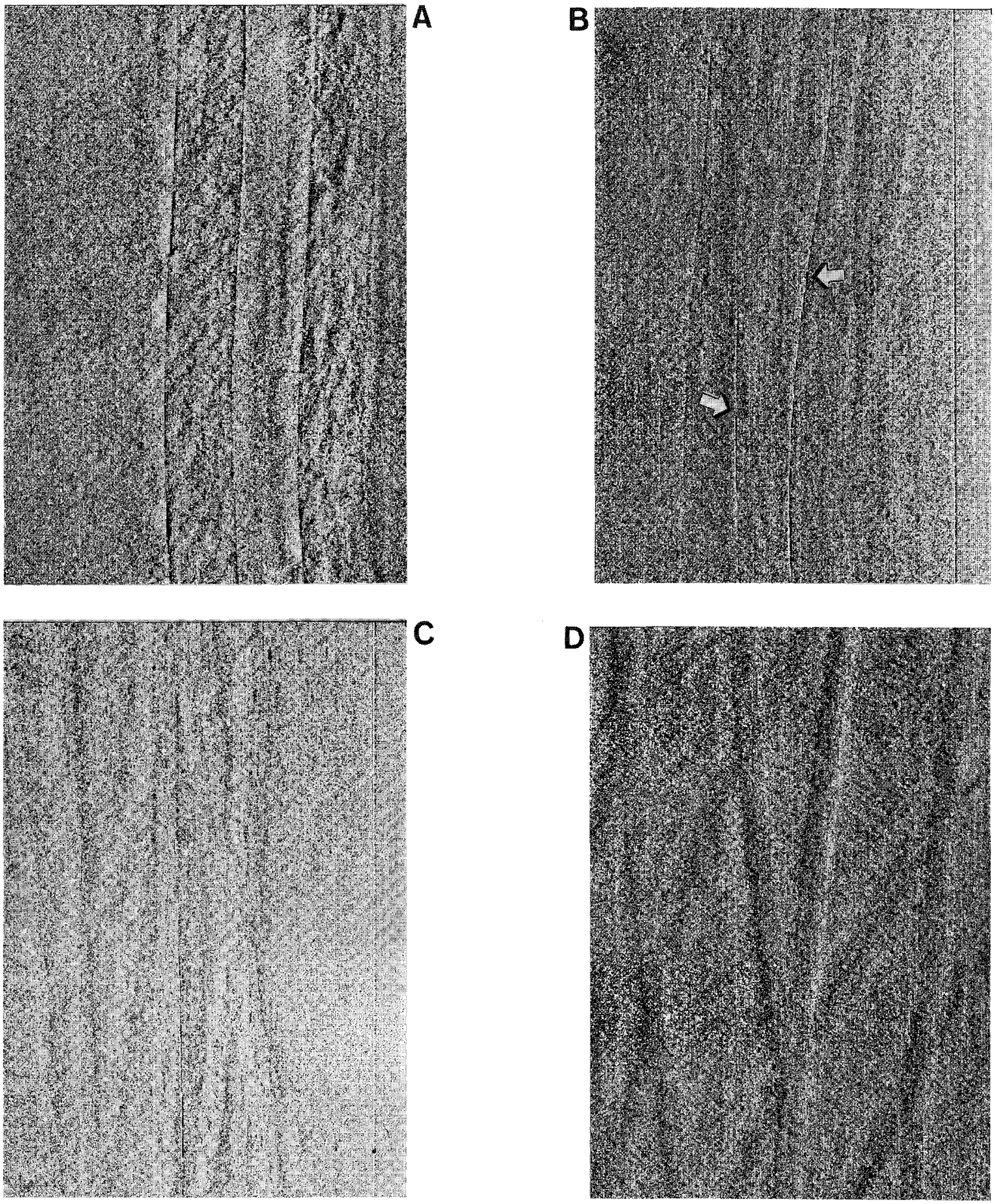


Fig. 2.5.2. Side-scan sonar recordings of trawled strips with different types of trawls and tracks of the Triple-D:

a. tracks of two 12m beam trawls (port and starboard);
b. strip trawled with 12m beam trawls (trawling intensity ca. 150%), after t1-sampling (tracks of Triple-D indicated by arrows);
c. strip trawled with 4m beam trawls (trawling intensity ca. 150%);
d. area heavily fished by commercial 4m beam trawlers.

TABLE 2.5.1

Field studies on the mortality of discards, the damage of invertebrates and the total direct mortality due to trawling . 4 TBB = 4m beam trawl; 4 TBBm = 4m beam trawl + matrix; 12 TBB= 12m beam trawl; 7 TBB = 7m beam trawl; OTB = otter trawl; OTBn = *Nephrops* otter trawl. tm = total direct mortality of invertebrates; md = mortality of discards; dam = damage to invertebrates.

Area	ICES quadrant	Water depth m	Grain size µm	Silt %	Year	Month	Commercial gear	Study item	Study nr
NORTH SEA (sandy)									
Dutch coast south	33F4	20	370	1	1994	June	4TBB,4TBBm	tm	S26
					1995	September	4TBB,12TBB,4TBBm	tm	S27
Dutch coast north	34F4	20	100-200	~5	1993	April	4TBB	tm	S28
Dutch Wadden coast	36F5	24	205-280	1-8	1992	June/July	4TBB	tm	S29
					1994	June	4TBB,12TBB,4TBBm	tm,md	S30
Belgium/Dutch sector	32F2, 32F3	10-40	250->350	<2	1992	Spring	4TBBm	md	S31
					1993	Spring	4TBBm	md	S32
					1995	Autumn	4TBBm	md	S33
Dutch coast north	33F4,34F4,35F4,34F3	10-25	175-350	<2	1992	Spring	4TBB, 12TBB	md	S34
					1993	Spring	4TBB	md	S35
					1993	Autumn	4TBBm, 12TBB	md	S36
					1995	Autumn	4TBBm	md	S37
German Bight	37F7	25	225	8	1994	September	4TBB,12TBB,OTB	tm	S38
North Sea	36F7	25	sandy	-	1993	May	7BT	dam	S39
NORTH SEA (silty)									
Oystergrounds	38F4	43	155-170	0.6-9	1992	March/April	12TBB	tm	S40
					1993	September	12TBB	tm	S41
					1994	September	4TBB,12TBB,OTB	tm	S42
Weisse Bank	38F6	45	~150	5-10	1995	May	4TBB, 12TBB,OTB	tm	S43
German Bight	36F5,37F5,37F6,38F6	20-40	150-<250	2-15	1995	Autumn	4TBBm, OTB	md	S44
IRISH SEA (muddy)									
western Irish Sea	36 E4 inshore	35	10-100	45-55	1995	May	OTBn	tm	S45
					1996	April, May	OTBn	tm	S46
western Irish Sea	36E4 offshore	75	10-100	45-55	1995	May	OTBn	tm	S47
					1994	May, June	OTBn	tm	S48
					1995	August	OTBn	tm	S49

TABLE 2.5.2

Sampling gears used in this study.

type of gear	sampling depth cm	sampling size m^2	mesh opening mm	target species
Reineck boxcorer	15 - 20	0.06	1 (sieve)	small in-/epi fauna
VanVeen grab	8 - 15	0.2	5 (sieve)	small in-/epi fauna
Day grab	8 -15	0.1	1 (sieve)	small in-/epi fauna
Triple-D	10	30	14	large in-/epi fauna
Kieler Kinderwagen	1-5	1000	10	in/epifauna

2.6. SCAVENGER RESPONSES TO TRAWLING

Introduction

Trawling inevitable results in the mortality of many non-target benthic species (van Beek *et al.* 1990; Kaiser & Spencer 1995; see also chapter 3.6). Mortality occurs via two pathways, discard mortality and non-catch mortality. Consequently trawling generates carrion which becomes available as food for scavengers. Some of the discards are eaten by seabirds (Furness *et al.* 1988; Hudson & Furness 1988; Camphuysen *et al.* 1995) while those that sink to the seabed become available to benthic scavengers. Those animals that are damaged by the trawl but remain on the seabed also become potential food for benthic scavengers; in addition, some animals become more vulnerable to predation as a result of sublethal physical damage caused by the trawl.

The importance of fisheries-derived carrion to benthic scavengers was investigated in the North Sea and Irish Sea using a variety of techniques.

2.6.1. FIELD INVESTIGATIONS

2.6.1.1. REPEATED TRAWLING

General Methodology

To test the hypothesis that predatory and scavenging species migrate into areas disturbed by bottom fishing gears, changes in the abundance of mobile epibenthic species were measured using repeated trawling before and after creating a fishing disturbance using a commercial trawl. In some of the studies, certain species of fish and invertebrates were retained from catches before and after creating the disturbances with the commercial gears, and changes in their food consumption and dietary composition ascertained (Stomach contents analyses: 2.6.1.4). Details of dates and locations of all the studies mentioned below are given in Figs. 2.6.1, 2.6.2 and Table 2.6.1.

Eastern Irish Sea

At each of three sites a trawling disturbance was created by fishing a 1.5 km treatment wayline 10 times using a 4m commercial beam trawl fitted with a chain matrix, flip-up ropes and an 80 mm diamond mesh cod-end. All fishing operations were conducted using the RV CORYSTES. At each site up to 6 replicate 2.8m beam trawl tows (Table 2.6.1) were completed on one or two control (un-fished) waylines and a treatment (fished) wayline, before and at intervals (about 24 h) after fishing the treatment wayline with the commercial 4m beam trawl (for precise details see Ramsay *et al.* 1996).

Western Irish Sea

These studies were performed in the *Nephrops* trawl grounds in the Irish Sea. A preliminary experiment to investigate migration of scavengers and predators into an area following trawling was conducted. A 3 km wayline was trawled with a modified otter trawl (mouth of net 18 m wide, 70mm diamond meshed codend, knot to knot) by the RV LOUGH BELTRA. The codend of the trawl was fitted with an outer 20 mm mesh cover to assess the abundance of smaller scavenging species. This wayline was then repeatedly trawled until an area of the seabed had been completely swept by the gear twice. The cover was left open during this period to allow undersized and damaged animals to pass through the meshes of the main net, and then retrawled 3 h and 72 h later with the cover closed.

In the following year, a fishing disturbance was created along 2 waylines, with two adjacent control waylines at a distance of about 500 m on either side. Initially, 2 or 3 tows, each of 10 min. duration were made with a 3m beam trawl, fitted with a 20 mm meshed codend liner, along each of the control and treatment waylines (5 tows in total on either treatment or control). The two treatment transects were then trawled using an otter trawl as before. The sampling protocol with the 3m beam trawl was then repeated 24 and 48 h after the completion of otter trawling. Once these samples had been collected, both control and treatment waylines were fished with the otter trawl to collect larger, less common, mobile scavenging species.

This study was repeated in 1996, when a fishing disturbance was created along only one wayline such that the seabed had been completely swept 4 times. Only 3 replicate samples were collected from the two adjacent control waylines.

Southern North Sea

At each location, a fishing disturbance was created using a small otter trawl (mouth of net 20 m wide, 80 mm diamond meshed codend) were studied on the Weisse Bank. On each of 3 consecutive days, the same wayline was trawled 3 times with a commercial otter trawl fished from the RV WALTHER HERWIG III. After an interval of 4 h, this line and adjacent untrawled areas were alternately trawled with the same otter trawl. Thus over the 3 days 9 tows were collected from disturbed and undisturbed areas.

At the 'Impact Box' a wayline was repeatedly trawled by the RV SOLEA using a 7m commercial beam trawl on two separate occasions. Towing speeds varied between 2.5-4 knots, and tow duration between 45-60 min. Changes in the abundance of epibenthic and fish species were recorded.

In another study, repeated trawling of a wayline with commercial 4m and 12m beam trawls was carried out at four locations in 1992 and 1993, with the aim of estimating the catch efficiency of commercial trawls. The 4m and 12m beam trawls were fished from the RV ISIS and RV TRIDENS, respectively. At the end of the first tow, the ship realigned so that the area left undisturbed between the trawls was swept by the gear on the return passage. Samples were collected with a fine-meshed 3m beam trawl before trawling and immediately afterwards.

In 1994 and 1995 a similar program was carried out with 12m beam trawls at 6 different locations. A treatment line was trawled 4-5 times (8-10 tows) with the 12m beam trawls as described before, leading to an estimated 2.5 to 3.5 times disturbance of the total surface. Samples with 3m beam trawl were collected 24 h before creating the fishing disturbance with the commercial gear, immediately afterwards and then at time intervals of about 12 and 24 h afterwards over a period of 2 to 4 days. In 1994 sampling with 3m beam trawl was restricted to single hauls over the treatment line and the control (reference) area. In 1995 replicate hauls were made with the 3m beam trawl. The 3m beam trawl was fitted with a meter wheel that measured the distance trawled over the bottom and allowed to estimate the surface swept by each haul.

From sampling in 1994 it became apparent that catches with fine-meshed 3m beam trawl in the morning were often lower than in the evening, hence to avoid diel variations in catchability all sampling was only undertaken in the evening during the experiments conducted in 1995.

Changes in the density of animals were expressed as a proportion of the untrawled density, estimated for animals caught in the initial 3m beam trawl tows prior to creating the fishing disturbance together with the estimates on the untrawled reference area. Thus the data are expressed as relative densities, values > 100% indicate immigration, those < 100% indicate depletion or emigration.

2.6.1.2. BAITED TRAPS

In order to identify scavenging benthic predators, baited traps of different types were used in the Irish Sea and in the southern North Sea. The selectivity of traps is highly variable. Therefore different types of traps (Fig. 2.6.3) were deployed to catch epibenthic predators or potential scavengers. Following initial trials the traps selected for use are indicated in Fig. 2.6.3, f, g, h, i. Traps were usually set for two days, for at least two tides and included one night, in order to compensate for effects of tidal currents or diurnal effects (see legend Fig. 2.6.2).

Traps were baited with different kinds of typical discarded material, and unbaited traps were included as controls. Duration of soak time (absorbing time) and the effect of distance from the shore were also examined.

For some sites an 'area of attraction' was calculated. Mean background densities of scavengers were estimated from catches from 3m beam trawl or benthos dredge samples. Numbers of animals caught in the traps were divided by their estimated density per m² in the vicinity of the traps, to estimate the area of attraction.

2.6.1.3. *IN SITU* OBSERVATIONS

Various methods were used to directly observe scavengers as they fed on discards. The rate of consumption of discards on the seabed was also investigated.

Scavengers feeding on discards - Eastern Irish Sea

Stills cameras with a time-lapse setting were deployed at 3 different sites in the Irish Sea baited with dragonets (*Callionymus lyra*) attached directly below the camera.

Video cameras baited with dead dragonets were also used to record the behaviour of scavengers feeding on discards in more detail (Ramsay *et al.* 1997b). For the first deployment the camera frame was baited with 6 dragonets and the following night the camera frame was baited with one dragonet to study the effects off the amount of carrion present. Numbers of hermit crabs (the main scavenger), feeding success and aggressive interactions were all examined in relation to crab size.

Scavengers feeding on trawl tracks - Eastern Irish Sea

The numbers and activities of scavengers along two transect lines (one treatment and one control) were recorded by divers before and after fishing the treatment line with a commercial scallop dredge (Red Wharf Bay). The dredging disturbance was created by a commercial scallop boat fishing eight scallop dredges each with a width of about 0.75 m.

Divers recorded numbers of mobile macrobenthic species within areas measuring 5 m by 2 m; for each species the number feeding were recorded and for the feeding individuals their food was also noted. A similar diver survey was carried out one year later, this time using a 4m beam trawl to create the fishing disturbance.

***In situ* consumption of discard fish by scavengers in the southern North Sea and rate of decay**

A separate set of experiments were carried out in the North Sea, to examine the rate of consumption of discards. Weighted fish were attached to nylon lines and lowered to the seabed. The fishes were retrieved after 1, 2 or 3 days of exposure. The rate at which these fish were consumed was measured by weighing the fish beforehand and also inspected on retrieval for signs of scavenger activity.

The rate of decay of dead fish (dab and whiting) was estimated in tanks with running seawater on board ship at the ambient seawater temperature and in the laboratory, at constant temperatures of 5, 10 and 15° C.

2.6.1.4. STOMACH CONTENTS ANALYSIS

Eastern Irish Sea - Beam Trawl

The investigation of the effects of beam trawling in the eastern Irish Sea concentrated on the diets of two hermit crab species, *Pagurus bernhardus* and *Pagurus prideaux* (Ramsay *et al.* 1996). A detailed review of the sampling design is given in Section 2.6.1.1. In April 1995, hermit crabs were collected from each 2.8m beam trawl catch and stored frozen. In the laboratory animals were defrosted and for each individual, thorax length was measured to ± 1 mm and the stomach was dissected out. Stomach contents were examined using a microscope and the points method (Hynes 1950; Williams 1981) was used to estimate the volumetric abundance of different phyla. The stomach contents of 20 randomly chosen crabs were analysed per treatment (fished or unfished control) on each day and the data pooled. For details of the statistical analyses used see Ramsay *et al.* 1996.

Stomach contents were filtered and dried at 60°C and weighed. Differences in the relationship between crab size (thorax length) and dry weight of stomach contents were calculated (Ramsay *et al.* 1996). In October 1995 the sampling protocol was repeated at the same site, but on this occasion, only changes in hermit crab size frequency distribution (based on the height of the right cheliped) was examined.

Western Irish Sea - Otter Trawl

Representative samples of the most abundant species present were collected before, and at intervals following, trawling (2.6.1.1). On return to the laboratory, approximately 60 each of whiting (*Merlangius merlangus*), haddock (*Melanogramus aeglefinus*), and *Nephrops* from each trawl were defrosted for analysis of stomach contents. For fishes, stomach fullness was noted on a scale from 0 (completely empty) to 5 (completely full) while the state of the gut contents was recorded using a scale ranging from 0 (empty) to 3 (intact prey). The stomach filling index (SFI) was also calculated (Hyslop 1980). Prey items were then removed, separated into phyla and weighed. Where possible, these were than identified to species level and their numbers recorded. *Nephrops* were defrosted and the foregut was dissected out. Prior to examining the contents, the degree of fullness of the foregut was estimated using the method decsribed by Wienberg (1980). A scale of 4 degrees was used to estimate the stomach fullness: 0 = Empty stomach; 10 = fullness of up to 10%; 50 = Stomach clearly more than 10% full but less than 50%; 100 = Full and bulging.

Southern North Sea - Otter Trawl

Possible dietary changes in fishes following otter trawling were investigated on the Weisse Bank in May 1995. Two size classes of dab (size range 12-16 cm and 19-25 cm) and one size class of grey gurnard (19-25 cm) were collected from 9 hauls taken in both the treatment and the control area over 3 consecutive days. Length and weight of each fish were measured on board and the stomach and gut were dissected out and fixed. A total number of 1600 stomachs were collected, and their contents weighed and where possible, identified to species level and SFI was estimated (Hyslop 1980).

Southern North Sea - Beam trawl

In 1992 dab, plaice and grey gurnard were collected for stomach contents analysis using the methods described above. Fish were also collected in spring and autumn in 1994 and 1995 from RV TRIDENS. Prey items were identified to species level, food composition was determined to ascertain dominance (number of a given prey specimen ingested as a fraction of the total number of prey specimens ingested) and occurrence (the fraction of fish in which the given prey species appears) (Hyslop 1980) and SFI was calculated.

2.6.2. LABORATORY INVESTIGATIONS

2.6.2.1. FEEDING & GROWTH OF SCAVENGERS

Estimates of the length-weight relationships and ash-free dry weight

The ash-free dry weight (afdw), and in some cases the relationship between size and weight, of different species of invertebrates was determined from frozen or fresh animals. Different parameters were used for body dimensions in the length-weight relationships: for fish total length; for starfish the total diameter between the tips of the stretched arms; for sea urchins the test diameter without spines; for ophiurids the oral disc diameter; for crabs carapax width; for hermit crabs the length or height of the largest claw (chela).

Further laboratory measurements of metabolism, food consumption and growth were carried out with selected species that showed scavenging behaviour in the field. These animals were stored in temperature controlled seawater tanks (2.5x0.6x0.6 m) with running seawater. They were regularly fed with fresh mussel meat *(Mytilus edulis)* or shrimp *(Crangon crangon),* and measurements were started after a period of about 1 month for acclimatisation to laboratory conditions and different constant temperatures.

Measurements of daily food consumption

Animals were held in constant temperature conditions, either single or in groups with a seawater supply flowing to waste. Animals were fed with weighted excess rations of food. Excess food was collected and weighed the next day, together with a control ration kept in a tank without animals for measurement of the change in weight of the food in seawater over the measuring period. Daily food consumption and growth were measured over periods of 1 to 4 weeks at each constant temperature according to methods described in Fonds *et al.* 1992b, using three different kinds of food: fresh mussel meat *(Mytilus edulis)*, deep frozen shrimp *(Crangon crangon)* or fresh fish (dab, plaice or dragonet).

Measurements of growth

In some experiments with starfish *(Asterias rubens)* and hermit crabs *(Pagurus bernhardus)* the relation between food ration and growth was estimated. Single animals were given different rations and growth plotted against food consumed, in order to estimate the efficiency of conversion of food into growth (Brown 1957). The maximum growth rate of different species was measured using standard techniques (Warren & Davies 1967; Fonds *et al.* 1992a) at different constant temperatures over periods of 4 weeks. The relationship between daily food consumption, growth and body weight was determined.

2.6.2.2. BEHAVIOUR OF SCAVENGERS IN THE LABORATORY

Video recording of feeding behaviour in the laboratory

The feeding behaviour, speed of movement (only *Asterias rubens*) and competitive behaviour of swimming crabs, hermit crabs, whelks and starfish was studied in a large sea water tank. Typical discard material was offered to groups of these species. The movements and interactions of the animals were recorded by time-lapsed video over 3 to 4 days, with a period of starvation of at least one day between trials.

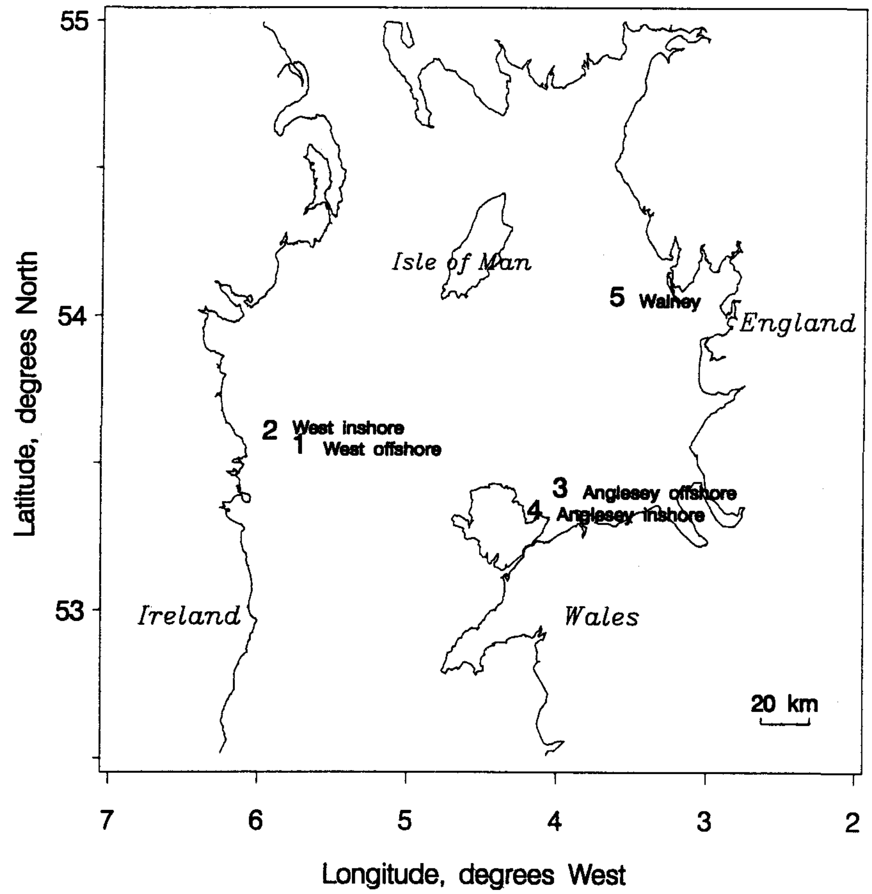


Fig. 2.6.1. Map of the Irish Sea showing the geographical positions of experimental sites. Dates and positions in the table below.

Nr on map	Year	Date	Net	Ship (R.V.)	Position North °N	Position North min.	Position East °E	Position East min.	Depth m	exposure hrs	exposure n
Stations for repeated trawling											
1	1994	29-1/1-11	OTTER T.	LOUGH BELTRA	53	36.52	5	45.19	72		
1	1995	29-8/2-9	OTTER T.	LOUGH BELTRA	53	37.08	5	46.03	70		
1	1996	(10-15)-4	OTTER T.	LOUGH BELTRA	53	36.60	5	45.04	71		
1	1994	29-10	4 m BT	CORYSTES	53	36.5	5	45.2	72		
1	1995	29-8	4 m BT	CORYSTES	53	37.1	5	46.0	70		
1	1996	10-4	4 m BT	CORYSTES	53	36.6	5	45.0	71		
3	1995	24-4	4 m BT	CORYSTES	53	26.5	4	01.7	39		
3	1995	27-10	4 m BT	CORYSTES	53	26.5	4	02.8	39		
4	1995	28-4	4 m BT	CORYSTES	53	21.6	4	11.5	145		
5	1995	2-11	4 m BT	CORYSTES	54	05.1	3	40.7	37		
Stations for baited traps											
1	1995	31-8	TRAPS	LOUGH BELTRA	53	35.33	5	45.60	72	24	16
2	1996	29-4	TRAPS	LOUGH BELTRA	53	38.14	5	58.47	34	24	54
3	1995	26-4	TRAPS	CORYSTES	53	26.60	4	00.60	41	25	10
3	1995	27-4	TRAPS	CORYSTES	53	26.60	4	00.64	41	31	10
4	1995	28-10	TRAPS	CORYSTES	53	21.07	4	00.76	24	23	10
4	1995	29-10	TRAPS	CORYSTES	53	21.08	4	00.78	25	48	10
5	1995	2-11	TRAPS	CORYSTES	54	05.43	3	40.13	33	24	10
3	1996	6-4	TRAPS	CORYSTES	53	26.60	4	00.74	43	26	10
3	1996	8-4	TRAPS	CORYSTES	53	26.55	4	00.68	42	22	10
Stations with baited cameras										hours	
1	1994	29-9	CAMERA	CORYSTES	53	26.19	4	02.01	38	17.3	
1	1996	6-4	CAMERA	CORYSTES	53	26.60	4	01.46	43	47.7	
2	1995	28-10	CAMERA	CORYSTES	53	22.1	4	12.18	24	75.6	
3	1995	2-11	CAMERA	CORYSTES	54	05.11	3	42.67	37	22.9	
3	1995	2-11	CAMERA	CORYSTES	54	05.64	3	39.64	32	14.1	

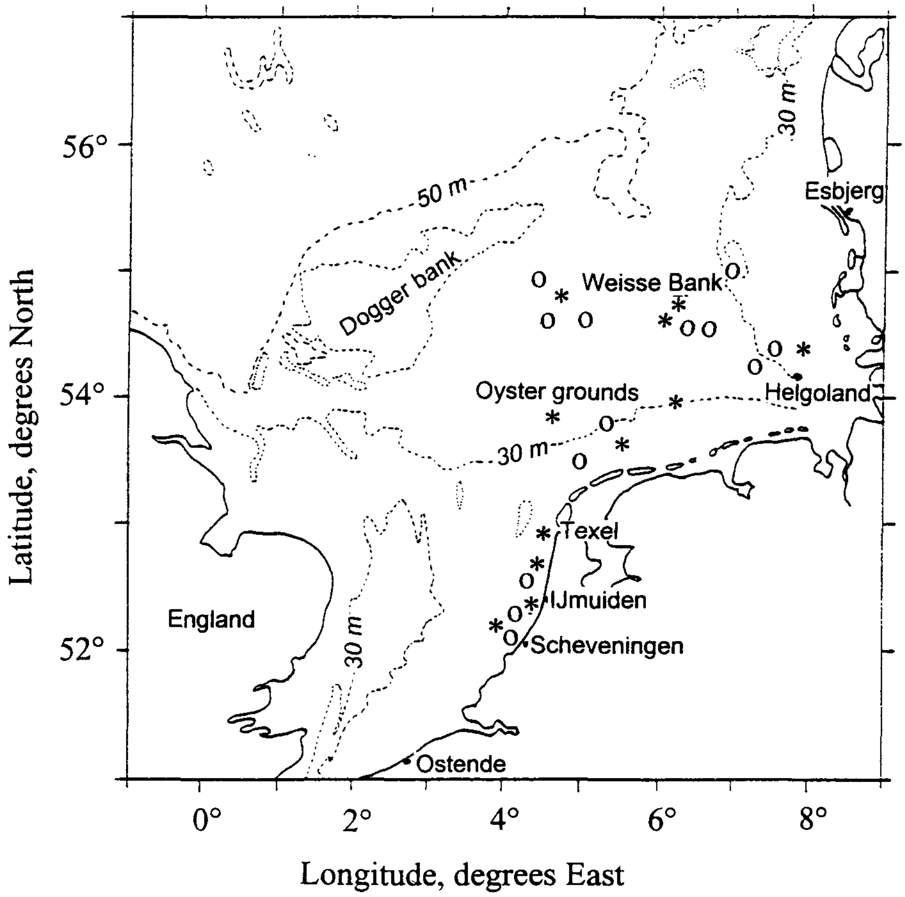


Fig. 2.6.2. Map of the southern North Sea showing the locations for repeated trawling (o) and for baited traps (*). Dates and positions below.

Nr.	Year	Date	Net	Ship (R.V.)	Position North °N	min.	Position East °E	min.	Depth m		
Stations for repeated trawling										Direction	
1	1992	25-6	4 m BT	ISIS	53	24.14	5	4.20	24	20-200	
2	1993	27-4	4 m BT	ISIS	52	37.51	4	33.11	15	20-200	
3	1992	2-4	12 m BT	TRIDENS	54	30.45	4	41.45	45	90-270	
4	1993	15-9	12 m BT	TRIDENS	54	32.28	5	66.04	44	50-230	
5	1994	8-6	12 m BT	TRIDENS	53	44.00	5	22.21	30	90-270	
6	1994	14-6	12 m BT	TRIDENS	52	13.30	4	12.24	20	30-210	
7	1994	31-8	12 m BT	TRIDENS	54	22.30	7	35.18	24	95-275	
8	1994	5-9	12 m BT	TRIDENS	54	57.24	4	39.18	42	90-270	
9	1995	3-5	12 m BT	TRIDENS	54	34.54	6	15.45	41	92-272	
10	1995	11-9	12 m BT	TRIDENS	52	13.03	4	9.42	20	26-206	
11	1992	22-9	7 m BT	SOLEA	54	12-14	7	06-30	35	90-270	
12	1995	16-8	OTTER T.	W.HERWIG	54	28-38	6	15-23	40	170-350	
Stations for baited traps										exposure days	n traps
1	1994	7-6	TRAPS	TRIDENS	53	42.6	5	23.1-24.8	30	2	14
2	1994	14-7	TRAPS	TRIDENS	52	11.3	4	9.26	19	2	7
3	1994	2-9	TRAPS	TRIDENS	54	23.8	7	47.45	25	2	35
4	1994	7-9	TRAPS	TRIDENS	54	42.9	4	42.9	42	2	35
5	1994	18-10	TRAPS	NAVICULA	52	53.1	4	41.0	8	2	15
6	1995	14-2	TRAPS	PELAGIA	54	28.5	6	7.9	41	2	19
7	1995	8-3	TRAPS	PELAGIA	52	48.1-2	4	31.5	22	2	20
8	1995	2-5	TRAPS	TRIDENS	54	36.0	6	17.0-9	40	1-3	45
9	1995	8-5	TRAPS	TRIDENS	53	55.8-56.3	6	12.2	30	1-3	45
10	1995	22-8	TRAPS	NAVICULA	52	21.3-24.4	4	7.2-31.5	8-19	1	12
11	1995	5-9	TRAPS	TRIDENS	52	13.2-18.3	4	7.1-18.6	22	2	36
12	1995	12-9	TRAPS	TRIDENS	52	14.7	4	6.6	22	1-3	36
13	1995	13-9	TRAPS	TRIDENS	52	12.8	4	4.9-5.4	22	2	21
12	1995	19-9	TRAPS	TRIDENS	52	12.7	3	37.9-38.5	28	2	36

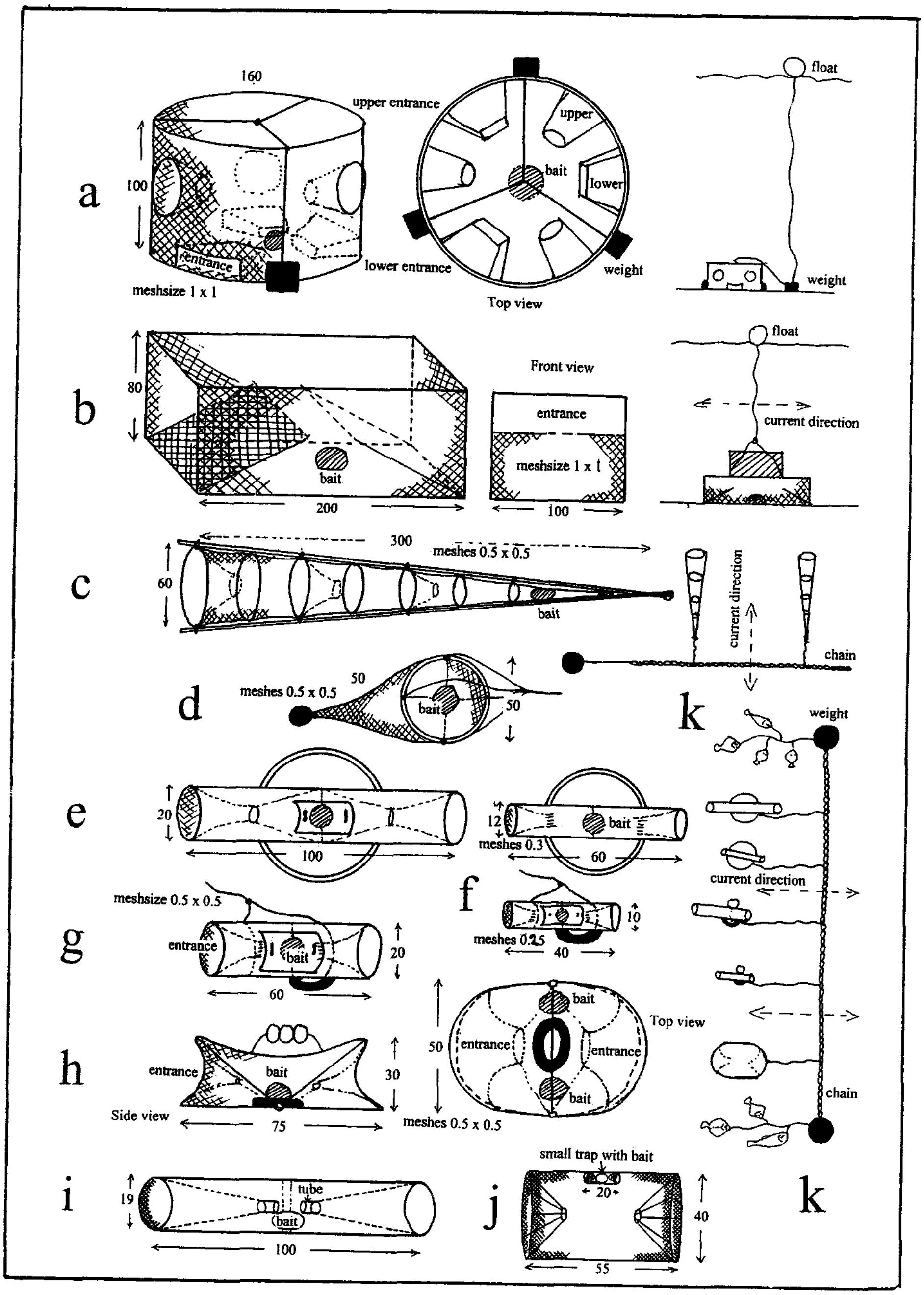


Figure 2.6.3. Different kinds of traps used in the investigations on preference of scavenging species for different kind of bait.

a. Round cage with lower- and upper entrances;
b. Rectangle cage with sloping entrances;
c. Commercial small fyke net;
d. Small lift-net with bait attached in the middle;
e. Large perspex- or PVC- pipes, attached to iron ring;
f. Small perspex- or PVC- Amphipod pipes, attached to iron ring;
g. Short perspex tubes with assymmetrical attached weight;
h. Commercial Danish crab-trap, weighted in the middle and small floatsat the top. Two entrances and two bags with bait.
i. Trap type used in the eastern Irish Sea, entrances narrowed with tubes
j. Modified shrimp pot used in the western Irish Sea, with baited small trap inside for Amphipods.
k. General arrangement of traps on the sea bottom (top view).

TABLE 2.6.1

Details of the sites studied, the commercial gears used to create a fishing disturbance and the sampling gears used. CS/G/Sh = coarse sand gravel and shell debris, mS = medium sand, fMs = fine muddy sand, fS = fine sand.

Site	Date	Depth	Bottom type	No. Days sampled after initial disturbance	Protocol
IRISH SEA					
MAFF/UWB					
Anglesey offshore	04/95	40 m	cS/G/Sh	4	10 tows 4 m beam trawl to create disturbance, 6 replicate tows 2.8 m beam trawl on each of 2 control and 1 disturbance line
Anglesey offshore	10/95	40 m	cS/G/Sh	3	As above, but only 3 replicate tows on each of the 2 control lines
Red Wharf Bay	04/95	12 m	mS	1	As above, but only 1 control line
Walney Island	11/95	36 m	fMs	3	As above, but only 3 replicate tows on each of the 2 control lines
MRI					
Offshore site	10/94	75 m	fMs	3	2 tows otter trawl to create disturbance. 1 tow immediately prior to and 1 tow 3 and 72 h after creating the disturbance, using the same trawl.
Offshore site	08/95	75 m	fMs	2	2 tows otter trawl, total of 5 replicate tows 3 m beam trawl on treatment and control lines.
Offshore site	04/96	75 m	fMs	2	4 tows otter trawl, total of 6 replicate tows 3 m beam trawl on treatment line, 3 replicates on 2 control lines
NORTH SEA					
AWI					
Impact Box	06/92	35 m	mS	1	2 tows 7 m beam trawl
	09/92	35 m	mS	1	7 tows 7 m beam trawl
Weiße Bank	05/95	40 m	fS	3	3 tows otter trawl to create disturbance, 3 replicate tows otter trawl on treatement and control lines on 3 consecutive days
NIOZ					
N. of Vlieland	06/92	24 m	mS	1	12 tows with a pair of 4 m beam trawls.
Coast N. Holland	04/93	15 m	mS	2	8 tows pair 4 m beamtrawls, treatment and control line sampled by duplo hauls with 3 m beamtrawl before and afterwards, another two tows with 4 m beam trawl in morning and evening next day.
Oystergrounds	04/92	45 m	fMs	1	4 times trawling with pair of 12 m beam trawls (8 tows, last tow nr. 8 about 3 hrs after tow 7).
Oystergrounds	09/93	44 m	fMs	2	5 times trawling (10 tows) with pair of 12 m beam trawls. Duplo samples with 3 m beam trawl before and afterwards (4 tows) both on treatment line and reference area. Trawling the line with 12 m beam trawls again the next day (2 tows).
Oystergrounds	09/94	42 m	fMs	3	5 times trawled (10 tows) with 12 m beam trawls, single samples with 3 m beam trawl every 12 hours on treatment line and reference area.
N. of Terschelling	06/94	30 m	mS	2	5 times trawled with 12 m beamtrawls as above, single samples 3 m beamtrawl every 12 hrs.
Coast S. Holland	06/94	20 m	mS	3	5 times trawled 12 m beamtrawls as above, single samples 3 m beam trawl every 12 hours.
	09/95	20 m	mS	4	4 times trawled (8 tows) with 12 m beamtrawl, duplo samples every 24 hrs with 3 m beam trawl.
NW of Helgoland	08/94	24 m	fS	2	5 times trawled 12 m beam trawls (10 tows), single samples with 3 m beamtrawl every 12 hours.
Weiße Bank	05/95	41 m	fMs	4	4 times trawled (8 tows) with 12 m beam trawl, duplo samples with 3 m beam trawl every 24 hrs.

2.7. COMPARISON OF UNDISTURBED AND DISTURBED AREAS

Introduction

While the immediate and short-term effects of fishing disturbance on benthic communities have been examined for a number of habitats (de Groot 1984; Currie & Parry 1996; Kaiser & Spencer 1996a), longer term studies are particularly scarce in the literature (Hall *et al.* 1993a). The spatial and temporal variability in benthic communities invariably means that long-term effects are difficult to identify. Comparisons are usually between areas which are "fished" and "un-fished", but interpretation can be difficult since "un-fished" areas are usually un-fished precisely because they differ from fishing grounds. A variant on the above approach has been to investigate localised areas within fishing grounds that are protected in some way (i.e. by presence of a light ship, Graham 1955; or wreck, Hall *et al.* 1993a). Another possible approach is to examine fishing effects experimentally, in an area that has been closed to fishing for many years.

Three studies comparing undisturbed and disturbed areas to investigate the long-term effects of fishing disturbance were carried out, utilising two essentially different methodologies. The unique opportunity offered by a previously unfished Scottish sealoch was utilised to carry out a manipulative disturbance experiment. Two other studies used the approach of Hall *et al.* (1993a), employing areas of seabed "protected" from fishing by the presence of wrecks in the German Bight and Irish Sea, and making comparisons with the surrounding fished areas.

2.7.1. LOCH GARELOCH

Study site

Loch Gareloch, Inverclyde, Scotland, is a sheltered fjordic sealoch in the upper reaches of the Firth of Clyde (Fig. 2.7.1).The Loch is approximately 9 km long and averages less than 1.5 km wide, with an estimated volume of 261×10^6 m^3 at MHWS. Fresh water input is negligible. Tidal currents of up to 5 knots occur over the shallow (12 m) sandy sill at the narrow (350 m) entrance to the loch, but in the deeper water of the main loch currents are greatly reduced and the seabed is muddy. The close proximity of the loch to the Clyde Estuary allows for frequent intrusions of estuary surface water throughout the year, thereby enhancing nutrient levels (Mackay & Halcrow 1976). Such frequent intrusions appear to inhibit bottom water stagnation and the associated reduction in dissolved oxygen concentrations that are recorded in other Clyde sea lochs (Edwards *et al.* 1986).

Owing to the presence of the R.N. Faslane Clyde Submarine Base, fishing in the loch is presently prohibited by the Inshore Fishing (Prohibition of Fishing and Fishing Methods) (Scotland) Order 1989. Prior to this Order, fishing was restricted by the Clyde Dockyard Port of Gareloch and Loch Long Order 1967. Anecdotal evidence suggests that although good catches of fish have been taken from the loch, very little trawling took place prior to the ban, and some areas may never have been trawled. The marine fauna supported by the loch has therefore remained undisturbed by fishing for over 25 years, and considerably longer than this in some places. The continued absence of fishing in the loch offers a unique opportunity to conduct a long term manipulative field experiment to examine the impact of fishing disturbance in a controlled manner. Through experimental manipulation of the site it has been possible to examine the changes in the benthos associated with an 16 month period of disturbance followed by an 18 month recovery period.

Survey procedure

A preliminary survey was carried out in Loch Gareloch in November 1993, during which treatment and reference areas were selected (Fig. 2.7.2), on the basis of similar depth (30-35 m), topography, epifauna and RoxAnn parameters. The sites chosen were to the sides of the loch, away from the deeper channel used by naval vessels. It is therefore thought very unlikely the propeller wash from such vessel would effect the seabed in the experimental areas in any way. Subsequent surveys were carried out one week later, and during May and October of 1994, 95 and 96 (Table 2.7.1). The same sampling techniques were used on each occasion.

Infaunal sampling was carried out using a 0.1 m^2 Day grab. Samples were washed over a 0.5 mm mesh, fixed in 5% formalin and preserved in 75% alcohol. The infauna were counted and identified to species where possible. From each grab, a small sample of sediment was collected for either organic carbon or particle size analysis. Organic carbon was determined using an elemental analyser. Granulometric samples were analysed by laser granulometry using a Malvern Mastersizer/E granulometer (Malvern Instruments). Underwater television surveys were carried out using a television camera mounted on a towed epibenthic sledge (Chapman 1985). The video signal was combined with a digital date/time signal and recorded for analysis. During the TV sledge tows the position of the vessel was recorded using differential GPS digitally logged every 15 sec, providing an accuracy of ± 15m. The locations of each animal seen on the video were later noted, and converted to densities using information on width of view and tow length.

Experimental trawling disturbance

Experimental trawling disturbance was carried out from a locally chartered fishing vessel (FV *Jeannie Stella*) using a modified rockhopper groundgear with no trawl attached. A gear diagram is provided in Fig. 2.7.3. Because of the repeated and intensive nature of the trawling activity we decided to conduct the experiment using a trawl with no net. The rationale for this decision was that the direct disturbance effects of the net are trivial compared to the rest of the gear, and that there was a risk that we would progressively deplete populations of scavenger species to low levels in the small and relatively enclosed loch if they were retained as catch. Since these scavengers are themselves potentially important mortality agents for exposed benthic fauna (Kaiser & Spencer 1994; 1996b) we felt that our experiment would be more realistic if their densities were preserved over the entire life of the experiment.

Trawling disturbance commenced in January 1994 and continued once per month until April 1995. Each disturbance event consisted of ten tows (approximately 45 mins duration at a speed of 2 knots) over the treatment area. Scanmar Netsonde units were deployed on the gear during two of the disturbance events and measured the distance between the trawl doors (the width of the disturbed track produced by each tow) to be 35-40 m, equating to 140-160% coverage of the treatment area on each day.

Experimental design

In analysing the effects of human activities on the environment, the basic Before/After, Control/Impact (or BACI) design of Bernstein & Zalinski (1983) and Stewart-Oaten *et al.* (1986) has been adopted by many researchers. Such a design involves replicated sampling over time (Underwood 1992). When multiple control and/or treatment sites are available, problems of spatial confounding (pseudoreplication, Hurlbert 1984) are avoided. Unfortunately, however, the unique size and nature of the present study (a site protected from fishing for almost 30 years) means that multiple control sites could not be established. Rather we were constrained to comparing a single impacted site with a single reference area. Such designs have been criticised as being only suitable to demonstrate differences between locations (Hurlbert 1984), and strictly speaking, this is certainly true. Such a design restrict statements about the effects of fishing outside Loch Gareloch. However, we feel that by following our experiment through a period of impact, followed by recovery, the conclusions we draw for this site are likely to be of wider relevance.

2.7.2. WEST GAMMA

Study site

The "West Gamma" is the wreck of an oil drilling platform which sank while on route to the Norwegian oil fields. The site location is 54°56.5′N 6°39.3′E, in the outer German Bight, approximately 60 nm northwest of Helgoland (Fig. 2.7.4).

The wreck sank in August 1990, in 43 m of water, reaching within 2 m of the surface at low water. As it presented a danger to surface navigation at this time, it was surrounded by four nautical buoys, enclosing an area of approximately 0.6 km² (Fig. 2.7.5). The area directly surrounding the wreck was protected from trawling activities by the size and the near surface position of the wreck as well as by the presence of the buoys. From May to August 1994 the wreck was cut off at 25 m below surface and subsequently the buoys were removed to remove the obstacle for surface shipping. Nevertheless the area around the wreck is still protected against trawling by the size of the wreck and by the scattered debris surrounding it.

Corresponding to the position of the study site on the side of the pleistocene Elbe River valley, the sediment is characterised by a gradient from silty fine sand in the western parts to medium to coarse sand in the east (Figge 1981; Fig. 2.7.5). The benthic fauna of the region is characterized by the *Amphiura filiformis* association sensu Salzwedel *et al.* (1985), and the area is subjected to average fishing activities (Polet *et al.* 1994), mainly fished with 12 m beam trawls.

According to the site-specific conditions the approach of Hall *et al.* (1993a) was modified. The "West Gamma" wreck and the protection of its surroundings by the buoys for four years provided the opportunity not only to compare fished and protected areas, but also to examine the development in the benthic community over a 5 year period since protection.

Survey procedure

Between August 1992 and August 1995 cruises with WWFS Atair (BSH Hamburg) and RV Victor Hensen (AWI Bremerhaven) were undertaken to carry out extensive grab and dredge sampling around the wreck (187 grab samples and 17 dredge samples; Table 2.7.1) in- and outside the protected area.

Infaunal samples were taken with 0.1 m^2 Van Veen grab, sieved on board (0.5 mm sieve) and stored in 5% buffered formalin. Samples were sorted, identified mainly to species level and counted in the laboratory. For every sample the depth of sediment in the grab and the sediment characteristics were recorded. In April and May 1994 a sediment core (10 cm^2 area and 10 cm depth) was taken from about every second sample for detailed sediment and organic carbon analysis. For a qualitative survey of the larger and more mobile fauna of a larger area, additional samples were taken in August and September 1992 and in April 1994 with a small frame dredge of 1 m width ("Kieler Kinderwagen") with 1 cm mesh size. The larger dredge material was partly identified on board, the remainder was preserved in 5% formalin for later identification.

2.7.3. IRON MAN AND 41 FATHOM FAST

Study site

Studies were carried out at two shipwreck sites in the Irish Sea *Nephrops* fishing grounds. *Nephrops* is a burrowing crustacean, and behavioural adaptions to ambient light levels mean that burrow emergence and therefore catch rates and fishing effort are highest at dawn and dusk in shallower grounds, and get closer to midday in deeper waters (Chapman 1980). This generally means that the shallower grounds are fished on the way to and from port while the deeper grounds are fished during the day, and are subject to greater effort.

The first wreck site, "Iron Man" is located at coordinates 53° 40.3'N 05° 59.22'W, on a muddy fine sand substrate in approximately 35m water depth (Fig. 2.7.1). Trawlers only fish this part of the *Nephrops* grounds at dawn and dusk, so the area is thought to be less heavily fished than the deeper areas. The second wreck site, "41 Fathom Fast", lies at coordinates 53°32.37N' 05° 43.79'W, on a sandy silt substrate in approximately 75 m water depth (Fig. 2.7.1), in a heavily fished area. While the exact date of sinking is not available for either wreck, anecdotal evidence suggests that both have been in place for more than fifty years and are avoided by all fishing trawlers.

The methodology employed at both sites involved the study of undisturbed (virgin) ground around a wreck (Hall *et al.* 1993a) and a comparison with fished grounds.

Survey procedure

Surveys were carried out in May 1995 ("Iron Man") and April 1996 ("41 Fathom Fast") (Table 2.7.1). Following location of each wreck, surveys by side-scan sonar, SCUBA diving (for the shallower site) and HYBALL ROV. Two Multibeacon transponder-responders were then positioned, one at either end of the wreck. A further Multibeacon was attached to the grab cable immediatly above the grab sampler. The system was interrogated by a Trackpoint II transceiver, which provides > ± 1 m accuracy in position fixing. Three transects, radiating out from the wreck into the *Nephrops* ground, were grab sampled. For the "Iron Man" site, transect length was about 400 m. Preliminary observations suggested this may not be sufficient to extend into the fishing area and for the "41 Fathom Fast" site transects of about 500-700 m were used. Six to eight stations with 2 grabs per station were included in each transect. Samples were also collected from the IMPACT II stations near to the wreck locations (see section 2.3) to allow for comparison with a fished area.

At both locations, samples were taken for both benthic macrofaunal identification and sediment grain size and organic carbon content. Sediment grain size distribution was assessed by the same method as used for Loch Gareloch, and organic carbon content was analysed by the chromic acid oxidation technique. Grab samples were sieved on a 0.5 mm mesh, on the deck of the research vessel, and fixed in 10% phosphate buffered formalin. In the laboratory they were sorted for their macrofauna and were divided into five major groups (polychaetes, molluscs, crustaceans, echinoderms and miscellaneous) and the biomass of each category measured after blotting dry on tissue paper. The fauna was then identified to species level, where possible.

To facilitate the investigation of possible changes along the transects from the wreck into the fished grounds, the samples taken from the different transects at a similar distance from the wreck were grouped together. At the Iron Man wreck, six replicates were used from each of three positions along the transects (Near 125 m, Middle 260 m, Far 400 m, distant from the wreck). At the 41 Fathom Fast wreck, three replicates were used from each of three positions along the transects (Near 50 m, Middle 250 m, Far 500 m).

2.7.4. DATA ANALYSIS

Data analysis was similar in each study, and the effects of fishing disturbance on infauna were examined in a number of ways. Changes in the total numbers of individuals, total number of species, total biomass, and abundance of selected individual species, using ANOVA (individual abundance data being ln x+1 transformed) or Box and Whisker plots and U tests. Measures of diversity were also calculated from the infaunal samples and examined for differences due to the effects of trawling.

If benthic assemblages respond to trawling disturbance by small, but consistent directional changes in the relative abundance of many species, this may not be identified by the above comparisons of univariate summary statistics. Such effects may, however, be detected using multivariate approaches (Field *et al.* 1982; Clarke 1993).The PRIMER statistical software was used to carry out multivariate analysis on the infaunal community data. A cluster analysis, using Bray-Curtis similarity index was performed on 4th root transformed data. From analysis of infaunal data the Bray-Curtis similarity index has been found to have high statistical power (Faith *et al.* 1991), and 4th root transformations are often recommended (Field *et al.* 1982; Clarke & Green 1988). The resultant similarity matrices were used to carry out non-metric multidimensional scaling, with differences between sites and dates tested with an *a priori* 'analysis of similarities' randomisation test (ANOSIM) (Clarke & Green 1988). In some cases the SIMPER routine was used to establish which species contributed most to similarity or dissimilarity between *a priori* groupings (Clarke 1993). *k*- dominance curves (Lambshead *et al.* 1983) were constructed to examine the species frequency distribution for each of the groups, and comparison of curves for abundance and biomass (ABC method, Warwick 1986) were used to assess levels of disturbance where species biomasses were available.

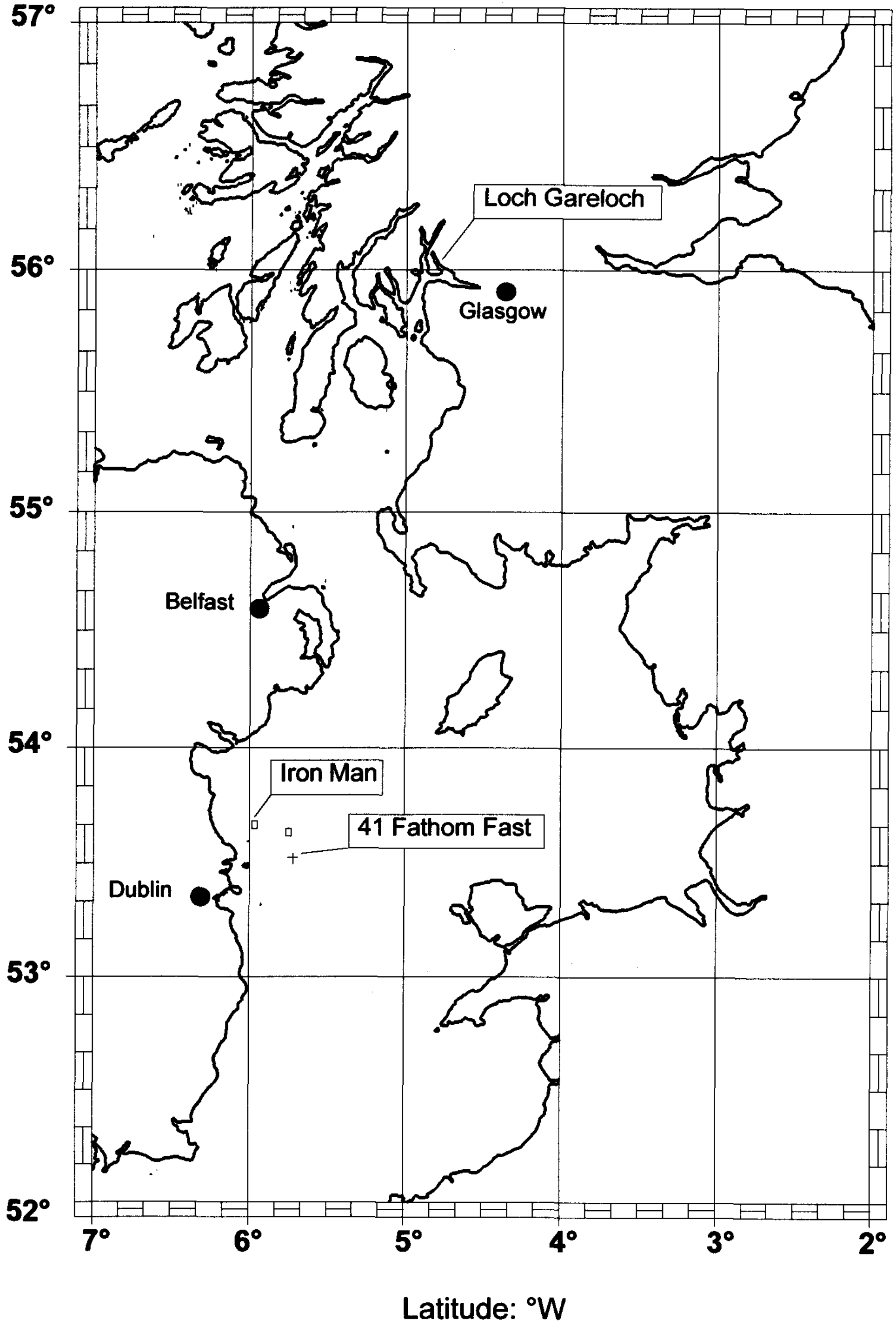


Fig. 2.7.1. Map of Irish Sea and west coast of Scotland showing Loch Gareloch and Irish Sea study sites.

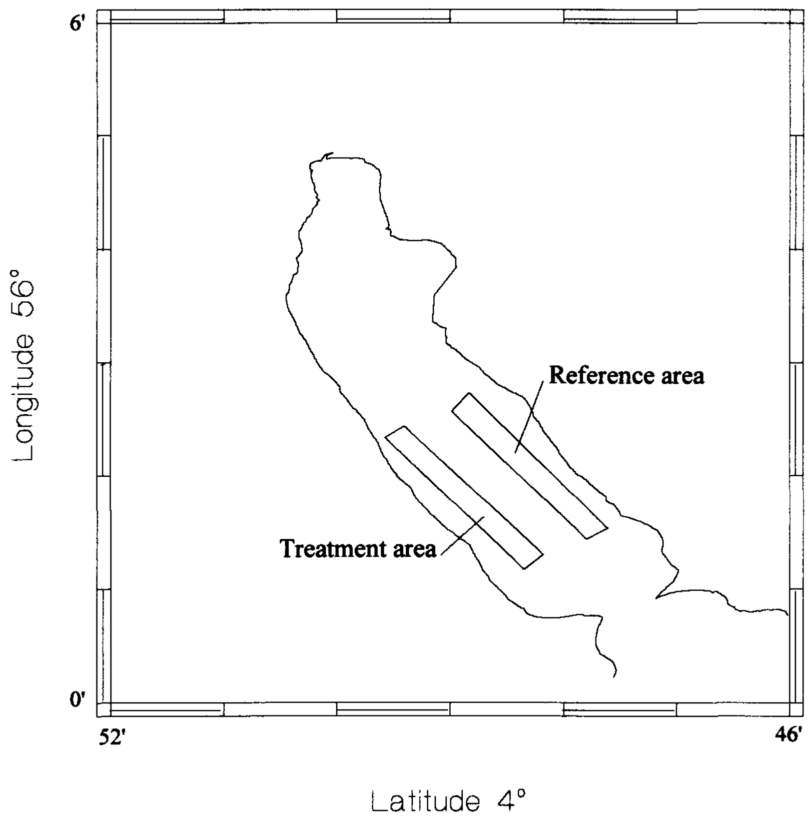


Fig. 2.7.2. Map showing treatment and reference area in Loch Gareloch.

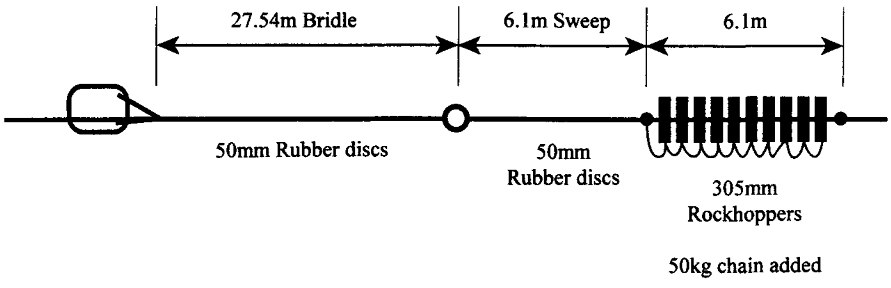


Fig. 2.7.3. Gear diagram of modified rockhopper gear used in Loch Gareloch.

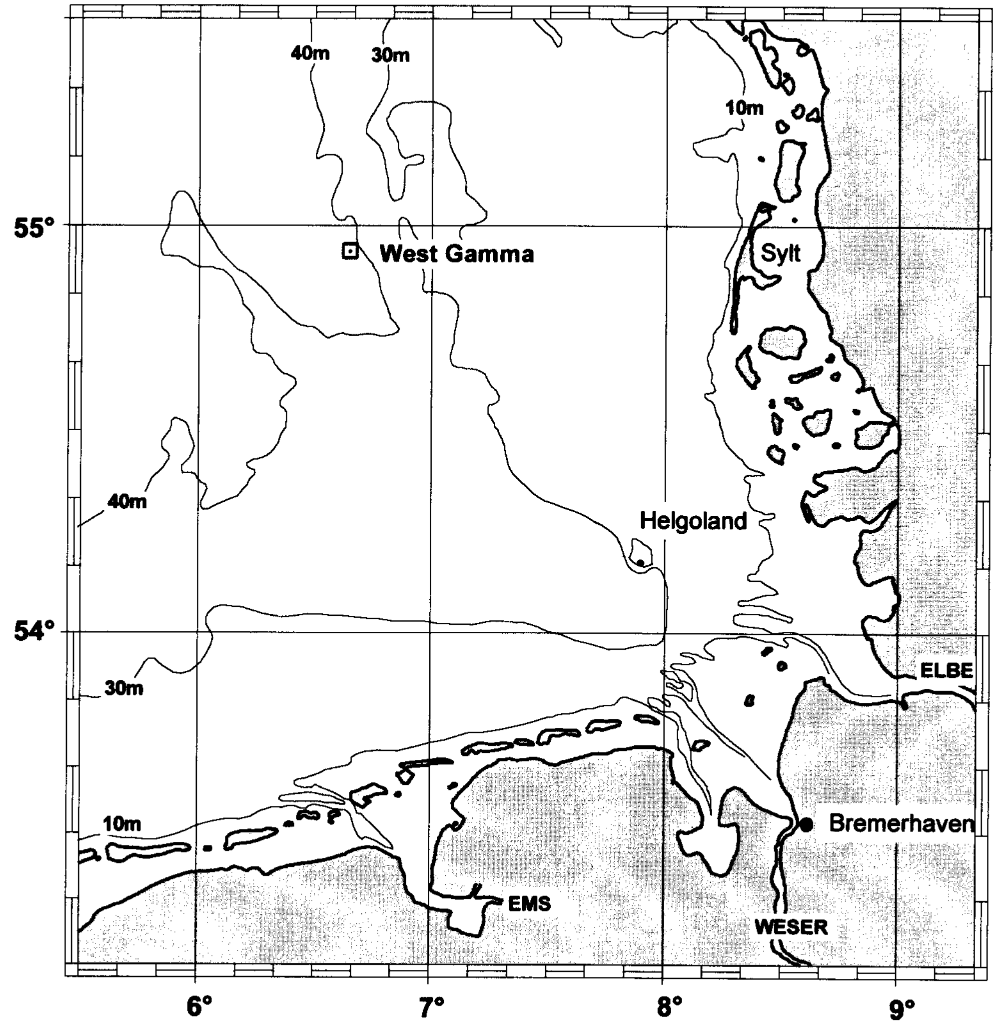


Fig. 2.7.4. The area of investigation "West Gamma" in outer the German Bight. The small frame indicates the area covered in Fig. 2.7.5.

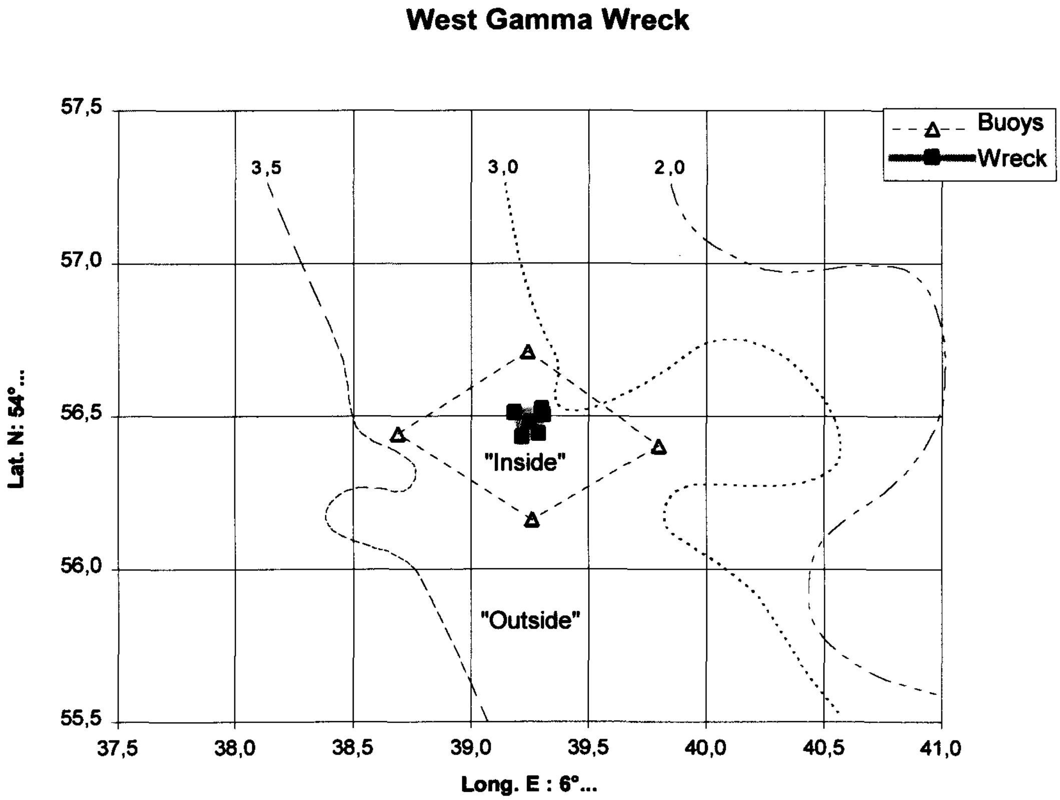


Fig. 2.7.5. The study area surrounding the West Gamma wreck. Distribution of sediment (medium grain size in Phi-notation).

TABLE 2.7.1

Summary of sampling details for projects comparing disturbed and undisturbed areas. DG - Day grab (0.1 m^2), TV - towed underwater television survey, V.V. - Van Veen grab (0.1 m^2), Dr. - small dredge (1 m width, 1 cm mesh), ROV - Remotely operated vehicle.

	Sampling dates	Sampling gear	Number of samples Fished	Number of samples Unfished	Comments
Loch Gareloch	November 93	DG TV	14 samples from each area		Preliminary survey
	May & October 94, 95, 96	DG TV	14 samples from each area		Disturbance programme Jan 94 - April 95
West Gamma	August 92	V.V. Dr.	2 1	29 3	Sank in August 1990
	September 92	V.V. Dr.	20 2	16 2	
	April 94	V.V. Dr.	22 6	21 3	
	May 94	V.V.	14	1	Samples for sediment mapping only
	August 94	V.V.	15	15	Buoys removed after sampling
	August 95	V.V.	12	18	
Iron Man	May 95	DG ROV	48 samples from each area		Results from wreck survey compared with fished area
41 Fathom Fast	April 96	DG ROV	25 samples from each area		Results from wreck survey compared with fished area

2.8. LONG TERM TRENDS IN DEMERSAL FISH AND BENTHIC INVERTEBRATES

Introduction

The longer term effects of demersal fisheries on benthic marine ecosystems are still a point of discussion. Investigations by means of experimental trawling showed that demersal fisheries increase the mortality of both target and by-catch species, but also of benthic species that are not caught in the nets but damaged by the passing fishing gear (Bergman & van Santbrink 1994a). In general, large long-living species with a low fecundity will be affected more than small short-living species with high fecundity. On the other hand, fisheries may be beneficial for scavenging species if their increased mortality is counterbalanced by an increasing food supply from discarded offal, by-catch and damaged animals in trawl tracks (Fonds & Groenewold 1996).

The effect of demersal fisheries on demersal fish and benthic invertebrates will also depend on the type of fishing gear in relation to the vertical distribution of the species. In an otter trawl, the groundrope slides over the seabed, whereas the otter doors plough into the bottom. Beam trawlers use heavy tickler chains or chain matrices in order to stimulate the target flatfish species to leave the bottom and enter into the net. Subsequently, otter trawl fisheries will mainly catch demersal fish and epifaunal invertebrates whereas beam trawls will also affect the infauna, i.e. the animals that live buried in the top-layer, approx.1-5 cm depending on the type of sediment. Two main problems in evaluating long-term effects of demersal fisheries on benthic ecosystems are that (i) most experimental work refers to short-term effects, i.e. immediate changes in abundance after one or several trawls, and (ii) consistent long-term series on the abundance of non-commercial species are scarce because non-commercial species were often ignored in fisheries research. Systematic scientific surveys that aim at the total benthic ecosystem and include by-catch fish and invertebrates did not start before the beginning of the 1970s, i.e. after a long period of intensive commercial fishing (e.g. van Leeuwen *et al.* 1994; Heessen 1996). Nevertheless there are early routine catches (1902-1912) stimulated by the ICES the invertebrate data of which could be reconstructed to more or less realistic catch protocolls (Stein *et al.* 1990) Thus, longer-term or earlier effects of demersal fisheries on demersal by-catch species have to be extracted from available time series, even though the data may not have been collected for this purpose. A large number of these studies on the macrozoobenthos of the North Sea (reviewed in Kingston & Rachor 1982) indicate clear changes in the faunal communities since the 1920ies, which were mostly attributed to pollution and eutrophication (Rachor 1990). These should, however, be re-analysed for possible effects of the developing trawl fishery in this century.

The total North Sea landings have increased since the beginning of the century from about 1 million tons to a maximum of nearly 3.5 million tons at the end of the sixties and the beginning of the seventies. From then on the landings have decreased to about 2.5, of which only 1.5 are caught for direct human consumption and about 1 are used for industrial purposes.

However, even before the fishery was well established in the North Sea and must have influenced at least the age composition of some target species such as haddock and herring. In the course of time the fishing methods, vessel types, target species and fishing effort have changed considerably. As a consequence, the effects on the particular stock compositions and the abundance of non-target species have increased with time.

After the second war the beam trawl was re-introduced as an effective gear in the plaice and sole fishery. Apart from the target species (plaice and sole) large amounts of invertebrate benthic species are caught or damaged. In addition, two more gears have a considerable impact on the sea floor and on the fish species under consideration. These are the otter trawls and the pair trawls.

In order to find long-term trends in fish and benthic populations that can be attributed to fishing induced changes

a) qualitative and quantitative historical benthos data have been collected and made available for comparison with recent data to detect possible changes introduced by the developing trawl fishing and

b) quantitative catch and by-catch data have been collected and their changes have been related to possible fishing induced effects.
The time covered by the data series is indicated in Fig. 2.8.1.

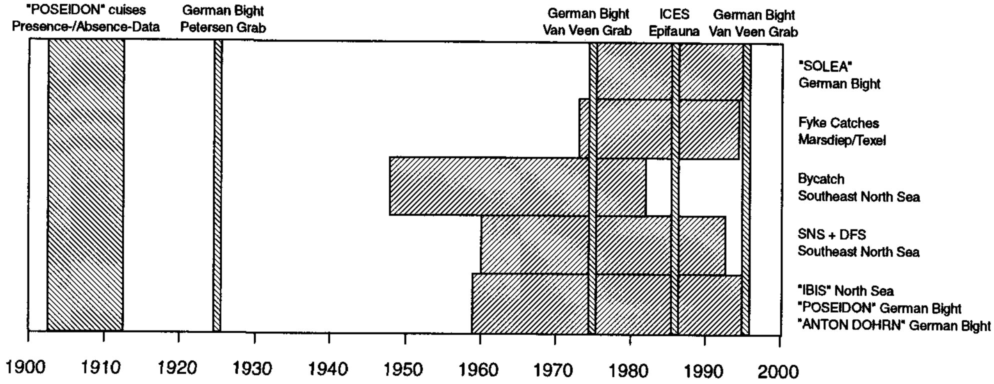


Fig. 2.8.1. Time covered by the data series.

2.8.1. HISTORICAL AND RECENT DATA ON EPIFAUNA IN THE SOUTHERN NORTH SEA

Historical epifauna data from 1902-1912 (Stein *et al.* 1990) (about 7000 records) were entered manually or converted from different data sources into a PC-Database (Microsoft ACCESS). These data were compared with epifauna data from the ICES-Benthos Survey 1986 in order to detect changes in the occurence of species that may be attributed to the fishery impact in this century.

In 1901 the „Deutsche wissenschaftliche Kommission für die internationale Meeresforschung" was founded to make it possible for Germany to participate in the international marine research that started after the foundation of the ICES. Kiel received a small marine laboratory with a biological and an oceanographic section. Every year from 1902-1908 four research voyages („Terminfahrten") were completed on board the „Poseidon" in the Baltic and the North Sea. Further expeditions were carried out from 1909-1912. These investigations were part of an international agreement on research voyages of different vessels in the North Sea. The „Poseidon" cruises took place in the months of February, May, August and November. With few exceptions the same stations were regularly visited.

All the material dates from the years of 1902-1912. Part of it was collected at German stations of the „Terminfahrten". In addition to these catches there is material, collected during the cruises which were made from 1903-1905 and in April 1906 by the „Biologische Anstalt Helgoland" to various locations in the North Sea. In the Zoological Museum Kiel the animals have tags in the jars stating details about location of sampling (station number), date of collection and - sometimes - fishing gear used. The positions as well as information about sediment and depth could be assigned to the station numbers with the help of literature.

These historical data published in Stein *et al.* 1990 originate from two sources. About two-thirds of the animals are present in the collection of the Zoological Museum Kiel. The other animals derive from references in „Wissenschaftliche Meeresuntersuchungen, Neue Folge Vols. VIII-XV". From these sources also the station data were reconstructed.Sample informations are listed in Table 2.8.1.1.

TABLE 2.8.1.1
Data set, type of gear, cruise data and number of stations.

Data set	Type of gear	Cruise	No. of stations
1902-1912	Dredge and diff. trawl-types	POSEIDON-Cruises and diff. other Cruises 1902-1912 (February, May, August, November)	403
Rumohr	standard Dredge	ICES North Sea survey May 86	5
Türkay	standard Dredge	ICES North Sea survey April 86	12
Duineveld	beam-trawl	ICES North Sea survey April 86	58

The mentioned species of all datasets were compiled: wrong spellings, synonyms and common names were replaced with the correct scientific name and higher taxonomic level (family, order, class, phylum) were added.

In 1902-1912 the whole area of the North Sea was sampled with various kinds of towed gears such as dredges, trawls, „Helgoländer Knüppelnetz" and shrimp trawls, for 1986 only data for the southern part of the North Sea are available. They were sampled with standard dredges and beam trawls. For the comparison the data had to be reduced to stations in the area between 0°30 to 7°00 East and 52°30 to 56°30 North (see Fig. 2.8.1.1). Stations with doubtful positions or depth-sediment-data and species which occur only on one or two stations were omitted. In total 56 stations from 1902-1912 were compared with 40 stations from 1986.

Since not all species were collected comparably only the groups of Decapoda, Echinoidea, Ophiuridea, Asteroidea, Gastropoda and Bivalvia were used which belong with the exception of the bivalves to the epifauna. In total 98 species were compared.

For the comparison of the data from 1902-12 and 1986, Clusteranalysis, MDS-plots (using Bray-Curtis-index), ANOSIM („Analysis of Similarities") and SIMPER („Similarity percentages") from the multivariate statistical software PRIMER (Warwick 1986) were used to group the stations according to the sediments and depth-strata and thus to identify species compositions. According to Künitzer *et al.* 1992 we used the depth strata < 30 m, 30-50 m and > 50 m which also coincide with changes in the main sediment characteristics (Irion, unpublished sediment data from the 1986 study).

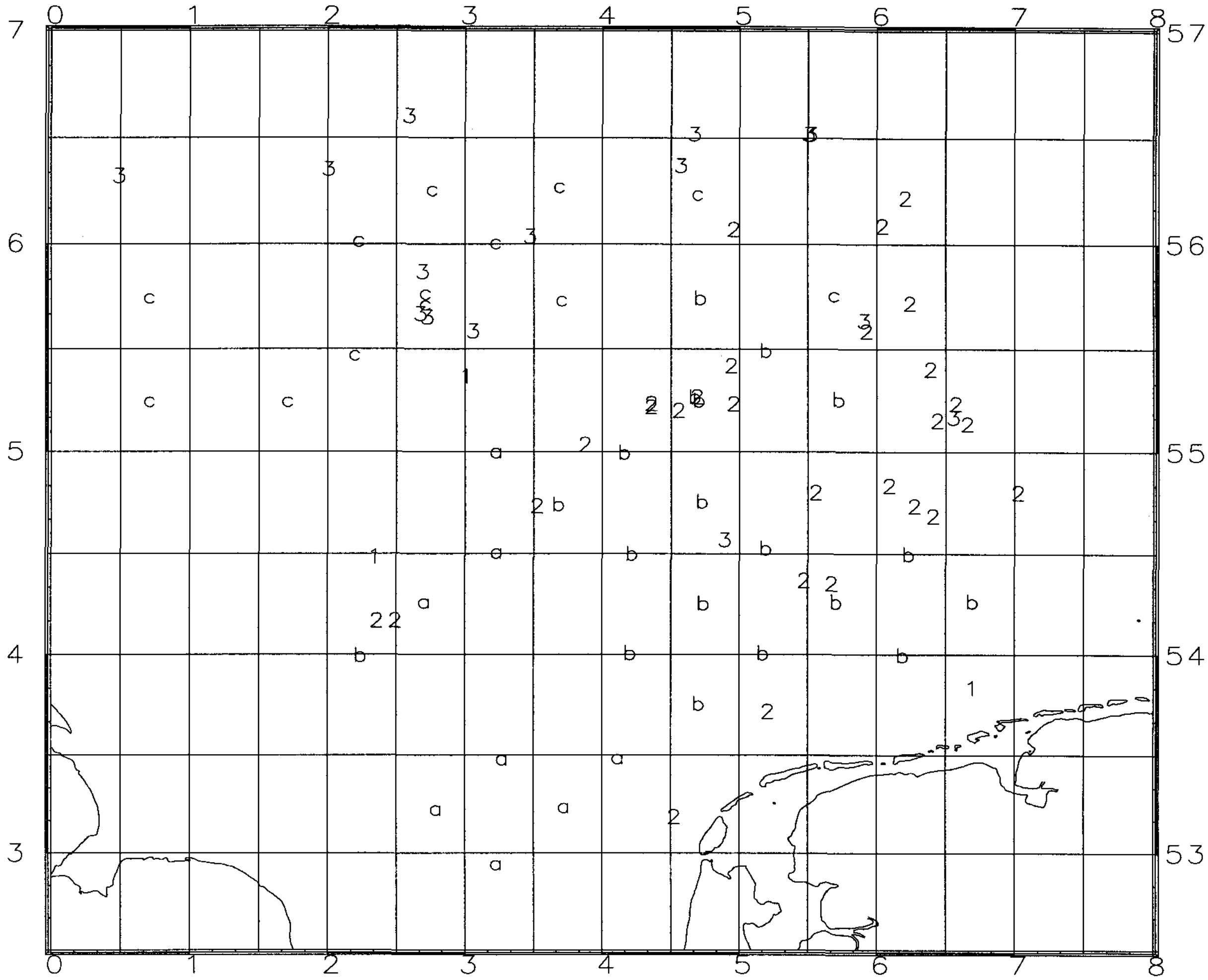


Fig. 2.8.1.1. Map of the selected stations:
1 = stations from 1902-12, depth 0-30 m
2 = stations from 1902-12, depth 30-50 m
3 = stations from 1902-12, depth > 50 m
a = stations from 1986, depth 0-30 m
b = stations from 1986, depth 30-50 m
c = stations from 1986, depth > 50 m

2.8.2. HISTORICAL AND RECENT DATA OF MACROINFAUNA IN THE GERMAN BIGHT

To detect possible long term changes in the community structure abundance and biomass of macro infauna historical benthos data from 1923/24 (Hagmeier 1925) and from 1975 (Salzwedel *et al.* 1985) were reanalysed. Additionally new data from 1995 were used to evaluate the present state. These data were produced by Richter (1996) and Bischoff (1996). Sampling dates are listed in Table2.8.2.1

TABLE 2.8.2.1
Cruise dates and number of samples taken.

Data set	Date of cruise			Type of grab	No. of stations
Hagmeier	6	- 18/7	1923	Petersen	50
	8	- 21/5	1924	Petersen	87
Salzwedel	27	- 30/10	1975	Van Veen	66
Richter and Bischoff	31/8.-	1/9	1995	Van Veen	15
	16	- 17/10	1995	Van Veen	17

In 1923/24 and 1975 the whole area of the wider German Bight was covered, while in 1995 only the part within the inner German Bight.

A direct statistical comparison of the data from 1923/24 with those from 1975 and 1995 was not possible for several methodical reasons. Hagmeier took his samples in May and July, used a "Petersen-grab", sieved the samples over 1mm-screens, identified only the bigger organisms on board to species level and summarised the rest in higher taxonomic groups. Further on, after grouping the stations according to their fauna and identifying benthic communities, he only mentions the mean abundance of the species per m² for each community. The original data are not available.

In 1995 the same methods were used as in 1975 (described in Salzwedel *et al.* 1985). Samples were taken in August (1995) and October (1975 and 1995) and the original data are available, allowing a direct comparison of these data sets. However from 1975 only the complete biomass per station and the average biomass per species group for the associations were recorded.

For the direct comparison of the faunal communities between 1975 and 1995, the number of stations from the investigation from Salzwedel *et al.* (1985) was reduced to those stations that had also been sampled in 1995.

For the comparison of the data from 1975 and 1995, Clusteranalysis and MDS-plots (using Bray-Curtis-index and fourth root transformed data) were used to group the stations according to the abundances of the benthic fauna and thus to identify macrozoobenthic associations. The geographical distribution of these association was plotted on a map to detect changes in the borders of these associations. After the identification of comparable associations in 1975 and 1995, the general characteristics of these associations were evaluated (No. of organisms, No. of species, Diversity (H'), Eveness (E), Biomass). Additionally the abundance of single species as well as the species spectrum were analysed to detect possible changes of these associations from 1975 to 1995. Key species will be identified that show obvious tendencies (new or disappeared, more or less abundant) these might be used as indicator species for a general trend.

2.8.3. LONG-TERM IMPACT OF DEMERSAL FISHERIES ON SEVERAL BY-CATCH SPECIES OF DEMERSAL FISH AND BENTHIC INVERTEBRATES IN THE SOUTH-EASTERN NORTH SEA

For the south-eastern North Sea, long-term trends in the number of several by-catch species of demersal fish and benthic invertebrates are examined and compared with trends and developments in fishery pressure of otter and beam trawlers. The hypothesis is tested that the number of bycaught fish and invertebrates as delivered to the Dutch Zoological Station at Den Helder between 1947 and 1981 was related to species-specific and gear-specific fishery-induced mortality.

Specimens were delivered by fishermen either by request (e.g. to be sold to universities for experimental purposes) or when a rare or unknown species was caught. In all cases the individuals were bought by the institute. For commercial species an amount more or less equal to the market price was paid, non-commercial species and specimens were bought for a set price. All animals considered in this analysis were preserved on board by storing them on ice.

The analysis was restricted to those by-catch species (Table 2.8.3.1) that (i) have a demersal life style, and (ii) were more or less regularly delivered to the Zoological Station during the entire sampling period, i.e. specimens never rejected by the employees of the station (de Vooys *et al.* 1991, 1993; de Vooys & van der Meer, in prep.; Philippart 1997). All individuals of the selected species originated from an area located northwest of the Netherlands, between 3° to 7° East and 52° to 55° North. The use of a dynamic catchability model made it necessary to restrict the study period to one without missing values, i.e. the period following the second World War. Furthermore, due to a change in collecting the by-catch data and a suspection of change in the behaviour of fishermen in delivering by-catch to the Zoological Station, the data from 1983 onwards are thought to be inconsistent with those from former years. For the remaining period, the time series of total annual numbers of animals were smoothed by taking 5 year running averages to diminish the noise of year-to-year variation and subsequently emphasize the long-term trends between 1947 and 1981.

TABLE 2.8.3.1

Scientific name, common name and vertical distribution of by-catch species of demersal fish and benthic invertebrates delivered to the Dutch Zoological Station by commercial fishermen between 1945 and 1981.

Scientific name	Common name	Vertical distribution
FISH		
*Mustelus mustelus**	Smooth hound	demersal shark
*Scyliorhinus caniculus**	Small spotted cat shark	demersal shark
*Raja clavata**	Roker	demersal ray
*Raja batis**	Common skate	demersal skate
*Dasyatis pastinaca**	Stingray	diurnal burying demersal ray
*Trachinus draco**	Greater weever	diurnal burying demersal fish
*Lophius piscatorius**	Angler	burying demersal fish
INVERTEBRATES		
*Buccinum undatum**	Common whelk	burrowing epifauna
Neptunea antiqua	Red whelk	burrowing epifauna
Colus gracilis	Slender spindle shell	burrowing epifauna
*Loligo vulgaris**	Common european squid	swimming epifauna
Eledone cirrosa	Lesser octopus	swimming epifauna
*Homarus gammarus**	European lobster	diurnal burrowing epifauna
*Nephrops norvegicus**	Norway lobster	diurnal burrowing epifauna
Cancer pagurus	Edible crab	diurnal burrowing epifauna
Liocarcinus puber	Velvet swimming crab	seasonal burrowing epifauna
Corystes cassivelaunus	Masked crab	shallow burrowing epifauna
Psammechinus miliaris	Green sea urchin	non-burrowing epifauna
Spatangus purpureus	Purple heart urchin	burrowing epifauna
Urticina felina	Dahlia anemone	sessile epifauna
Aphrodita aculeata	Sea mouse	shallow burrowing epifauna

* also targeted by commercial fisheries

Fishing effort is related to the number of vessels and the effort per vessel, e.g. the number of fishing hours, type of fishing gear and the power of the engines (usually expressed in horse power (hp) of kilo Watt (kW)). Data on the number of vessels were available from national statistics. Unfortunately, data on the actual effort per vessel are scarce, incomplete and sometimes not even correct (Anon. 1995). Fishing effort of otter trawling was available as the number of otter trawl vessels at 5 year intervals from 1946 to 1990 (H. Polet, *in lit.*). Estimates of mean annual otter trawl fishing effort were calculated by linear interpolation of these numbers, smoothed by the 5 years running averages. For this type of fishing gear it had to be assumed that the fishing effort per vessel had not changed during the study period, i.e. from 1945 to 1983. Fishing effort of beam trawling was available in horse-power days, i.e. the number of fishing days of the Dutch beam trawl fleet multiplied by the total engine power (hp) of those vessels (Rijnsdorp & van Leeuwen 1994). Mean annual beam trawler effort was also smoothed by taking 5 years running averages. Both the fishing effort of otter and beam trawling were scaled to 1 by dividing the effort in a particular year by the maximum effort during the post-war period of the specific type of fishing gear.

When delivering by-catch to the Zoological Station at Den Helder, the registration numbers of the providing fishing vessels were consistently noted from the early 1950s onwards. This indicated that over 250 different fishing vessels were involved. Most ships originated from the ports of Den Helder, Texel and Wieringen, only a few fishing ships came from other ports. Some ships delivered animals haphazardly whilst others showed a more consistent delivery pattern over time. Between 1952 and 1990, 1088 of the total of 4177 by-catches of invertebrates were delivered in a regular fashion by 7 vessels. It is assumed that the composition of the fleet involved in sampling this kind of by-catch was similar to that of the entire Dutch fleet (e.g. an equal ratio between otter and beam trawlers and a similar fishing effort per vessel) and that the fraction of the sampling fleet compared to the total Dutch fleet was constant. From these data, no estimate can be supplied on the proportion of delivered by-catch relative to the total by-catch in the area considered because the total effort of the international fleet within the study area between 1945 and 1983 is unknown.

The number of animals in an area can change by several processes, i.e. birth, mortality, immigration and emigration. For the fisheries catchability model, it had to be assumed that immigration and emigration did not occur and that birth rate was equal to natural death rate for the entire study period. Subsequently, the number of animals at the end of a particular year is calculated as population size at the beginning of that year (which is equal to the number of animals at the end of the foregoing year minus the number of animals caught (by-catch B) as the result of otter and beam trawling during that year (Philippart 1997). The number of animals caught in a particular year is assumed to be a function of the total number of animals present at the beginning of a particular year and the fishing mortality during that year which is related to the gear-specific fishing effort of otter trawlers and beam trawlers. The fisheries catchability model was fitted by means of iterative estimation of 3 parameters, i.e. the otter trawl catchability coefficient (q_1), the beam trawl catchability coefficient (q_2) and the number of animals that were present at the beginning of the study period, i.e in 1946.

2.8.4. SHIFTS IN THE BENTHIC COMMUNITY OF THE SOUTH-EASTERN NORTH SEA DURING EXTENSIVE BEAMTRAWL FISHERY

For the southeastern North Sea, long-term trends in the abundance of demersal fish and benthic invertebrates are examined and compared with spatial variation in fishery pressure of bottom trawlers. The hypothesis is tested that the effect of fisheries on the abundance of demersal fish and benthic invertebrates is related to increased mortality on the one hand and increased possibilities for scavenging on the other hand.

The selection of species for analysis of effects of beamtrawl fishery (Table 2.8.4.1) was based on the following criteria. Firstly, the selection was restricted to species with a demersal life style and located within the range of the fishing gear of beam trawlers, i.e. between 35 cm above the bottom and 5 cm in the sediment. Secondly, long-term series on abundance had to be available for different areas within the south-eastern North Sea and these data had to be indicative for the population size. Thirdly, the species had to present in the entire south-eastern North Sea and not be at the edges of their distribution range. Fourthly, the list of species should have included target flatfish, non-target flatfish and roundfish, and epifaunal and infaunal invertebrates. However, no long-term data sets on infauna was available because most sampling surveys were conducted with bottom trawls, which generally do not supply reliable data on infauna abundances.

TABLE 2.8.4.1

Commercial interest and taxonomical group of 10 demersal fish and benthic invertebrate species selected for analysis of effects of beam trawl fishery in the south-eastern North Sea, including an indication of the catch efficiency, catch mortality, non-catch mortality and ability to scavenge based on experimental fishing results and field observations (after Bergman & van Santbrink 1994a; Cadée *et al.* 1995; Fonds 1994; Fonds & Groenewold 1996).

Species	Common name	Commercial interest	Category	Catch efficiency	Catch mortality	Non-catch mortality	Ability to scavenge
Callionymus lyra	Dragonet	non-target	roundfish	low	high	low	high
Eutrigla gurnardus	Grey gurnard	non-target[a]	roundfish	high	high	low	high
Limanda limanda	Dab	non-target[a]	flatfish	high	high	low	high
Pleuronectes platessa	Plaice	target	flatfish	high	high	low	high
Solea solea	Sole	target	flatfish	high	high	low	low
Pagurus bernhardus	Hermit crab	non-target	crustacean	low	low	low	high
Liocarcinus holsatus	Velvet swimming crab	non-target	crustacean	low	high	low	high
Asterias rubens	Starfish	non-target	echinoderm	high	low	low	high
Echinocardium cordatum	Sea potato	non-target	echinoderm	low	high	high	low
Buccinum undatum	Common whelk	non-target	mollusc	low	high	high	low

[a] non-target species but marketed when caught

The selection of time series of demersal fish and benthic invertebrates for analysis of effects of beam trawl fishery (Table 2.8.4.1) was based on the following criteria. Firstly, the sampling had to be performed consistently, i.e. no substantial variation has occurred in gear type, mesh-size, towing speed and haul duration. Secondly, the series had to cover a period of at least 10 years without missing values. Thirdly, the series had to cover the coastal zone of the south-eastern North Sea. Eventually 3 surveys were selected (Fig. 2.8.4.1), i.e. International Bottom Trawl Survey (Heessen 1996; Knijn *et al.* 1993), Sole Net Survey (Buijs *et al.* 1994; van Leeuwen 1993) and Demersal Fish Survey (van Leeuwen *et al.* 1994).

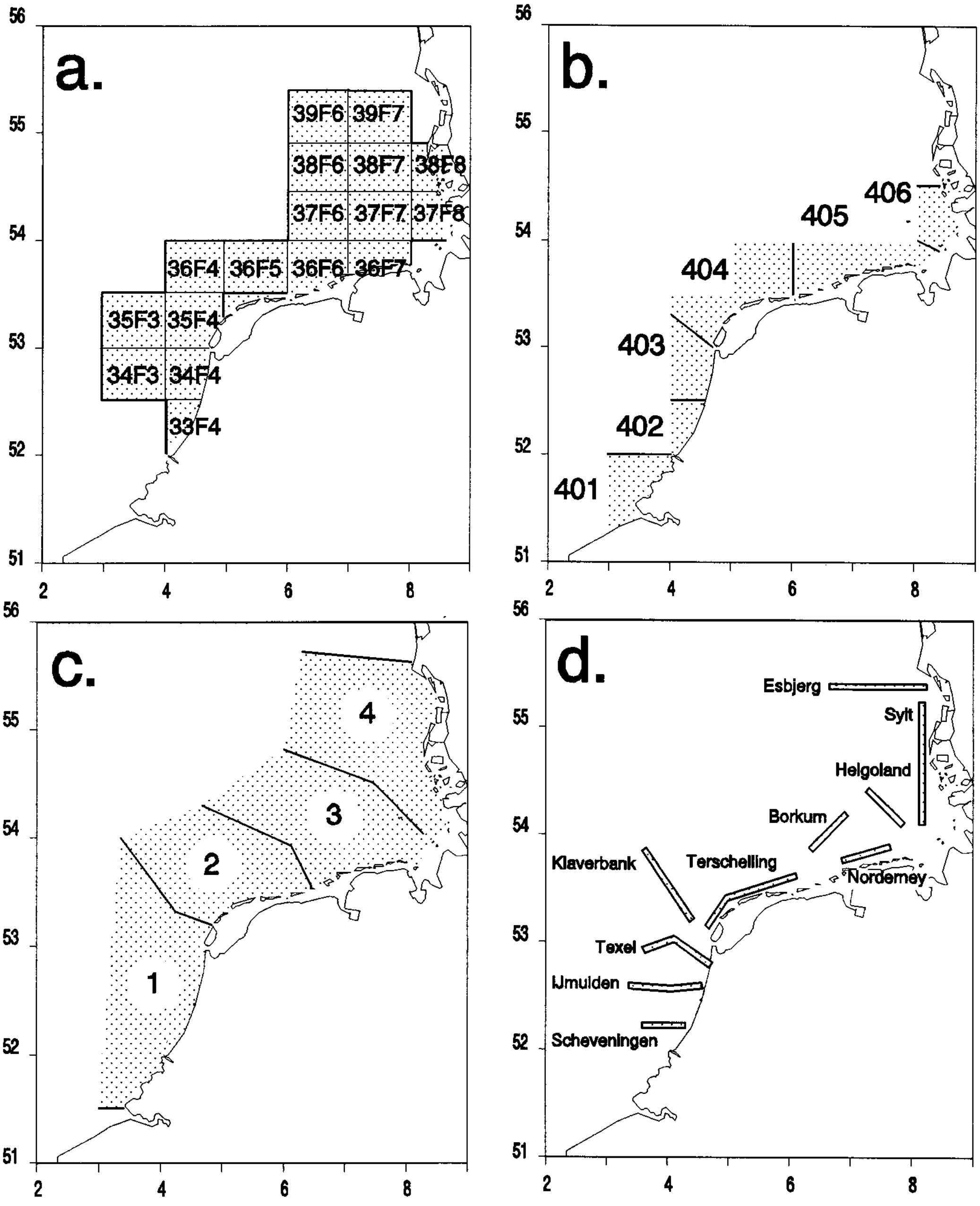


Fig. 2.8.4.1 Location of sampling areas in the (south-eastern) North Sea; (a) sampling ICES quadrants of International Bottom Trawl Surveys and International Young Fish Surveys (fish), (b) sampling areas of Demersal Fish Surveys (fish), (c and d) sampling areas and transacts of Sole Net Surveys (fish and invertebrates, respectively).

TABLE 2.8.4.2
Sampling surveys used for analysis of effects of beam trawl fishery on demersal fish (F) and benthic invertebrates (I) in the south-eastern North Sea.

Survey	Period	Gear	F/E	Years	Unit	Source
IBTS	Feb	Otter trawl	F	1980-1995	catch·10 h^{-1}	Database ICES
SNS	Sep-Nov	Beam trawl	F	1969-1990	catch·h^{-1}	Van Leeuwen e.a. 1993
			I	1972-1991	catch·h^{-1}	Database NIOO-CEMO
DFS	Sep-Nov	Beam trawl	F	1980-1993	catch·h^{-1}	Database DLO-RIVO

The geographical distribution of beam trawl effort in the south-eastern North Sea is approximated by means of the sum of the fishing hours of all bottom trawlers per ICES quadrant of the Dutch fleet between 1974 and 1993 and of the German fleet between 1977 and 1993 (Fig. 2.8.4.2). For the Dutch data, the fishing hours between 1974 and 1982 refer to beam trawling only, whilst the data of fishing hours between 1988 and 1993 refer to the total effort of beam trawlers, otter trawlers and pair trawlers (De Groot & Verboom 1994). The German data on fishing effort refer to the entire bottom trawling fleet, i.e. beam trawlers, otter trawlers and paired trawlers. The number of fishing hours is only a rough indication of fishing effort in time and space, because it does not take into account the year-to-year differences in composition of the fishing fleet.

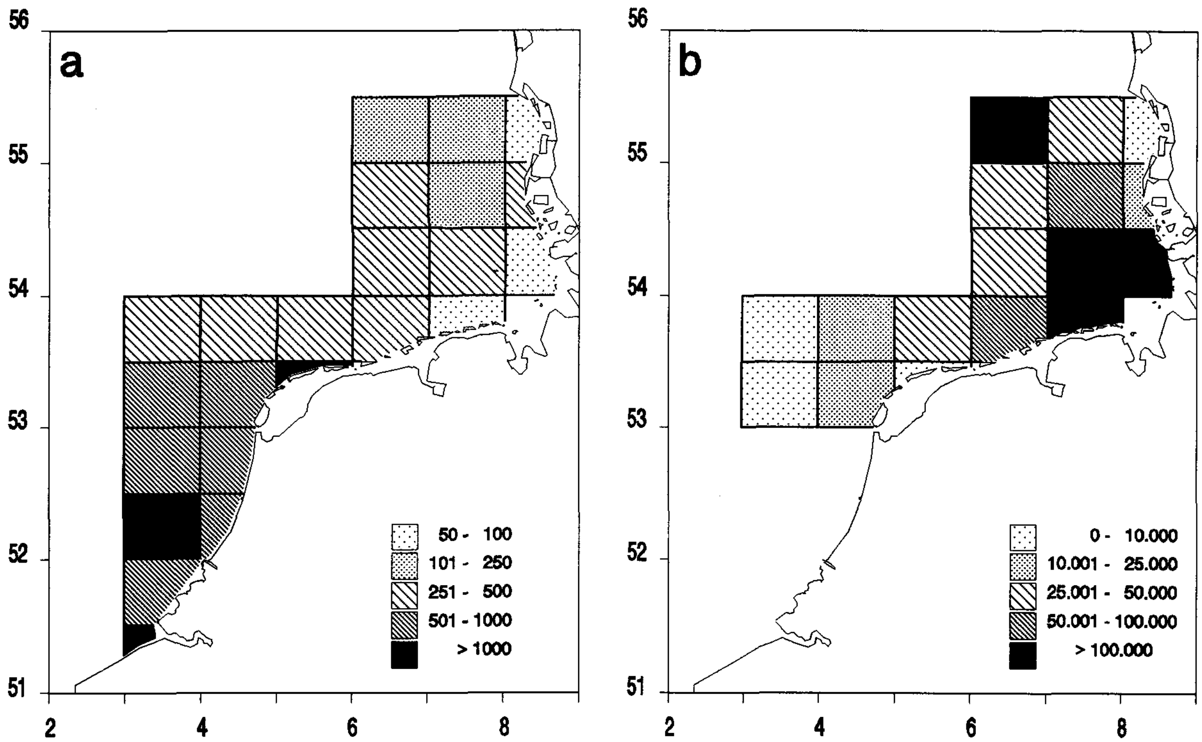


Fig. 2.8.4.2 (a) Total fishing effort (fishing hours 100 n.m.$^{-2}$) of Dutch bottom trawl fleet in the south-eastern North Sea between 1974 and 1994 (source: de Groot & Verboom 1994), (b) Total fishing effort (fishing hours quadrant^{-1}) of German bottom trawl fleet in the south-eastern North Sea between 1977 and 1994 (source: ICES).

Assuming that the abundance data (n) are representative for the population size (N), the annual rate of increase or decrease of the population was be estimated by means of linear regression of log-transformed time series. Non-significant trends can be the result of either the absence of a trend or of the failure of detecting it, e.g. because the study period was not long enough. In our analysis, a non-significant trends were considered to be the result of absence of change, i.e. representing an zero rate of increase.

2.8.5. LONG-TERM FLUCTUATIONS OF FISH RECRUIT ABUNDANCE IN THE WESTERN WADDEN SEA IN RELATION TO VARIATION IN THE MARINE ENVIRONMENT

For the western Wadden Sea, variations in the abundance of fish recruits were examined and compared with variations in the environment. The hypothesis is tested that the number of fish recruits as caught with a stake net or a large fyke net (kom-fuik (Dutch)) located at the western edge of the Wadden Sea (Fig. 2.8.5.1) is related to natural variation such as hydrographical conditions, water temperature and primary and secondary production.

The stake net was in operation from April to October from 1960 until the present day. It was emptied almost every morning from Monday to Friday. Catches were sorted immediately and all specimens identified to species level. For the present analysis (Philippart *et al.* 1996), only samples were selected which relate to fishing periods of approximately one day (24 ± 12 h), since fish that had stayed in the stake net longer may have decayed or been consumed by crustaceans. A selection was made for those species for which (i) the assumption that on average a constant fraction of western Wadden Sea populations has been sampled seemed reasonable (van der Meer *et al.* 1995), and (ii) the recruits could be identified in the reported catch (Table 2.8.5.1). Fish were divided into length classes from 1972 onwards and lengths were individually measured from 1979 onwards. Subsequently, stake net catches sampled between 1960 and 1971 had to be discarded because information on size was not sufficient to discriminate recruits from the total catch. For each of the selected fish species, the average abundance of recruits in the stake net catches was calculated for every month. Missing values within every data set were predicted (Philippart *et al.* 1996). For each species, a period of two months was selected for which the average abundance was used as an annual index of recruit abundance (Table 2.8.5.1). This selection was based on the observed seasonal change in relative abundance of the 0-group and I-group fish within the selected size groups.

TABLE 2.8.5.1
Family name, species name, common name, maximum size (cm) of fish classified as recruits, and two-month period selected for the calculation of the annual index of recruit abundance of 12 fish species caught in a stake net in the Marsdiep tidal inlet between 1972 and 1994.

Family	Species	Common name	Size	Period
Clupeidae	*Clupea harengus*	herring	10	Sep-Oct
	Alosa fallax	twaite shad	20	Sep-Oct
Gadidae	*Gadus morhua*	cod	20	Jul-Aug
	Merlangius merlangus	whiting	20	Sep-Oct
	Pollachius pollachius	pollack	20	Aug-Sep
Cyclopteridae	*Cyclopterus lumpus*	lumpsucker	10	Sep-Oct
Carangidae	*Trachurus trachurus*	scad	20	Aug-Sep
Mugilidae	*Chelon labrosus*	grey mullet	20	Sep-Oct
Bothidae	*Scophthalmus maximus*	turbot	20	Sep-Oct
Pleuronectidae	*Pleuronectes platessa*	plaice	15	Aug-Sep
	Platichthys flesus	flounder	15	Aug-Sep
Soleidae	*Solea solea*	sole	15	Sep-Oct

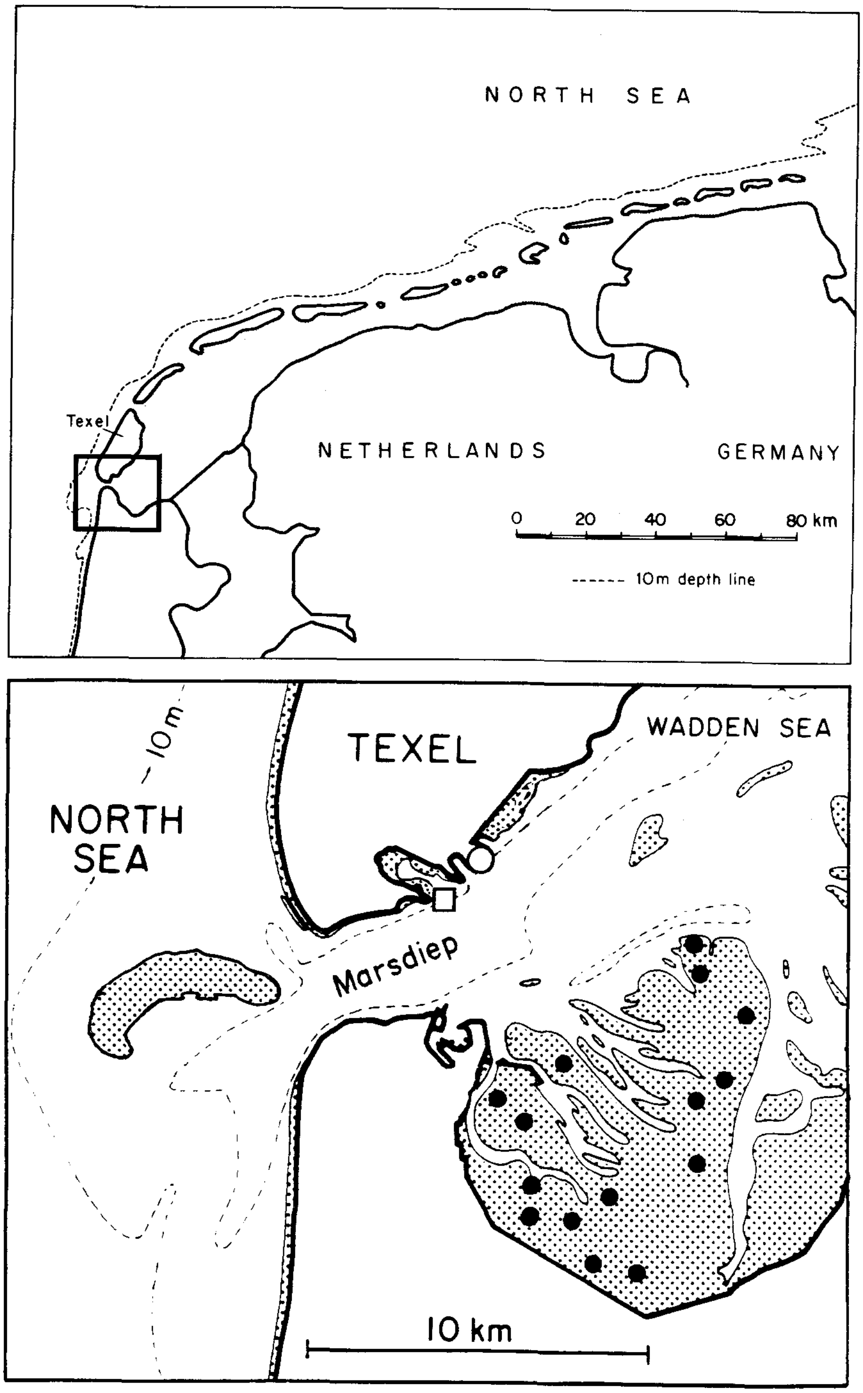


Fig. 2.8.5.1. Location of stake net (□) and phytoplankton sampling (O) station in the Marsdiep, the western-most tidal inlet of the Wadden Sea, and locations of 15 fixed zoobenthos stations (●) at Balgzand tidal flats.

Before further analysis, the abundance of fish recruits was logarithmically transformed to approximate normality: $\log_e$ (numbers per month + 1). For each species, the year-to-year variability of the recruit numbers was indexed by means of the standard deviation of the log-transformed time series (McArdle 1995). The covariability between species was examined by means of a Principal Component Analysis (PCA) that was performed on the correlation matrix of these species by means of SYSTAT (Wilkinson 1988). The results of the PCA were visualized in a so-called biplot (Gabriel 1971).

The North Atlantic Oscillation (NAO) index, i.e. the winter (average of December, January and February) sea level pressure at Ponta Delgada on the Azores minus that at Akureyi in Iceland, provides a measure of the strength of the mid-latitude westerly circulation over the North Atlantic (Dickson & Brander 1993) and subsequently an indication of the strength of the wind-driven North Sea circulation (Reid *et al.* 1992) during winter. Most of the selected fish start to spawn in winter/spring. For fish which spawn in the North Sea and use the Wadden Sea only as a nursery area for their juveniles. Due to a lack of sufficient data on the interannual variation in tidal currents and location of spawning areas, the NAO index is applied as a crude index of the transport rate of eggs and larvae across the southeastern North Sea.

Water temperature and chlorophyll concentration have been measured from a jetty in the Marsdiep tidal inlet in close proximity of the stake net. Temperature has been measured daily at 8:00 AM since 1948 (van der Hoeven 1982). Winter temperatures were obtained by averaging monthly means of water temperature of December, January and February. No long-term records of potential food items for fish recruits were available and little is known about their diet. It could be that the food supply for fish recruits, i.e. secondary production for all species with exception of the grey mullet which is a herbivore, was positively related to primary productivity during the entire year. In the western Wadden Sea, an increase in chlorophyll and primary production was accompanied by an increase in zoobenthos biomass and a change in zoobenthos species composition (Beukema & Cadée 1986; Beukema 1991a). Productivity of the Wadden Sea was expressed as the annual average chlorophyll content of the water which is related to the annual primary production in this area (Cadée & Hegeman 1991). Sampling of phytoplankton took place during high tide, almost every week in spring and summer and less frequently during the rest of the year (Cadée & Hegeman 1974; Cadée 1992). For 1974 to 1994, annual values of chlorophyll-a concentrations were calculated from 12 monthly averages. Zoobenthos was sampled in spring at 15 fixed stations on Balgzand, a 50 km^2 tidal-flat area in the westernmost part of the Wadden Sea in late winter, i.e. February-March (Fig. 2.8.5.1). Biomass of shore crabs (*Carcinus maenas*) and shrimps (*Crangon crangon*) has been determined as the difference between dry mass and ash mass, i.e. the ash-free dry mass (Beukema 1993).

The covariability between the four environmental variables was examined by means of a PCA using the correlation matrix. To compare the values of the environmental variables with the inter-annual variability in recruit numbers, each variable was standardized to mean 0 and variance 1. The subsequent standardized values were divided into four classes, i.e. higher than 1 standardized unit (s.u.), values between 1 s.u. and 0, values between 0 and -1 s.u., and lower than -1 s.u. Circles indicating the values of these environmental variables were projected on the principal component scores in the biplot of recruit abundance in the Wadden Sea.

2.8.6. ABUNDANCE OF DAB, GREY GURNARD AND TRAWLABLE BIOMASS IN RELATION TO FISHING EFFORT

This investigation was to correlate historical data on fishing effort with the abundance of those fish species which are effected by fishing gear. It was expected that especially in areas wih high fishing effort the abundances of those species must decrease.

Even though the effort data are partly available on national basis, they are not yet available on an international and structured form. Therefore, no time series of the international fishing effort in the roundfish areas and in the total North Sea are available at present, in order to relate the presented changes in abundance directly to fishing effort. The latter however is one of the most potential factors causing these changes. Still, such an investigation is possible in the German Bight on a much smaller scale, in the ICES statistical rectangle 37F7 off the island of Helgoland (Fig. 2.8.6.1).

For this rectangle time series of effort data were available from Netherlands and Germany, which provide the main fleets in the German Bight.

The German series of the effort and landings statistics starts in 1977. Prior to the introduction of the legal obligation for the fishermen in 1985 to list the catch and effort data in log-books, the majority of the landings by the German cutter fleet in the North Sea was reported to the Bundesforschungsanstalt für Fischerei (BFA). The Dutch effort data were taken from De Groot & Verboom 1994. This series starts in 1974. Unfortunately no Dutch effort data are available between 1983 and 1988. The trends in combined effort of these fleets were assumed to be as representative for the entire international effort in that area.

A small area (Box A; Fig. 2.8.6.1) of 10 to 10 nm in the north-western part of ICES rectangle 37F7 (near Helgoland) was selected in 1987 as a special area to detect possible changes in fish assemblage with time. Intensive fishing by the German fishery research vessels, using the GOV-standard otter trawl, took place in that area; at least two experiments per year during quarters 2 and 3, each of 20 to 30 hauls within 3 days.

Since the installation of the Plaice Box in 1989, the rectangle 37F7 is divided into an inner part, where trawling was forbidden for large cutters of more than 300 horse power during quarter 2 and 3 and an outer part with no restriction in effort and where the Box A is situated. Since 1994 the large beam-trawlers are totally banned from the Plaice-Box.

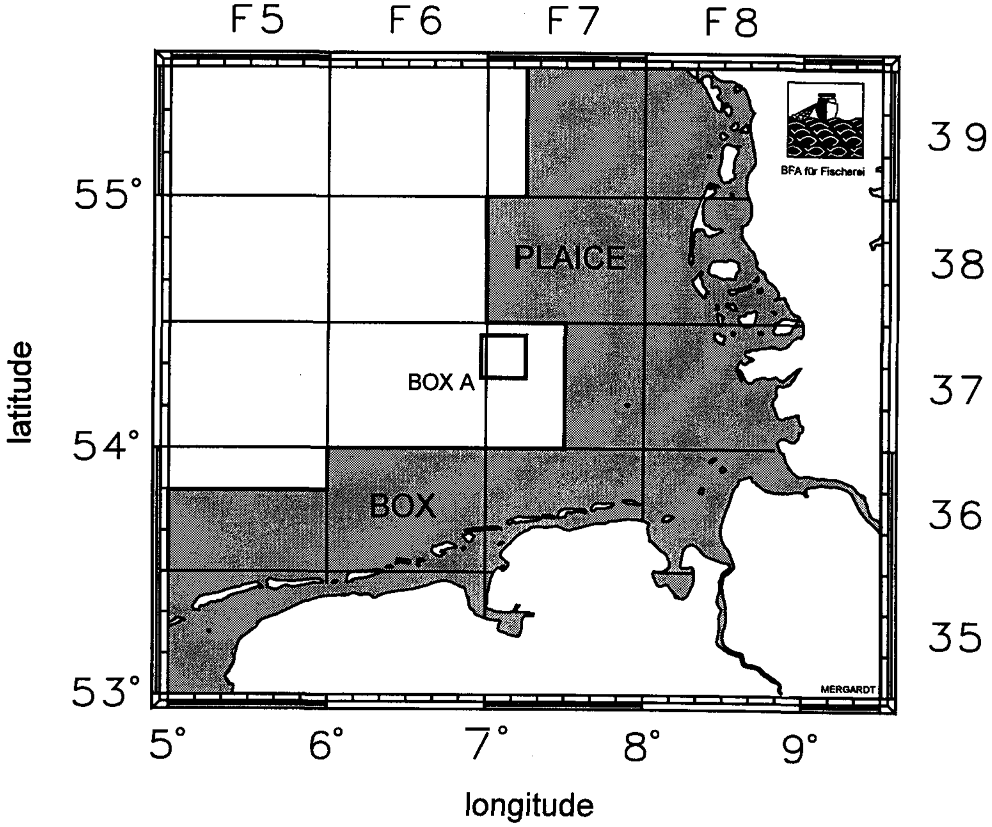


Fig. 2.8.6.1. The location of the Box A area of 10 to 10 nm near Helgoland which was used to detect possible changes in fish assemblages.

2.8.7. TRENDS IN ABUNDANCE AND LENGTH OF EIGHT TARGET AND NON-TARGET FISH SPECIES IN THE NORTH SEA

Time series for the first (Jan.-Mar.) and third quarter (Jul.-Sept.) of the year were used to detect possible trends in abundance in 8 North Sea fish species wich can be related to fising activities.

The time series for the first quarter consists of data from the International Bottom Trawl Survey (IBTS) from 1976 onwards, of 2 surveys of the German fishery research vessel ANTON DOHRN (1) in 1962 and 1963 and of 3 surveys of the German RV POSEIDON in 1977, 1978 and 1979. The time series of the third quarter is more inconsistent. It only comprises 4 phases within the period from 1959 onwards. Table 2.8.7.1 gives the number of hauls per quarter and year for the total North Sea and separately for each of the ICES roundfish areas (RA; Fig. 2.8.7.1). Roundfish areas being covered by less than 6 hauls were considered to be insufficiently sampled, they were excluded from the calculation and marked in the table (shadowed figures).

During all research surveys only otter trawls were used, the nets however were different and each net could also be equipped with different ground ropes related to the roughness of the bottom (Table 2.8.7.2). The methods and gears used in the IBTS are described in a manual by Anon. (1996b).

In order to indicate possible changes in the abundance and length composition over the time period as an effect of the fishery, eight fish species were chosen to represent different groups:

The spurdog *Squalus acanthias* is mainly caught by demersal otter trawls as well as semi- and pelagic trawls. Two species of rays were chosen. *Raja clavata* is a more southerly distributed species, whereas *Raja radiata* is a more boreal species and prefers lower temperatures. The monk fish *Lophius piscatorius* and the grey gurnard *Eutrigla gurnardus* are caught by otter and beam trawls, whereas the flatfish *Limanda limanda* (dab) is mainly caught by beam trawls in the southern North Sea. Catches and landings of these above mentioned species are made only occassionally; and there is no aimed fishing on these species. Target species in the North Sea fishery are represented in this study by the plaice *Pleuronectes platessa* and the whiting *Merlangius merlangus*, which are targeted by flatfish beam trawlers and otter trawlers (roundfish fishery).

The inconsistency of the time series is not only effected by the changes in nets and ground gears, but also by the improvement in standardisation of the catching procedure, in the processing of the catch and in the registration of the catch data. To make the data more comparable over the time period it was necessary to compensate for differences in the catching efficiencies of the gears in use. The IBTS standard trawl (GOV and the rubber disk groundrope) was taken as the reference gear. The conversion factors for the other combinations of nets and ground gears are listed in Table 2.8.7.3. In addition some unpublished results of the experiment in 1986 and the factors for the Aberdeen 48 ft trawl and the Granton trawl, given by Knijn *et al.* (1993). Conversion factors were only available for the more abundant species like dab, grey gurnard, plaice and whiting.

Calculating the mean abundance of one species per roundfish area, firstly the catches were averaged per rectangle and secondly per roundfish area. The mean catch in number per hour for a species in a roundfish area was then multiplied by 10 in order to obtain sufficient high values also for more rare species. The catch rates given for the entire North Sea are stratified means weighted by the number of rectangles in the roundfish areas being sampled.

To indicate a possible trend in the length compositions of the species within the time series, the size range (cm) for each species was divided into 3 classes as follows:

1. *Squalus acanthias* (spurdog)	(<40; 40-69; >69)
2. *Raja clavata* (thornback ray)	(<20; 20-39; >39)
3. *Raja radiata* (starry ray)	(<20; 20-39; >39)
4. *Pleuronectes platessa* (plaice)	(<15; 15-29; >29)
5. *Lophius piscatorius* (angler)	(<20; 20-39; >39)
6. *Eutrigla gurnardus* (grey gurnard)	(<15; 15-24; >24)
7. *Limanda limanda* (dab)	(<10; 10-19; >19)
8. *Merlangius merlangus* (whiting)	(<20; 20-34; >34)

The proportion of each length range was calculated per year, per roundfish area and for the entire North Sea using only the data of the more consistent first quarter. Furthermore, the mean length per species and year was calculated for the whole North Sea and plotted over time.

To show the variability in the spatial, seasonal and inter-annual distribution of the species, the percentual coefficient of variation was calculated using the mean abundances per RA in quarter 1 (spatially), per RA in quarter 1 and 3 (seasonally) and per year in quarter 1 (inter-annually).

The linear regression analysis and the mean values were taken to test the trends in abundance and length. The trends in abundance were calculated by using the stratified mean values for the entire North Sea in quarter 1 for the shortened period 1980 to 1995, for the preceding years from 1976 to 1979 not all of the 7 RA's have been covered (Table 2.8.7.1a).

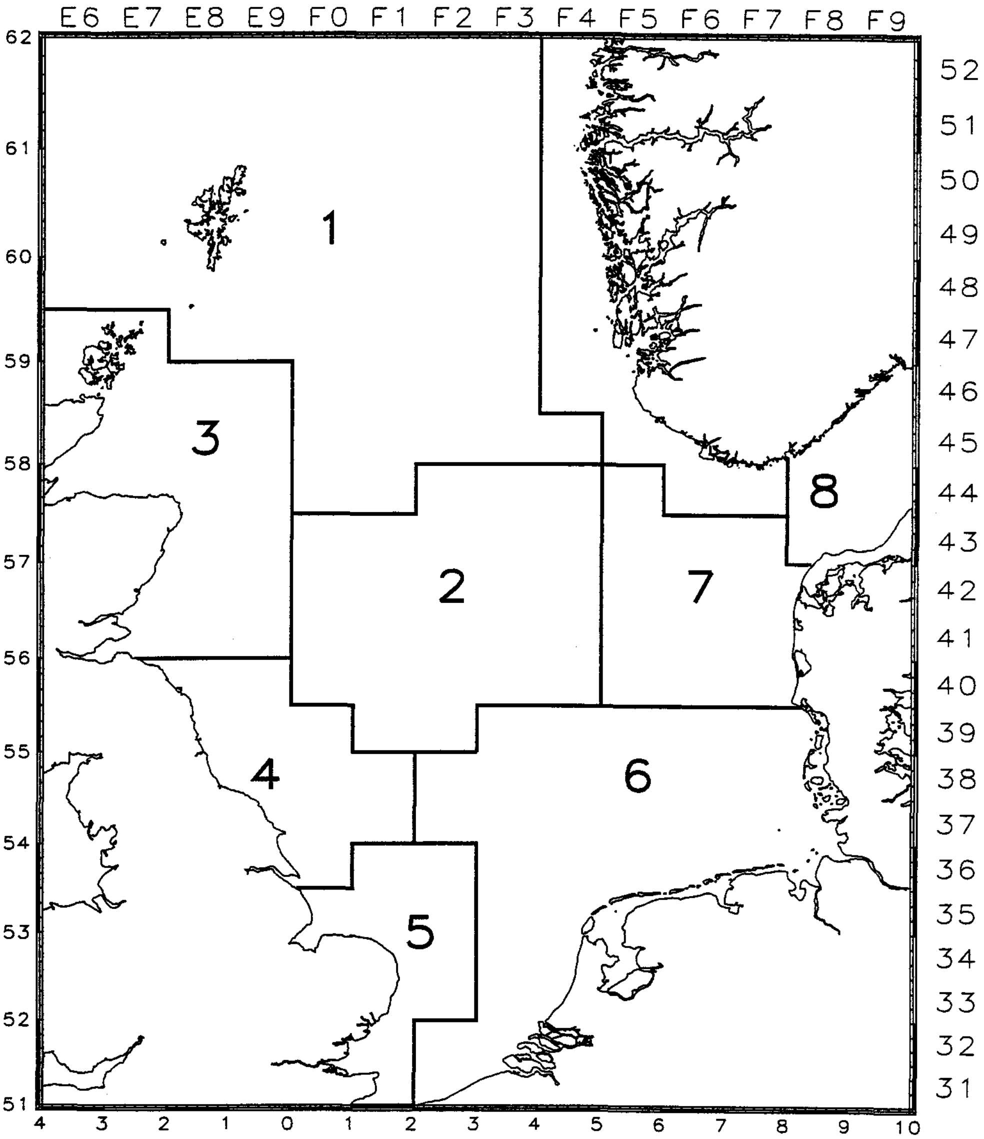


Fig. 2.8.7.1. Map of the North Sea with Roundfish areas.

TABLE 2.8.7.1a.

Number of hauls per year and roundfish area (quarter I).

year	roundfish area 1	2	3	4	5	6	7	total
1962	15	13	9	4	3	16	7	67
1963	15	16	9	5	4	16	7	72
1976	3	10	10	7	2	41	13	86
1977	17	11	19	5	0	51	7	110
1978	17	23	22	10	3	44	8	127
1979	4	18	31	4	0	41	12	110
1980	29	8	13	12	6	61	12	141
1981	10	21	16	18	6	78	16	165
1982	16	30	27	5	17	71	18	184
1983	78	60	52	17	21	101	26	355
1984	86	58	43	20	24	129	30	390
1985	91	66	49	26	18	135	30	415
1986	88	51	42	26	19	158	29	413
1987	83	64	44	26	16	144	29	406
1988	89	54	46	29	20	82	46	366
1989	74	63	40	21	20	119	45	382
1990	80	54	46	26	16	77	37	336
1991	92	69	34	21	19	100	48	383
1992	81	51	38	24	19	96	27	336
1993	79	44	39	21	19	98	27	327
1994	72	56	46	23	21	69	28	315
1995	68	52	33	24	18	65	32	292
total	1187	892	708	374	291	1792	534	**5778**

TABLE 2.8.7.1b.

Number of hauls per year and roundfish area (quarter III).

year	roundfish area 1	2	3	4	5	6	7	total
1959	32	23	10	3	1	44	18	131
1960	16	16	13	5	3	46	11	110
1978	16	30	7	12	5	28	7	105
1983	70	47	18	8	0	12	27	182
1984	70	46	13	10	0	17	24	180
1985	45	23	24	10	2	13	8	125
1986	43	26	117	9	2	22	8	227
1991	65	52	40	18	11	48	19	253
1992	62	68	51	29	16	74	20	320
1993	61	54	36	30	17	84	18	300
1994	61	49	33	29	16	59	18	265
total	541	434	362	163	73	447	178	**2198**

(shaded) no. of hauls not sufficient

TABLE 2.8.7.2
Specification of vessels and gears in the data sets.

year	quarter	vessel	gear	ground rope
1959	3	A. Dohrn I	Kuttertrawl	roller gear
			180ft manila	roller gear
			180ft perlon	roller gear
1960	3	A. Dohrn I	Kuttertrawl	roller gear
			180ft manila	roller gear
1962	1	A. Dohrn I	180ft manila	roller gear
1963	1	A. Dohrn I	180ft manila	roller gear
1976	1	IBTS	several	rubber discs+rollers
1977	1	IBTS	several	rubber discs+rollers
	1	Poseidon	180ft perlon	rope with chains
1978	1	IBTS	several	rubber discs+rollers
	1	Poseidon	180ft perlon	rope with chains
	3	A. Dohrn II	180ft perlon	chains and rollers
1979	1	IBTS	several	rubber discs+rollers
	1	Poseidon	180ft perlon	rope with chains
1980	1	IBTS	several	rubber discs
1981	1	IBTS	several	rubber discs
1982	1	IBTS	GOV	rubber discs+rollers
1983	1	IBTS	GOV	rubber discs+rollers
	3	W. Herwig II	180ft perlon	roller gear
1984	1	IBTS	GOV	rubber discs+rollers
	3	W. Herwig II	180ft perlon	roller gear
1985	1	IBTS	GOV	rubber discs+rollers
	3	W. Herwig II	GOV	roller gear
1986	1	IBTS	GOV	rubber discs+rollers
	3	W. Herwig II	GOV	roller gear
1987	1	IBTS	GOV	rubber discs
1988	1	IBTS	GOV	rubber discs
1989	1	IBTS	GOV	rubber discs
1990	1	IBTS	GOV	rubber discs
1991	1	IBTS	GOV	rubber discs
	3	IBTS	GOV	rubber discs
	3	Scotia	Aberdeen 48ft	roller gear
	3	Cirolana	Granton	discs
1992	1	IBTS	GOV	rubber discs
	3	IBTS	GOV	rubber discs
	3	Scotia	Aberdeen 48ft	roller gear
	3	Cirolana	Granton	discs
1993	1	IBTS	GOV	rubber discs
	3	IBTS	GOV	rubber discs
	3	Scotia	Aberdeen 48ft	roller gear
	3	Cirolana	Granton	discs
1994	1	IBTS	GOV	rubber discs
	3	IBTS	GOV	rubber discs
	3	Scotia	Aberdeen 48ft	roller gear
	3	Cirolana	Granton	discs
1995	1	IBTS	GOV	rubber discs

TABLE 2.8.7.3
Conversion factors between gears, related to GOV (standard).

gear	plaice (n)	dab (n)	grey gurnard (n)	whiting (n)
GOV(standard)	1.00	1.00	1.00	1.00
GOV(roller gear)	0.58	0.57	0.45	1.40
180ft (perlon; roller gear)	1.41	0.67	0.53	1.51
180ft (manila; roller gear)	1.00	0.48	0.66	1.07
Kuttertrawl (roller gear)	3.90	1.86	1.92	5.68
Aberdeen 48 ft	5.74	1.58	6.17	4.72
Granton	1.33	0.58	0.77	4.21

No conversion factors for the rare species like spurdog, rays and angler fish.

3. RESULTS

3.1. SIZE OF BOTTOM TRAWLING FLEETS

Introduction

The IMPACT-project focus on the effects of bottom trawling on the benthic ecosystems in the North Sea and the Irish Sea. In order not to restrict the conclusion to the present day situation it was decided to make the link with the past and provide data on fishing activities, fishing fleets and fishing gears, for the past 100 years.

3.1.1. HISTORICAL REVIEW OF FISHING FLEETS AND GEARS

3.1.1.1. FISHING FLEETS

Before the introduction of steam vessels in 1884, the Belgian, German and Dutch fleet consisted only of rowing boats and sailing vessels. The smaller coastal vessels, usually not decked and with a flat keel, operated within a 10 miles range from the coast. The medium coastal vessels, with a keel length between 9 and 12 m operated in a range of 25 miles from the coast. The larger Belgian vessels, with a length over all of 16 to 18 m, operated from the English south-east coast up to the Dutch coast (Terschelling). In summertime they fished for cod on the Dogger Bank, the Faroes and even up to Iceland. Also for the other North Sea countries a wide spread of the effort for the larger vessels is reported for the end of the 19th century. By then fishing was carried out in the whole North Sea, the Dogger Bank, the Great Fisher Bank towards the coast of Norway, Iceland, the Barents Sea etc.

The numbers of sailing vessels (Figs 3.1.1 to 3.1.3) reached a maximum between 1910 and 1920, with over 600 for Belgium and over 5000 (of which 500 trawlers) for the Netherlands. Also for Germany the numbers of sailing vessels reached a maximum in this period, but the data presented in the graph only include herring drifters. These herring luggers had a length between 22 and 28 m, a breadth between 5 and 6 m and a tonnage between 60 and 100 GRT. In Fig. 3.1.2 the numbers of "trawling" sailing vessels are shown and include 10% of the sailing fleet. Though numbers of sailing vessels were high, the effort exerted was low and mainly passive fishing methods were applied. These numbers decreased drastically after 1920 when the diesel engine appeared on fishing vessels. As for the tonnage, the Dutch vessels had an average GRT of 11 in 1910 decreasing to 3.5 in 1950 whereas the trawling sailing vessels had an average GRT of 31 in 1910 decreasing to 16 in 1940.

Starting from 1884 the first steam vessels (Fig. 3.1.1 to 3) were introduced in the Belgian, the Dutch and the German fishery. This new type of fishing vessel caused the first boost in trawling effort that, together with the introduction of the otter trawl, probably produced a much higher disturbance of the seafloor compared with non-motorised boats. The steamtrawlers knew their highest success by the end of the 1920's. Thereafter their numbers decreased to almost zero after the Second World War. The steamtrawlers were not limited in their choice for fishing grounds and were less dependent on weather conditions. They fished in the southern and central North Sea, the English Channel, Rockall and Moray Firth but most of the effort was concentrated on Iceland, West of Scotland, northern North Sea and the Bristol Channel.

The first vessels equipped with a diesel engine (Fig. 3.1.1 to 5) were introduced about 1901. They had an increasing success and were, after the 50's the only type of vessel active in the sea-fishery. This motorization caused a second drastic increase in trawling effort. The choice of the fishing grounds, which were mainly fished with otter trawls, depended very much on the vessels' engine power but fishing was soon carried out through the whole of the North Sea. As with steamtrawlers, the otter trawl was the most popular gear.

In the early 60's the beam trawl was re-introduced in the Belgian, Dutch and German fishery. While this gear used to be a light wooden construction, at that time still used by German shrimp trawlers, it was now replaced by a double rig (at both sides of the vessel) heavy steel gear often equipped with tickler chains and later sometimes chain matrices. Since it was soon clear that the catchability of this gear increased with the number of tickler chains and higher towing speed had no negative effect on the catches, there was a continuing trend for increasing engine powers (Fig. 3.1.4 & 5). Consequently the smaller vessels in this fleet almost disappeared in favour of larger vessel with engine powers up to 3000 kW. The maximum engine power has been legally limited to 883 kW for Belgium and 1470 kW (for new building from 1989 on) for the Netherlands. The number of otter trawlers gradually went down in favour of beam trawlers.

Figures 3.1.6 to 8 illustrate the progress of the total landings. These landings have been split up, where possible, into flatfish, roundfish, pelagic and shellfish and prawn catches. It is clear that the most important group is the demersal fish. Pelagic fish used to be important for Belgium, but is almost absent in the landings since the 80's. For the Netherlands the pelagic landings remain fairly constant, but these are landed especially by large freezer trawlers (which are not included in the figures). *Nephrops* and shrimp only make up a small percentage of the total landings but are quite constant for both countries over the years. For Belgium it is clear that the total landings show a continuous decline since the early 60's. For the Netherlands, on the other hand, there was a peak in 1985 but the pictures before and after are not really different.

Figures 3.1.9 & 10 show the trend for engine power and tonnage since the beginning of this century. The total engine power has been increasing constantly, except for the last years.

3.1.1.2. FISHING GEARS

Four types of fishing vessels, each using one or more typical fishing gears, can be distinguished: sailing vessels, steam vessels, otter trawlers and beam trawlers.

Due to its restricted towing force and its dependence on wind speed, sailing vessels were not able to apply heavy gears or gears needing hydrodynamic forces to open the net. Consequently, mainly stationary gear or light weight trawls were used in this fishery. The following types of fishing gears were used aboard sailing vessels:

- Beam trawls with a wooden beam with a length up to 10 m, iron beam trawl shoes, 90 cm high. Since these gears were towed by sailing vessels they were quite light. The target species were flatfish and roundfish like cod and whiting. Most of the vessels stopped using these trawls by the end of the 19th century and switched to passive fishing gear.
- Stownets (Fig. 3.1.11): the stownets usually had a length between 25 and 35 m. The length of the beam, which opened the net horizontally, was about 7 m long. The gear had a stationary position on the seabed during fishing operation and was attached to an anchor with a weight of over 70 kg. The target species were herring and sprat.
- Driftnets (Figs 3.1.12 & 13), with a total length of about 900 m, consisting of individual nets with a length of 36 m and a depth of 7 m. While fishing, these nets were attached to the vessel. The target species was herring and other pelagic species.
- Otter trawls (Figs 3.1.14): The first otter trawls appeared by the end of the 19th century. At that time the otter boards were directly attached at the wings of the net. They were seldom used by sailing vessels.

The appearance of steam boats and, later, vessels equipped with diesel engines, made it possible to make a profitable use of the otter trawl. At first the otter boards were directly attached to the netwings but later long bridles and sweeps were inserted between boards and wings in order to increase the fishing circle and swept area (Fig. 3.1.15). Also new methods of rigging the gear, new types of groundgear and new types of otter boards increased catchability and gave the fishery access to new fishing grounds. These developments came gradually and appeared at different times in different countries or regions. It is impossible to give dates when the otter trawl's catchability took a big step forward. Otter trawls can be constructed to fish pelagic but in the cutter fishery mainly the demersal otter trawl has been used. In the 70's the Danish pair trawl (Fig. 3.1.16) became increasingly popular. Driftnets were only still used on the smaller vessel till the 1940's.

In 1959 the first modern beam trawl (Fig. 3.1.17) was introduced. It was based on the same principle as the wooden beam trawls, but now they were much heavier, completely constructed of steel. Also the use of tickler chains or chain matrixrices increased the weight of the gear and increased the fishing efficiency. Soon many vessels switched to the beam trawl fishery, first on a seasonal basis and later continuously, as well for the shrimp as for flatfish fishery. By the end of the 80's over 80% of the Belgian and Dutch fishing vessels merely fished with beam trawls.

In the beginning of this century the numbers of vessels in the Belgian, Dutch and German fishery were very high. These were, however, non-motorised vessels, applying mainly passive gear or light weight beam trawls. The impact of these fisheries on the seafloor was probably quite low. With the introduction of the steam engine (end 19th century), and later the diesel engine (1920's), the fishery soon changed from mainly passive to mainly active fishing, applying mostly bottom otter trawls. This probably had consequences for the fish stocks and bottom fauna, especially when new types of rigging and groundgear increased the catchability and gave the fishery access to new fishing grounds. The introduction of the beam-trawl (1960's) was the start of a continuous increase of engine powers. Vessels sizes increased as well as the weight of the gears.

The obvious conclusion of this review would be that during the past century the development in fishing methods gradually increased the catchability and that vessel development lead to a continuous increase of the input of power into the fishery.

3.1.2. SIZE OF THE BOTTOM TRAWL FLEETS - PRESENT SITUATION

The first step in the preparation to the fleet inventory was the division of the fishing fleets into sub-fleets. This was necessary because of the wide range in vessel sizes in the fleets considered, with engine powers ranging from less than 74 kW up to 3000 kW (Table 3.1.1 & 2). In Table 3.1.2 the data for the Irish and Scottish fleet are incomplete due to the absence of or incomplete statistics. It was decided to apply *engine power* classes. The two main reasons for this were:

- engine power is the basis for the vessel classes in the national databases and a lot of data needed in this project will have to be extracted from these databases and
- engine power can be considered as an important factor in the potential impact of the fishery on the marine environment.

Since the goal of the study is to define an average vessel and fishing gear for each sub-fleet the variation of vessel and gear parameters within each sub-fleet should be as small as possible. Consequently sub-fleets were chosen such as to get vessel groups with similar characteristics.

Following classes were defined: class 1: 70-191 kW; class 2: 192-221 kW; class 3: 222-800 kW; class 4: 801-1100 kW; class 5: 1101-1500 kW; class 6: >1500 kW.

Class 1 contains coastal beam trawlers targeting shrimp. Class 2 consists mainly of the so called Eurocutters fishing with beam trawls for shrimp but mainly for flatfish. Class 3 is the only sub-fleet with some importance for otter trawling (Belgium) and pair trawling (Netherlands). The other vessels are older beam trawlers, often former otter trawlers adapted for beam trawling. Class 4 contains mainly beam trawlers and is important for Belgium since it contains the distinct 883 kW group which is the maximum hp-limit in Belgium. Class 5 and 6 consist mainly of Dutch vessels which merely are modern beam trawlers.

For each subgroup in the North Sea and Irish Sea the numbers of vessels have been extracted from the national databases together with the landings for each participating country according to the gear they were caught with (Table 3.1.2). This was the basis for the choice of gears to be included in the inquiry.

The total number of Belgian, Dutch, German, Irish and UK fishing vessels active in the North Sea and the Irish Sea is 3425. England and Wales and Scotland account for 1238 and 1057 vessels respectively. These consist, however, mainly of vessels with low engine powers. The Netherlands, Germany, Belgium and Ireland account for 482, 367, 149 and 132 vessels respectively. About 2000 of the vessels have an engine power below 221 kW, 1000 have an engine power between 222 and 800 kW and the rest (1425 vessels) lie above 800 kW.

From the landings in Table 3.1.2 it is clear that beam trawling is the most important fishery in Belgium and the Netherlands. Demersal otter and pair trawling is only marginally important. Other types of fisheries like longlining and gillnetting are almost absent. For England and Wales otter trawling is the most significant fishing method in the three lower engine power classes. In these classes, the beam trawl has a comparable importance as the demersal pair trawl, the seine net, gillnets and longlines. In engine power class 1, dredging is the most important fishing method, for the landed catch weight. The vessels with engine powers above 800 kW operate mainly the beam trawl. For Scotland, the demersal otter and pair trawl are the most significant gears. The beam trawl only accounts for a very small percentage of the total Scottish landings. In Ireland otter trawling is the most important fishing method. The beam trawl is only operated on a small number of vessels.

3.1.3. DISCUSSION

Fishing has been an important industry since the beginning of this century. The high numbers of sailing fishing vessels and steamtrawlers demonstrate that in early nineteen hundreds the North Sea was already intensely fished. The fishery at that time mainly used passive fishing gears but trawl nets were already in use on board of the steam trawlers and the larger sailing vessels. The impact of fisheries on the marine environment is thus not new. Technological advances during this century made an increase of this impact possible, with the introduction of the diesel engine, the otter trawls able to fish rough grounds, the beam trawl and modern navigation equipment as the main steps.

Detailed historical data on fishing vessels and certainly fishing gears used are very scarce and often not available in the statistics which makes it difficult to clearly assess the historical impact of the fishery on the environment. Even present day fisheries statistics give little information on fishing gears. Therefore the detailed inventory of vessels and gears in this report is a valuable tool in relation with the impact studies of this project.

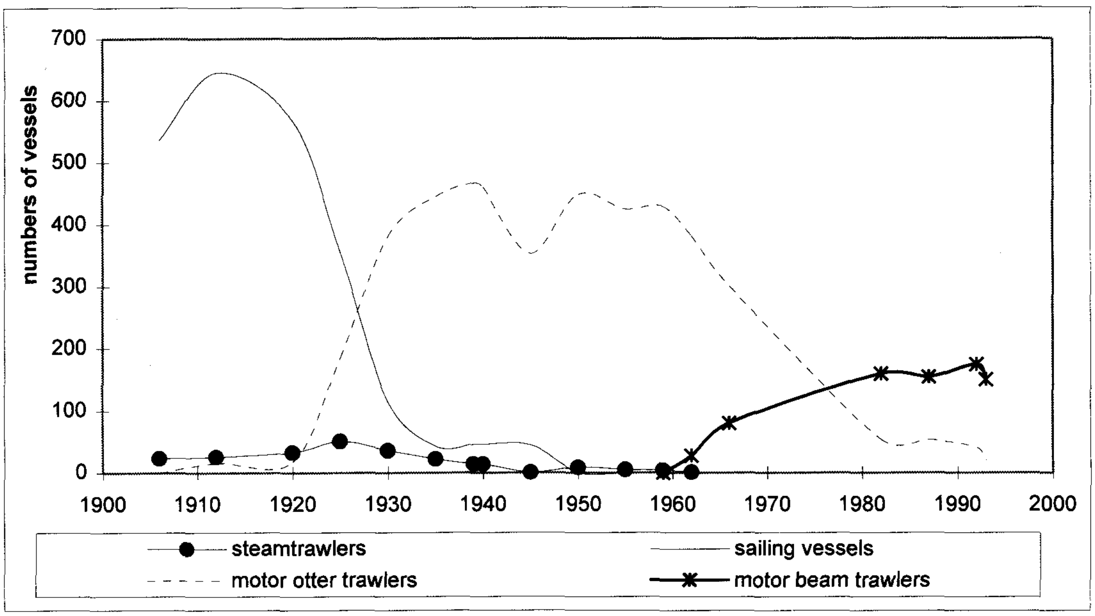


Fig. 3.1.1. Vesselnumbers in the Belgian fleet.

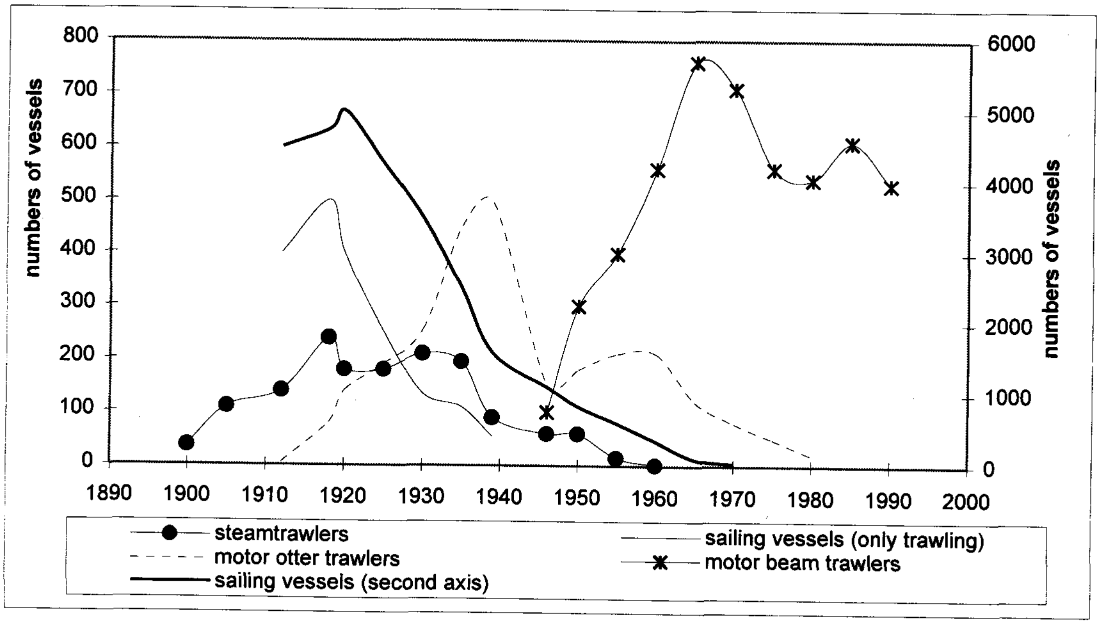


Fig. 3.1.2. Vesselnumbers in the Dutch fleet*.

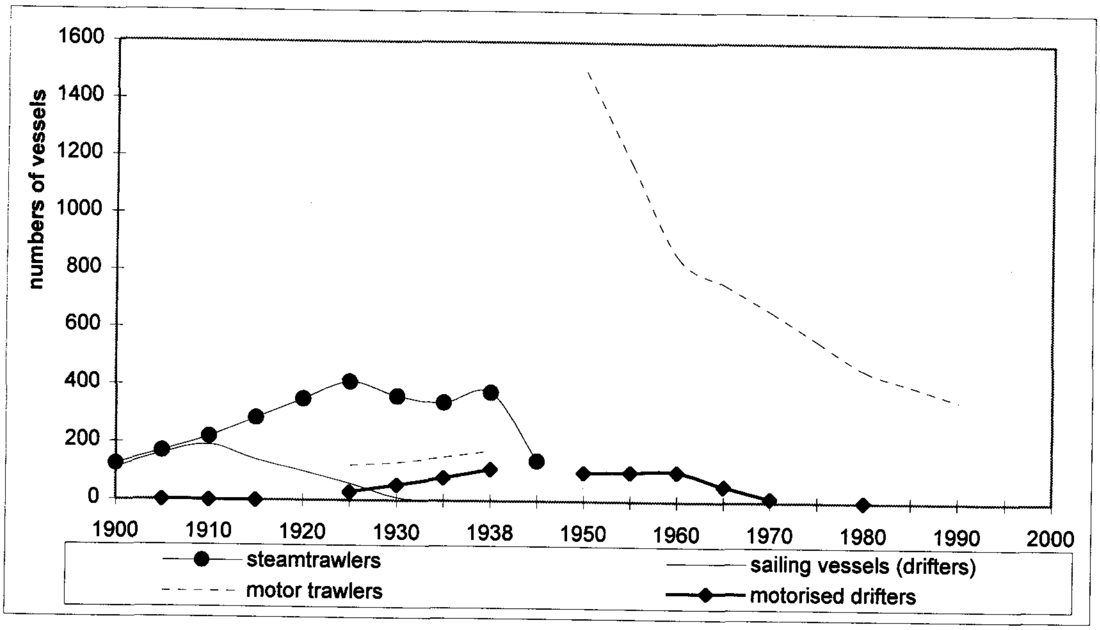


Fig. 3.1.3. Vesselnumbers in the German fleet.

* The Netherlands: exclusive large stern trawlers and mollusc dredgers.

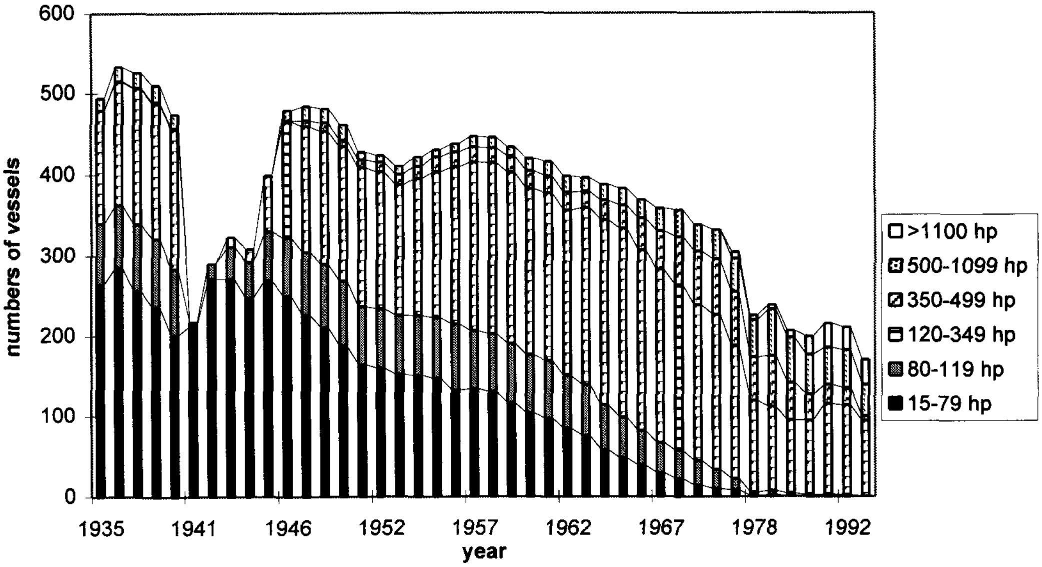


Fig. 3.1.4. Numbers of trawlers per engine power class - Belgium.

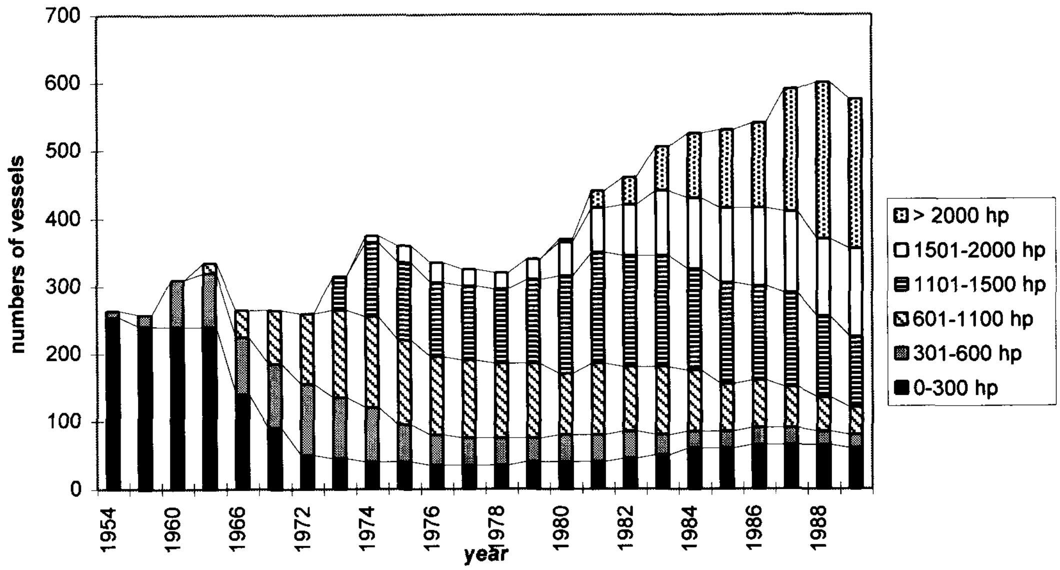


Fig. 3.1.5. Numbers of trawlers per engine power class - Netherlands*.

* The Netherlands: exclusive large stern trawlers and mollusc dredgers.

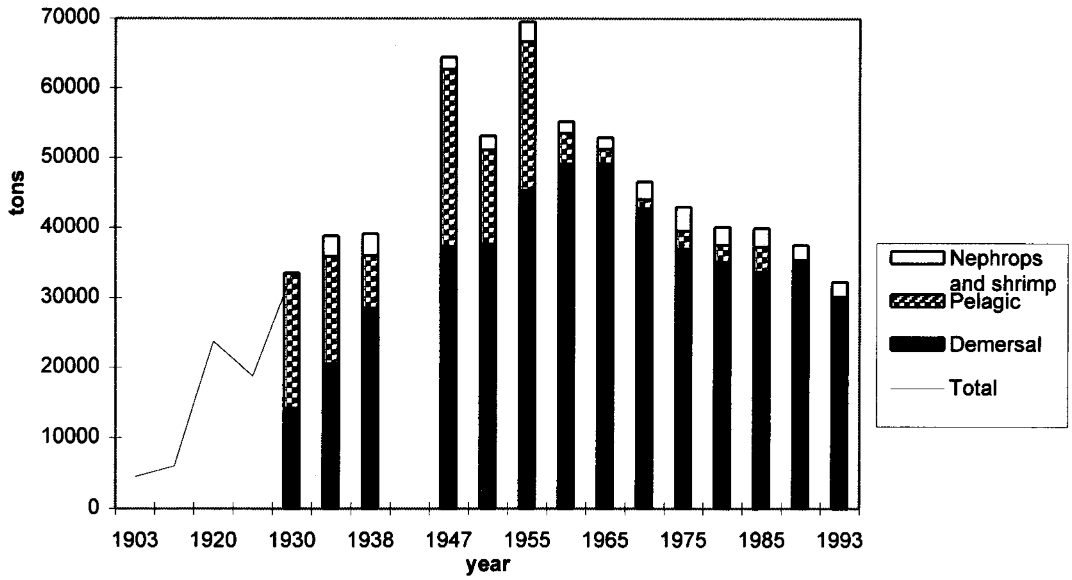


Fig. 3.1.6. Fish landed by Belgian fishing fleet.

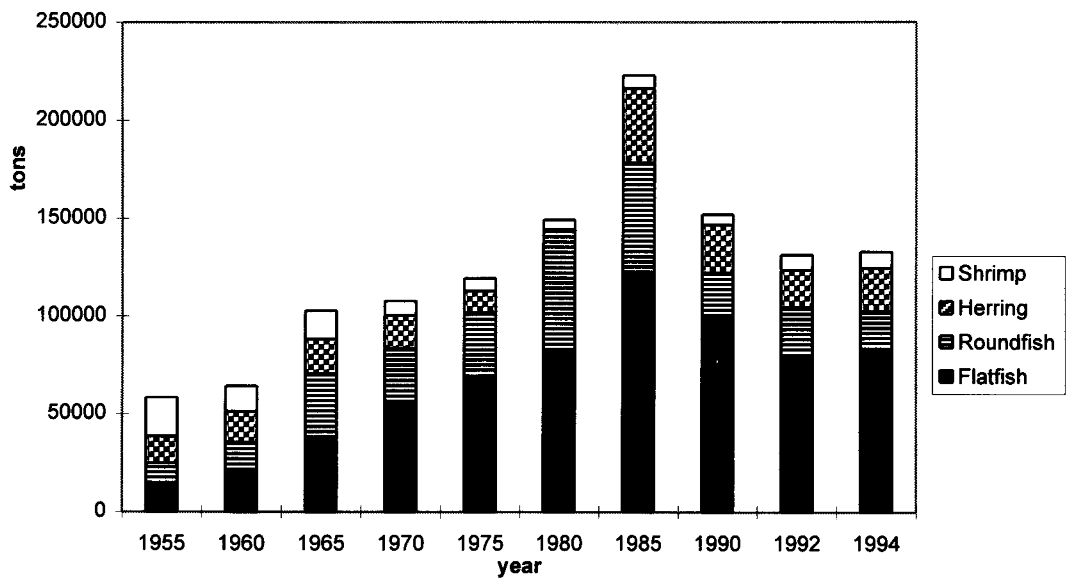


Fig. 3.1.7. Fish landed by Dutch fishing fleet*.

* The Netherlands: exclusive large stern trawlers and mollusc dredgers.

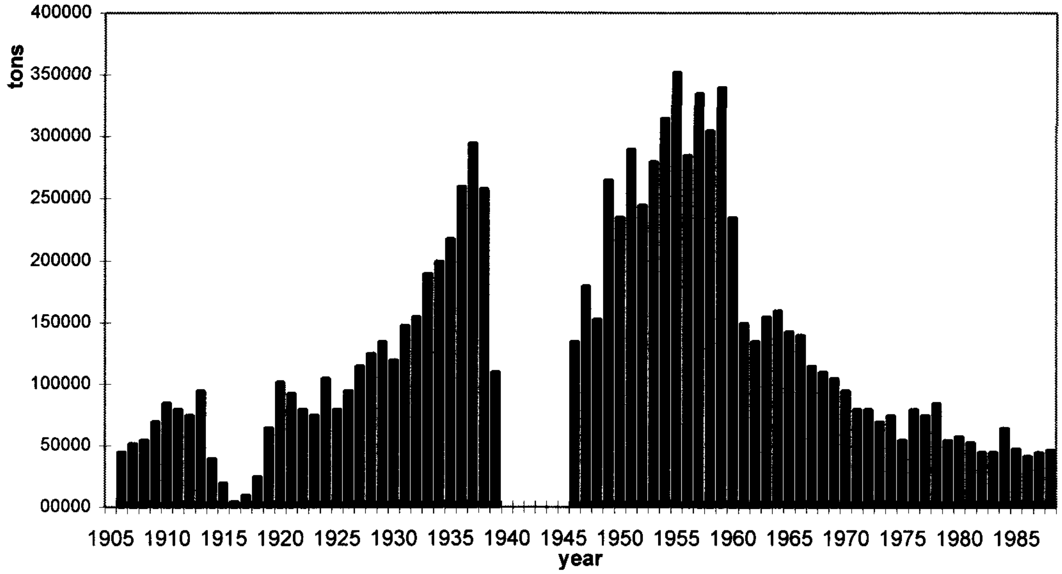


Fig. 3.1.8. Fish landed by the German fishing fleet - total landings.

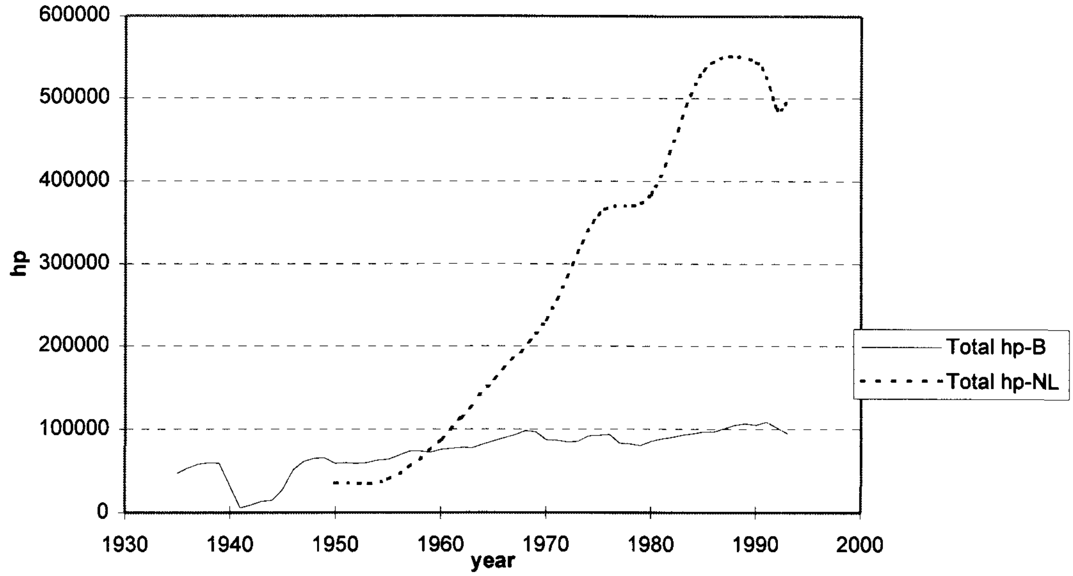


Fig. 3.1.9. Total engine power of fishing fleet (ecl. wind power).

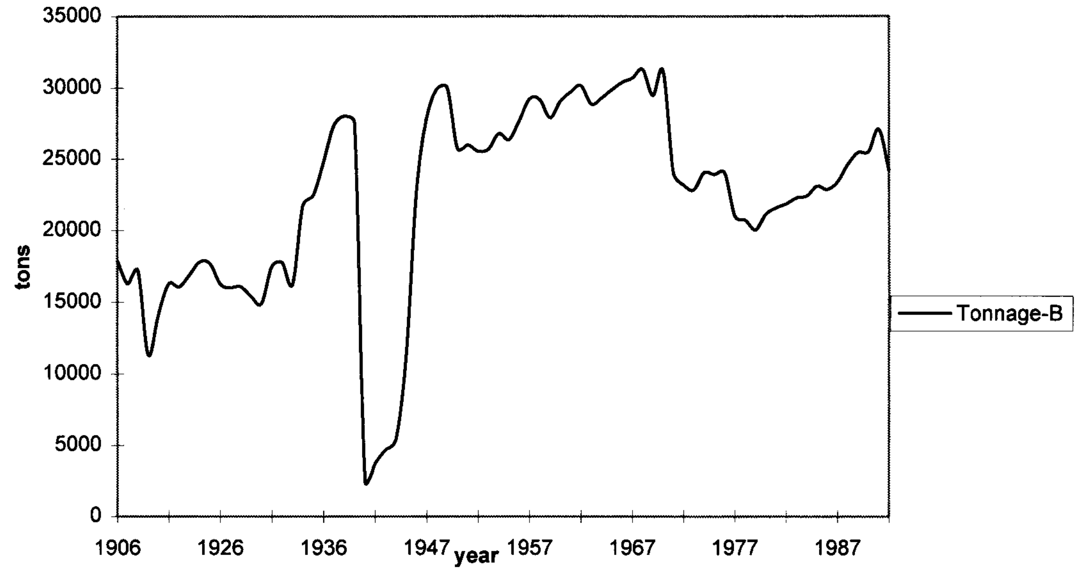


Fig. 3.1.10. Tonnage of Belgium fishing vessels.

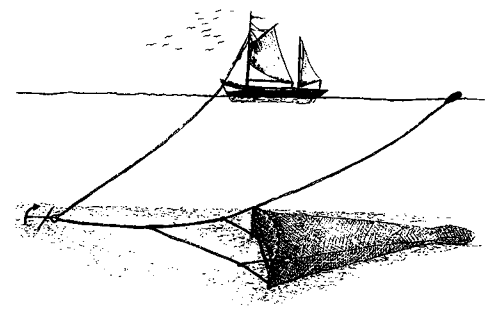


Figure 3.1.11

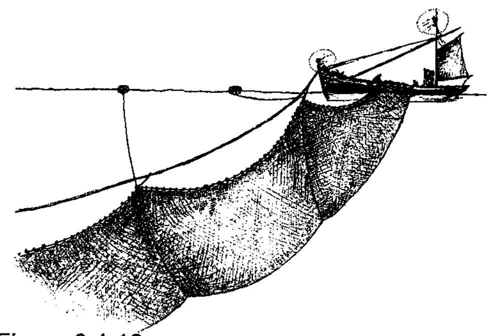


Figure 3.1.12

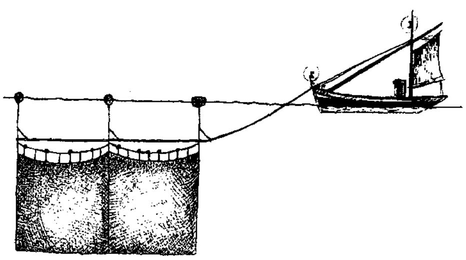


Figure 3.1.13

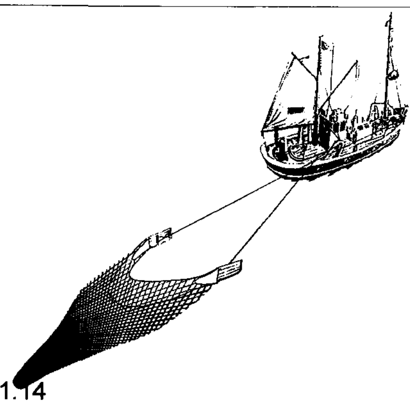


Figure 3.1.14

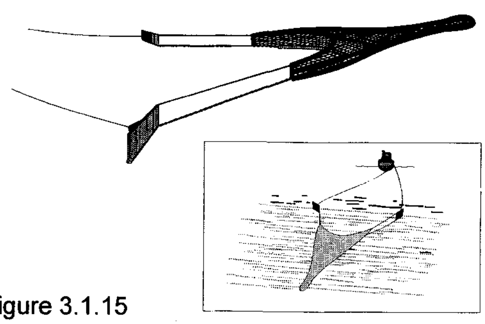


Figure 3.1.15

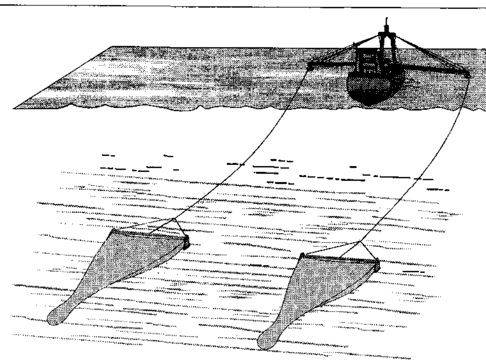


Figure 3.1.17

Figure 3.1.11 - Stownet, used by sailing vessels
Figure 3.1.12 - Driftnet, used by sailing vessels
Figure 3.1.13 - Driftnet, used by sailing vessels
and later also by motorvessels
Figure 3.1.14 - Early otter trawl
Figure 3.1.15 - Otter trawling
Figure 3.1.16 - Demersal pair trawling
Figure 3.1.17 - Beam trawling

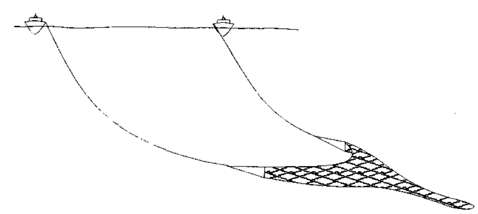


Figure 3.1.16

TABLE 3.1.1
The numbers of vessels in the fishing fleets per country and per sub-fleet.

Engine power class	Main fishery	B	E	G	I	NL	S
70-191 kW	shrimp beam trawling	27		221		120*	
	flatfish beam trawling (tickler chains)						
	flatfish beam trawling (chainmat)						
	otter trawling			2	51		291
	other				3		80
	total	**27**	**804**	**223**	**54**	**120**	**371**
192-221 kW	shrimp beam trawling			51		30	
	flatfish beam trawling (tickler chains)	10			3	95*	2
	flatfish beam trawling (chainmat)	36*					
	otter trawling	9*		6	11		53
	other						13
	total	**55**	**90**	**57**	**14**	**125**	**68**
222-800 kW	shrimp beam trawling						
	flatfish beam trawling (tickler chains)				7	38*	2
	flatfish beam trawling (chainmat)	32					
	otter trawling	5		24	50		369
	other	1		2	4		219
	total	**38**	**274**	**26**	**61**	**38**	**590**
801-1100 kW	shrimp beam trawling						
	flatfish beam trawling (tickler chains)	5		2	2	36	1
	flatfish beam trawling (chainmat)	27				1	
	otter trawling			2			3
	other						2
	total	**32**	**30**	**4**	**2**	**37**	**6**
1101-1500 kW	shrimp beam trawling						
	flatfish beam trawling (tickler chains)			1	1	84**	5
	flatfish beam trawling (chainmat)						
	otter trawling						5
	other						3
	total	**0**	**26**	**1**	**1**	**84**	**13**
> 1500 kW	shrimp beam trawling						
	flatfish beam trawling (tickler chains)					74**	7
	flatfish beam trawling (chainmat)						
	otter trawling			7			
	other						2
	total	**0**	**14**	**7**	**0**	**74**	**9**

* : mixed fishery

** : tickler chain beam trawls, sometimes in combination with the chainmat

TABLE 3.1.2
Landings for each sub-fleet - all areas (1993).

Vessel type	Engine power, kW (hp)	Fishing method	Total catch (ton)					
			B	E&W	G	I	N	S
Cutters	70-191 (95-260)	shrimp beam trawling	480 ton		341 ton		4540 ton	
		flatfish beam trawling	249 ton	1390 (x)	153 ton		450 ton	2475 ton (xx)
		demersal otter trawling	9 ton	8710 ton	100 ton		50 ton	65750 ton (xx)
		demersal pair trawl	45 ton	1349 ton				34356 ton (xx)
		seine net		1565 ton				54867 ton (xx)
		dredge		18554 ton				7789 ton (xx)
		pelagic trawl	26 ton	1725 ton				16618 ton (xx)
		gillnetting		2267 ton				75 ton (xx)
		longlining		1749 ton				39 ton (xx)
		total	**809 ton**	**37309 ton**			**5040 ton**	
		Numbers of vessels =>	**27 vessels**	**804 vessels**	**251 vessels**	**54 vessels**	**120 vessels**	**371 vessels**
	192-221 (261-300)	shrimp beam trawling	594 ton		2207 ton		3960 ton	
		flatfish beam trawling	3521 ton	732 ton (x)	1690 ton		8570 ton	
		demersal otter trawling	1344 ton	1702 ton	661 ton		580 ton	
		demersal pair trawl	120 ton	270 ton			1020 ton	
		seine net		105 ton				
		dredge		70 ton				
		pelagic trawl	26 ton	354 ton				
		gillnetting		119 ton				
		longlining		14 ton				
		total	**5605 ton**	**3364 ton**			**14130 ton**	
		Numbers of vessels =>	**55 vessels**	**90 vessels**	**75 vessels**	**14 vessels**	**129 vessels**	**68 vessels**
	222-800 (301-1088)	shrimp beam trawling						
		flatfish beam trawling	9696 ton	1948 ton (x)			1070 ton	
		demersal otter trawling	2928 ton	10316 ton	13521 ton		180 ton	
		demersal pair trawl	53 ton	1833 ton	814 ton		6020 ton	
		seine net		1070 ton				
		dredge		508 ton				
		pelagic trawl		1615 ton			590 ton	
		gillnetting		218 ton				
		longlining		911 ton				
		total	**12677 ton**	**18418 ton**			**7860 ton**	
		Numbers of vessels =>	**37 vessels**	**274 vessels**	**36 vessels**	**61 vessels**	**38 vessels**	**590 vessels**
	801-1100 (1089-1496)	shrimp beam trawling						
		flatfish beam trawling	13157 ton	3531 ton (x)	1314 ton		10800 ton	
		demersal otter trawling		396 ton	2034 ton		250 ton	
		demersal pair trawl					50 ton	
		seine net						
		dredge		27 ton				
		pelagic trawl		217 ton			10870 ton	
		gillnetting						
		longlining						
		total	**13157 ton**	**4171 ton**			**21970 ton**	
		Numbers of vessels =>	**30 vessels**	**30 vessels**	**5 vessels**	**2 vessels**	**37 vessels**	**6 vessels**
	1101-1500 (1501-2100)	shrimp beam trawling						
		flatfish beam trawling		3703 ton (x)	629 ton		30080 ton	
		demersal otter trawling		1563 ton				
		demersal pair trawl						
		seine net						
		dredge						
		pelagic trawl					12540 ton	
		gillnetting						
		longlining						
		total	**0 ton**	**5266 ton**			**42620 ton**	
		Numbers of vessels =>	**0 vessels**	**26 vessels**		**1 vessels**	**84 vessels**	**13 vessels**
	> 1500 (> 2100)	shrimp beam trawling						
		flatfish beam trawling		412 ton (x)			36420 ton	
		demersal otter trawling			41224 ton			
		demersal pair trawl						
		seine net						
		dredge						
		pelagic trawl		814 ton				
		gillnetting						
		longlining						
		total	**0 ton**	**1226 ton**			**36420 ton**	
		Numbers of vessels =>	**0 vessels**	**14 vessels**		**0 vessels**	**74 vessels**	**9 vessels**

(x) : The beam trawl fleet, shrimp and flatfish beam trawlers combined
(xx) : All engine power classes combined
Abbreviations: B=Belgium, E&W=England and Wales, G=Germany, I=Ireland, N=Netherlands, S=Scotland

3.2. FISHING GEARS USED BY DIFFERENT FISHING FLEETS

Introduction

The effects of bottom trawling were studied in this project with a selection of the most typical fishing gears used in the North Sea and Irish Sea bottom trawling. In order to make the link with the real situation in the fishing industry it was necessary to make an inventory of the fishing gears used together with all necessary technical details and operational parameters. An inquiry among netting and fishing gear companies and skippers and vessel owners seemed the best way to obtain this information.

For impact studies it is not enough to know details on the fishing gears used. It is also necessary to know the geographical distribution of the use of the different types of fishing gear in order to be able to link the effect of a gear to the sensitivity of a specific area. Therefore data on fishing effort were collected for all participating countries.

The sub-fleets mentioned in Table 3.2.1 were selected to be included in the vessel and gear inventory. Each were given an appreciation of their relative importance as a fishery.

For each of the sub-groups an inquiry form was made up with questions on vessel characteristics, fishing gear characteristics and operational parameters. The base list of parameters agreed upon by the three participants is given in Table 2.2.1.

It is important to keep in mind that the data presented hereafter have been collected in the period 1994-1996 and can vary in time due to changing fishing opportunities, new technologies and economic factors.

3.2.1. FISHING GEAR INVENTORY

3.2.1.1. SHRIMP BEAM TRAWLING

Figure 3.2.1 shows the basic type of beam trawl. This is a demersal fishing gear and is used to target flatfish and shrimps. The net is kept open horizontally by means of a steel beam, which is supported at both sides by the beam trawl shoes. The construction of the net is rather simple and consists of a top and a lower panel and a codend where the catch accumulates. The top panel is attached to the headline, which is rigged to the beam trawl shoes. The lower panel is attached to the bobbin rope, which has to be rather heavy in order to maintain the bottom contact. Although the basic construction of the beam trawl is rather simple, this gear often shows typical alterations to adapt the gear for certain fishing operations. A fishing vessel equipped for beam trawling tows two gears simultaneously, one at each side, by means of two outrigger beams (Fig. 3.1.17).

Shrimp (*Crangon crangon*) are caught along the coasts, in estuaries and in the Wadden Sea, usually on sandy fishing grounds, by the smaller type beam trawlers. These vessels with engine powers below 221 kW are allowed to fish within the 12 miles zone with beam trawls, according to the EU-regulation no. 55/87, if each beam length is below 4.5 m. Beams over 4.5 m long are also allowed for shrimp trawling if the vessel appears on a specific list published by the European Commission. According to EU-regulation 3554/90 these vessels can also catch sole within the 12 miles zone with a beam length over 4.5 m 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.

The gear is a lightweight beam trawl without tickler chains or chain matrix. The legal minimum mesh size is 20 mm and a large mesh codend cover protects the codend.

In the North Sea, 22 Danish, 247 German, 228 Dutch, 36 Belgian and 98 UK vessels target shrimp continuously or on a seasonal basis.

Technical and operational details – shrimp beam trawlers - 70-191 kW

Vessel (Table 3.2.2): The average engine power of a vessel in the 70-191 kW sub-fleet is 151 kW (206 hp). The average length over all (LOA) and breadth is 17 m and 5.1 m respectively. The tonnage of the vessels is given in two units: GRT and GT. GRT is an older unit, measured at the inside of the vessel, and is smaller than GT which is measured at the outside of the vessel. GT is a unit agreed upon in the Convention of Geneva in 1969 (active in 1982) and all recent measurements are done in this unit. Consequently there are two groups of vessels, one with an average tonnage of 32 GRT and one of 39 GT. 80% of the vessels have a kort nozzle with an average propeller diameter of 1.3 m. A controllable pitch does not occur in the shrimper fleet in Belgium but in the Netherlands a series of 6 shrimp beam trawlers (built in 1981) have been equipped with a controllable pitch. A GPS-system and a videoplotter have become standard navigation equipment aboard these vessels for navigation and storage of fishtracks. Decca navigation systems are only on board as a back up.

Operational parameters (Table 3.2.2): The towing speed relative to the bottom is 2.5-3 knots. Warp depth ratio is 2 to 2.5/1, depending on seafloor condition and depth. All vessels use single warps with a diameter between 16 and 20 mm. Since the gears used are rather light, and the optimal towing speed for catching shrimp with the type of fishing gear used lies around 2.5 knots, the engine powers installed in the vessels can be rather low. Consequently none of the vessels have secondary engines to deliver power for non-propulsion activities.

In Belgium, the fishery in this sub-fleet is usually carried out during night-time. The vessels mainly stay at sea for only 12 hours. In wintertime one trip can take up to 36 hours. In the Netherlands a trip mostly takes 36 hours except for Zeeland and South-Holland where daytrips are common. In Germany the shrimp fishery in this sub-fleet takes usually daytrips. The catchability of shrimp highly depends on the light intensity, with catchability decreasing with increasing light intensity. Consequently, day-fishing will only be successful if the visibility in the water is poor and during daytime fishermen will select fishing grounds on this characteristic. The shrimp fishery is a coastal and estuarine fishery often carried out close to the homeport. The fishing grounds usually are sandy and free of large obstacles like stones and boulders. In the North Sea this fishery is carried out in the UK, in the Wash and the Humber estuary and from the Belgian coast up to the Danish coast.

With an average speed of 2.75 knots and an average beam length of 7.65 m a typical fishing vessel of this fleet will fish an area of 0.08 km^2 in 1 hours fishing, i.e. with the two trawls. Knowing that about 15% of the fishing time is used for hauling and setting the gear, this vessel will, in practice, fish a surface of 0.07 km^2 in one hours fishing.

Catch handling (Fig. 3.2.1): The codends are emptied in a hopper, where a continuous waterflow leads the catch onto a conveyer belt. This belt ends in the shaking or rotating riddle where large shrimp are separated from small shrimp and by-catch and trash (In Belgium and the Netherlands mainly rotating riddle, in Germany 80% shaking and 20% rotating riddle). These three fractions are collected in baskets. Fish to be landed are picked out manually, in the hopper and/or at the end of the rotary sieve. By-catch and small shrimp are usually thrown overboard manually (surface disposal). Large shrimp are poured in the boiler. Shrimps for the local market are boiled in seawater, with the addition of salt. Shrimps to be processed in peeling factories are boiled in seawater without extra salt. After boiling the shrimp, which sometimes contain small fish, are manually scooped and put in a washing drum, which speeds up the cooling process and washes out the small fish. Shrimps are then filled in cooling trays, which are placed outboard of the vessel. After this the shrimp are stored in baskets or boxes, on the deck, until landed. In the Netherlands the shrimps are cooled in water and stored in plastic bags in the fishhold, on ice.

Fishing gear (Table 3.2.3): Two thirds of the shrimp beam trawls have a beam length of 8 meter. The other one third have a width of 7 meter. The vertical net opening is 0.5 to 0.65 m. The surface of the sole plate is on average 270 cm^2. All data on the dimensions of the gear are gathered in Fig. 3.2.1. Average dimensions are given in mm and minima and maxima are given between brackets.

The average weight, in air, of the shoe, the beam and the bobbins are 200 kg, 260 kg and 300 kg respectively. The whole gear has an average weight, in air, of about 1.1 ton. On average, the Dutch shrimp beam trawls have a 200 kg higher weight compared to the Belgian and the German fleet. Tickler chains are never used when targeting shrimp. The weight of the net in water is negligible. Due to the design, the net will usually not touch the seafloor while fishing, except for the codend when the catch accumulates.

It is important to keep in mind that the weights of the gears and the gearparts mentioned in this report are weighed above water. The weight on the bottom is quite smaller because of the upward pull in the warps, the upward force exerted by the hydrodynamic forces on the netting and the weight reduction of steel in water compared to air.

The length of the headline is mostly 20 cm shorter than the beam. Diameter of the headline is 16 mm. Headline material is PA (polyamide), PE (polyethylene)or "Atlas" (misced steel and PE rope). The groundrope length depends on the length of the beam (Table 3.2.3). It's diameter is 14 or 16 mm and the material is mixed PE with steel wire. The bobbins consist of rubber cylinders, with a diameter of 18 to 22cm, which are mounted on rigid steel axes which allow the cilinders to roll. The net-design usually depends on the skipper and is quite standard for all vessels. Only two vessels use a net provided by the netting industry. Netting material usually is single braided PA, sometimes PP (polypropylene) or PE. The codend usually is 200 meshes long and 200 on the circumference and made of meshes of 22 mm single braided PA. Numbers of meshes in the selvedge is 4 to 6. All nets are equipped with a large mesh cover, 50 meshes long and 50 meshes on the circumference, sometimes provided with chafers.

Many vessels use a sieve net for some period in the year to reduce by-catches. It is made of meshes of 50 to 70 mm PE. It leads to a reduction of the by-catch.

Technical and operational details – shrimp beam trawlers - 191-221 kW

The fishing vessels in this fleet will usually not only target shrimp. They are so called multipurpose vessels which will switch between shrimp beam trawling, flatfish beam trawling (see section 3.2.2.2) and otter trawling (see section 3.2.3) depending on the season, quota and catch opportunities. Time allocated to each of the fisheries is with the available data impossible to determine and is also very variable from vessel to vessel and year tot year. For the Belgian and Dutch vessels flatfish beam trawling can be considered as the main fishery, whereas for the German fleet shrimp beam trawling would be the main activity.

Vessel (Table 3.2.2): The average engine power of a shrimp trawler in the 192-221 kW sub-fleet (so-called Eurocutters) is 215 kW (292 hp). The average LOA and breadth is 20.5 m and 5.5 m respectively. The tonnage of the vessels is given in two units: GRT and GT (see section 3.2.2.1). The average tonnage for this sub-fleet is 39.5 GRT and 66.5 GT. The average propeller diameter is 1.4 m. Also for these shrimp trawlers, controllable pitch does not occur. A GPS-system and a videoplotter are standard navigation equipment aboard these vessels for navigation and storage of fishtracks. Decca navigation systems are only on board as a back-up.

Operational parameters (Table 3.2.2): In this fleet there are two distinct groups of trawlers: the more traditional shrimpers which carry out a comparable fishery to the previous group and the modern vessels which land shrimps for industrial processing. The latter fish at towing speeds relative to the bottom of 3 knots. Warp depth ratio is 2.5/1 to 3/1, depending on seafloor condition and depth. Most vessels use single warps with a diameter between 16 and 20 mm.

The fishery in this sub-fleet is carried out during nighttime for the traditional shrimpers if the water is clear. The vessels mainly stay at sea for only 12 to 18 hours, except in wintertime when a trip can last up to 50 hours. The modern shrimp trawlers, which have a refrigerated fish hold often stay at sea for a longer period, up to five days (Monday till Friday). This is a coastal and estuarine fishery. Due to the larger size of the vessels compared to the previous sub-fleet, the range of these vessels is quite larger. The fishing grounds usually are sandy and free of large obstacles like stones and boulders.

With an average speed of 2.7 knots and an average beam length of 7.9 m a typical fishing vessel of this fleet will fish a surface of 0.08 km^2 in 1 hours fishing. Knowing that about 15% of the fishing time is used for hauling and setting the gear, this vessel will, in practice, fish a surface of 0.067 km^2 in one hours fishing.

Catch handling (Fig. 3.2.1): Catch handling is similar to the vessels in sub-fleet 70-191 kW, be it that the new technology is mainly installed on the larger and more recently built vessels. Contrary to the sub-fleet 70-191 kW, the by-catch is discarded through a tube which leads straight from the rotary sieve to an opening in the hull of the vessel which discards the trash sub-surface. The transfer of large shrimp from the rotary sieve to the boiler is, in a few cases, done by means of a tube that leads the shrimp. Scooping the shrimp out of the boiler and transfer to the cooling device is also automated. On the Eurocutters the shrimps are stored on ice in plastic bags or boxes in a refrigerated fish hold. Fishing trips often take two up to five days.

Fishing gear (Table 3.2.3): The fishing gear for shrimps used in this sub-fleet is similar to the one used in the 70-191 kW sub-fleet.

3.2.1.2. FLATFISH BEAM TRAWLING

Flatfish beam trawlers usually are larger vessels with engine powers over 221 kW operating in the open sea. These vessels are not allowed to fish within the 12 miles zone. The vessels with engine powers below 221 kW are specialised to fish flatfish within the 12 miles zone and the plaice box. The length of the beams ranges from 4 to 12 m. Beamlengths over 12 m, and over 9.5 m in the 12-miles-zone, are prohibited by law.

The gear (Fig. 3.2.2) is a rather heavy beam trawl equipped with tickler chains to disturb the flatfishes from the seabed. The tickler chains are attached between the beam trawl shoes. Additional net-tickler chains often are included in the gear and are rigged 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 engine 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, because the drag exerted by the chains reduces the opening between the otter boards. 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. Its diameter (weight) and the bottom type mainly determine the resistance of a tickler chain during fishing operation. A heavy chain will penetrate too much in a soft bottom and will consequently increase the towing resistance to an unacceptable level. Accordingly, soft bottoms will demand gears with light chains and hard bottoms will permit heavy chains.

For operation on rough grounds beam trawls can be equipped with chain matrices (Fig. 3.2.2). Chain matrices are rigged between the beam and the groundrope and prevent boulders 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 gears with chain matrices are also called round nets (R-nets). The largest vessels combine the chain matrix configuration with some extra chains.

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 construction as the shrimp nets, but they are made of heavier netting yarns and have bigger meshes. V-nets have much slack netting in the belly in order to permit a good bottom contact of the groundrope. The legal minimum mesh size for sole is 80 mm (in the North Sea below 54°N) and for plaice is 100 mm.

In Belgium the most important fishing gear is the chain matrix beam trawl. Tickler chain gear is used as the main gear on a minority of the vessels. Many skippers will, however, use this gear as an alternative. In the Netherlands, the main fishing gear is the beam trawl rigged with tickler chains and two distinct beam trawler groups appear, the "gears west" and the "gears east". The gears west comprise the fishery in Zeeland, Zuid-Holland and IJmuiden. These gears are used mostly on hard sandy bottoms, west of 4°E and on grounds with small stones and sanddunes in the southern North Sea. The gears east comprise the vessels operating from the harbours north of Den Helder. These are operated on softer grounds, sometimes silty, east of 4°E. Flatfish beam trawling is of minor importance in Germany, compared to shrimp beam trawling.

Technical and operational details - flatfish beam trawlers - 70-191 kW

For most of the vessels in this engine power class shrimping is the main fishing activity (see section 3.2.1.). Flatfish beam trawling is of minor importance in this engine power range and is carried out by some vessels, on a seasonal basis, e.g. in May-June when good sole-catch opportunities occur. Still, since catch opportunities are very variable, the fishing effort in the two types of fishery (shrimp or flatfish beam trawling) as well as the exact periods and time spans can change dramatically from year to year.

The details on vessels are comparable to the ones in the sub-fleet "shrimp beam trawling, 70-191 kW". The details on operational parameters and fishing gear are comparable to the next sub-fleet, be it that the fishing gear is of a lighter type.

Technical and operational details - flatfish beam trawlers - 191-221 kW

Of the 55 Belgian vessels in this engine power class, 36 fish with beam trawls rigged with a chain matrix and 10 with beam trawls rigged with tickler chains. Most of the chain matrix beam trawlers will, depending on the season and the quota, switch to tickler chain gear for shorter periods. Shrimp trawling can be a seasonal fishery for some of these vessels. The other 9 vessels are otter trawlers. Of the 129 Dutch vessels active in this fleet, over 30 will only target shrimp, 15 switch from shrimp beam trawling to flatfish beam trawling and otter trawling, 25 switch from shrimp beam trawling to flatfish beam trawling and Danish pair trawling, 30 use the flatfish beam trawl and the otter trawl and 25 only target flatfish with the beam trawl. For the flatfish beam trawls, a chain matrix is only rigged to a minority of the fishing gears. Of the 75 German vessels active in this sub-fleet only 6 are otter trawlers. The others are shrimp beam trawlers that will seasonally switch to flatfish beam trawling.

Vessel (Table 3.2.2): The average engine power of a vessel in the 191-221 kW sub-fleet is 219 kW (297 hp). The average length and breadth is 23 m and 5.8 m respectively. The tonnage of the vessels is 67 GRT and 77 GT. 90% of the vessels have a kort nozzle with an average propeller diameter of 1.5 m. The most recently built 221 kW vessels have a propeller of 2.5 m. Note that the kort nozzle and the propeller diameter have an important influence on the pulling force of the vessel. A rule of thumb is that a kort nozzle increases the pulling force with 30% and that a 20% increase in propeller diameter gives an increase of 10% to the pulling force of the vessel. A controllable pitch does not occur in this fleet. A GPS-system and a videoplotter are standard navigation equipment aboard these vessels for navigation and storage of fishtracks. Decca navigation systems are only on board as a back up. None of the vessels are equipped with an automatic warpload-measuring-safety-system. Looking at the age structure of this fleet, two separate groups appear: one half with an age of over 25 years and one half younger than 12 years. The same groups occur for the type of secondary engines on board. The older vessels have low powered (< 40 kW) secondary engines which are only used as a back-up in case of a breakdown of the main engine. The more recently built vessels have secondary engines of up to 150 kW engine power. These are used constantly for non-propulsion activities (like for electricity, hauling and veering) in order to be able to use the power of the main engine solely for propulsion. This is important because these types of vessels have an upper limit of 221 kW for the main engine (EC-regulation no. 55/87).

Operational parameters (Table 3.2.2): The average towing speed relative to the bottom of a chain matrix and a tickler chain beam trawler is 3.6 and 4.5 knots respectively. Warp depth ratio is 2.5 to 4/1. Dutch vessels using tickler chain gear will often use a depth/warplength ratio of 1/5 on harder bottoms. 60% of the vessels use single warps with a diameter between 20 and 24 mm. The other 40% use double warps with a diameter between 20 and 22 mm. The double warp system is used to reduce the tension in the warps and on the winches but has the disadvantage that veering and hauling time is longer.

The duration of a fishing trip in this sub-fleet is quite variable. Due to the size, these vessels are rather dependent on weather conditions. The distance to the fishing ground, and consequently the duration of one seatrip, also depends upon the season. A standard seatrip will take 3 to 7 days for

Belgian vessels and 4 to 5 days for the Dutch vessels. The fishing grounds are often within the 12 miles zone. Rough grounds are fished with beam trawls rigged with a chain matrix but for grounds which are free from stones and boulders the beam trawl rigged with tickler chains is preferred.

With an average speed of 3.6 knots and an average beam length of 5.2 m a typical chain matrix beam trawler of this fleet will fish a surface of 0.07 km² in 1 hours fishing. Knowing that about 10% of the fishing time is used for hauling and setting the gear, this vessel will, in practice, fish a surface of 0.063 km² in one hours fishing. The vessels fishing with tickler chains tow a less wide beam trawl (4.4 m) but at a higher speed (4.6 knots) and will fish a surface of 0.067 km² in one hours fishing.

Catch handling (3.2.3): One third of the Belgian vessels and 90% of the Dutch vessels have a conveyor belt installed to handle the catch. In this case the codends are emptied into a hopper, where a continuous waterflow leads the catch onto the conveyer belt. The marketable fish are sorted out on this belt and the discards are disposed immediately, through a tube, above or sub-surface (for the newer vessels). The other two thirds of the Belgian and 10% of the Dutch vessels empty the codends on the deck of the vessel and pick out the fish manually. After sorting, the discards are shovelled over board or washed through the port-holes with water. It is obvious that the time that discards are on board of the vessel is substantially longer than with a conveyor belt. Many skippers made the remark that the quality of the marketable fish and the condition of the discards had improved since the installation of the belt.

Fishing gear (Table 3.2.3):

- Beam trawl rigged with a chain matrix (Fig. 3.2.2 & 3):

The main parts of a beam trawl rigged with a chain matrix are the beam, the shoes, the chain matrix, the bobbins and the net. Fishing operation will be such as to ensure a continuous bottom contact of the shoes, the bobbins and part of the chain matrix (about 2/3's) in order to optimise the fishing efficiency. The rigging of the net is designed to minimise the bottom contact of the netting material and only the codend will touch the seafloor as catch accumulates. The weight of a typical 4m beam trawl is 1800 kg. The beam (inclusive bridles), the shoes, the bobbins and the chain matrix weigh 300 kg, 500 kg, 170 kg and 550 kg respectively. The weight of a typical 8 m beam trawl used by the Eurocutters is 2200 kg. The beam (inclusive bridles), the shoes, the bobbins and the chain matrix weigh 390 kg, 600 kg, 177 kg and 570 kg respectively. Notwithstanding the double size of this 8 m beam trawl, the weight is only slightly higher compared to the 4.5 m trawl. This is due to the use of lighter chains and larger quadrants in the chain matrix and lighter material for the beam and the shoes. A 221 kW vessel would not be able to tow an 8 m beam trawl with a normal weight at the necessary towing speed.

In this sub-fleet, the beamlength of a beam trawl rigged with a chain matrix is 4, 4.5 or 8 m with an average beam length of 5.1 m. The surface of the sole plate of the beam trawl shoe is on average 300 cm². The vertical net opening is 0.55 m. The length of the groundrope is 9.2 m for a 4m beam and 12.5 m for an 8 m beam. The bobbins consist of rubber cylinders with a diameter of 25cm mounted on a steel wire. The chain matrix consists of a flexible grid of chains, with a link diameter of 14 mm or 18 mm, with quadrants of 5 on 5 or 3 on 3 shackles respectively. The larger quadrants and lighter chains are used to construct a light chain matrix and thus a lighter fishing gear. This has the advantage that with the same engine power, a wider beam can be used and that fishing can be carried out on softer grounds. A flip-up rope, rigged to reduce the amount of boulders entering the net, is of minor importance in this sub-fleet.

The mesh size in the net is 120 mm throughout the net, made of single braided PE and on half of the vessels double braided in the belly of the net. The codend mesh size in the North Sea is legally set at 80 mm for sole fishery and 100 mm for plaice fishery. The netting material usually is double braided PE. One quarter of the Belgian and almost all Dutch vessels use a codend cover (160-200 mm mesh opening).

- Beam trawl rigged with tickler chains (Fig. 3.2.2 & 3):

The weight of the beam, the shoes, the groundrope and the tickler chains is 350, 510 kg, 200 kg and 370 kg respectively. The whole gear weighs on average 1500 kg. This weight is lower than the weight of the beam trawls rigged with a chain matrix used in this sub-fleet. This is why the towing speed with tickler chain gear is higher. The weight of a typical Dutch beam trawl rigged with tickler chains is 1200 kg for the beam + shoes and 350 to 600 kg for the tickler chains.

In this sub-fleet, the beamlength of a beam trawl rigged with tickler chains is 4 or 6 m with an average beam length of 4.5 m. The surface of the sole plate of the beam trawl shoe is on average 260 cm². The vertical net opening is 0.53 m. The length of the groundrope is 10.5 m for a circular shaped groundrope and 17 m for a V-shaped groundrope. The deeper cutting in the belly of the net to obtain the V-shape is used to be able to insert a larger amount of tickler chains, which enlarge the fishing efficiency of the trawl. The groundrope consists of bare chain (diameter 18 mm) with a central rubber roller, ± 4 m long, made of rubber discs with a diameter between 200 and 300 mm. The gear is rigged with 4 to 7 tickler chains and 4 to 7 net-tickler chains. The diameter of the tickler chains is on average 16 mm. For the net tickler chains the diameter usually increases from 10 mm for the longest chain to 14 mm for the shortest one. A flip-up rope is of minor importance in this sub-fleet.

The mesh size in the net is 120 mm throughout the net, made of single braided PE or single braided PA. The codend mesh size is 80 mm (sole) or 100 mm (plaice). The codend netting material usually is double braided PE. Ten percent of the Belgian and all vessels use a codend cover.

Technical and operational details - flatfish beam trawlers - 222-800 kW

This sub-fleet contains in Belgium 37 vessels, of which 5 otter trawlers. The other 32 are beam trawlers operating the beam trawl rigged with a chain matrix as the main gear. About 30% of these beam trawlers operate the beam trawl rigged with tickler chains as an alternative, depending on the season and the quota. For the Netherlands, 24 of the vessels in this engine power class operate the beam trawl rigged with tickler chains for one quarter of their total effort. The average age of these vessels is over 20 years and their number is decreasing (from 40 in 1991 to 24 in 1994). The main fishery for this fleet is Danish pair trawling which is carried out north of Hoek van Holland. The German vessels in this engine power class do not operate the beam trawl.

Vessel (Table 3.2.2): The average engine power of a vessel in the 222-800 kW sub-fleet is 588 kW (799 hp). The average length and breadth is 32 m and 7.5 m respectively. The tonnage of the vessels is 147 GRT and 221 GT. 80% of the Belgian vessels have a kort nozzle with an average propeller diameter of 2.4 m. The Dutch trawlers are mainly older vessels without kort nozzle. A controllable pitch does not occur in this fleet. A GPS-system and a videoplotter are standard navigation equipment aboard these vessels for navigation and storage of fishtracks. Decca navigation systems are only on board as a back up. About 1/5th of the vessels are equipped with an automatic warpload measuring safety system. Some of the older vessels have low powered (< 40 kW) secondary engines which are only used as a back up in case of a breakdown of the main engine. But the majority have secondary engines of up to 250 kW engine power. These are used for non-propulsion activities in order to be able to use the power of the main engine solely for propulsion.

Operational parameters (Table 3.2.2): The average towing speed relative to the bottom is 4.1 knots. Warp depth ratio is 3/1 if the vessel is towing a chain matrix gear and 4.5/1 for tickler chain gear. 65% of the Belgian vessels use single warps with a diameter of 32 mm. The other 35% use double warps with a diameter of 28 mm. In the Netherlands single warps have a diameter of 28 mm and double warps have a diameter of 20 mm.

The duration of a fishing trip will be between 5 and 12 days. All fishing grounds within the North Sea are within the range of these vessels. Rough grounds are fished with beam trawls rigged with a chain matrix but for grounds that are free from stones and boulders, the beam trawl rigged with tickler chains is preferred.

With an average speed of 4.1 knots and an average beam length of 9.6 m a typical chain matrix beam trawler of this fleet will fish a surface of 0.15 km^2 in 1 fishing hours. Knowing that about 10% of the fishing time is used for hauling and setting the gear, this vessel will, in practice, fish a surface of 0.13 km^2 in one fishing hour. In the same fleet, occasionally, also tickler chain gear is used. In this case the beamlength is larger, 11 m, and towing speed 4.1 knots. The surface fished in one fishing hour is 0.15 km^2.

Catch handling (Fig. 3.2.4): About 90% of the vessels have a conveyor belt installed to handle the catch. In this case the codends are emptied into a hopper, where a continuous waterflow leads the catch onto the conveyer belt. The marketable fish are sorted out on this belt and the discards are disposed immediately, through a tube, sub-surface. On board of the other vessels the codends are emptied on the deck of the vessel and fish is picked out manually. After sorting, the discards are shovelled over board or washed through the port-holes with water.

Fishing gear (Table 3.2.3):

- Beam trawl rigged with a chain matrix (Fig. 3.2.2 & 4):

The weight of a typical 9 m beam trawl is 3900 kg. The beam (inclusive bridles), the shoes, the bobbins and the chain matrix weigh 810 kg, 490 kg, 350 kg and 1450 kg respectively. The weight of a typical 10.5 m beam trawl is 5000 kg. The beam (inclusive bridles), the shoes, the bobbins and the chain matrix weigh 930 kg, 800 kg, 360 kg and 2210 kg respectively.

In this sub-fleet, the average beam length of a beam trawl rigged with a chain matrix is 9.6 m. In the Netherlands the western fleet operates 8.5 m and the eastern fleet 10 m beams. The surface of the sole plate of the beam trawl shoe is on average 360 cm^2. The vertical net opening is 0.58 m. The length of the groundrope is on average 16 m. The bobbins consist of rubber cylinders with a diameter of 25cm mounted on a steel wire. The chain matrix consists of a flexible grid of chains with a shackle diameter of 18 mm and with quadrants of 5 on 3 shackles. A flip-up rope is used on 70% of the vessels.

The mesh size in the net is 120 mm throughout the net, made of single braided PE in the top panel and double braided PE in the belly of the net. Occasionally netting material with a mesh size of 150 mm is used if sole is not the target species. The codend mesh size in the North Sea is 80 mm for sole and 100 mm for plaice. The codend netting material is double braided PE. Almost half of the Belgian and all Dutch vessels use a codend cover.

- Beam trawl rigged with tickler chains (Fig. 3.2.2 & 4):

The weight of the beam, the shoes, the groundrope and the tickler chains is 1600, 1270 kg, 500 kg and 1000 kg respectively. The whole gear weighs on average 4800 kg.

In this sub-fleet, the beamlength of a beam trawl rigged with tickler chains is 11 m. The surface of the sole plate of the beam trawl shoe is on average 530 cm^2. This surface is rather high compared to the beam trawl rigged with a chain matrix in this same sub-fleet. The reason is that tickler chain gear is often used on softer grounds and a larger sole plat will prevent the gear from digging in the seafloor. The vertical net opening is 0.53 m. The length of the groundrope is 28 m. The groundrope consists of bare chain (diameter 22 mm) with a central rubber roller, ± 6 m long, made of rubber discs with a diameter between 230 and 300 mm. The gear is rigged with 7 tickler chains and 6 to 10 net-tickler chains. The shackle diameter of the tickler chains is 18 mm. For the net tickler chains the diameter usually increases from 11 for the longest chain to 22 for the shortest one. None of the vessels use a flip-up rope.

The mesh size in the net is 120 mm throughout the net, made of single braided PA in the top panel and double braided PA in the belly of the net. The codend mesh size is 80 mm (sole) or 100 mm (plaice). The codend netting material is double braided PA. Thirty percent of the vessels use a codend cover.

Technical and operational details - flatfish beam trawlers - 801-1100 kW

This sub-fleet contains in Belgium 32 vessels, all beam trawlers. 5 of these vessels use the beam trawl rigged with tickler chains continuously and 27 operate the beam trawl rigged with a chain matrix. Of these 27 vessels, 22 use the chain matrix continuously and 5 also operate the beam trawl rigged with tickler chains as an alternative depending on the season and the quota. In the Netherlands 25 tickler chain and 1 chain matrix beam trawlers are active in this engine power class, of which 7 in the western fleet. In Germany 2 tickler chain beam trawlers are active in this fleet.

Vessel (Table 3.2.2): The average engine power of a vessel in the 801-1100 kW sub-fleet is 884 kW (1203 hp). The average length and breadth is 36 m and 8 m respectively. The tonnage of the vessels is 307GT. All vessels have a kort nozzle with an average propeller diameter of 2.6 m. A controllable pitch was installed on 10% of this sub-fleet. A GPS-system and a videoplotter are standard navigation equipment aboard these vessels for navigation and storage of fishtracks. Decca navigation systems are only on board as a back-up. About 1/4th of the Belgian and few of the Dutch vessels are equipped with an automatic warpload measuring safety system. All vessels have secondary engines installed with engine power of up to 250 kW. These are used for non-propulsion activities in order to be able to use the power of the main engine solely for propulsion.

Operational parameters (Table 3.2.2): The average towing speed relative to the bottom is 4.5 knots with chain matrix gears and 6 knots with tickler chain gears. Warp depth ratio is 3/1 if the vessel is towing a chain matrix gear and 4.5/1 for tickler chain gear. 30% of the vessels use single warps with a diameter of 32 mm. The other 70% use double warps with a diameter of 28 mm.

The duration of a fishing trip lies between 7 and 18 days in the Belgian and 4 to 5 days in the Dutch fleet. The operational range of these vessels is very large and often fishing grounds outside of the North Sea are visited (e.g. Irish Sea, Bay of Biscay). Rough grounds are fished with beam trawls rigged with a chain matrix but for grounds that are free from stones and boulders the beam trawl rigged with tickler chains is preferred.

With an average speed of 4.5 knots and an average beam length of 10.6 m a typical chain matrix beam trawler of this fleet will fish a surface of 0.18 km^2 in 1 fishing hours. Knowing that about 10% of the fishing time is used for hauling and setting the gear, this vessel will, in practice, fish a surface of 0.16 km^2 in one fishing hour. In the same fleet also tickler chain gear is used. In this case the beamlength is larger, 11.4 m, and towing speed 6 knots. The surface fished in one fishing hour is 0.23 km^2.

Catch handling (Fig. 3.2.4): All vessels have a conveyor belt installed to handle the catch. The codends are emptied into a hopper, where a continuous waterflow leads the catch onto the conveyer belt. The marketable fish are sorted out on this belt and the discards are disposed immediately, through a tube, sub-surface.

Fishing gear (Table 3.2.3):

- Beam trawl rigged with a chain matrix (Fig. 3.2.2 & 4):

The weight of a typical 11 m beam trawl is 5600 kg. The beam (inclusive bridles), the shoes, the bobbins and the chain matrix weigh 1100 kg, 900 kg, 430 kg and 2000 kg respectively.

In this sub-fleet, the average beamlength of a beam trawl rigged with a chain matrix is 10.6 m. The surface of the sole plate of the beam trawl shoe is on average 475 cm^2.The vertical net opening is 0.61 m. The length of the groundrope is on average 18.5 m. The bobbins consist of rubber cylinders with a diameter of 25cm mounted on a steel wire. The chain matrix consists of a flexible grid of chains, with a shackle diameter of 18 mm, with quadrants of 5 on 3 shackles. A flip-up rope is used on 90% of the vessels.

The mesh size in the net is 120 mm throughout the net, made of single braided PE in the top panel and double braided PE in the belly of the net. Occasionally netting material with a mesh size of 150 mm is used if sole is not the target species. The codend mesh size in the North Sea is 80 mm for sole and 100 mm for plaice. The codend netting material is double braided PE. Almost half of the vessels use a codend cover.

- Beam trawl rigged with tickler chains (Fig. 3.2.2 & 4):

The weight of the beam, the shoes, the groundrope and the tickler chains is 1850, 1600 kg, 600 kg and 1150 kg respectively. The whole gear weighs on average 6000 kg.

In this sub-fleet, the beamlength of a beam trawl rigged with tickler chains is 11.4 m. The surface of the sole plate of the beam trawl shoe is on average 635 cm². Again, this surface is rather high compared to the beam trawl rigged with a chain matrix in this same sub-fleet. The reason is that tickler chain gear is often used on softer grounds and a larger sole plat will prevent the gear from digging in the seafloor. The vertical net opening is 0.43 m. The length of the groundrope is 32 m. The groundrope consists of bare chain (diameter 22 mm) with a central rubber roller, ± 6.5 m long, made of rubber discs with a diameter between 320 and 400 mm. The gear is rigged with 7 tickler chains and 11 net-tickler chains. The shackle diameter of the tickler chains is 18 mm. For the net tickler chains the diameter usually increases from 10 for the longest chain to 22 for the shortest one. About 1/5th of the vessels use a flip-up rope.

The mesh size in the net is 120 mm throughout the net, made of single braided PA in the top panel and single or double braided PA in the belly of the net. A minority of the nets is made of polypropylene (PP) or PE. The codend mesh size is 80 mm (sole) or 100 mm (plaice). The codend netting material is double braided PE. Twenty percent of the Belgian and all Dutch vessels use a codend cover.

Technical and operational details - flatfish beam trawlers - > 1101 kW

This sub-fleet is only of importance for the Netherlands with a total of 174 vessels. Beam trawlers with engine powers above 1100 kW do not occur in Belgium and in Germany only one such vessel is active. In the Netherlands, new building during the last 15 years has been divided between the so-called Eurocutters (engine power < 221 kW) for fishing within the 12-miles-zone and large high powered vessels (> 1400 kW). Only a few vessels were built with engine power between 221 and 1400 kW. The design of the larger vessels does not differ strongly from the smaller ones, as described in the previous chapters.

Vessel (Table 3.2.2): The vessels are 40-45 m long and 8.5-10 m wide. All vessels have a kort nozzle of which some have a controllable pitch. About one third of the vessels are equipped with an automatic warpload-measuring-safety-system. In the 1101-1800 kW engine power class, 70 vessels are active in the Dutch eastern fishery and 33 in the western fishery. In the engine power class > 1500 kW 44 vessels ,built before 1989, are active in the eastern and 27 in the western fishery.

Operational parameters: The warps are usually double but for vessels with an engine power above 1470 kW a triple warp system is used (diameter 28 to 32 mm) because of the high tensions in the warps. Towing speed is 6 to 7 knots. Usually one fishing trip takes 4 to 5 days and sometimes (5 to 10% of the trips) 11 to 12 days.

Catch handling: All vessels have a conveyor belt installed to handle the catch. The codends are emptied into a hopper, where a continuous waterflow leads the catch onto the conveyer belt. The marketable fish are sorted out on this belt and the discards are disposed immediately, through a tube, sub-surface.

Fishing gear (Fig. 3.2.2 & 4): About 15 vessels operate the beam trawl rigged with a chain matrix, all others use beam trawls rigged with tickler chains. The beam trawls rigged with a chain matrix usually are of the type where the chain matrix is rigged in combination with tickler chains. These gears have a somewhat higher weight compared to the tickler chain gear. The beam trawls rigged with tickler chains used in the eastern Dutch fishery are rigged with chains with lighter shackles (but equal or usually higher in number) compared to the ones in the western Dutch fleet. The maximum beam length is 12 m since 1989. A consequence of this is that the towing speed is about 0.5knots higher compared to before 1989. All vessels use a codend cover.

For the 1101-1500 kW engine power class, the weight of the beam+shoes and the groundrope is 3800 kg and 700 kg respectively. The total set of tickler chains weigh 2000 kg for the "gears-west" and 3000 kg for "gears-east". The total weight of the gear is on average 6500 kg. A beam trawl rigged with a chain matrix in this fleet weighs about 7000 kg.

For the > 1500 kW engine power class, the weight of the beam+shoes and the groundrope is 4500 kg and 950 kg respectively. The tickler chains weigh 2500 kg for the "gears-west" and 5000 kg for "gears-east". The total weight of the gear is on average 8000 kg for the "gears east" and 11.000 to 12.000 kg for the "gears west". A beam trawl rigged with a chain matrix in this fleet weighs up to 13.000 kg.

3.2.1.3. DEMERSAL OTTER TRAWLING

Demersal otter trawls have been designed to catch flatfish (e.g. sole, plaice) and roundfish (e.g. cod, whiting). 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 attached 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 for the fish. At the trawl mouth the groundrope assures good contact with the bottom and the square prevent fish from escaping. For the calculation of catch efficiency of otter trawls in e.g. this impact study two methods are applied. For fish that are herded by the bridles and the sand clouds the width between the otter boards is used to calculate the surface fished. For invertebrates that are not influenced by a herding effect, the distance between the net wings is used. For the calculation of direct mortatlity of invertebrates the distance between the wings + the distance over which the bridles scrape over the seabed is used.

Otter trawls used in the North and Irish Sea exist in a wide variety and mainly have *Nephrops* and roundfish like cod, haddock and whiting as target species.

Technical and operational details - 191-221 kW

The main target species in the Belgian fishery for this sub-fleet, which comprises 9 vessels, is *Nephrops*. Skippers may, however, decide to switch to roundfish trawling in certain periods of the year or even during some part of a seatrip because of good catch opportunities or low *Nephrops* catches. In the Netherlands otter trawlers exert only 1 to 2% of the fishing effort in this sub-fleet. Also in Germany this fishery is of minor importance with a total of 8 vessels operating otter trawls.

Vessel (Table 3.2.2): The average engine power of a vessel in the 191-221 kW otter trawler sub-fleet is 221 kW (300 hp). The average length and breadth is 24.8 m and 6.1 m respectively. The tonnage of the vessels is 78 GRT and 94 GT. None of the vessels have a kort nozzle. The average propeller diameter is 1.9 m. A controllable pitch does not occur in this fleet. A GPS-system and a videoplotter have become standard navigation equipment aboard these vessels for navigation and storage of fishtracks. Decca navigation systems are only on board as a back up.

Operational parameters (Table 3.2.2): The towing speed relative to the bottom is 3.5 knots. While the towing speed in beam trawling has no important effect on the dimensions of the fishing gear, in otter trawling it is one of the main factors influencing the vertical and horizontal opening of the trawl. Each gear has an optimum speed in relation to the dimension envisaged by the fishermen. Only low powered secondary engines are installed on board of these otter trawlers. Warp depth ratio is 3/1.

All vessels use single warps with a diameter between 18 and 24 mm. The duration of a fishing trip is very variable and can vary between a few days and 2 weeks.

With an average speed of 3.5 knots and an average horizontal opening between the otter boards of 18 m, a typical fishing vessel of this fleet will fish a surface of 0.12 km^2 in 1 fishing hours. Knowing that about 15% of the fishing time is used for hauling and setting the gear, this vessel will, in practice, fish a surface of 0.1 km^2 in one fishing hour.

Catch handling (Fig. 3.2.5): After emptying the codend in a box on the deck of the vessel the catch is being sorted. The catch is shovelled on a sorting table and hand-sorted by the crew. While sorting the catch it is graded in *Nephrops* to be landed whole, *Nephrops* to be tailed and fish. The discards are collected in baskets and then returned to the sea or washed overboard by a constant flow of water from a hose laying on the deck. None of the Belgian otter trawlers are equipped with a conveyer belt to process the catch.

Fishing gear (Table 3.2.2 & Fig. 3.2.5): The fishing gear used in this sub-fleet is the otter trawl. Some attempts have been made to introduce twin and triple gears but the traditional two-panel single otter trawl is still the standard.

A variety of otter boards is used. The wooden rectangular otter boards are still used aboard many vessels. Other otter boards are the polyvalent oval metal and metal V-boards. All trawls used by side trawlers have two panels and are demersal or semi-pelagic. Headline lengths vary between 27 and 38 m. The groundrope consists of rope rounded wire or chain and are often provided with bobbins in the central part. Most trawls are made of polyethylene netting with mesh sizes up to 140 mm in the front part of the trawl, decreasing to 100 in front of the codend. Codends consist of double braided polyethylene and have standard dimensions (100 round x 50 meshes long).

The *Nephrops* trawl is a traditional two-panel bottom trawl. The otter boards used are wooden rectangular boards with a weight of 340 kg, 2.2 m long and 1.2 m high. The vertical net opening is 1 m. The horizontal opening between the otter boards lies between 15 and 20 m. The headline length is 28 m and consists of mixed rope. The groundrope is 35 m long. The central part of the groundrope (± 20 m) consists of wire rounded with netting and rope. The rest, together with the lower bridle is made of chain. The upper bridle consists of wire or mixed rope. Both bridles usually have a length of about 6 m. Depending on the bottom condition one or more tickler chains can be used to raise *Nephrops* and flatfish from the seafloor.

The typical net in the Irish Sea *Nephrops* fishery is a 25-fathom single trawl. Many boats also use a twin trawl arrangement. The mesh size used with twin trawls is similar to that used by single trawls, but the net size of each trawl is somewhat smaller c. 18-20 fathoms. All trawlers operating in the Irish Sea since 1 January 1994 must include a square mesh escape panel in the net.

The netting material of the net is always PE with a mesh size of 100 mm throughout the net. The codend is made of double braided PE or single braided PA.

The *Nephrops* trawl used in the Irish Sea single or twin arrangements. For the twin gears, a two- or a three-winch arrangement is possible. The former is used mainly on smaller vessels and the latter is typical for larger vessels. The mesh size throughout the net is 70 mm. In order to reduce by-catches, mainly whiting and haddock, in the *Nephrops* fishery all net are provided with a square mesh escape panel in the top panel, just in front of the codend.

Technical and operational details - 222-800 kW

In the North Sea there is a high variability in vessel types and fishing gear types in this sub-fleet. Side trawlers as well as stern trawlers occur. The fishing gears can be demersal or semi-pelagic and single, twin or triple gear arrangements. This fleet comprises 4 Belgian and 24 German vessel. In the Netherlands otter trawlers only carry out 2 to 3% of the effort in this engine power class.

Vessel (Table 3.2.2): The average engine power of a vessel in the 222-800 kW otter trawler sub-fleet is 407 kW (553 hp). The average length and breadth is 24.8 m and 7.2 m respectively. The tonnage of the vessels is 184 GT. None of the vessels have a kort nozzle. A controllable pitch does not occur in this fleet. A GPS-system and a videoplotter have become standard navigation equipment aboard these vessels for navigation and storage of fishtracks. Decca navigation systems are only on board as a back up.

Operational parameters, catch handling and fishing gear are comparable to the 191-221 kW otter trawler sub-fleet but the variability in characteristics is much higher.

3.2.2. DISTRIBUTION OF FLEET ACTIVITIES

In order to get an idea of the areas where the different fishing gears are used, data on the geographical spread of the activities of the different sub-fleets have been collected. Fishing effort data per ICES statistical rectangle have been collected. These have been divided for each sub-fleet and fishing gear defined in the inventory. The year 1994 was chosen as a reference, since during phase 2 of the project no more recent data were available. In addition to the three participating countries (Belgium, Germany and the Netherlands) the participants from England, Scotland and Ireland gave their co-operation in providing data on the effort of their fleets. The data have been presented as circles proportional to the effort (hours fished) for each sub-fleet (Figs 3.2.6 to 3.2.23). In addition the numbers of vessels per sub-fleet and per country are given in Table 3.1.1.

Effort data for the German 70-221 kW-engine power sub-fleet, for the beam trawlers, could not be split up into shrimp and flatfish beam trawling in the national database. Data produced in Prawitt (1996), however, gave an indication about the order of magnitude of the relative importance of both types of fisheries. This showed that about ¾ of the effort is allocated to the shrimp beam trawl and about ¼ to the flatfish beam trawl. It should be kept in mind that this is a rough estimate, which can change from year to year, but it is the only figure available for the moment. The same problem occurs with the English effort data. In this case no key was available to split up the data into shrimp and flatfish beam trawl effort data. All beam trawl effort data for the 70-221 kW-engine power sub-fleet have been inserted as "flatfish beam trawling" in graphs 3.2.8 and 3.2.9. In the North Sea, however, English beam trawlers only target shrimps in The Wash and the Humber estuary. Consequently all effort data outside of this area can be allocated to flatfish beam trawling. In The Wash and the Humber estuary the effort data can be mainly allocated to shrimp beam trawling.

The Scottish effort data were only available for all engine power classes combined. These data were thus not used in the graphs for separate engine power classes but only in the graphs 3.2.21 to 3.2.23 with effort per type of fishing gear combined over all engine power classes.

3.2.3. DISCUSSION

Vessel data are expressed as units according to the international standards. There is, however, one exception for the tonnage. Here the units GRT and GT occur mixed in the data and some caution should be kept (see section 3.2.1.1.). An important element in the navigation of the vessels is the fact that GPS and the videoplotter have recently become standard equipment. This gives the vessels the opportunity to fish very accurately and has made dangerous or previously inaccessible grounds accessible to the fishery and has made the impact of fisheries more widespread than before.

For the operational data, towing speed has been collected in interviews with skippers and has not been measured during fishing activity. This makes the accuracy questionable. These data have, however, been backed up with data from experimental seatrips in other projects and adjusted where necessary.

The way the catch is processed on board of the vessel is an important element for the survival of discards. During the last years more attention is given to develop "discard friendly" catch handling. An example here is where the codends are emptied in boxes filled with water in order to reduce the time that organisms are exposed to the air. These methods are, however still in the experimental or even in the design phase and have not been mentioned in this review.

This chapter gives, amongst others, a description of fishing gears. One might draw conclusions on the impact of a fishing gear on the seabed from this information. The most obvious data to make such conclusions are e.g. the weights of the fishing gears. When these data are analysed together with the operational data it is clear that a heavier fishing gear will not necessarily penetrate deeper in the seabed compared to a lightweight gear. One should be reluctant to draw firm conclusions without taking operational parameters into account.

Since Belgium, the Netherlands and Germany have been the main providers of data for the fleet and gear inventory, most detailed information is available for the beam trawl, which is the main fishing gear in these countries. For the otter trawl the information is not as detailed because of the smaller data set and also because the variation in otter trawl-types is much higher.

In the section "Distribution of fleet activities" an attempt was made to give an idea of the geographical spread of the fishing activities of the different sub-fleets. This was based on the data recorded in the logbooks which is present on each fishing vessel in the North Sea. The resolution of these data is very low and does not indicate whether certain areas within the ICES statistical rectangles are trawled or not. For this purpose data on the microdistribution of fishing effort are necessary and are for the moment only available for a small sector of the Dutch beam trawl fleet (Rijnsdorp *et al.* 1996). The sampling intensity in this study was 13% of the fleet fishing with 12m beam trawls and less than 1% for the vessels fishing with 4m beam trawls.

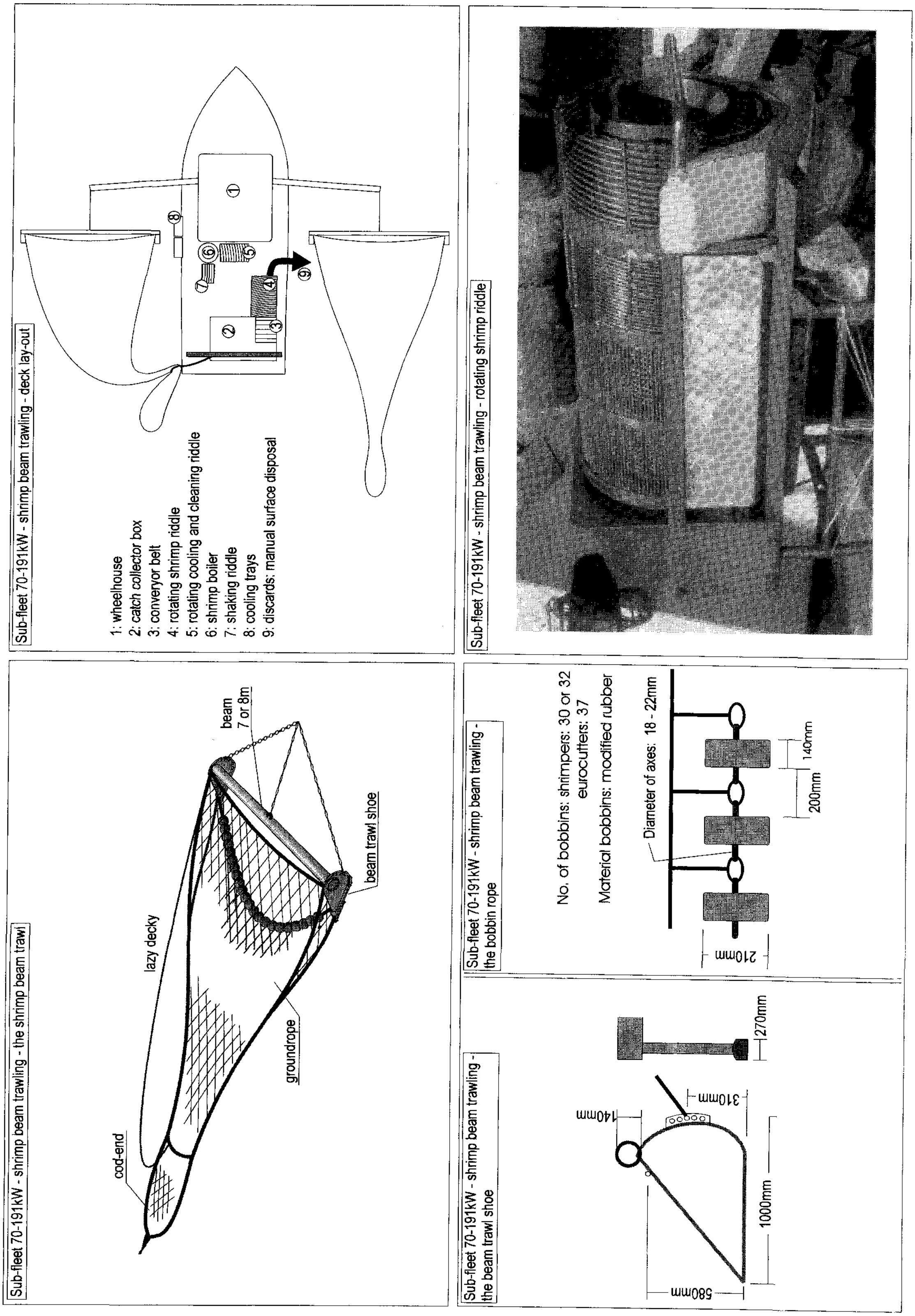


Fig. 3.2.1. Shrimp beam trawling, sub-fleet < 191 kW.

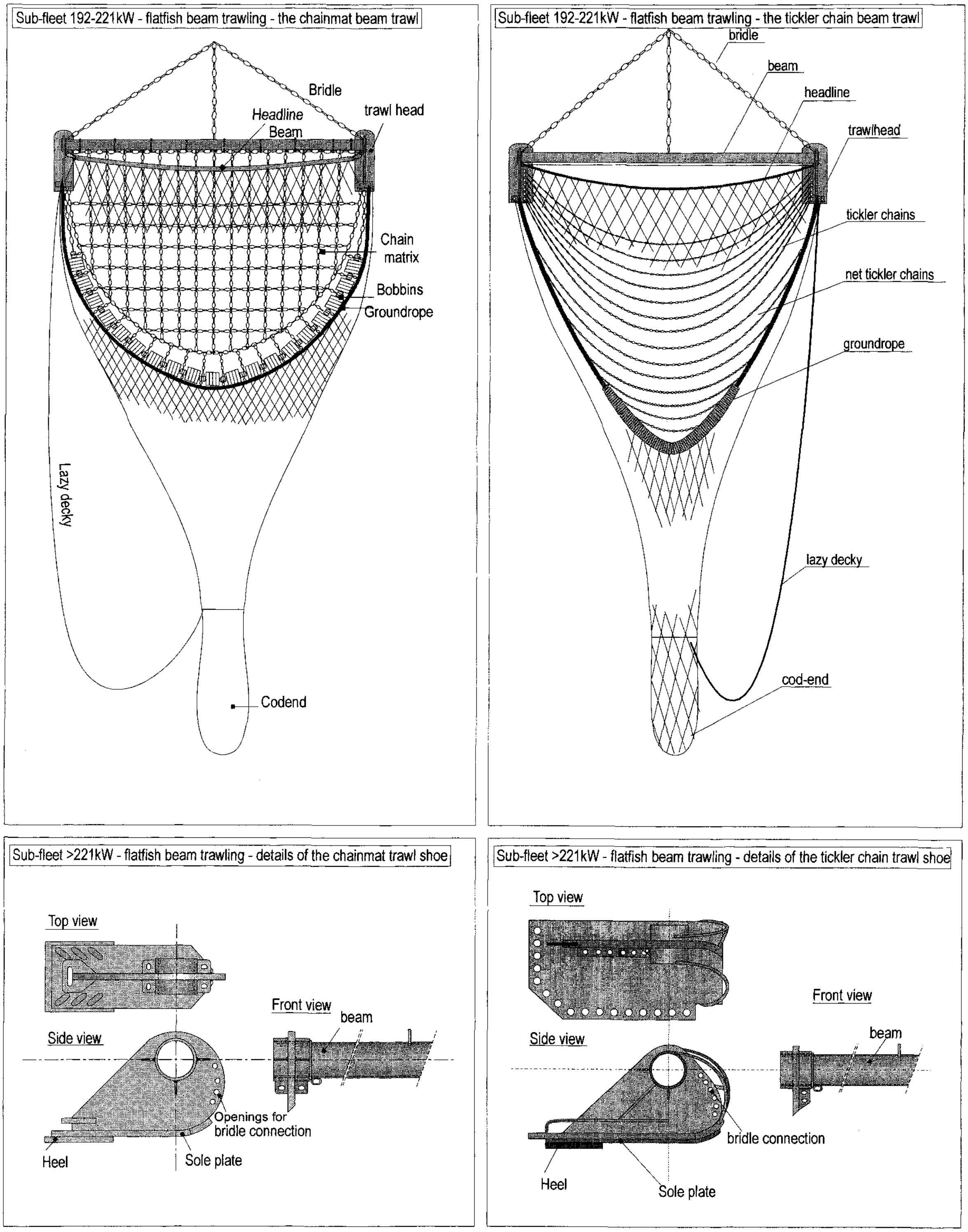


Fig. 3.2.2. Flatfish beam trawls, equipped with chainmat and with tickler chains, sub-fleets > 221 kW.

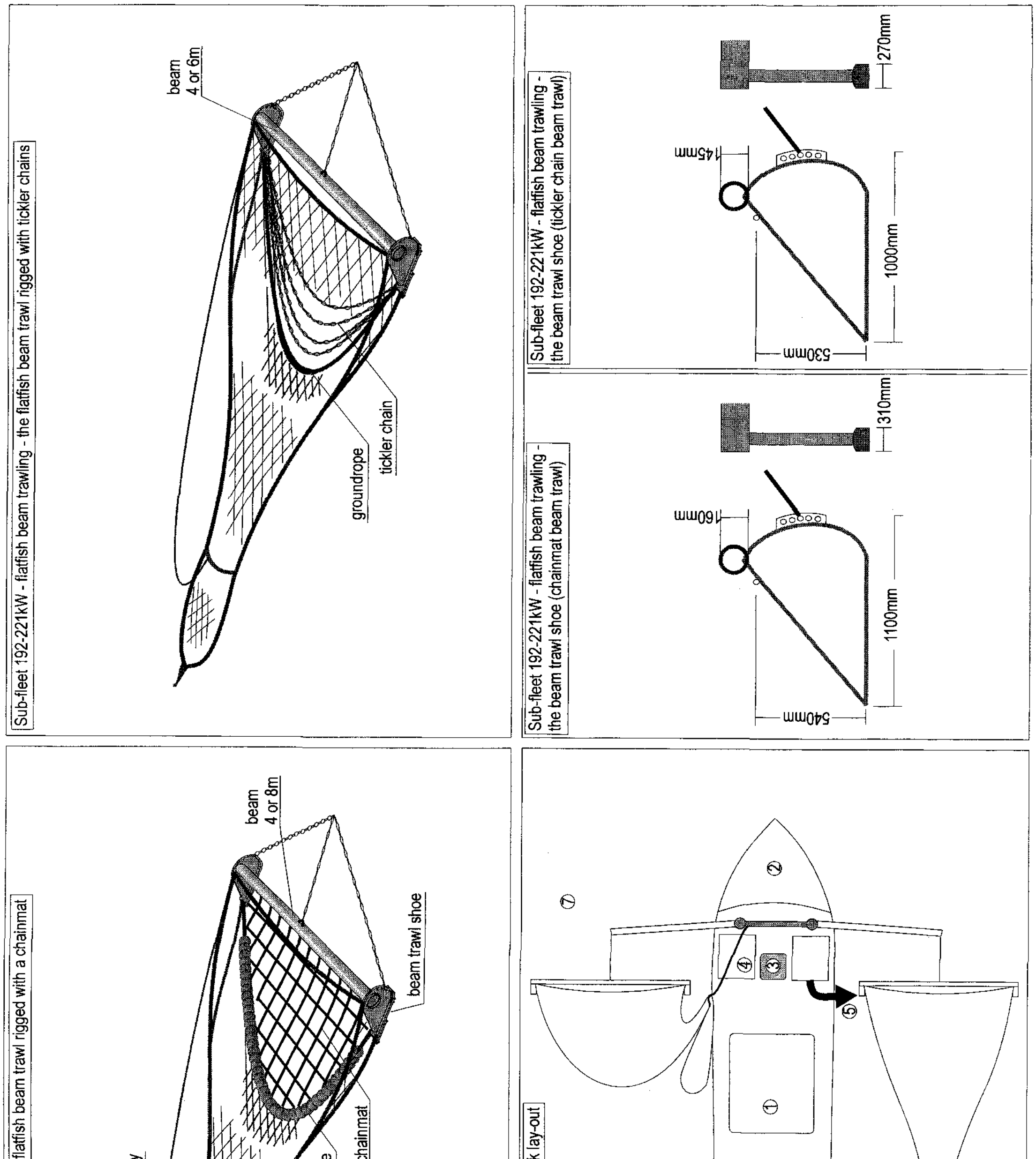


Fig. 3.2.3. Flatfish beam trawling, sub-fleet 192-221 kW.

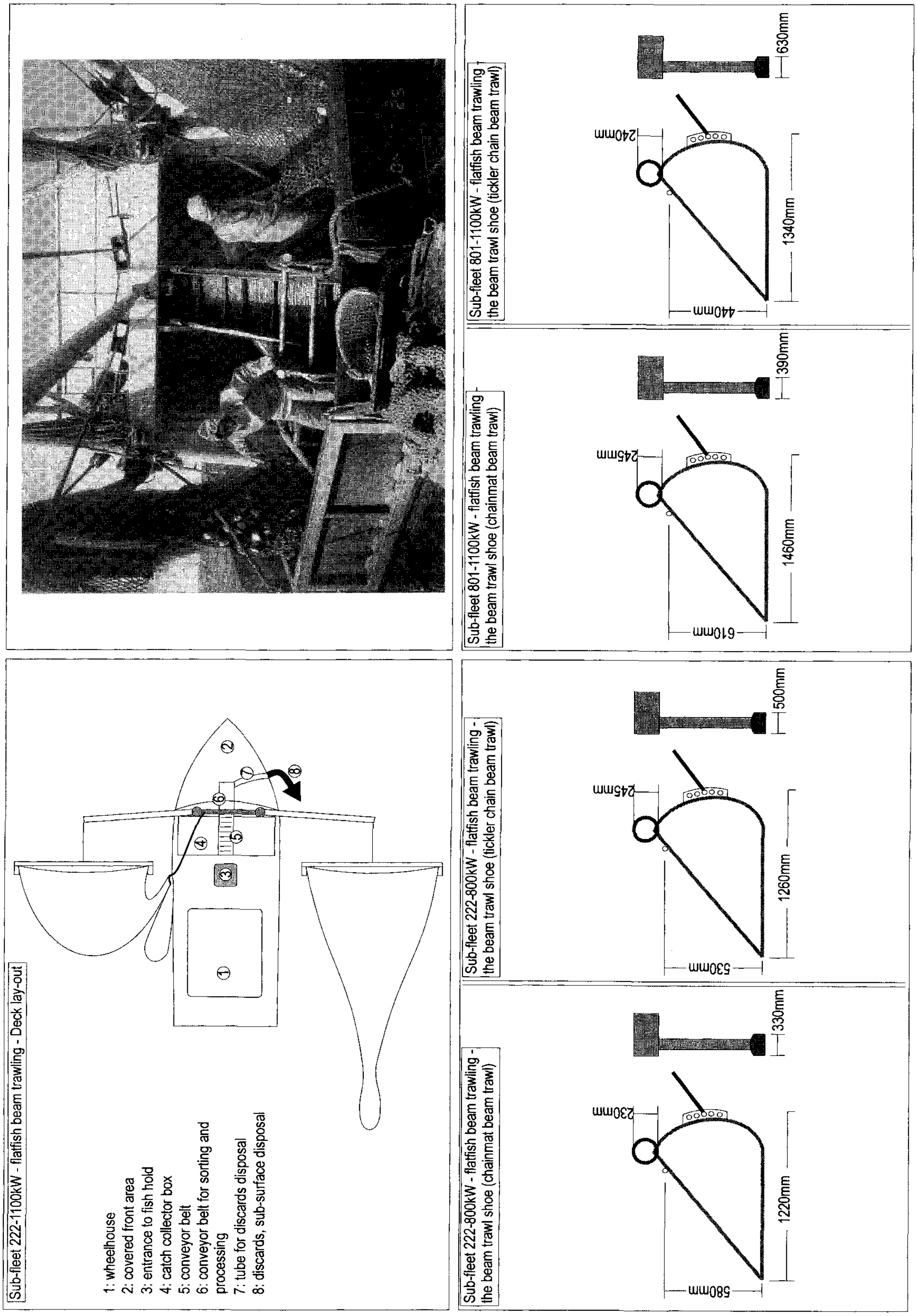


Fig. 3.2.4. Shrimp beam trawling, sub-fleet 222-1100 kW.

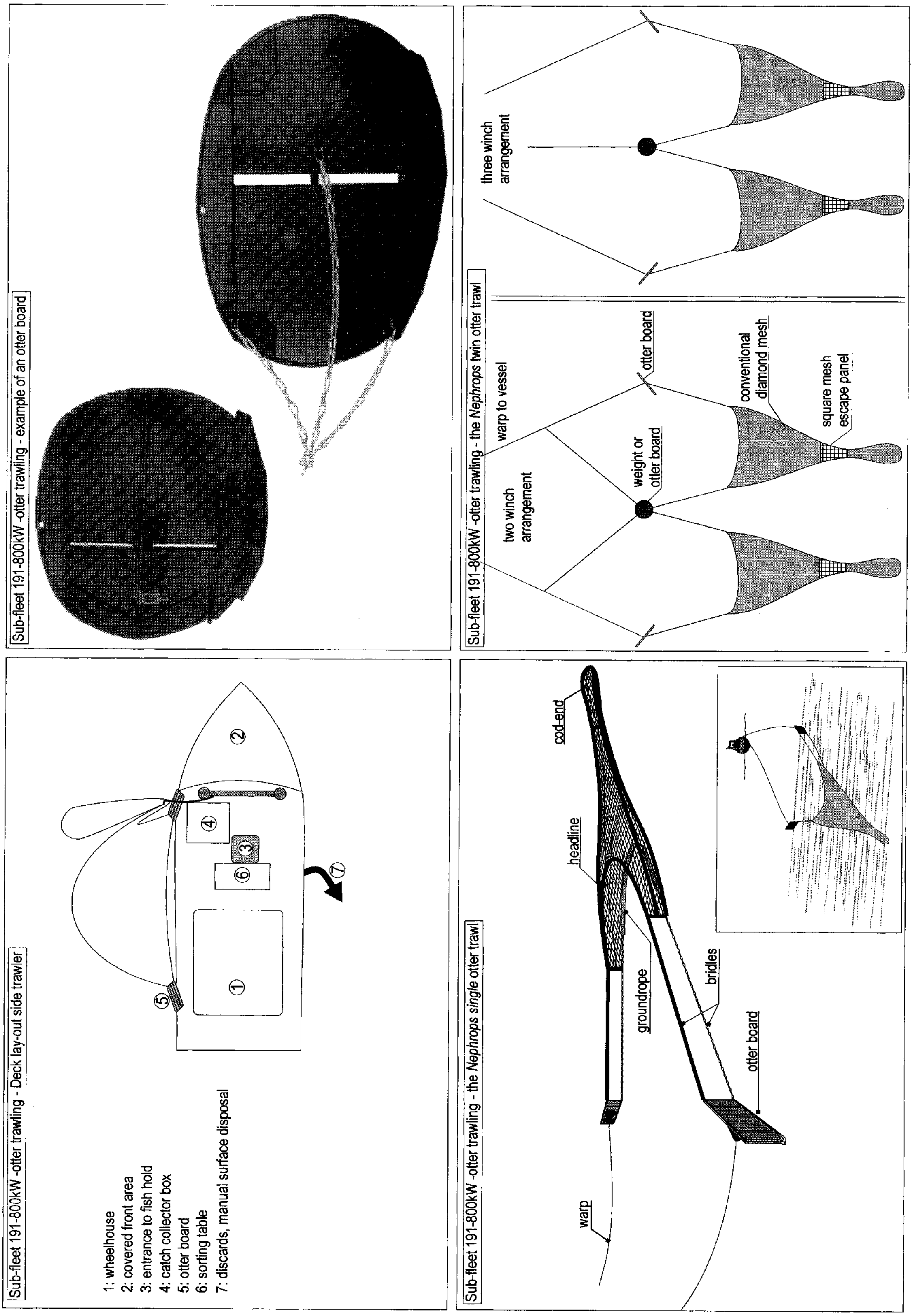


Fig. 3.2.5. Demersal otter trawling.

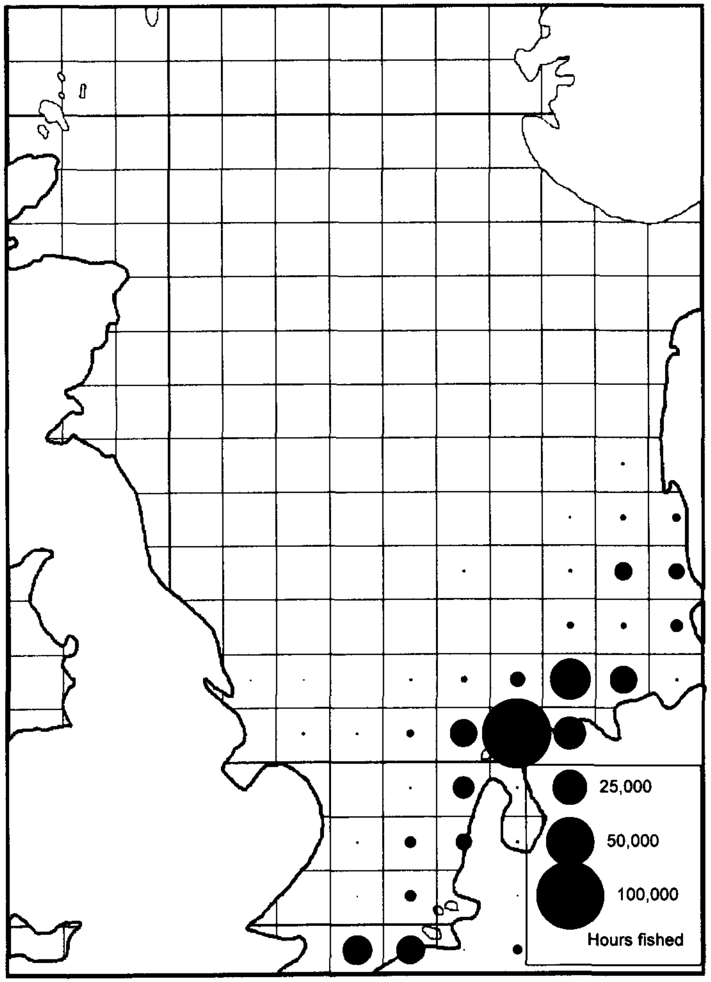


Fig. 3.2.6. Fishing effort - shrimp beam trawling - 70-191 kW Belgium, Germany, Netherlands.

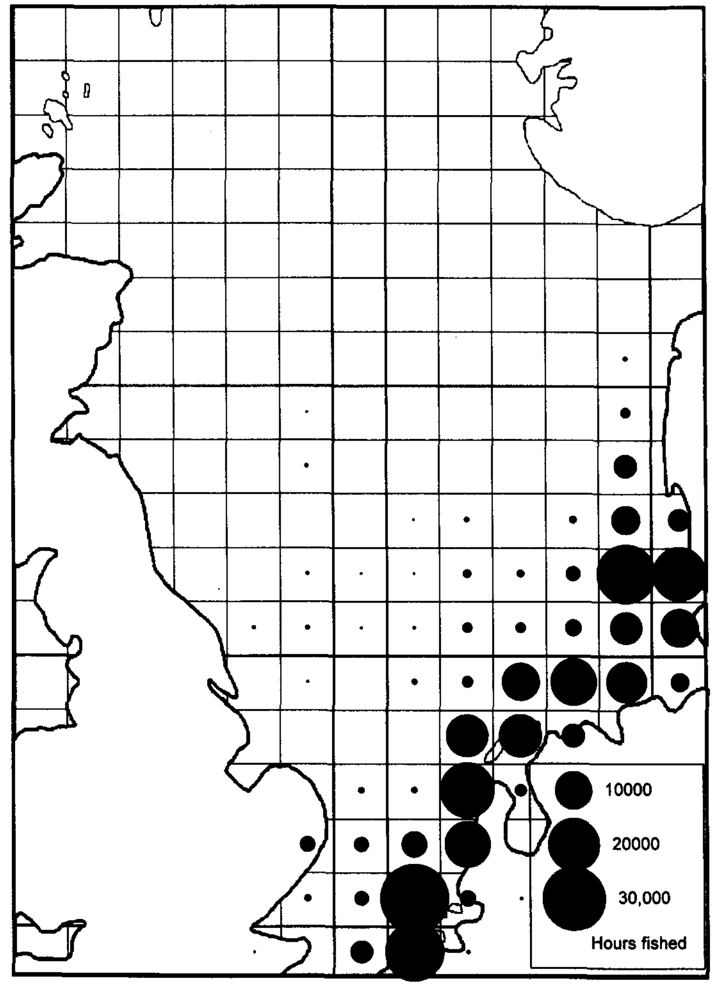


Fig. 3.2.7. Fishing effort - shrimp beam trawling - 191-221 kW Belgium, Germany, Netherlands.

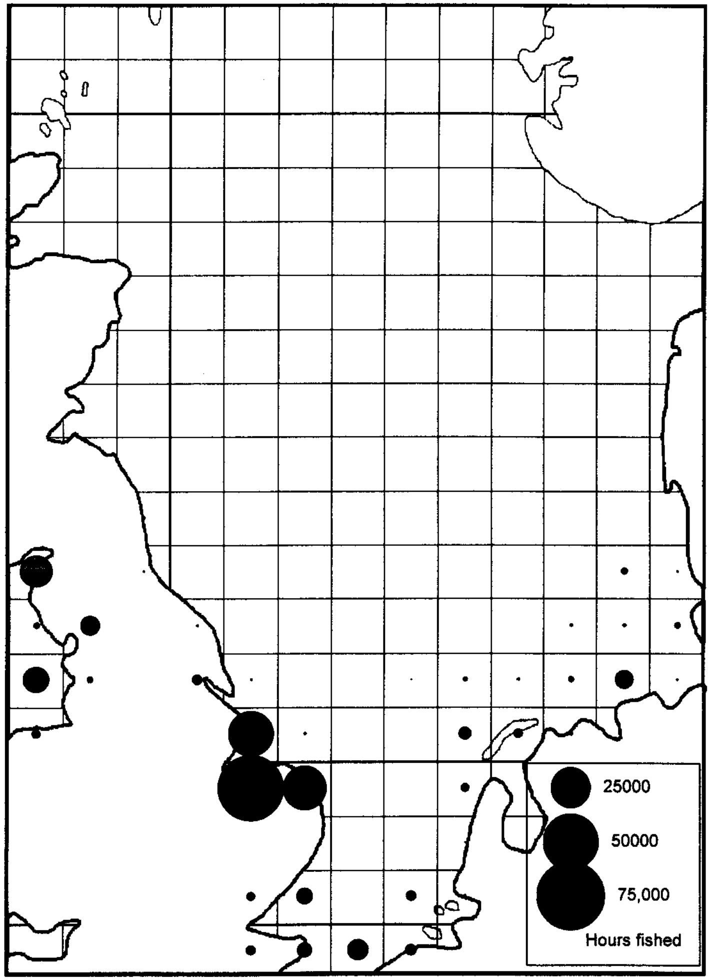


Fig. 3.2.8. Fishing effort - flatfish beam trawling - 70-191 kW
Belgium, Germany, Netherlands.

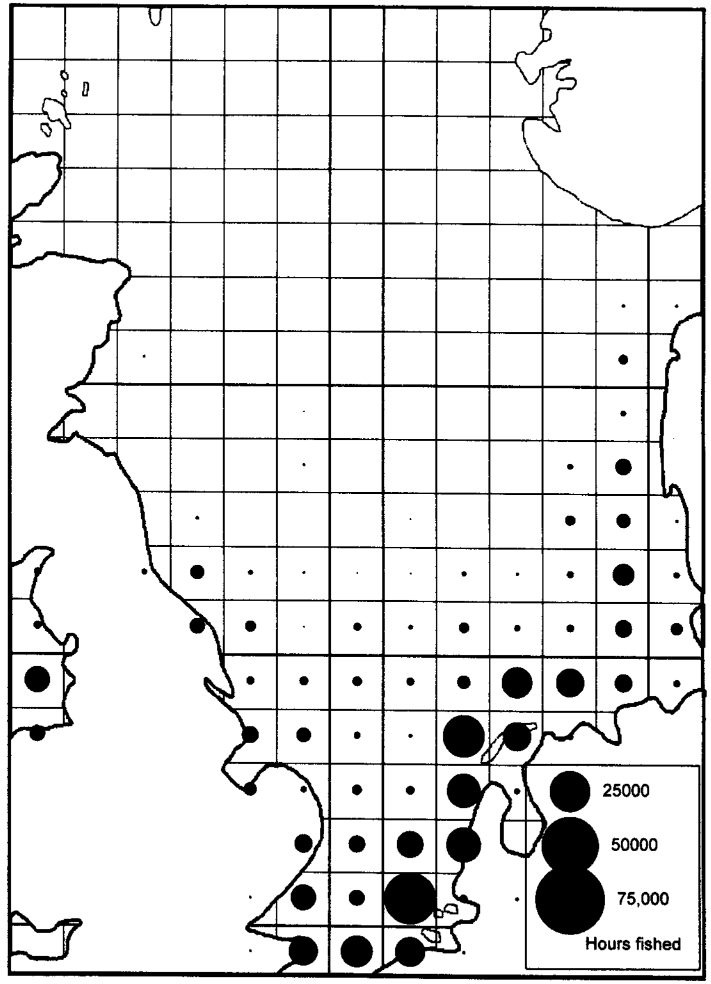


Fig. 3.2.9. Fishing effort - flatfish beam trawling - 191-221 kW
Belgium, Germany, Netherlands.

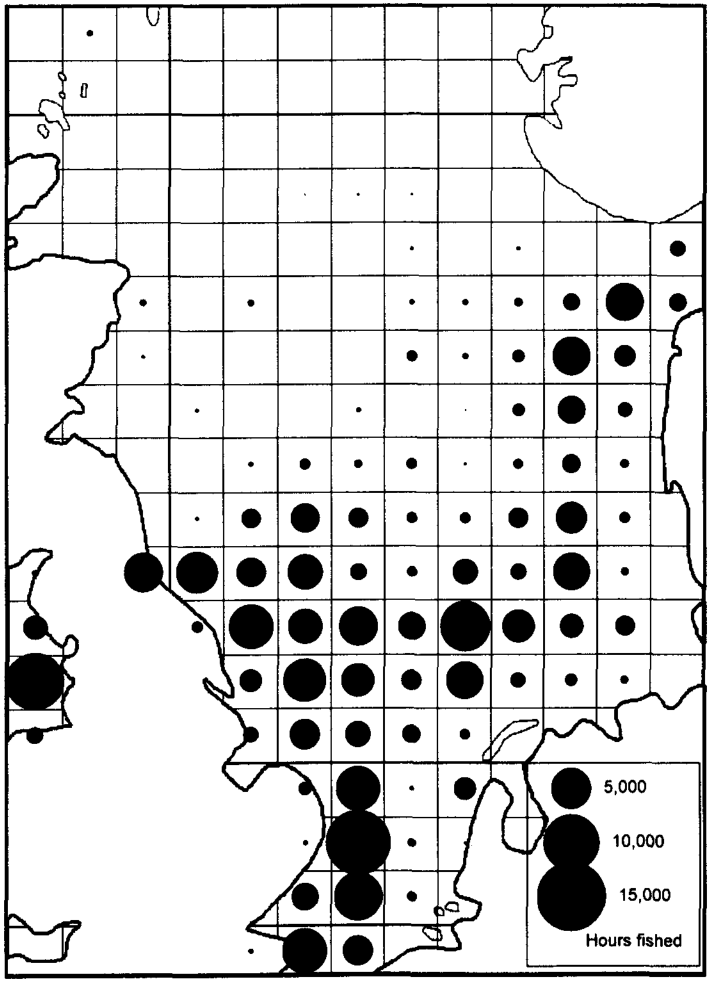


Fig. 3.2.10. Fishing effort - flatfish beam trawling - 222-800 kW
Belgium, Germany, Netherlands.

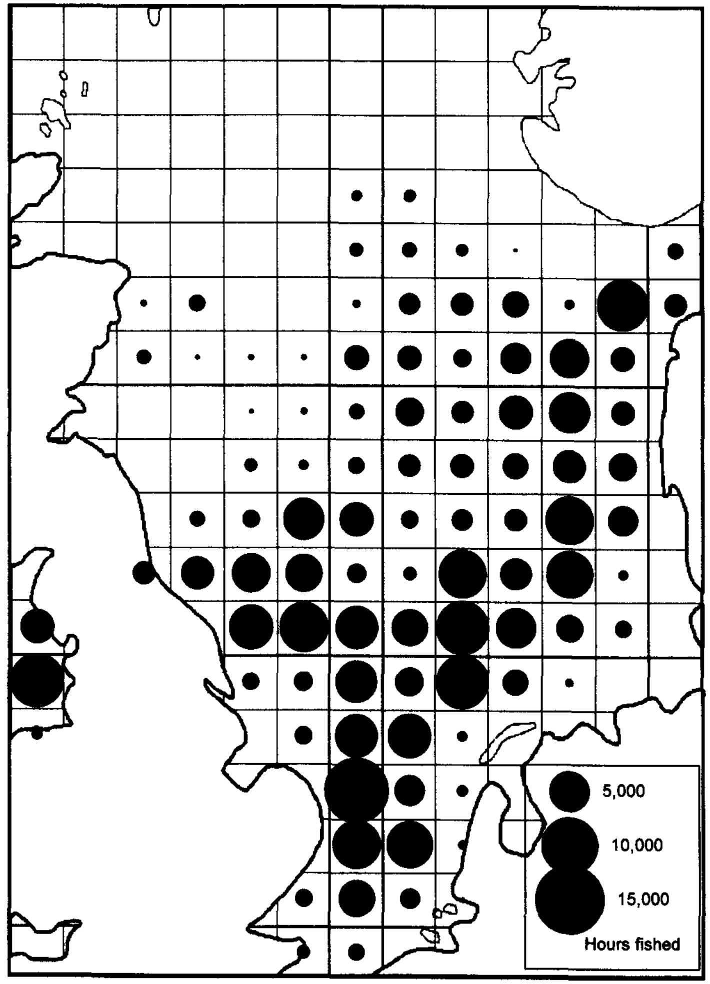


Fig. 3.2.11. Fishing effort - flatfish beam trawling - 801-1100 kW
Belgium, Germany, Netherlands.

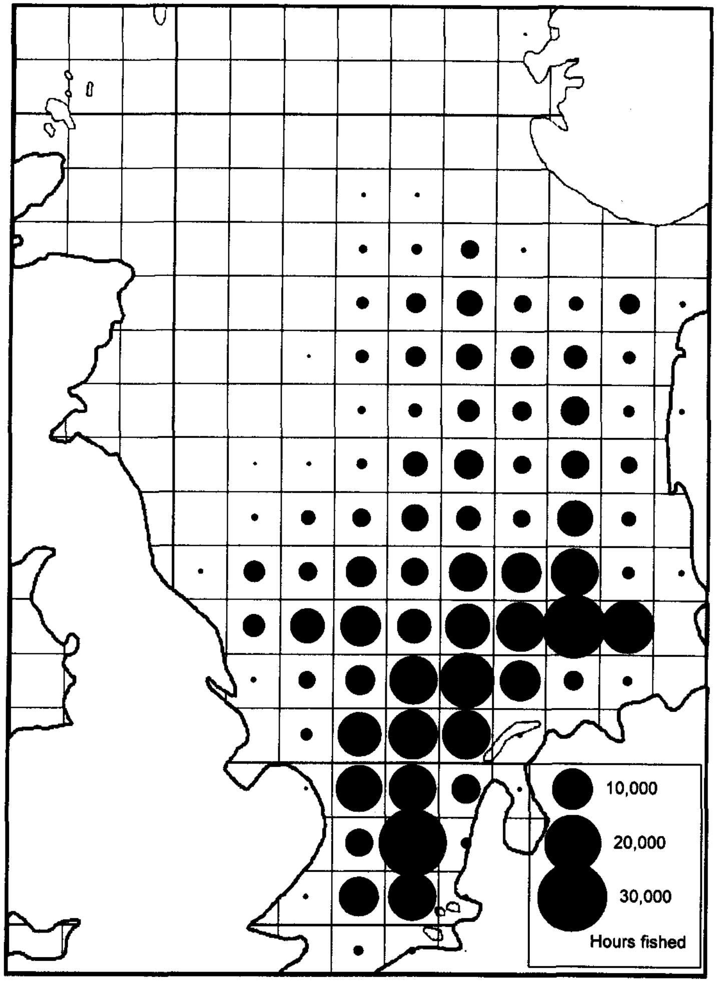


Fig. 3.2.12. Fishing effort - flatfish beam trawling - 1101-1500 kW
Belgium, Germany, Netherlands.

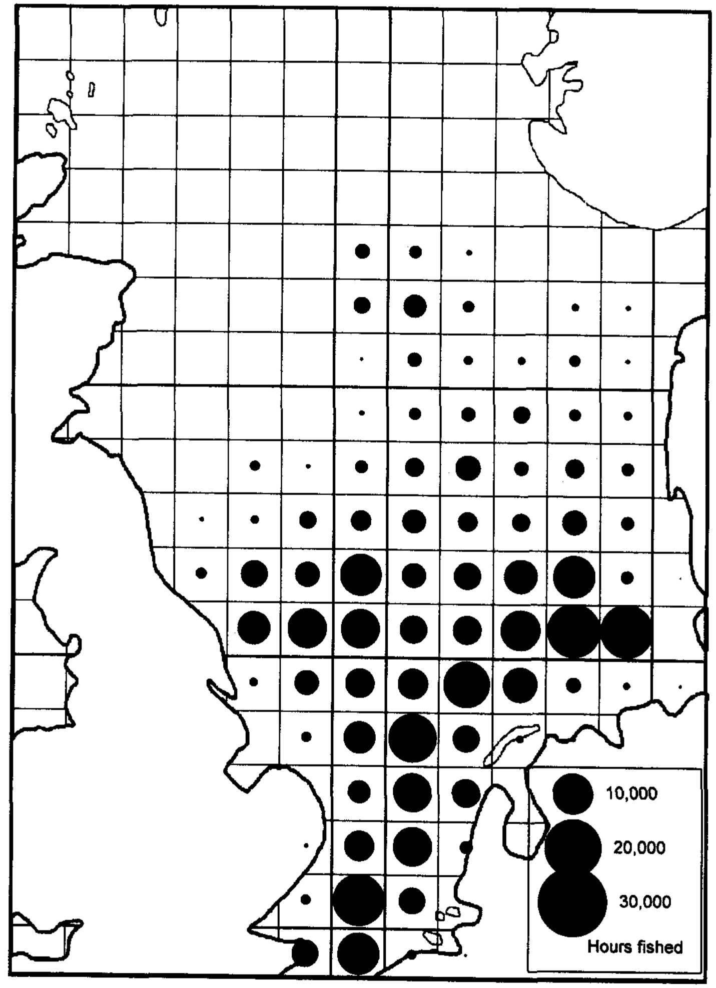


Fig. 3.2.13. Fishing effort - flatfish beam trawling - > 1500 kW
Belgium, Germany, Netherlands.

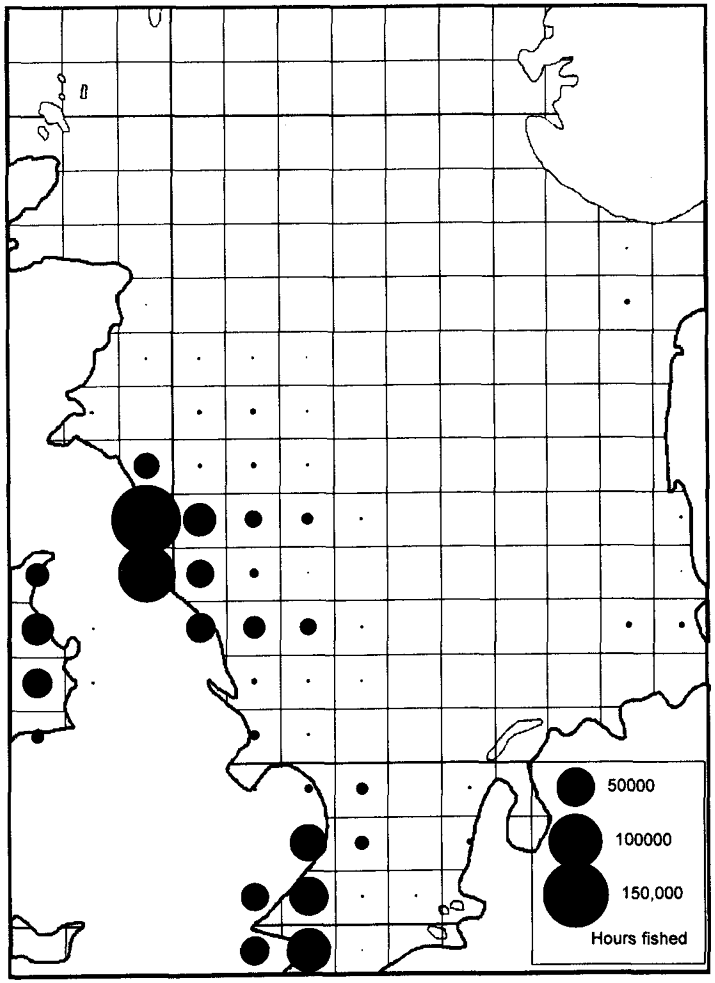


Fig. 3.2.14. Fishing effort - otter trawling - 70-191 kW
Belgium, Germany, Netherlands.

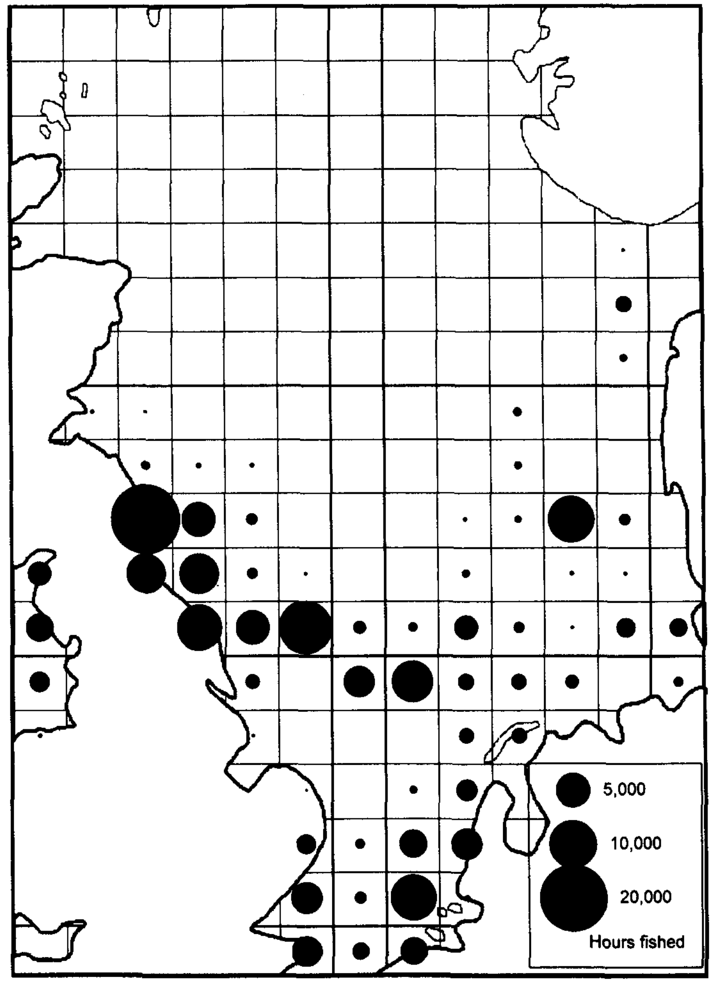


Fig. 3.2.15. Fishing effort - otter trawling - 192-221 kW
Belgium, Germany, Netherlands.

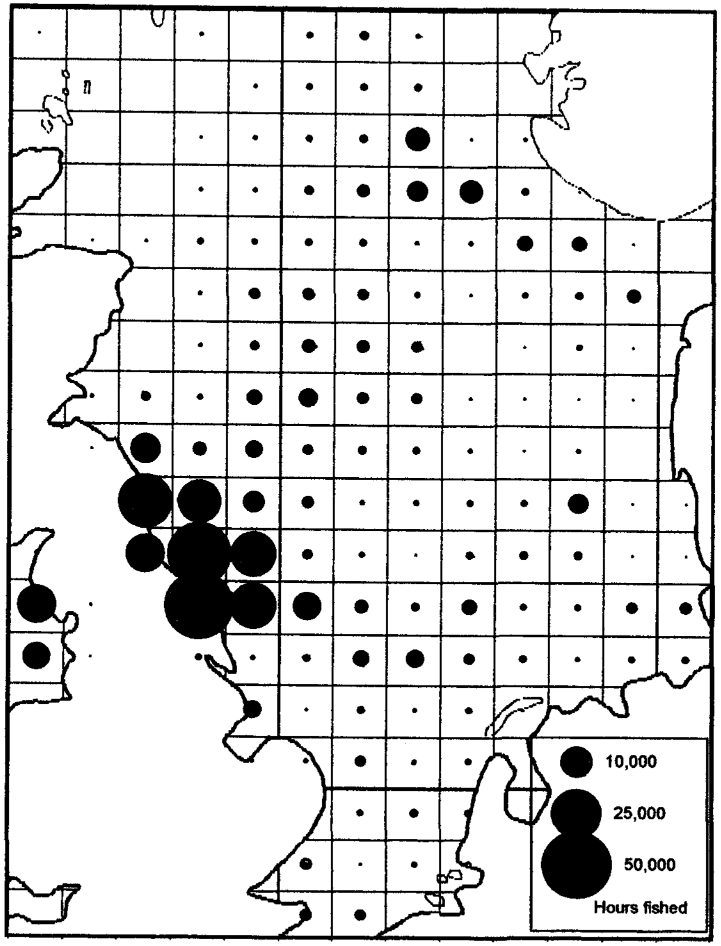


Fig. 3.2.16. Fishing effort - otter trawling - 222-800 kW
Belgium, Germany, Netherlands.

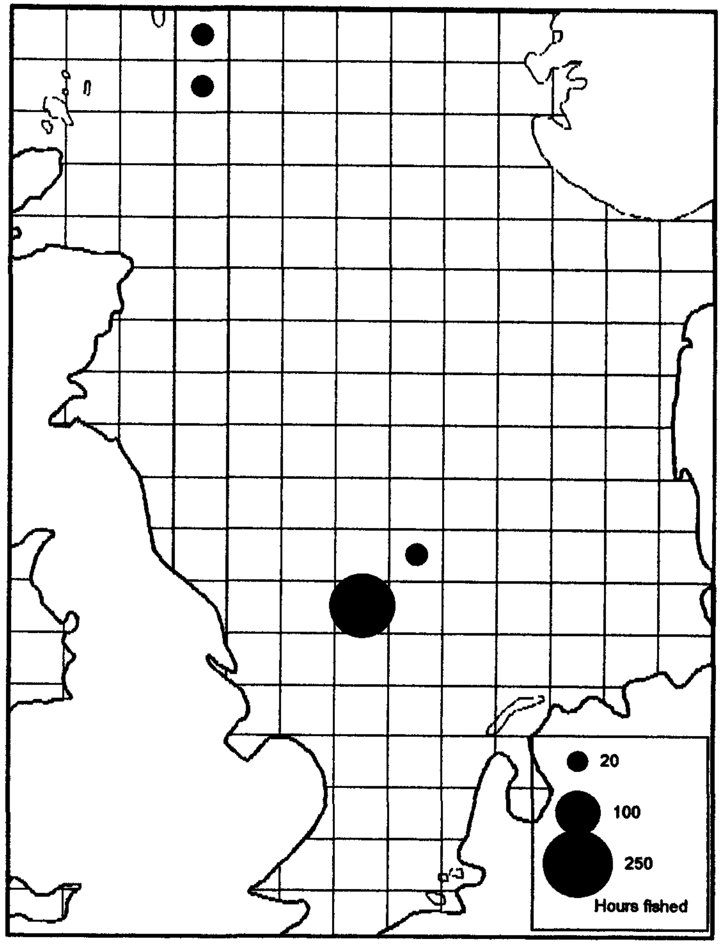


Fig. 3.2.17. Fishing effort - otter trawling - 801-1100 kW
Belgium, Germany, Netherlands.

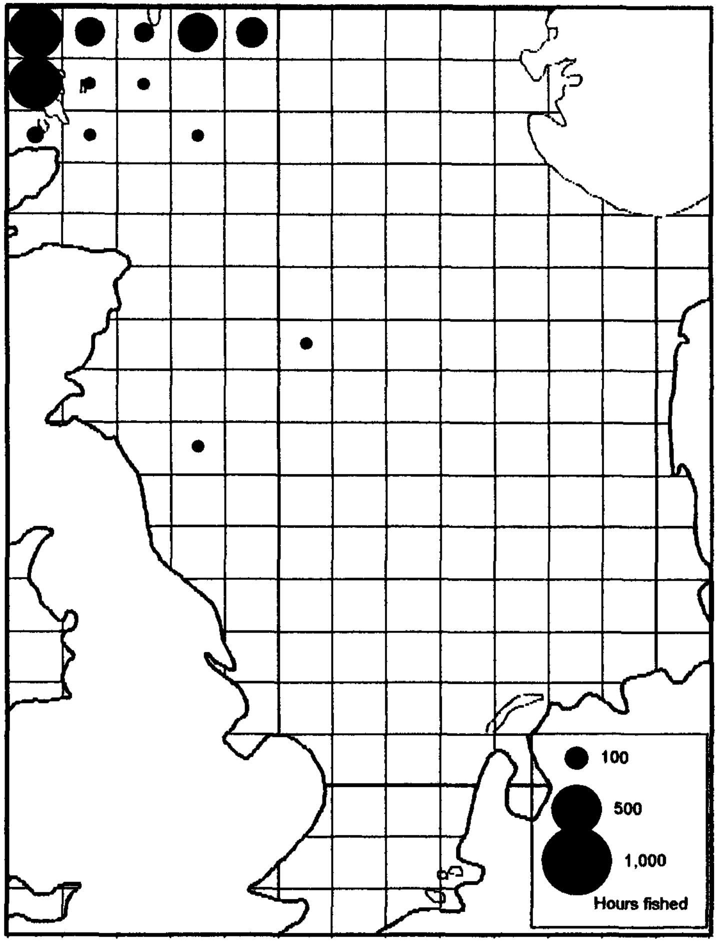


Fig. 3.2.18. Fishing effort - otter trawling - 1101-1500 kW
Belgium, Germany, Netherlands.

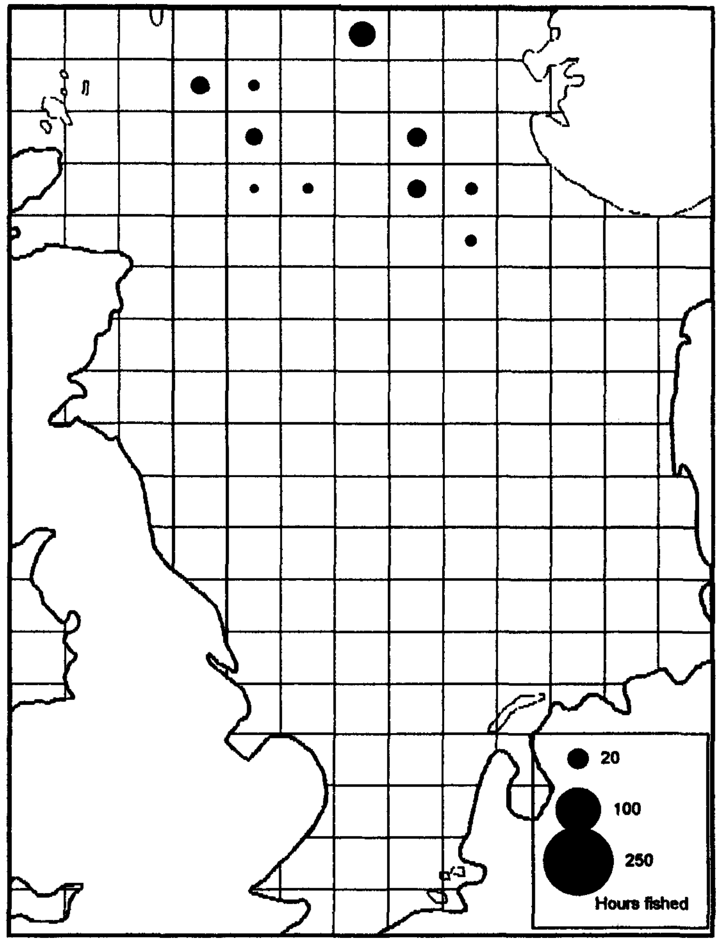


Fig. 3.2.19. Fishing effort - otter trawling - > 1500 kW
Belgium, Germany, Netherlands.

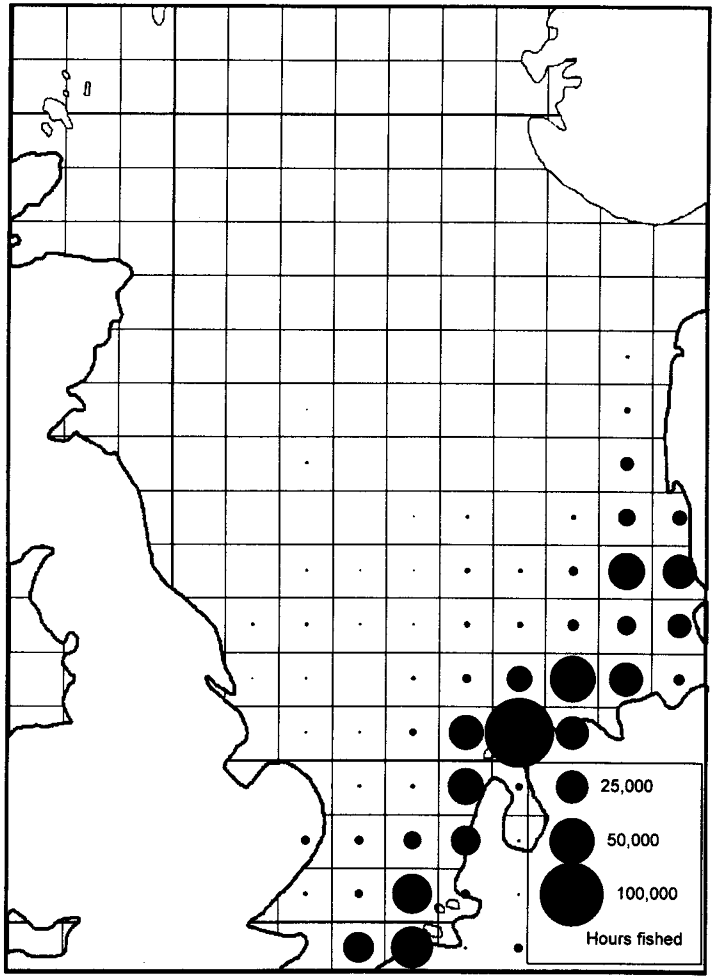


Fig. 3.2.20. Fishing effort - shrimp beam trawling - all engine power classes -Belgium, England, Germany, Netherlands, Scotland.

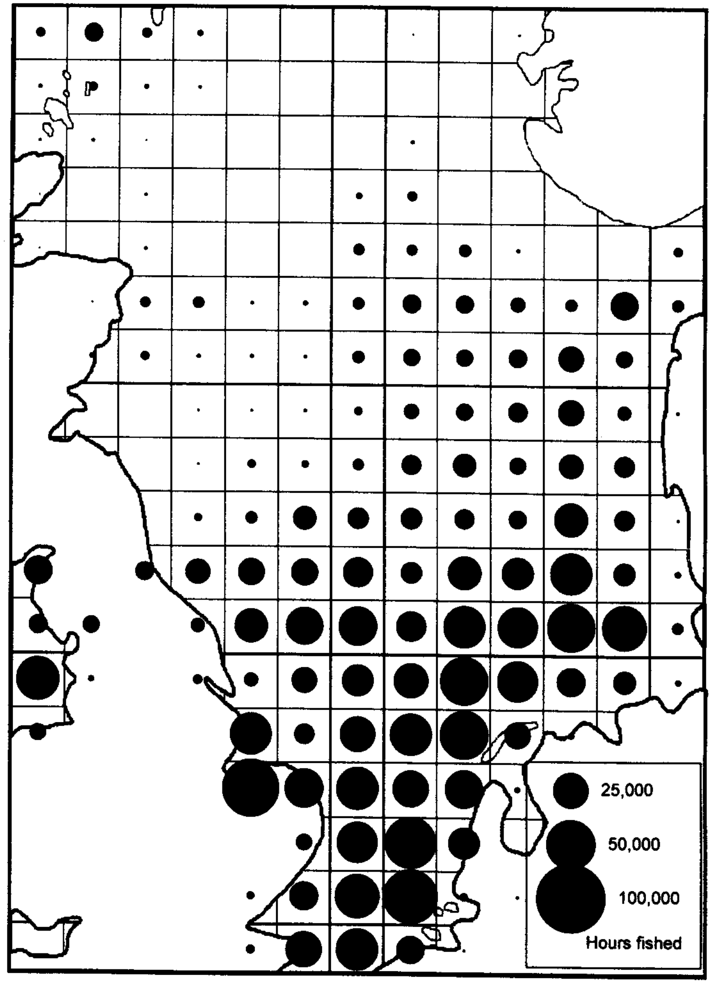


Fig. 3.2.21. Fishing effort - flatfish beam trawling - all engine power classes -Belgium, England, Germany, Netherlands, Scotland.

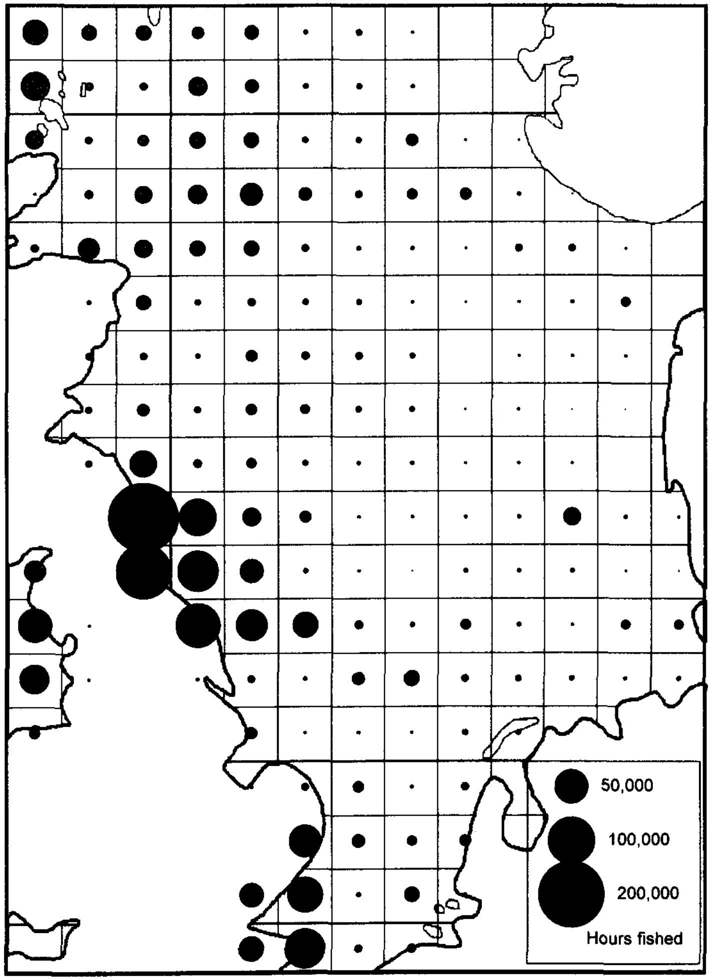


Fig. 3.2.22. Fishing effort - otter trawling - all engine power classes - Belgium, England, Germany, Netherlands, Scotland.

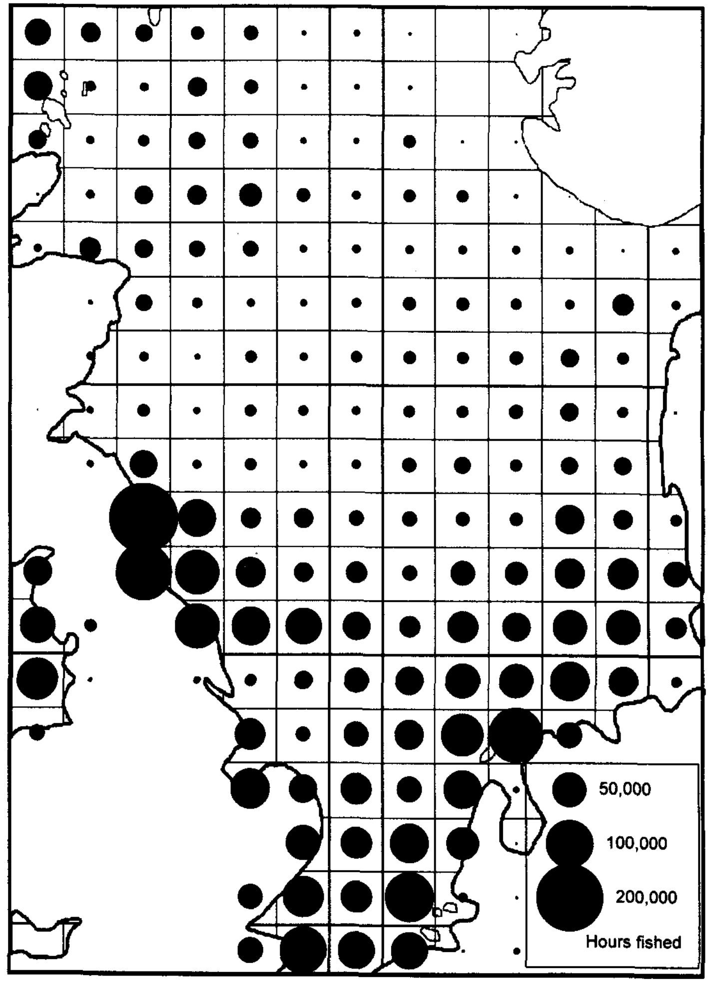


Fig. 3.2.23. Fishing effort - beam + otter trawling - all engine power classes -Belgium, England, Germany, Netherlands, Scotland.

TABLE 3.2.1
Sub-fleets to be included in the vessel and gear inventory

Engine power class (kw)	Fishing method	Belgium	Germany	Netherlands
70-191	shrimp beam trawling	xx	xx	xx
	flatfish beam trawling	x	x	x
192-221	shrimp beam trawling	xx	xx	xx
	flatfish beam trawling	xx	x	xx
	demersal otter trawling	x	o	x
222-800	flatfish beam trawling	xx	o	xx
	demersal otter trawling	x	x	x
801-1100	flatfish beam trawling	xx	o	xx
1101-1500	flatfish beam trawling	o	o	xx
> 1500	flatfish beam trawling	o	o	xx

xx: high importance, x: medium importance, o: small importance

TABLE 3.2.2a
Vessel and operational data for the Belgian fishing fleet.

	70-191 kW		192-221 kW			222-800 kW		801-1100 kW
	shrimp beam trawling	flatfish beam trawling	shrimp beam trawling	flatfish beam trawling	demersal otter trawling	flatfish beam trawling	demersal otter trawling	flatfish beam trawling
Engine power (kW)	151 (88-191) *		215 (191-221)	219 (193-221)	221 (219-221)	588 (368 - 795)	407 (265-551)	884 (817 - 1067)
LOA (m)	17 (14-21)		20.5 (17.5-24)	22 (17.5-28)	24.8 (16.5-28)	32 (27 - 38)	28.4 (25.9-32.3)	36 (30.5 - 40.5)
Breadth (m)	5.1 (4.2-5.8)		5.5 (5-6)	5.8 (4.8-6.8)	6.1 (5-6.5)	7.5 (6.3 - 8.5)	7.2 (6.5-7.8)	8 (6.5 - 9)
Tonnage	32 BRT-39GT		39.5 BRT-66.5GT	67 BRT-77GT	78BRT-94GT	147BRT-221GT	184GT	307GT
Kort nozzle	80%		90%	90%	0%	80%	0%	100%
Propeller diameter (m)	1.3 (1.2-1.6)		1.4 (1.3-1.8)	1.5 (1.3-1.8)	1.9	2.4 (1.8 - 3.2)		2.6 (2.1 - 4.3)
Controllable pitch	none		none	none	none	none	none	10%
Positioning system	GPS (Decca)		GPS (Decca)	GPS (Decca)	GDS(Decca)	GPS (Decca)	GPS(Decca)	GPS (Decca)
Warp depth ratio	2 to 2.5/1		2 to 2.5/1	2.5 to 4/1	3/1	3 (C), 4.5 (T) **	3/1	3 (C), 4.5 (T) **
Average towing speed (knots)	2.5		2.5	3.5 (C), 4.6(T)**	3.5	4.1	4	4.5 (C), 6(T)**
Single - double warp system	single		60% - 40%	60% - 40%	all single	65% - 35%	all single	30% - 70%
Diameter of the warps (mm)	18 - 20		20 - 24	20 - 24	18-24	32(sngl) - 28(dbl)	21	32(sngl) - 28(dbl)
Duration of one seatrip	1/2 to 2 days		1/2 to 5 days	3 to 7 days	5 to 15 days	5 to 12 days	5 to 12 days	7 to 18 days
Surface trawled in 1 hour (km²)	0.06		0.06	0.063(C), 0.067(T) **		0.13(C), 0.15(T) **		0.16(C), 0.23(T) **

* : average (minimum - maximum)

** : **C** stands for chainmat beam trawls and **T** for tickler chain beam trawls

TABLE 3.2.2b

Vessel and operational data for the Dutch fishing fleet.

PART 1 - GEARS WEST*	70-191 kW	192-221 kW	222-800 kW	801-1100 kW	1101-1500 kW	> 1500 kW (1)	Comments
No. of vessels (1991 - 1994)	20 - 15 (2)	57 - 53	17 - 4	25 - 7	25 - 33	31 - 27	(1): after 1988, new built max = 1470kW
LOA (m)	18.5 (14-23)	23 (18-25)	28 (22-35)	35 (29-38)	37 (33-42)	42 (36-46)	(2): mainly shrimp fishing in the Wadden Sea
Breadth (m)	4-6	5-6.5	6-8	7-8.5	7.5-9.5	8.5-10	
Tonnage (GT)	50 (20-70)	80 (32-140)	130 (60-210)	200 (150-270)	305 (260-450)	410 (300-550)	
Kort nozzle	90%(except older vessels)	90%	90%	99%	99%	99%	
Propeller diameter (m)	1.2	1.2 (shrimp) 2.5 (flatfish)	2.0 (1.5-2.5)	2.45 (2.0-2.9)	3.0 (2.4-3.6)	3.2 (3.0-3.4)	
Controllable pitch	1 series of 6 shrimpers (built 1981) and 2 flatfish beam trawlers						
Positioning system	GPS(Decca)	GPS(Decca)	GPS(Decca)	GPS(Decca)	GPS(Decca)	GPS(Decca)	DGPS on recent vessels
Warp depth ratio	3/1	3.5/1 to 5/1	3.5/1 to 5/1	3.5/1 to 5/1	3.5/1 to 5/1	3.5/1 to 5/1	3/1 in areas with steep sanddunes
Towing speed (knots)	2.5-3 (shrimp) 4 (otter trawl)	2.5-3 (shrimp) 4.5 (beam trawl)	4-5 (beam trawl) 4 (otter trawl)	6-7	6-7.5	6.5-8	

* : Harbours west of IJmuiden. Mostly hard sandy bottom, west of 4° E, small stones and sanddunes in the South

TABLE 3.2.2c
Vessel and operational data for the Dutch fishing fleet.

PART 2 - GEARS EAST*	70-191 kW	192-221 kW	222-800 kW	801-1100 kW	1101-1500 kW	> 1500 kW
No. of vessels (1991 - 1994)	108 - 103	61 - 75	23 - 20	28 - 19	52 - 70	46 - 44
LOA (m)	18.5 (14-23)	23 (18-25)	28 (22-35)	35 (29-38)	37 (33-42)	42 (36-46)
Breadth (m)	4-6	5-6.5	6-8	7-8.5	7.5-9.5	8.5-10
Tonnage (GT)	50 (20-70)	80 (32-140)	130 (60-210)	200 (150-270)	305 (260-450)	410 (300-550)
Kort nozzle	90%(except older vessels)	90%	90%	99%	99%	99%
Propeller diameter (m)	1.0 (0.8-1.6)	1.4 (shrimp) 2.0 (flatfish)	2.0 (1.5-2.5)	2450 (2000-2900)	3000 (2400-3600)	3200 (3000-3400)
Controllable pitch	1 series of 6 shrimpers (built 1981) and 2 flatfish beam trawlers					
Positioning system	GPS(Decca)	GPS(Decca)	GPS(Decca)	GPS(Decca)	GPS(Decca)	GPS(Decca)
Warp depth ratio	3/1	3.5/1 to 5/1	3.5/1 to 5/1	3.5/1 to 5/1	3.5/1 to 5/1	3.5/1 to 5/1
Average towing speed (knots)	2.5-3 (shrimp) 4 (otter trawl)	2.5-3 (shrimp) 4.5 (beam trawl)	4-5 (beam trawl) 4 (otter trawl)	5-7	6-7.5	6.5-8

* : Softer grounds east of 4° E, sometimes silty. In summertime often softer: less ticklers

TABLE 3.2.2d

Vessel and operational data for the German fishing fleet.

	<70 kW	70-191 kW		192-221 kW	
	shrimp beam trawling	shrimp beam trawling	demersal otter trawling	shrimp beam trawling	demersal otter trawling
Engine power (kW)	35.4 (5-68)*	159 (74-191)	162 (159-165)	217 (197-221)	219 (206-221)
LOA (m)	8.4 (5-13)*	16.1 (9-25)	16 (15-17)	20.3 (15-25)	22 (19-26)
Tonnage	3.7 (12-113)*	30.5 (5-90)	23 (23-23)	102 (41-167)	107 (107-107)

	222-800 kW	801-1100 kW		1101-1500 kW	>1500 kW
	demersal otter trawling	flatfish beam trawling	demersal otter trawling	flatfish beam trawling	demersal otter trawling
Engine power (kW)	516 (243-784)	910 (908-912)	1007 (993-1020)	1104 (1104-1104)	2909 (1620-3530)
LOA (m)	30 (24-36)	37 (34-39)	36 (35-36)	38 (38-38)	74 (44-92)
Tonnage	240 (100-425)	260 (249-271)	347 (269-425)	244 (244-244)	2140 (671-3071)

* : average (minimum - maximum)

different between treatments and controls as shown by the median test. Differences between distinct fishing intensities with the 12m beam trawl were hard to detect. Only the penetration depth of the prism of the 300% level with the 12m beam trawl was different to the 200% level with the 4m beam trawl. The surface roughness showed no differences between treatments. The conclusion is that heavy beam trawling in this area removes the upper 1 cm sediment layer as indicated by the differences in the penetration depth of the prism that is limited by deeper, densely packed sediment layers (fine sand). This is also confirmed by the comparison of the surface roughness between treatments and controls. The small scale topography was flattened since the amplitude of the ripples was reduced by 1 cm. The video observations made across the fishing tracks confirmed the point source REMOTS findings. More material was suspended with heavy trawling.

Longer term effects

Side-scan sonar observations

This section gives the main results of the side-scan sonar observations on tracks fished with a 4m beam trawl. An example is given in Fig. 3.3.15. Detailed reports are given in De Moor *et al.* (1992) and Anon. (1996a).

1992 observations on the Flemish banks

Side-scan sonar observations were made on the Goote Bank area near the Belgian coast (Fig. 3.3.16). The selection of the test areas was based on the occurrence of sandy rather than silty sediments. Seabed superficial sediment samples were taken with a Van Veen grab sampler at regular intervals on the fished tracks. The grain size parameters in each individual area vary considerably along the sampled line. In zone IV the natural mean values varied between >884 µm and 374 µm and the silt content between 12.10% and 1.43%. In zone II the natural mean values varied between 591 µm and 439 µm and the silt content between 1.37% and 1.00%. In zone I the natural mean values varied between 530 µm and 293 µm and the silt content between 21.20% and 4.70%.

On test zone IV four parallel tracks about 3 km long and at a distance of about 40 m from each other were fished with the 4m beam trawl. In total 10 side-scan sonar observations of the trawl marks were made between 15 minutes and 52 hours after fishing. A graphical representation of the visibility of the trawl marks as a function of time is given in Fig. 3.3.17. At the end, only very vague marks along 41% of the track could be spotted. On 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. On 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 for this purpose. Probably the depth of penetration was not very pronounced. No clear correlation could be made between the visibility of the trawl marks and the grain size of the sediment. The longest visibility of the tracks, however, occurred on the coarse sand area of zone IV.

1993 observations on the Flemish banks

Zone I was fished twice on approximately the same track. The tracks were observed 21 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 out.
A further attempt was made to correlate the visibility of the trails on zone I with the type of bottom samples (Fig. 3.3.18). Again sediment samples were taken with a Van Veen grab 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. 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 was 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 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.

Again the penetration depth could not be deduced from the recorded sonographs.

1996 observations on the Scheveningen area and on the Flemish Banks

Side-scan sonar observations were made on the Dutch coast (Scheveningen area, Fig. 3.3.19) and on the Belgian coast (Goote Bank, Fig. 3.3.16).

Scheveningen area

The side-scan sonar observations were made on three nearby parallel tracks on each of which five consecutive fishing operations had taken place. The observations of the tracks were made just before fishing and several times after fishing, up to nearly 37 hours later. The sediment composition in the area was very homogenous and consisted mainly of fine and very fine sand (see next paragraph *Results from RoxAnn surveys* for details). The trails were clearly visible 16 hours (Scheveningen 3 area) and up to 22 hours (Scheveningen 1 area) after fishing, though not over the complete length of the track. One track (Scheveningen 2 area) was observed up to 37 hours after fishing. At that time only a short section was still visible while most of the trails could only be vaguely detected.

Goote Bank

The superficial sediment on the track consisted of nearly equal parts of fine and very fine sand and of shell debris and gravel (see next paragraph for details). The track to be observed was fished four times and side-scan sonar recordings were made up to 22.5 hours after fishing. Even at the end of the observations the trails were still clearly visible.

Results from RoxAnn surveys

Useful RoxAnn surveys were performed on one location on the Dutch coast (Scheveningen area, Fig. 3.3.19) and two locations on the Belgian coast (Goote Bank and Negenvaam, Fig. 3.3.16). The results of the grain size analysis of Van Veen grab samples on the different locations are given in Table 3.3.2. The values of relevant RoxAnn parameters, before fishing (t0), are given in Table 3.3.3. E1 is derived from the first echo from the echo sounder and is a relative measure for the roughness of the sediment. E2 is derived from the second echo and is a relative measure for the hardness.

Scheveningen area

The sediment on the Scheveningen area is homogenous and consists mainly of medium and fine sand (Table 3.3.2). There are only very few particles sized >2 mm. This is confirmed by the relatively low values of E1 and E2 and by their low variation (Table 3.3.3 and Figs 3.3.20a and 3.3.20b at t0). Five consecutive hauls were made over the same track. The track was observed by RoxAnn 0.5, 3, 5 and 15 hours after fishing. The E1 and E2 parameters along the track are compared with the values before disturbance (t0) in Fig.s 3.3.20a and 3.3.20b for each observation. Immediately after fishing (t0+0.5) the seabed disturbance is very clear. The E1 value dropped, indicating that the "roughness" has decreased. The E2 value on the contrary increased considerably indicating a harder bottom. Both the changes in E1 and E2 can be explained by the lighter sediment fractions being suspended by the gear. Note that the increase in E2 is variable. This is probably due to the fact that during the RoxAnn surveys not all sea bottom surfaces sampled by the echo sounder were equally affected by the fishing gear. It appears from the time series that the suspended sediment particles deposited rather quickly. After 3 hours the parameters E1 and E2 were again close to the t0 value and after 15 hours no difference could be distinguished. It should be noted, however, that the disturbance by the gear as recorded by the side-scan sonar became only less visible at the end of the time series.

Goote Bank

The surface sediment on the Goote Bank consisted on average of 47% fine and very find sand and of 41% shells and gravel (Table 3.3.2). The presence of the shells and gravel in the sediment is reflected by the higher values of both E1 and E2 (Table 3.3.3 at t0), indicating that the bottom is rougher and harder. The track was fished four times, RoxAnn surveys took place before fishing (t0) and at 3,10, 20 and 24 hours after fishing. Due to the relatively lesser content of light particles, the change in the sediment characteristics was less pronounced than on the Scheveningen area. The E1 and E2 values were dominated by the presence of large particles and the suspension of the lighter particles after passage of the trawl caused only minor changes.

Negenvaam

The sediment on the Negenvaam area was not as homogenous as on the two other locations (Tables 3.3.2 and 3.3.3). Although it contained a lot of very fine sand there was also a considerable amount of larger particles. The effect of trawling on E1 and E2 was limited and soon faded away completely.

3.3.2.2. OTTER TRAWLS

Immediate effects

The immediate effects of otter trawling could be derived for a *Nephrops* otter trawl in the Irish Sea.

Results from Sediment Profile Imaging

The Sediment Profile Imaging (SPI) photographs show the sediment of the study area to be a well oxygenated mud, with a generally mounded appearance, due primarily to the presence of *Nephrops norvegicus* burrows (Fig. 3.3.21). Apparent Redox Potential Discontinuity (RPD) depths were about 8 cm. In photographs taken after repeated trawling of the ground, however, a general flattening of the sediment surface was apparent (Fig. 3.3.22). This was often manifested by the collapsing and burying of *Nephrops* burrows and the filling in of the openings. A layer of light resuspended material was seen to cover the sediment surface, often to a depth of about 2 cm. This deposition of resuspended fine sediment seems to occur not only at trawled stations, but also at those close by. This sometimes results in an apparent redox rebound, where a thin anoxic layer was apparently temporarily formed at the original sediment surface, beneath the newly resettled superficial sediment layer. This seems to break down after a few days and the more normal 8+ cm RPD depth was restored. However, these observations can only be tentative since they are based solely on interpretation of the photographs, and no redox profiles were measured. Some sediment profile images showed deep tracks cut about 14 cm into the sediment surface (Fig. 3.3.23). These may result from the passage of the trawl doors along the bottom, although there was no method for confirming these observations.

Results from Video and Stills observations

The direct physical disturbance of the sediment layer, observed by SPI photography, was confirmed by HYBALL ROV video footage. This showed that the passage of the net resulted in an obvious smoothing of the sediment surface, leaving clear parallel lines interspersed with wider smooth regions. Evidence of the passage of the trawl doors was not clearly seen in any of the video passes. This suggests that either the impact is not as great as suggested by the SPI images or may result from missing them in this soft sediment area where resuspended fine material often obscured the video images. Fewer openings of *Nephrops* burrows were seen in the areas swept by the net. This would seem to suggest that the delicate and complex structure of the burrow systems are collapsed and filled in by the action of the gear.

Sessile epifauna in the tracks of the trawl net and groundrope, such as *Virgularia mirabilis* (Sea-pen) and *Sabella* sp. (Fan-worm), are seen to remain following trawling. Evidence of injury to the distal portion of some of the sea pens was commonly observed, presumably due to the rubbing action of the net as it passes over. The tubes of *Sabella* sp. also appeared to protrude further from the sediment which may make them more available to predators. Whilst both sea-pens and *Sabella* sp. were found in the by-catch of the *Nephrops* trawls, it would appear that disturbance, rather than removal, of sessile benthic epifauna is the most common result following the trawl passage.

Longer term effects

Longer term effects of otter trawling were studied in a Scottish loch.

Side-scan sonar observations

The side-scan sonar record from the preliminary survey indicated that both the treatment and reference areas were flat and devoid of any distinct topographic features (Fig. 3.3.24a). The surveys carried out while the experimental trawling program was ongoing showed evidence of considerable physical disturbance to the seabed in the treatment area (Fig. 3.3.24b) while the seabed in the reference area remained undisturbed. The disturbance appeared as a number of troughs in the seabed, running in a roughly Northwest/Southeast direction. It is assumed that these are the tracks left by the trawl doors, an assumption supported by the fact that the tracks run in the same direction as the experimental trawling. In a number of cases, parallel tracks can be seen 35-40 m apart, corresponding to the distance between the trawl doors. Disturbance tracks could still be seen in the treatment area 18 months after the end of the experimental trawling, although the marks were very faint by this time.

Results from RoxAnn surveys

Transects of E1 (roughness) parameter values along the loch for each survey are shown in Fig 3.3.25. These plots show a loess smooth of the E1 data in relation to distance from a nominal point at the southern end of each experimental area. It can be seen that the differences in roughness between the treatment and reference areas increased during the disturbance programme (Fig. 3.3.25b-d) and declined during the recovery period (Fig. 3.3.25e & f), the two areas being indistinguishable after 18 months recovery. No differences between the areas in the E2 (hardness) parameter were identified throughout the survey period.

3.3.3. DISCUSSION

Pressure

The pressure force exerted by a 4m beam trawl 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 remain 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 greater upwards pull and the beam will lift off the bottom. From the present experiments it appears that the pressure exerted by the sole plates varies from 1.7 $N.cm^{-2}$ to 3.2 N/cm^{-2} (0.173-0.316 $kgf.cm^{-2}$) when fishing against the current at towing speeds (over the ground) of 4 kn and 6 kn, respectively. In Belgian commercial fishing with this gear, 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 $N.cm^{-2}$ (0.2 $kgf.cm^{-2}$) and 1.7 $N.cm^{-2}$ (0.17 $kgf.cm^{-2}$) respectively. Bottom contact was lost at 6 kn or 7 kn depending on whether the gear was towed against or with the current. These values are for warp lengths equal to three times the depth, the standard warp length / depth ratio. With shorter warp lengths, e.g. on soft grounds, the pressure will be lower since the warp lift force will increase. 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 matrix and the bobbin gear exert only a limited pressure on the seabed.

Since larger vessels use heavier gears, the pressure force exerted by a beam trawl increases with vessel engine power but the increase is less than proportional. The increase in gear weight, however, is compensated by larger sole plate dimensions and a higher towing speed. As a result, heavy and light beam trawls will exert sole plate pressures of the same magnitude. This is in agreement with the results of measurements made by Van der Hak & Blom (1990). They calculated that for a 12m / 7000 kg beam trawl, the sole plates exerted a pressure of 1.47 $N.cm^{-2}$ (0.15 $kgf.cm^{-2}$). Taking into account that it was presumed that the entire sole plate was in contact with the bottom, this value is quite close to the results of the present study. Even earlier studies point in the same direction. Margetts & Bridger (1971) calculated that the pressure of a 9m beam plus trawl heads with a total weight of 324 kg (283 kg in water) is 0.1 $kg.cm^{-2}$. For comparison, a 556 kg (in water) otter board exerts a pressure of 0.236 kg/cm^2. These values, however, do not take account of the upwards pull of the warps.

Effects of beam trawling

From the penetration depth of the REMOTS prism it can be estimated that on densely packed fine sand with a silt layer on top heavy beam trawling will result in the removal of the upper 1 cm sediment layer. REMOTS and video observations revealed that the passage of a beam trawl flattens the seabed and exposes shell debris at the surface. While differences between treatments and control were very clear, differences between treatments were not. Only a 300% fished area with a 12 beam trawl could be distinguished from a 200% fished area with a 4m beam trawl.

The longer term effects of fishing with a 4m beam trawl could be judged from the side-scan sonar recordings and the RoxAnn surveys. The movement of the trawl over the seabed causes the suspension of the lighter sediment fractions. The RoxAnn surveys indicated that the bottom becomes harder and less rough. The changes were most pronounced in an area with a lot of fine and very fine sand. The original situation, however, was quickly restored. On the most disturbed areas the "hardness" and "roughness" characteristics regained their original values in less than 15 hours.

The duration that beam trawl marks remained visible after fishing also depended on the upper sediment layer. On a seabed consisting of mainly coarse sand the tracks remained visible for up to 52 hours, whereas on sediments with mainly finer particles the tracks were completely faded after

37 hours. 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.

Effects of otter trawling

The passage of a *Nephrops* trawl was found to have a generally minor physical and visual impact on the soft sedimentary seabed, represented by a flattening of the normally mounded sediment surface and some disturbance of the sessile epifauna. Fewer openings of Nephrops burrows were seen in the trawled area which suggest that the delicate and complex structure of the burrow system may be severely damaged by the action of the gear.

The main physical effect of otter trawling appears to be the tracks left in the sediment by the trawl doors, as indicated by the experiments in the Scottish loch. Both the side-scan sonar and the RoxAnn surveys results are in general agreement on the time scale over which the effects are noticeable at this sheltered muddy site. Both indicate clear physical effects while trawling is ongoing, and suggest that after 18 months these effects are almost indistinguishable (no effect noticeable from RoxAnn but very faint tracks identified from sides scan sonar).

The present study confirms the opinion of the ICES Study Group on the Effects of Bottom Trawling (Anon. 1988) that areas with a soft bottom or with low tidal flows are more likely to be physically affected by bottom trawling than areas with hard bottoms and strong tidal currents or turbulence e.g. caused by gales in shallow waters.

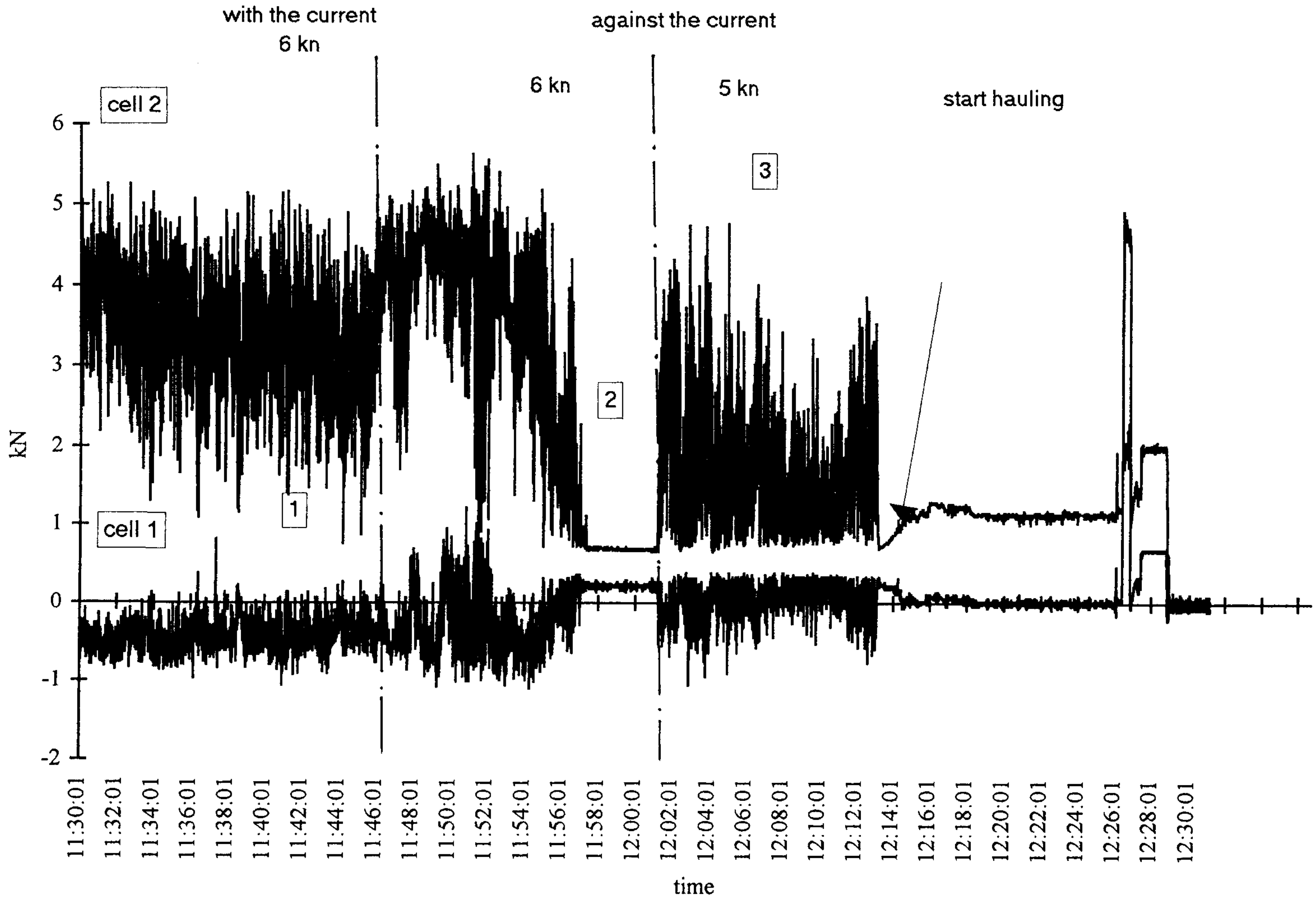


Fig. 3.3.1. Vertical forces exerted by the sole plate.

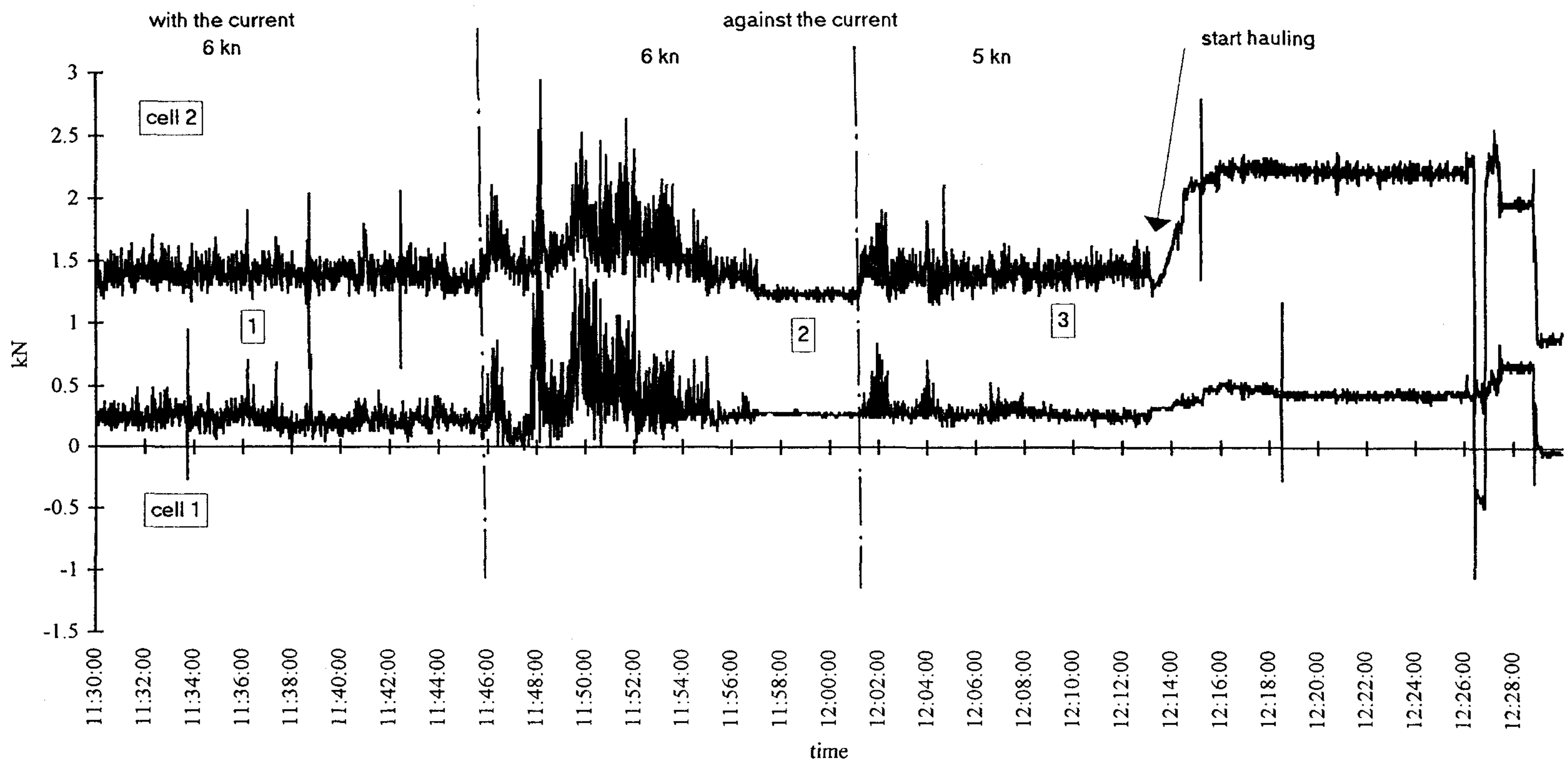


Fig. 3.3.2. Horizontal forces.

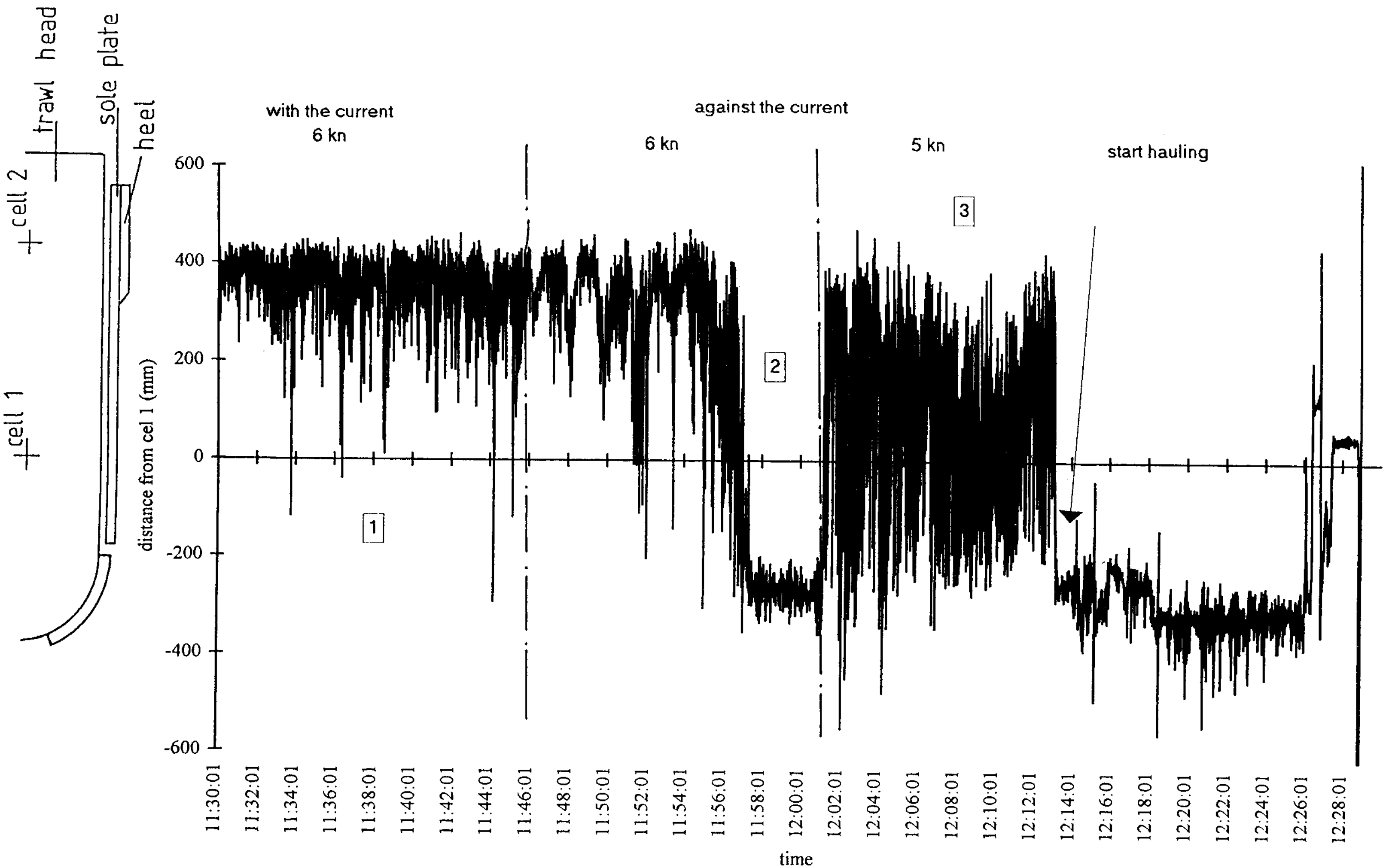


Fig. 3.3.3. Centre of pressure.

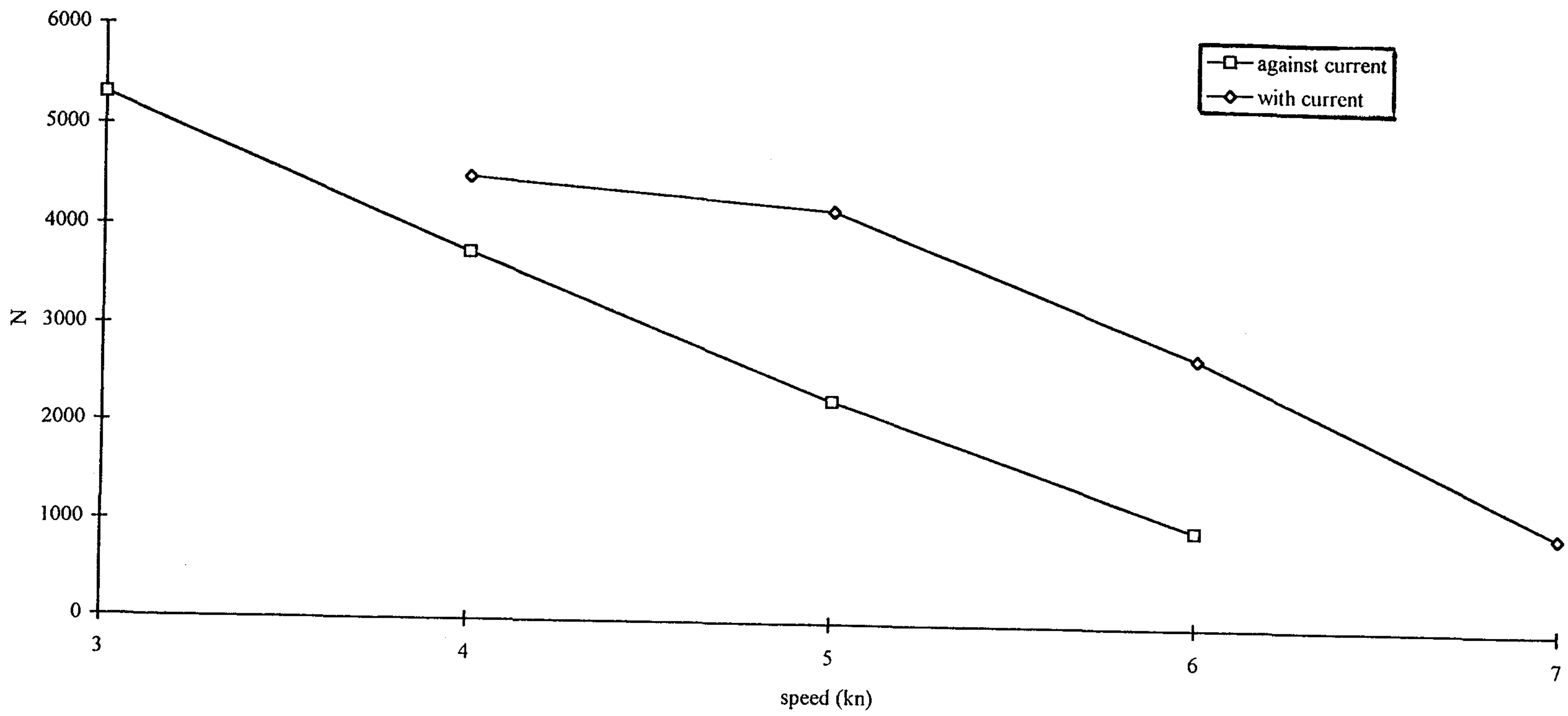
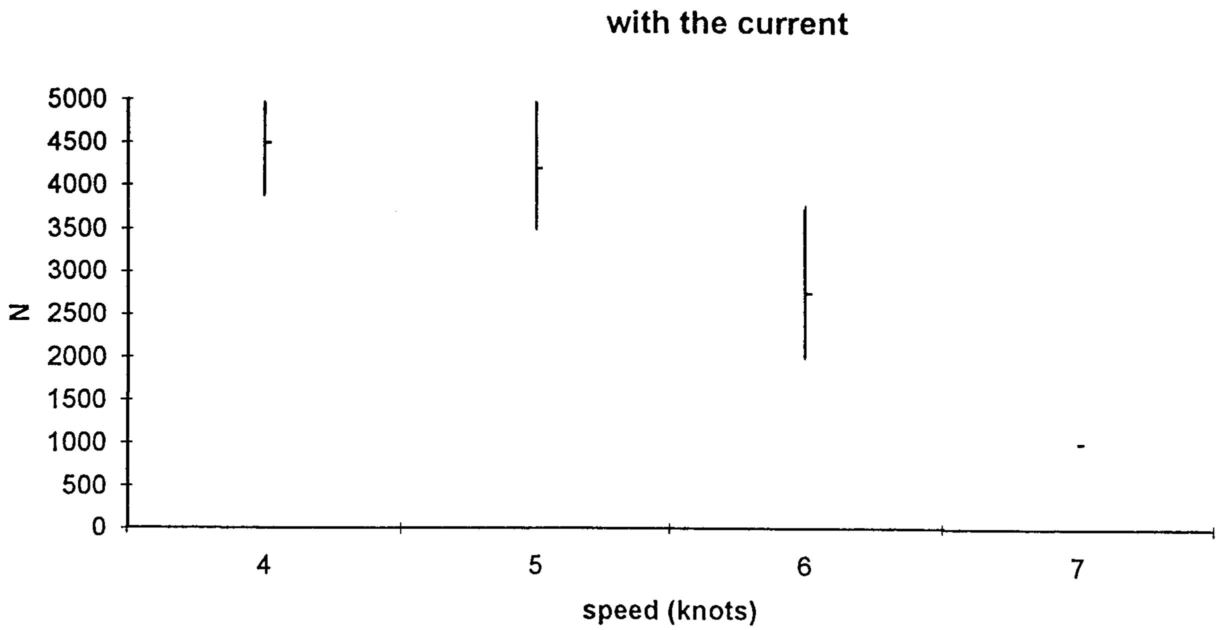


Fig. 3.3.4. Average pressure force.



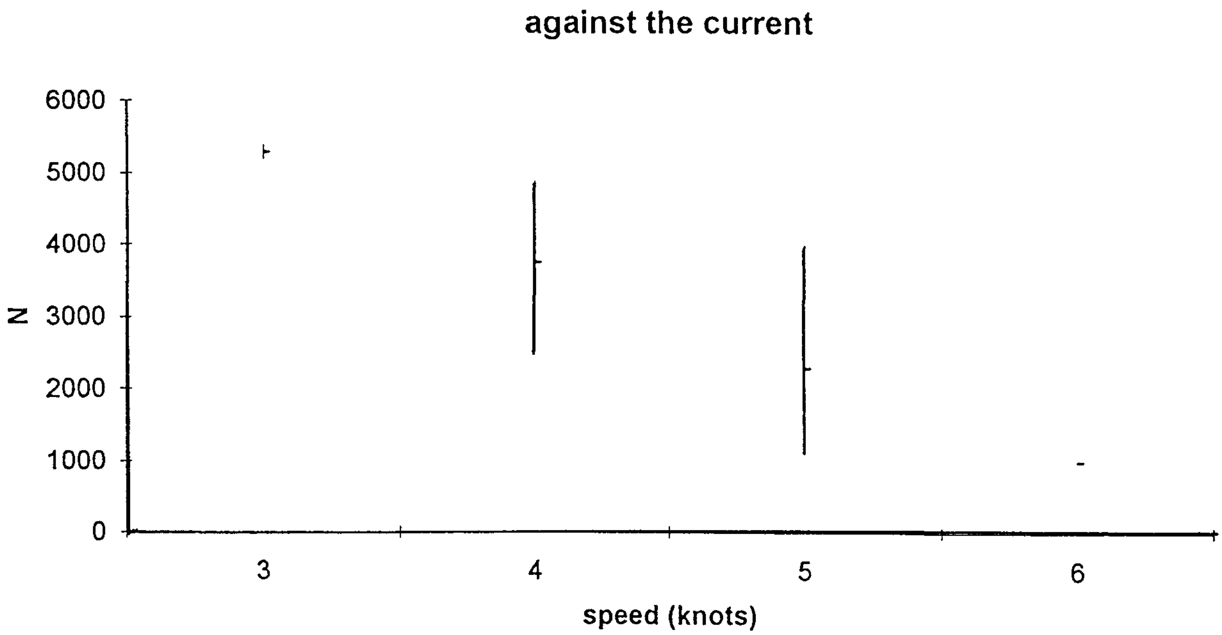


Fig. 3.3.5. Pressure foce limits.

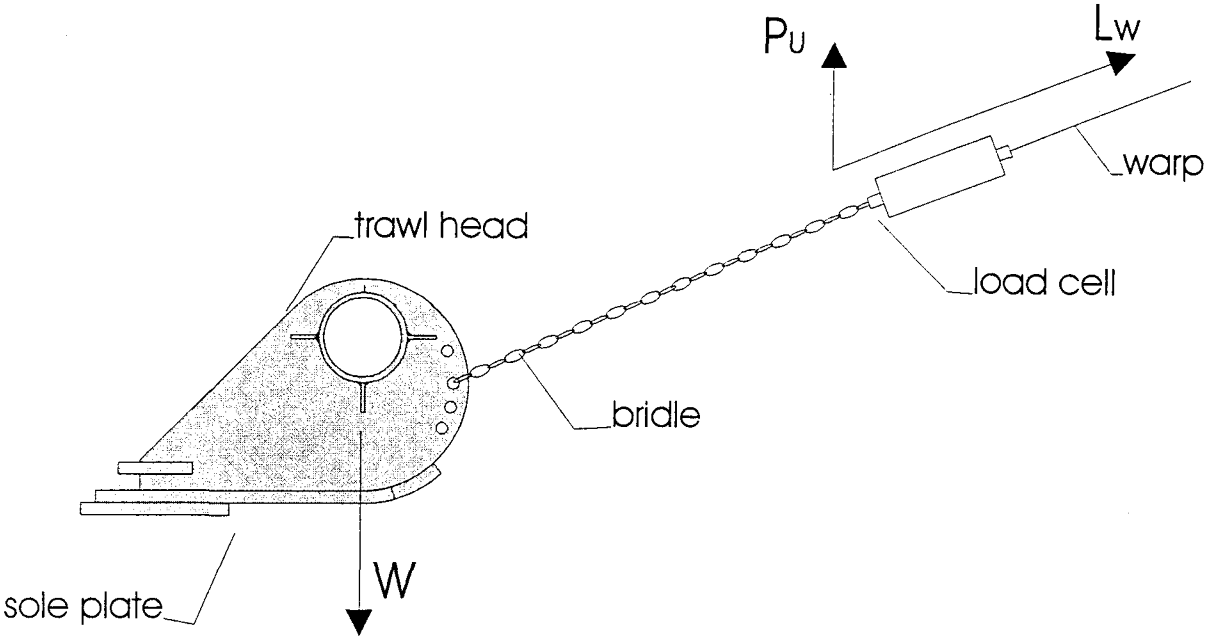


Fig. 3.3.6. Warp load measurements.

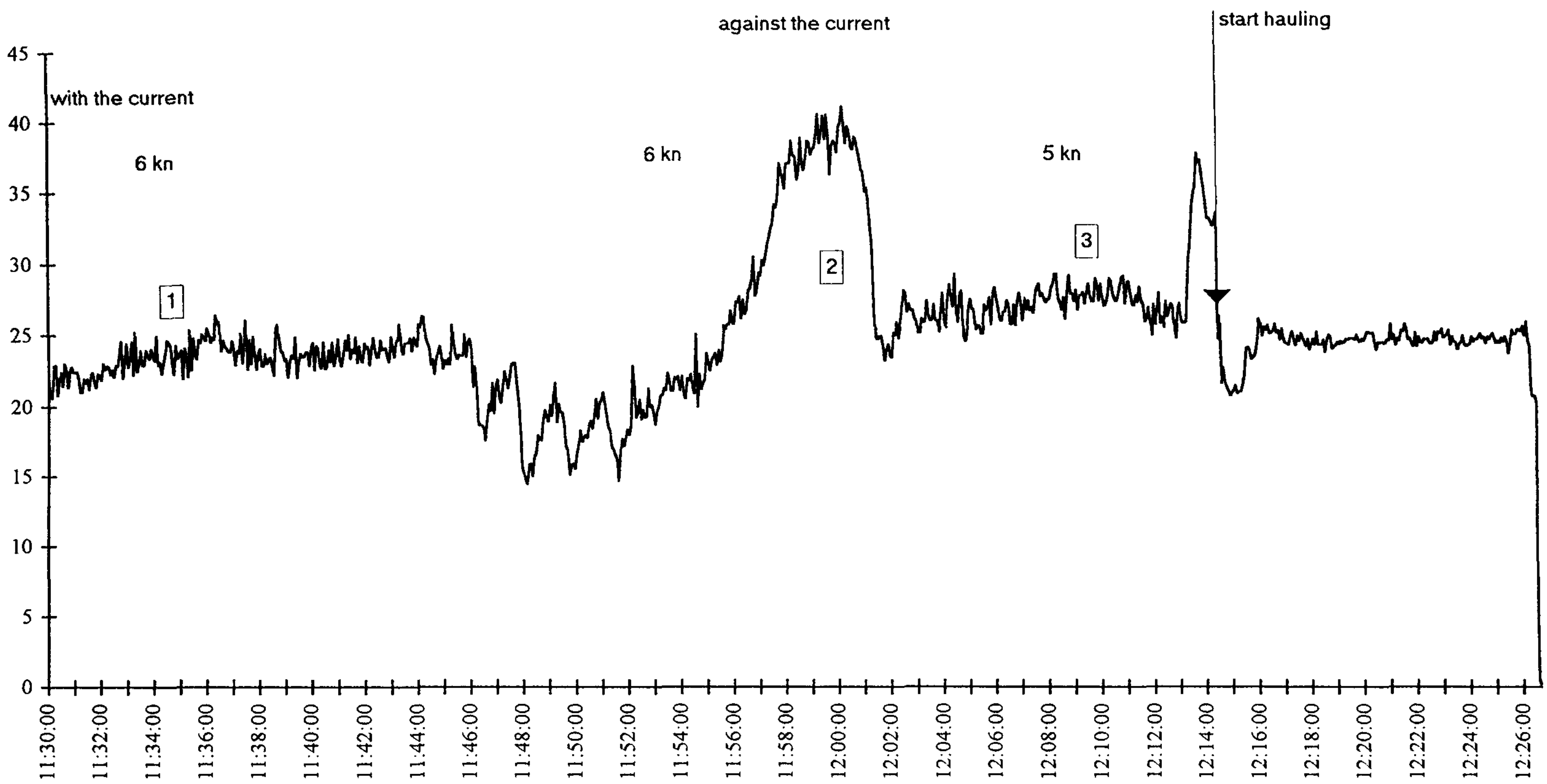
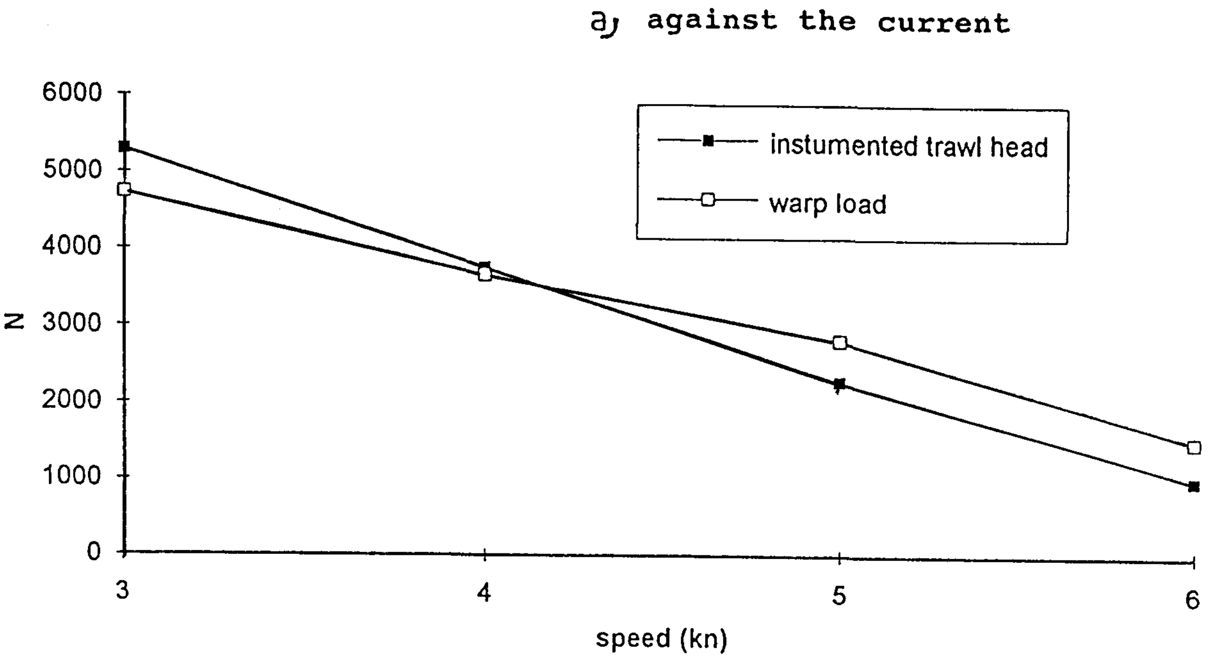


Fig. 3.3.7. Warp load.



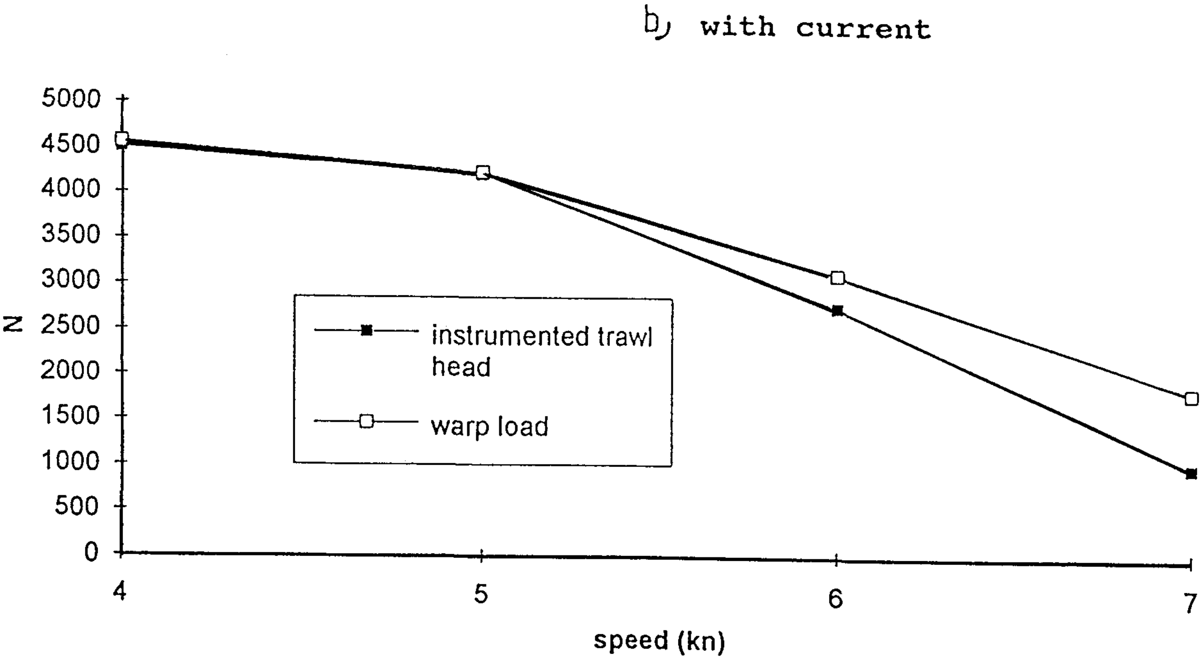


Fig. 3.3.8. Comparison of the pressure loads measured by the instrumented trawl head and calculated from the warp load.

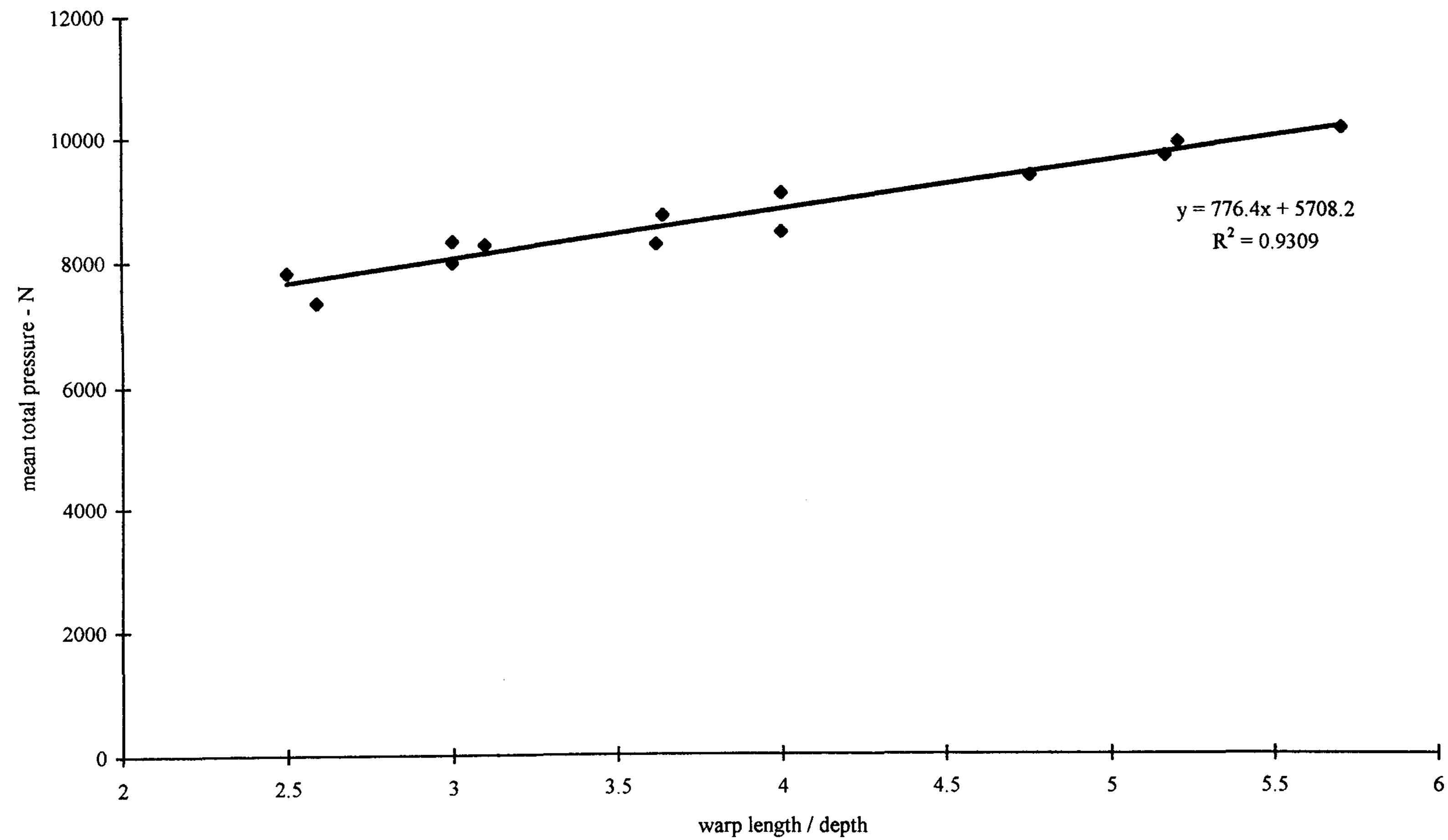


Fig. 3.3.9. Total gear pressure vs warp length/depth ratio.

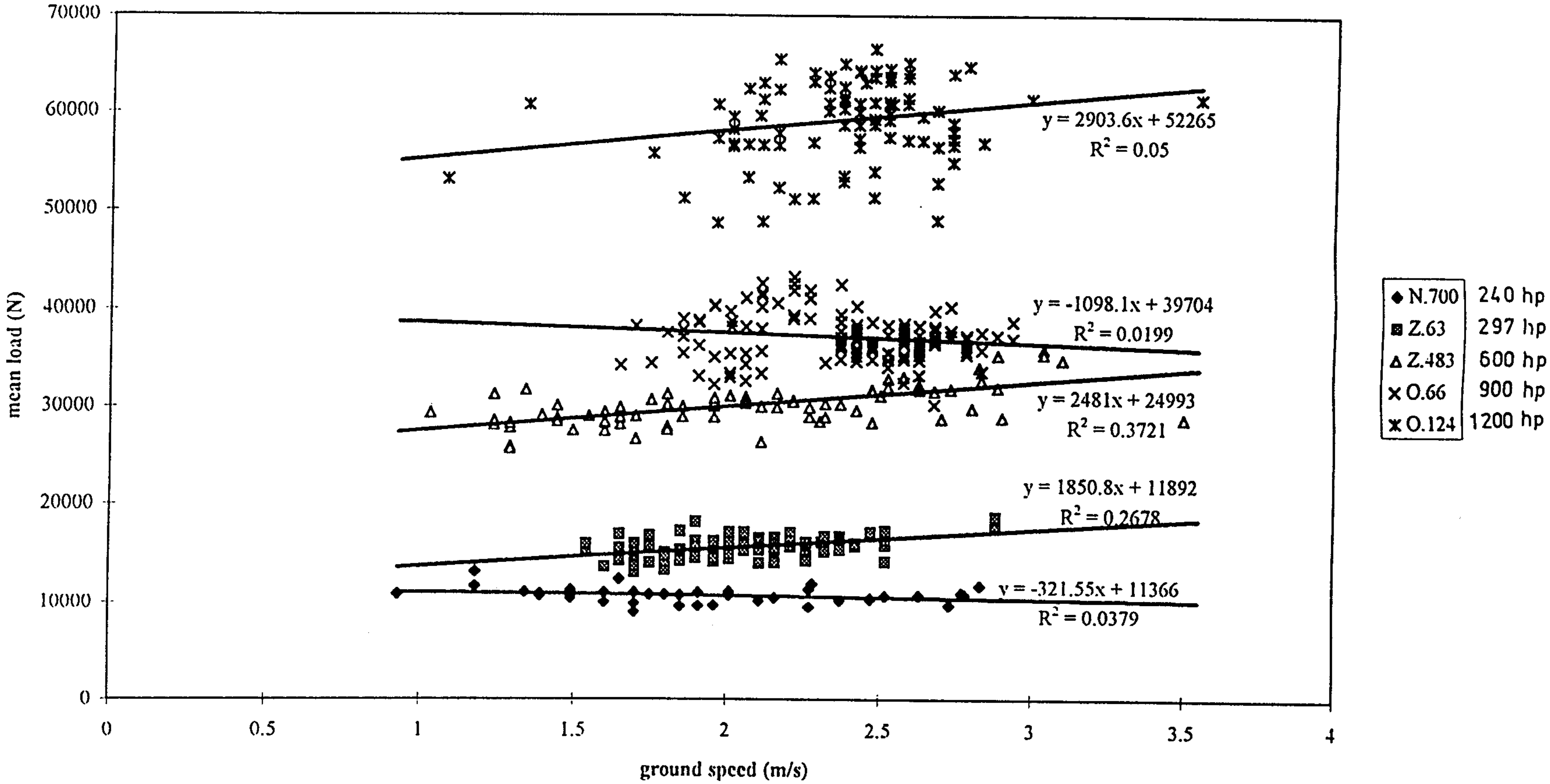


Fig. 3.3.10. Mean loads vs ground speed.

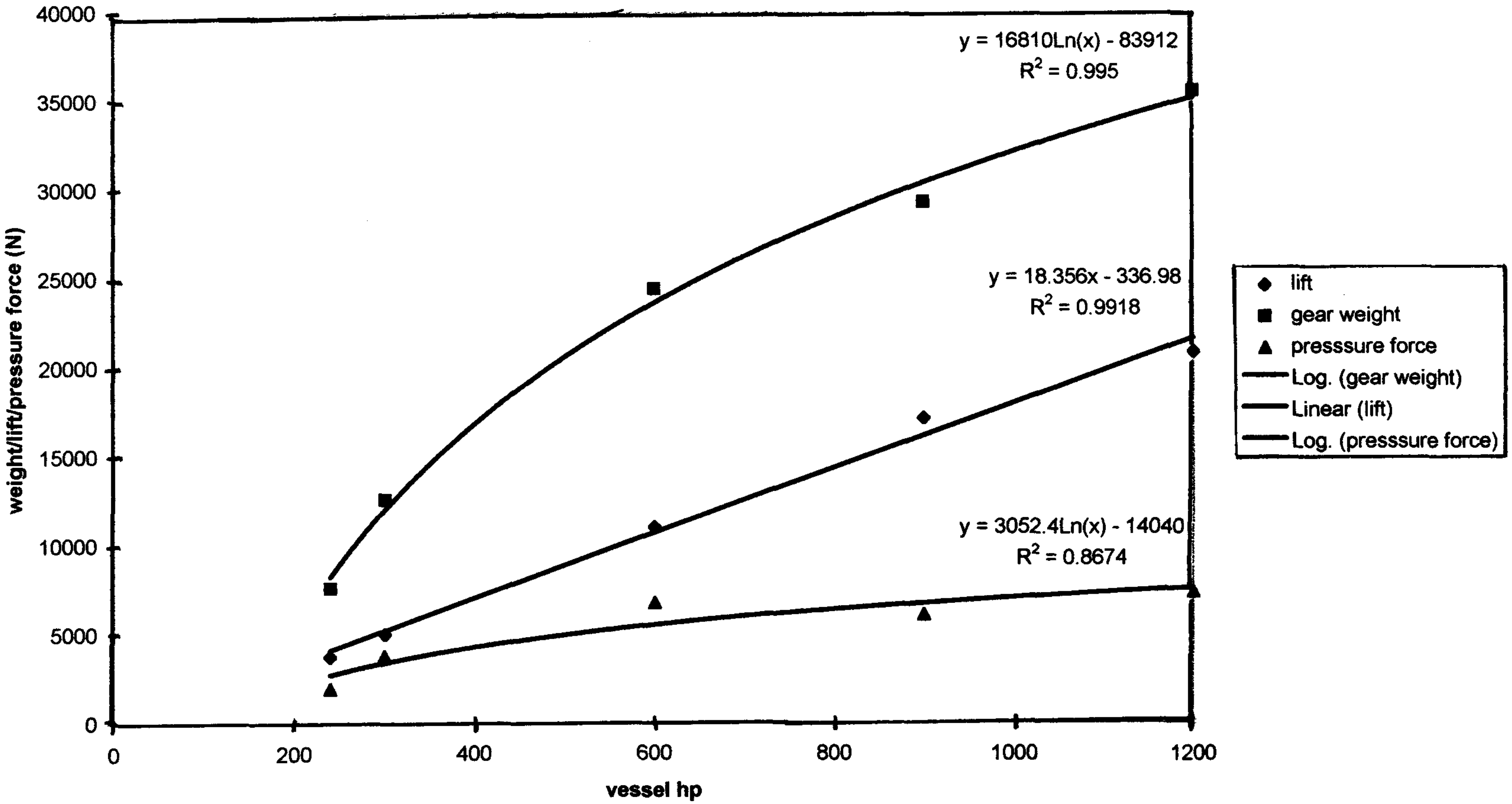


Fig. 3.3.11. Determination of pressure force vs vessel hp.

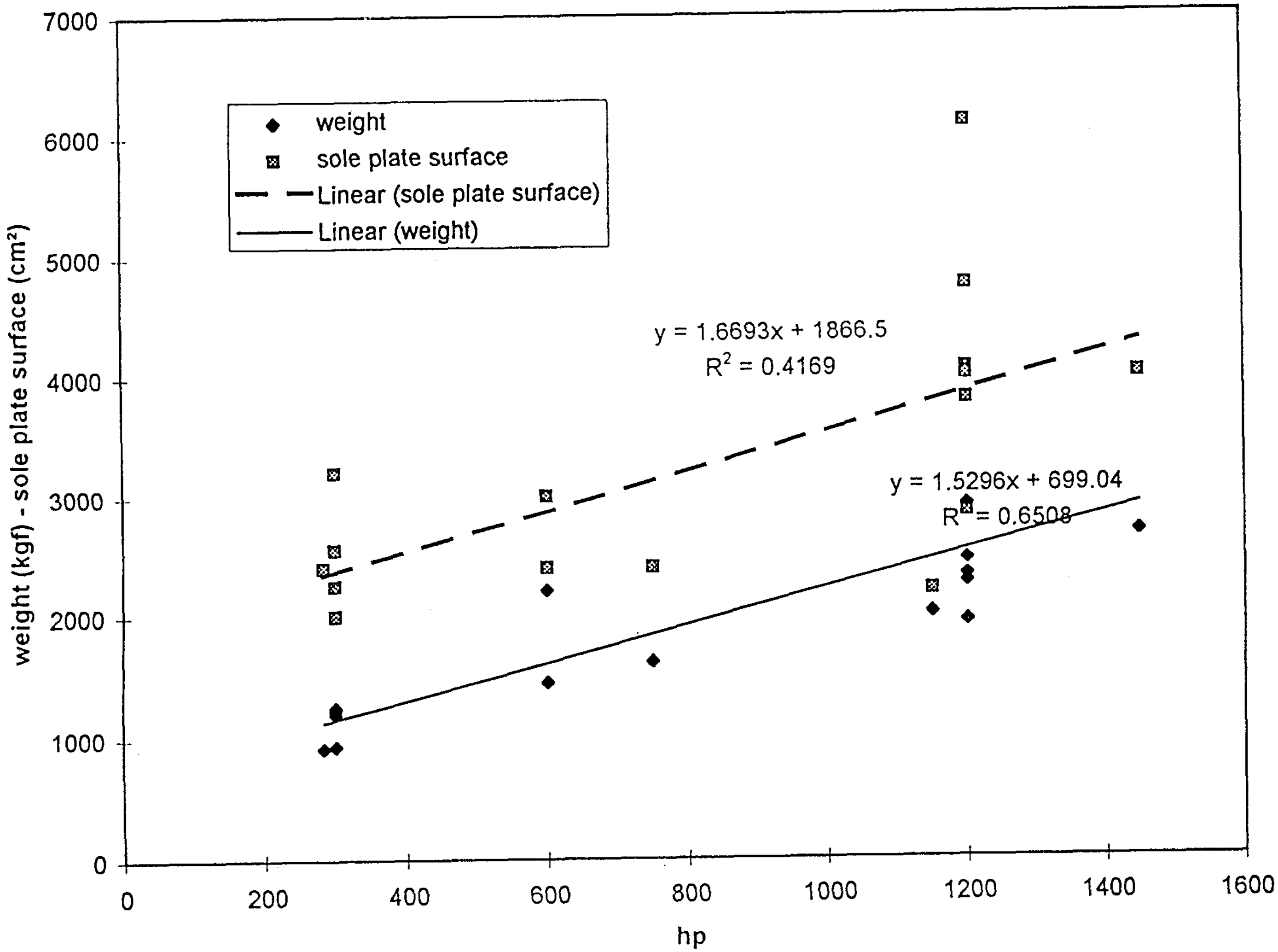


Fig. 3.3.12. Weight (beam + trawl heads + bridles + block) and sole plate surface.

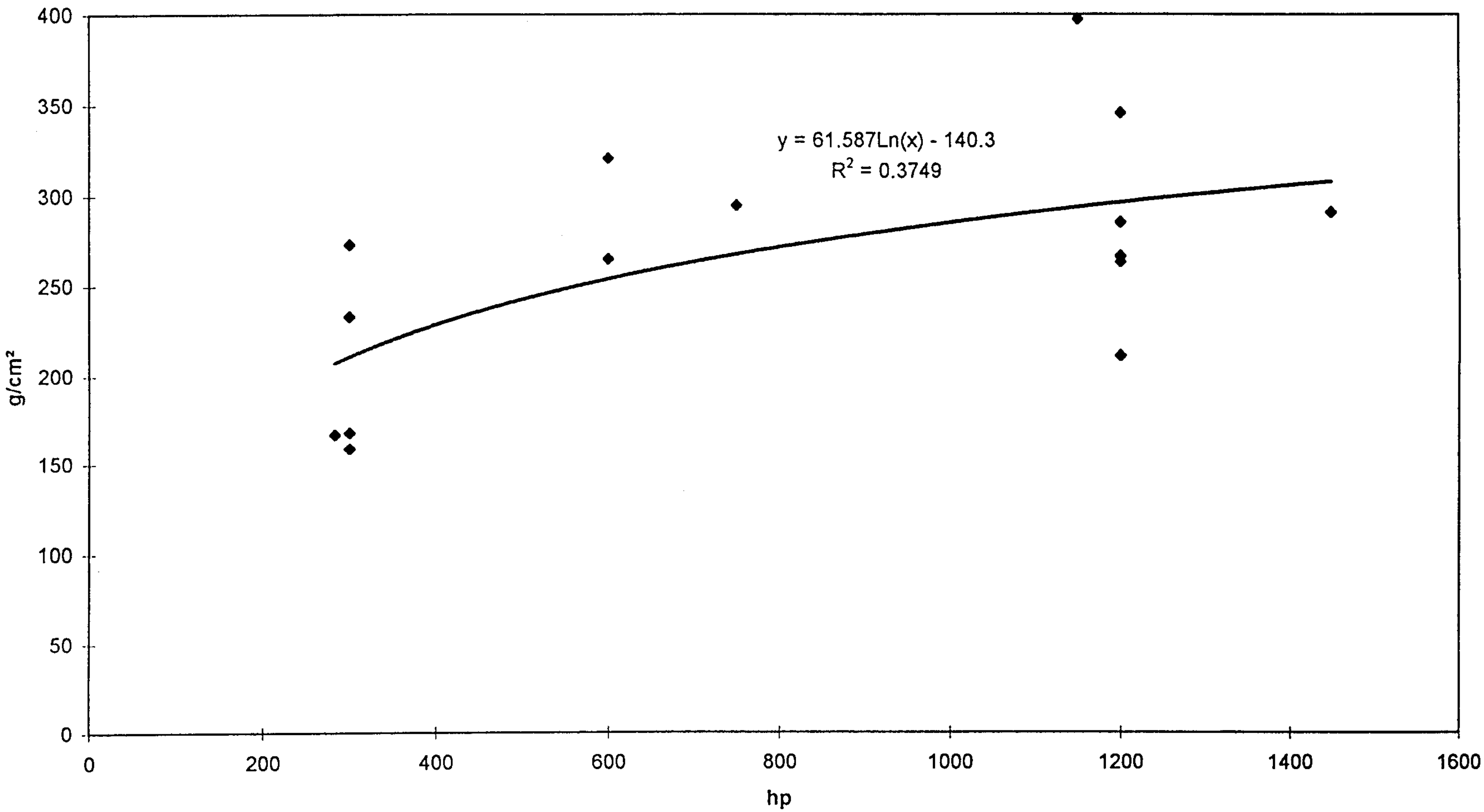
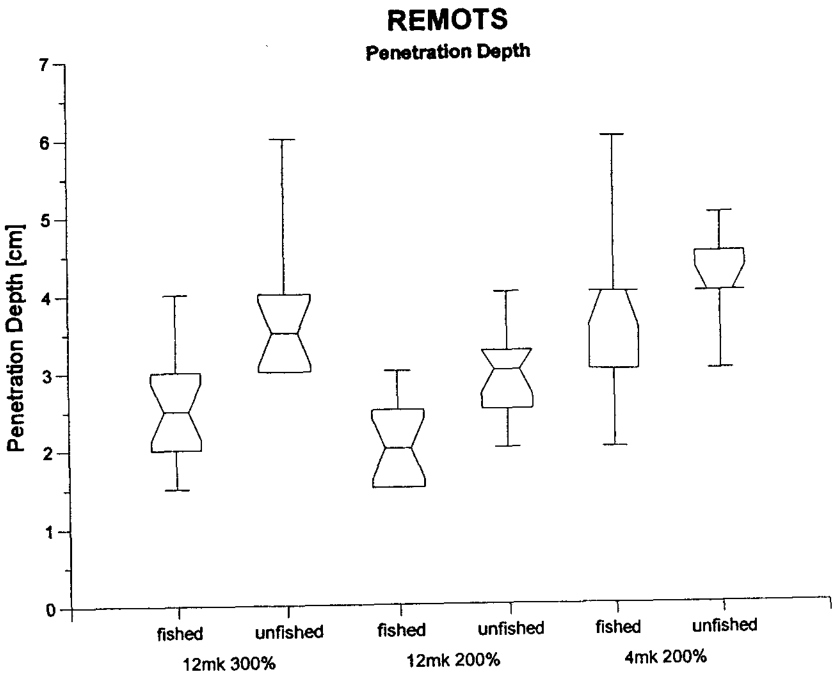


Fig. 3.3.13. Weight (beam + trawl heads + bridles + block) per cm^2 sole plate surface.



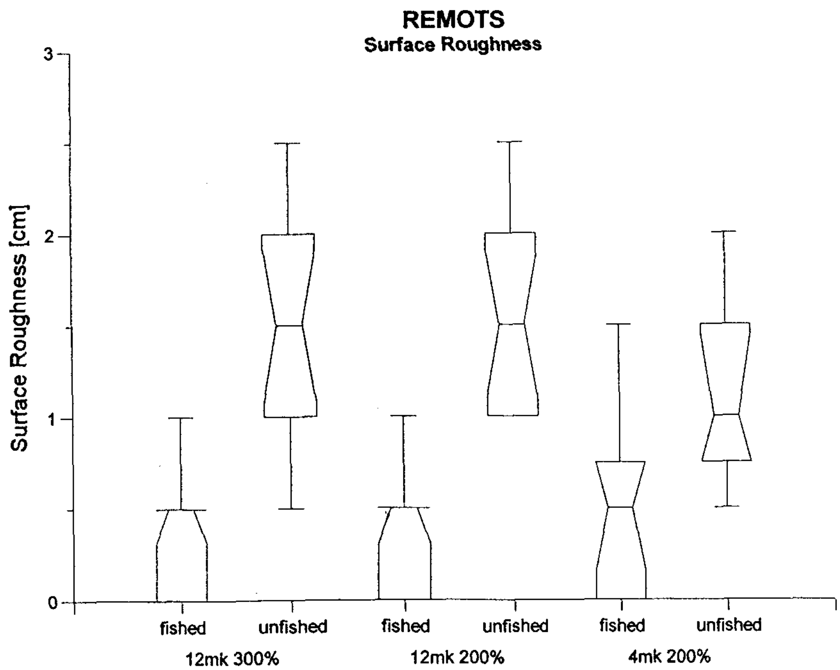


Fig. 3.3.14. Box-and-whisker plots of REMOTS observations of sea floor disturbance by beam trawling (Weisse Bank).

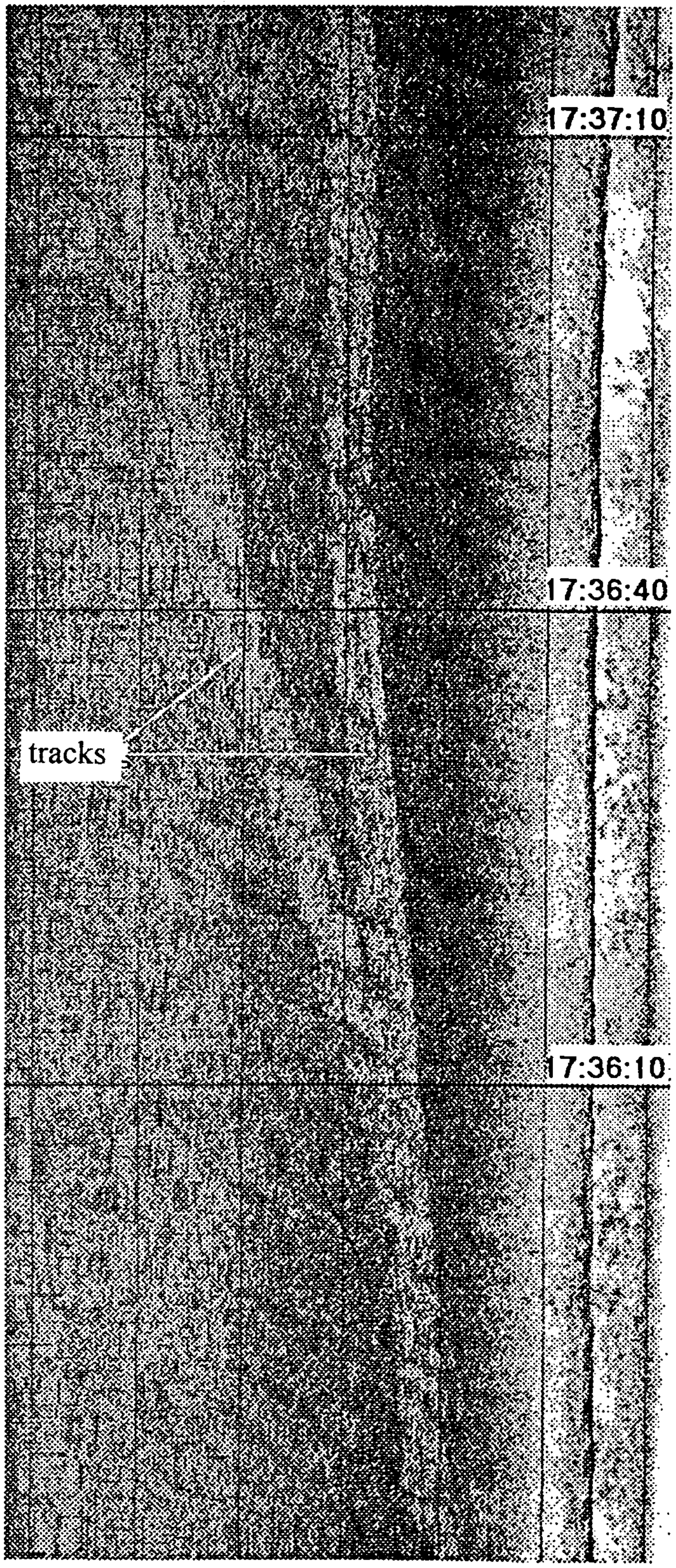


Fig. 3.3.15. Section of side-scan sonar recording - 4m beam trawl with chain matrix.

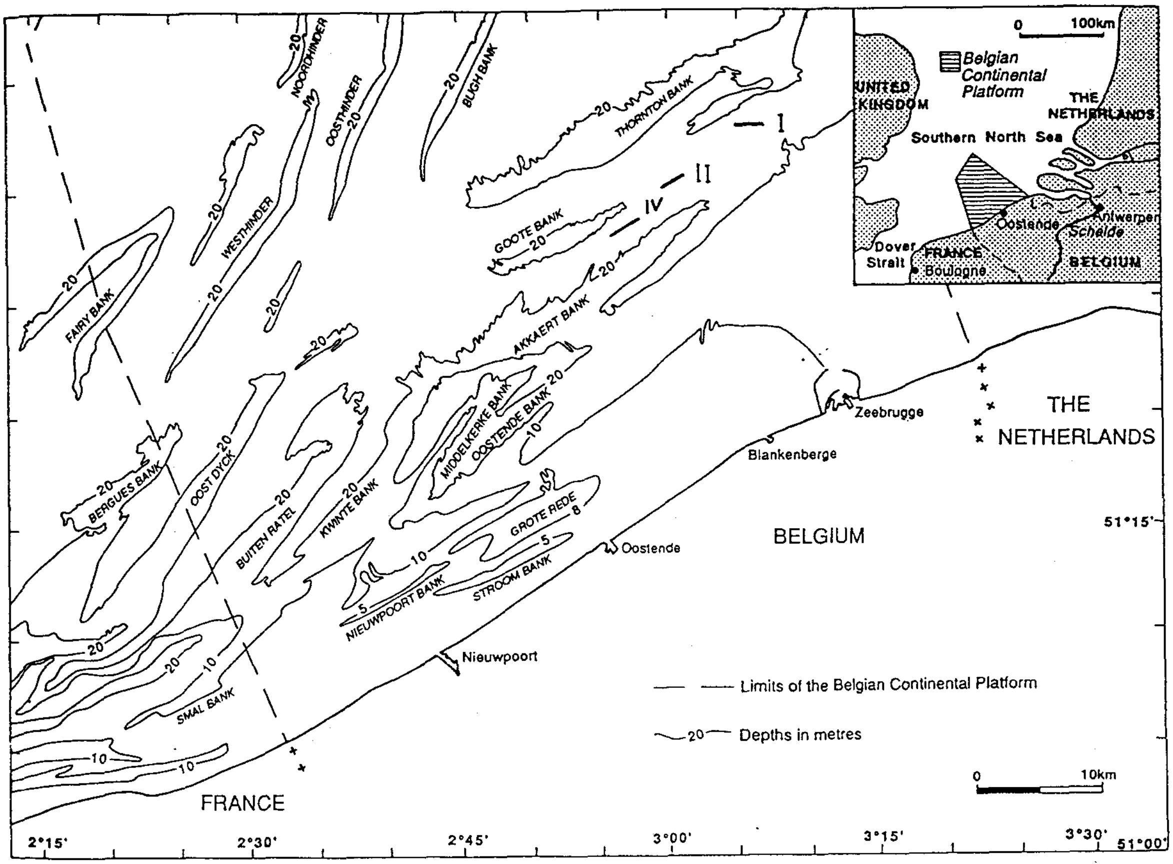


Fig. 3.3.16. Working areas (I, II, IV) for the side-scan sonar observations.

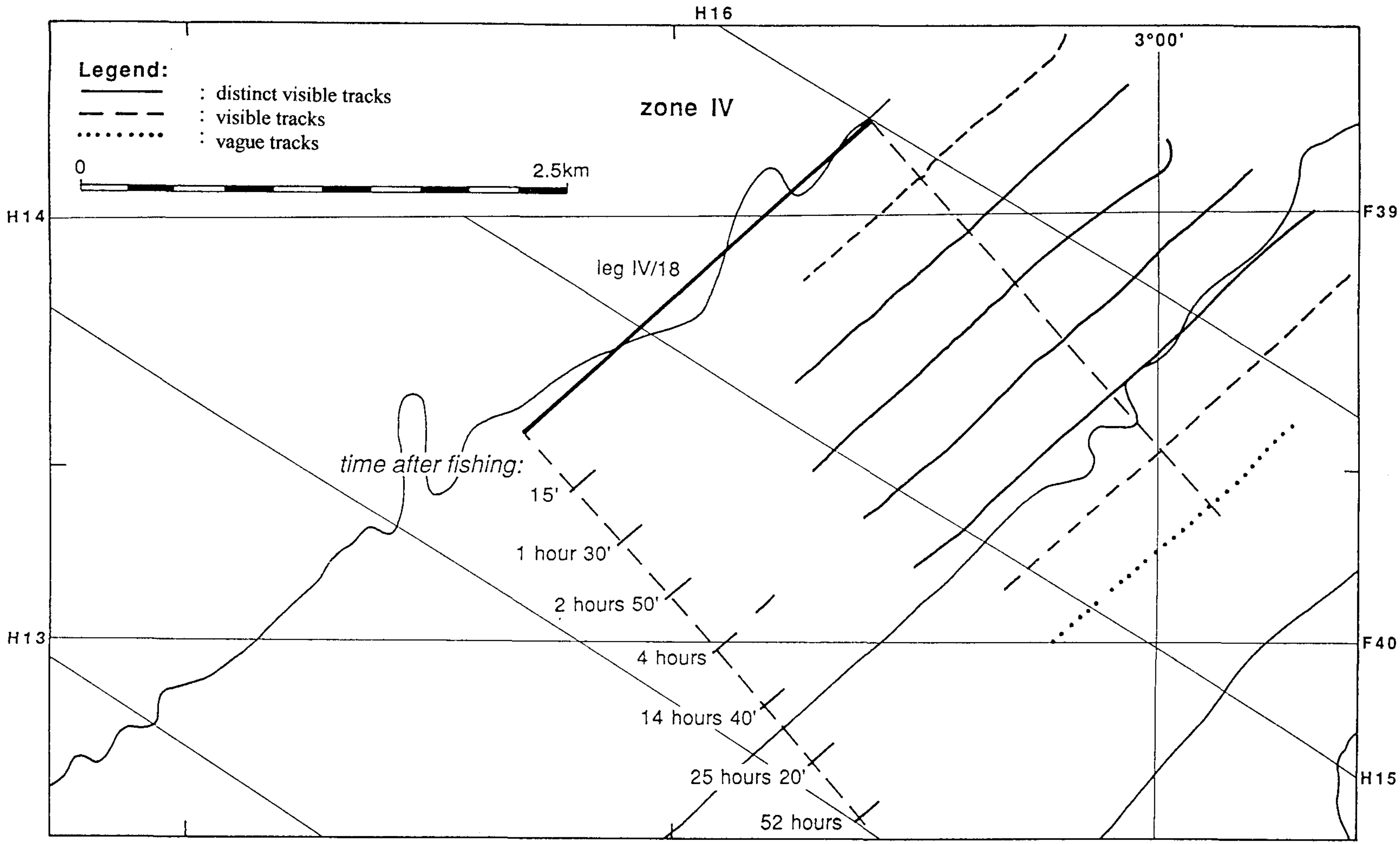


Fig. 3.3.17. Visibility of tracks as a function of time (area IV).

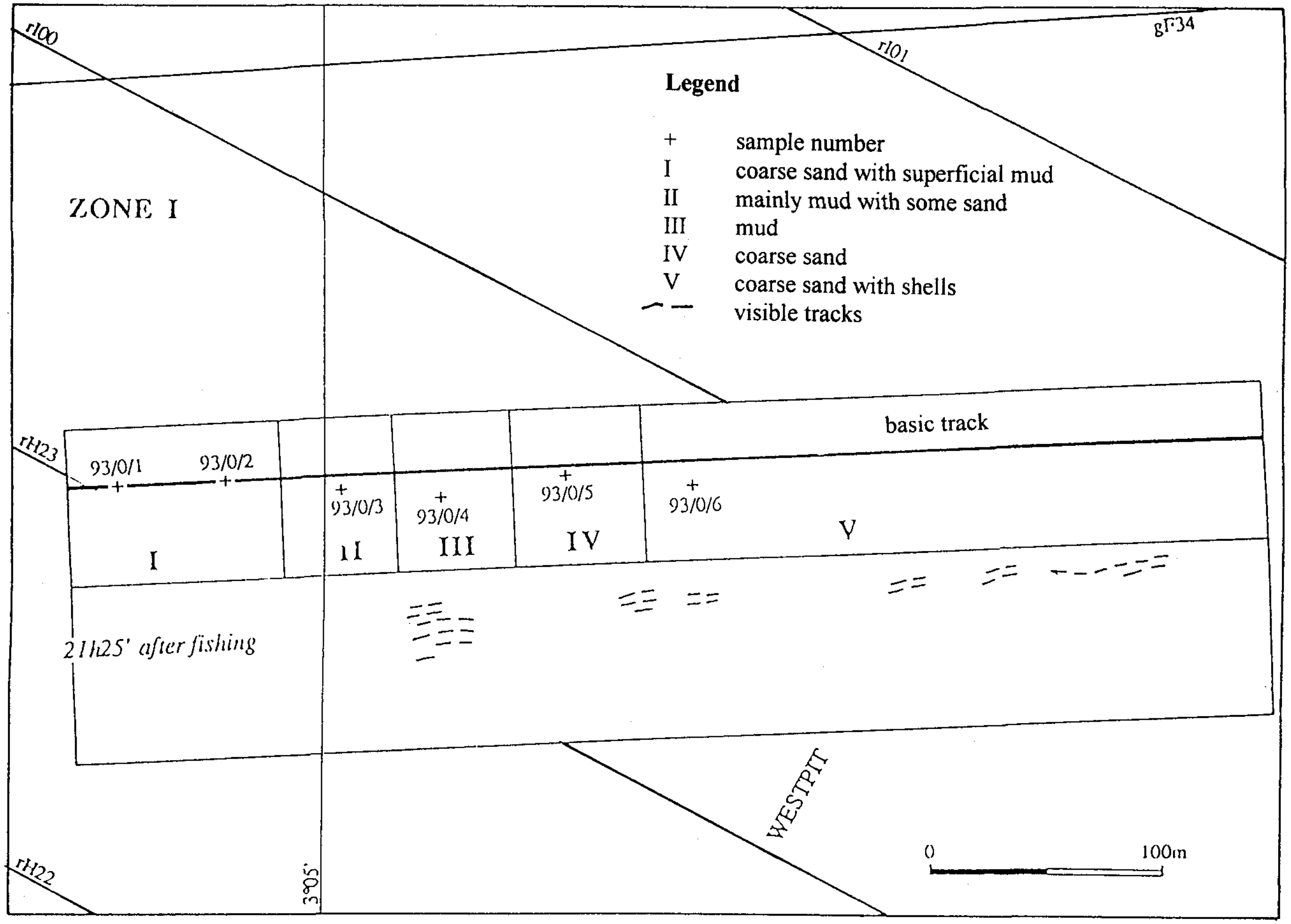


Fig. 3.3.18. Visibility of tracks related to the different sediment types, 21 h 25 min after fishing.

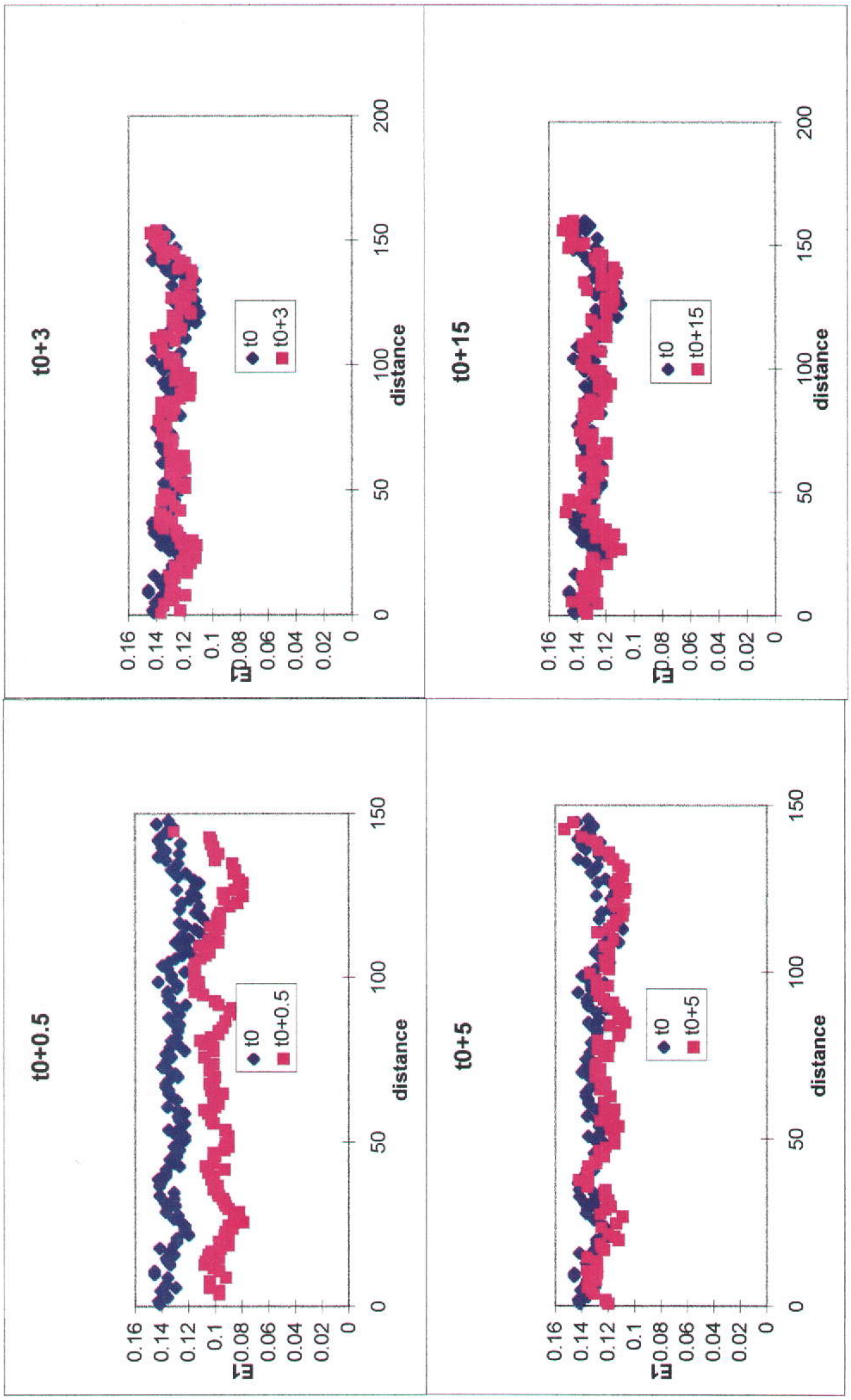


Fig. 3.3.20a. RoxAnn E1-values Scheveningen area.

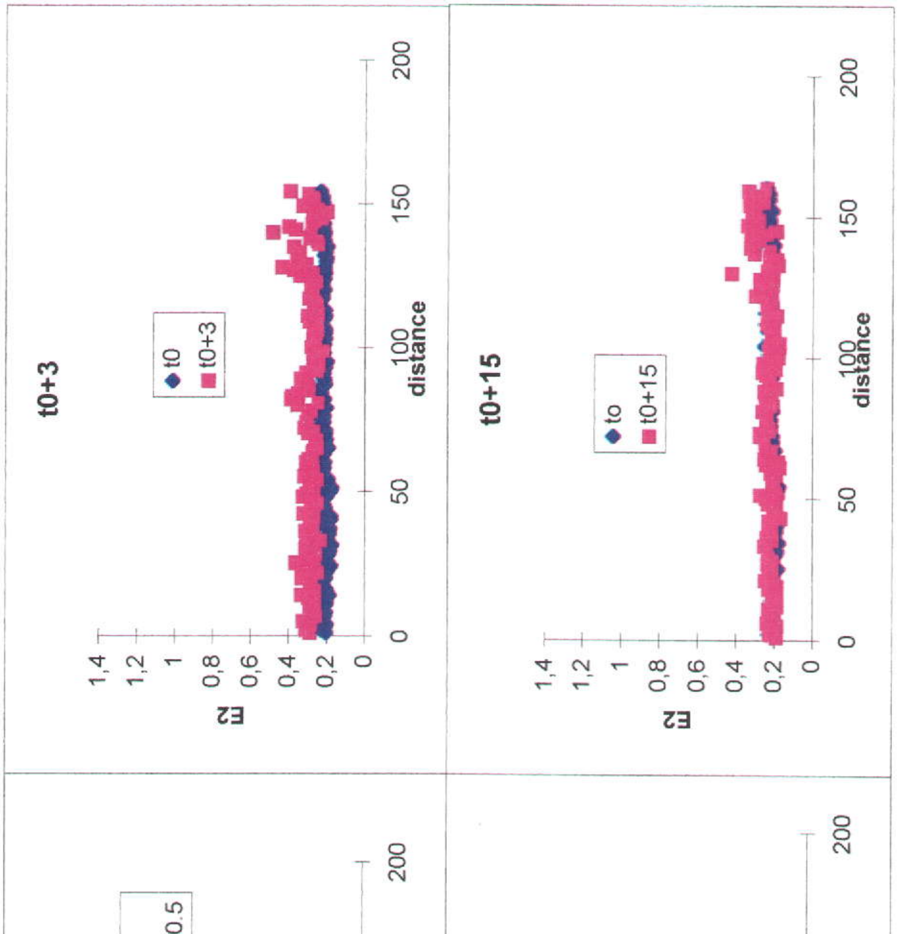


Fig. 3.3.20b. RoxAnn E2-values Scheveningen area.

Fig. 3.3.21. SPI photograph of the sediment before trawling.

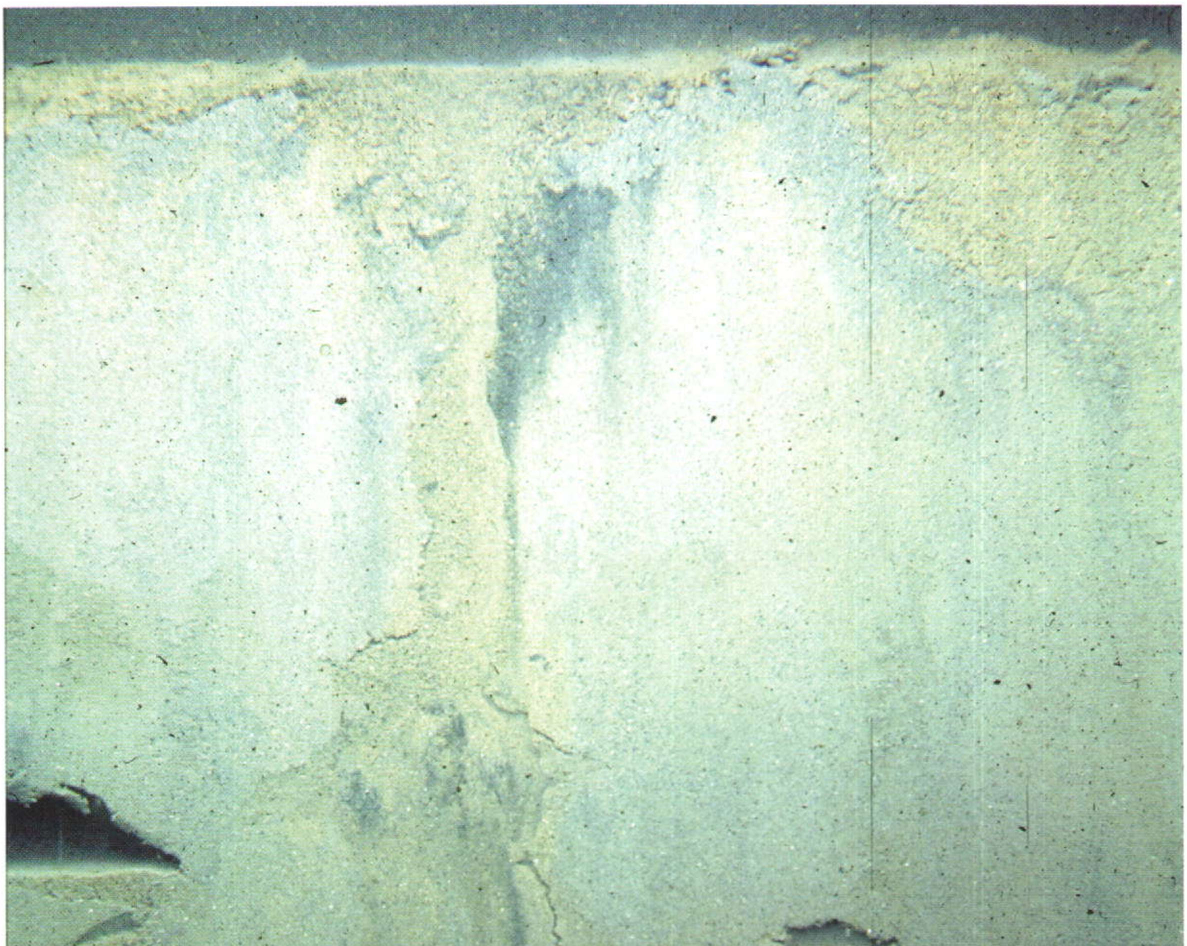
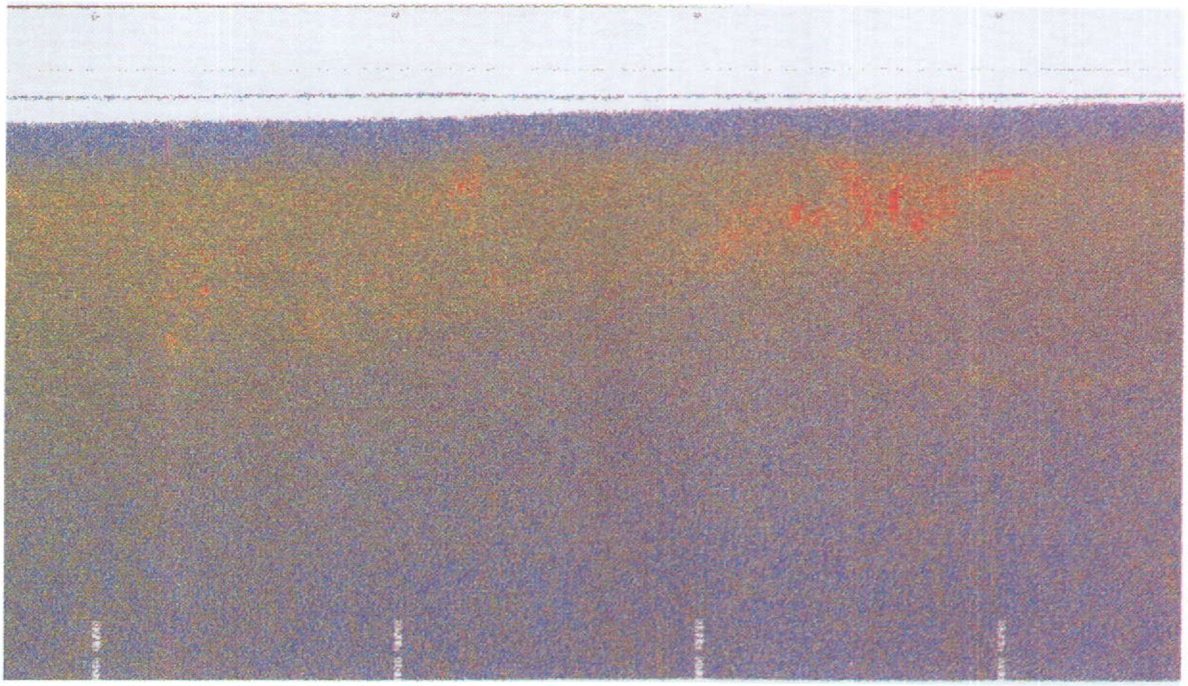


Fig. 3.3.22. SPI photograph of the sediment after trawling.

Fig. 3.3.23. SPI photograph of the sediment with possible disturbance by a trawl door.

a



b

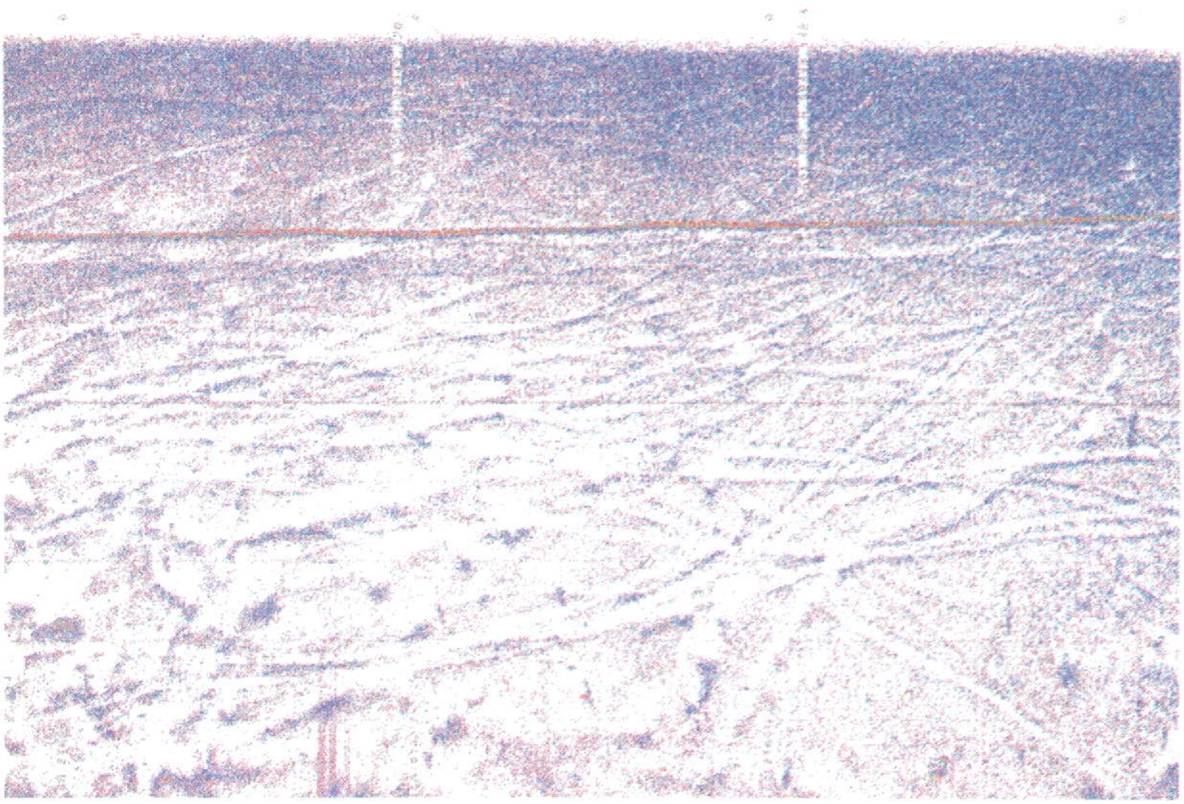


Fig. 3.3.24 **a**) Portion of the side-scan sonar record from the preliminary survey showing the seabed in the treatment area before experimental disturbance. **b**) Portion of the side-scan sonar record obtained following 10 months of disturbance, showing disturbed seabed in the treatment area.

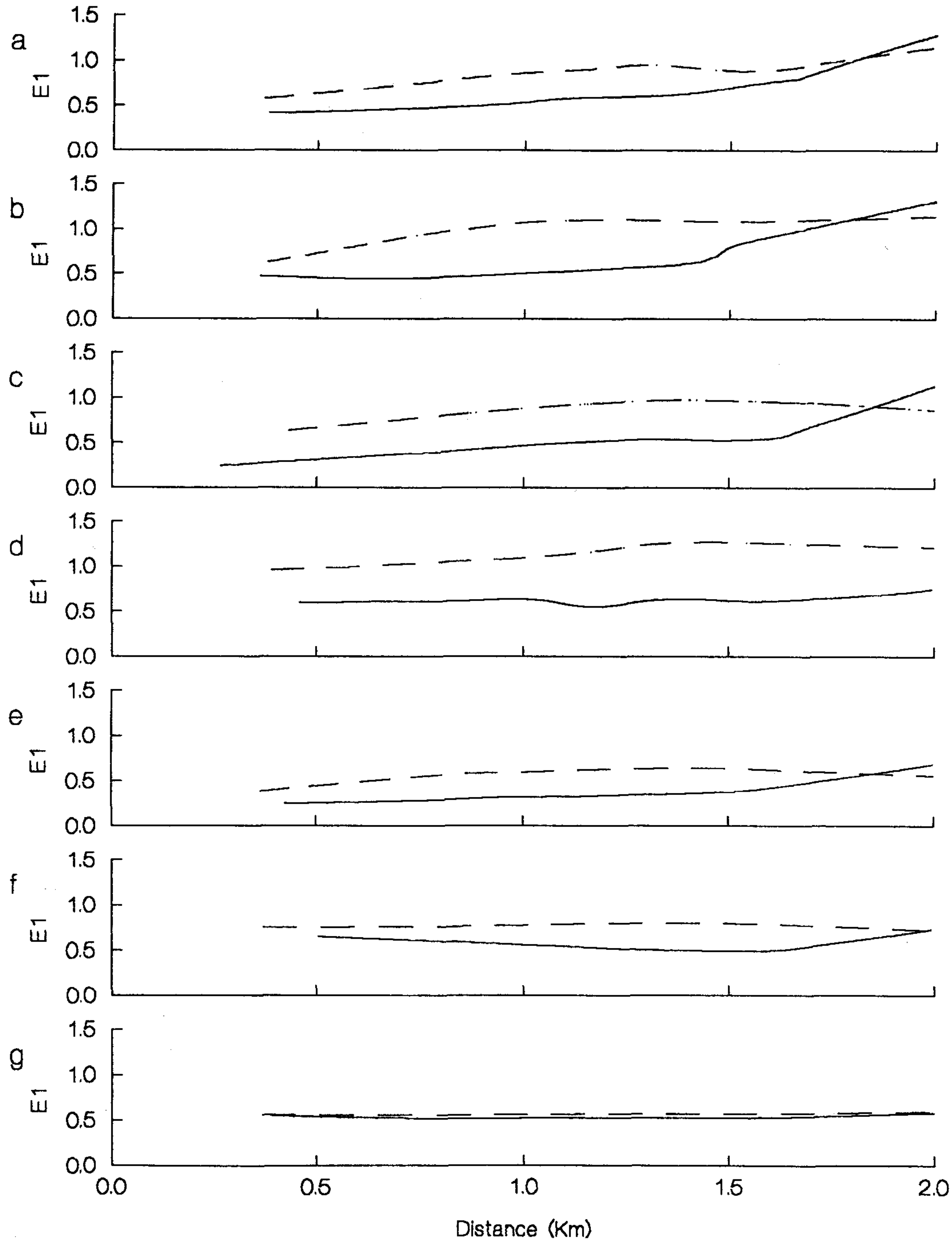


Fig. 3.3.25. Transect of E1 (roughness parameter) values along the loch for treatment (dashed line) and reference (solid line) areas. Figures shows (a) preliminary survey, (b) 5 months disturbance, (c) 10 months disturbance, (d) 16 months disturbance, (e) 6 months recovery, (f) 12 months recovery and (g) 18 months recovery.

3.4. CATCH EFFICIENCY OF COMMERCIAL TRAWLS

Introduction

Along with marketable target species, both undersized target species and non-target species are caught in commercial bottom trawls. The amounts of this by-catch can be considerable (van Beek 1990). The by-catch of undersized target and non-target organisms is discarded into the sea.

In this chapter, the catch composition in different trawls, used in the flatfish (North Sea) and *Nephrops* (Irish Sea) fisheries, are described by weight and compared. Furthermore, the catch efficiency of commercial trawls, i.e. the fraction of the initial numbers of animals in the trawl path that is retained in the trawl, is determined for small sized fish and invertebrates in different types of North Sea flatfish trawls.

3.4.1. CATCH COMPOSITION

Flatfish trawls in the North Sea

The catch composition of the different trawls was analyzed in four regions and in different seasons. The mean weights of the fish and invertebrates (marketable as well as discard) caught were estimated per hectare trawled and per hour fishing (Tables 3.4.1 and 3.4.2).

Marketable fish accounted for 5 to 29% of the total catch of all beam trawl hauls and 14 to 33% of total catch in the otter trawl hauls. Sole comprised between 1 and 14% of the total beam trawl catches, and was almost negligible in the otter trawls catches. The discarded weight of fish was at least as high as the marketable catch, but often three to four times more, and was usually dominated by flatfish (10-50% of the total catch, mostly dab or plaice) both in beam and otter trawls. The weight of discarded roundfish was largely dependent on the occurrence of juvenile whiting or gurnard, and usually formed a relatively small proportion (< 5%) of the total catch: less than 1 kg per ha. The higher by-catch of roundfish along the Dutch Wadden coast and in the German Bight in Spring 1995 was mainly due to the occurrence of small sized gurnards.

The discarded weight of invertebrates was always relatively high, usually several times the total weight of marketable fish. The invertebrate catch was almost always dominated by echinoderms (starfishes, heart urchins), crustaceans being the second most important group (swimming crab, masked crab). The catch composition varied considerably, according to geographical location of the studies. Obviously this variation is related to the distribution of species, e.g. the highest catches of the heart urchin *Echinocardium cordatum* and the starfish *Astropecten irregularis,* were found in the Oystergronds and German Bight where the highest densities occur.

The results of the analyses of variance, carried out to compare the catch composition per hectare trawled of different types of trawls that were used simultanuously in the same location, are given in Table 3.4.3. The 4m beam trawl with tickler chains generally caught more marketable fish and invertebrates than the 4m beam trawl rigged with a chainmatrix both in June 1994 and September 1995; no differences were found in the weights of discarded fish.

In the Dutch coastal zone, the 12m beam trawl with tickler chains caught more marketable fish than both types of 4m beam trawls (June 1994, September 1995), whereas such difference was not found in the German Bight (May 1995). In the German Bight, however, the 4m beam trawl caught more discard fish than then 12m beam trawl, while this difference was not found along the Dutch coast (except for small roundfish in September 1995). In both study areas, the 4m beam trawl caught more crustaceans than the 12m beam trawl. In the September study along the Dutch coast, the 4m beam trawl also caught more echinoderms resulting in a significant higher total weight of invertebrates in this trawl. In the German Bight, the 12m beam trawl caught more echinoderms (especially *Echinocardium cordatum*) and, overall, a higher total weight of invertebrates.

The 12m and 4m beam trawls caught more marketable flatfish, discard fish (flatfish and roundfish) as well as invertebrates than the otter trawl both in May 1995 and September 1994. In this first study, however, the differences found might be partially due to larger mesh size in the codend of the otter trawl (10 cm versus 8 cm).

Nephrops trawls in the Irish Sea

Tables 3.4.4 and 3.4.5 present the mean weight of the *Nephrops*, discarded fish and invertebrates caught, estimated per hectare trawled and per hour fishing in an intensively trawled area. The target species, *Nephrops norvegicus,* generally made up about 50% of the total catch by weight per hectare trawled, with the exception of 15% in study in the Spring 1996. About 75% of the biomass of these *Nephrops* (juveniles and offal) were discarded (mean = 1.11 kg/hectare ± 0.34). The by-catch was dominated by fish, that generally made up on 35 to 50% of the total catch, of which a major part consisted of whiting. In the field studies all fish were undersized and, thus, discarded. Invertebrates contributed up to on average 5% to the total catch, mostly crustaceans (38% of the invertebrate by-catch by weight), and molluscs (27%). Echinoderms and polychaetes totalled 20 and 12%, respectively. The most commonly caught crustacean species were the pandalid *Dichelopandalus bonnieri*, and the shrimp *Crangon allmanni*. Although not numerically very abundant, the red whelk, *Neptunea antiqua*, represented a sizeable portion of the catch by weight. Among the echinoderms, the common starfish *Asterias rubens* was the most abundant. The polychaete *Aphrodita aculeata*, the sea mouse, was also common.

The catch composition changed seasonally and annually (Table 3.4.6). More *Nephrops* and roundfish were caught in Autumn than in Spring, and more invertebrates caught in 1995 than in 1994.

3.4.2 CATCH EFFICIENCY FOR SMALL SIZED FISH AND INVERTEBRATES

Obviously not all the benthic fish and invertebrates in the trawl path are caught in trawl nets: some animals are small enough to pass through the meshes, other live too deeply into the sediment to be reached by the groundrope or the tickler chains. Of the animals initially present in the path of a trawl, the percentage that is retained in the trawl net and hauled aboard the trawler is the "catch efficiency" of the trawl. The catch efficiency of a commercial trawl can be determined when a single haul is made in an area with a known density of benthic fauna. In these studies, this initial density was determined in a number of well-defined areas, either with the Triple-D (larger sized in-and epifauna), Reineck boxcorer (small sized infauna) or a fine meshed 3m beam trawl (fish and in the Irish Sea: epibenthos).

For fish, the catch efficiency of commercial 12m beam trawls was calculated in seven studies. The catch efficiency of 4m beam trawls was determined in two studies, both in the sandy Dutch coastal zone. The field studies indicated that in the 4m and the 12m beam trawls the catch efficiency was nil for all 0-group flatfish, all yearclasses of solenette *Buglossidium luteum,* hooknose *Agonus cataphractus,* sandeel *Ammodytes tobianus,* dragonet *Callionymus lyra* (< 10 cm), three-bearded rockling *Gaidropsarus vulgaris,* whiting *Merlangius merlangus* (< 20 cm), goby *Pomatoschistus* spp., and lesser weever *Trachinus vipera*. Both trawl types showed a catch efficiency of up to 10% for scaldfish *Arnoglossus laterna,* gurnard *Trigla* spp.(< 15 cm) and dragonet (> 10 cm).

Whereas the maximum catch efficiency is theoretically 100% (*i.e.* all specimens present in the trawl path are caught), for the largest size classes of larger fish species "catch efficiency" results were found to be consistently *over* 100%. A likely explanation for these aberrant values is a relatively low catch efficiency of the 3m beam trawl for these species: compared to commercial trawls, the fishing speed is (much) lower and the 3m beam trawl is not as wide as the commercial gear, leading to higher sideways escape for the more agile species. For these larger size classes of fish in 12m and 4m beam trawls - and for all fish and invertebrate species in ottertrawl and 4m beam trawl with chain matrix - data on catch efficiencies are available only in the form of *relative* differences in weights in the catches (see chapter 3.4.1).

For most invertebrate species encountered in the North Sea studies, the catch efficiency of 4m and 12m beam trawls was less than 10%, and for almost half of the species much less than 5% (Table 3.4.7). Only for the largest length classes of common starfish *Asterias rubens, Astropecten irregularis,* hermits *Pagurus bernhardus* and seamouse *Aphrodita aculeata,* did catch efficiencies of beam trawls rise up to well over 10%, in a single case even up to 40-70%. In flatfish ottertrawls the catch efficiency for all invertebrate species in the study was much lower (< 3%) than in all types of beam trawls. In the *Nephrops* trawl, catch efficiency could be determined for only a limited number of epibenthic species as the 3m beam trawl to determine initial densities, was not suitable to sample infauna. Catch efficiencies were estimated at 2, 3, 4 and 12% for *Crangon allmani,* nudibranch mollusc *Dendronotus frondosus, Dichelopandalus bonneri* and *Pasiphaea sivado* respectively.

Comparing the results for 12m and both types of 4m beam trawls (ticklers or chain matrix), the catch efficiencies are in general similar, with the exception of a few species. Large *Astropecten irregularis* seemed to be caught more efficiently in the 4m beam trawls (with ticklers) than in the 12m beams, whereas large *Aphrodite aculeata* were caught with a lower efficiency. *Pagurus bernhardus* was caught with a lower efficiency in the 4m beam trawl with chainmat than in the other beam trawls. However, as the variation between the replicate experiments was considerable, and the number of replicate studies was low, the differences found between the beam trawls remain questionable. For all trawls, no clear difference was found between catch efficiencies in offshore silty areas and coastal sandy areas. For 12m and 4m beam trawls, a somewhat higher catch efficiency was observed for *Asterias rubens* in sandy areas, and a lower catch efficiency for male *Corystes cassivelaunus.*

For a number of species, the initial densities were too low to be estimated reliably in the Triple-D sampling and, therefore, catch efficiency could not be calculated for e.g. *Cancer pagurus* and *Buccinum undatum.* For the large and sedentary bivalves *Arctica islandica* and *Acanthocardia echinata,* however, an estimate of the initial density could be obtained from studies in which a line was repeatedly trawled with a 12m beam trawl (see chapters 2.6 & 3.6). The initial density of these species is estimated from the sum of the all catches of the subsequent hauls, assuming that most of the specimens present on the line were caught during this intensive trawling. As it is likely that the actual densities were considerably higher (in all cases the numbers in the last haul were hardly lower than in previous hauls!), the calculated catch efficiencies for *Arctica islandica* and *Acanthocardia echinata* (10 and 20% respectively) should be considered as over-estimates.

3.4.3. DISCUSSION OF RESULTS

Catch composition

The species composition of commercial catches largely depends on the faunal composition in the trawling site. In the North Sea for instance, several studies have established that there are several regions with different assemblages of in- and epibenthic fauna (Dyer *et al.* 1983; Duineveld *et al.* 1991; Künitzer *et al.* 1992). Therefore, possible differences in the catch composition of different types of gears could only be estimated if data were collected simultaneously in parallel hauls in some selected areas. Some of these areas, however, are seldom or never fished with all of the different gear types involved in the studies. This was taken into account in the studies: an otter trawl was not used in the southern study areas, a 4m beam trawl equipped with a chain matrix not in the northern study areas. Since even in the most southern study areas, commercial trawlers seldom use 4m beam trawl with chainmats, the catch composition in the studies using this gear could differ from catches in commercial fishing grounds. Although the absolute figures found in these studies may therefore be not fully realistic, the differences in catch composition (i.e. the higher invertebrate by-catch in 4m beam trawls with tickler chains than in those with a chainmatrix) are assumed to be reliable, also for areas other than the study areas.

The at least ten times higher amount of discards (fish and invertebrates) found in the beam trawl compared to the otter trawl in Autumn 1994 might be partially due to the difference in mesh size (8 cm versus 10 cm). In Spring 1995, however, both gears were rigged with a 8 cm cod end and the same differences were found per hectare trawled. This remarkably similar result may be caused by the presence of a roller on the groundrope of the otter trawl in the Autumn 1994 study, which was absent in Spring 1995, as it was shown by Dahm & Wienbeck (1996) that attachment of a roller gear may considerably affect the catch efficiency of an otter trawl. The lower amount of discarded invertebrates and flatfish may be a result of the reduced penetration into the seabed of the otter trawls, that are rigged without tickler chains. From the mid-sixties onwards, more and more fishermen employed a beam trawl instead of an otter trawl. The efficiency of the beam trawl was much higher than that of the otter trawl, resulting in lower costs and larger marketable catches. The change to beam trawls also resulted in larger amounts of discarded fish and invertebrates.

Along the Dutch Coast, more marketable fish was caught with a 12m than with a 4m beam trawl with tickler chains. In the German Bight, no difference was found in catch composition between the 12m and the 4m beam trawl with tickler chains in the catch of marketable fish per area trawled. Within the same time span, however, a larger area can be fished with 12m beam and therefore, more fish and more animals are discarded per hour fishing.

Regarding the *Nephrops* fishery in the Irish Sea, the only part of *Nephrops* that actually tends to be landed is the tail or abdomen. Undersized *Nephrops* and the head region of commercially sized individuals are generally discarded. The mean weight of *Nephrops* discarded from the experimental trawling in an area of intense trawling activity was calculated at 75% by weight of *Nephrops* caught, and was comprised primarily of small individuals (< 2.5 cm carapace length). This is only slightly higher than the recent 63% calculated by Evans *et al.* (1994) for the North Sea *Nephrops* fishery, but substantially higher than the estimate of 34% calculated by Hillis & Grainger (1985) for the whole Irish Sea.

Recent studies have suggested a large degree of local variability in several biological parameters such as density, size composition and growth of *Nephrops* (Tuck *et al.* 1997). While environmental variability (i.e. in sediment type, general hydrographic conditions etc.) will be largely responsible, an additional factor may be spatially variable fishing pressure (Tully & Hillis 1995). Tully *et al.* (1989) showed that a lowering of the mean size occurred in areas of greatest fishing intensity. If this is the case, it could account for the higher discard levels, especially of small *Nephrops*, calculated from the experimental trawls.

In commercial *Nephrops* fisheries the by-catch of this fishery is composed of a wide range of species. While part of this by-catch may have value and is retained (i.e. large cod and whiting), a considerable quantity of juvenile fish are discarded by the fleet, as it operates in the vicinity of the gadoid nursery grounds. Since the 1st January 1994, legislation has been in place banning Irish vessels fishing in the Irish Sea for Nephrops with nets "with a mesh size of 70 millimetres or more but less than 80 millimetres, unless it has incorporated in it as part of the net, a square mesh panel, which has a minimum mesh size of at least 75 millimetres". This should increase the level of fish escaping from the net and thus reduce the quantities of whiting discarded by the Irish fleet.

Catch efficiency for small sized fish and invertebrates

The catch efficiency for small fish and invertebrates was found to be generally low, which is in accordance to Fonds *et al.* (1992b) and Dahm *et al.* (1996). The catch efficiency of a trawl is determined by (i) the ability of a species to escape sideways, over or underneath the trawl, (ii) the number of specimens that are washed through the meshes (mesh size selection), and (iii) the penetration depth of the trawl *vs.* the mean burrowing depth of a species. Regarding these factors, the following remarks can be made:

(i) The fishing speed of modern trawlers is 4 to 7 knots. Sideways escape, in front of the trawl, of relatively low mobile small fish or invertebrates, may therefore be considered negliglible. It can be assumed that a large proportion of even the most agile, large flatfish species will enter the net. The low catch of demersal fish (flatfish and roundfish) per area trawled in otter trawls might be - at least partly - explained by a less deep penetration into the seabed.

(ii) Obviously, the most important factor as to why the catch efficiency is low for most invertebrates and small fish is their size: most invertebrates reach a maximum length of only a few cm, much less than the mesh size of the commercial trawl nets in the studies (8 cm stretched in sole fisheries). Fonds *et al.* (1992b) found even lower numbers of invertebrates and undersized fish in beam trawls with 10 cm mesh size nets than in 8 cm mesh size nets. For the largest sizeclass of e.g. *Asterias rubens*, *Pagurus bernhardus*, *Liocarcinus holsatus*, the catch efficiency found might be an underestimate for the largest specimens in this size class, as the result represents a mean for the whole size class. As the mean size of a species may differ between replicate studies, this may cause the sometimes large variation in results for a certain trawl type. Differences found in catch efficiencies between the various gears and bottom types may, therefore, be partly due to this variation, especially when the size class is wide. For example, the differences found in the catch efficiency of beam trawls on soft and sandy sediments for large starfish may be due to the fact that in soft bottom areas starfish in the largest size classes are generally smaller than in sandy coastal areas, as was observed in the studies.

Mesh size selection is dependent on the volume of the catch. A larger catch will increase the clogging of the meshes, which may lead to an increased catch of small specimens. The higher catch efficiencies in 4m and 12m beam trawls for starfish (*Asterias rubens*, *Astropecten irregularis*) in coastal sandy areas, compared to offshore soft bottom areas can be explained by the generally higher densities of benthic fauna in coastal areas, which led to larger catch volumes. In the studies, the hauls taken with the commercial trawls were relatively short: haul length was about 10 to 20 times shorter than in commercial fisheries. This may have led to unrealistic low catch efficiencies as in longer hauls more animals will be retained in the mass of the catch. This is supported by Dahm *et al.* (1996) who found that 10-20% of the undersized plaice were caught in a 7m beam trawl rigged for sole fisheries (mesh size 8 cm) in hauls of 1 hour. In exceptional cases with bigger amounts of by-catch, however, the retained share rose above 50%. For most small species, however, showing a low catch efficiency (such as most bivalve species), the catch efficiencies appeared to remain low even in catches from long hauls of "commercial" length, as these species were retained in very low numbers (see 3.4.1).

(iii) Penetration depth of the trawl is an important factor determining the catch efficiency for invertebrate species, as most of these species burrow into the sediment. The lower catch efficiency of the otter trawl for many invertebrate species than of the beam trawl, was found both in short experimental and long commercial (3.4.1) hauls, and might be due to the shallower penetration depth of this gear, which has no tickler in front of the groundrope. The lower catch efficiency for *Pagurus bernhardus* of 4m beam trawls with chainmats in short and long hauls (a result which is confirmed by data obtained from a study carried out in the Irish Sea, Kaiser & Spencer 1996a), compared to those with tickler chains, may also be related to a difference in the penetration depth. In general, beam trawls rigged out with more and heavier tickler chains caught more infaunal organisms (Graham 1955; Bridger 1970; de Groot 1984; Creutzberg *et al.* 1987).

The catch efficiency results for burrowing species that show a periodical vertical migration in the sediment, may have been biased due to the time schedule of the field studies. All catches with commercial gears in the studies were done during daytime, but as commercial fisheries are also active during nighttime, this may have led to an under-estimation of the actual catch efficiency for night-active species such as crabs. It can be assumed that this under-estimation is limited in beam trawls, as the penetration depth of these trawls (up to 6 cm, Laban & Lindeboom 1991; Bergman & Hup 1992) is sufficient to reach the night-active species even during daytime, when they hide in the sediment. For less penetrating gears, such as ottertrawls, the catch efficiency in commercial hauls at night might be considerably higher for night-active species than the presented results, and may theoretically even equal the values found for beam trawls.

Despite the variation in the data and the limited number of replicates, the results generally give a good indication of the catch efficiency of commercial gears: under normal conditions, as encountered in the studies, the catch efficiency is very low for a major part of the benthic community, as most species are small and/or burrow deeply into the sediment. Special conditions, in which the catch efficiency of non-target species is radically higher, will, if they occur, generally be avoided by fishermen. For instance, fishermen will not enter areas with high densities of *Echinocardium cordatum* during the spawning period of this species, when the usually deeply burrowed specimens migrate to the upper layers of the sediment. Fishing in such areas will lead to massive catches of this species, and will hinder the catch of target species.

TABLE 3.4.1

Catch composition of North Sea fisheries: retained and discarded weight (kg) per hectare trawled in the four selected areas (sem = standard error of means; 4 TBB= 4m beam trawl with tickler chains; 12 TBB = 12m beam trawl with tickler chains; 4 TBBm = 4m beam with chain matrix; OTB = otter trawl).

AREA	4.1 (DUTCH COAST SOUTH)																													
YEAR	1992						1993			1993			1994									1995								
SEASON	Spring						Spring			Autumn			Spring									Autumn								
GEAR (No.of observations)	4TBBm (3)			4TBB (1)			4TBB (3)			12TBB (1)			4TBBm (13)			12TBB (5)			4TBB (13)			4TBBm (5)			12TBB (13)			4TBB (20)		
kg/ha	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%
marketable sole	0.8	0.8	3	0.6	.	2	1.0	0.6	1	1.7	.	14	0.2	0.0	2	1.8	0.5	10	0.9	0.1	5	0.1	0.0	1	0.9	0.1	6	1.0	0.1	5
other marketable flatfish	1.5	1.5	5	0.7	.	3	7.5	0.9	6	1.2	.	9	0.9	0.1	9	1.9	0.2	11	1.6	0.1	9	0.6	0.0	6	2.7	0.2	18	1.4	0.1	7
marketable roundfish	0.5	0.5	2	0.0	.	0	0.3	0.1	0	0.0	.	0	0.1	0.0	1	0.7	0.3	4	0.2	0.1	1	0.1	0.0	0	0.7	0.2	5	0.4	0.1	2
discarded flatfish	0.4	0.4	1	2.7	.	11	22.8	10.2	19	0.9	.	7	1.7	0.1	18	3.6	0.9	20	2.4	0.3	13	4.3	0.2	39	6.0	1.0	41	7.0	0.6	36
discarded roundfish	1.2	1.2	5	0	.	0	0.1	0.0	0	0.1	.	0	0.4	0.2	5	0.8	0.3	5	0.3	0.1	2	0.1	0.0	0	0.5	0.1	3	0.2	0.0	1
polychaetes	0.1	0.1	0	0	.	0	0.0	0.0	0	0	.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
crustaceans	0.3	0.3	1	1.2	.	5	2.6	0.8	2	0.9	.	7	0.8	0.2	8	1.0	0.3	5	1.3	0.4	7	1.4	0.3	13	1.8	0.4	12	4.8	0.5	24
echinoderms	22.1	22.1	83	20.1	.	80	76.2	39.8	64	7.9	.	62	5.3	0.8	56	8.2	1.3	46	11.7	2.5	64	4.5	0.4	41	1.8	0.3	13	4.7	0.5	24
molluscs	0	0	0	0.0	.	0	8.3	5.2	7	0.1	.	1	0.0	0.0	0	0	0	0	0.0	0.0	0	0	0	0	0.2	0.1	1	0.1	0.1	1
marketable fish	2.7	2.7	10	1.3	.	5	8.8	1.5	7	2.9	.	23	1.2	0.1	13	4.4	0.5	25	2.7	0.2	14	0.8	0.1	7	4.3	0.5	29	2.8	0.2	14
discarded fish	1.6	1.6	6	2.7	.	11	22.9	10.3	19	1.0	.	7	2.1	0.3	23	4.4	0.8	24	2.6	0.4	14	4.4	0.2	39	6.5	1.0	44	7.2	0.6	37
invertebrates	22.5	22.5	84	21.3	.	84	87.1	44.1	73	8.9	.	70	6.1	0.9	64	9.2	1.3	51	13.1	2.8	71	5.9	0.6	53	3.8	0.7	26	9.6	0.7	49
total	26.8	26.8	100	25.3	.	100	118.8	58.0	100	12.8	.	100	9.5	1.3	100	17.9	2.6	100	18.4	3.4	100	11.1	0.9	100	14.6	2.3	100	19.6	1.6	100

AREA	4.2 (DUTCH WADDEN COAST)														
YEAR	1992			1994						1995					
SEASON	Spring			Spring						Spring					
GEAR (No.of observations)	4TBB (1)			12TBB (2)			4TBB (2)			12TBB (11)			4TBB (1)		
kg/ha	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%
marketable sole	0.8	.	1	1.0	0.0	2	1.0	0.2	2	6.0	1.4	6	0.9	.	2
other marketable flatfish	1.3	.	3	3.9	0.3	8	4.5	0.4	8	3.9	0.1	4	0.4	.	1
marketable roundfish	0.3	.	1	0.2	0.1	0	0.1	0.1	0	0.3	0.1	0	1.5	.	4
discarded flatfish	6.8	.	13	19.3	2.5	39	22.4	4.8	42	51.2	19.5	51	5.3	.	14
discarded roundfish	0.0	.	0	1.1	0.1	2	0.4	0.4	1	5.9	1.9	6	2.5	.	7
polychaetes	0	.	0	0	0	0	0	0	0	0	0	0	0	.	0
crustaceans	1.0	.	2	1.8	.	4	1.6	.	3	2.6	0.8	3	6.6	.	17
echinoderms	40.3	.	80	21.8	.	44	23.6	.	44	28.1	7.1	28	21.7	.	56
molluscs	0	.	0	0	0	0	0	0	0	2.3	0.9	2	0	.	0
marketable fish	2.4	.	5	5.1	0.2	10	5.6	0.5	10	10.2	1.4	10	2.7	.	7
discarded fish	6.8	.	13	20.4	2.6	41	22.8	4.2	43	57.1	19.8	57	7.9	.	20
invertebrates	41.3	.	82	23.7	10.2	48	25.2	6.9	47	33.1	7.6	33	28.3	.	73
total	50.5	.	100	49.2	13.0	100	53.5	11.5	100	100.4	28.9	100	38.9	.	100

AREA	4.3 (OYSTERGROUNDS)						4.4 (GERMAN BIGHT)																	
YEAR	1992			1993			1993			1994						1995								
SEASON	Spring			Autumn			Autumn			Autumn						Spring								
GEAR (No.of observations)	12TBB (3)			12TBB (3)			12TBB (1)			12TBB (2)			OTB (3)			OTB (7)			12TBB (13)			4TBB (10)		
kg/ha	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%
marketable sole	0.2	0.1	1	0.4	0.1	2	1.4	.	10	3.0	0.1	5	0	0	0	0.0	0.0	0	6.6	1.2	6	4.5	1.0	7
other marketable flatfish	0.8	0.2	3	4.4	1.9	26	0.7	.	5	3.1	0.1	5	0.9	0.2	14	0.4	0.1	13	5.2	0.9	4	4.8	0.9	8
marketable roundfish	0.3	0.2	1	0.1	0.1	1	0.2	.	2	0.4	0.3	1	0	0	0	0.6	0.1	19	2.1	0.4	2	1.9	0.4	3
discarded flatfish	4.3	0.7	15	4.3	1.0	25	2.8	.	21	30.4	7.2	46	1.1	0.3	17	1.4	0.2	43	15.8	5.8	13	23.7	6.5	38
discarded roundfish	0.4	0.1	1	0.3	0.1	2	0.0	.	0	0.8	0.4	1	2.3	0.8	36	0.1	0.0	4	1.8	0.3	1	3.7	0.9	6
polychaetes	1.2	0.5	4	1.4	0.8	8	0	.	0	0.0	0.0	0	0	0	0	0.0	0.0	0	0.9	0.4	1	1.1	1.0	2
crustaceans	1.8	0.6	6	1.5	0.4	9	1.8	.	14	3.2	0.7	5	1.7	0.7	26	0.2	0.1	6	2.9	0.5	2	4.7	0.5	8
echinoderms	16.1	10.8	56	3.6	0.2	21	5.7	.	43	24.3	4.3	37	0.5	0.2	7	0.3	0.0	8	82.7	25.3	70	17.2	2.3	28
molluscs	3.5	1.7	12	1.0	0.7	6	0.5	.	4	0.1	0.1	0	0	0	0	0.2	0.0	6	0.1	0.0	0	0.2	0.1	0
marketable fish	1.3	0.4	5	4.9	2.0	29	2.3	.	17	6.5	0.5	10	0.9	0.2	14	1.1	0.1	33	13.9	2.4	12	11.2	2.0	18
discarded fish	4.7	0.9	16	4.7	1.0	27	2.8	.	22	31.3	7.6	48	3.5	0.9	53	1.6	0.2	47	17.6	5.8	15	27.4	7.0	44
invertebrates	22.5	12.3	79	7.6	1.6	44	8.0	.	61	27.7	5.1	42	2.1	0.9	33	0.7	0.1	20	86.6	25.8	73	23.1	3.3	37
total	28.5	13.6	100	17.1	4.6	100	13.1	.	100	65.5	13.1	100	6.5	2.0	100	3.3	0.4	100	118.1	34.0	100	61.7	12.3	100

TABLE 3.4.2

Catch composition of North Sea fisheries: retained and discarded weight (kg) per hour fishing in the four selected areas (sem = standard error of means; 4 TBB= 4m beam trawl with tickler chains; 12 TBB = 12m beam trawl with tickler chains; 4 TBBm = 4m beam with chain matrix; OTB = otter trawl).

AREA	4.1 (DUTCH COAST SOUTH)																													
YEAR	1992						1993			1993			1994									1995								
SEASON	Spring						Spring			Autumn			Spring									Autumn								
GEAR (No.of observations)	4TBBm (3)			4TBB (1)			4TBB (3)			12TBB (1)			4TBBm (13)			12TBB (5)			4TBB (13)			4TBBm (5)			12TBB (13)			4TBB (20)		
kg/hour	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%
marketable sole	4.1	1.7	2	6.8	-	2	3.1	1.7	1	90.0	-	14	0.7	0.1	2	17.1	5.0	10	2.7	0.4	5	0.4	0.1	1	10.7	1.5	6	2.9	0.3	5
other marketable flatfish	12.2	2.0	7	8.5	-	3	22.2	2.7	6	61.6	-	9	2.6	0.3	9	17.4	2.0	11	4.5	0.3	9	2.1	0.1	6	30.5	2.3	18	4.2	0.2	7
marketable roundfish	2.0	1.2	1	0.1	-	0	1.0	0.2	0	0.8	-	0	0.3	0.1	1	6.2	3.0	4	0.5	0.2	1	0.1	0.1	0	7.8	1.9	5	1.2	0.4	2
discarded flatfish	4.9	2.0	3	31.6	-	11	67.8	30.2	19	46.8	-	7	5.1	0.8	18	32.4	8.2	20	6.8	1.1	13	14.3	0.6	39	71.0	12.6	41	20.5	1.8	36
discarded roundfish	7.4	2.2	4	0.0	-	0	0.3	0.0	0	2.8	-	0	1.4	0.7	5	7.4	2.8	4	0.9	0.2	2	0.2	0.0	0	6.0	1.2	4	0.5	0.1	1
polychaetes	0.4	0.3	0	0.0	-	0	0.0	0.0	0	0.0	-	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
crustaceans	1.8	0.6	1	13.6	-	5	7.7	2.5	2	48.6	-	7	2.3	0.5	8	8.8	2.9	5	3.8	1.0	7	4.6	0.7	12	21.5	4.9	13	14.3	1.6	25
echinoderms	131.6	58.7	80	238.3	-	80	227.7	119.9	64	410.0	-	62	15.8	2.6	56	75.3	12.7	46	34.1	7.8	64	15.1	1.8	41	21.6	3.7	13	13.6	1.3	24
molluscs	0.0	0.0	0	0.1	-	0	24.7	15.7	7	4.6	-	1	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	2.4	1.3	1	0.4	0.2	1
marketable fish	18.3	4.6	11	15.4	-	5	26.3	4.6	7	152.4	-	23	3.6	0.4	13	40.6	5.4	25	7.7	0.7	14	2.6	0.3	7	49.1	5.3	29	8.3	0.6	14
discarded fish	12.3	2.5	7	31.6	-	11	68.2	30.2	19	49.6	-	7	6.5	1.1	23	39.7	6.8	24	7.7	1.1	14	14.5	0.6	39	77.0	13.4	45	21.0	1.9	36
invertebrates	133.8	59.6	81	252.0	-	84	260.1	133.0	73	463.2	-	70	18.1	2.8	64	84.1	13.0	51	38.0	8.6	71	19.7	2.2	54	45.5	9.2	27	28.3	2.3	49
total	164.4	66.7	100	299.0	-	100	354.5	167.7	100	665.2	-	100	28.1	4.3	100	164.5	25.3	100	53.4	10.5	100	36.7	3.0	100	171.6	27.9	100	57.5	4.8	100

AREA	4.2 (DUTCH WADDEN COAST)															4.3 (OYSTERGROUNDS)						4.4 (GERMAN BIGHT)																	
YEAR	1992			1994						1995						1992			1993			1993			1994						1995								
SEASON	Spring			Spring						Spring						Spring			Autumn			Autumn			Autumn						Spring								
GEAR (No.of observations)	4TBB (1)			12TBB (2)			4TBB (2)			12TBB (11)			4TBB (1)			12TBB (3)			12TBB (3)			12TBB (1)			12TBB (2)			OTB (3)			OTB (7)			12TBB (13)			4TBB (10)		
kg/hour	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%
marketable sole	2.2	-	1	9.7	0.2	2	3.2	0.7	2	64.2	10.4	4	3.8	-	2	13.3	4.6	1	14.1	6.1	3	64.3	-	11	34.0	1.5	5	0.0	0.0	0	0.4	0.2	0	180.2	34.0	5	16.6	3.3	7
other marketable flatfish	3.9	-	3	38.1	2.3	8	14.8	1.2	8	48.9	1.0	3	1.9	-	1	49.5	15.1	3	154.6	93.8	28	31.9	-	5	35.4	-1.1	5	12.3	4.0	19	16.6	2.7	16	139.4	18.4	4	17.7	3.6	8
marketable roundfish	0.9	-	1	2.1	1.1	0	0.3	0.3	0	6.2	3.9	0	6.4	-	4	16.7	10.6	1	4.2	3.9	1	10.3	-	2	4.9	3.7	1	0.0	0.0	0	23.3	2.9	22	56.6	8.9	2	7.4	1.5	3
discarded flatfish	20.1	-	13	189.3	25.9	39	73.0	15.4	42	536.0	200.0	37	23.6	-	14	245.5	39.3	15	129.3	30.3	24	131.4	-	21	348.2	73.5	46	15.1	6.6	24	53.7	9.6	50	513.4	234.7	14	85.9	23.2	38
discarded roundfish	0.0	-	0	10.3	0.6	2	1.3	1.3	1	62.7	17.4	4	11.2	-	6	20.4	8.4	1	11.7	6.4	2	1.6	-	0	9.4	4.4	1	26.3	5.0	41	4.7	0.9	4	57.7	12.7	2	13.7	3.0	6
polychaetes	0.0	-	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	-	0	71.4	35.4	4	31.9	16.2	6	0.0	-	0	0.1	0.1	0	0.0	0.0	0	0.0	0.0	0	24.2	16.4	1	3.7	3.5	2
crustaceans	3.1	-	2	17.6	-	4	5.2	-	3	52.6	34.2	4	29.4	-	17	106.9	42.7	6	49.5	21.0	9	83.8	-	14	37.5	8.9	5	7.9	2.8	12	2.5	0.8	2	104.3	30.1	3	17.4	2.1	8
echinoderms	119.3	-	80	213.1	-	44	77.0	-	44	650.7	422.8	45	95.8	-	56	933.9	621.8	56	129.9	45.1	24	265.4	-	43	281.7	57.0	37	2.3	1.2	4	3.3	0.3	3	2524.9	897.7	70	62.8	7.2	28
molluscs	0.0	-	0	0.0	0.0	0	0.0	0.0	0	20.5	5.5	1	0.0	-	0	198.4	98.1	12	19.2	5.2	4	23.8	-	4	1.5	1.1	0	0.0	0.0	0	2.5	0.5	2	4.4	1.6	0	0.8	0.2	0
marketable fish	7.1	-	5	49.9	1.4	10	18.2	1.7	10	119.3	13.1	8	12.1	-	7	79.4	30.0	5	172.9	103.8	32	106.5	-	17	74.3	3.3	10	12.3	4.0	19	40.2	5.6	38	376.2	55.4	10	41.7	7.6	18
discarded fish	20.1	-	13	199.6	26.5	42	74.3	14.1	43	598.7	200.2	42	34.8	-	20	266.4	46.7	16	141.0	36.0	26	133.0	-	22	357.6	77.9	48	41.4	8.3	65	58.4	9.3	55	571.1	239.3	16	99.6	24.9	44
invertebrates	122.3	-	82	230.9	98.5	48	81.9	22.0	47	723.8	455.0	50	125.2	-	73	1310.6	709.5	79	230.4	55.4	42	373.0	-	61	320.9	67.0	43	10.2	4.0	16	8.2	1.3	8	2657.8	929.2	74	84.7	10.4	37
total	149.6	-	100	480.5	128.4	100	174.4	37.7	100	1441.8	668.3	100	172.1	-	100	1656.4	786.2	100	544.4	195.2	100	612.4	-	100	752.7	148.3	100	63.9	16.3	100	106.8	16.2	100	3605.1	1224.0	100	226.0	42.9	100

TABLE 3.4.3

Comparison of catch composition of different trawl types in North Sea fisheries. results of analyses of variance on retained and discarded weight per hectare trawled (4 TBB= 4m beam trawl; 12 TBB = 12m beam trawl; 4 TBBm= 4m beam with chain matrix; OTB = otter trawl).

	analyses of variance p-value		catch composition (kg/ha) 12TBB	4TBB	4TBBm	OTB
June 1994: 4TBBm - 4TBB (DUTCH COAST SOUTH) (parallel lines)						
total marketable fish	0.041	4TBB>4TBBm		2.1	1.4	
all marketable flatfish	0.042	4TBB>4TBBm		2	1.3	
marketable sole	0.003	4TBB>4TBBm		0.7	0.2	
marketable roundfish	ns			0.1	0.2	
total discard fish	ns			2.3	2.4	
discard flatfish	ns			2.1	1.7	
discard roundfish	ns			0.2	0.7	
total invertebrates	0.043	4TBB>4TBBm		8.2	3.9	
Annelida	ns			0	0.0	
Arthropoda	ns			0.8	0.8	
Echinodermata	0.021	4TBB>4TBBm		7.4	3.1	
Mollusca	ns			<0.1	0.0	
June 1994: 12TBB - 4TBB (DUTCH COAST SOUTH) (parallel lines)						
total marketable fish	0.014	12TBB>4TBB	4.4	3.3		
all marketable flatfish	ns		3.7	3.1		
marketable sole	ns		1.8	1.1		
marketable roundfish	ns		0.7	0.2		
total discard fish	ns		4.4	3		
discard flatfish	ns		3.6	2.7		
discard roundfish	ns		0.8	0.3		
total invertebrates	ns		9.2	13.7		
Annelida	ns		0.0	0		
Arthropoda	0.025	4TBB>12TBB	1.0	1.3		
Echinodermata	ns		8.2	12.4		
Mollusca	ns		0.0	<0.1		
September 1995: 12TBB - 4TBBm - 4TBB (DUTCH COAST SOUTH)						
total marketable fish	0.000	12TBB>4TBB>4TBBm	4.3	2.8	0.8	
all marketable flatfish	0.000	12TBB>4TBB>4TBBm	3.6	2.4	0.8	
marketable sole	0.000	12TBB,4TBB>4TBBm	0.9	1.0	0.1	
marketable roundfish	ns		0.7	0.4	<0.1	
total discard fish	ns		6.5	7.2	4.4	
discard flatfish	ns		6.0	7.0	4.3	
discard roundfish	0.000	12TBB>4TBB,4TBBm	0.5	0.2	0.1	
total invertebrates	0.000	4TBB>4TBBm,12TBB	3.8	9.6	5.9	
Annelida	ns		0.0	0.0	0.0	
Arthropoda	0.000	4TBB>4TBBm,12TBB	1.8	4.8	1.4	
Echinodermata	0.000	4TBB>4TBBm,12TBB	1.8	4.7	4.5	
Mollusca	ns		0.2	0.1	0.0	
September 1994: 12TBB - OTB (GERMAN BIGHT)						
total marketable fish	0.004	12TBB>OTB	6.5			0.9
all marketable flatfish	0.005	12TBB>OTB	6			0.7
marketable sole	0.000	12TBB>OTB	3			0.0
marketable roundfish	ns		0.4			0.3
total discard fish	0.010	12TBB>OTB	31.3			3.5
discard flatfish	0.005	12TBB>OTB	30.4			1.4
discard roundfish	ns		0.8			2.1
total invertebrates	0.035	12TBB>OTB	27.7			2.1
Annelida	ns		0			0.0
Arthropoda	ns		3.2			1.7
Echinodermata	0.001	12TBB>OTB	24.3			0.5
Mollusca	0.034	12TBB>OTB	0.1			0.0
May 1995: 12TBB - 4TBB - OTB (GERMAN BIGHT)						
total marketable fish	0.000	4TBB,12TBB>OTB	20.2	17.6		1.1
all marketable flatfish	0.000	4TBB,12TBB>OTB	17.5	15.4		0.4
marketable sole	0.001	4TBB,12TBB>OTB	2.7	7.5		<0.1
marketable roundfish	ns		10.0	2.3		0.6
total discard fish	0.000	4TBB>12TBB>OTB	27.8	52.4		1.6
discard flatfish	0.000	4TBB>12TBB>OTB	26.0	46.3		1.4
discard roundfish	0.000	4TBB>12TBB>OTB	1.8	6.0		0.1
total invertebrates	0.000	12TBB>4TBB>OTB	128.5	26.2		0.7
Annelida	ns		1.8	2.7		<0.1
Arthropoda	0.000	4TBB>12TBB>OTB	2.5	4.7		0.2
Echinodermata	0.000	12TBB>4TBB>OTB	124.1	18.6		0.3
Mollusca	ns		0.2	0.2		0.2

TABLE 3.4.4

Catch composition of *Nephrops* fisheries in the Irish Sea: kg per hectare trawled.

YEAR	1994			1994			1995			1995			1996		
SEASON	Spring			Autumn			Spring			Autumn			Spring		
no. of observations	8			7			5			8			6		
	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%
Nephrops	1.9	0.3	**39**	5.9	2.4	**53**	3.2	0.9	**53**	7.8	1.5	**57**	3.1	1.7	**15**
invertebrates	0.4	0.1	**7**	0.2	0.1	**2**	0.8	0.3	**13**	0.7	0.1	**5**	0.4	0.1	**2**
roundfish	2.5	0.4	**51**	4.8	0.7	**44**	2.0	0.4	**33**	4.5	0.4	**33**	16.8	7.4	**82**
whiting	1.6	0.4	**34**	4.4	0.6	**40**	1.3	0.4	**21**	1.8	0.2	**13**	14.0	6.3	**68**
poor cod	0.2	0.1	**4**	0.3	0.1	**2**	0.0	0.0	**0**	0.2	0.1	**1**	0.1	0.1	**1**
flatfish	0.1	0.0	**2**	0.1	0.0	**1**	0.1	0.0	**1**	0.6	0.1	**5**	0.4	0.1	**2**

TABLE 3.4.5

Catch composition of *Nephrops* fisheries in the Irish Sea: kg per hour fishing.

YEAR	1994			1994			1995			1995			1996		
SEASON	Spring			Autumn			Spring			Autumn			Spring		
no. of observations	8			7			5			8			6		
	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%
Nephrops	16.0	2.7	**24**	52.5	21.0	**34**	25.1	7.2	**37**	63.8	13.3	**39**	25.9	14.3	**7**
invertebrates	3.0	0.7	**4**	2.0	0.7	**1**	6.4	2.3	**9**	6.0	0.8	**4**	3.0	0.9	**1**
roundfish	46.7	8.1	**69**	98.1	14.7	**63**	34.9	6.4	**51**	82.4	9.0	**50**	318.5	140.2	**90**
whiting	30.8	7.4	**45**	89.2	14.0	**58**	22.1	6.1	**33**	32.5	4.3	**20**	265.5	119.0	**75**
poor cod	3.6	1.2	**5**	5.1	1.8	**3**	0.2	0.1	**0**	3.2	1.1	**2**	2.4	1.1	**1**
flatfish	2.2	0.4	**3**	2.2	0.8	**1**	1.5	0.3	**2**	11.1	1.7	**7**	7.0	2.2	**2**

TABLE 3.4.6

Nephrops fisheries in the Irish Sea: analyses of variance on weight of retained *Nephrops* and discarded invertebrates (excl. discarded *Nephrops*) and fish, in studies in the offshore area in spring and autumn 1994 and in spring and autumn 1995.

	season	year	season*year
Nephrops	0.001	ns	ns
Invertebrates	ns	0.000	ns
Roundfish	0.003	ns	ns
Whiting	0.002	ns	ns
Poor cod	0.020	ns	ns
Flatfish	ns	0.004	ns

TABLE 3.4.7

Catch efficiency of different types of bottom trawls for invertebrates, expressed as percentages of the initial density in the seabed (Triple-D sampling). All results obtained from North Sea studies, except the *Nephrops* trawl (Irish Sea; sampling gear 3m beam trawl). - = no (reliable) data available; * = densities estimated in box corer sampling.

Trawl type	12m beam trawl		4m beam trawl		4m beam trawl w. chainmatrix	otter trawl	*nephrops* trawl
Sediment type	soft	sand	soft	sand	sand	sand/soft	soft
[no. of experiments]	[5]	[5]	[3]	[7]	[3]	[4]	[1]
MOLLUSCS							
Acanthocardia echinata (adult)	<20 [3]	-	-	-	-	-	-
Dendronotus frondosus	-	-	-	-	-	-	3
Arctica islandica (adult)	<10 [4]	-	-	-	-	-	-
Ensis spp., *Mya truncata, Lutraria lutraria* (adult)	0 [4]	0 [2]	0 [3]	0 [7]	0 [3]	0 [4]	-
small (1-5 cm) bivalve species	0 [5]	0 [5]	0 [3]	0 [7]	0 [3]	0 [4]	-
ECHINODERMS							
Asterias rubens < 7 cm	1 [1]	4 [2]	-	3 [3]	4 [1]	0 [1]	-
Asterias rubens 7-11 cm	5 [1]	28 [2]	14 [1]	22 [3]	10 [1]	2 [2]	-
Asterias rubens > 11 cm	10 [1]	70 [2]	28 [1]	40 [3]	38 [1]	2 [2]	-
Astropecten irregularis < 4 cm	1 [4]	0 [1]	0 [3]	0 [1]	-	0 [3]	-
Astropecten irregularis 4-5 cm	3 [4]	1 [1]	2 [3]	2 [1]	-	0 [3]	-
Astropecten irregularis 5-6 cm	3 [4]	6 [1]	9 [3]	15 [1]	-	0 [3]	-
Astropecten irregularis > 6 cm	6 [4]	8 [1]	26 [3]	15 [1]	-	0 [3]	-
Echinocardium cordatum 3-5 cm	0 [5]	0 [5]	0 [3]	0 [7]	0 [3]	0 [4]	-
Trochythyona elongata (adult)	0 [3]	-	0 [2]	-	-	0 [2]	-
Ophiura spp. < 1 cm	0 [1]	0 [5]	0 [1]	0 [2]	-	0 [2]	-
Ophiura texturata 1-3 cm	8 [2]	9 [2]	3 [1]	7 [5]	1 [1]	0 [2]	-
Psammechinus miliaris (adult)	0 [1]	0 [1]	-	6 [1]	-	-	-
CRUSTACEANS							
Corystes cassivelaunus male (> 1 cm)	6 [5]	1 [5]	7 [3]	0 [7]	2 [3]	0 [4]	-
Corystes cassivelaunus female (> 1cm)	0 [5]	0 [5]	1 [3]	0 [5]	0 [3]	0 [4]	-
Dichelopandalus bonneri	-	-	-	-	-	-	4
Pagurus bernardus < 1 cm	0 [5]	0 [5]	0 [3]	0 [5]	0 [3]	0 [4]	-
Pagurus bernardus > 1 cm	11 [5]	10 [5]	14 [3]	7 [7]	2 [3]	1 [4]	-
Liocarcinus holsatus 1-3 cm	1 [3]	1 [5]	1 [3]	0 [5]	0 [3]	0 [4]	-
Liocarcinus holsatus > 3 cm	6 [3]	8 [5]	5 [3]	8 [7]	9 [3]	0 [4]	-
Parsiphaea sivado	-	-	-	-	-	-	12
Crangon spp. and small (1-2 cm) crab species	0 [1-3]	0 [2]	0 [2]	0 [6]	0 [3]	0 [4]	2
OTHER GROUPS							
Aphrodita aculeata 3-7 cm	10 [3]	-	2 [2]	-	-	0 [1]	-
Aphrodita aculeata > 7 cm	21 [3]	-	5 [2]	-	-	1 [1]	-
other polychaetes*, sipunculids, anemones	0 [5]	0 [5]	0 [3]	0 [7]	0 [1]	0 [4]	-

3.5. DIRECT MORTALITY DUE TO TRAWLING

Introduction

In commercial trawling, undersized commercial fish, non-target fish and invertebrate species are caught and discarded into the sea. A certain fraction of these discards does not survive their stay in the net and the sorting on board the trawler (Houghton, Williams & Blacker 1971). Evidence is available of serious effects on coelenterates, annelid worms, molluscs, echinoderms and crustaceans (Graham 1955; Bridger 1970; Margetts & Bridger 1971; de Groot 1973). In this chapter, results are presented of field studies in the North Sea and in the Irish Sea that were carried out to estimate the proportion of animals caught in commercial beam and otter trawls that was brought aboard dead, or died within a few hours or days (see chapter 2.5).

Mortality not only occurs among caught and subsequently discarded animals, but also in animals in the trawl path that come in contact with the gear without being caught. This phenomenon is well known as an effect of dredging for clams and scallops on populations of the bivalves, sabellid worms and burowing ceriathid anemones (Hall, Basford & Robertson 1990; Brown 1989; Langton & Robinson 1990). Also for flatfish trawling, a number of publications gave indications for impacts on benthic populations, although quantitative data on the direct mortality in the trawl path are scarce (Anon. 1988, 1989; Rees & Eleftheriou 1989; Witbaard 1989; Krost 1990; Holme 1983). In this IMPACT project, the occurrence of damage in invertebrates due to contact with tickler chains in a beam trawl was described, and detailed field studies in North Sea and Irish Sea were undertaken to calculate the total direct mortality of invertebrates, consisting of both the mortality of caught animals and of animals in the trawl path (see chapter 2.5).

3.5.1. MORTALITY OF DISCARDS

The proportion of caught animals that were brought aboard dead or that died during the sorting of the catches (immediate discard mortality) is given in Table 3.5.1. Table 3.5.2 presents the percentage mortality of animals that are normally discarded alive, but that died within three days in the sea water tanks on board due to being damaged (secondary discard mortality). In Table 3.5.3. both mortalities are summarized by calculating the proportion dead specimens among all animals after three days on board.

Starfish and brittlestars (*Asterias rubens, Astropecten irregularis, Ophiura* sp.) generally showed a very low discard mortality, less than 10%. The mortality of molluscs varied considerably: the quahog *Arctica islandica*, showed high immediate discard mortalities (almost 90%), whereas whelks (*Buccinum undatum)* showed neither immediate mortality or mortality within three days. About 60 to 70% of the catch of the edible crab (*Cancer pagurus*), the masked crab (*Corystes cassivelaunus*) and the swimming crab (*Liocarcinus holsatus*) died, whereas hermit crab (*Pagurus bernhardus*) showed lower mortality (less than 25%). For flatfish, discard mortality was at least 50%, but mostly 80 to 100%. It was further noticed that all gadoid roundfish such as cod (*Gadus morhua*) and whiting (*Merlangius merlangus*) died within a few minutes after being brought aboard. It is therefore considered that the immediate mortality is 100%.

For most species, neither the immediate nor secondary discard mortalities in a particular trawl differed largely between the replicate studies. Occasionally, however, large differences between studies (sometimes more than double values) were found, e.g. for helmet crabs, in the 4m beam trawls with chainmatrices (immediate mortality), for *Ophiura* spp. in the 12m beam trawls and for sole in the 4m beam trawls with chainmatrices (secundary mortality).

For most species, neither the immediate nor secondary discard mortalities showed clear differences between the four types of trawls. The edible crab showed a higher discard mortality (immediate as well as secondary) in the 12m beam trawl than in the 4m beam trawl, *Astropecten irregularis* showed a higher immediate mortality in the otter trawls than in the 12m beam trawls, although the mortalities were measured in autumn and spring respectively. The 4m beam trawls with chainmatrices tended to cause a lower discard mortality than beam trawls with tickler chains, in helmet and hermit crabs, *Ophiura* spp., dab, plaice and sole.

3.5.2. DAMAGE OF INVERTEBRATES

In a sandy area in the North Sea, the occurrence of damaged invertebrates in a 1m dredge (Kieler Kinderwagen) attached behind the tickler chains was compared to that in a reference dredge in front of the ticklers. In the dredge towed behind the ticklers, higher percentages of damaged specimens of *Asterias rubens, Ophiura* spp., *Carcinas maenas, Corystes cassivelaunus* were caught than in the reference dredge. The percentages of damaged individuals in some other species (*Buccinum undatum, Aphrodita aculeata, Chamelea gallina, Nucula* spp., *Spisula* spp., *Corbula* spp. and shrimps) could not be related to the position of the dredge.

3.5.3. TOTAL DIRECT MORTALITY OF INVERTEBRATES

3.5.3.1. NORTH SEA

Detailed studies were carried out to quantify the total direct mortality of invertebrates due to 100 to 200% trawling intensity with different types of trawls. This total mortality is expressed as a percentage of the densities in the seabed before trawling. The estimate of total mortality is based on the difference between the initial densities in study strips and the remaining densities after trawling, to which the surviving discards in the trawls (calculated from results in 3.5.1.) were added. Densities were mainly determined using a dredge (Triple-D), although in a number of studies a grabsampler was used to sample small sized, abundant species. Total mortalities were calculated for a number of sedentary and low-mobile infauna and epifauna species (Table 3.5.4, 3.5.5) and can be summarized as follows:

Many small-sized bivalves species showed total mortalities up to 30% of the initial densities in the seabed; larger-sized bivalve species suffered mortalities up to 40% (for a few species even 80%), e.g. *Gari fervensis, Dosinia lupinus, Fabulina fabula, Spisula subtruncata.* Mortality of gastropods such as *Lunatia catena* and *Turritella communis* (juv.) ranged from 10 to 30%.

Total mortalities in starfish (*Astropecten irregularis, Ophiura texturata, Amphiura filiformis)* could rise up to 30%. A mortality up to 90% was found for the sea urchin *Echinocardium cordatum.* Because this species usually shows a distribution down to about 20 cm in the sediment and only animals in the upper 10 cm are sampled with the Triple-D, this mortality is an overestimation for the whole population. Based on the depth-frequency distribution (see chapter 2.5) and the assumption that animals living deeper than 10 cm are not damaged by the trawl, the mortality for the whole population was estimated as 10-50%.

Small-sized crustaceans (cumaceans, gammarids) showed total mortalities up to 30% due to trawling with 12m beams. About 5-40% of the adult population masked crabs (*Corystes cassivelaunus*) appeared to be killed; 30 to 60% of the juveniles. The crab *Thia scutellata* showed mortalities between 10 and 30%. In silty areas up to 40% of the small tube-dwelling polychaete *Pectinaria koreni* were killed due to 12m beams; the mortality of all other small annelids (24 species) was negligible. The sea mouse *Aphrodita aculeata*, the sipunculid *Golfingia* spp. and the tunicate *Pelonaia corrugata* showed mortalities between 5 and 20%.

Within some species size dependent differences in total mortality were found. In silty areas, large (> 2 cm) specimens of *Chamelea gallina* showed a mortality of 40% due to beam trawls and 18% due to otter trawls, whereas for smaller specimens the mortality was less than 2%. Similar differences in mortalities were found for different size classes (> 7 cm; < 7 cm) of *Aphrodita aculeata.* In sandy areas, small (< 1 cm) specimens of *Lunatia catena* showed a mortality of about 60% in beam trawls, whereas for larger specimens the mortality was less than 4%. In *Corystes cassivelaunus* total mortality appeared to be sex dependent; females generally showed a lower total mortality than males. In *Spisula subtruncata* a density dependent difference in total mortality due to 4m beam trawls was found. Specimens in low densities (about $0.1/m^2$) showed a mortality of about 30%, in extremely high densities (> $20/m^2$) the total mortality increased up to 60%.

Mortality in relation to trawling intensities

To estimate the impact of the trawling intensity on the total mortality of invertebrate species, an extra 12m beam trawl-strip was trawled with an intensity of 300% in two of the studies, next to the strips trawled with an intensity of 200%. In a sandy seabed, mortalities in the heavily trawled strip appeared to be higher for a number of bivalve species (e.g. *Chamelea gallina*, juv. *Ensis* spp., *Spisula solida* and *S. subtruncata*) and the crab *Thia scutellata* (Fig. 3.5.1). In a similar study in a silty area, however, no clear differences in mortalities were found.

Mortality in relation to different types of trawls

Differences in total mortalities of benthos species due to trawling with different types of gears can be studied only under similar conditions regarding e.g. sediment type and season. Therefore, only a selection of the studies that led to the mean result in Table 3.5.5 was used to estimate these differences, i.e. those studies in which two or more different commercial gears were used simultaneously. Because of this selection the mean mortality estimates in Fig. 3.5.2 may differ from the results presented in that table.

For the majority of benthos species involved, differences in total mortalities due to trawling with 4m or 12m beam trawls were not obvious, neither in sandy coastal nor in offshore silty areas. In the hard-sandy coastal zone, 4m beam trawls with tickler chains did not cause consistently higher or lower mortalities than 4m beams with chain matrices , although higher mortalities were found in at least three infaunal species *(Spisula solida, Ensis* juv., *Thia scutellata*). Mortalities due to otter trawling and beam trawling were compared in one sandy location only. In this location, otter trawling caused mortalities in benthic species in the same order of magnitude as beam trawls. In silty areas (three locations), however, otter trawling clearly caused less mortality than beam trawling in a number of species (e.g. *Chamelea gallina, Dosinia lupinus,* tunicates, *Astropecten irregularis,* juvenile *Corystes cassivelaunus, Aphrodita aculeata*).

Mortality in relation to sediment type

For a number of species, that occurred in sufficient densities (> 5*100 m^{-2}) in sandy and silty areas, the impact of sediment type on total mortality could be determined (Table 3.5.5). In silty areas a trend was found for higher mortalities due to 4m and 12m beam trawls than in sandy areas in *Chamelea gallina, Mactra corallina* and *Echinocardium cordatum.* A lower mortality was observed in male *Corystes cassivelaunus.*

Relative vulnerability of invertebrate species

To examine the relative vulnerability of the species listed in Table 3.5.5, the species have, in each study and for each trawl type, been ranked according to their total mortality estimates. Based on their mean ranking for all studies in a particular sediment, the species have been sorted into decreasing vulnerability (Table 3.5.6). In general, *Echinocardium cordatum, Corystes cassavilaunus* (male), and bivalves such as *Phaxas pellucidus, Dosinia lupinus, Mactra corallina, Abra abra* and two *Spisula* species appeared to be the most vulnerable species. Bivalves like *Ensis, Corbula gibba, Chamelea gallina,* and starfish (e.g. *Astropecten irregularis, Ophiura texturata*) were relatively resistent to bottom trawling.

3.5.3.2. IRISH SEA

Total mortality of invertebrates was estimated following about 200% trawling with a *Nephrops* otter trawl at a coastal and a deeper station in the north-western Irish Sea. Total mortality was calculated based upon the difference between the initial densities in the study strips and the remaining densities after trawling. Densities were determined using a 0.1 m^2 Day grab.

Amongst the molluscs at the inshore station, most species showed a decrease in numbers following trawling (Table 3.5.7). The bivalves *Abra* sp. (mostly *A. nitida*) showed mortality levels of 6 and 20% respectively in the 1995 and 1996 experiments. Over the two years, 1995 and 1996, *Corbula gibba* showed a mortality of 29 and 58% respectively, *Thyasira flexuosa* 0 and 28%, while for *Dosinia lupinus,* mortalities as diverse as 3 and 87% were estimated. Mortality of gastropods such as *Cylichna cylindracea* was about 1 to 37%, while *Turritella communis* showed widely fluctuating mortality levels. Due to insufficient sampling occasions, low faunal density and small size of sampler used, statistical significance was difficult to calculate accurately for many species.

Small crustacean species (tanaids, copepods and amphipods) all showed mortality levels ranging of 60 to 100%. With the exception of *Nephtys hombergii* (gallery dweller) which showed a 70 and 7% decrease respectively in 1995 and 1996, and *Laonice cirrata* (tube dweller) showing a 17 to 57% mortality (Table 3.5.7), most of the other polychaetes (often opportunistic or scavenging species) increased in numbers following trawling.

Size measurements were not routinely made. However, it was observed that for some bivalve species, individuals taken in the post-trawling samples tended to be smaller than those taken before trawling (e.g. *Dosinia lupinus, Mysia undata*). As these larger individuals had not been found among the by-catch of the *Nephrops* trawls, this suggests that mortality of at least the larger animals occurred in the trawl path.

By contrast, the offshore station, which had a sediment quite similar to the inshore station, though somewhat finer, has a similar fauna with fewer species than the fauna found at the inshore station. With the exception of the prawns (*Nephrops norvegicus*), the benthic macrofauna is very sparse, both in numbers of species and individuals, and is characterised by small polychaetes with a few crustaceans and bivalves. Most of these individuals are species which have a small adult size or juveniles of larger species. This paucity of fauna, when coupled to fluctuating densities for many species, (Table 3.5.8) and the associated low biomass (mean biomass is about 24 g * m^{-2}) has rendered any quantitative assessment of the direct mortality impossible. For example, *Synelmis klatti*, shows numbers increasing after trawling in one experiment, while in others numbers remain constant or drop.

3.5.4. DISCUSSION OF RESULTS

3.5.4.1. MORTALITY OF DISCARDS

It was found that a considerable part of the discard does not survive the handling on board the trawler. The immediate discard mortality of fish depends on the species characteristics (e.g. fragility), the catch composition (e.g. presence or absence of stones, other species, etc.) and the haul duration (see e.g. van Beek, van Leeuwen & Rijnsdorp 1990; Main & Sangster 1990). Summarizing the immediate and secondary discard mortality, more than half - and for many species at least three quarters - of the undersized fish caught and returned to the sea after processing the catch, died within the first three days. Among surviving fish that returned to the sea, mortality *after* these three days might be considerable as well. This was demonstrated in discarded fish from shrimp trawlers, showing a considerable mortality after three days due to infections in small wounds (Lüdemann 1993).

The immediate discard mortality of invertebrate species, in particular molluscs and crabs, largely depends on the species characteristics: their vulnerability and burrowing behaviour. Erect, sessile epifauna, especially the long living and slow growing species like anemones, sponges, hydrozoans, bryozoans, and *Alcyonium gelatinosum* showed to be the most vulnerable species in the catches of non-hydraulic dredges for scallops (Dare 1992). In the IMPACT study, also some bivalves appeared to be very breakable: about 90% of the *Arctica islandica* in the catch had broken shells. This is also found in previous fieldstudies (Bergman & Hup 1992).

In general, clear, consistent differences have not been found in discard mortality - neither immediate nor secondary - between the four trawl types, with the possible exception for the 4m beam trawls with chain matrices, which tended to cause somewhat lower mortalities than beam trawls with tickler chains for some species. It should be noted, however, that if (minor) differences exist, these may have been unnoticed as the variation between the replicate studies is sometimes considerable and the number of studies is low. This variation may be due to slightly different routines in handling the catch onboard the trawler or due to differences in e.g. water and air temperature, haul duration and catch size, to which the survival chances of discard are likely to be related. The found different result for the 4m beam trawls with chain matrices may be due to one of these factors showing an extreme value in one or more of the few studies on which this result was based. The secondary discard mortalities found for animals caught with a 4m beam trawl with chainmat are, however, similar to those found by Kaiser & Spencer (1995) in the Irish Sea.

Like in fish, the secondary discard mortality may be considerably under-estimated at least for some invertebrate species, as mortality among damaged/injured specimens will also occur after the duration of the experiments (three days). In the whelk *Buccinum undatum*, it was demonstrated that, although of none of animals caught in a 12m beam trawl died within 3 days, mortality after 2 weeks in the laboratory reached 70 to 90%, compared to 0 to 8% in whelks that were collected in bait-pots (Cadée *et al.* 1995).

Despite the fact that the discard mortality is high for small fish and several invertebrate species, discard mortality is generally very low (a few percent) when expressed as a percentage of the initial density, because of the low catch efficiency of the commercial gears for these species. Discard mortality is low compared to the total mortalities of up to 30 - 40% of the initial density - and sometimes even higher - that were found in several sedentary or low mobile molluscs, crustaceans, echinoderms as well as in some other groups of invertebrates. It can therefore be concluded, and that for these species the discard mortality played only a minor role, and that the direct mortality mainly occurred in the trawl path.

3.5.4.2. TOTAL DIRECT MORTALITY OF INVERTEBRATES

In the studies in the North Sea and the Irish Sea, total mortalities could not be calculated for fish and highly mobile epibenthic species (e.g. *Asterias rubens, Liocarcinus holsatus, Dichelopandalus bonnieri, Pagurus bernhardus, Crangon* spp), as these are predominantly predators and may immigrate rapidly into the recently trawled strip, to scavenge on damaged and exposed "victims" in the trawl path (see chapter 3.6). Indeed, densities in the trawlpath after trawling of these species were regularly found to have increased instead of decreased.

Nevertheless, some relatively low mobile species (e.g. *Thia polita, Ophiura texturata*) in which increased densities were seldom found, were included in the studies. Total mortalities in these species might be underestimated, as a part of the "survivors" on the trawl path may in fact be immigrants. For example, in the mobile *Lunatia catena*, a lower mortality was found for large specimens compared to small specimens, which may be related to a more rapid immigration of these larger ones.

The choice of a certain type of sampling gear has consequences for the reliability of estimate of total mortality. Grab samplers such as a box corer, Van Veen grab or Day grab were used to sample highly abundant, mostly small sized infauna. For lower abundance often larger sized species, these gears usually give unreliable density estimates, as sampling occasions are usually limited. Therefore, the mortalities that were estimated in the Irish Sea using a Day grab, are reliable only for high abundance, mostly small species. In the North Sea, attention was focused on the larger sized, low abundant in- and epifauna, that was sampled with the Triple-D benthosdredge. Grabs and box corers were used in only few occasions. *Echinocardium cordatum* was difficult to sample in the Triple-D (this species being too fragile and deeply burried), and in most locations in too low abundance to be sampled reliably with grabsamplers. The estimated mortality for this species was primarily based on the Triple-D sampling, after a correction (based on literature as well as unpublished data) for the depth frequency distribution.The Kieler Kinderwagen was used to demonstrate the occurrence of damage in epibenthic species caused by tickler chains. It revealed relative differences in damaged species directly after the passage of the tickler chains. No attempts were made to obtain quantitative results.

Due to the inevitable inaccuracy in positioning of the experimental trawling, it was not possible to realise a homogeneous trawling intensity of 100% in the study strips. To avoid large unfished patches, a somewhat higher intensity of 150% was aimed at, but in practice trawling appeared to range from 100% to 200%. The absolute percentages of trawling in the strips might affect the recorded mortalities of some infauna species, as was suggested by the field study on the impact of different trawling intensities (200 versus 300%) in sandy sediments. The differences in total mortality recorded between the various types of trawls may therefore be biased by the variability in the trawling intensities. However, in general it can be assumed that the mortality measured is a realistic estimate for normal commercial trawling practice, in which the same strips are often trawled frequently within a few days.

Mortality in relation to different types of trawls

The total mortality due to otter trawling was lower than due to beam trawling for a number of burrowing species in silty areas (e.g. bivalves, crustaceans, tunicates). Apparently otter trawls disturbed these sediments less deeply than beam trawls. In the field studies, total mortality due to the contact of groundrope plus bridles was measured. Mortality due to the doors could not be measured as, for logistic reasons, it was impossible to sample in the track of one door (tracks of the doors were positioned outside the trawled study strip). Even if mortality due to the doors is higher than that due to the groundrope, this should only cause a slight under estimation of total mortality in otter trawls, as the width of path travelled by the two doors is less than 10% of the width of the groundrope path. Although in the single study in a sandy area such differences in mortality between these trawls were not found, a single study, such as this, cannot justify the conclusion that otter trawls penetrate into hard-sand to the same depth as beam trawls.

Neither in coastal sandy nor in offshore silty areas, did any of the types of beam trawls (12m, 4m with ticklers or chain matrices) cause significantly different total mortalities for the majority of the benthic species involved. The differences in mortalities found for individual species are presumably generated by random variation in the data. Even the extreme differences in mortality in *Spisula subtruncata* and *Phaxas pellucidius* between the 12m and the 4m beam trawling in sandy areas, may at least partly be explained by this variation: in this case the total mortality due to the 12m beam trawl is likely to be underestimated, as e.g. a much higher mortality due to this trawl was found in the more robust *Spisula solida.* The higher total mortalities that were found due to 4m beams with ticklers when compared to 4m beams with chain matrices for at least three infauna species (*Spisula solida, Ensis* spp. juv., *Thia scutellata*), suggests a less deep disturbance of the seabed by the trawl with chainmat.

In some infauna species (*Echinocardium cordatum*, some bivalves), the total mortality in silty areas was higher than in sandy areas, in both 4m beam trawl and 12m beam trawl studies. This suggests a deeper penetration of beam trawls into a softer seabed, leading to higher mortalities. The higher mortalities that were found in male *Corystes cassivelaunus* (showing a more or less epibenthic behaviour) in sandy areas compared to silty areas are unlikely to be related to the penetration depth of the trawl.

Relative vulnerability of invertebrate species

In general, small sized species (e.g. *Mysella bidentata, Nucula nitidosa, Cylichna cylindracea, Amphiura filiformis*; see Table 3.5.4) showed relatively low total mortalities, when compared to larger sized species: probably these small animals are dispersed by the bow wave in front of the trawl. The high mortality of the relatively small tube building polychaete *Pectinaria koreni* may be due to its fragility and its occurrence in the uppermost layer. For small individuals of the tube building worm *Lanice conchilega* (< 1.5 cm) a similar high mortality was measured (Bergman & Hup 1992). The small bivalve *Tellimya ferruginosa* lives associated with *Echinocardium cordatum*, which may explain the approximately similar mortality recorded for these two species.

Most of the larger sized species that appeared to be more resistent to trawling in the North Sea studies (Table 3.5.6) were relatively robust (e.g. *Astropecten irregularis, Ophiura texturata, Chamelea gallina, Corbula gibba*), or burrow deeply into the sediment (like *Ensis* spp.). In studies in the Western Baltic, robust bivalve species such as *Corbula* and *Astarte* were mentioned to have a high mechanical resistence in contacts with the door of an otter trawl (Rumohr & Krost 1991). Most species in the group with the highest vulnerability (Table 3.5.6) were very fragile (*Echinocardium cordatum, Phaxas pellucidus, Mactra corallina*), or less fragile but live in the uppermost layer of the sediment, in reach of the trawl (*Spisula* spp.). In studies in Strangford Lough (Northern Ireland), the fragile epibenthic bivalve *Modiolus modiolus* also showed high mortality due to scallop dredging (Brown 1989).

In addition to different trawl types and sediment types, the total mortality within a species may vary due to size, shape (e.g. sexual dimorphism), burrowing behaviour (size or sex-dependent or seasonal) and density. In silty areas in the North Sea, individuals of *Chamelea gallina* smaller than 2 cm showed lower mortality than larger sized ones. These juveniles might be more easily swept away undamaged by the trawl than larger ones, because of their lower mass, or their shallower burrowing depth. Smaller-sized sea mouse (*Aphrodita aculeata*) also showed lower mortalities, probably for the same reason. In sandy areas this size-dependent mortality in *Chamelea gallina* was less clear, probably because smaller individuals are more fixed in the seabed and suffer larger mortality due to a contact with the trawl. In the Irish Sea studies, individuals collected after trawling tended to be smaller than those found before trawling (e.g. *Dosinia lupinus, Mysia undata*), suggesting that larger individuals showed higher direct mortalities. The IMPACT studies revealed that total direct mortality in the trawl path is generally lower for small individuals than for large sized ones. This difference is probably related to the type of impact on the different size classes of benthos: a passing trawl will affect small sized benthos mainly through perturbation of the sediment (which is comparable to natural disturbance, e.g. storm), it will affect larger sized benthos mainly through direct contact, damaging the animals. Therefore, the supposed low impact of trawling on benthos that inhabit mobile sediments (Kaiser & Spencer 1996b) is only a correct assumption for small sized animals, for which the passage of a trawl is more or less similar to frequent natural disturbances, to which these animals are adapted. For larger sized species, however, direct mortalities are caused by the contact with the tickler chains, and the impact is incomparable to any natural disturbance. For these larger animals mortalities in mobile sediments are not necessarily lower than in stable sediments. The differences in total mortalities of infauna species, between stable silty areas and mobile sandy areas, that were found in the IMPACT studies, are likely related to a deeper penetration of beam trawls into a softer seabed.

The total mortalities due to beam and otter trawling were lower for female *Corystes cassivelaunus* than for males. This difference may be related to the sexual dimorphism in this species, but a different burrowing depth between sexes may also play a role.

In *Echinocardium cordatum*, the total mortality was estimated as 15 to 55%. It can be assumed that all animals in the upper sediment layers, that are in reach of the trawl, are killed, due to their fragility. The mortalities might therefore increase up to 90% during the relative short reproduction season when animals migrate to the surface layers of the sediment. Small individuals (5-10 mm), that were mainly found at a depth of 2-4 cm showed a direct mortality of 55% after a threefold trawling with 12 beam trawls (Bergman & Hup 1992). Apparently a considerable fraction of this juvenile population was swept away undamaged by the bow wave of the trawl.

The density dependent total mortality in *Spisula subtruncata* might be related to the occurrence of a less solid texture of the upper sediment layers in the case of higher faunal abundances, leading to an increased penetration depth and therefore an enhanced vulnerability for trawling.

Some bivalves *Lutraria lutraria, Mya truncata, Nucula nitidosa* and anemones frequently showed higher densities in the Triple-D sampling after trawling than before. This suggests that a larger fraction of the population came in reach of the Triple-D after trawling, e.g. because the top layer of the sediment was resuspended due to the trawling. It can be assumed that these species were hardly affected by trawling, as they usually stay in sediment layers deeper than the penetration depth of the trawls (about 6 cm, Laban & Lindeboom 1991). In the Irish Sea studies, several annelids were found to increase as well after trawling (e.g. *Chaetozone setosa, Prionospio fallax, Scolelepis tridentata, Nephtys incisa),* which was presumably due to resuspension of the top layer or an upward migration of specimens, that initially live too deep to be sampled with the Day-grab.

In the North Sea studies, many species, such as *Cucumaria elongata, Aequipecten opercularis, Acanthocardia echinata, Aporrhais pespelicani, Spisula elliptica, Thracia convexa, Macropodia* spp. *Ebalia* spp., *Cancer pagurus, Buccinum undatum*, were found occasionally in the sampling, but abundances were too low to draw any conclusions on mortality due to trawling. It is to be expected that those species that live in reach of the tickler chains, and that are not robust, will suffer significant total mortalities due to trawling. Moreover, in *Buccinum undatum*, trawling may cause a considerable mortality due to mortality of caught and discarded animals (see discussion above) and due to effects on the development of embryos, when the egg-capsules that are normally attached to the seabed are torn loose and are carried along in tidal currents.

All species for which mortalities were estimated, are species that are still common in the North Sea, even in sections that have been frequently trawled during the last twenty-five years. This indicates that these species are at least to some extent resistant to beam trawling (either due to a low direct mortality, or due to other factors such as a high rate of reproduction). However, abundances of species may have changed due to commercial trawling, and more vulnerable species may have become rare or may even have disappeared in certain areas (e.g. *Modiolus modiolus, Panomya arctica, Ostrea edulis, Spatangus purpureus, Sabellaria spinulosa*). Generally, these are fragile species that live in reach of the tickler chains, and are likely to suffer significant total mortalities due to trawling.

At the offshore station in the Irish Sea, the biomass and numbers of species are insufficient to assess the direct impacts of trawling on the benthos. As the major difference between the sites appears to be the intensity of fishing (the offshore station is subject to a higher trawling effort about 5 times per m^2 per year from Irish vessels alone; 1994 Irish Department of Marine Sciences Statistics), this may suggest that the larger, more vulnerable species have disappeared due to longterm, intensive commercial trawling. While it is not uncommon to find impoverished benthic fauna in offshore mud associations (Jones 1952; McIntyre 1961), the fauna described from the offshore station in the present study appears to be exceptionally impoverished. It is also interesting to note that in the early 1900's, prior to the start of the present intensive *Nephrops* trawling, large numbers of the burrowing echinoid (*Brissopsis lyrifera*) were commonly found in the by-catch of trawls in the north western Irish Sea (Massy 1912) but this species is now seldom found. The species and biomass poor fauna now present at the offshore station may therefore represent an artificial man-made community, adapted to the regular fishing disturbance experienced at this site.

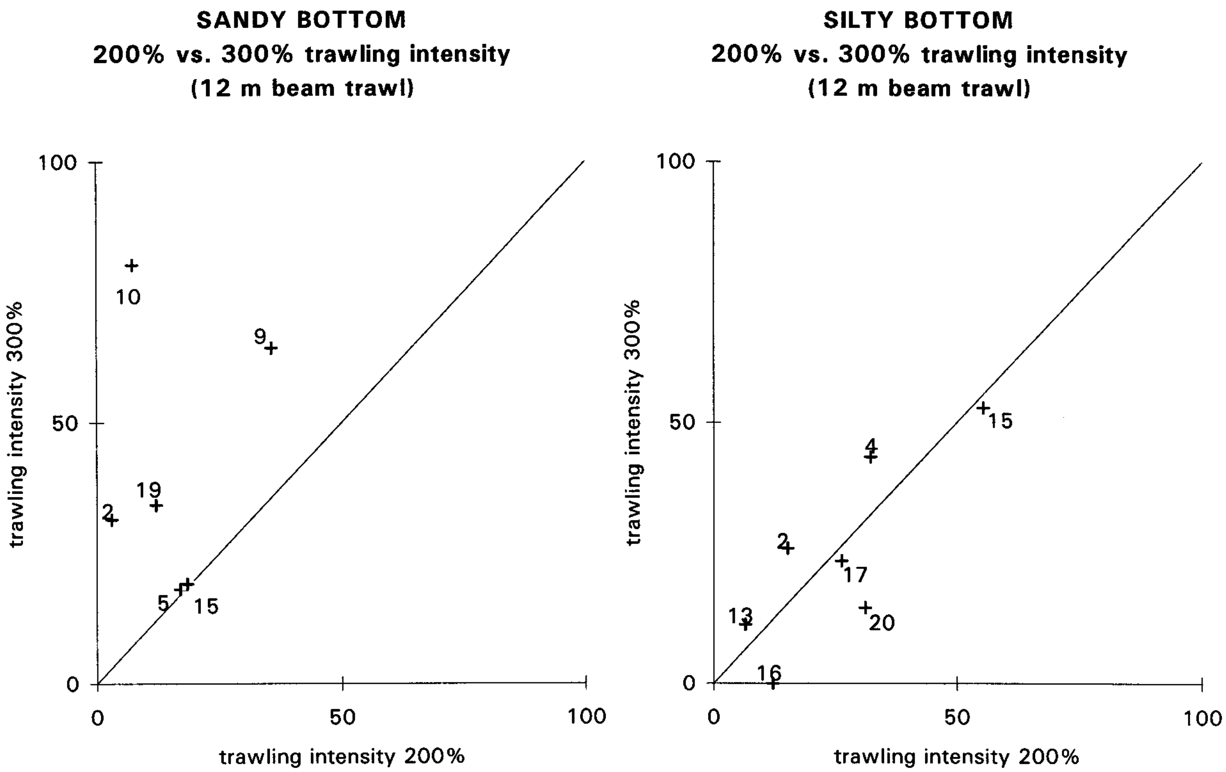
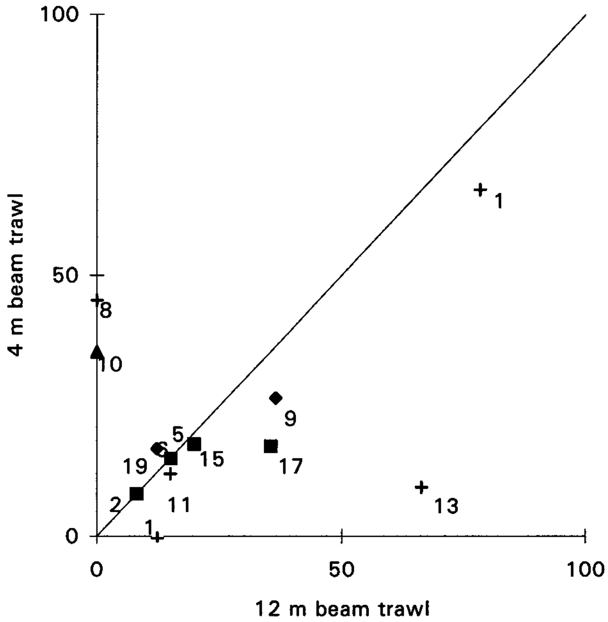
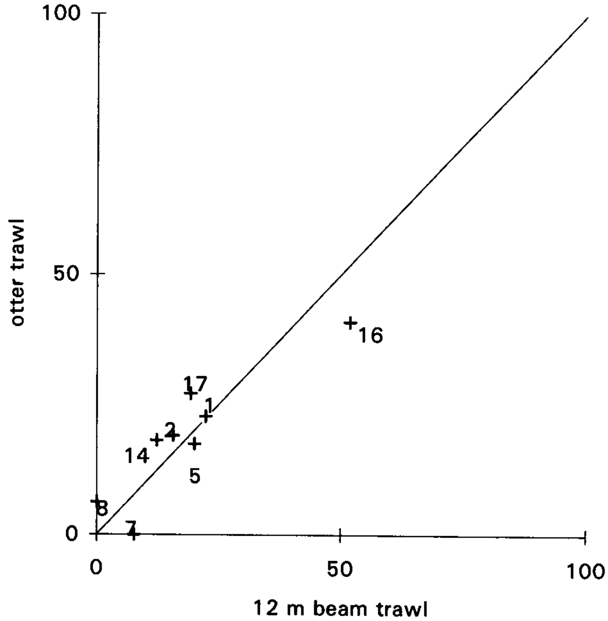


Fig. 3.5.1. Comparison of direct mortalities caused by different trawling intensities with 12m beam trawls in a sandy and a silty area (a 200% trawling intensity vs. a more heavily trawled 300% strip. All results are obtained from 1 study per sediment type. Only species with an initial abundancy of at least 10 specimens per 100 m^2 are included. Numbers refer to species, see Fig. 3.5.2.

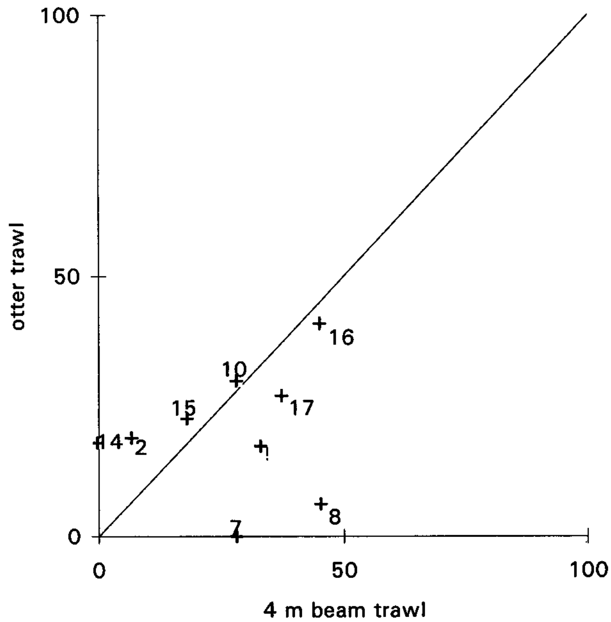
SANDY BOTTOM
12 m beam trawl - 4 m beam trawl



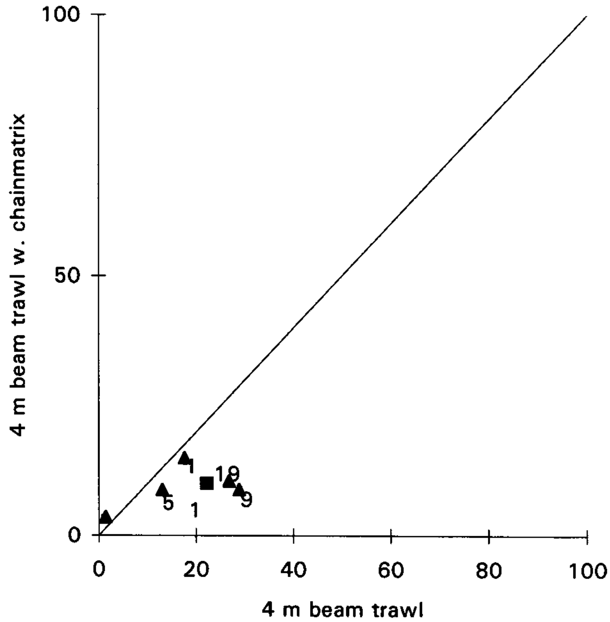
SANDY BOTTOM
12 m beam trawl - otter trawl



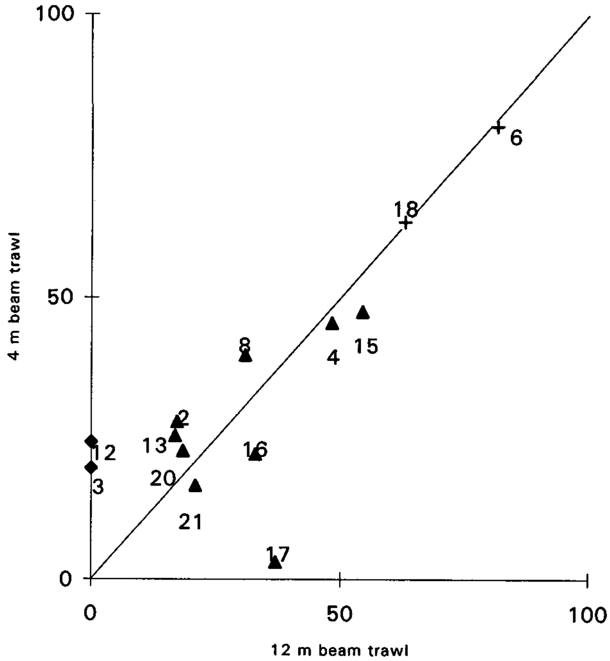
SANDY BOTTOM
4 m beam trawl - otter trawl



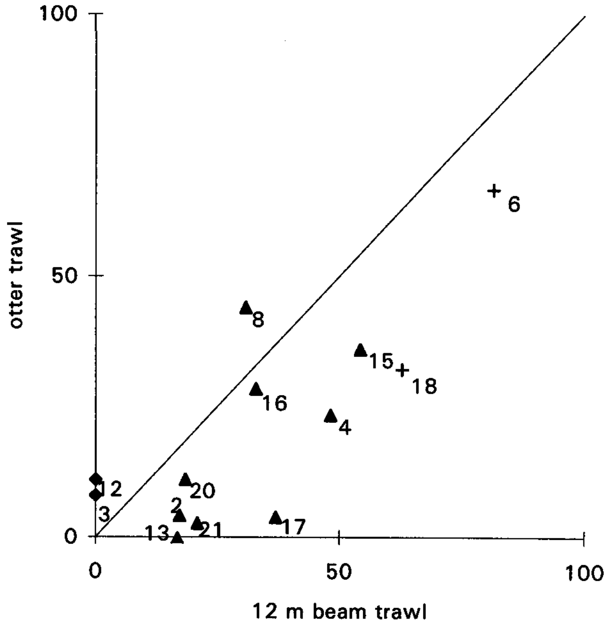
SANDY BOTTOM
4 m beam trawl - 4 m beam trawl w. chainmatrix



SILTY BOTTOM
12 m beam trawl - 4 m beam trawl



SILTY BOTTOM
12 m beam trawl - otter trawl



SILTY BOTTOM
4 m beam trawl - otter trawl

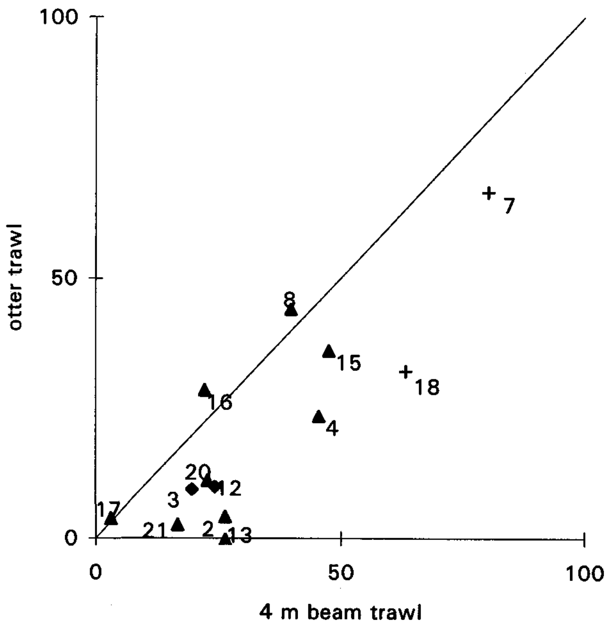


Fig. 3.5.2. Comparison of direct mortalities caused by different commercial gears, in sandy and silty areas. Symbols denote the number of studies from which the results are obtained:

✚	=	1 study
◆	=	2 studies
▲	=	3 studies
■	=	4 studies

Only species with an initial abundancy of at least 10 specimens per 100 m² are included: 1. *Fabulina fabulus*; 2. *Chamelea gallina*; 3. *Corbula gibba*; 4. *Dosinia lupinus*; 5. *Ensis* spp; 6. *Gari fervensis*; 7. *Mactra corallina*; 8. *Phaxas pellucidus*; 9. *Spisula solida*; 10. *Spisula subtruncata*; 11. *Lunatia catena*; 12. *Turritella communis*; 13. *Astropecten irregularis*; 14. *Ophiura texturata*; 15. *Echinocardium cordatum*; 16. *Corystes cassivelaunus* (male); 17. *C. cassivelaunus* (female); 18. *C. cassivelaunus* (juv); 19. *Thia polita*; 20. *Aphrodita aculeata*; 21. *Pelonaia corrugata*.

TABLE 3.5.1

Immediate mortality (# in test = number of animals used in experiments; %mort = % mortality) *=data from Fonds *et al.* 1992b.

GEAR	4 m beam with chain matrix						4 m beam trawl						otter trawl		12 m beam trawl									
SEASON/YEAR	Spring 1993		Spring 1994		Autumn 1995		Spring 1992		Spring 1993		Spring 1994		Autumn 1995		Autumn 1990*		Spring 1991*		Spring 1992		Autumn 1993		Spring 1994	
AREA	Belgian/Dutch sector						Dutch coast north						German Bight		-		-		Dutch coast north					
	# in test	%mort	# in test	%mort	# in test	%mort	# in test	%mort	# in test	%mort	# in test	%mort	# in test	%mort	# in test	%mort	# in test	%mort	# in test	%mort	# in test	%mort	# in test	%mort
INVERTEBRATES																								
Acanthocardia echinata															104	42	220	54	898	44	529	52		
Aphrodita aculeata					38	8											377	1						
Arctica islandica															231	74	419	94	1384	87	84	84		
Asterias rubens													22	5			950	2						
Astropecten irregularis													112	31			658	4						
Buccinum undatum					81	2									27	0	153	0			198	0		
Cancer pagurus							49	22							68	46	45	84	14	40	70	41		
Corystes cassivelaunus			121	38	124	9					121	38	136	52			4200	42	696	39			138	54
Liocarcinus depurator					122	29																		
Liocarcinus holsatus					408	44							237	30										
Liocarcinus spp.			893	62	530	41	701	22	36	33	893	62	237	30	66	53	380	44	146	52	215	42	449	57
Nephrops norvegicus					296	10																		
Ophiura sp.			1311	2							390	1					789	5					215	3
Pagurus bernhardus			177	3	94	6					77	3					456	18					79	4
Spisula spp.									210	32											102	24		
FISH																								
Limanda limanda	18	39	167	68	146	70	64	94	115	97	526	80	2209	81					108	57	74	67	221	94
Platichthys flesus							8	89	52	6			224	37										
Pleuronectes platessa	13	85	44	43	374	37	144	77	45	29	290	60							48	42	93	34	207	49
Scophthalmus sp.							28	79																
Solea solea	57	28	6	33	127	23					67	48									55	47	30	40
Triglidae indet.			27	81							96	80							81	65	73	73	9	89

TABLE 3.5.2

Secondary mortality. #test = number of animals used in experiments; % mortality after 2 (%mort.2d) or 3 (%mort.3d) days; *=data from Fonds *et al.* 1992b.

GEAR	4m beam with chainmats				4m beam trawl				12m beam trawl					
SEASON/YEAR	Spring 1992		Spring 1993		Spring 1992		Spring 1993		Autumn 1990*		Spring 1991*		Autumn 1993	
AREA	Belgian/Dutch sector				Dutch coast north				-		-		Dutch coast north	
	# in test	%mort.3d	# in test	%mort.3d	# in test	%mort.3d	# in test	%mort.2d	# in test	%mort.3d	# in test	%mort.3d	# in test	%mort.2d
INVERTEBRATES														
Acanthocardia echinata									58	**3**	50	**8**	391	**3**
Aphrodita aculeata											246	**5**	142	**4**
Arctica islandica									54	**0**	30	**13**	15	**7**
Asterias rubens	62	**0**			200	**4**					550	**4**	215	**3**
Astropecten irregularis					88	**7**			233	**9**	163	**10**	214	**4**
Buccinum undatum									20	**0**	138	**0**	36	**0**
Cancer pagurus					41	**15**			26	**27**			29	**28**
Chlamys opercularis											52	**0**		
Corystes cassivelaunus					10	**30**					746	**43**		
Liocarcinus sp.	33	**3**	66	**20**	117	**22**			61	**16**	151	**15**	321	**23**
Ophiura sp.	59	**0**			153	**9**			112	**29**	656	**8**	328	**31**
Pagurus bernhardus	23	**0**			27	**7**			112	**9**	112	**13**		
Spisula spp.							245	**1**					134	**3**
FISH														
Limanda limanda	14	**79**	11	**0**	37	**89**	101	**84**					87	**99**
Platichthys flesus					26	**58**	42	**76**						
Pleuronectes platessa	22	**32**	2	**0**	69	**80**	89	**83**					85	**92**
Scophthalmus maximus					27	**48**	35	**23**						
Scophthalmus rhombus					15	**87**	16	**75**						
Solea solea	29	**83**	41	**15**	27	**67**	99	**55**					57	**91**
Triglidae indet.													20	**100**

TABLE 3.5.3
Immediate, secondary and total discard mortality (* values measured in the field are given between brackets).

	4m beam trawl w. chain matrix			4m beam trawl			otter trawl			12m beam trawl		
	imme-diate	sec.	total	imme-diate	sec.	total	imme-diate	sec.	total	imme-diate	sec.	total
INVERTEBRATES												
Acanthocardia echinata										48	4	49
Aphrodita aculeata	8									1	5	6
Arctica islandica										87	5	88
Asterias rubens		0			4		5			2	4	6
Astropecten irregularis					7		31			4	8	11
Buccinum undatum	2									0	0	0
Cancer pagurus				22	15	34				52	28	66
Corystes cassivelaunus	23			38	30	57	52			42	43	67
Liocarcinus spp.	54	14	61	44	22	56	30			50	20	60
Nephrops norvegicus	10											
Ophiura sp.	2	0	2	1	9	10				5	17	21
Pagurus bernhardus	4	0	4	3	7	10				16	11	25
Spisula spp.				32	1	33				24	3	26
FISH												
Limanda limanda	67	44	81 (50)	84	85	98	81		(93)	79	99	100
Platichthys flesus				17	69	74	37					
Pleuronectes platessa	39	29	57 (57)	62	82	93			(58)	44	92	96
Scophthalmus maximus				79	34	86						
Scophthalmus sp.					81					33		
Solea solea	25	43	(83)	48	58	78				45	100	100
Triglidae indet.	81			80						70	91	97

TABLE 3.5.4

Initial densities and direct mortality estimates (% of initial density) of small sized species sampled with a Reineck box corer in a study on silty sediments, involving 12m beam trawls, and a study on sandy sediments, involving 4m beam trawls.

	study area	mean t0 n/1 m²	mortality (%) (*=sign.,P< 0.05)
BIVALVES			
Arctica islandica (length 2-3 mm)	silty	27	**28**
Corbula gibba (1-11 mm)	silty	715	**14**
Donax vittatus (20-35 mm)	sandy	25	**14**
Mysella bidentata (2-3 mm)	silty	794	**6**
Nucula nitidosa (2-10 mm)	silty	15	**6**
Spisula sp. juv. (1-6 mm)	sandy	32	**28**
Tellimya ferruginosa (2-7 mm)	sandy	16	**27***
GASTROPODS			
Cylichna cylindracea (height 3-8 mm)	silty	41	**20**
Turritella communis (5-15 mm)	silty	21	**28***
ECHINODERMS			
Amphiura sp. (disc 2-6 mm)	silty	898	**14**
CRUSTACEANS			
Callinassa subterranea (length 5-40 mm)	silty	87	**6**
Cumacea (3-7 mm)	silty	10	**31***
Gammaridea (2-11 mm)	silty	27	**39**
ANNELIDS			
Pectinaria koreni (4-20 mm)	silty	75	**43***
Magelona papillicornis	silty	22	**41***
Scoloplos armiger	silty	24	**26**
24 Annelid spp. (exc *Pectinaria*)	silty	125	**~0**

TABLE 3.5.5

Mean mortalities (% of initial densities) of benthic invertebrates due to trawling with different gears in sandy and silty areas (Triple-D sampling). The number of strips on which a result is based is given, as well as the mean initial density of the species in these strips. Mortality estimates were tested in each strip (paired t-test on log-data; one-sided sedentary species, two-sided mobile species; p= 0.05): *,**,.. = sign result in one strip, two strips, etc. In each strip, mortalities were estimated in species that were sufficiently abundant (> 5/100 m²). Replicate results were averaged after a weighing based on the 95% confidence intervals. The species *Fabulina fabula* is sampled with Van Veen grab. Initial densities of *Echinocardium cordatum* could not be estimated reliably with the Triple-D (see text).

TRAWL / SEDIMENT		12 m beam trawl SILTY			4 m beam trawl SILTY			otter trawl SILTY			12 m beam trawl SANDY			4 m beam trawl SANDY			4 m b.tr. + chainmat SANDY			otter trawl SANDY		
		n of lines	initial density n/100m²	mort. %	n of lines	initial density n/100m²	mort. %	n of lines	initial density n/100m²	mort. %	n of lines	initial density n/100m²	mort. %	n of lines	initial density n/100m²	mort. %	n of lines	initial density n/100m²	mort. %	n of lines	initial density n/100m²	mort. %
BIVALVES	(length)																					
Abra alba	1-1.5 cm	4*	6	**25**	3**	10	**52**	3	6	**~0**	-	-	-	-	-	-	-	-	-	-	-	-
Fabulina fabula	1-1.5 cm	-	-	-	-	-	-	-	-	-	1*	9323	**78**	1*	11492	**66**	-	-	-	-	-	-
Angulus tenuis	2-3 cm	-	-	-	-	-	-	-	-	-	-	-	-	2	46	**21**	-	-	-	-	-	-
Arctica islandica	8-11 cm	3*	4	**8**	2*	4	**31**	2	7	**12**	-	-	-	-	-	-	-	-	-	-	-	-
Chamelea gallina	1-3 cm	4*	240	**17**	3**	340	**26**	3	319	**4**	4	126	**8**	7*	103	**6**	3*	123	**4**	1	168	**19**
Corbula gibba	1 cm	2	173	**~0**	2*	205	**20**	2	198	**9**	-	-	-	-	-	-	-	-	-	-	-	-
Dosinia lupinus	1-4 cm	4**	62	**43**	3**	87	**46**	3*	89	**23**	-	-	-	-	-	-	-	-	-	-	-	-
Ensis spp.	10-20 cm	3**	8	**~0**	3**	4	**11**	3**	5	**~0**	4*	248	**15**	7**	209	**13**	3*	303	**9**	1	54	**18**
Gari fervensis	4-6 cm	1*	24	**82**	1*	19	**80**	1*	26	**66**	-	-	-	-	-	-	-	-	-	-	-	-
Mactra corallina	3-5 cm	2	3	**22**	2	8	**35**	2*	9	**31**	1	10	**8**	2	13	**12**	-	-	-	1	13	**~0**
Mysia undata	1.5-3 cm	1*	7	**48**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Phaxas pellucidus	1.5-3 cm	4**	10	**38**	3*	10	**40**	3*	13	**44**	1	56	**~0**	1*	77	**45**	-	-	-	1	69	**6**
Spisula solida	2-5 cm	-	-	-	-	-	-	-	-	-	2*	147	**36**	3***	148	**29**	3*	172	**9**	-	-	-
Spisula subtruncata (low density)	1.5-3 cm	-	-	-	-	-	-	-	-	-	3	15	**~0**	3*	10	**33**	2*	13	**40**	1	20	**30**
Spisula subtruncata (high dens.)	1.5-3 cm	-	-	-	-	-	-	-	-	-	-	-	-	1*	2405	**61**	-	-	-	-	-	-
GASTROPODS	(height)																					
Lunatia catena	1-3 cm	-	-	-	-	-	-	-	-	-	1	65	**15**	1	52	**14**	-	-	-	-	-	-
Turritella communis	3-6 cm	3*	45	**8**	2	27	**24**	2	29	**10**	-	-	-	-	-	-	-	-	-	-	-	-
ECHINODERMS	(diameter)																					
Astropecten irregularis	3-6 cm	4*	198	**17**	3**	226	**26**	3	229	**0**	1*	33	**66**	1	25	**9**	-	-	-	-	-	-
Echinocardium cordatum	3.5-5 cm	4****	-	**54**	3***	-	**48**	3**	-	**36**	4****	-	**20**	*****	-	**18**	3***	-	**15**	1*	-	**23**
Ophiura texturata	5-11 cm	-	-	-	-	-	-	-	-	-	1	456	**12**	3	172	**4**	1	28	**10**	1	459	**18**
CRUSTACEANS	(carapax w)																					
Corystes cassivelaunus (male)	2-3 cm	4*	25	**31**	3	33	**22**	3*	32	**28**	2**	17	**52**	2*	19	**43**	-	-	-	1	11	**41**
Corystes cassivelaunus (female)	2 cm	4**	142	**39**	3	205	**3**	3	193	**4**	4*	20	**35**	5	15	**10**	3	5	**11**	1	31	**27**
Corystes cassivelaunus (juv)	<1.5 cm	1*	88	**63**	1*	81	**63**	1	77	**32**	-	-	-	-	-	-	-	-	-	-	-	-
Thia scutellata	1-1.5 cm	-	-	-	-	-	-	-	-	-	2	69	**12**	3*	152	**27**	3*	118	**11**	-	-	-
OTHER GROUPS	(length)																					
Aphrodita aculeata	3-14 cm	4*	11	**12**	3	13	**23**	3	13	**11**	-	-	-	-	-	-	-	-	-	-	-	-
Golfingia sp.	3-7 cm	2	8	**28**	2	9	**7**	2*	17	**46**	-	-	-	-	-	-	-	-	-	-	-	-
Pelonaia corrugata	3-7 cm	3*	13	**21**	3	12	**17**	3	17	**3**	-	-	-	-	-	-	-	-	-	-	-	-

TABLE 3.5.6

Ranking of invertebrate species according to their mean relative vulnerability to trawling on silty and sandy areas. The species with the highest mean rank number is the most vulnerable. The number of study strips on which the ranking was based is indicated. Species are included only when mortalities could be calculated for at least 5 strips.

Silty areas	nr. of strips	mean rank	Sandy areas	nr. of strips	mean rank
Echinocardium cordatum	10	8.0	*Corystes cassivelaunus* (male)	5	9.1
Phaxas pellucidus	10	7.3	*Spisula subtruncata*	10	6.9
Dosinia lupinus	10	6.5	*Spisula solida*	8	6.6
Mactra corallina	6	6.4	*Echinocardium cordatum*	15	5.6
Golfingia sp.	6	5.9	*Corystes cassivelaunus* (female)	13	5.5
Corystes cassivelaunus (male)	10	4.9	*Thia scutellata*	8	4.3
Abra alba	10	4.9	*Ophiura texturata*	6	3.6
Turritella communis	7	4.4	*Ensis* spp. adult	15	3.1
Arctica islandica	7	4.4	*Chamelea gallina*	15	3.0
Corystes cassivelaunus (female)	10	3.9			
Aphrodita aculeata	10	3.9			
Pelonia corrugata	9	3.7			
Chamelea gallina	10	3.7			
Corbula gibba	6	3.3			
Astropecten irregularis	10	3.1			
Ensis spp. adult	9	0.8			

TABLE 3.5.7

Initial densities and direct mortality estimates (% of initial density) of small sized species sampled with a Day grab in two studies at the inshore Station (north western Irish sea) on silty sand sediments, due to *Nephrops* otter trawling. Only species which occurred at a density of > 10 individuals/m^2 are included. (* = statistically significant).

Year	Size (mm)	1995 Mean t_0 (n/1m^2)	1995 mortality (%)	1996 Mean t_0 (n/1m^2)	1996 mortality (%)
BIVALVES					
Abra sp.	(1-15)	256	**6**	1161	**20**
Corbula gibba		22	**29**	146	**58***
Thyasira flexuosa	(1-5)	10	**0**	57	**28**
Dosinia lupinus	(1-28)	11	**87**	20	**3**
Nuculoma tenuis	(1-5)	17	**59**		
Mysella bidentata	(1-4)			21	**72**
GASTROPODS					
Cylichna cylindracea	(1.5-6)	29	**37**	59	**1**
CRUSTACEANS					
Tanaids		21	**93***	29	**58**
Copepoda		42	**93**	231	**67**
Amphipoda		21	**60**		
Protomedia fasciata		10	**100**		
Pariambus typicus				23	**34**
ANNELIDS					
Nephtys hombergii	(3-90)	58	**70***	70	**7**
Laonica cirrata		10	**57**	4	**17**

TABLE 3.5.8

Results from four experiments at the offshore station in the Irish Sea, listing species which occurred at a density of > 10 individuals/m^2. The mean numbers with standard deviation are given from before and after trawling.

month, year	June '94		June '94		May '95		Aug. '95	
before/after trawling	before	after	before	after	before	after	before	after
	no./m^2 ±stdev	no./m^2 ±stdev	no./m^2 ±stdev	no./m^2 ±stdev	no./m^2 ±stdev	no./m^2 ±stdev	no./m^2 ±stdev	no./m^2 ±stdev
POLYCHAETS								
Abyssoninoe hibernica					57 ±21	48 ±31	50 ±24	48 ±33
Ancistrosyllis groenlandic	11 ±8	5 ±6	16 ±17	18 ±18			11 ±21	18 ±38
Chaetozone setosa							11 ±13	18 ±17
Cossura sp.	13 ±20	10 ±12					21 ±14	21 ±23
Euclymene oerstedi			42 ±28	14 ±17				
Glycera rouxii	20 ±17	15 ±13	14 ±12	21 ±13	11 ±11	7 ±8	10 ±14	9 ±8
Laonice cirrata	41 ±31	25 ±27	46 ±54	13 ±21	19 ±35	28 ±55	25 ±26	23 ±29
Levinsenia gracilis	138 ±200	63 ±79	205 ±159	179 ±201	184 ±200	147 ±76	250 ±184	184 ±59
Lumbrineris scopa	41 ±39	28 ±13	52 ±24	38 ±29				
Magelona minuta			11 ±12	13 ±10	13 ±17	12 ±8	18 ±21	16 ±7
Nephtys incisa	26 ±24	18 ±17	35 ±29	35 ±26	41 ±26	47 ±32	48 ±41	55 ±33
Nephtys sp. (juv.)	10 ±13	0 ±0	9 ±14	14 ±21				
Ophelina acuminata			14 ±13	8 ±12			20 ±25	25 ±19
Prionospio fallax	48 ±68	10 ±14	330 ±269	200 ±126	321 ±280	187 ±180	431 ±381	791 ±307
Scolelepis tridentata			11 ±9	10 ±16			5 ±8	10 ±5
Spiophanes kroyeri							29 ±25	33 ±25
Synelmis klatti	30 ±18	30 ±34	51 ±37	44 ±30	31 ±24	50 ±42	29 ±25	28 ±31
Oligochaeta	16 ±20	10 ±12	27 ±29	28 ±32				
CRUSTACEANS								
Copepoda	14 ±20	60 ±74	11 ±14	8 ±9	11 ±29	5 ±6		
Harpinia antennaria			40 ±56	18 ±13				
Harpinia laevis			24 ±33	15 ±16				
Ostracoda	8 ±8	18 ±22	30 ±21	23 ±25				
MOLLUSCS								
Abra sp.	13 ±19	8 ±5	78 ±141	69 ±86	91 ±111	53 ±76	253 ±302	408 ±242
Nuculoma tenuis			20 ±33	19 ±16				