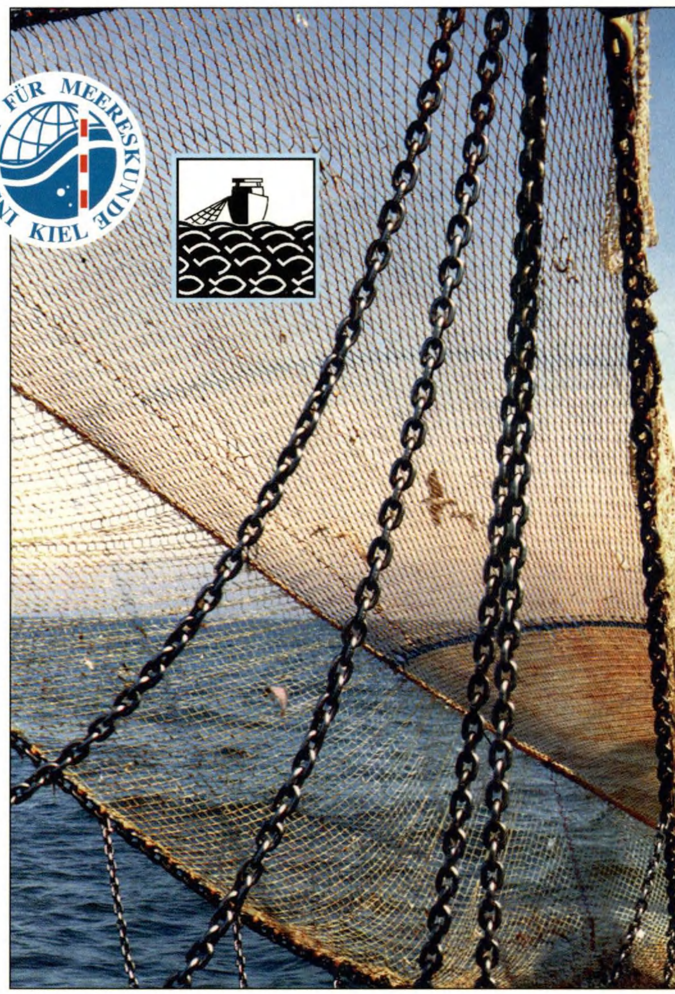
NIOZ-RAPPORT 1998 - 1
RIVO-DLO REPORT C003/98

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



RESEARCH PROJECT FINANCED BY THE EUROPEAN COMMUNITY
CONTRACT NUMBER: AIR2-CT94-1664

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ISSN 0923 - 3210

Cover design: H. Hobbelink

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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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All authors contributed to the other chapters.

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[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.

Subproject 1A. 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.

Subproject 1B. 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.

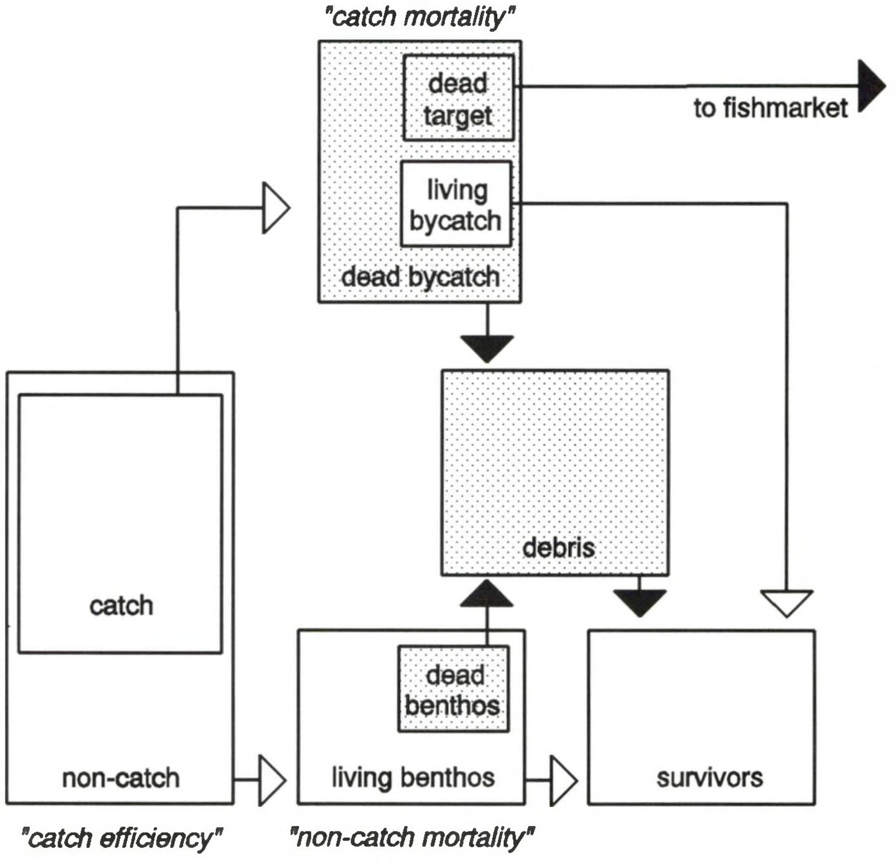


Fig. 1. Direct effect of beam trawling on demersal fish and benthic invertebrates as related to (1) the catch efficiency (i.e. the number of fish and invertebrates that is caught in the nets devided by the total number of animals in the trawl track before fishing), (2) the catch mortality (i.e. the number 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 fishing boats. Feeding success is also related to bird size and handling ability, hence kittiwakes, *Rissa tridactyla,* consume smaller sized fish whereas gannets, *Sula bassana,* take the largest components of the discards. The inability of smaller gull species to swallow large fish whole makes them vulnerable to kleptoparasitism by larger gull species, great skuas, *Catharacta skua,* and gannets (Furness 1996). These patterns of change in seabird populations have been repeated in Australia and the Falkland Islands (Blaber & Wassenberg 1989). Furness (1996) postulates that scavenging seabird numbers in the North Sea are currently limited by the quantity of available fisheries discards. Camphuysen *et al.* (1993) advocated that any changes in mesh-size regulations to reduce the proportion of catch discarded should be introduced gradually to avoid adverse effects for competitively inferior seabird species.

According to Camphuysen *et al.* 's (1993) estimates, seabirds consume about 50% of all the material discarded into the North Sea. The remainder sinks to the seabed whereupon it becomes available to midwater and benthic predators and scavengers. Few studies have recorded the consumption of discarded material in midwater. Cetaceans and sharks feed on material discarded from shrimp trawlers in the Torres Strait, Australia (Hill & Wassenberg 1990; Wassenberg & Hill 1990) and killer whales, *Orcinus orca* were similarly observed feeding on fish slipping through the meshes of nets at freezer trawlers off the Shetland Islands (Couperus 1994). Whether this food source has significant consequences for populations of marine mammals remains unknown. The paucity of studies with respect to midwater scavenging behaviour probably reflects sampling difficulties (Britton & Morton 1994).

Fishing activities provide two main sources of food for benthic scavengers. Firstly, as food falls that originate from discards and by-catch that are not consumed by seabirds and midwater predators and scavengers. Secondly, as demersal trawls and dredges are dragged across the seabed they dig-up, displace, damage or kill a proportion of the epi- and infaunal animals in the path of the gear. In addition, some of the animals caught in the net may escape the codend, but subsequently die. These latter sources of carrion have been termed 'non-catch' mortality (Bergman & van Santbrink 1994a). Food falls of carrion are regarded as perturbations in deep-sea benthic communities, as they promote diversity by providing pulses of organic matter to localised areas of the seabed (Dayton & Hessler 1972). In this environment, scavengers move large distances to consume carrion, demonstrating the importance of this food source (Dayton & Hessler 1972). It is perhaps surprising that the influence of carrion generated from fishing activities on the benthic communities of shelf seas is relatively unstudied. The behaviour of scavenging fish species in response to trawling disturbance is frequently exploited by North Sea trawlers which have been observed lining up to fish the same tow. Kaiser & Spencer (1994) observed 35 times as many fish shoals over a recently beam trawled line compared with adjacent unfished areas which implied that fish moved into areas of disturbance. Similarly, gadoids were observed to aggregate around newly disturbed pits in sandy sediments (Hall *et al.* 1993a). Dietary analyses of gurnards and whiting caught on recently beam trawled and undisturbed areas revealed that both species consumed significantly greater numbers of the amphipod, *Ampelisca spinipes* within the fished area. This amphipod constructs a tube that protrudes from the surface of the seabed which makes it vulnerable to contact with bottom fishing gear. Interestingly, gurnards normally eat large prey items such as shrimps, *Crangon* spp., and swimming crabs, *Liocarcinus* spp., but preferentially selected *A. spinipes* when feeding within the trawl tracks. This switch in diet, implied that large numbers of amphipods were made available to predatory fish as a result of trawling (Hughes & Croy 1993). Adult queen scallops, *Aequipecten opercularis,* do not occur in the diet of whiting under normal circumstances. However, after trawling the distinctive orange gonads of these bivalves were recorded in whiting stomach contents, indicating that these molluscs had been damaged by the trawl (Kaiser & Spencer 1994). Similar responses to fishing disturbance were also recorded for dab, *Limanda limanda,* which were attracted to animals damaged by the trawl within 20 minutes, and increased to three times their former abundance after 24 h (Kaiser & Spencer 1996a). However, these responses varied between different habitats. Although dabs aggregated in trawled areas in shallow (< 20 m) sandy habitats (Kaiser & Spencer 1996b), in deeper (40 m) muddy sediments dab abundances were reduced 24 h after fishing (Kaiser & Ramsay 1997). However, the diet composition of those dab captured in the trawled area differed significantly from those captured in adjacent undisturbed areas. Dab from the undisturbed areas mainly consumed the arms of the brittlestar *Amphiura* spp. which lie on the surface of the sediment, whereas those feeding in the disturbed area greatly increased their intake of brittlestars and fed predominantly on the oral discs of brittlestars. This suggests a more localised reponse to fishing disturbance in the deeper muddy habitat, and emphasises the influence of local environmental conditions predator behaviour (Kaiser & Ramsay 1997).

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 charactecrics (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.

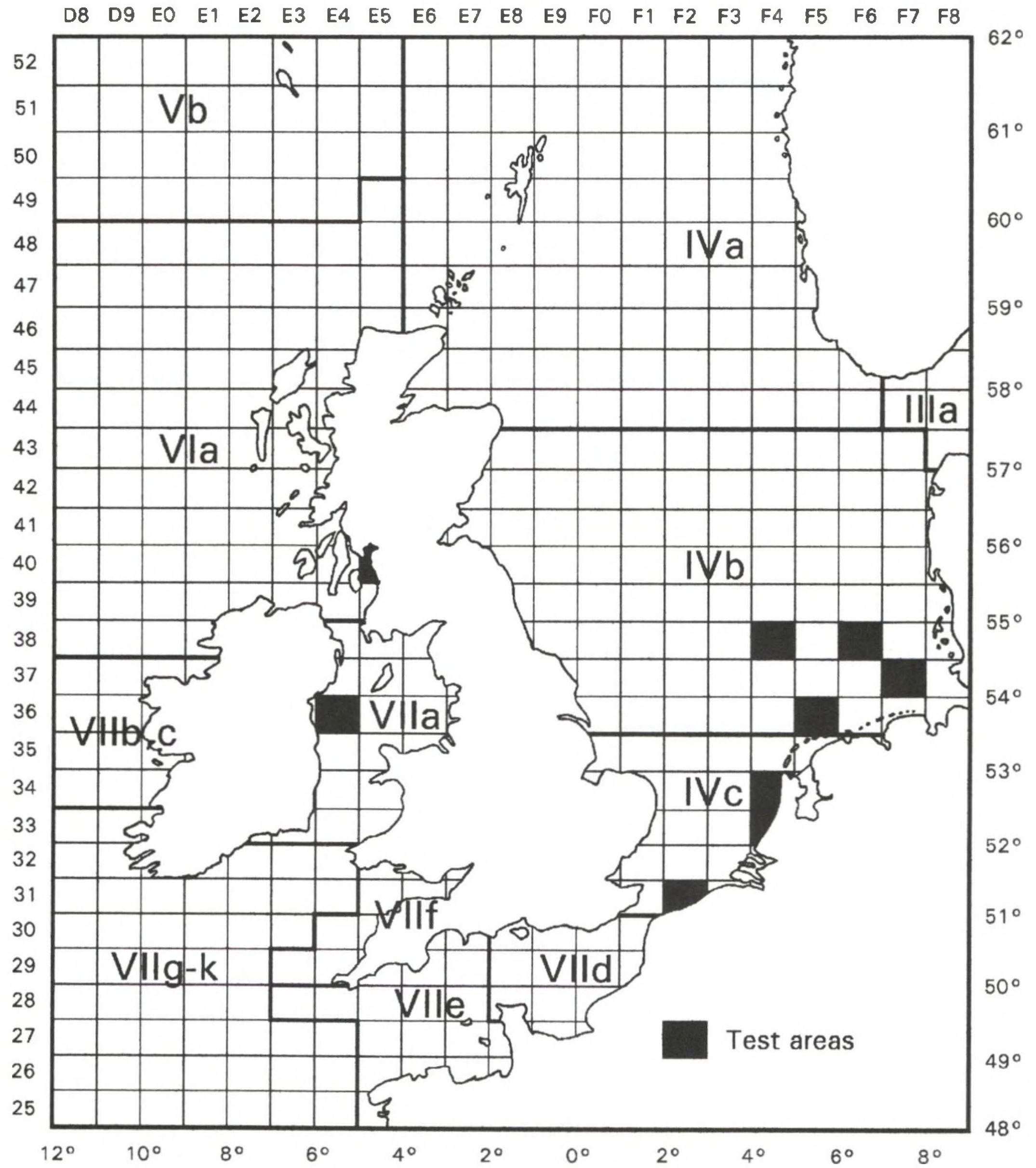


Fig. 2.3.1. Fishing areas physical impact studies.

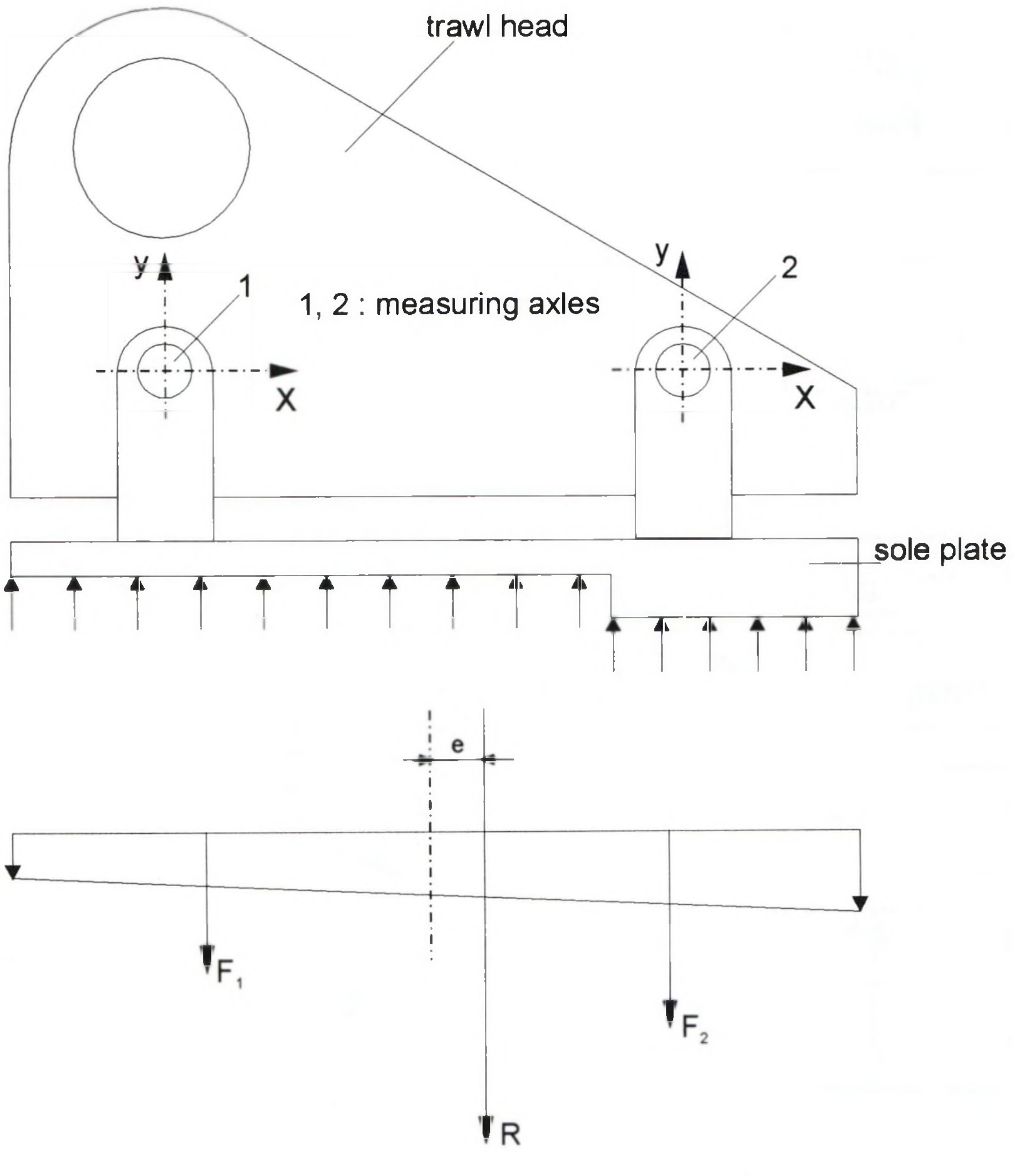


Fig. 2.3.2. Instrumented trawl head - principle.

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.

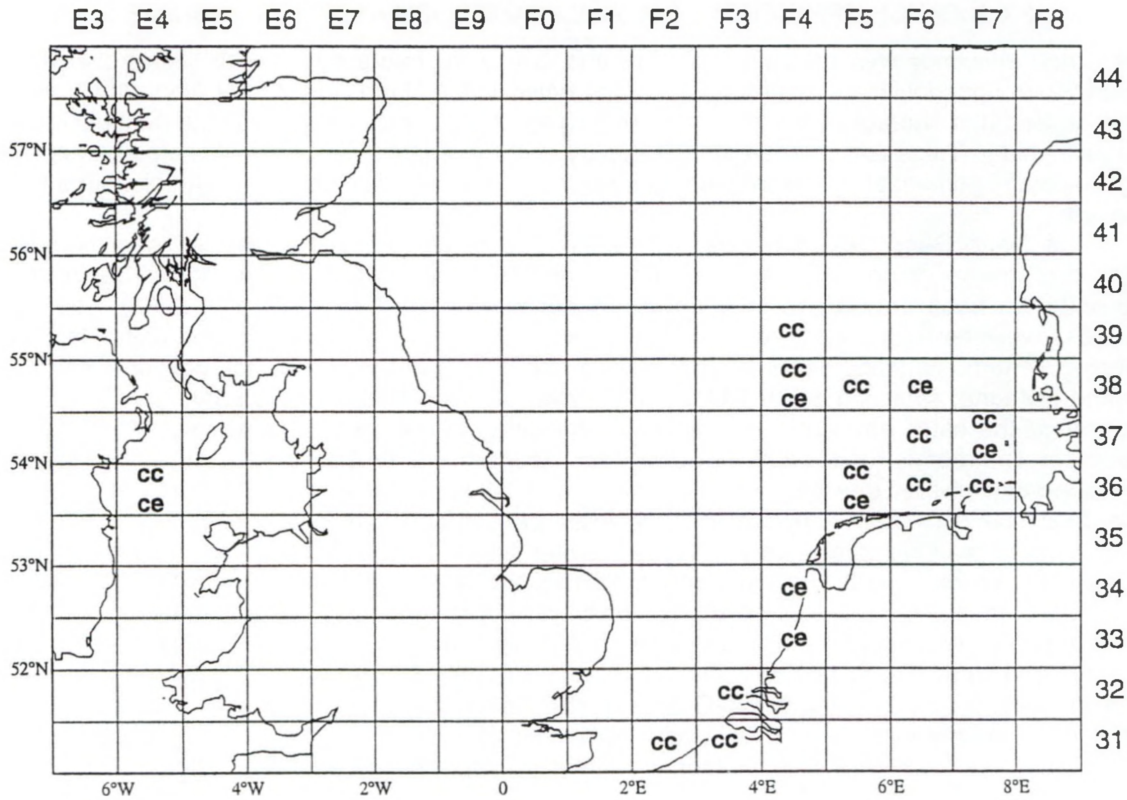


Fig. 2.4.1. Locations of field studies on relative catch composition (cc) and catch efficiency (ce).

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.

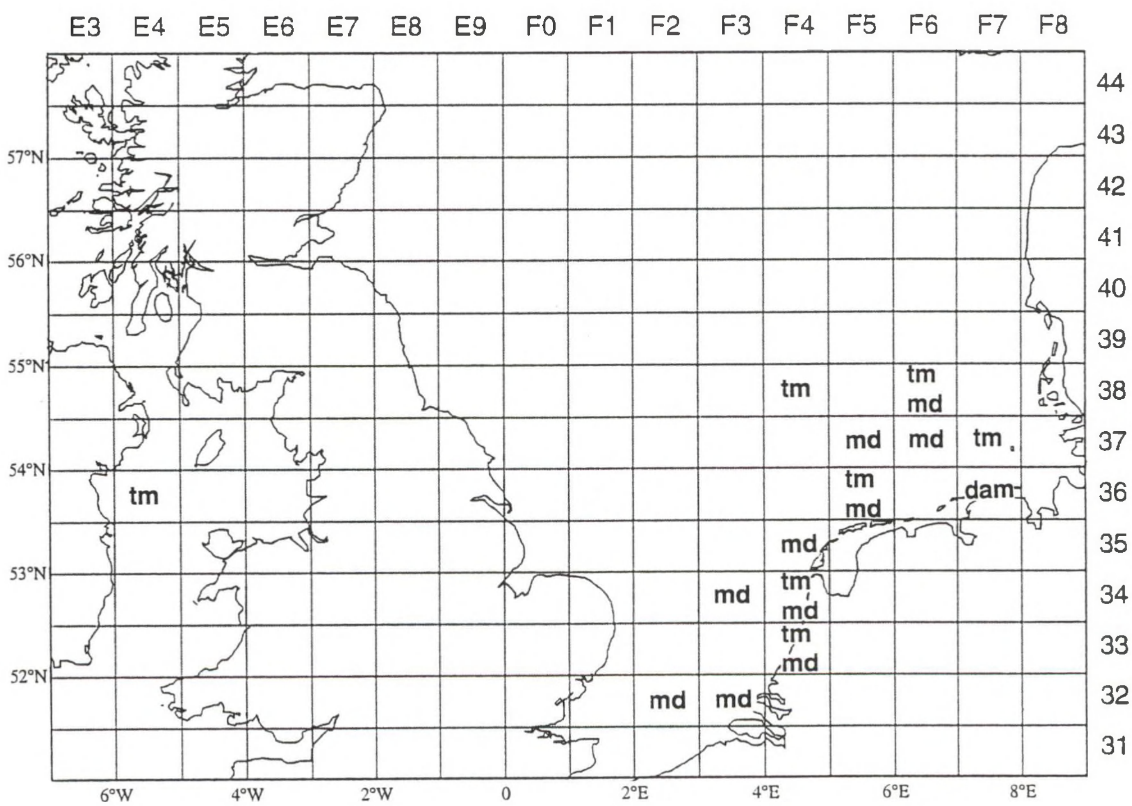


Fig. 2.5.1. Locations of field studies on mortality of discards, damage to invertebrates and total direct mortality. tm = total direct mortality of invertebrates; md = mortality of discards; dam = damage to invertebrates.

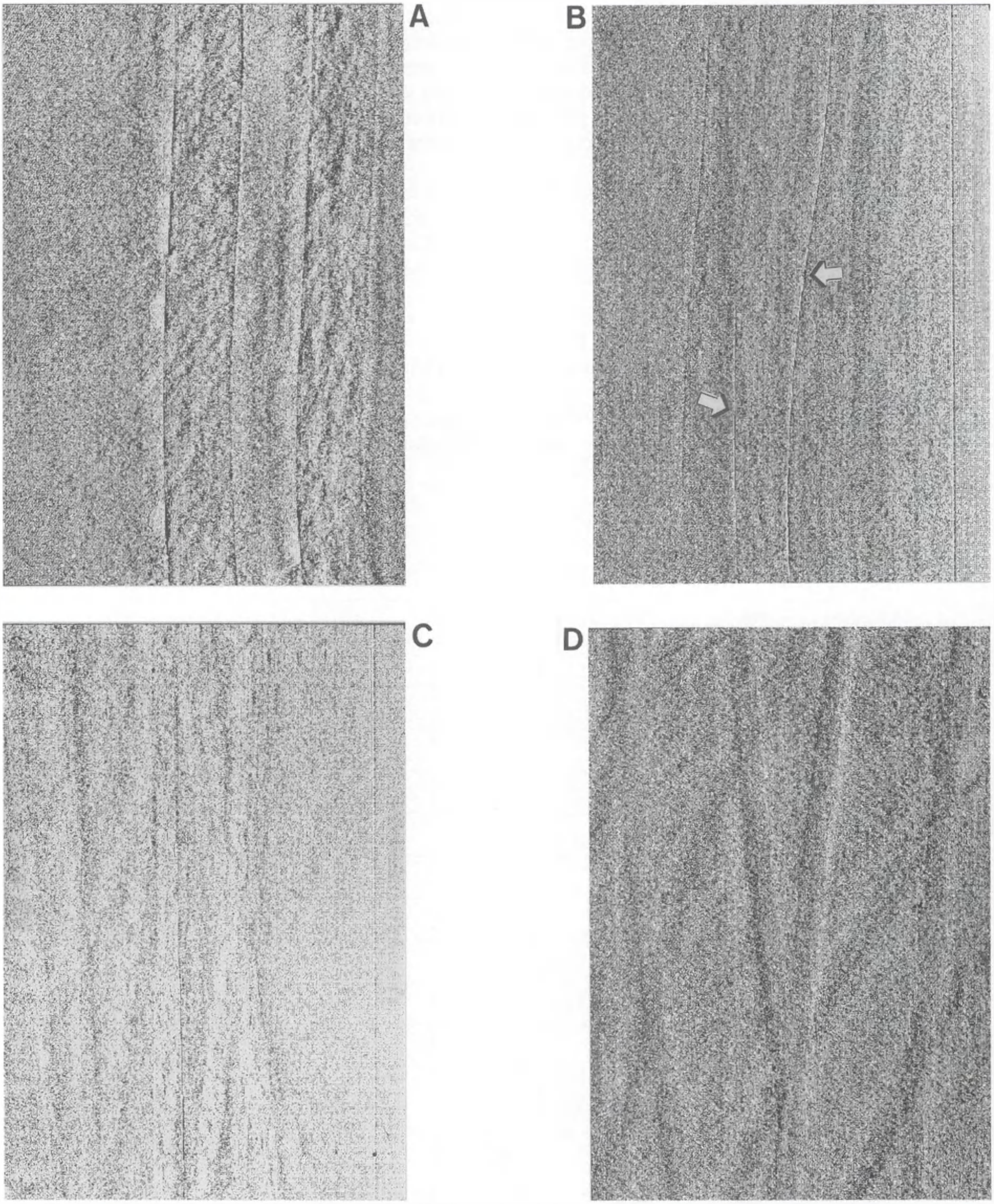


Fig. 2.5.2. Side-scan sonar recordings of trawled strips with different types of trawls and tracks of the Triple-D:

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 m^2 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.

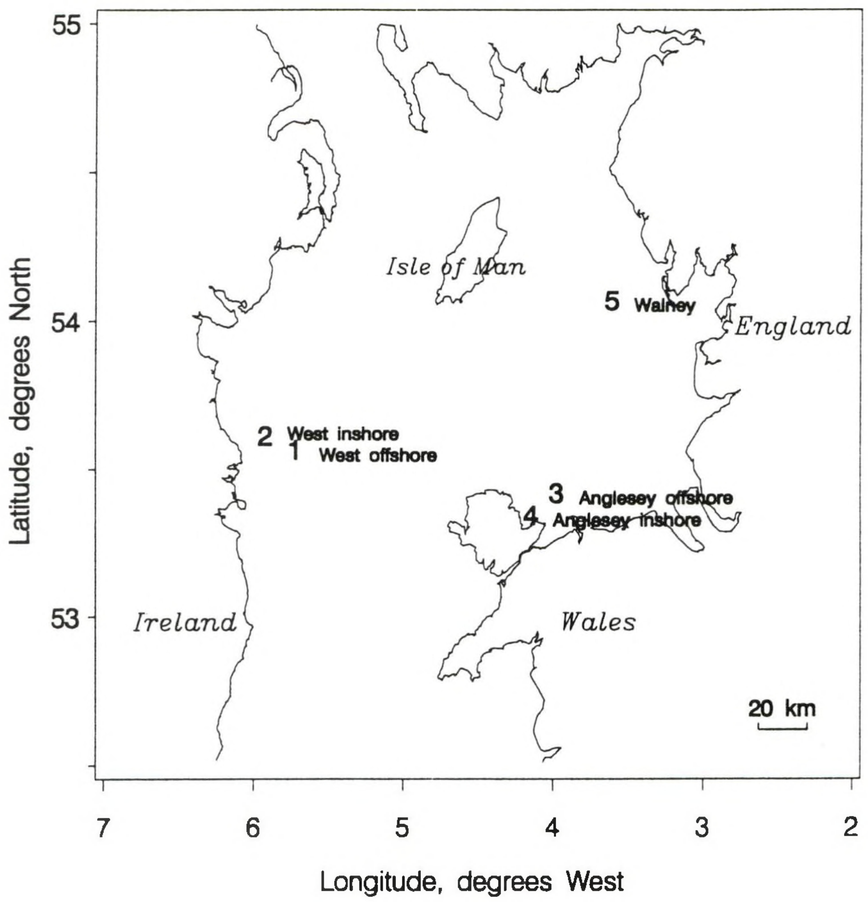


Fig. 2.6.1. Map of the Irish Sea showing the geographical positions of experimental sites. Dates and positions in the table below.

Nr on map	Year	Date	Net	Ship (R.V.)	Position North °N	Position North min.	Position East °E	Position East min.	Depth m		
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		
										exposure	
Stations for baited traps										hrs	n
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	

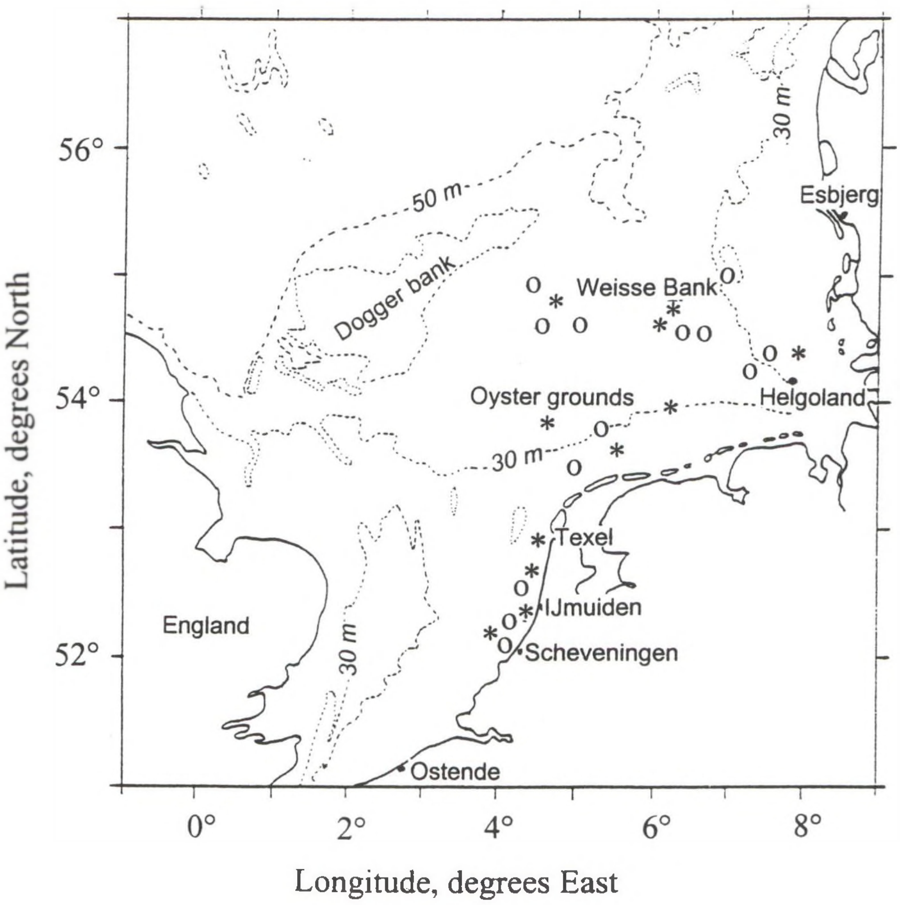


Fig. 2.6.2. Map of the southern North Sea showing the locations for repeated trawling (o) and for baited traps (*). Dates and positions below.

Nr	Year	Date	Net	Ship (R.V.)	Position North °N	Position North min.	Position East °E	Position East 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

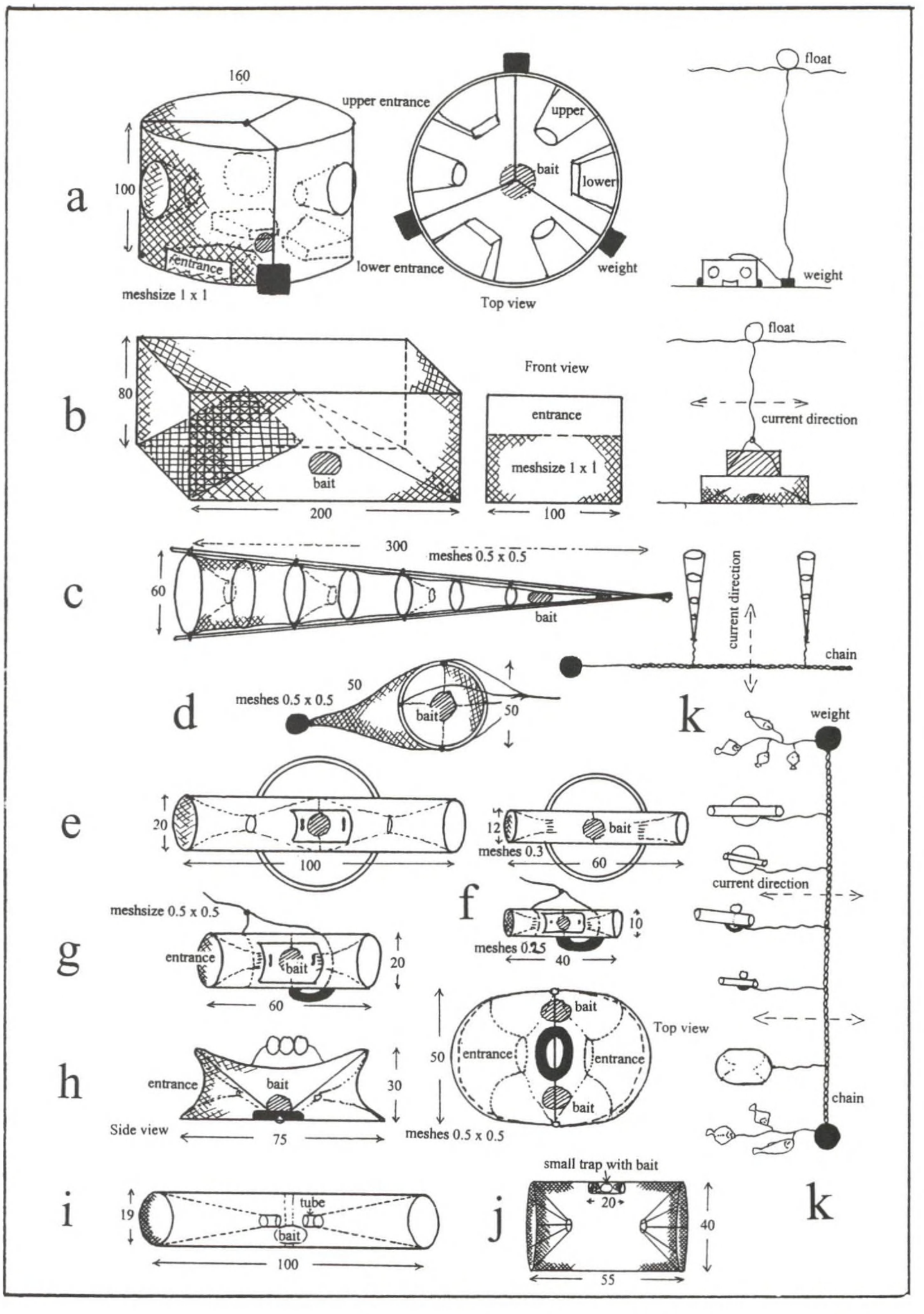


Figure 2.6.3. Different kinds of traps used in the investigations on preference of scavenging species for different kind of bait.

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.

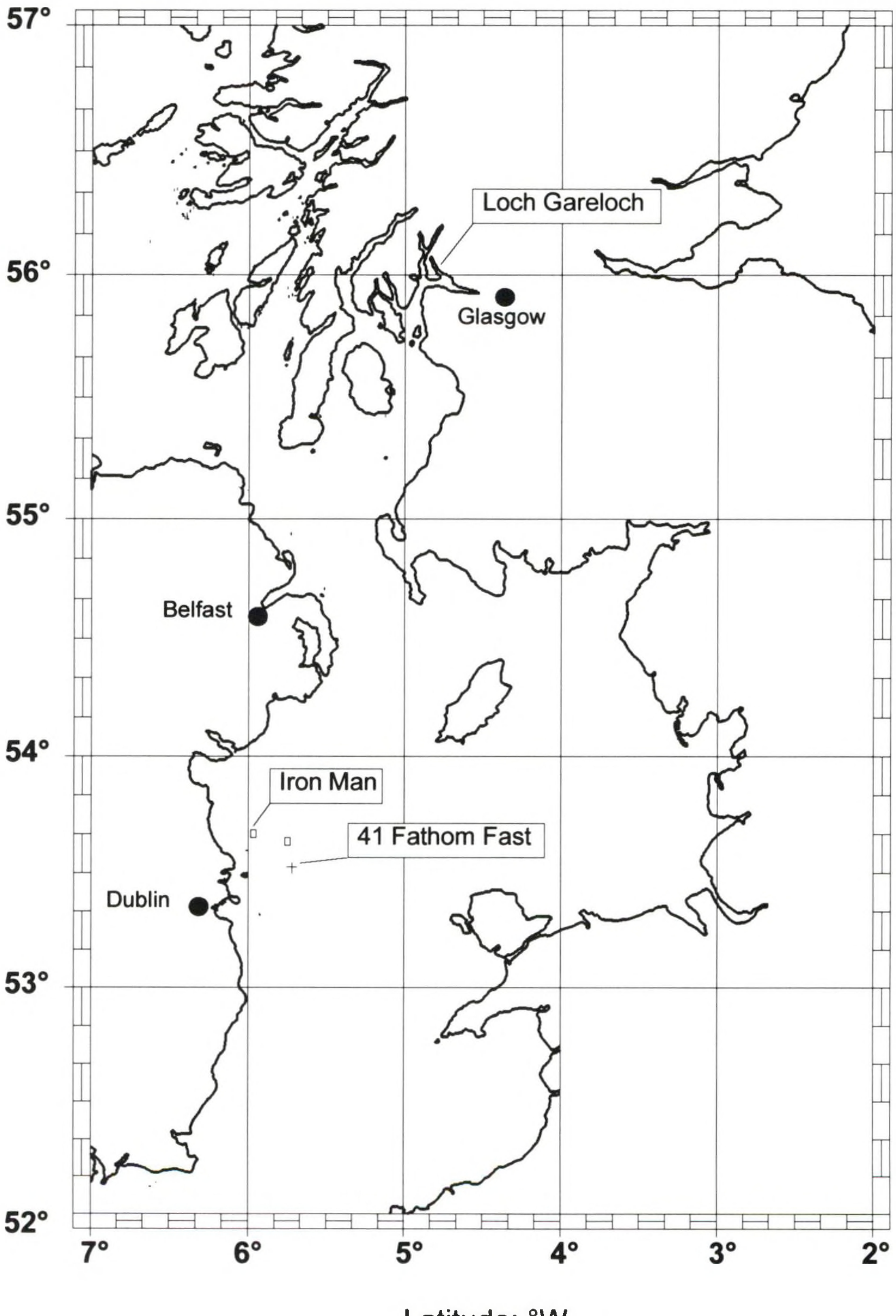


Fig. 2.7.1. Map of Irish Sea and west coast of Scotland showing Loch Gareloch and Irish Sea study sites.

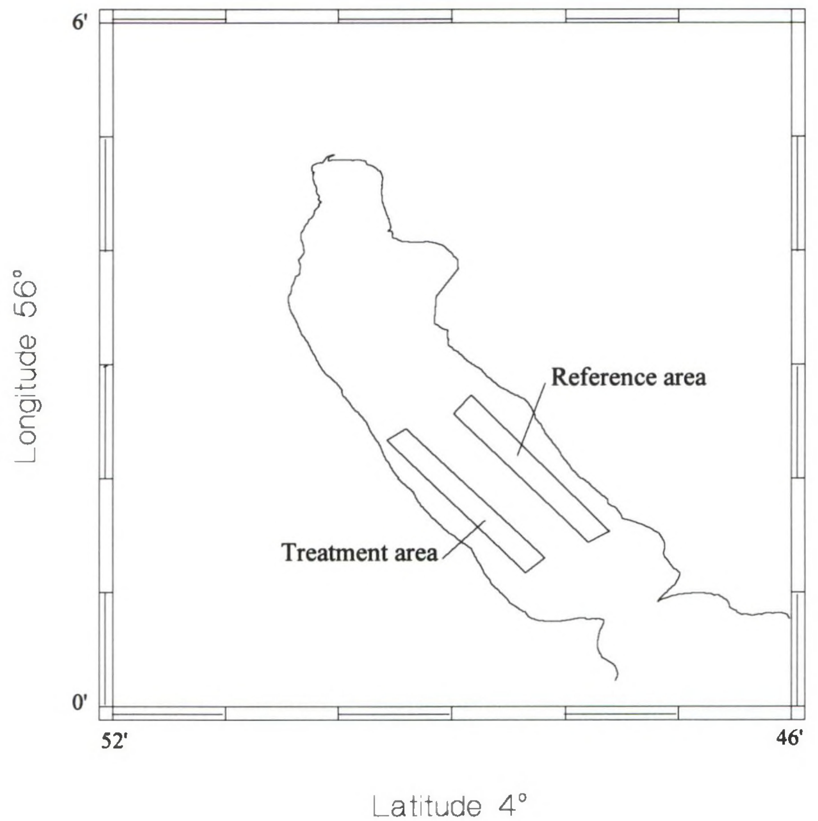


Fig. 2.7.2. Map showing treatment and reference area in Loch Gareloch.

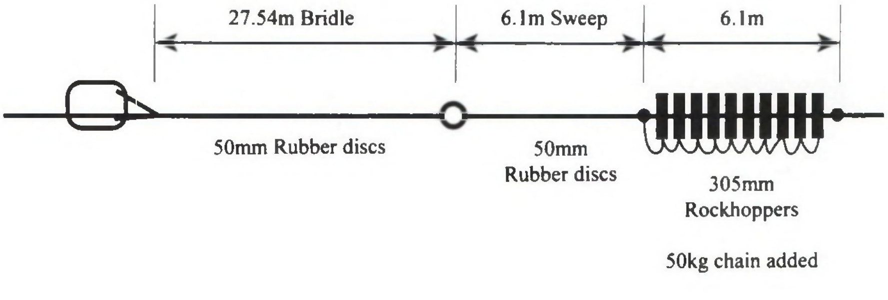


Fig. 2.7.3. Gear diagram of modified rockhopper gear used in Loch Gareloch.

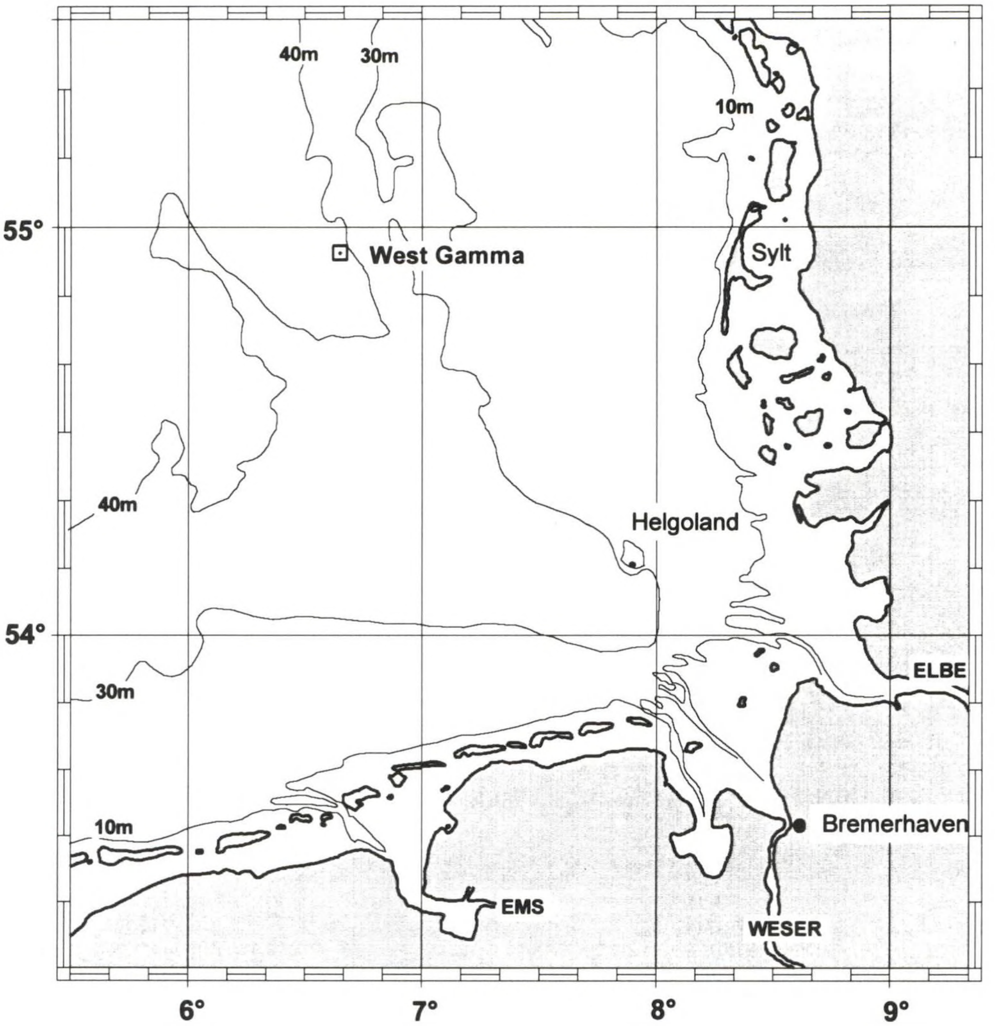


Fig. 2.7.4. The area of investigation "West Gamma" in outer the German Bight. The small frame indicates the area covered in Fig. 2.7.5.

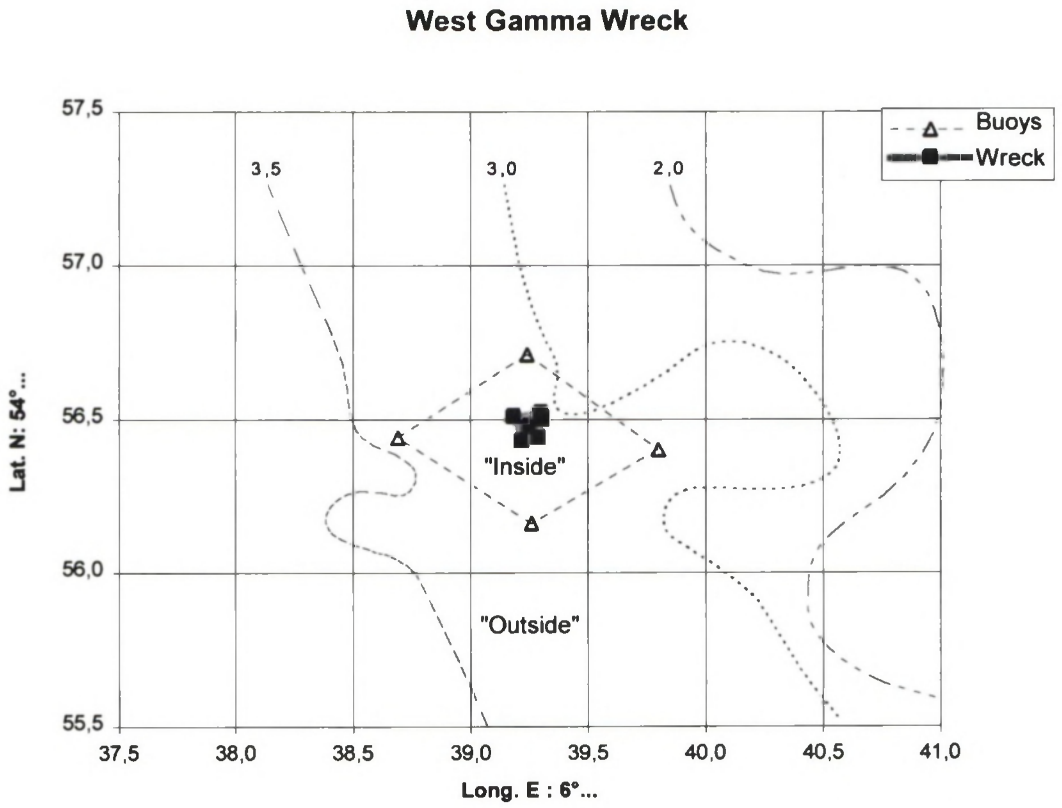


Fig. 2.7.5. The study area surrounding the West Gamma wreck. Distribution of sediment (medium grain size in Phi-notation).

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	- 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.

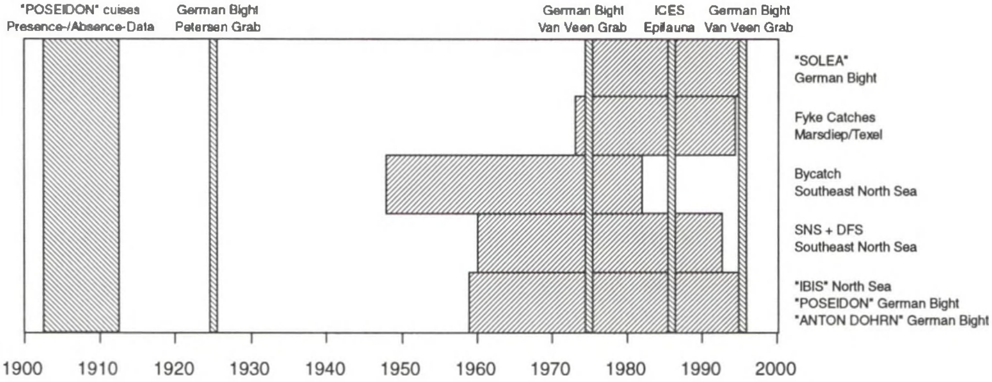


Fig. 2.8.1. Time covered by the data series.

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).

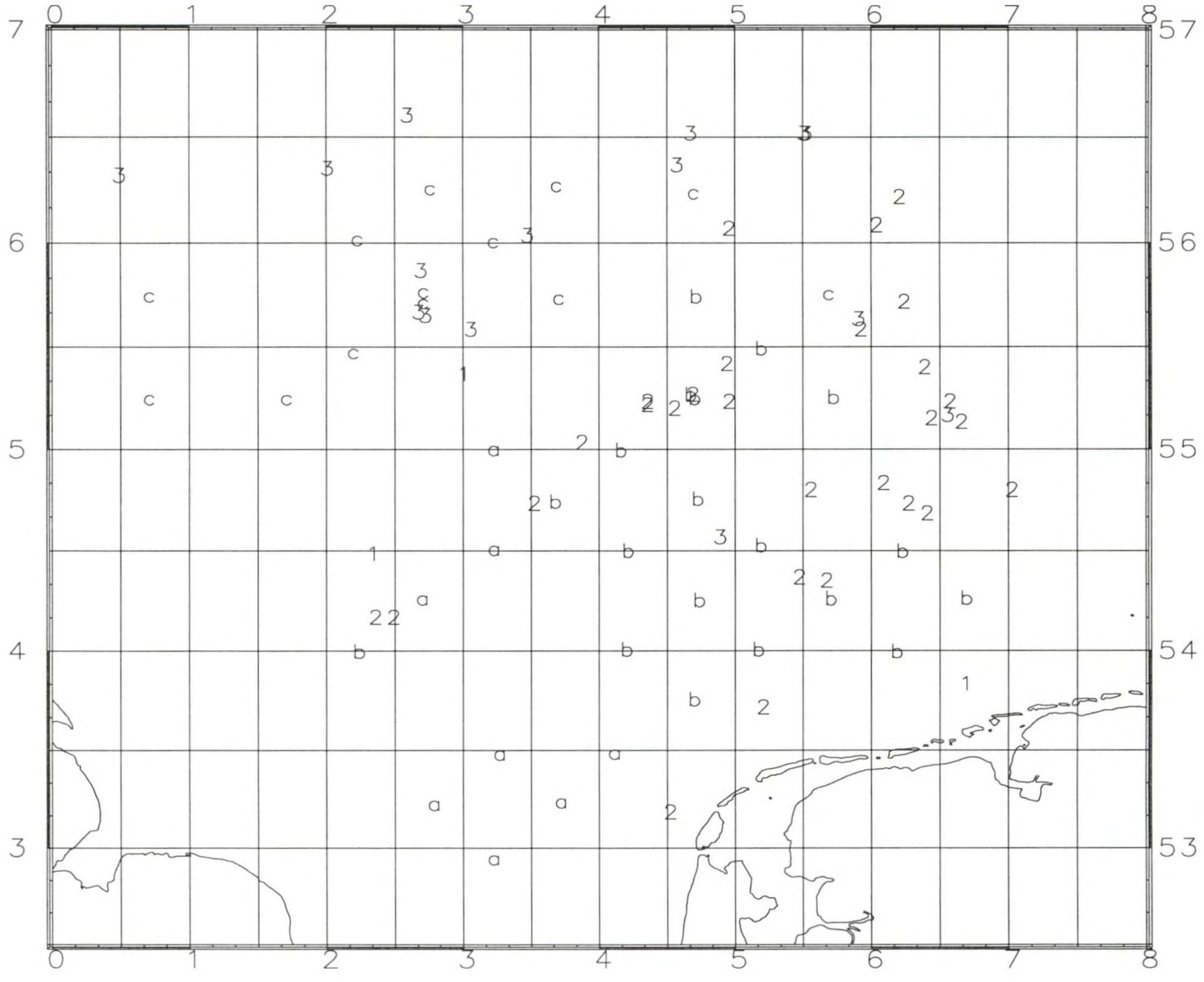


Fig. 2.8.1.1. Map of the selected stations:
1 = stations from 1902-12, depth 0-30 m
2 = stations from 1902-12, depth 30-50 m
3 = stations from 1902-12, depth > 50 m
a = stations from 1986, depth 0-30 m
b = stations from 1986, depth 30-50 m
c = stations from 1986, depth > 50 m

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).

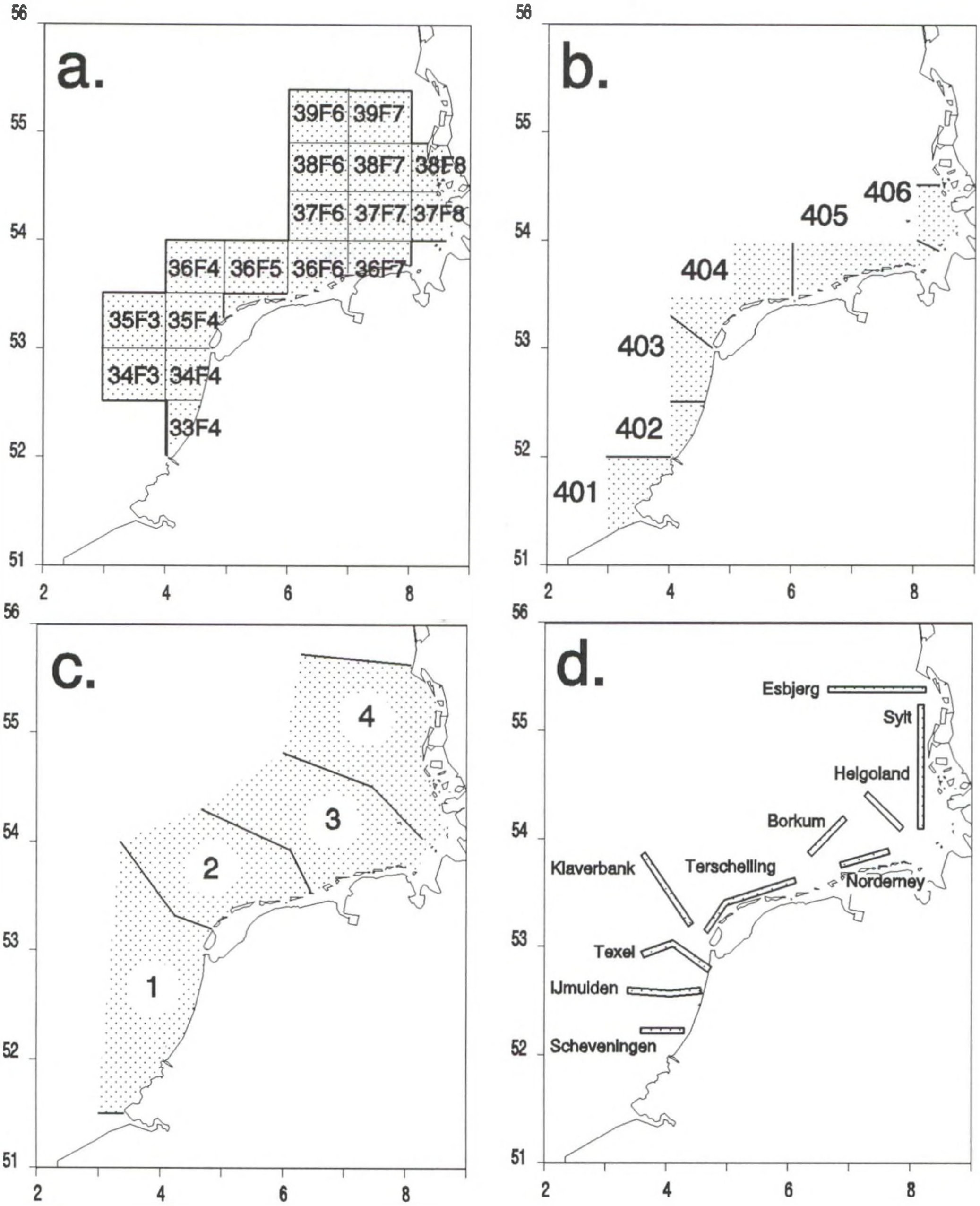


Fig. 2.8.4.1 Location of sampling areas in the (south-eastern) North Sea; (a) sampling ICES quadrants of International Bottom Trawl Surveys and International Young Fish Surveys (fish), (b) sampling areas of Demersal Fish Surveys (fish), (c and d) sampling areas and transacts of Sole Net Surveys (fish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

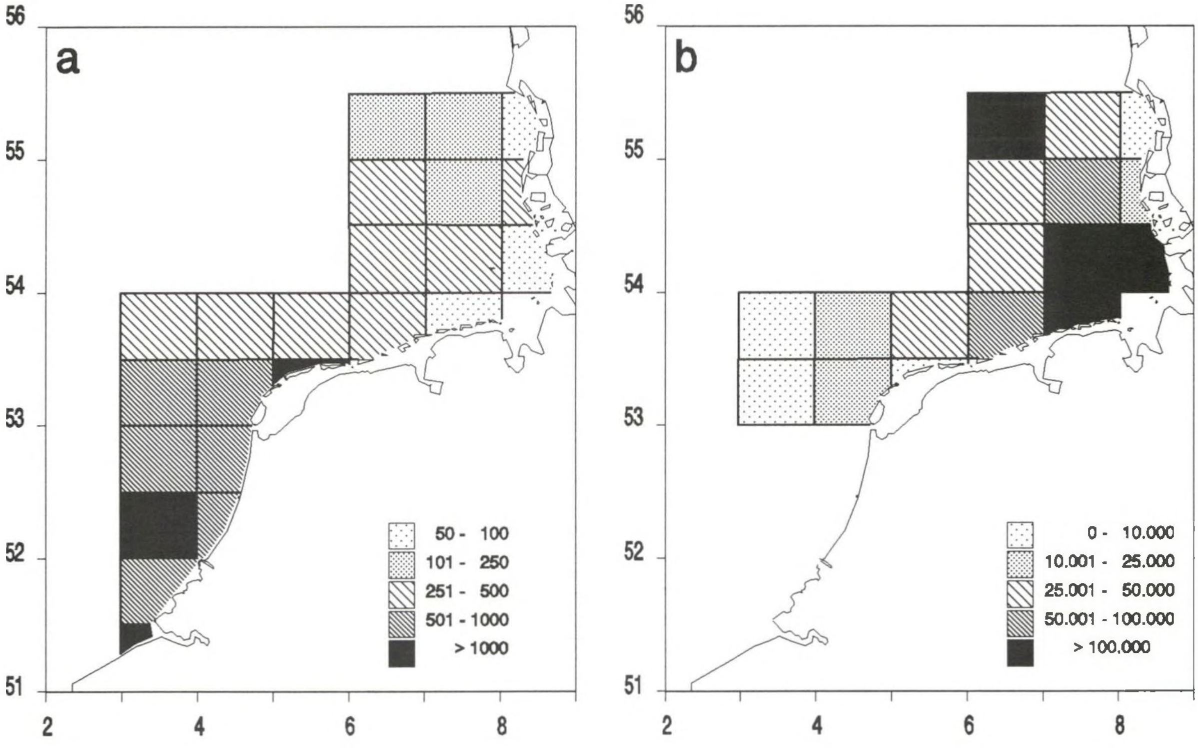


Fig. 2.8.4.2 (a) Total fishing effort (fishing hours 100 n.m.$^{-2}$) of Dutch bottom trawl fleet in the south-eastern North Sea between 1974 and 1994 (source: de Groot & Verboom 1994), (b) Total fishing effort (fishing hours quadrant^{-1}) of German bottom trawl fleet in the south-eastern North Sea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

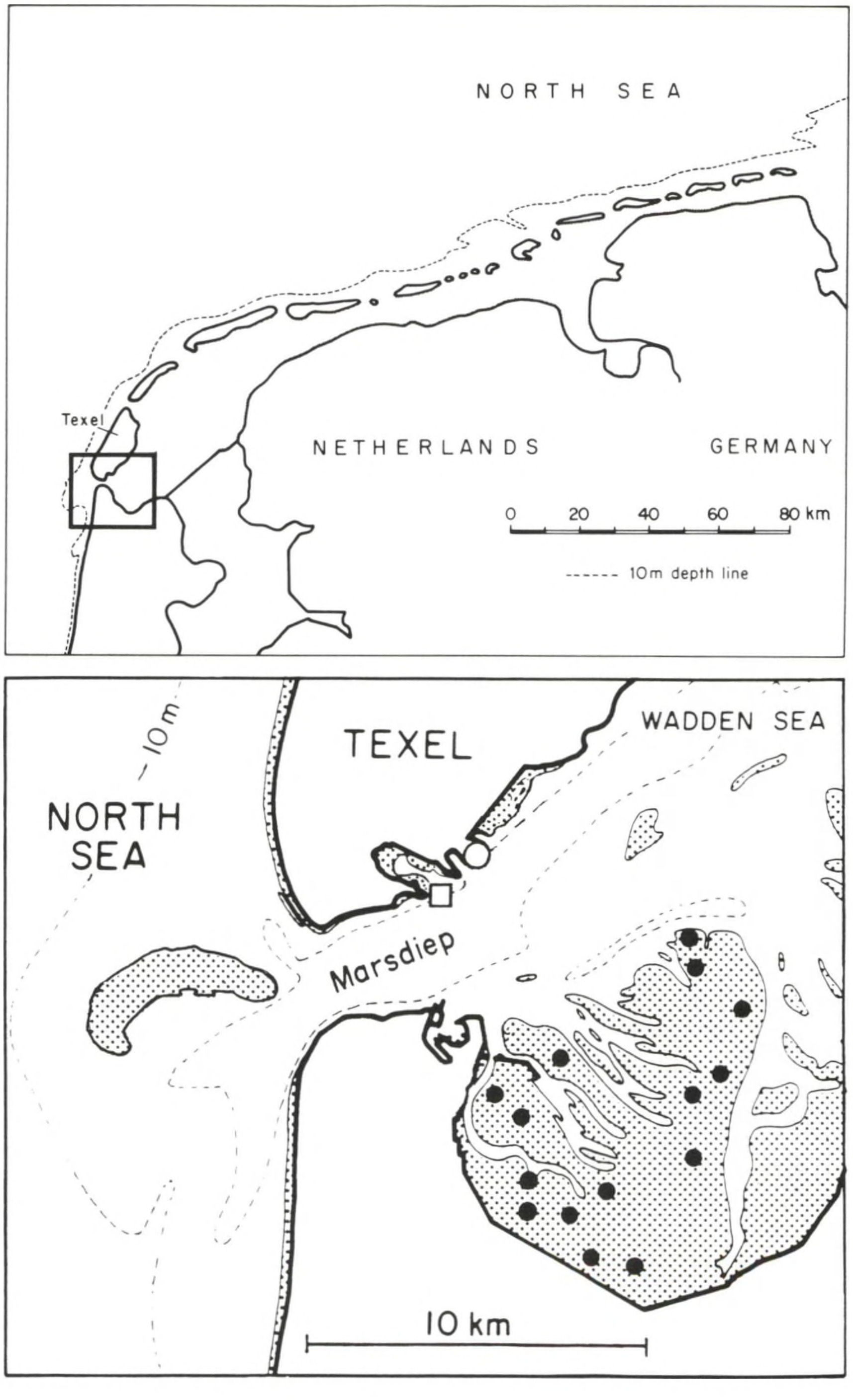


Fig. 2.8.5.1. Location of stake net (□) and phytoplankton sampling (O) station in the Marsdiep, the westernmost tidal inlet of the Wadden Sea, and locations of 15 fixed zoobenthos stations (●) at Balgzand tidal flats.

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.

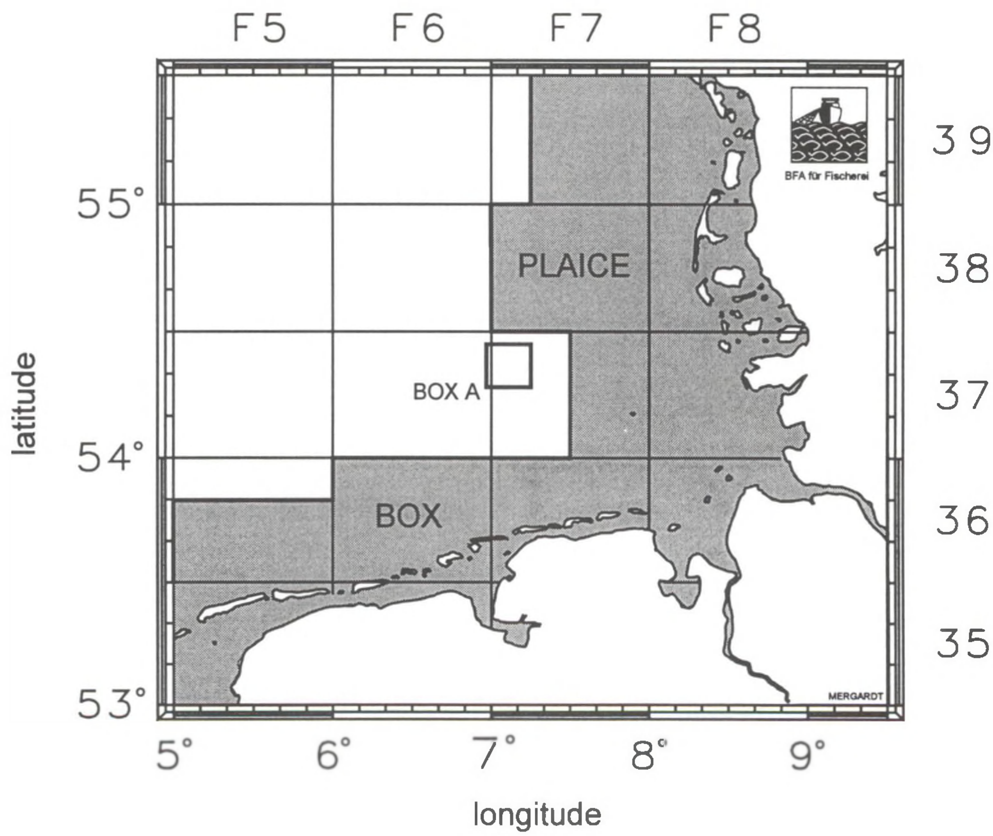


Fig. 2.8.6.1. The location of the Box A area of 10 to 10 nm near Helgoland which was used to detect possible changes in fish assemblages.

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).

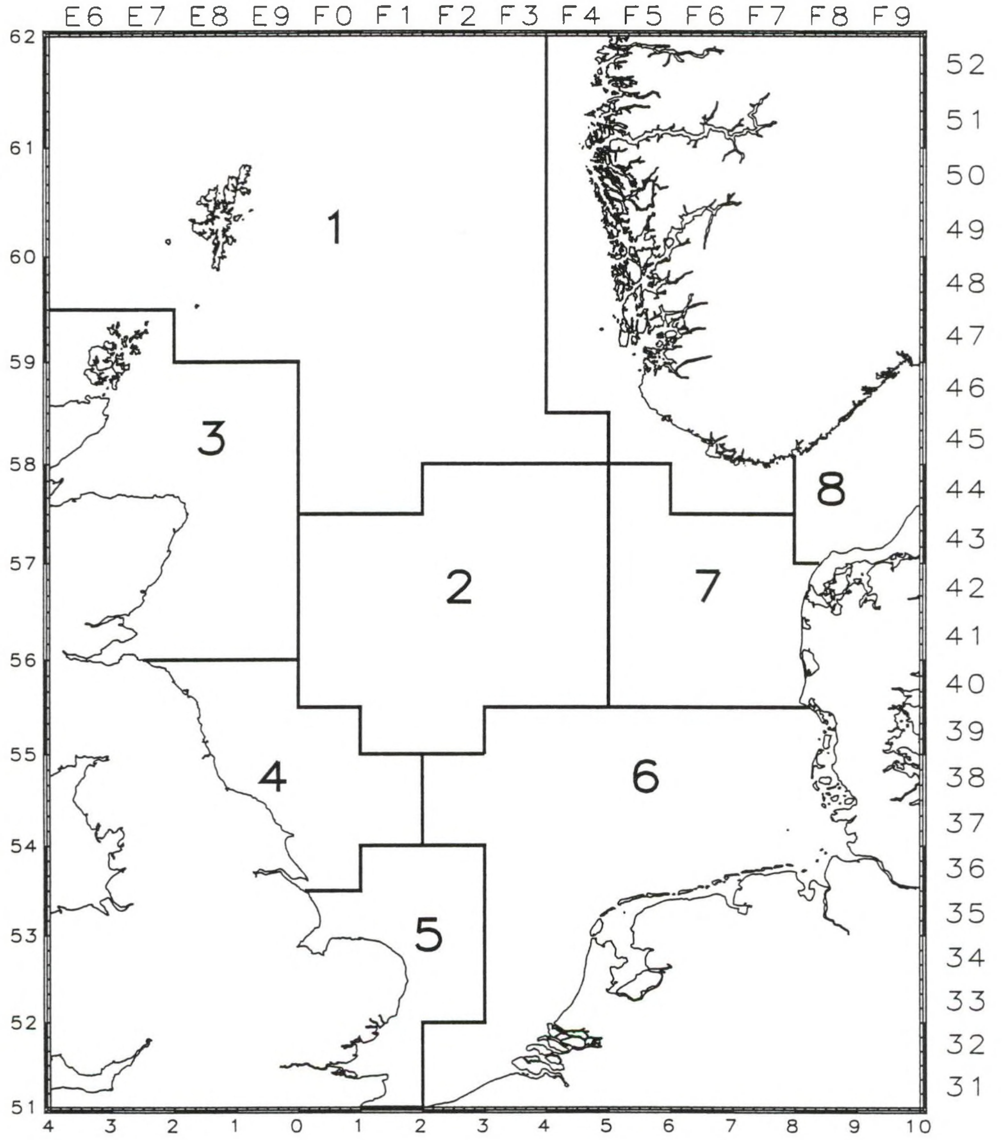


Fig. 2.8.7.1. Map of the North Sea with Roundfish areas.

TABLE 2.8.7.1a.

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

year	roundfish area							total
	1	2	3	4	5	6	7	
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							total
	1	2	3	4	5	6	7	
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 19^{th} 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.

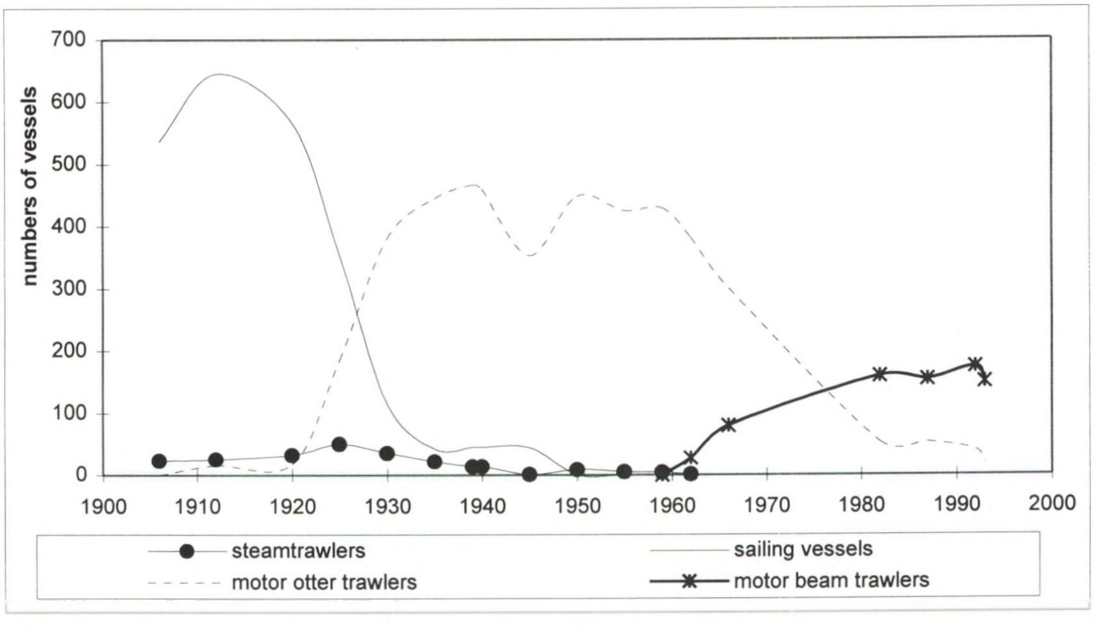


Fig. 3.1.1. Vesselnumbers in the Belgian fleet.

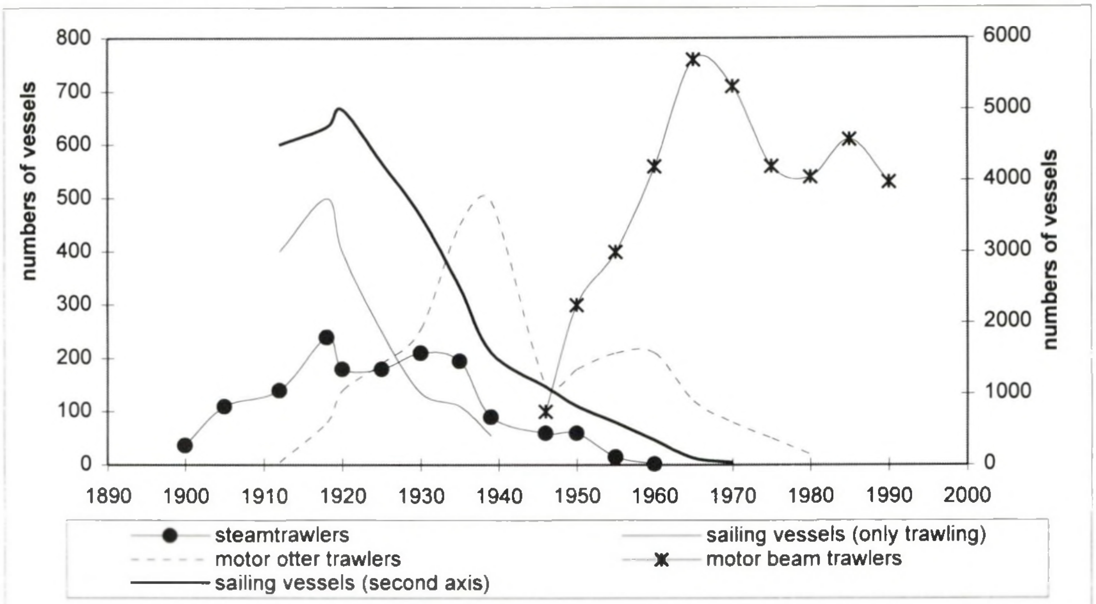


Fig. 3.1.2. Vesselnumbers in the Dutch fleet*.

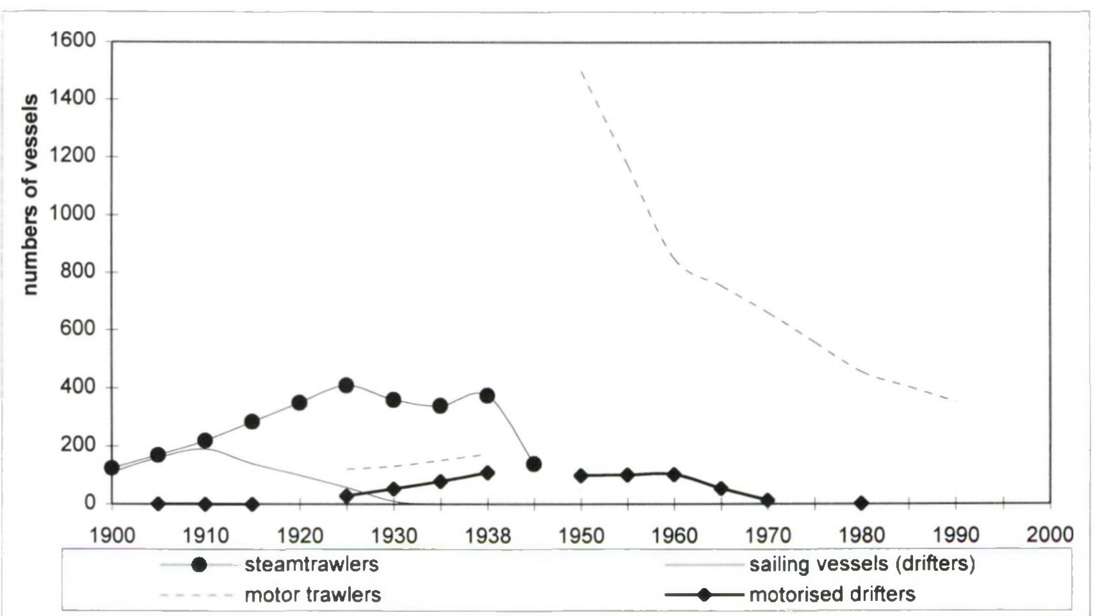


Fig. 3.1.3. Vesselnumbers in the German fleet.

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

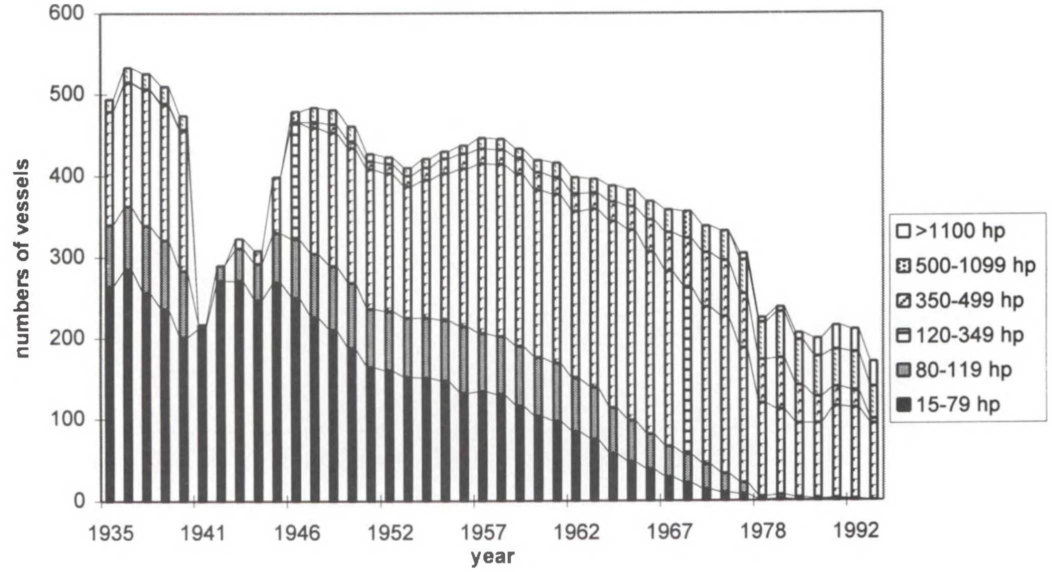


Fig. 3.1.4. Numbers of trawlers per engine power class - Belgium.

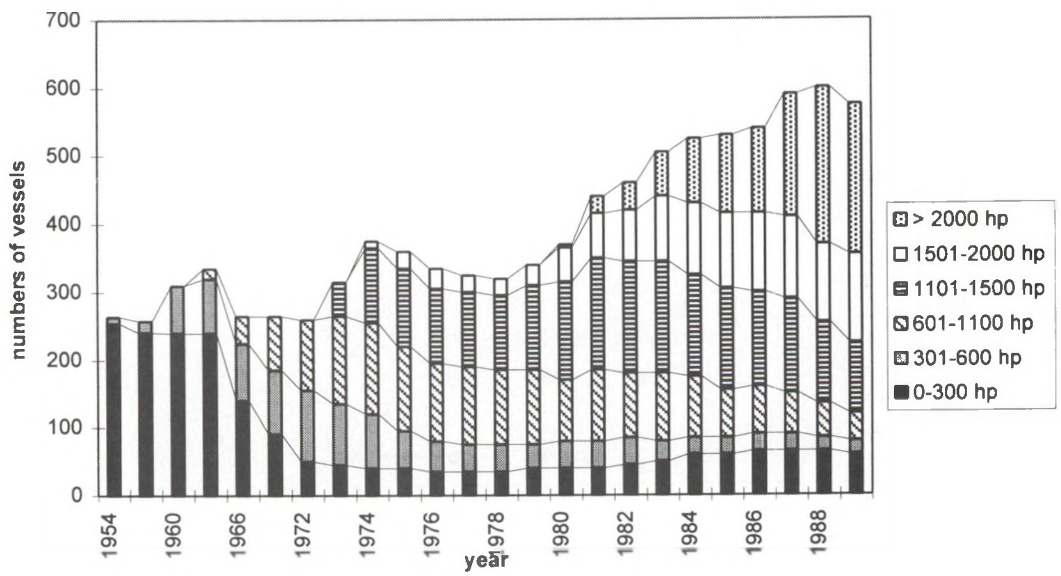


Fig. 3.1.5. Numbers of trawlers per engine power class - Netherlands*.

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

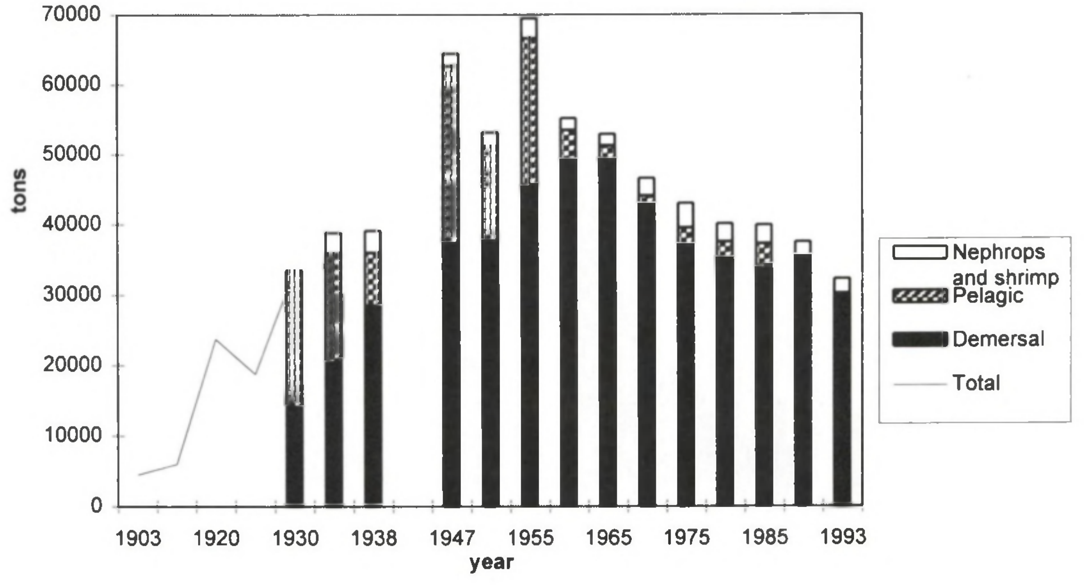


Fig. 3.1.6. Fish landed by Belgian fishing fleet.

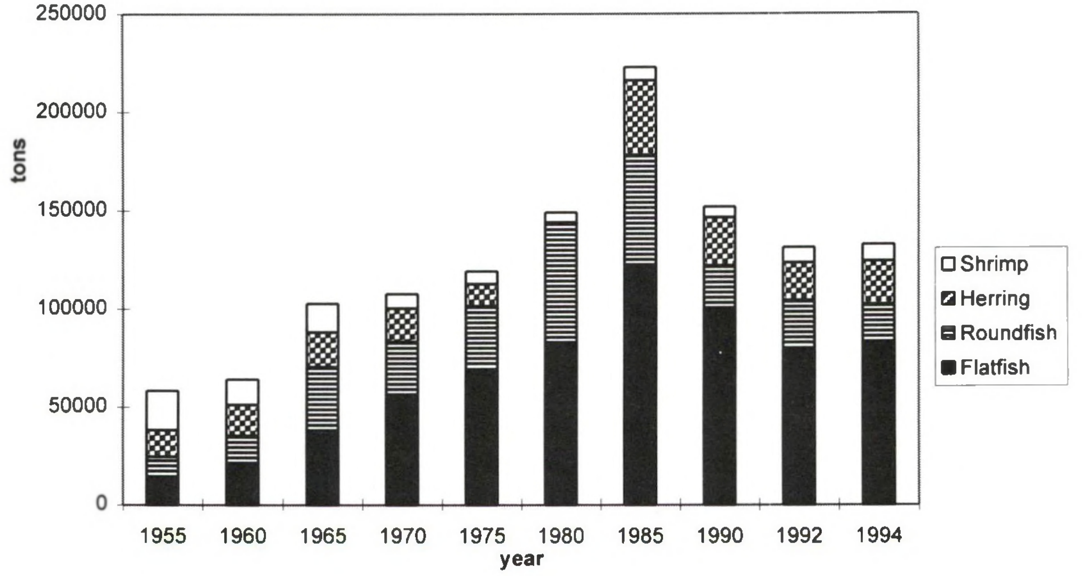


Fig. 3.1.7. Fish landed by Dutch fishing fleet*.

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

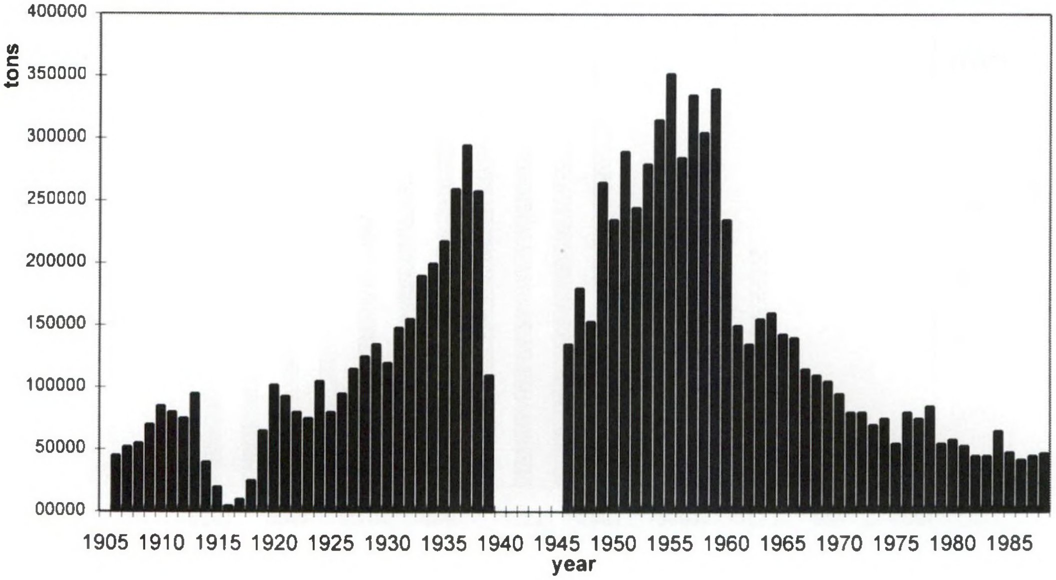


Fig. 3.1.8. Fish landed by the German fishing fleet - total landings.

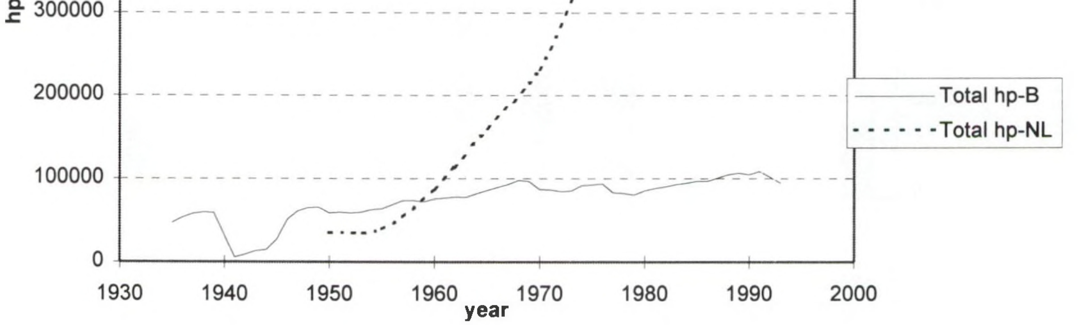


Fig. 3.1.9. Total engine power of fishing fleet (ecl. wind power).

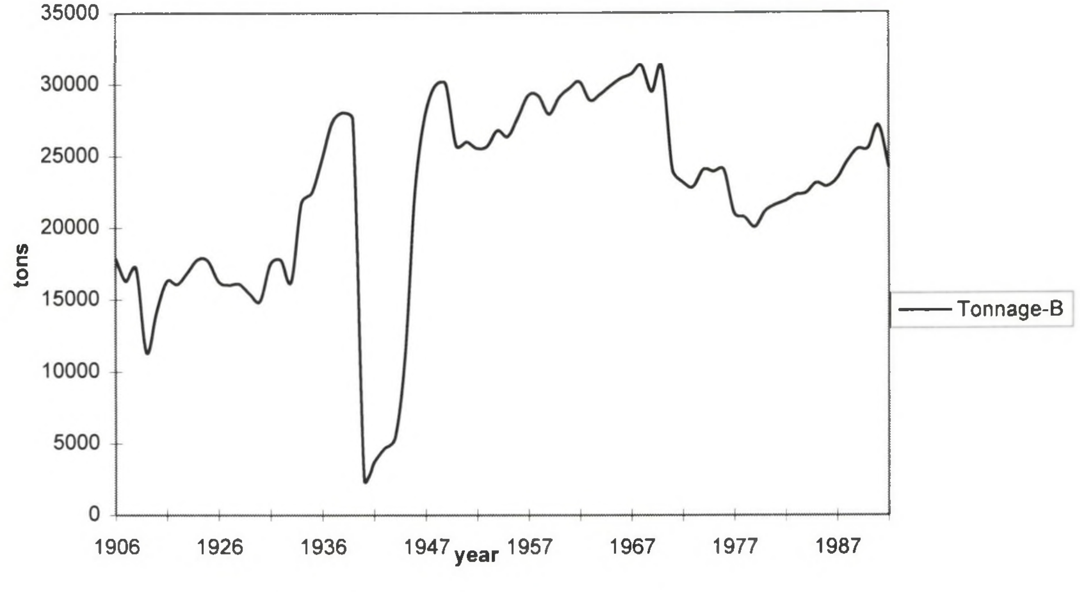


Fig. 3.1.10. Tonnage of Belgium fishing vessels.

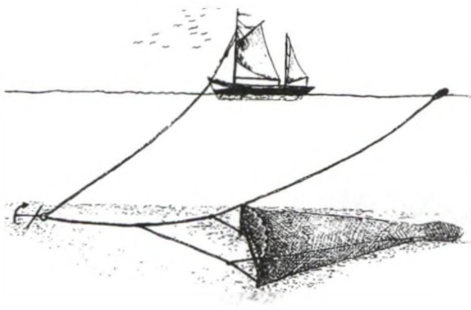


Figure 3.1.11

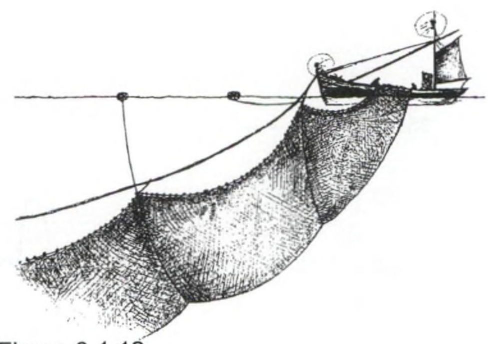


Figure 3.1.12

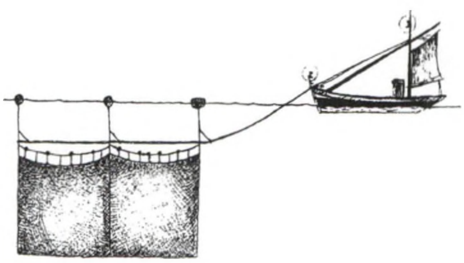


Figure 3.1.13

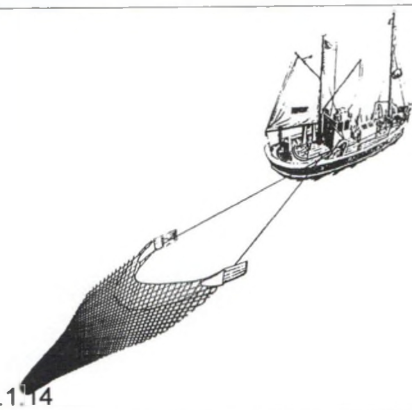


Figure 3.1.14

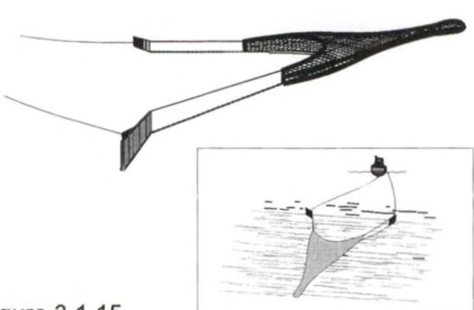


Figure 3.1.15

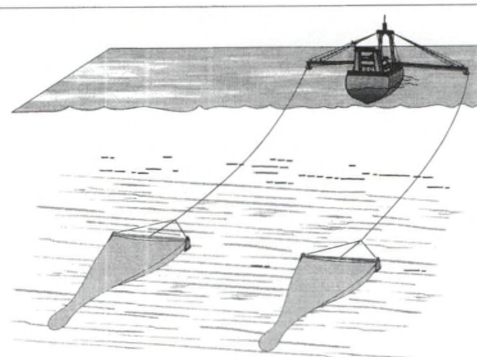


Figure 3.1.17

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

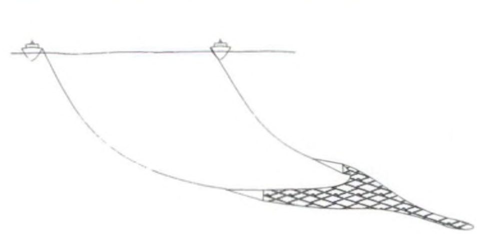


Figure 3.1.16

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 km^2 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 km^2 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 km^2 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 cm^2. 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 cm^2. 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 $1/5^{th}$ 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 $1/5^{th}$ 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.

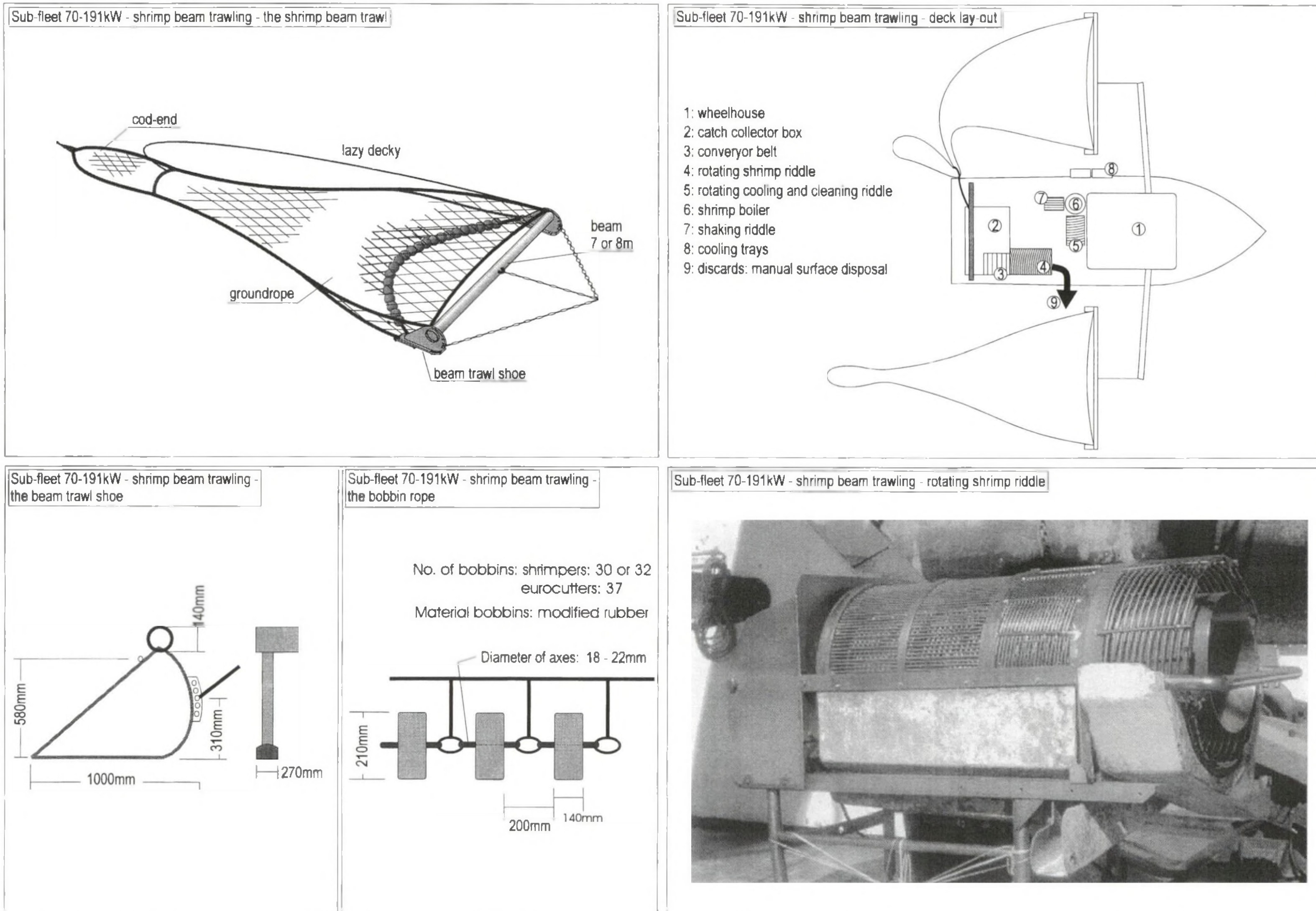


Fig. 3.2.1. Shrimp beam trawling, sub-fleet < 191 kW.

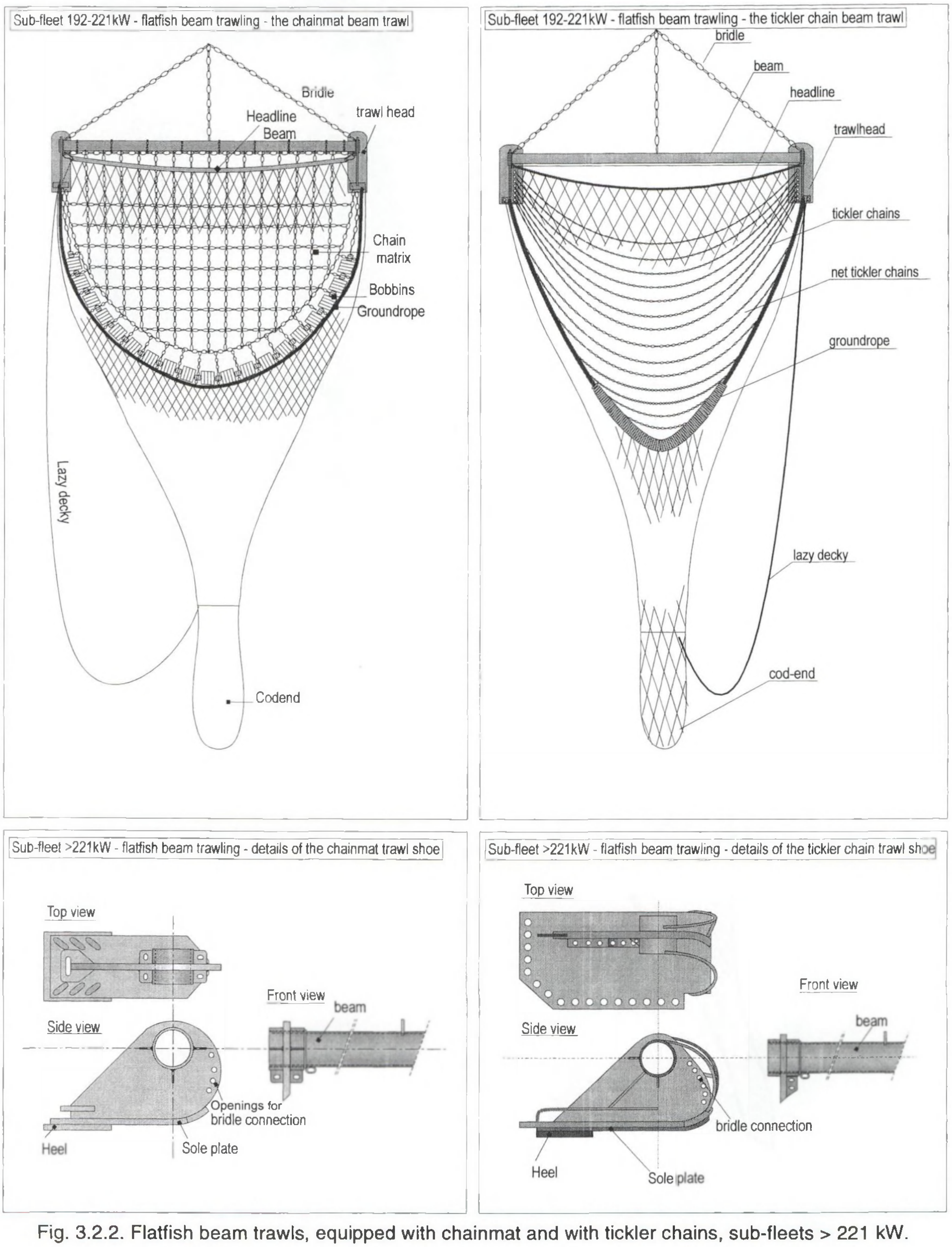


Fig. 3.2.2. Flatfish beam trawls, equipped with chainmat and with tickler chains, sub-fleets > 221 kW.

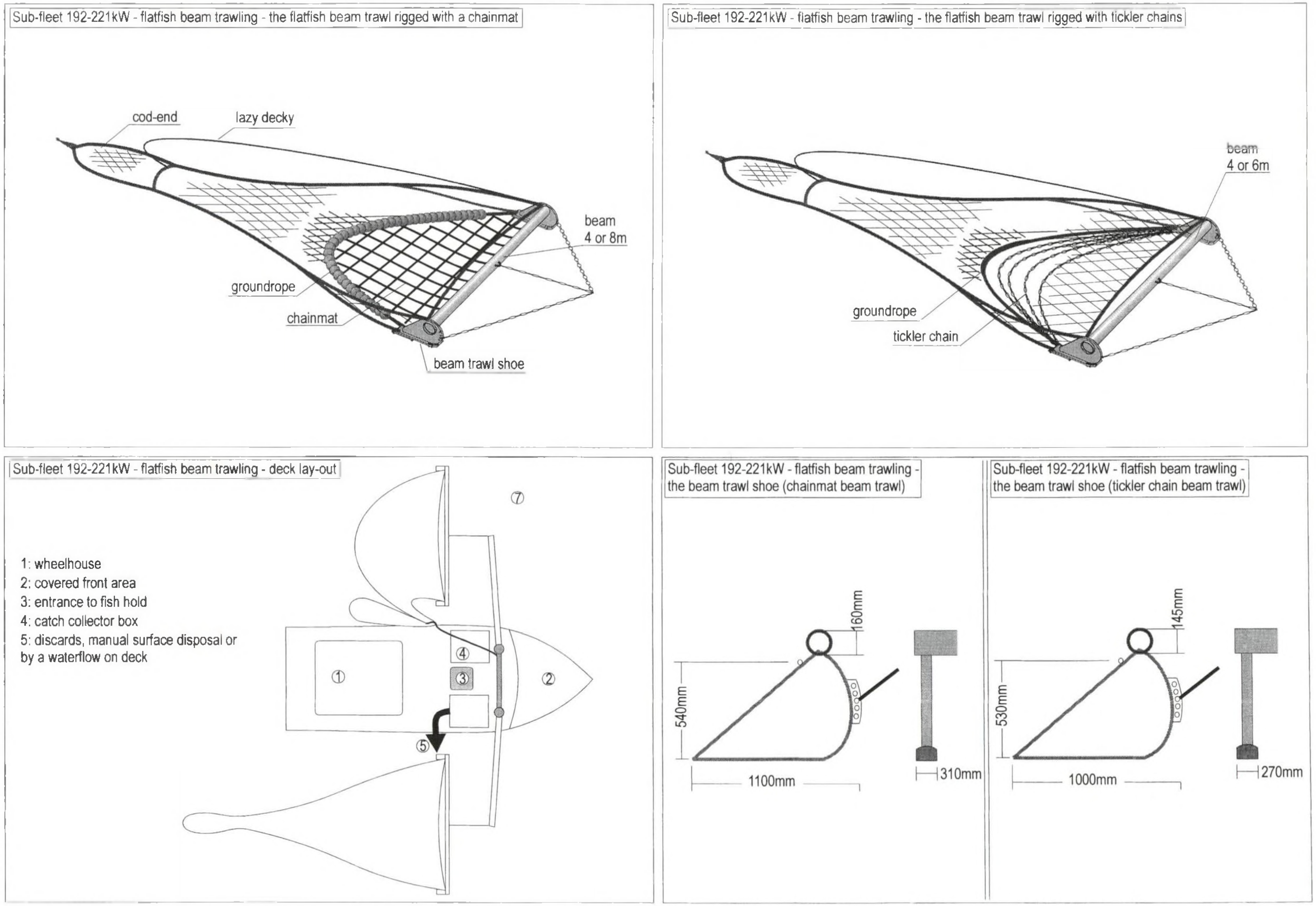
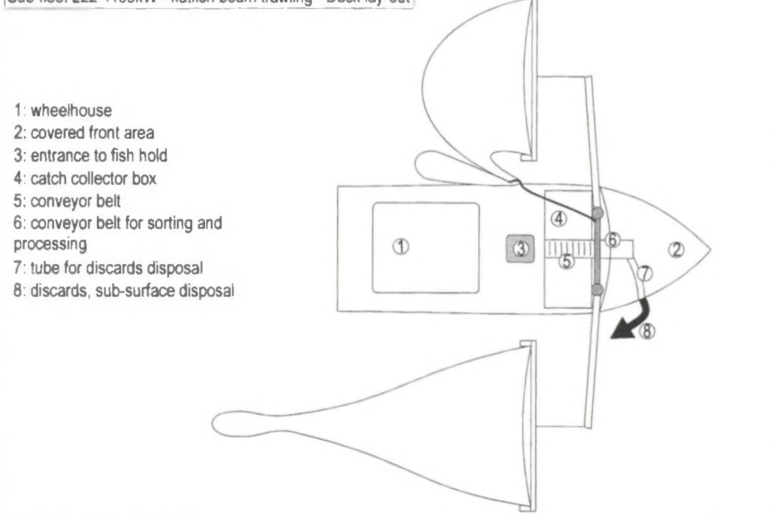
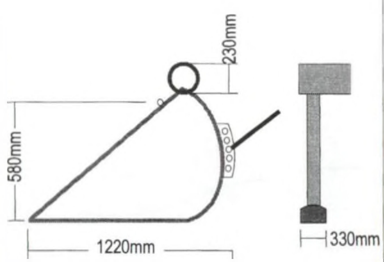


Fig. 3.2.3. Flatfish beam trawling, sub-fleet 192-221 kW.

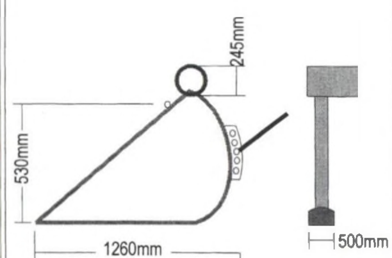
Sub-fleet 222-1100kW - flatfish beam trawling - Deck lay-out



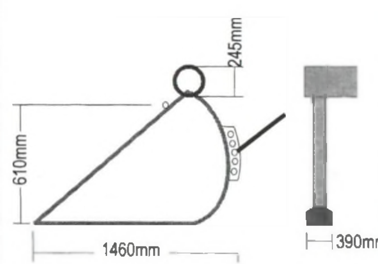
Sub-fleet 222-800kW - flatfish beam trawling - the beam trawl shoe (chainmat beam trawl)



Sub-fleet 222-800kW - flatfish beam trawling - the beam trawl shoe (tickler chain beam trawl)



Sub-fleet 801-1100kW - flatfish beam trawling - the beam trawl shoe (chainmat beam trawl)



Sub-fleet 801-1100kW - flatfish beam trawling the beam trawl shoe (tickler chain beam trawl)

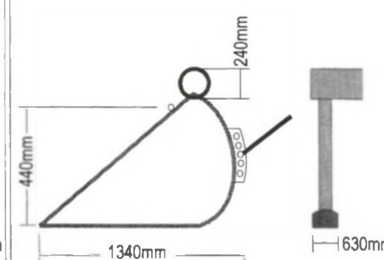


Fig. 3.2.4. Shrimp beam trawling, sub-fleet 222-1100 kW.

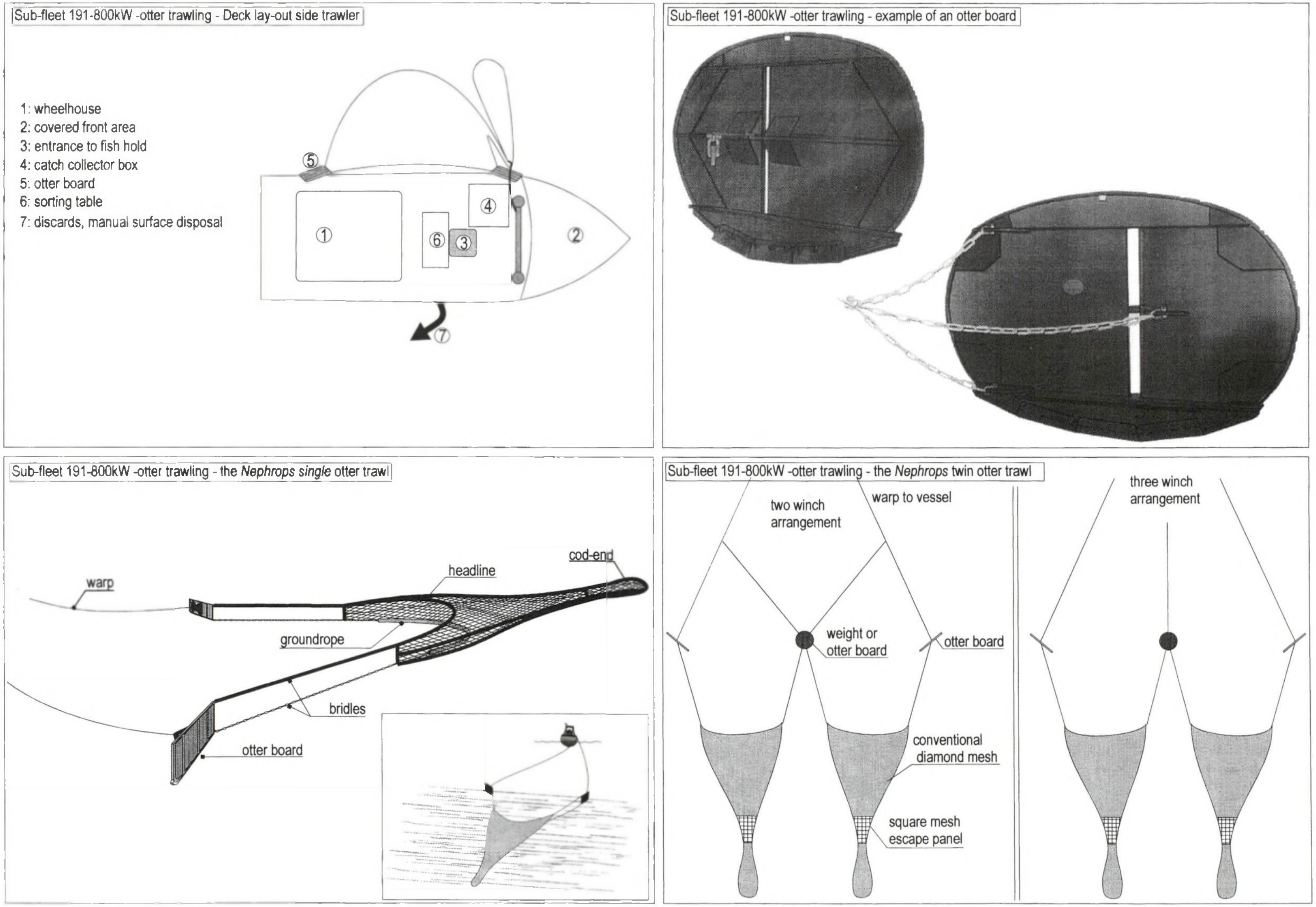


Fig. 3.2.5. Demersal otter trawling.

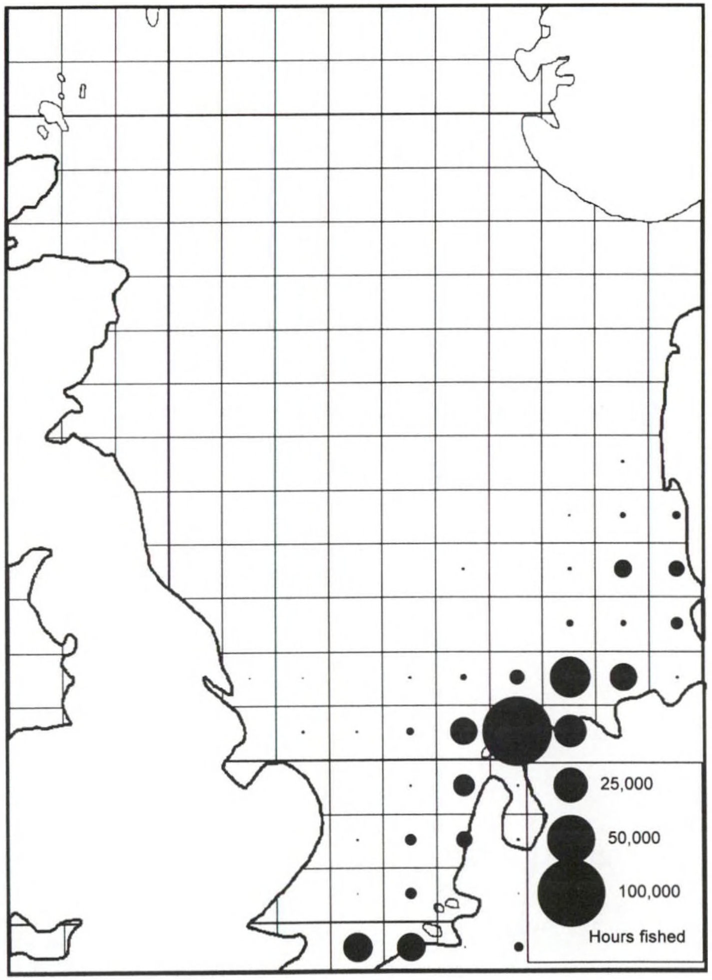


Fig. 3.2.6. Fishing effort - shrimp beam trawling - 70-191 kW
Belgium, Germany, Netherlands.

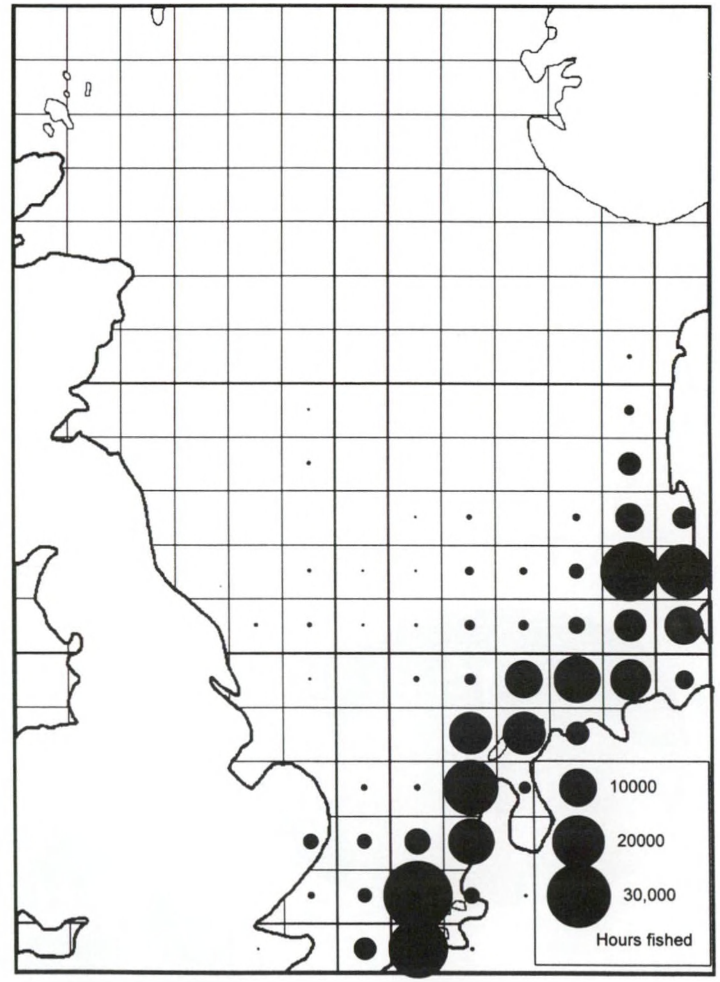


Fig. 3.2.7. Fishing effort - shrimp beam trawling - 191-221 kW
Belgium, Germany, Netherlands.

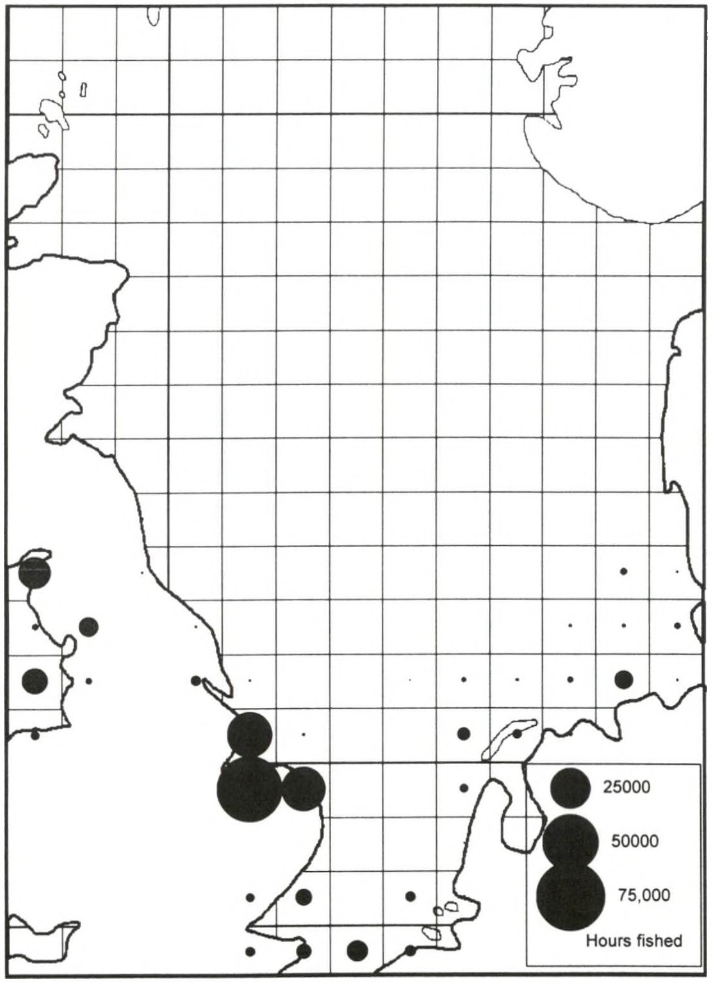


Fig. 3.2.8. Fishing effort - flatfish beam trawling - 70-191 kW
Belgium, Germany, Netherlands.

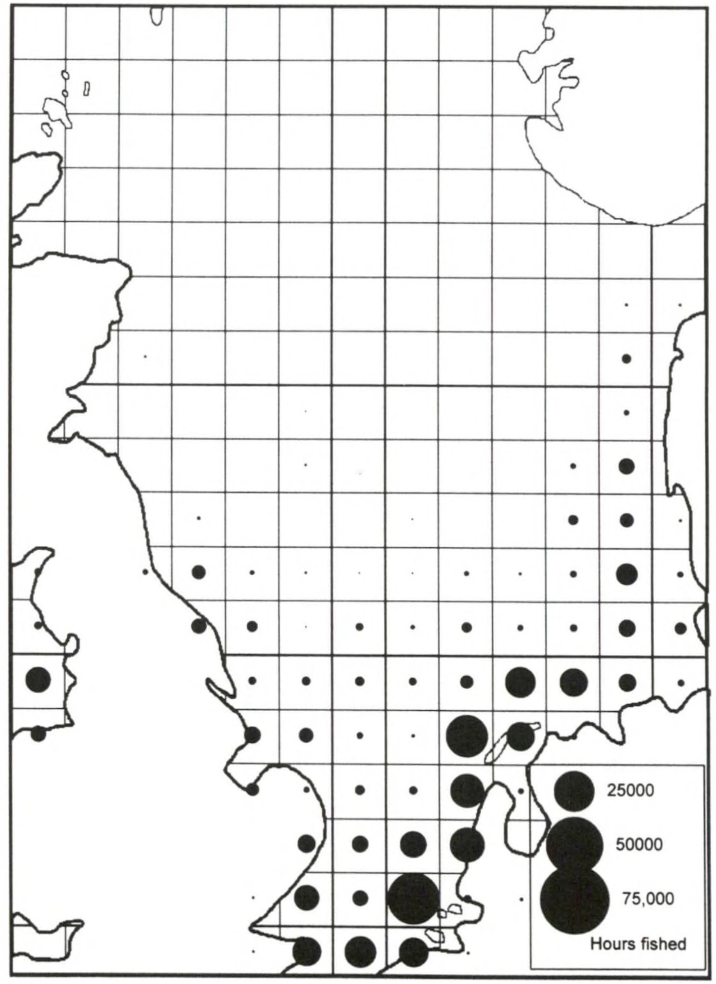


Fig. 3.2.9. Fishing effort - flatfish beam trawling - 191-221 kW
Belgium, Germany, Netherlands.

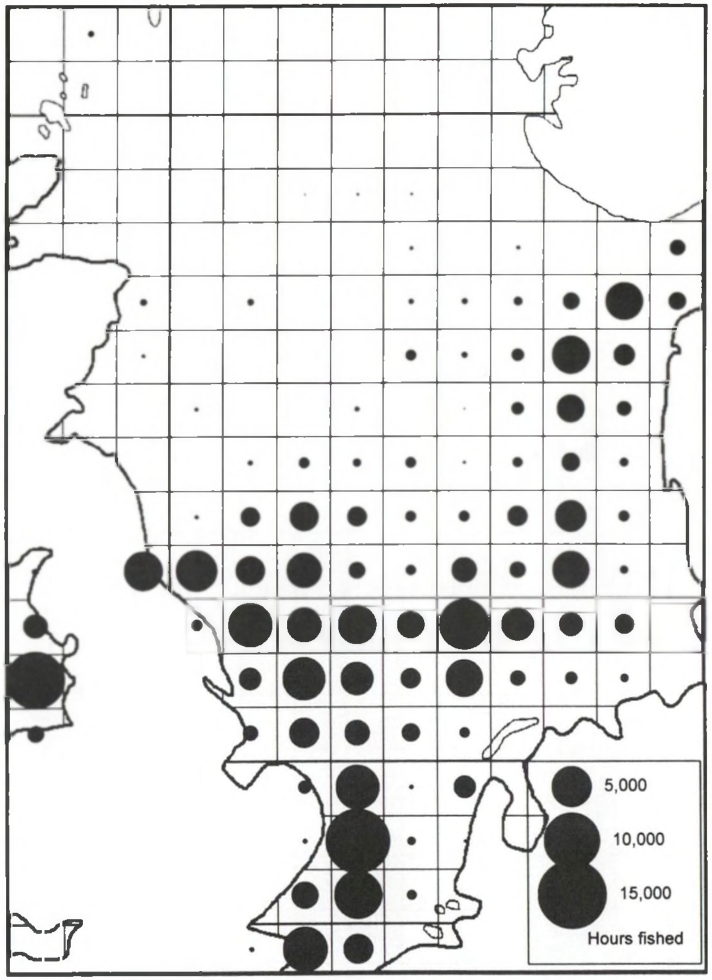


Fig. 3.2.10. Fishing effort - flatfish beam trawling - 222-800 kW
Belgium, Germany, Netherlands.

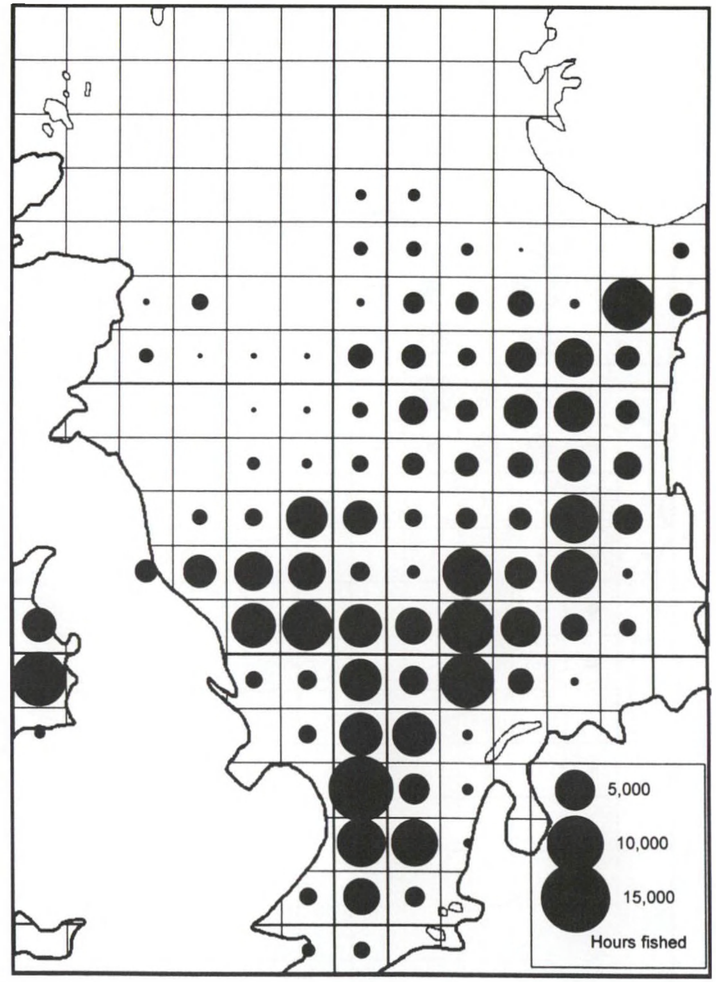


Fig. 3.2.11. Fishing effort - flatfish beam trawling - 801-1100 kW
Belgium, Germany, Netherlands.

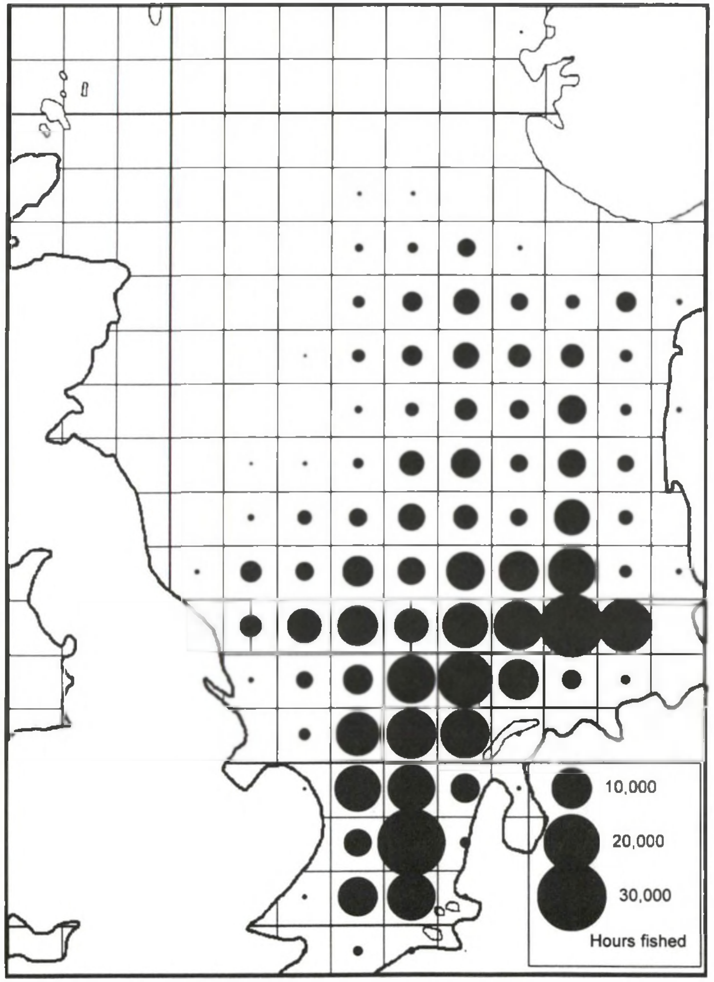


Fig. 3.2.12. Fishing effort - flatfish beam trawling - 1101-1500 kW
Belgium, Germany, Netherlands.

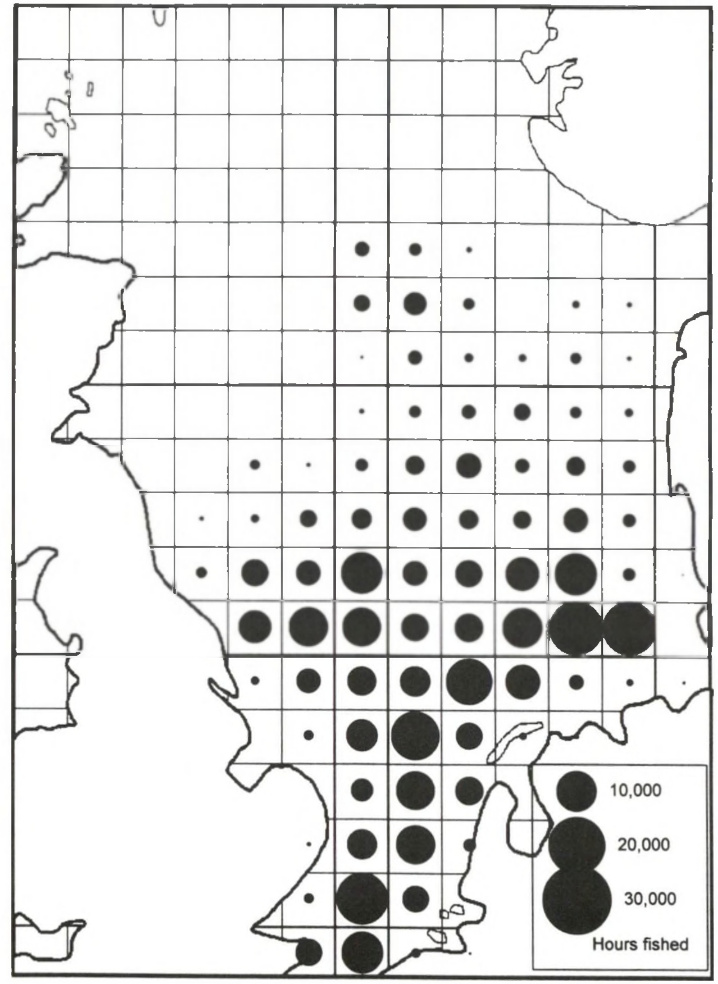


Fig. 3.2.13. Fishing effort - flatfish beam trawling - > 1500 kW
Belgium, Germany, Netherlands.

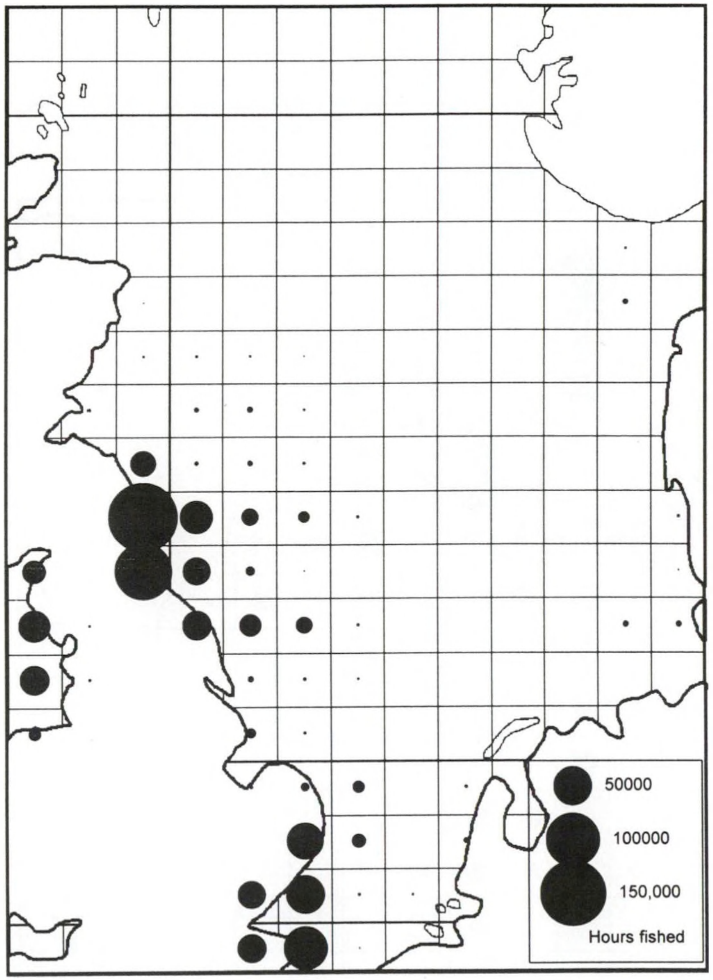


Fig. 3.2.14. Fishing effort - otter trawling - 70-191 kW
Belgium, Germany, Netherlands.

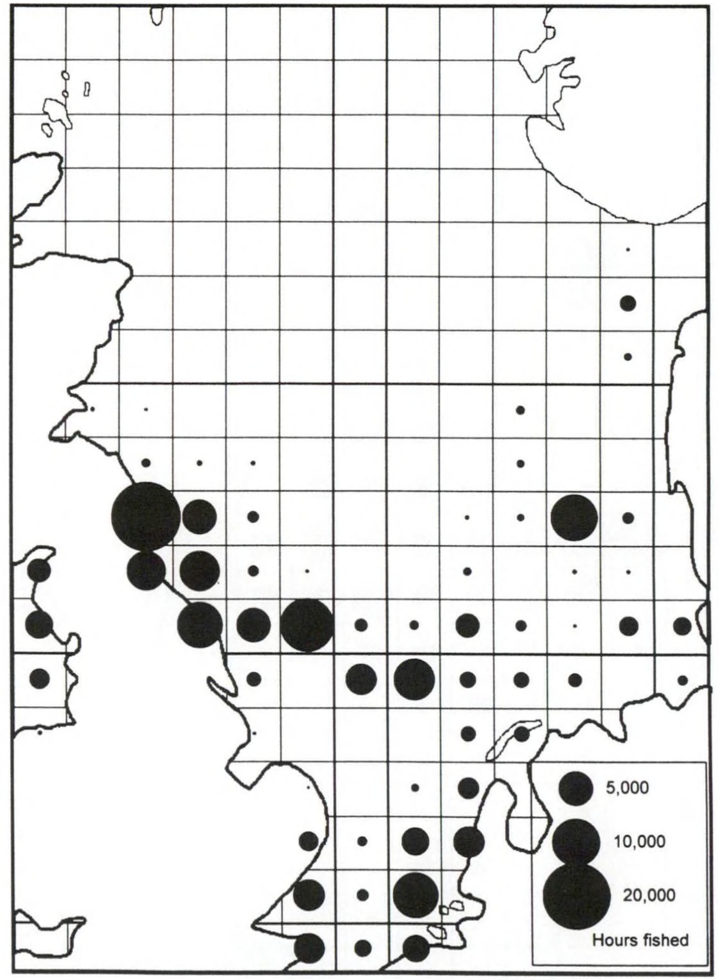


Fig. 3.2.15. Fishing effort - otter trawling - 192-221 kW
Belgium, Germany, Netherlands.

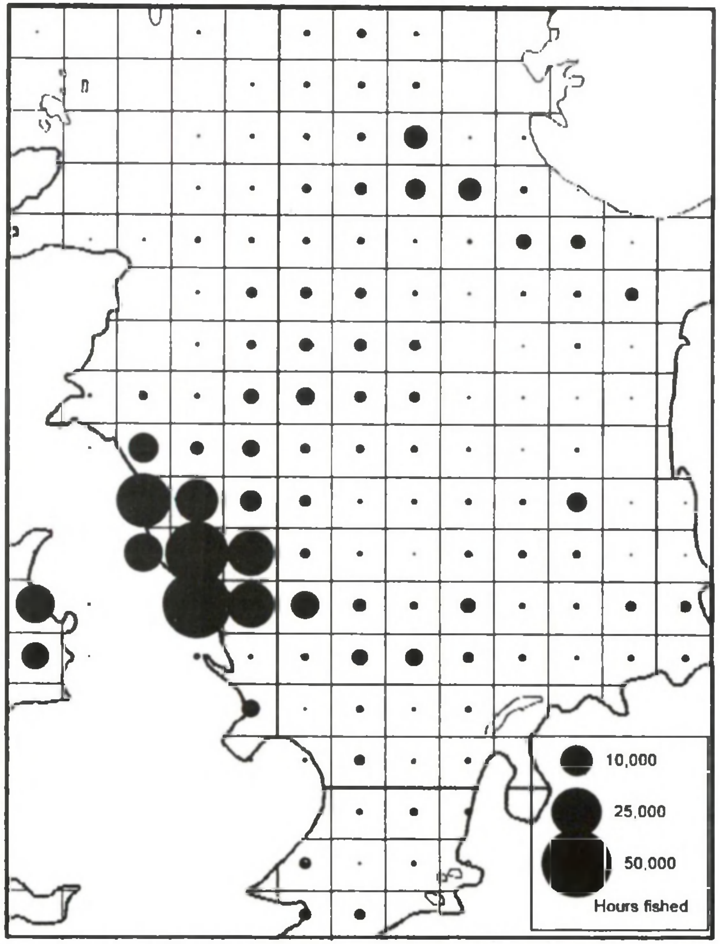


Fig. 3.2.16. Fishing effort - otter trawling - 222-800 kW
Belgium, Germany, Netherlands.

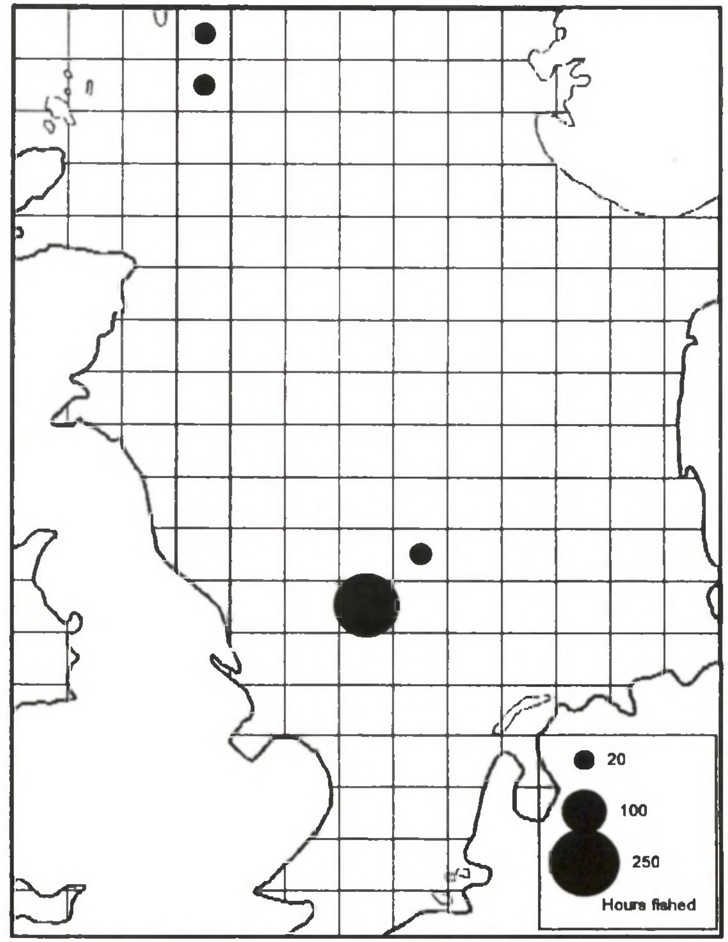


Fig. 3.2.17. Fishing effort - otter trawling - 801-1100 kW
Belgium, Germany, Netherlands.

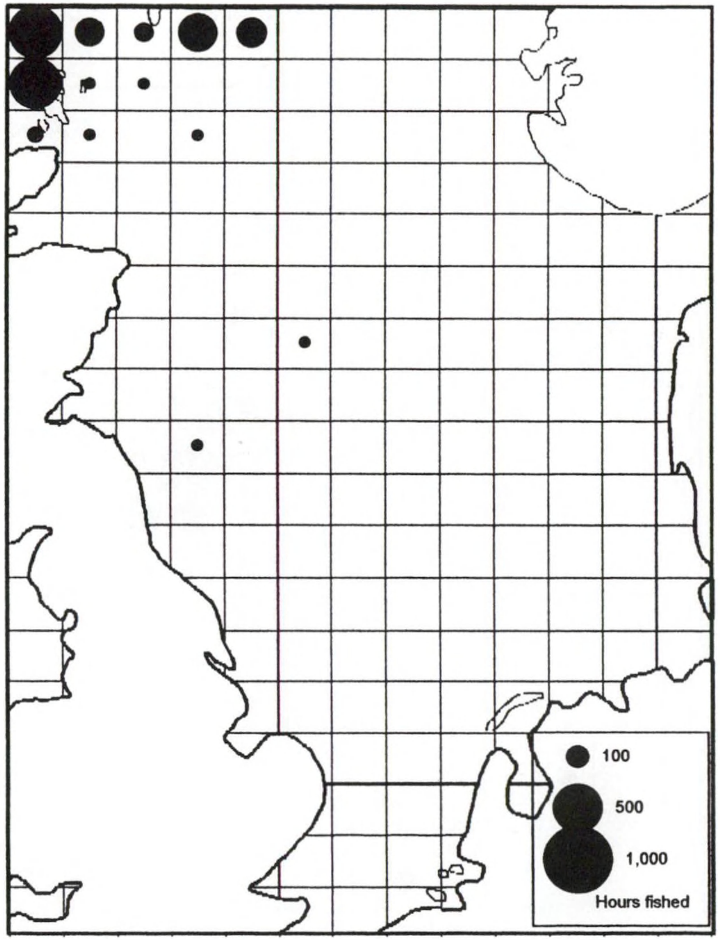


Fig. 3.2.18. Fishing effort - otter trawling - 1101-1500 kW
Belgium, Germany, Netherlands.

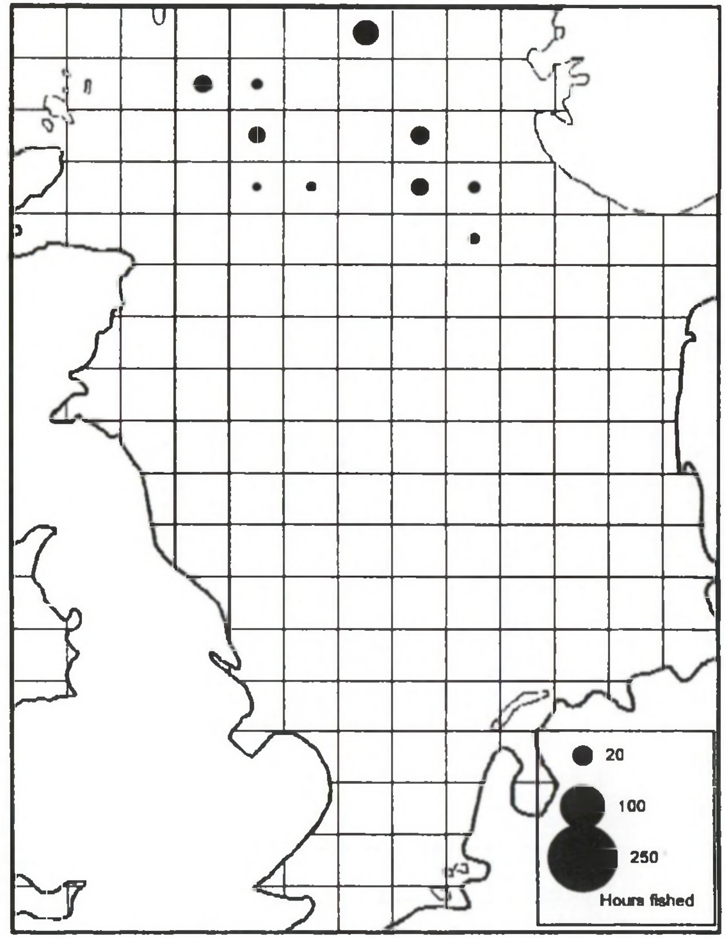


Fig. 3.2.19. Fishing effort - otter trawling - > 1500 kW
Belgium, Germany, Netherlands.

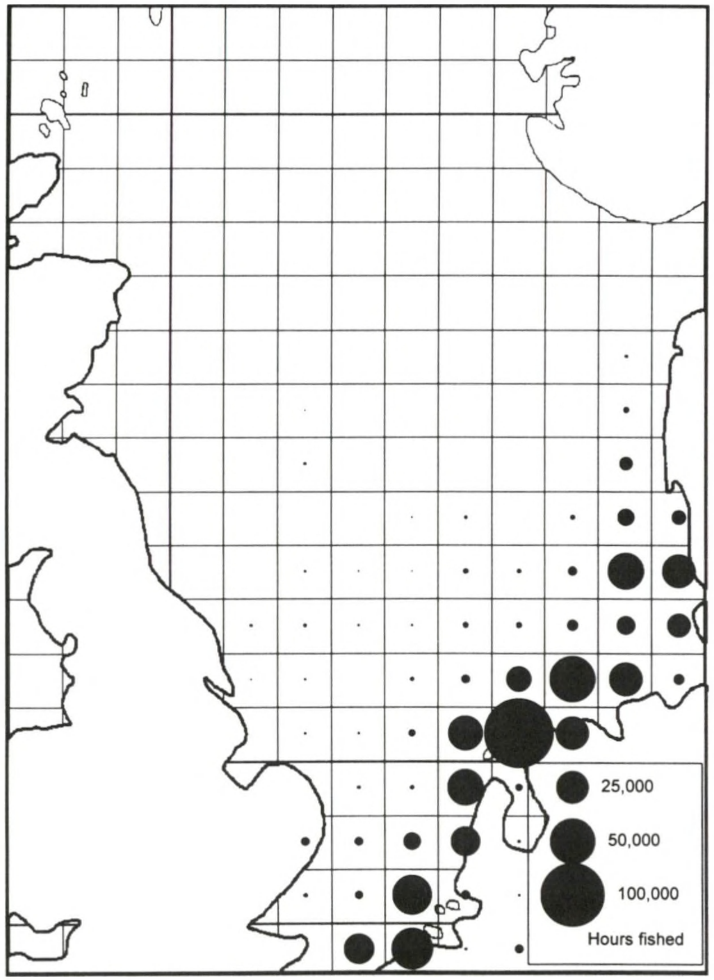


Fig. 3.2.20. Fishing effort - shrimp beam trawling - all engine power classes -Belgium, England, Germany, Netherlands, Scotland.

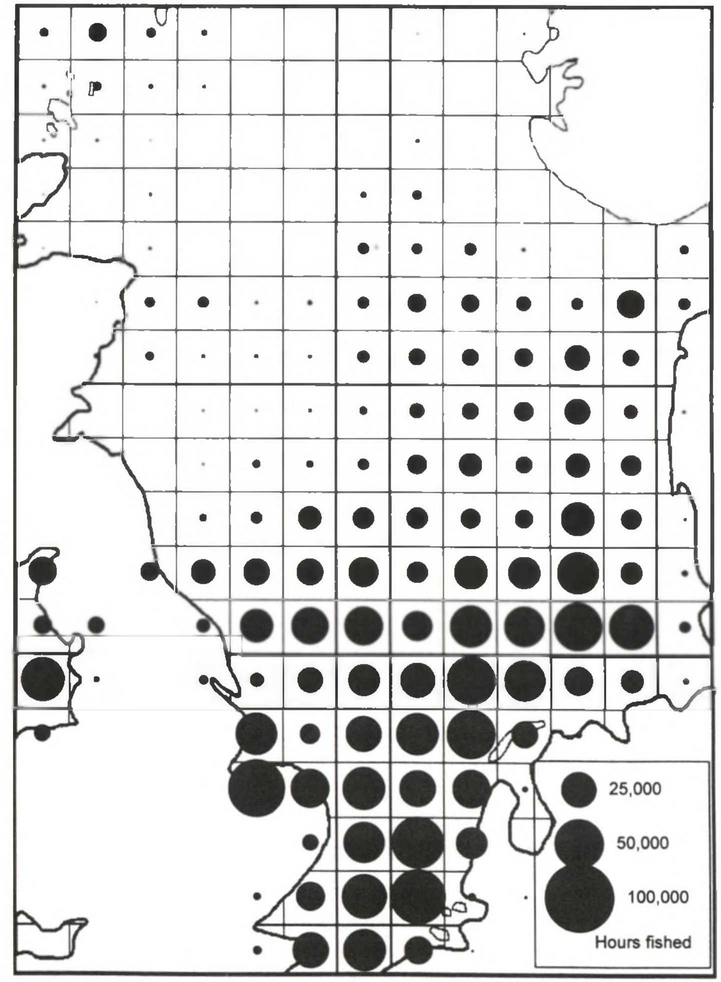


Fig. 3.2.21. Fishing effort - flatfish beam trawling - all engine power classes -Belgium, England, Germany, Netherlands, Scotland.

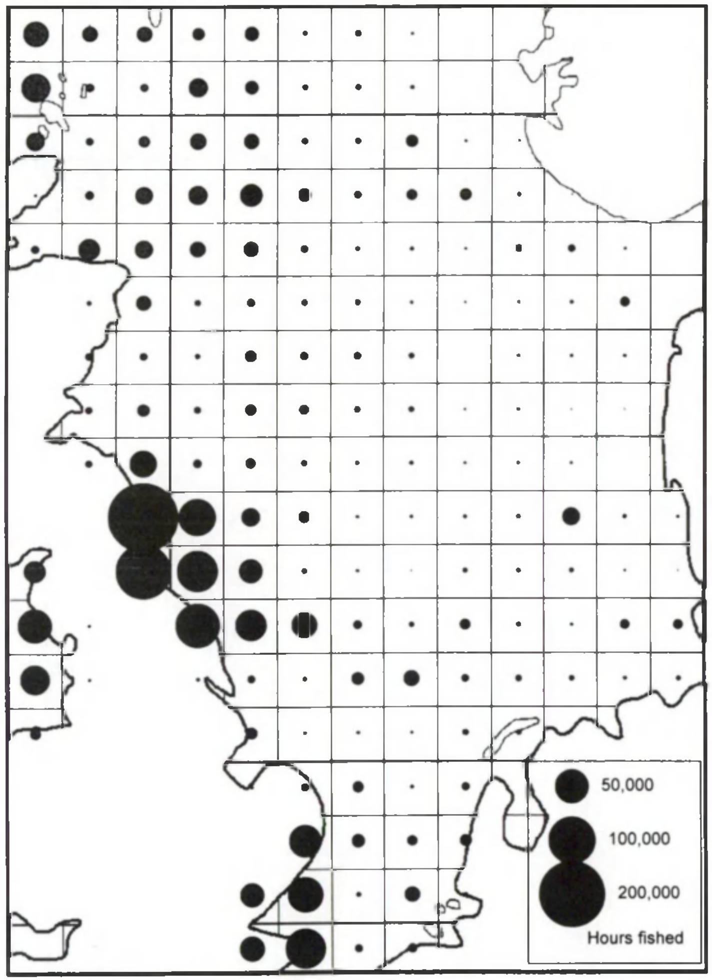


Fig. 3.2.22. Fishing effort - otter trawling - all engine power classes - Belgium, England, Germany, Netherlands, Scotland.

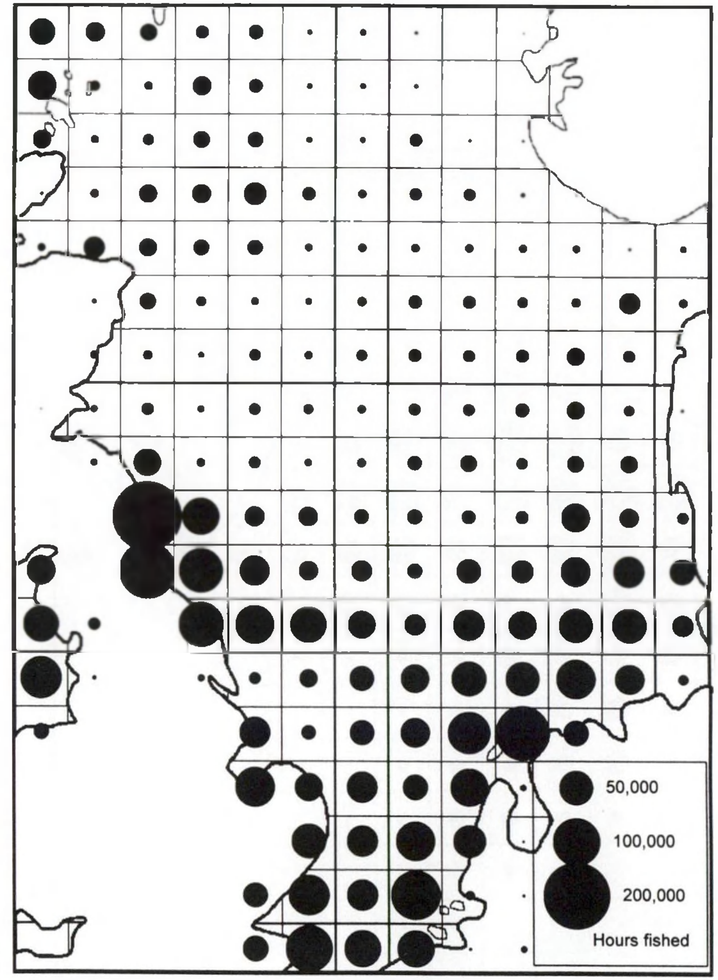


Fig. 3.2.23. Fishing effort - beam + otter trawling - all engine power classes -Belgium, England, Germany, Netherlands, Scotland.

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)

TABLE 3.2.3a
Gear data for the Belgian fishing fleet.

	70-191 kW	192-221 kW			222-800 kW		801-1100 kW	
	shrimp beam trawling	shrimp beam trawling	flatfish beam trawling		flatfish beam trawling		flatfish beam trawling	
			chain mat gear ***	tickler chain gear ***	chain mat gear	tickler chain gear	chain mat gear	tickler chain gear
Beam length (m)	(35%) - 8 (65%	(35%) - 8 (65%	5.1 (4 - 8) *	4.4 (4 - 6) *	9.6 (7.5 - 11.8)	11	10.6 (9.4 - 11.5)	11.4 (10.5 - 12)
Weight beam (kg)	260	260	300 (4m beam) 390 (8m beam)	350	810 (9m beam) 930 (10.5m beam)	1600	1100 (11m beam)	1850
Weight 1 shoe (kg)	200	200	250 (4m beam) 300 (8m beam)	255	245 (9m beam) 400 (10.5m beam)	635	450 (11m beam)	800
Weight bobbins (kg)	300	300	170 (4m beam) 175 (8m beam)	200	350 (9m beam) 360 (10.5m beam)	500	430 (11m beam)	600
Weight of the chain mat (kg)	N/A.	N/A.	550 (4m beam) 570 (8m beam)	N/A	1450 (9m beam) 2210 (10.5m beam)	N/A	2000 (11m beam)	N/A
Weight of the tickler chains (kg)	N/A.	N/A.	N/A.	370	N/A	1000	N/A	1150
Weight gear (kg)	1100	1100	1800 (4m beam) 2200 (8m beam)	1500	3900 (9m beam) 5000 (10.5m beam)	4800	5600 (11m beam)	6000
Weight gear (kg/kW)	7.3	7.3	8.2 (4m beam) 10.0 (8m beam)	6.8	7.1 (9m beam) 8.5 (10.5m beam)	8.2	6.4 (11m beam)	6.8
Surface of the sole plate (cm^2)	270	270	300.0	260.0	360	530	475	635
Vertical netopening (c.l. beam) (m)	0.65	0.65	0.55 (0.42 - 0.70) *	0.53 (0.42 - 0.70)	0.58	0.53	0.61	0.43
Length groundrope (m)	8.6 (7m beam) ; 10 (8m beam)	8.6 (7m beam) ; 10 (8m beam)	9.2 (4 m beam) ; 12.5 (8 m beam)	10.5 or 17	16	28	18.5	32
Diameter groundrope (mm)	Ø bobbins: 210 ; Ø axes: 20	Ø bobbins: 210 ; Ø axes: 20	Ø bobbins: 250 ; Ø steel wire: 24 - 32	Ø chain: 18 Ø roller: 200 to 300	Ø bobbins: 250 ; Ø steel wire: 28 - 32	Ø chain: 22 Ø roller: 230 to 300	Ø bobbins: 250 ; Ø steel wire: 30 - 34	Ø chain: 22 Ø roller: 320 to 400
Material groundrope	steel axes + rubber bobbins	steel axes + rubber bobbins	steel wire + rubber bobbins	chain + central rubber roller	steel wire + rubber bobbins	chain + central rubber roller	steel wire + rubber bobbins	chain + central rubber roller
Flip-up rope	none	none	15%	10%	70%	none	90%	20%
Vessels with tickler chain gear	none	none	65%	100%	35%	100%	20%	100%
Diameter of the shackles (mm)			N/A.	ticklers: 16 net ticklers: 10 to 14	N/A	ticklers: 18 net ticklers: 11 to 22	N/A	ticklers: 18 net ticklers: 11 to 22
Vessels with chainmat gear	none	none	100%	0%	100%	0%	100%	0%
Diameter of the shackles (mm)	N/A	N/A	14 or 18	N/A	18	N/A	18	N/A
Dimension of the quadrants (mm)	N/A	N/A	25 long on 25 wide or 35 long on 35 wide	N/A	35 long on 25 wide	N/A	35 long on 25 wide	N/A
Mesh size net (mm)	32 to 24 **	32 to 24 **	120	120	120 - few 150	120	120 - few 150	120
Netting material net	PA-sngl	PA-sngl	top panel: PE-sngl ; belly: PE-sngl or dbl	PE-sngl (67%), PA-sngl (33%)	top panel: PE-sngl ; belly: PE-dbl few sngl	top panel: PA-sngl ; belly: PA-dbl	top panel: PE-sngl ; belly: PE-dbl few sngl	top panel: PA-sngl ; belly: PA-sngl or dbl
Mesh size cod-end (mm)	22	22	80 or 100	80 or 100	80 or 100	80 or 100	80 or 100	80 or 100
Netting material cod-end	PA-single	PA-single	PE-dbl	PE-dbl	PE-dbl	PA-dbl	PE-dbl	PE-dbl
cod-end cover	yes (100%)	yes (100%)	25%	10%	45%	30%	45%	20%

* : average (minimum - maximum)
** : from trawlmouth to trawlend
*** : vessels which operate a chainmat beam trawl or a tickler chain beam trawl as the main gear.

TABLE 3.2.3b
Gear data for the Belgian fishing fleet.

	192-221 kW demersal otter trawling	222-800 kW demersal otter trawling
Target species	*Nephrops*	*Nephrops*
Type otter board	wooden rectangular	wooden rectangular
Weight otter board (kg)	340	420
Dimensions otter board (m)	2.2 on 1.2	2.4 on 1.2
Vertical netopening (c.l. beam) (m)	1	
Length groundrope (m)	35	35
Diameter groundrope (mm)	chain: 16 bobbins: 120	chain: 18 bobbins: 120
Length headline (m)	28	28
Diameter headline (mm)	18	18
Material headline	mixed rope	mixed rope
Lower bridles, length (m)	6	4.3
Lower bridles, diameter (mm)	16	16
Lower bridles, material	chain	chain
Upper bridles, length (m)	6	4.3
Upper bridles, diameter (mm)	16	14
Upper bridles, material	mixed PE and steel	steel wire
Mesh size net (mm)	100	100
Netting material net	PE	PE
Mesh size cod-end (mm)	70	70
Netting material cod-end	PE or PA	PE
cod-end cover	no	no

TABLE 3.2.3c
Gear 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	Comments
Beam length (m)	6-9 (1)	4.5-9 (1)	5-8		11-12	12	(1) 9m is maximum for shrimp trawl
Weight beam + shoes (kg)	900	1200	1700		3750	4500	
Weight beam + shoes (kg/kW)	4.5-5.5	5.5	4.5-5.5		2.2-3	1.4-2.5	
Weight of the chain mat (kg/kW)	N/A	1.8	1.8		1.4-1.8	1.4-1.8	
Weight of the tickler chains (kg/kW)	N/A	1.5-2.5	1.5-2.5		1.3-2.0	1.0-1.9	
Weight of the net tickler chains (kg/kW	N/A	0.3-0.4			0.3-0.35	0.2-0.35	
Weight tickler chain beam trawl (kg/kW)		8-10			4.1-5.8	3.0-5.0	
Weight chainmat beam trawl (kg/kW)		8-9.7			3.1-3.3	2.5-3.6	
Vertical netopening (c.l. beam) (m)	0.6-0.9	0.4-0.5	0.4-0.5	0.4-0.5	0.32-0.5	0.3-0.5	+ 0.15m for chainmat beam trawl
Length groundrope (m)	.3 x beam length (2	13-18	17-23		30-35	35-37	(2) shrimp trawl
Length of the roller (m)	N/A	3	3		6-8	8	
Second groundrope diameter (mm)		22			24-26	26-28	= steel chain, 3 to 6m just in front of roller
Diameter groundrope (mm)	Ø bobbins: 180-220	Ø chain: 22 Ø roller: 50 to 100	Ø chain: 22 Ø roller: 50 to 100		Ø chain: 26 Ø roller: 200 to 350	Ø chain: 26-30 Ø roller: 200 to 400	
Material groundrope	steel axes + rubber bobbins	chain + central rubber roller	chain + central rubber roller	chain + central rubber roller	chain + central rubber roller	chain + central rubber roller	
Flip-up rope	struction, most nylon rope, sometimes with floats - occasionally used						
Tickler chain gear							
No. of tickler chains	N/A	5	5 to 6		6 to 10	10	
Diameter of the shackles (mm)	N/A	20	22		22 to 26	24 to 28	shortest chains have largest diameters
Length of tickler chains (m)	N/A	7 to 14	10 to 16		14 to 27	15 to 28	
No. of net tickler chains	N/A	5 to 6	5 to 6		8 to 11	9 to 12	
Diameter of the shackles (mm)	N/A	10 to 13	10 to 13		12 to 16	13 to 16	
Chainmat gear							
Diameter of the shackles (mm)	N/A	14 (l) & 10 (w)			18 (l) & 14 (w) or 16 (l) & 26 (w)	26 (l) & 18 (w)	
Dimension of the quadrants (mm)	N/A	25 to 30 long 20 to 25 wide			30 to 35 long 25 to 30 wide	30 to 35 long 25 to 30 wide	
Mesh size net (mm)	24 to 20 (3)	120 to 80 (sole) 120 to 100 (plaice)	120 to 80 (sole) 120 to 100 (plaice)		240 to 80 (sole) 240 to 100 (plaice)	240 to 80 (sole) 300 to 100 (plaice)	(3) shrimp trawl
Netting material net	PP	PA	PA		PA	PA	belly and cod-end double braided

* : mostly hard sandy bottom, west of 4° E, small stones and sanddunes in the South
** : from trawlmouth to trawlend

TABLE 3.2.3d
Gear 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	Comment
Beam length (m)	6-9 (1)	4.5 or 9 (1)	7-11	10-12	12	12	(1) 9m maximum for shrimp
Weight beam + shoes (kg)	900	950 to 1200	1400 to 2600	2000 to 3000	3400 to 5000	4000 to 6000	trawl
Weight beam + shoes (kg/kW)		4.5-5.5	3.2	3.1	2.9-3.4	1.9-3.3	
Weight of the chain mat (kg/kW)	N/A	N/A	N/A	N/A	N/A	N/A	
Weight of the tickler chains (kg/kW)	N/A	0.6-1.4	0.8-1.2	0.8-1.0	0.8-1.0	0.5-1.0	
Weight of the net tickler chains (kg/kW)	N/A	0.3-0.6			0.27-0.35	0.20-0.35	
Weight tickler chain beam trawl (kg/kW)		6.0-7.8	4.4-5.4		3.8-5	3.0-4.0	
Weight chainmat beam trawl (kg/kW)	N/A	N/A	N/A	N/A	N/A	N/A	
Vertical netopening (c.l. beam) (m)	0.4-0.5	0.4-0.5	0.4-0.5	0.4-0.5	0.32-0.5	0.3-0.5	
Length groundrope (m)	7-12	16-20	18-32	26-35	33-36	36-38	
Length of the roller (m)	N/A	3	3-6	6	8	8	
Second groundrope diameter (mm)	N/A	N/A	N/A	N/A	N/A	N/A	
Diameter groundrope (mm)	Ø bobbins: 180-220	Ø chain: 14-18 Ø roller: 100 to 200	Ø chain: 14 to 18 Ø roller: 200 to 300	Ø chain: 17 to 20 Ø roller: 250 to 400	Ø chain: 18 to 22 Ø roller: 300 to 400	Ø chain: 36-38 Ø roller: 400 to 500	
Material groundrope	steel axes + rubber bobbins	chain + central rubber roller	chain + central rubber roller	chain + central rubber roller	chain + central rubber roller	chain + central rubber roller	
Flip-up rope	Not often used						
Tickler chain gear							
No. of tickler chains	N/A	5-6	5-7	5-10	5-10	6-11	less tickler chains if more net tickler chains
Diameter of the shackles (mm)	N/A	12-16	12-16	14-20	19-22	19-24	shortest tickler chains have +5mm diameter
Length of tickler chains (m)	N/A	7 to 11	10 to 14		16 to 26	15 to 28	
No. of net tickler chains	N/A	5 to 7	6 to 10	12 to 13	10 to 16	10 to 16	
Diameter of the shackles (mm)	N/A	8 to 13 (2)	10 to 12	8 to 11	12 to 14	10 to 14	(2) largest shackles for hard
Chainmat gear	N/A	N/A	N/A	N/A	N/A	N/A	bottoms near the coast
Diameter of the shackles (mm)							
Dimension of the quadrants (mm)							
Mesh size net (mm) **	24 to 20	120 to 80 (sole) 120 100 (plaice)	120 or 160 to 80 (sole) 120 or 160 to 100 (plaice)	160 or 240 to 80 (sole) 120 or 240 to 100 (plaice)	260 to 80 (sole) 260 to 100 (plaice)	260 to 80 (sole) 260 to 100 (plaice)	
Netting material net	PP	PA	PA		PA	PA	cod-end double braided

* : Den Helder and east of Den HelderSofter grounds east of 4°E, sometimes silty. In summertime often softer, less ticklers.
** : from trawlmouth to trawlend

3.3. PHYSICAL IMPACT

Introduction

The aim of the present study was to update the knowledge of the physical impact of both modern beam trawls and otter trawls. Immediate and longer term effects were studied using modern techniques such as REMOTS, SPI, side-scan sonar and RoxAnn. Experiments performed in different areas allowed to correlate the observed effects to different substrates and different hydrographic conditions.

3.3.1. PRESSURE EXERTED BY A BEAM TRAWL

3.3.1.1. PRESSURE MEASUREMENTS

Pressure exerted by the sole plates

Figure 3.3.1 gives a typical representation in graphical form of pressure measurements made with the instrumented trawl head. It is the result of a series (1 hour) of measurements during a particular haul under normal trawling conditions and allows for the description of the mechanical performance of the gear. The Figure shows the vertical forces acting on the two measuring axles in the instrumented trawl head. When fishing with the current at a speed of 6 knots over the ground, situation (1), the load on the aft axle (cell 2) has a positive value of about 3.5 kN (385 kgf), whereas the load on the first axle (cell 1) has a negative value. This indicates that the aft part of the sole plate is in firm contact with the bottom, whereas there is no bottom contact at all at the front part. The negative value measured in cell 1 is due to the moment of both the pressure and friction forces with regard to cell 2. After changing the course of the ship by 180°, the gear is towed against the current. As the speed over the ground is kept constant at 6 knots, the speed of the gear relative to the water increases and the gear tends to lift off the ground. This case occurs in situation (2) in which the sole plate has completely lost bottom contact. The forces now acting on the loads cells are determined by the water pressure on the sole plate only. When the speed is lowered to 5 knots, bottom contact is restored (situation (3)). The fact that both the loads in cell 1 and cell 2 are positive indicates that the sole plate touches the seabed more horizontally than in situation (1). The decrease in speed is however not enough to keep the sole plates on the ground all the time. The soles plates regularly lose bottom contact, which is indicated by the forces in cells 1 and 2 being equal to the water pressure, as in situation (2). The same sequences can be distinguished in Fig. 3.3.2 illustrating the horizontal or friction forces acting on the sole plate. The position of the centre of pressure can be calculated from the equilibrium equation Σ(moments) = 0. The result is graphically represented in Fig. 3.3.3 and confirms the conclusions drawn above:

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

Figure 3.3.4 shows the average pressure force, i.e. the resultant vertical force, as calculated from data obtained during four valid hauls. The warp length was kept at 90 m for depths varying from 23 m to 30 m. If the gear is towed against the current the pressure force decreases from 5300 N (540 kgf) at a towing speed (over the ground) of 3 knots to 1000 N (102 kgf) at 6 knots. If the gear is towed with the current an increase in towing speed from 4 to 7 knots results in a decrease of the average pressure force from 4500 N (459 kgf) to 1000 N (102 kgf). At low speeds the pressure force will normally act on the full surface of the sole plate, while at high speeds only the heel of the sole plate will be in bottom contact.
The pressure can be calculated as

pressure = pressure force / sole plate area.

The sole plate dimensions are 750 mm x 350 mm, the heels measure 250 mm x 350 mm.
The average pressure in the present experiments:
- fishing at 3 kn against the current with full sole plate contact:
  5300 N / 75x35 cm^2 = 2.019 $N.cm^{-2}$ (0.206 $kgf.cm^{-2}$)
- fishing at 5 kn against the current with heel contact only:
  2280 N / 25x35 cm^2 = 2.606 $N.cm^{-2}$ (0.266 $kgf.cm^{-2}$)
- fishing at 4 kn with the current and with full sole plate contact:
  4500 N / 75x35 cm^2 = 1.71 $N.cm^2$ (0.174 $kgf.cm^{-2}$)
- fishing at 6 kn with the current and with heel contact only:
  2750 N / 25x35 cm^2 = 3.14 $N.cm^{-2}$ (0.320 $kgf.cm^{-2}$)

At towing speeds of 6 kn (against the current) and 7 kn (with the current) the downward force on the gear is not sufficient to keep the trawl heads in contact with the bottom (identical to situation 2 in Fig. 3.3.1). In general it can be stated that the 4m beam trawl exerted average pressures on the sea bottom varying from 1.7 $N.cm^{-2}$ to 3.1 $N.cm^{-2}$ (or from 0.17 $kgf.cm^{-2}$ to 0.32 $kgf.cm^{-2}$). An inquiry among Belgian skippers showed that in commercial fishing Eurocutters tow 4m beam trawls at an average speed of 3 kn or 4 kn, depending on whether the gear is towed against or with the tide. Under these circumstances the sole plate pressure will be 2 $N.cm^{-2}$ (0.20 $kgf.cm^{-2}$) and 1.7 $N.cm^{-2}$ (0.17 $kgf.cm^{-2}$) respectively.

The pressures obtained are mean values at the given towing speeds. In general the pressure forces are not constant but vary constantly as can be seen in Fig. 3.3.1. These variations consist of more or less regular undulations of the average pressure and numerous peak values. Figure 3.3.5 gives the maximum and minimum values of the pressure force undulation at each towing speed. These maxima and minima all fall within the limits of the forces given above. The peak values, recorded at 1 sec intervals, did not exceed 6000 N (612 kgf).

The periodic variations in the pressure forces correspond well with the heave of the ship as indicated by the echo sounder's heave compensator. The frequency of both phenomena is about 14 periods/sec. The same periodic changes can be recognised in all other force measurements as well as in the shift of the pressure centre. Variations of the seabed morphology however are also superimposed on the variations due to the ship's movements. It is clear that the transmission of vessel movements to the gear may cause lifting of the gear off the bottom in circumstances with light bottom contact. This will cause the sole plates to bounce over the seabed.

Total gear pressure

The pressure of the complete gear on the bottom can be calculated from the weight of the gear and the upwards pull of the warp. This upwards pull was measured by means of an underwater tension meter inserted between the warp end and the beam trawl's bridles (Fig. 3.3.6). The graphical representation of the warp load, for the same time interval as for the instrumented trawl head experiment discussed above, is given in Fig. 3.3.7. It should be noted that the warp loads are averaged over 4 sec intervals, whereas 1 sec intervals were used in the instrumented trawl head measurements.

For a heavy load at the lower end of the trawl warp, as is the case in beam trawling, the warp curvature can be neglected and the upwards pull exerted by the warp on the gear is determined by (Fig. 3.3.6)

$$P_u = L_w \cdot \sin\alpha = L_w \cdot D/L \qquad (1)$$

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

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

$$P = (W - P_u)/2 \qquad (2)$$

in which W is the weight underwater of (trawl heads + beam + bridles), equal to 13290 N (1355 kgf).

The average pressure force calculated from the warp load as compared with the pressure force measured with the instrumented trawl head is presented in Fig. 3.3.8. The difference in pressure obtained by both measurement methods is not substantial. However, when fishing with the current the difference in pressure load seems to increase with increasing speeds (Fig. 3.3.8b). At these higher speeds the trawl heads have lost bottom contact, but this is not yet the case for most of the chain matrix and the bobbin rope. These gear components are attached to the trawl head at positions up the sole plate. The weight of ground gear affects the warp load, and hence the upwards component, but not the values recorded by the instrumented trawl head.

The pressure by the gear on the seabed also depends on the ratio between the depth and the length of the warp. The shorter the warp length, the larger will be the upwards pull exerted by the warp on the gear as indicated by equation (1) above. The total gear pressure was calculated from the warp load for four hauls at a constant towing speed of 4 knots but for warp lengths varying between 2.5 and 5.7 times the water depth. The results are graphically presented in Fig. 3.3.9. There is a clear linear relationship between the pressure and the ratio warp length / depth expressed by:

pressure = 776.4 (L/D) + 5708.2 ($R^2 = 0.93$).

3.3.1.2. RELATION BETWEEN GEAR PRESSURE AND ENGINE POWER

Calculated from former sea trials on commercial vessels

Figure 3.3.10 shows the warp load against ground speed for 5 Belgian beam trawlers involved in former sea trials (Anon. 1996a). The vessel and gear characteristics are given in Table 3.3.1).The warp load increases with vessel hp but is only slightly dependent on ground speed in the observed speed range. The reason for this is that when towing the r.p.m. (revolutions per minute) of the engine is kept constant. Under this condition the drag of the gear must be equal to the tow pull at all times (*e.g.* with different tidal streams) and the towing speed will result from this equilibrium.

The pressure force exerted by the gear on the sea bottom can be calculated from

pressure force = gear weight - lift force.

The lift force, at an average towing speed, can be calculated from the warp load data presented in Fig. 3.3.10. A linear relationship exist between the lift force and the vessel hp (Fig. 3.3.11):

lift force = 18.356*(vessel hp) - 336.98 ($R^2 = 0.99$)

The underwater weight of the gears can be expressed by (Fig. 3.3.11):

gear weight = 16810*Ln(vessel hp) - 83912 ($R^2 = 0.99$)

The resulting pressure force can be expressed as (Fig. 3.3.11):

$$\text{pressure force} = 3052.4*\text{Ln(vessel hp)} - 14040 \quad (R^2 = 0.87)$$

The pressure force exerted on the bottom increases with vessel hp but at less than a proportional basis (Fig. 3.3.11).

From fleet inquiry data

The pressure exerted by the sole plates depends on the weight of (beam + trawl heads + bridles + block) rather than on the weight of the complete gear. The net, the ground gear and the tickler chains rest on the bottom and do not participate in the pressure generated by the sole plates. In case of a beam trawl rigged with a chain matrix most of the chains rest on the seabed but some are attached to the beam and will participate in the pressure generated by the sole plates. Furthermore the pressure on the sea bottom will depend on the surface of the sole plates.

Figure 3.3.12 shows the weight of the above mentioned gear components together with the sole plate surfaces as obtained from an inquiry made on board 16 Belgian beamers. Both parameters increase proportionally with vessel hp and the slope of the trendlines differ only slightly, the sole plate surface being the steepest.

The weight per cm^2 of the sole plate, which can be considered as a measure for the pressure exerted on the seabed, is plotted against vessel hp in Fig. 3.3.13. The trendline is logarithmic and indicates that the average pressure increases slowly with vessel hp

$$\text{weight/cm}^2 = 61.587*\text{Ln(vessel hp)} - 140.3 \qquad (R^2 = 0.37)$$

The pressure value calculated from this expression varies between 2 $N.cm^{-2}$ (0.204 $kgf.cm^{-2)}$ and 3 $N.cm^{-2}$ (0.306 $kgf.cm^{-2)}$ for a 300 hp and a 1400 hp vessel respectively. These values are remarkably close to the pressures measured during the field studies: 1.7-3.1 $N.cm^{-2}$ (0.187-0.316 $kgf.cm^{-2}$)

The results on the pressure / vessel hp relationship show that under normal conditions light and heavy beam trawls exert pressure forces of the same magnitude. The reason is that the difference in weight will be compensated by a higher towing speed and a larger sole plate surface.

3.3.2. SEA FLOOR DISTURBANCE

3.3.2.1. BEAM TRAWLS

Immediate effects

During the SOLEA and MITRA cruises in September 1994 and May and September 1995 both video profiles and REMOTS sediment profile photographs (REMOTS not in Sept 95) at different trawl tracks in an experimental box north of Heligoland were taken. The bottom of the September 1994 cruise consisted of densely packed fine sand with a silt layer on top. This sediment was too hard to detect clear differences between the various gear types (beam trawl and otter trawl) with both of these imaging methods. The navigational accuracy was too imprecise in the earlier cruises to find the different trawl tracks with the precision needed. Nevertheless some basic patterns of physical impact were found such as the surface pattern was flattened, ripple layers were removed and shell debris exposed on the surface. This was consistent both in REMOTS and the video recordings.

During the MITRA cruise in May 1995 the navigation was close to optimal and side-scan sonar recordings helped to identify the actual trawl tracks. The results from this cruise showed significant differences in the penetration depth of the REMOTS prism (Fig. 3.3.14a) for all treatments (fished tracks) and the controls (unfished). Also the surface roughness (Fig. 3.3.14b) was significantly 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 (tO) 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.

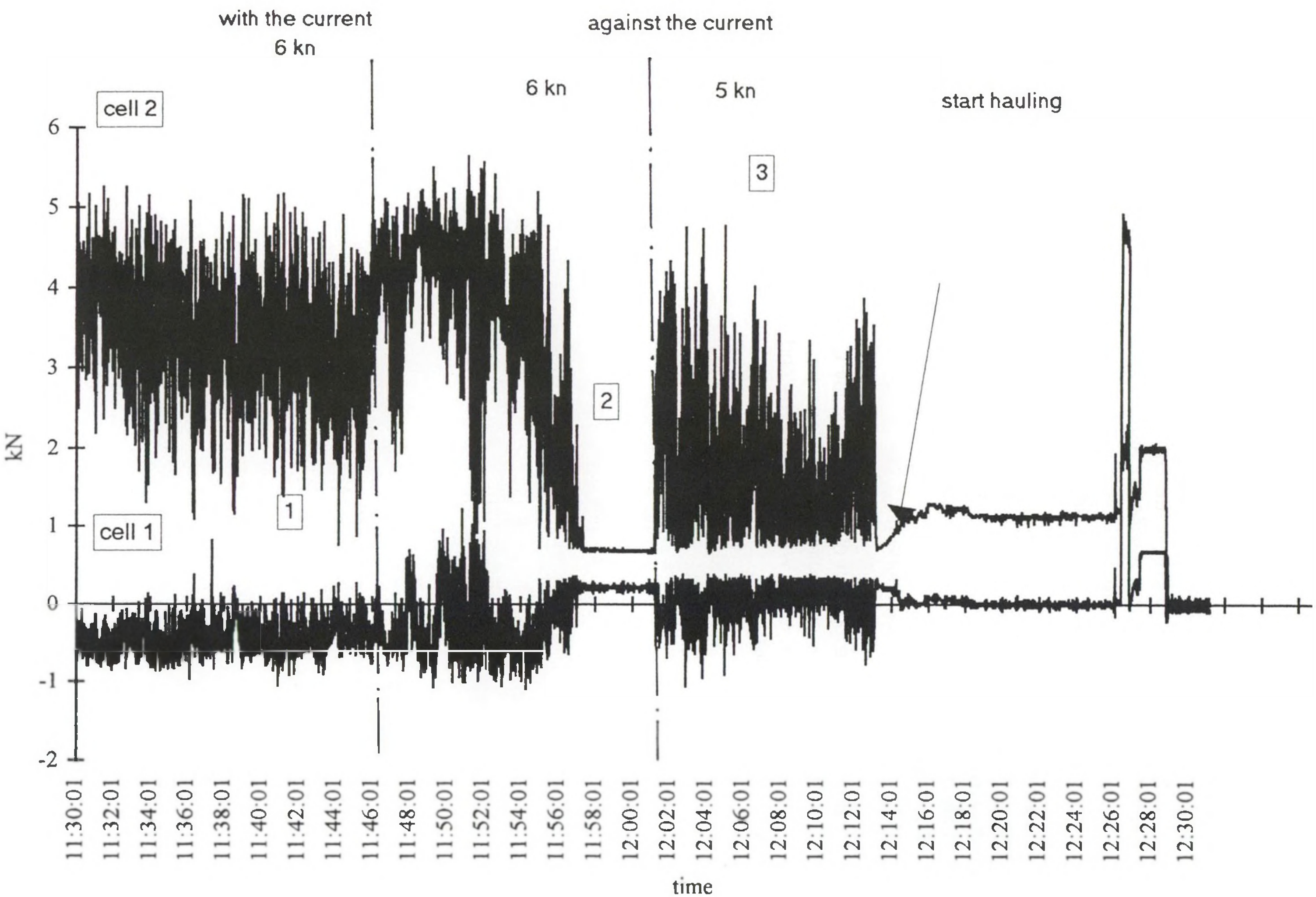


Fig. 3.3.1. Vertical forces exerted by the sole plate.

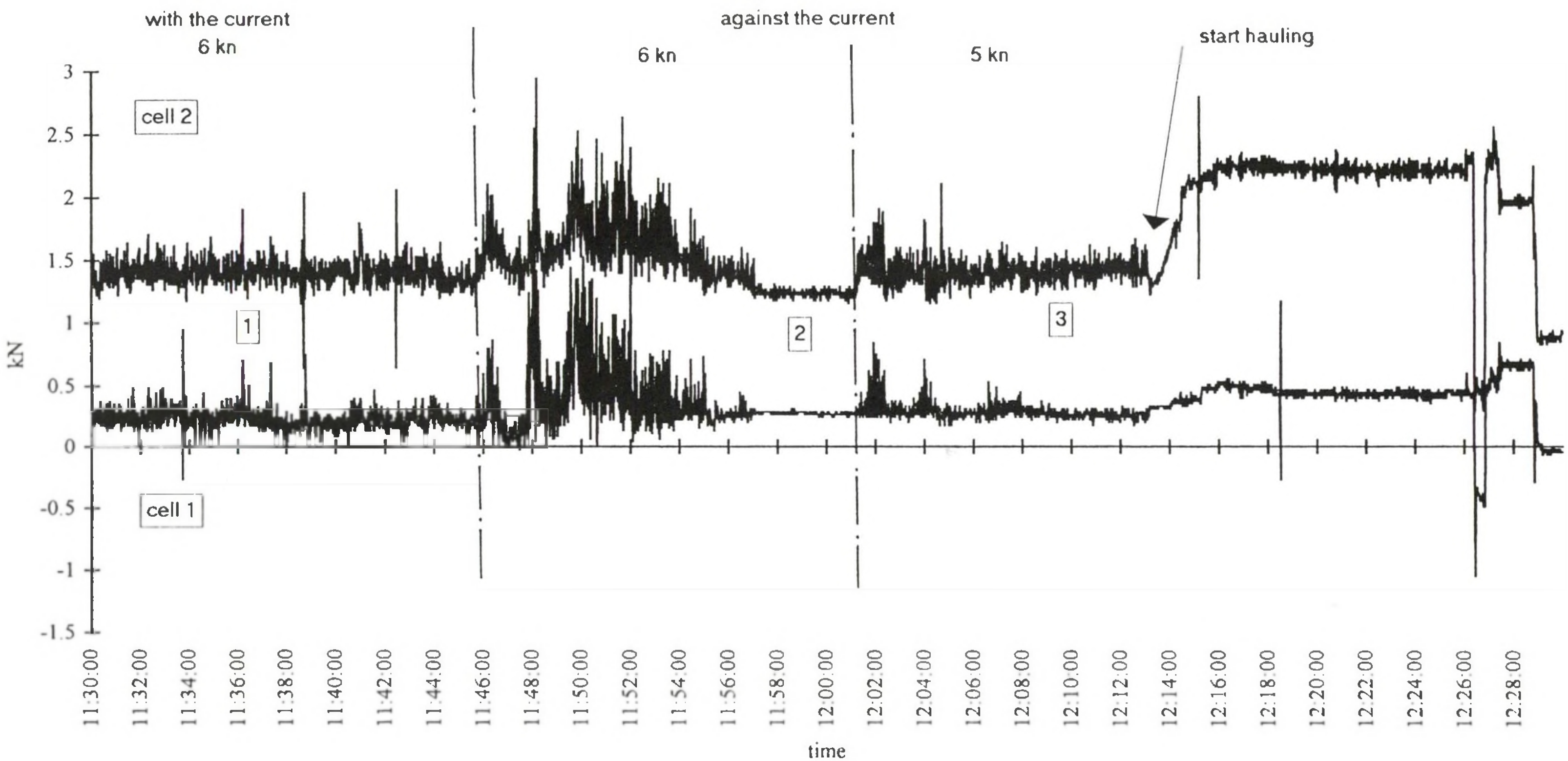


Fig. 3.3.2. Horizontal forces.

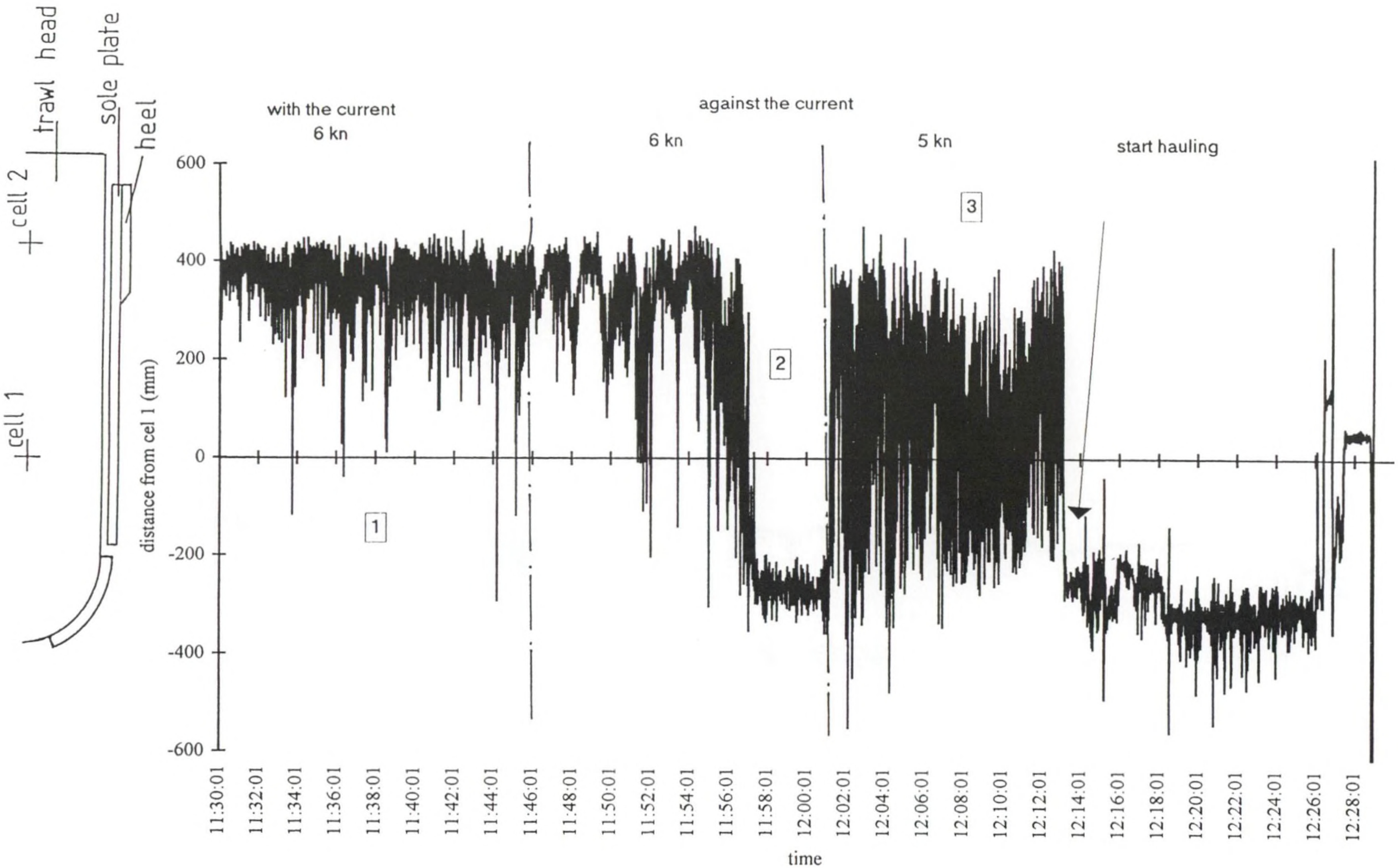


Fig. 3.3.3. Centre of pressure.

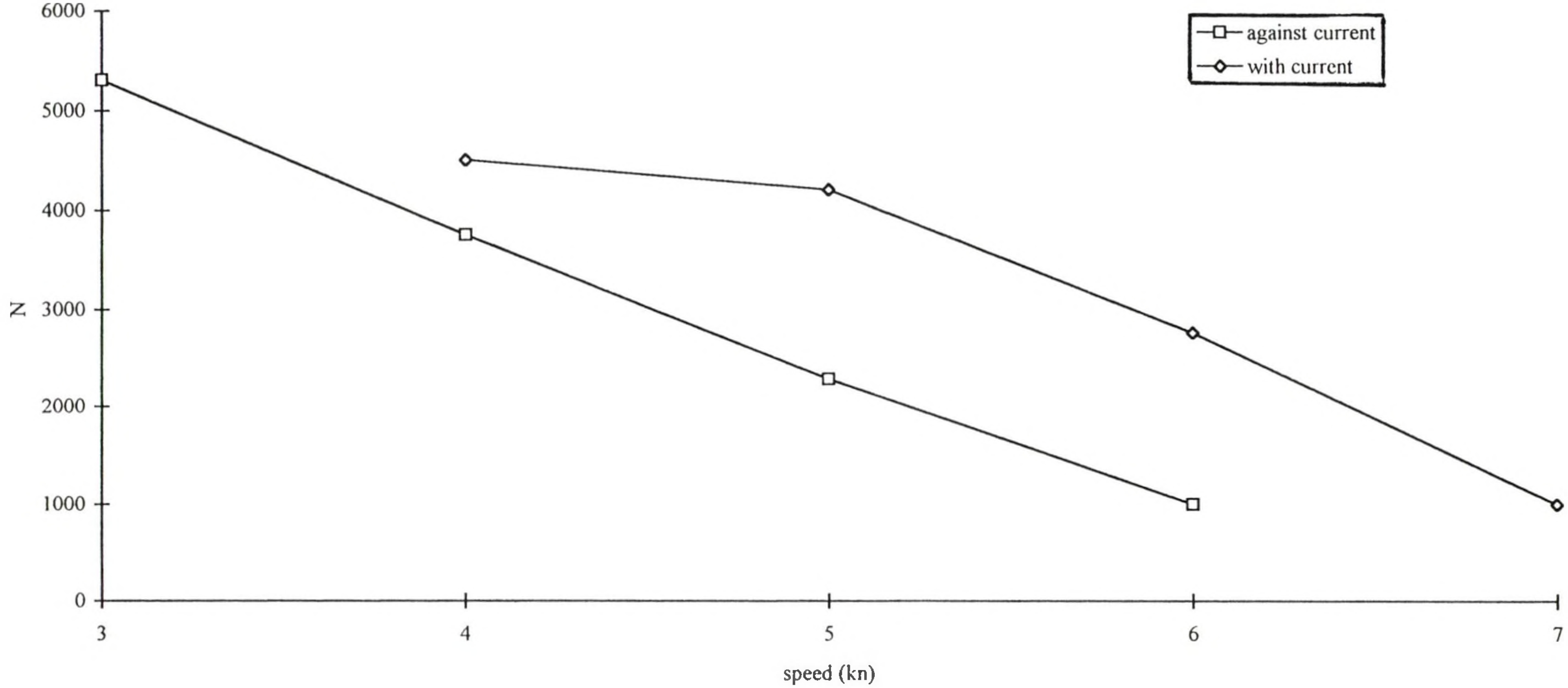
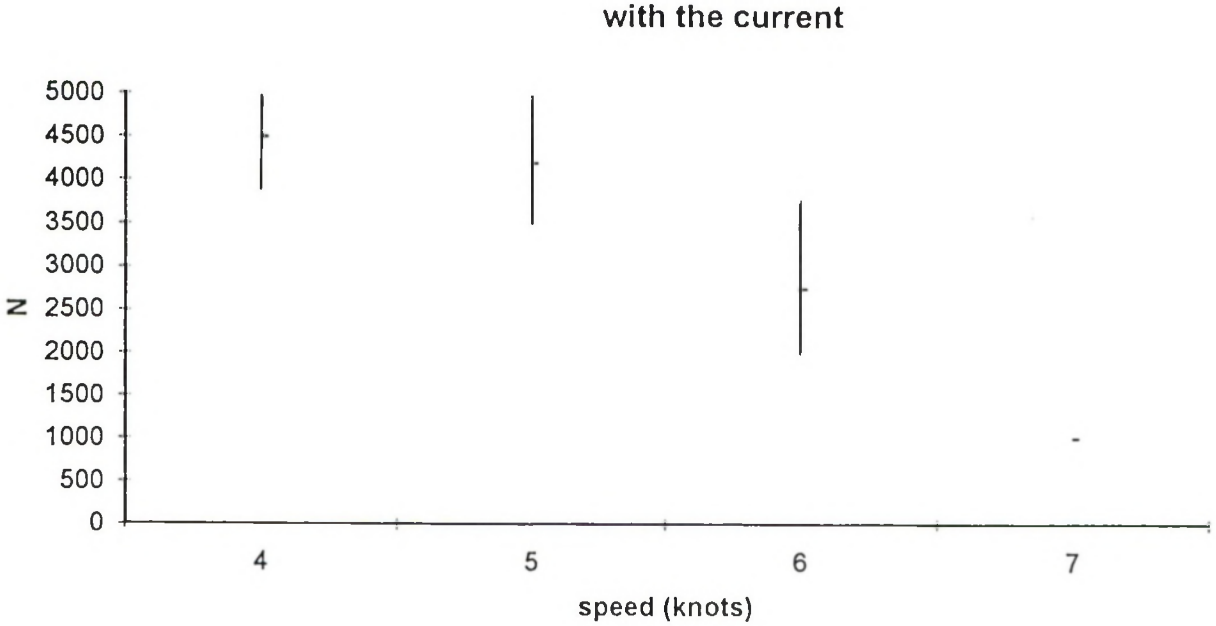


Fig. 3.3.4. Average pressure force.



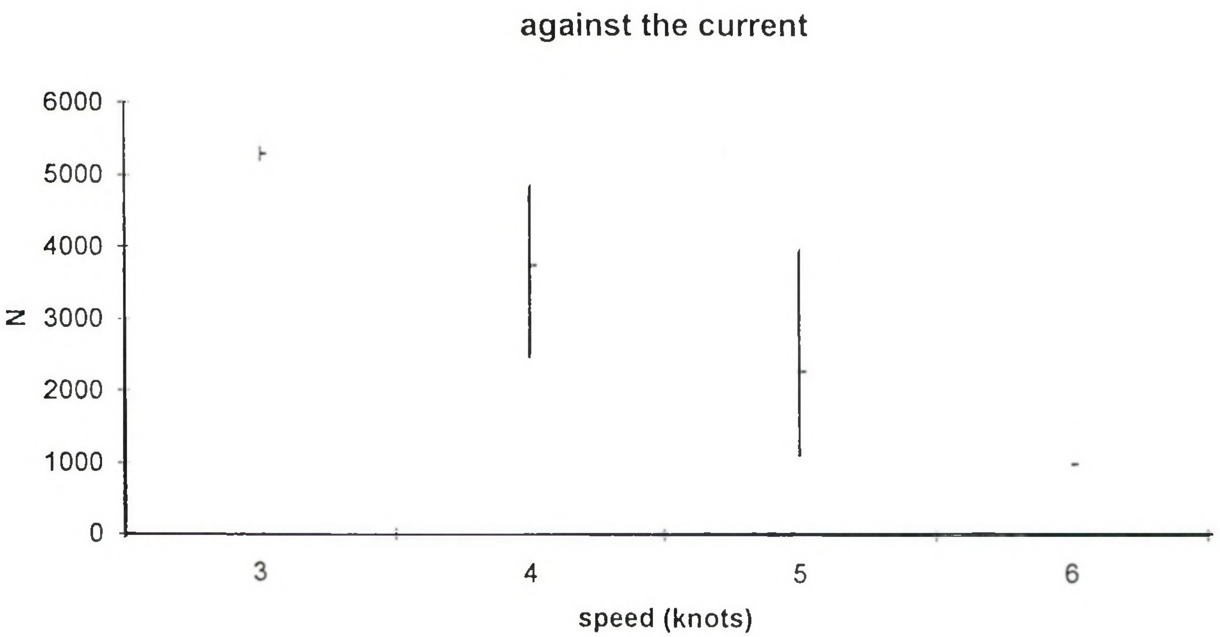


Fig. 3.3.5. Pressure foce limits.

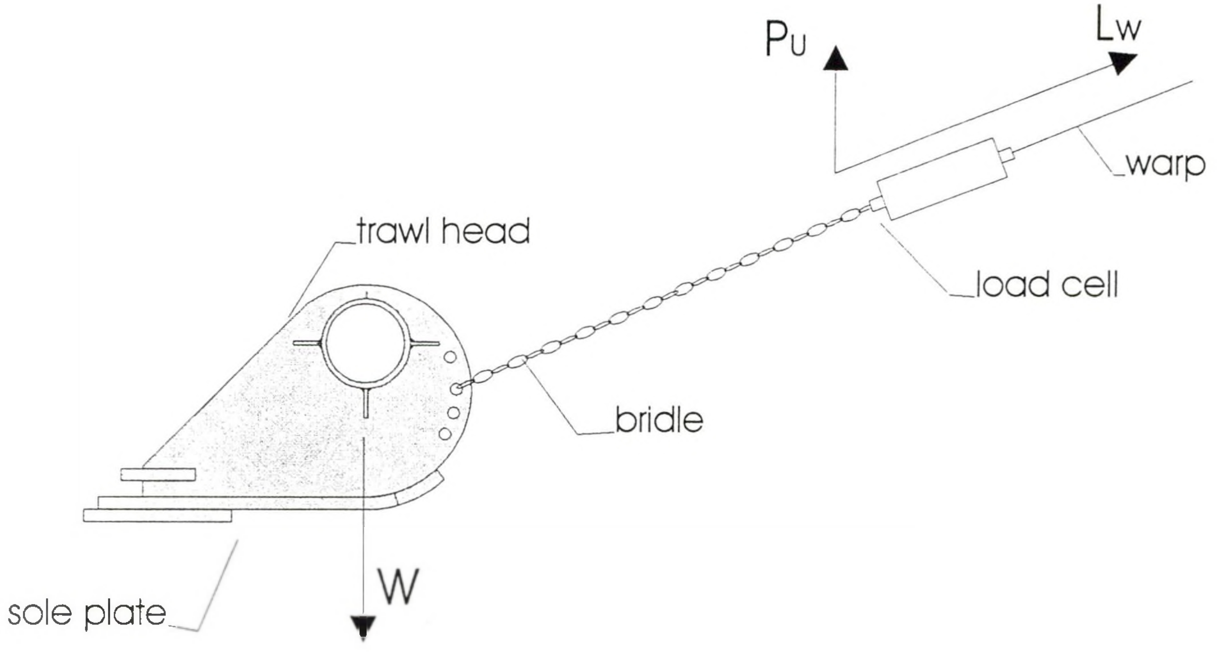


Fig. 3.3.6. Warp load measurements.

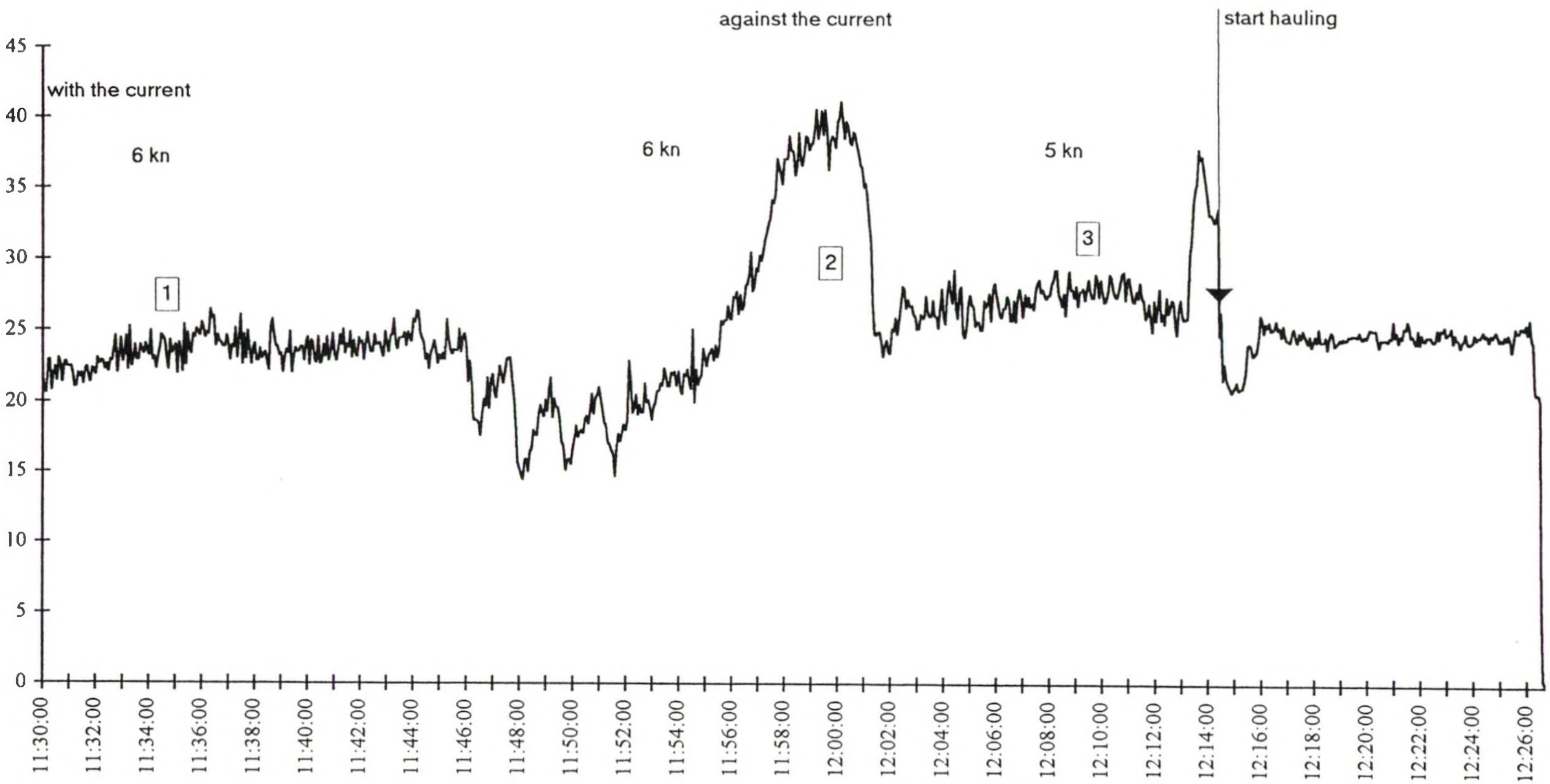
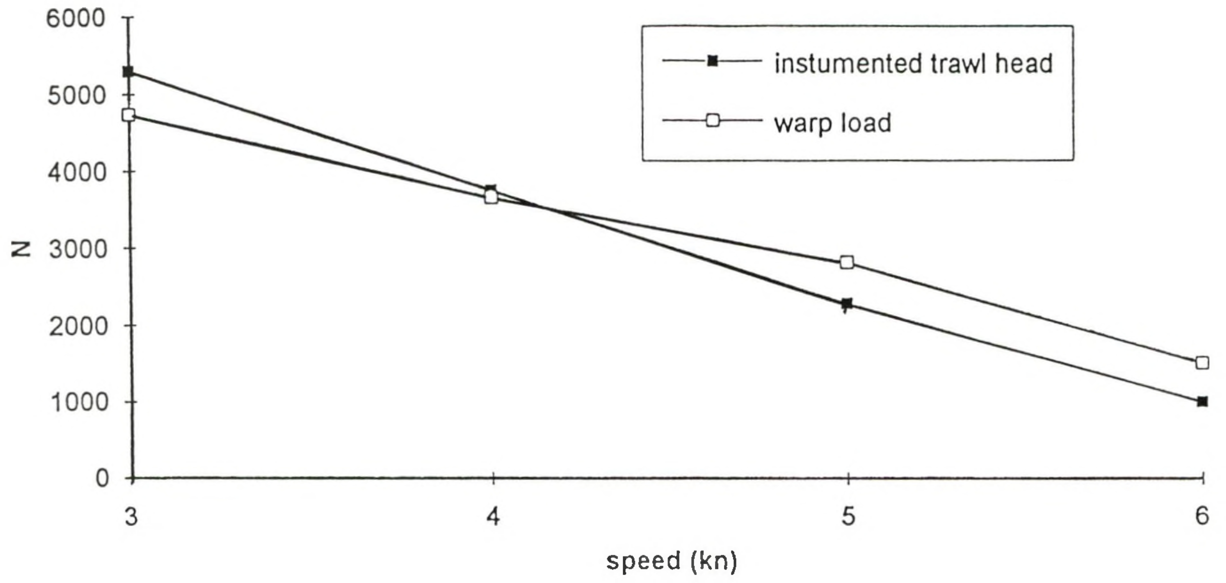


Fig. 3.3.7. Warp load.

a) against the current



b) with current

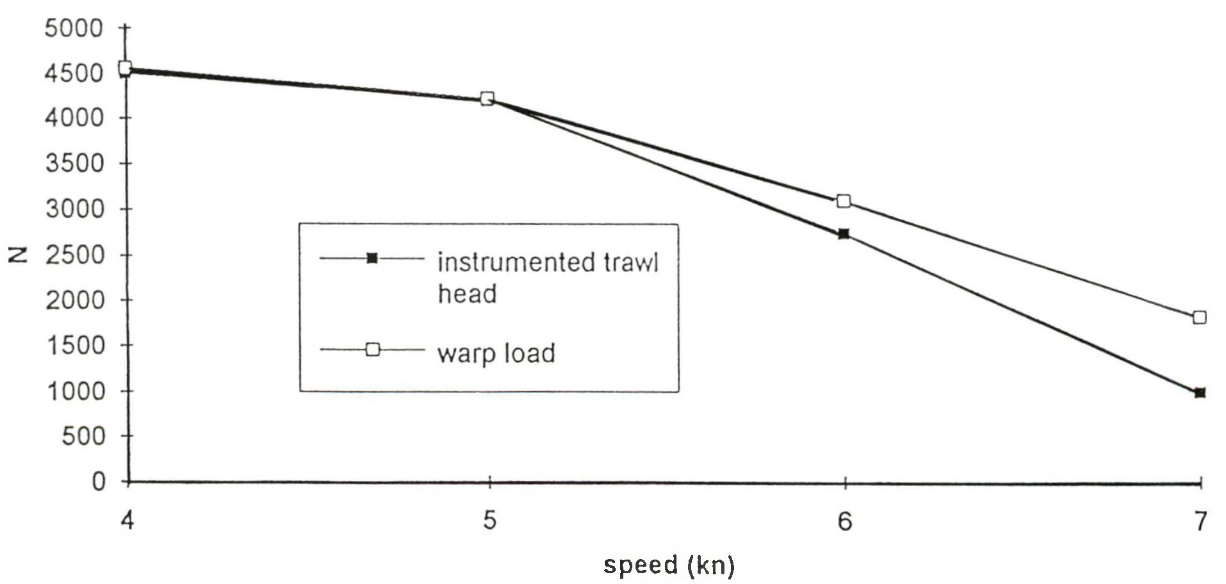


Fig. 3.3.8. Comparison of the pressure loads measured by the instrumented trawl head and calculated from the warp load.

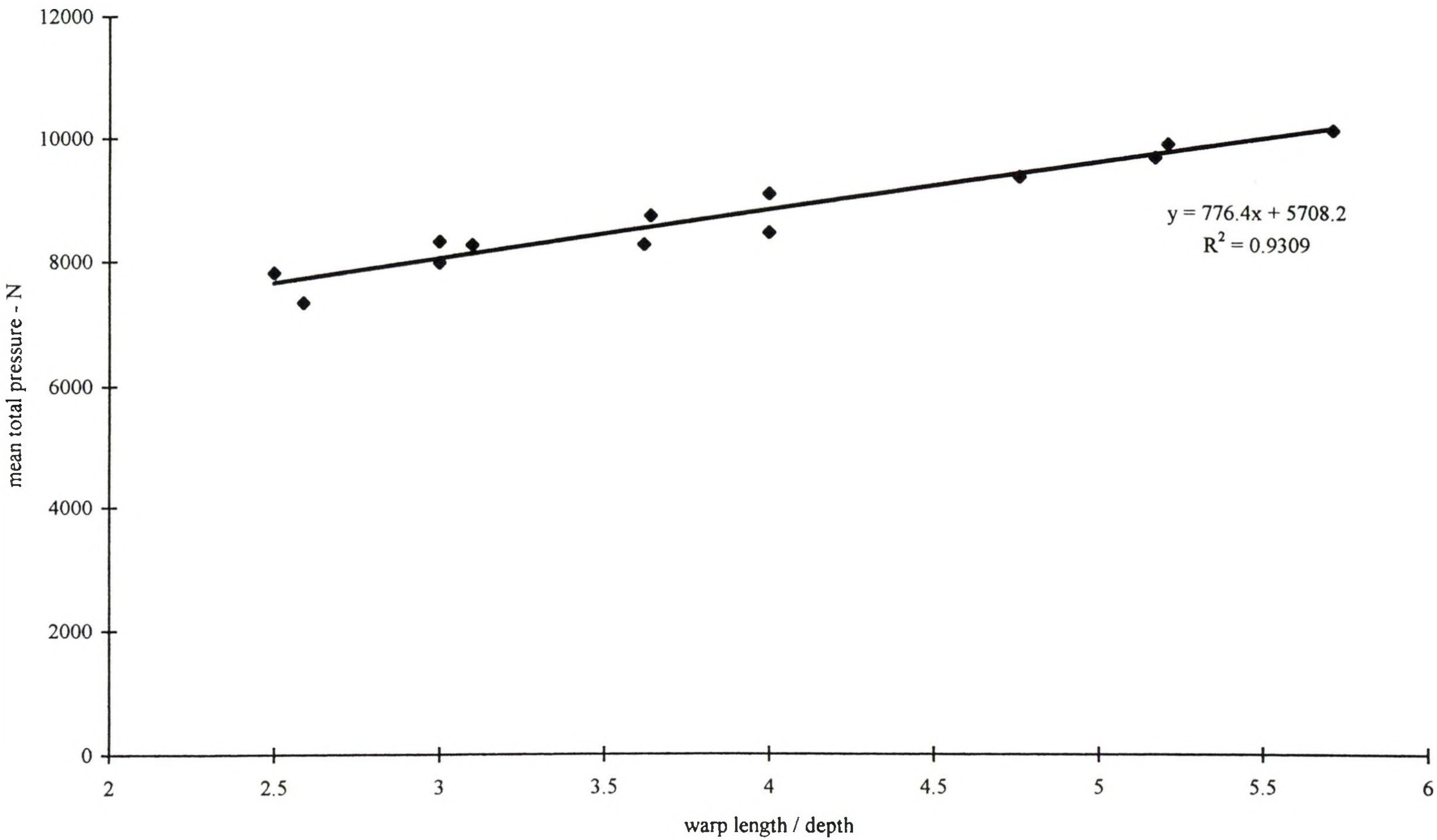


Fig. 3.3.9. Total gear pressure vs warp length/depth ratio.

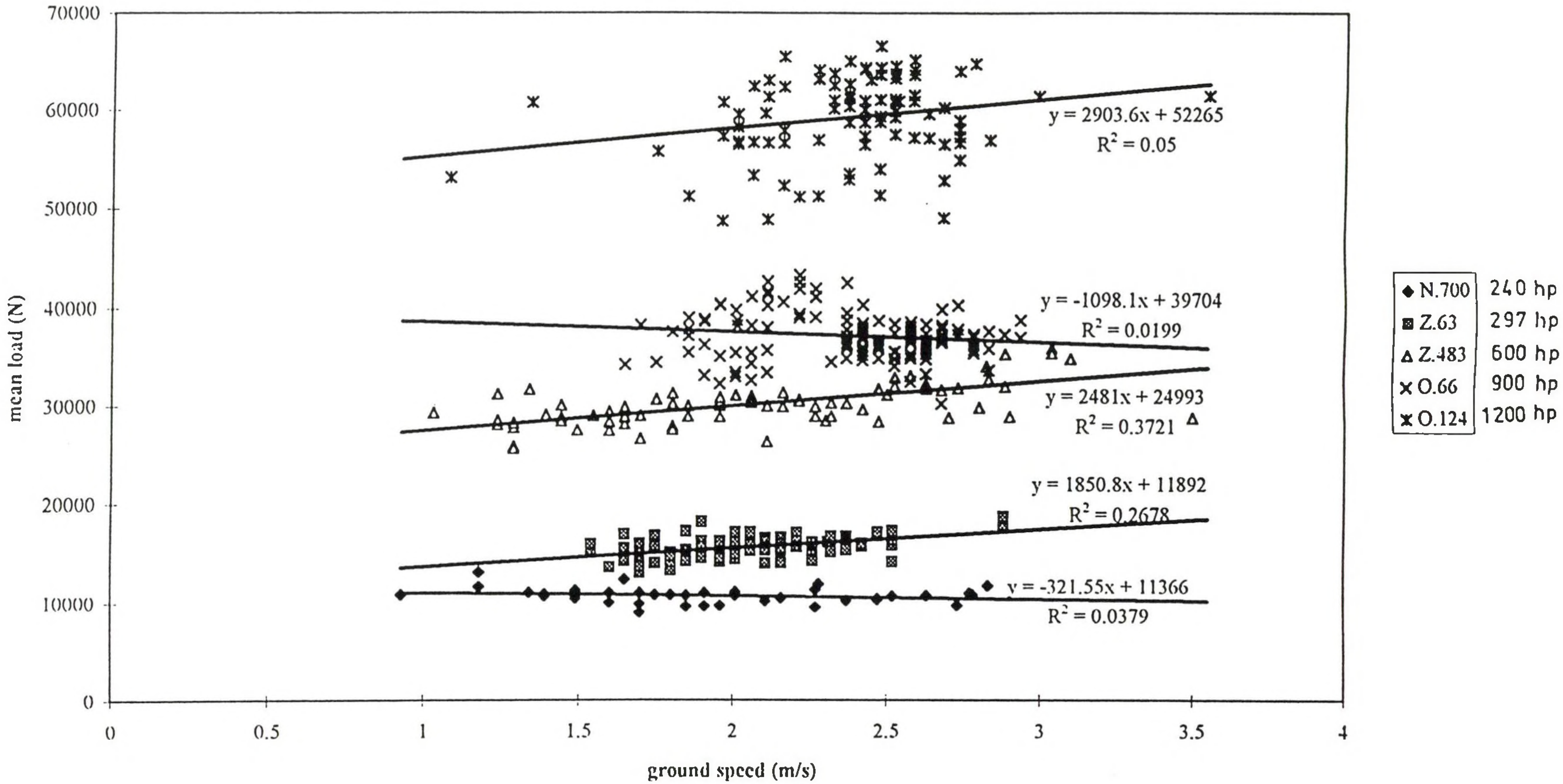


Fig. 3.3.10. Mean loads vs ground speed.

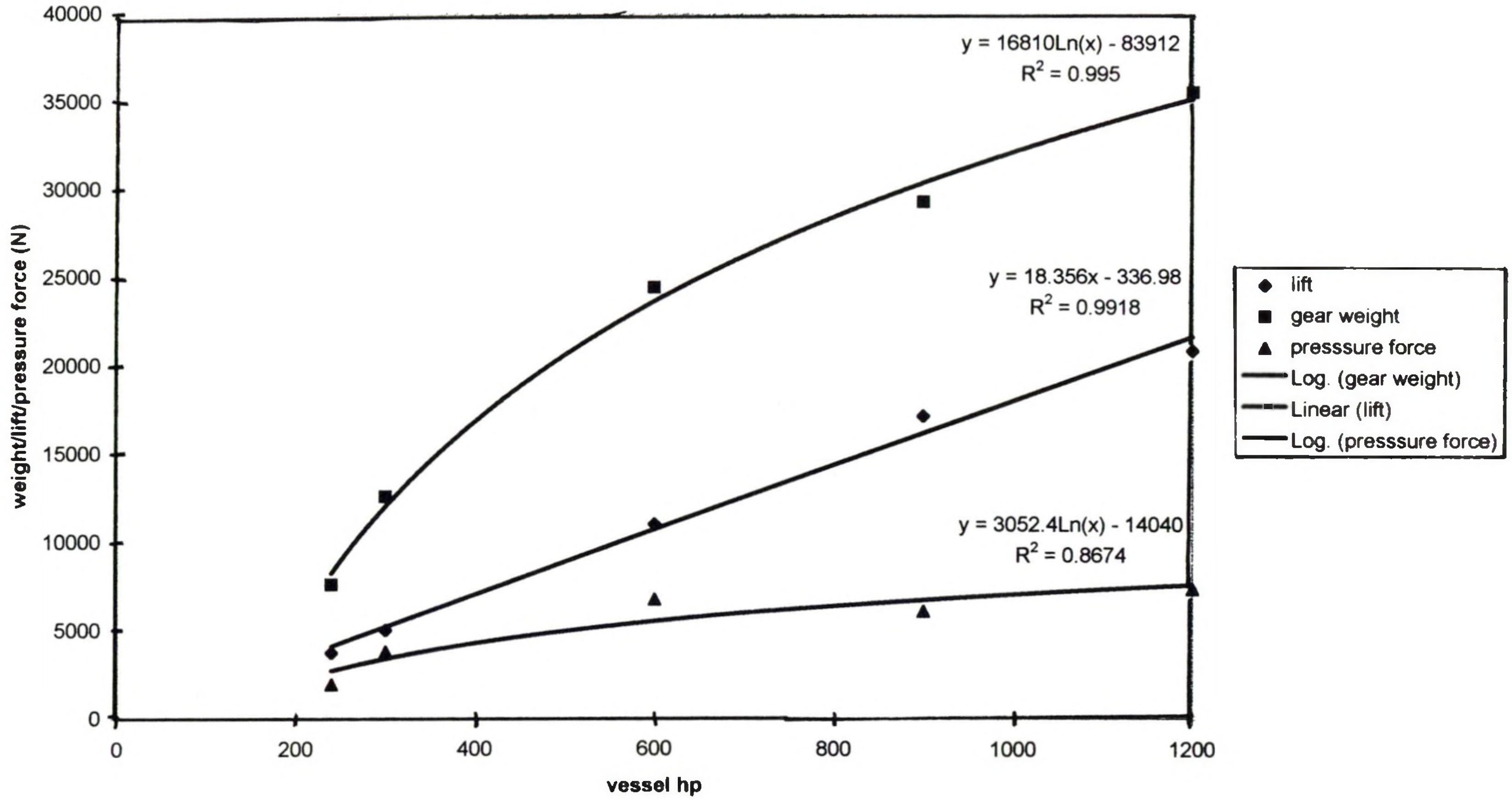


Fig. 3.3.11. Determination of pressure force vs vessel hp.

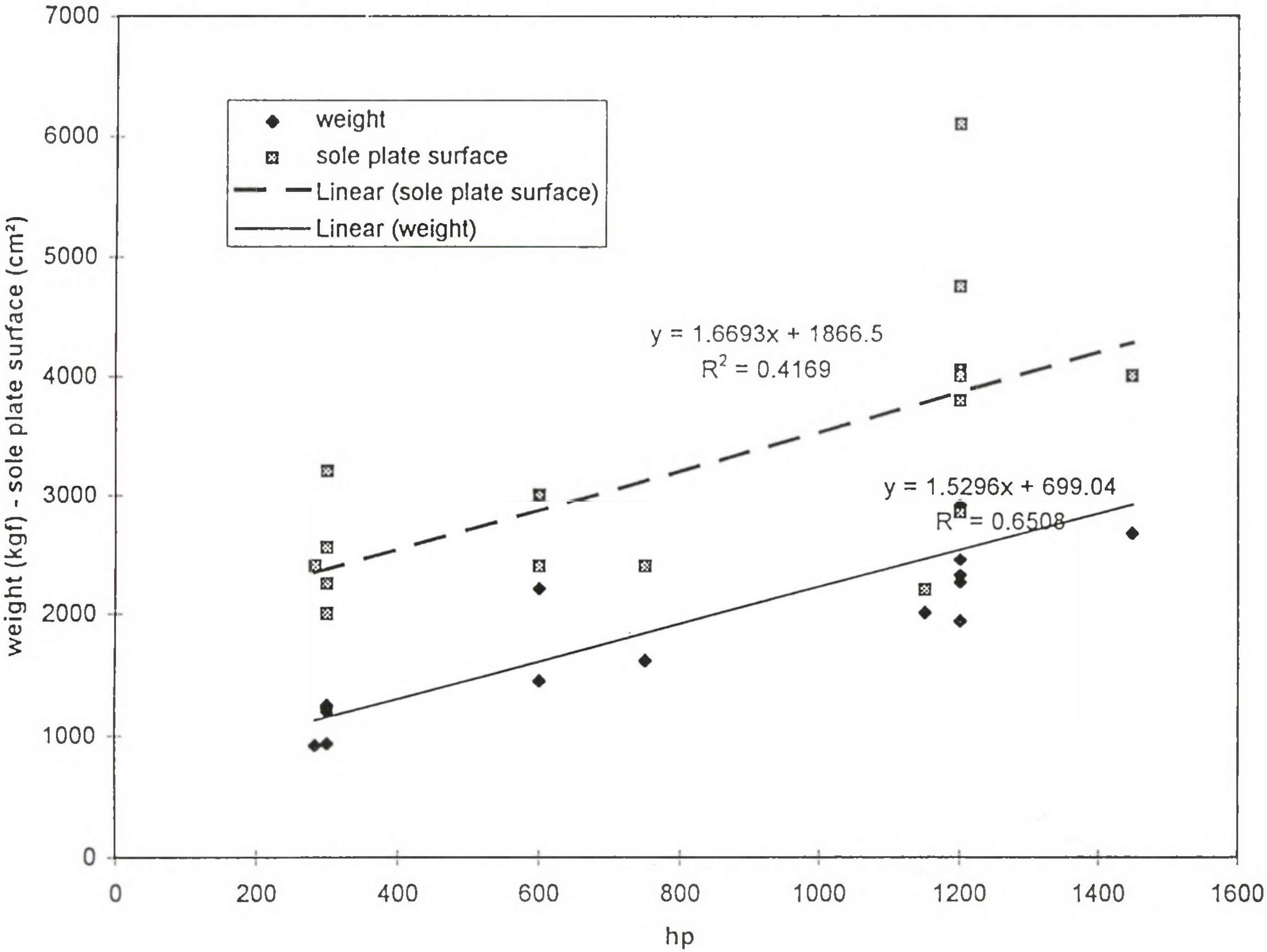


Fig. 3.3.12. Weight (beam + trawl heads + bridles + block) and sole plate surface.

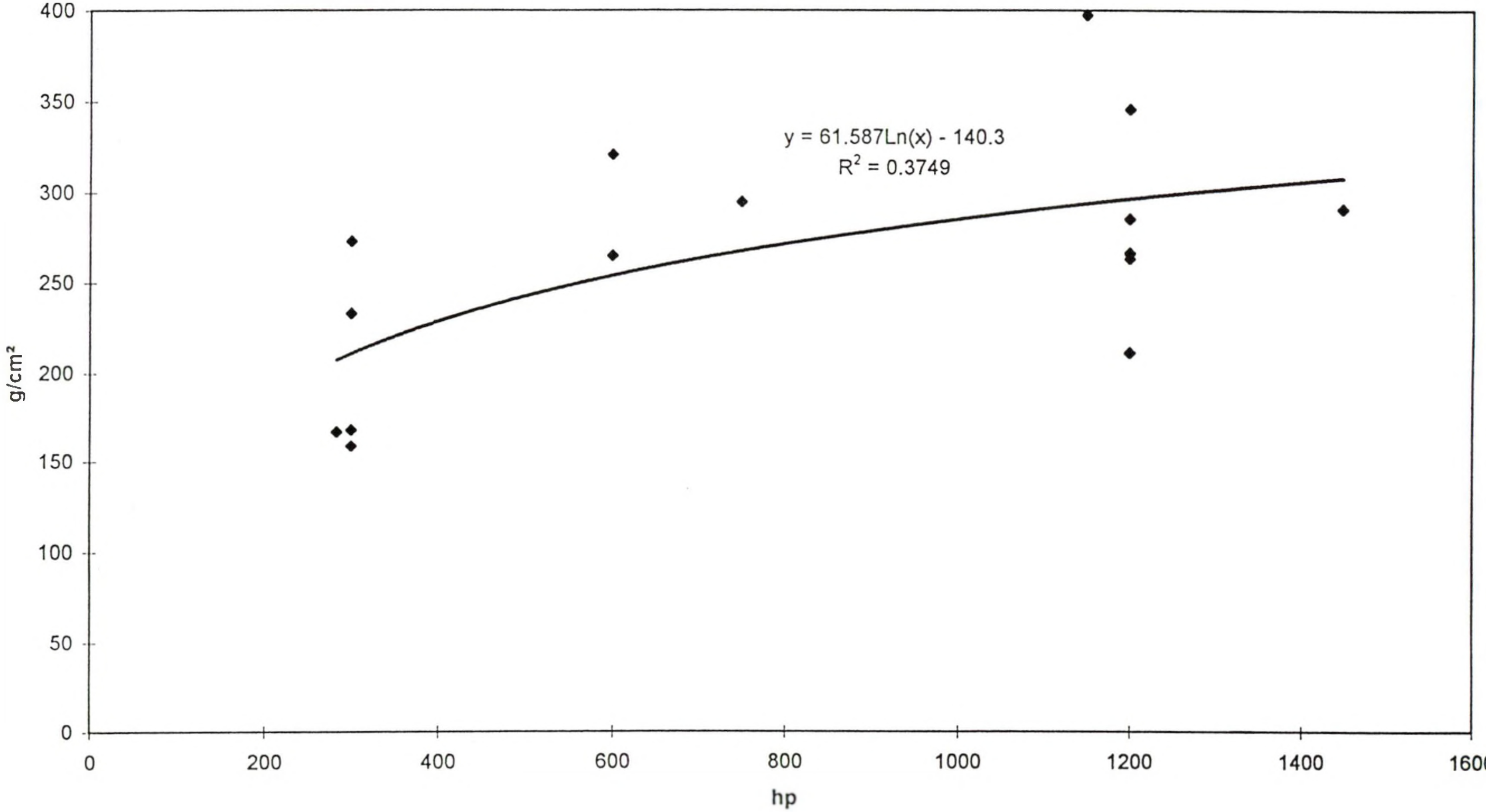
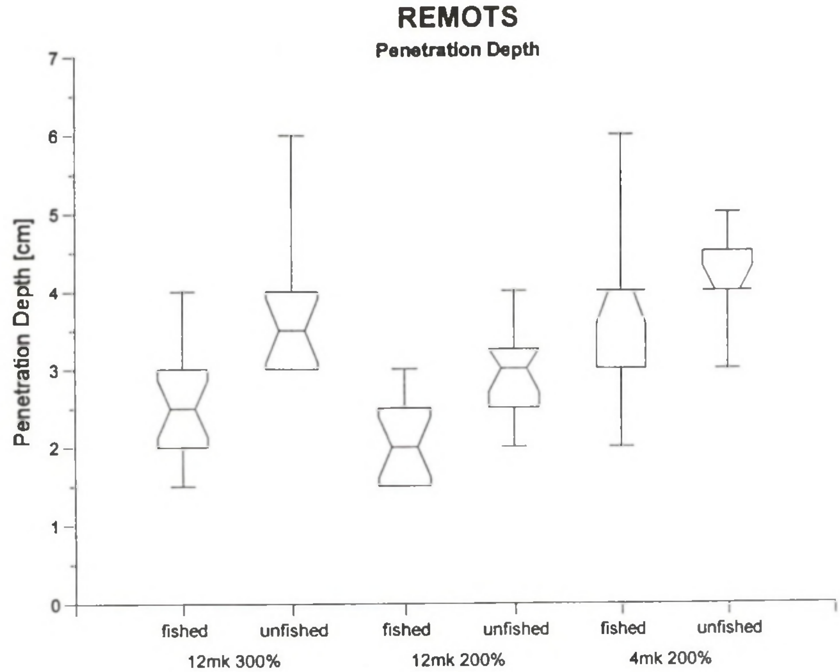


Fig. 3.3.13. Weight (beam + trawl heads + bridles + block) per cm^2 sole plate surface.



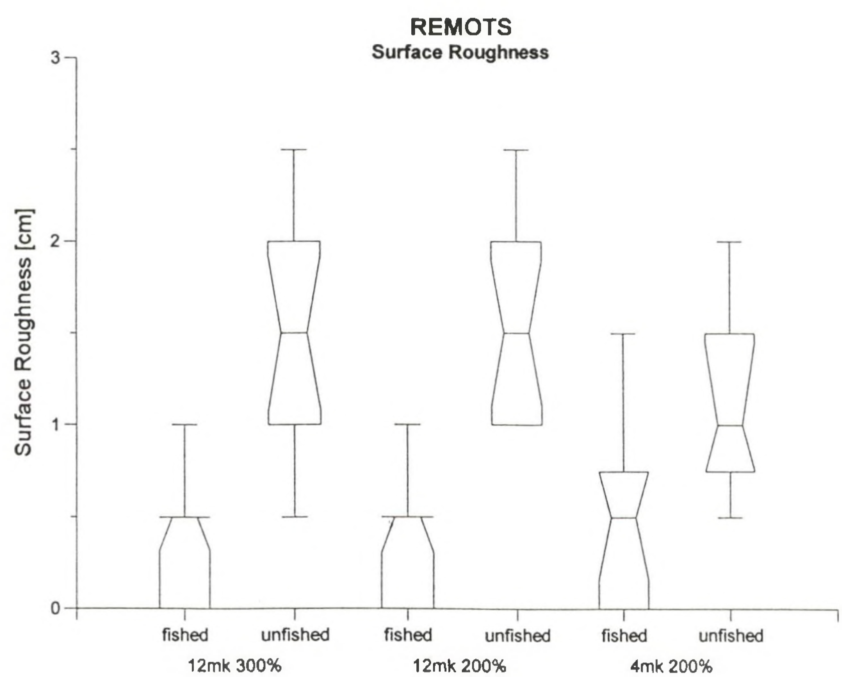


Fig. 3.3.14. Box-and-whisker plots of REMOTS observations of sea floor disturbance by beam trawling (Weisse Bank).

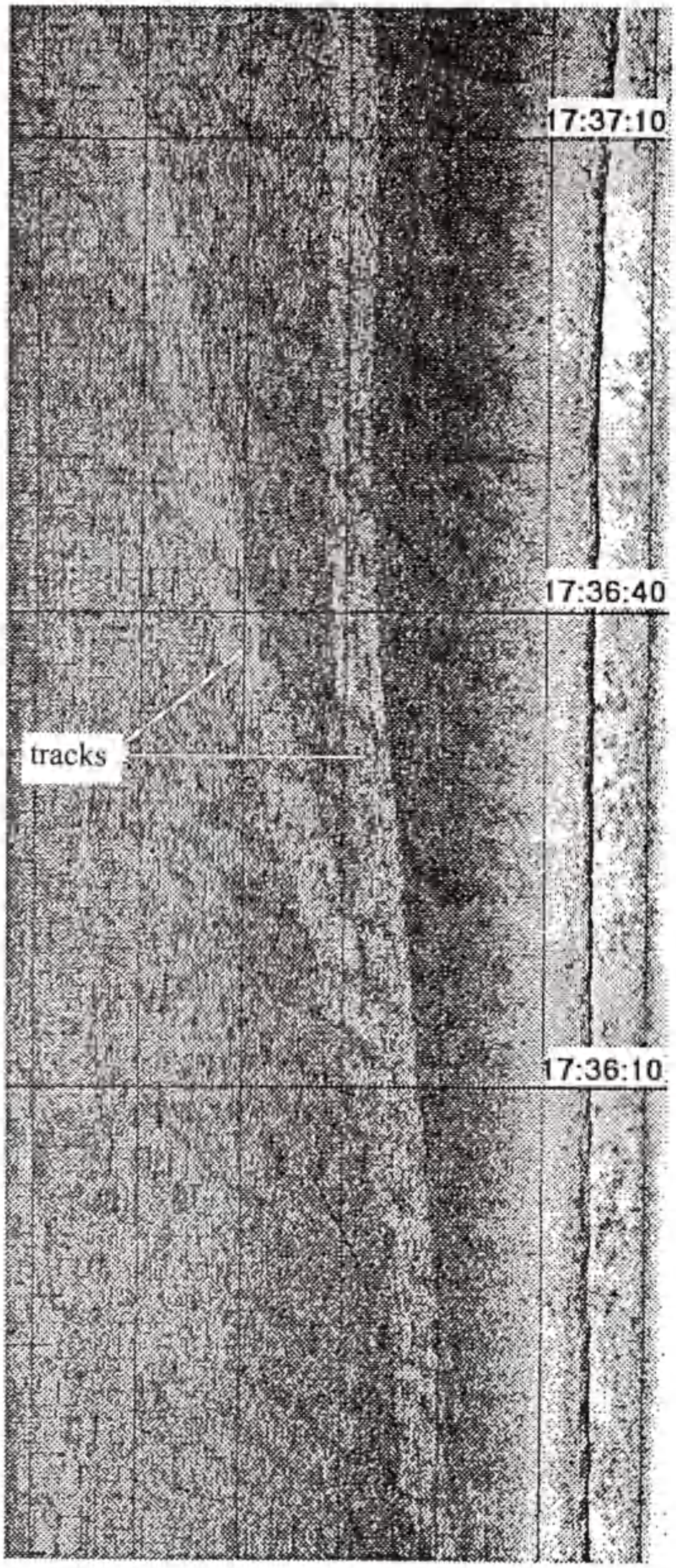


Fig. 3.3.15. Section of side-scan sonar recording - 4m beam trawl with chain matrix.

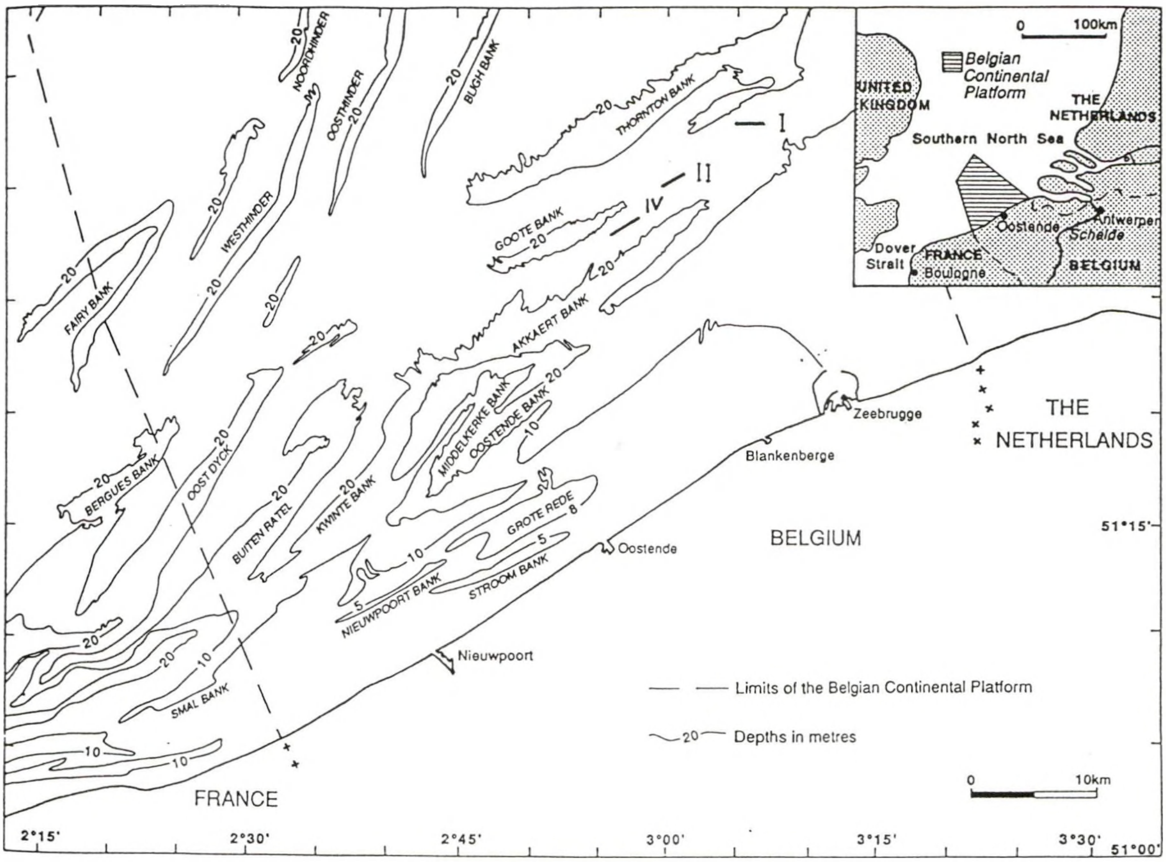


Fig. 3.3.16. Working areas (I, II, IV) for the side-scan sonar observations.

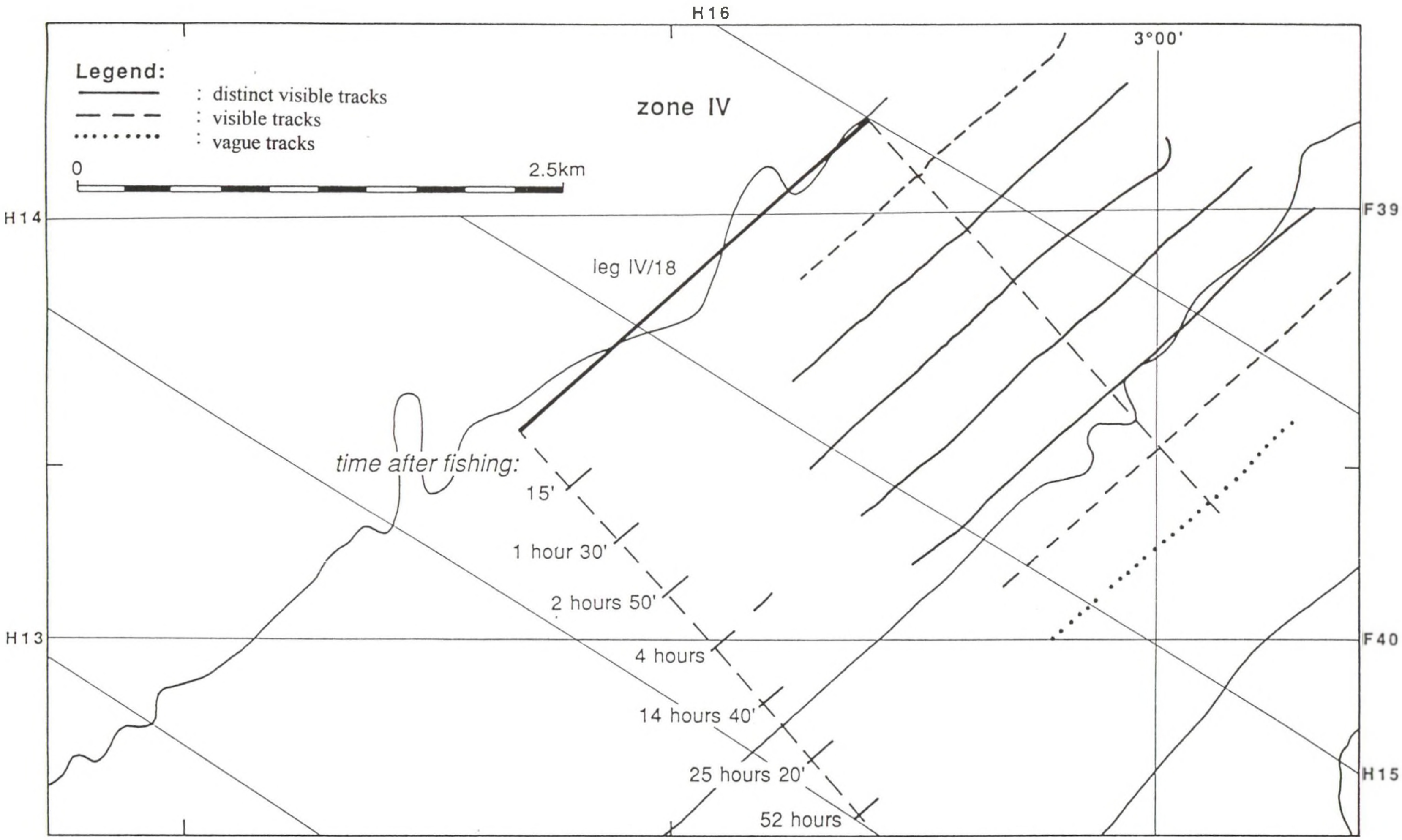


Fig. 3.3.17. Visibility of tracks as a function of time (area IV).

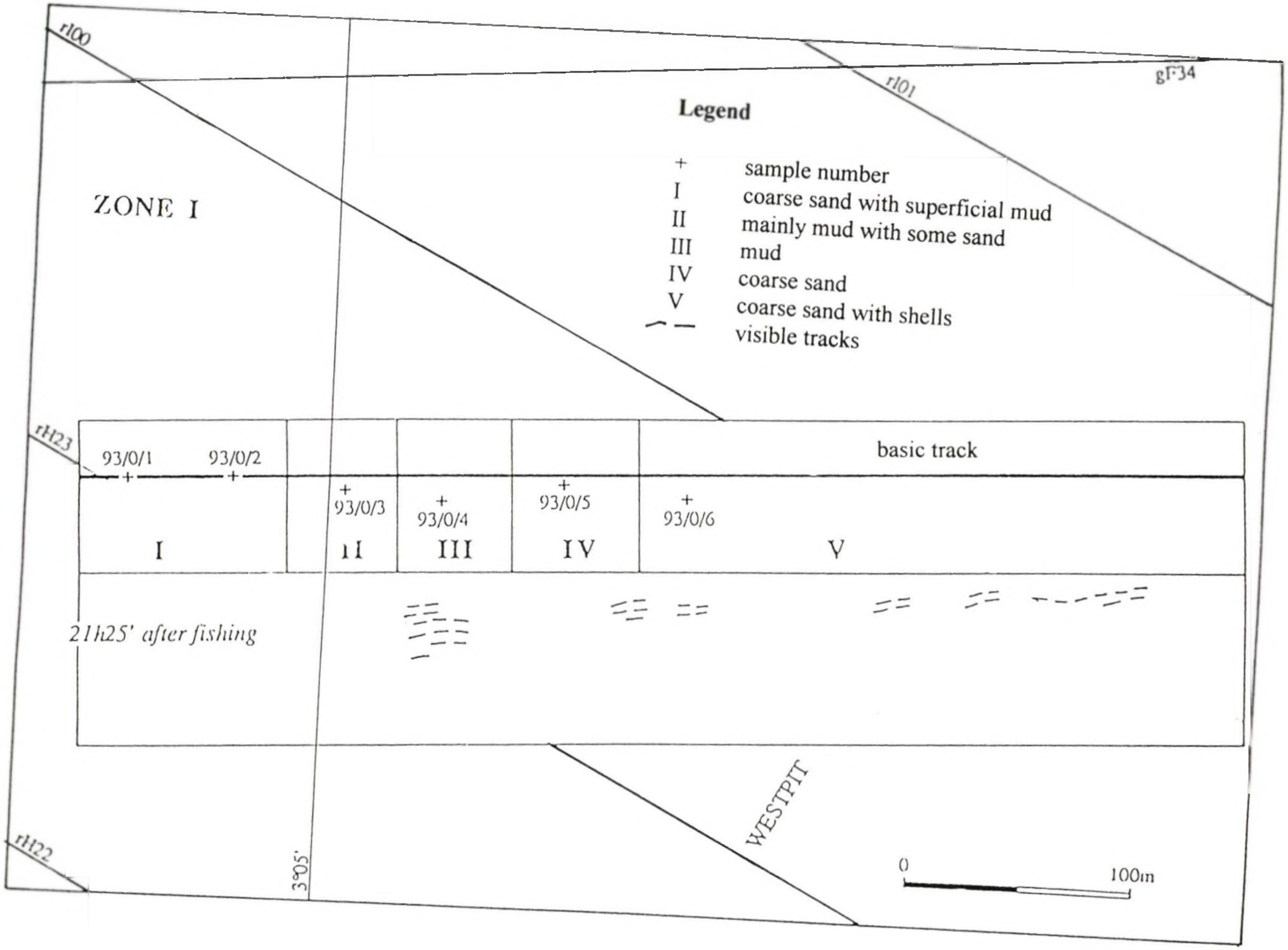


Fig. 3.3.18. Visibility of tracks related to the different sediment types, 21 h 25 min after fishing.

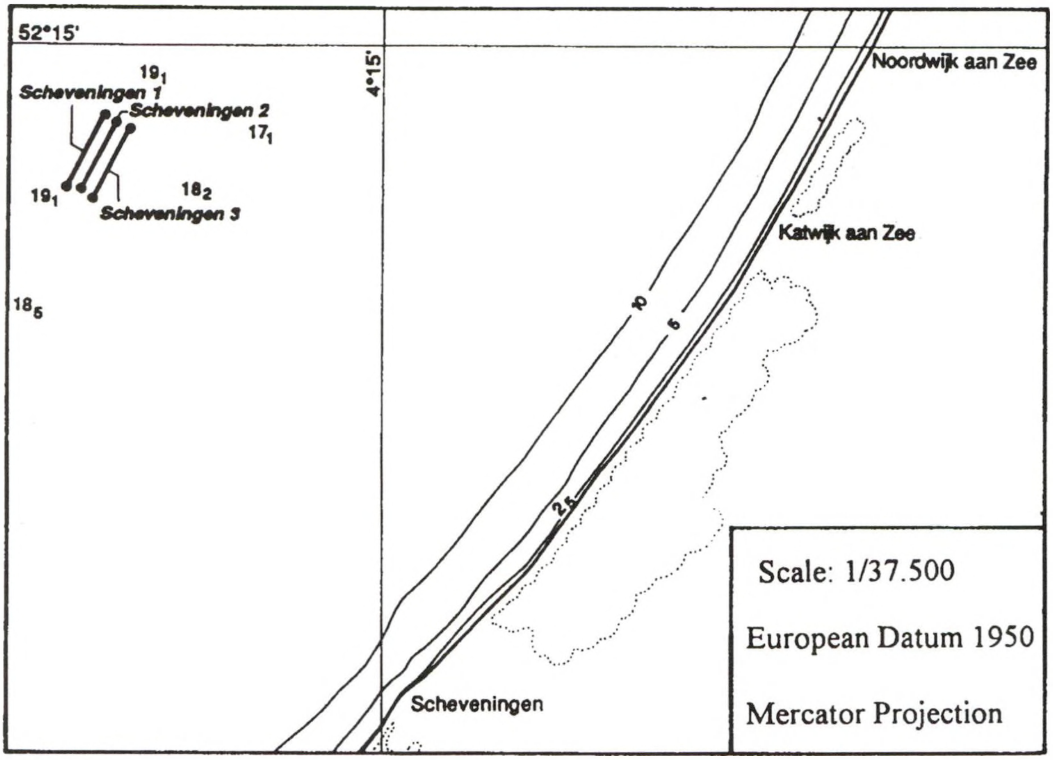


Fig. 3.3.19. The Scheveningen area with location of the central reference track.

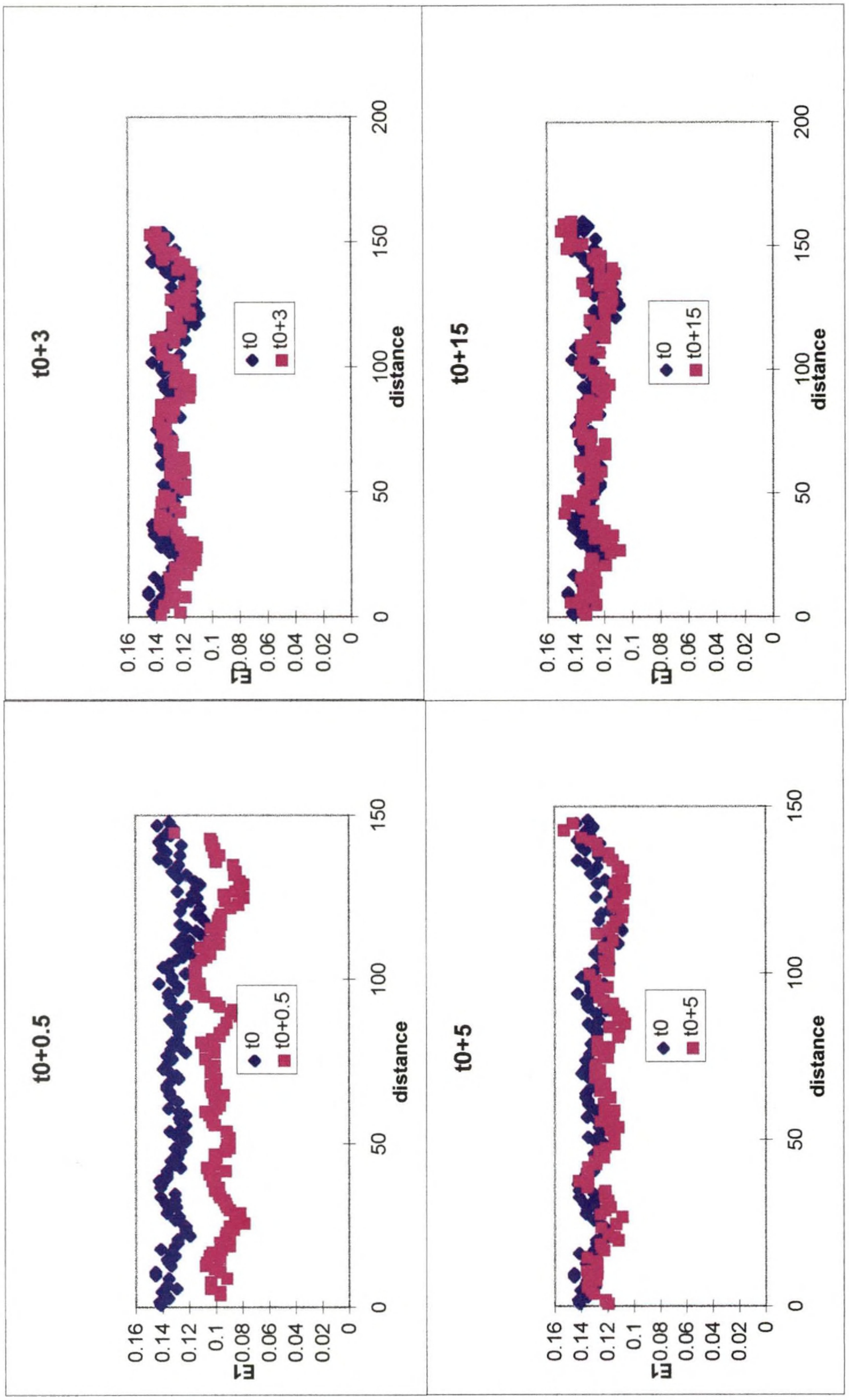


Fig. 3.3.20a. RoxAnn E1-values Scheveningen area.

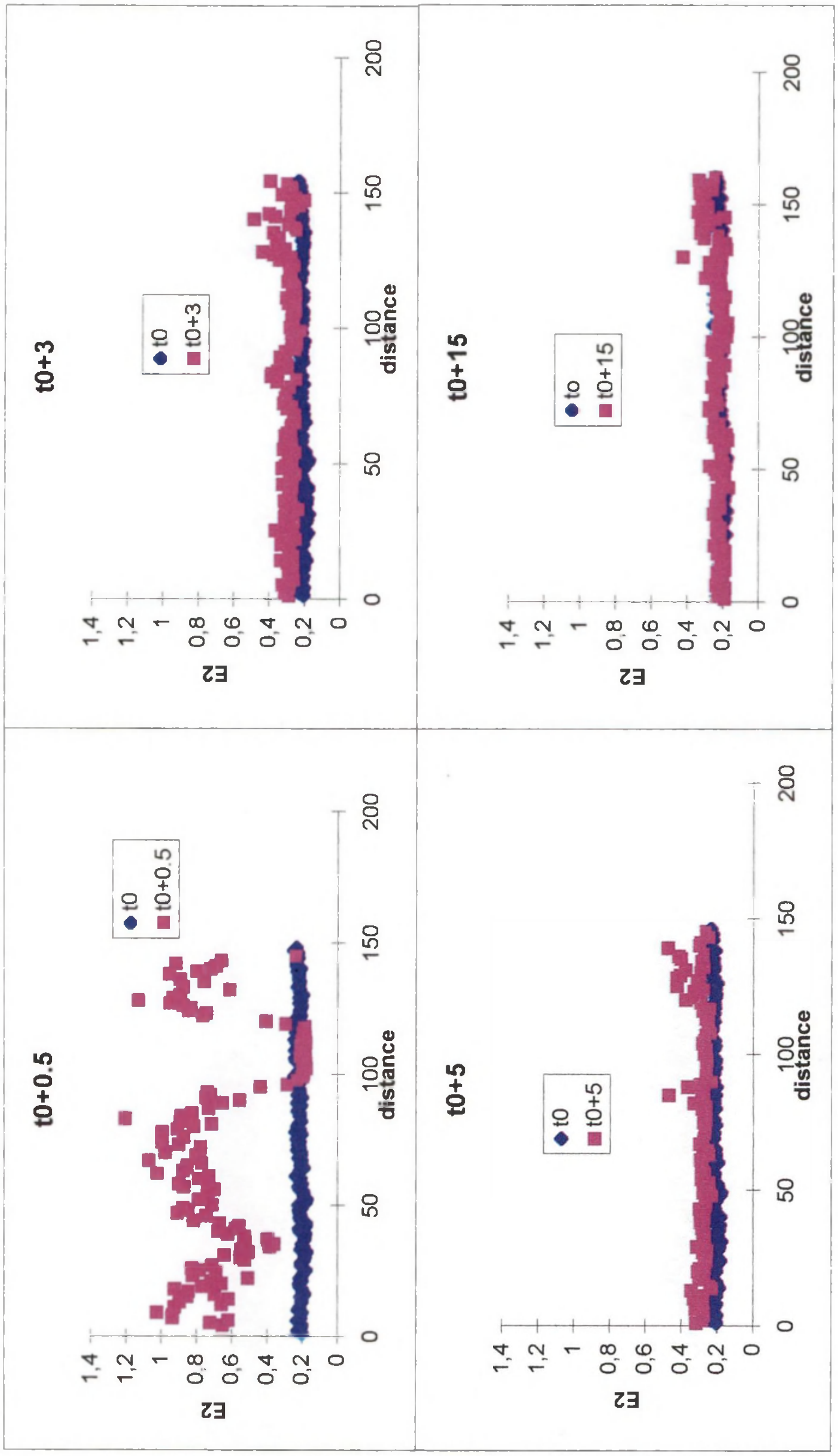


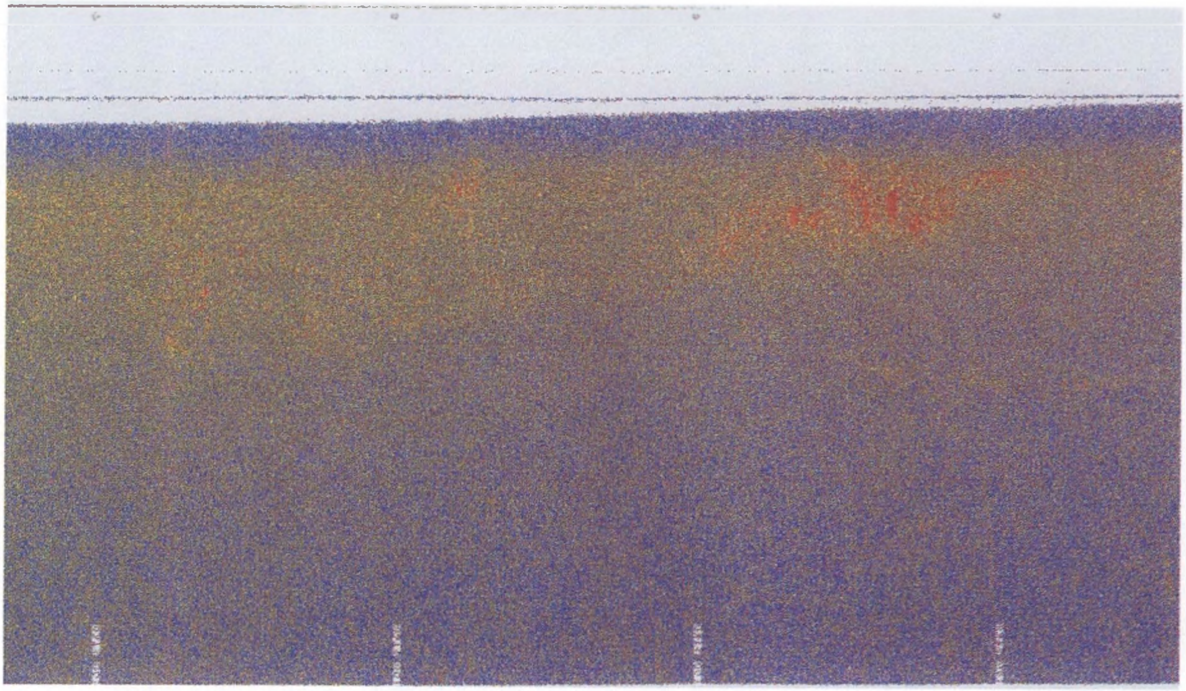
Fig. 3.3.20b. RoxAnn E2-values Scheveningen area.

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

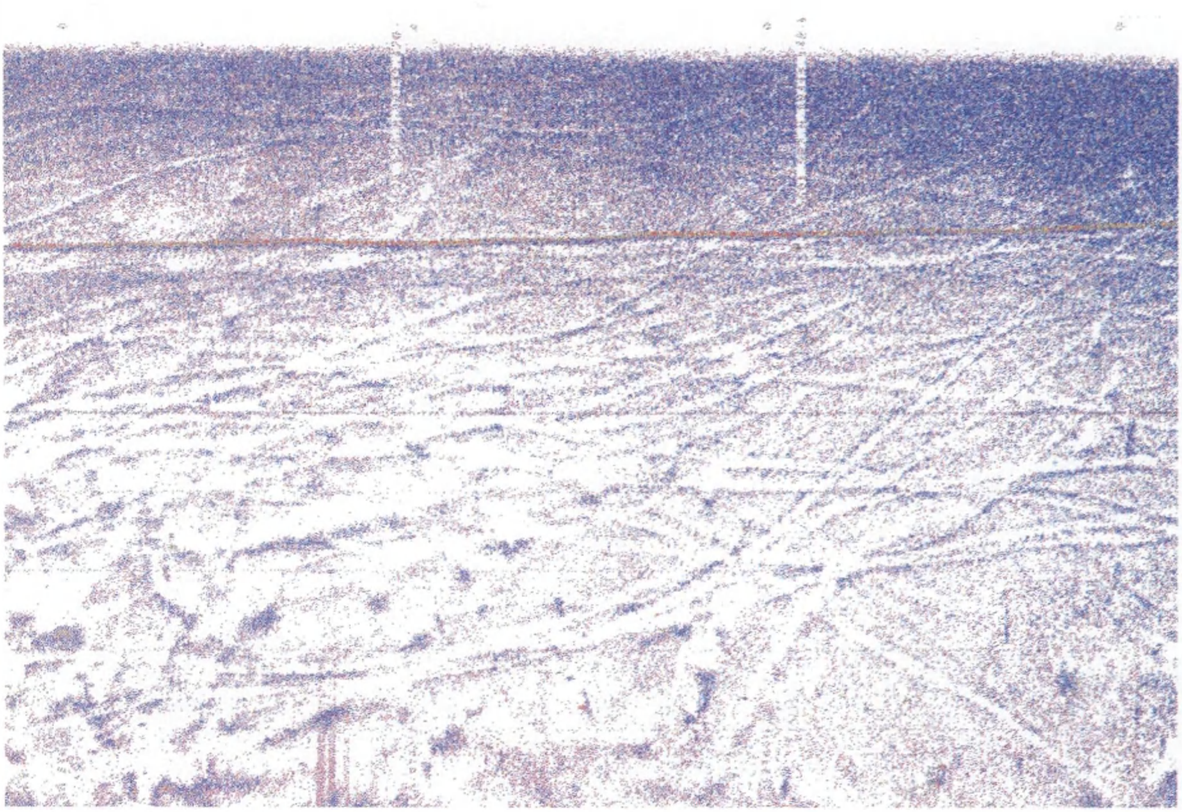


Fig. 3.3.24 **a**) Portion of the side-scan sonar record from the preliminary survey showing the seabed in the treatment area before experimental disturbance. **b**) Portion of the side-scan sonar record obtained following 10 months of disturbance, showing disturbed seabed in the treatment area.

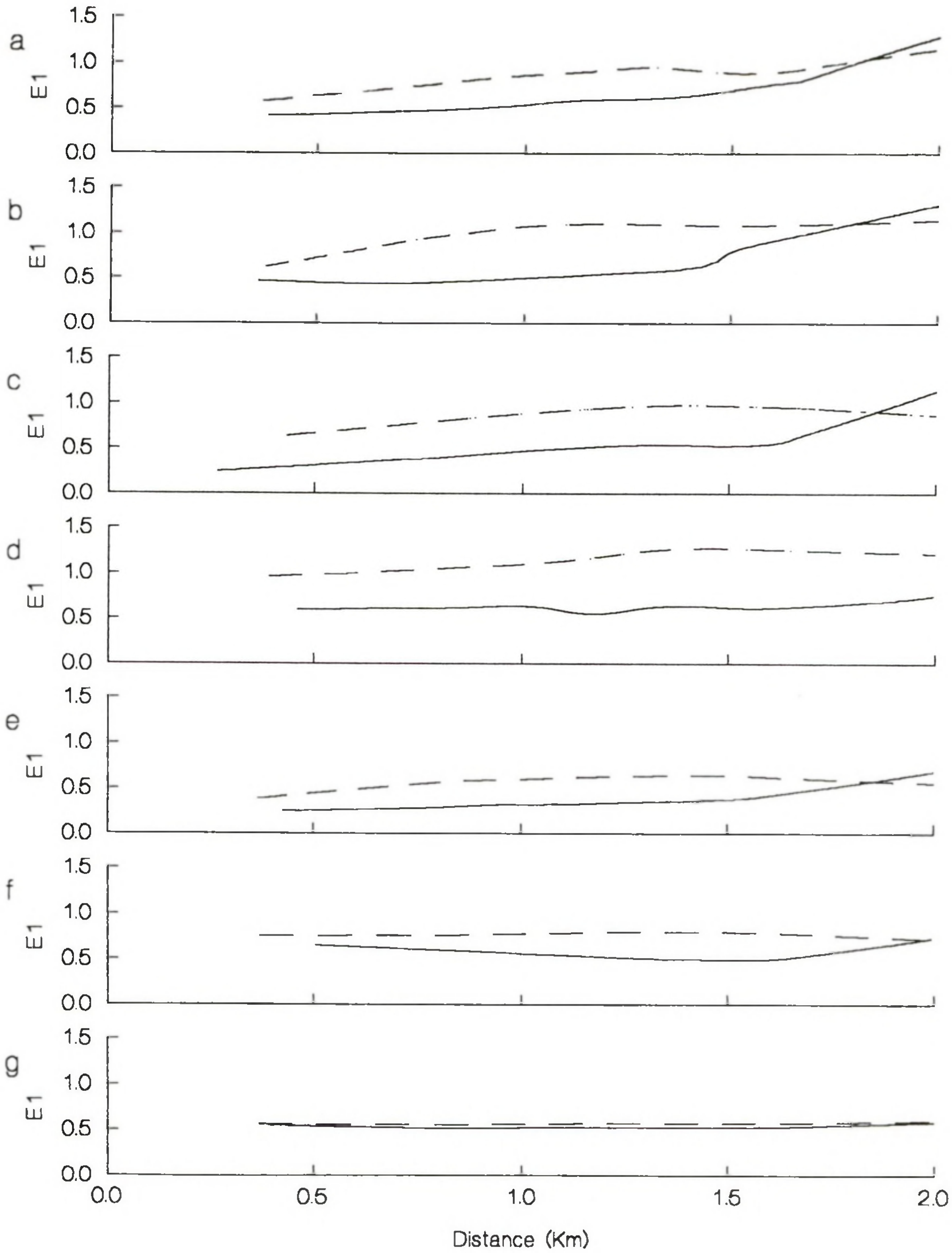


Fig. 3.3.25. Transect of E1 (roughness parameter) values along the loch for treatment (dashed line) and reference (solid line) areas. Figures shows (a) preliminary survey, (b) 5 months disturbance, (c) 10 months disturbance, (d) 16 months disturbance, (e) 6 months recovery, (f) 12 months recovery and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

TABLE 3.3.1
Vessel and gear characteristics

Vessel *	hp-class	hp	GRT (t)	LOA (m)	Gear type **	Beam length (m)	Gear weight (kg)
N.700	<270	240	29.91	16.80	TBB, tickler chains	4	986
Z.63	270-300	297	68	20.04	TBB, tickler chains	4	1635
Z.483	600-899	600	187	34.21	TBB, chain matrix	9.5	3180
O.66	900-1100	900	224	30.58	TBB, chain matrix	10	3821
O.124	>1100	1200	259	32.23	TBB, chain matrix	10.3	4642

* Belgian vessel registration numbers
** TBB: twin beam trawl

TABLE 3.3.2
Grain size analysis (%) at RoxAnn locations

Sediment classification (Folk 1954)		Scheveningen	Goote Bank samples			Negenvaam samples			
Description	Fraction		1	2	3	1	2	3	4
gravel	>2000 µ	0.40	43.96	32.18	47.92	1.03	4.60	1.73	8.49
very coarse sand	>1000 µ	0.06	5.22	4.73	6.83	1.27	0.78	3.08	1.48
coarse sand	> 500 µ	1.83	3.26	3.68	3.26	5.13	4.10	17.10	3.11
medium sand	> 250 µ	67.86	28.94	30.38	16.99	32.21	16.21	47.89	12.89
fine sand	> 125 µ	27.19	15.44	26.42	22.24	57.26	67.99	28.22	65.57
very fine sand	> 63 µ	1.55	1.47	1.16	1.40	1.32	2.96	0.79	3.66
mud	< 63 µ	1.11	1.71	1.45	1.36	1.78	3.36	1.19	4.80

TABLE 3.3.3
Values of RoxAnn parameters at the different locations

Area	E1/E2	Average	Min	Max	St. dev.
Scheveningen	E1	0.1305	0.109	0.146	0.00782
	E2	0.2141	0.175	0.252	0.01557
Goote Bank	E1	0.4037	0.36	0.453	0.01943
	E2	0.4692	0.379	0.611	0.04403
Negenvaam	E1	0.2178	0.143	0.316	0.05719
	E2	0.2248	0.101	0.527	0.08492

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		
SEASON	Spring						Spring			Autumn			Spring		
GEAR (No.of observations)	4TBBm (3)			4TBB (1)			4TBB (3)			12TBB (1)			4TBBm (13)		
kg/ha	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
other marketable flatfish	1.5	1.5	5	0.7	-	3	7.5	0.9	6	1.2	-	9	0.9	0.1	9
marketable roundfish	0.5	0.5	2	0.0	-	0	0.3	0.1	0	0.0	-	0	0.1	0.0	1
discarded flatfish	0.4	0.4	1	2.7	-	11	22.8	10.2	19	0.9	-	7	1.7	0.1	18
discarded roundfish	1.2	1.2	5	0	-	0	0.1	0.0	0	0.1	-	0	0.4	0.2	5
polychaetes	0.1	0.1	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
echinoderms	22.1	22.1	83	20.1	-	80	76.2	39.8	64	7.9	-	62	5.3	0.8	56
molluscs	0	0	0	0.0	-	0	8.3	5.2	7	0.1	-	1	0.0	0.0	0
marketable fish	2.7	2.7	10	1.3	-	5	8.8	1.5	7	2.9	-	23	1.2	0.1	13
discarded fish	1.6	1.6	6	2.7	-	11	22.9	10.3	19	1.0	-	7	2.1	0.3	23
invertebrates	22.5	22.5	84	21.3	-	84	87.1	44.1	73	8.9	-	70	6.1	0.9	64
total	26.8	26.8	100	25.3	-	100	118.8	56.0	100	12.8	-	100	9.5	1.3	100

AREA	4.1 (DUTCH COAST SOUTH)														
YEAR	1994						1995								
SEASON	Spring						Autumn								
GEAR (No.of observations)	12TBB (5)			4TBB (13)			4TBBm (5)			12TBB (13)			4TBB (20)		
kg/ha	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%
marketable sole	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	1.9	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	0.7	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	3.6	0.8	20	2.4	0.3	13	4.3	0.2	39	6.0	1.0	41	7.0	0.8	36
discarded roundfish	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	0	0	0	0	0	0	0	0	0	0	0	0	0	0
crustaceans	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	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	0.0	0	0	0	0	0.2	0.1	1	0.1	0.1	1
marketable fish	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	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	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	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)															4.3 (OYSTERGROUNDS)					
YEAR	1992			1994						1995						1992			1993		
SEASON	Spring			Spring						Spring						Spring			Autumn		
GEAR (No.of observations)	4TBB (1)			12TBB (2)			4TBB (2)			12TBB (11)			4TBB (1)			12TBB (3)			12TBB (3)		
kg/ha	mean	sem	%	mean	sem	%	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	0.2	0.1	1	0.4	0.1	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	0.8	0.2	3	4.4	1.8	26
marketable roundfish	0.3	-	1	0.2	0.1	0	0.1	0.1	0	0.3	0.1	0	1.5	-	4	0.3	0.2	1	0.1	0.1	1
discarded flatfish	6.8	-	13	19.3	2.6	39	22.4	4.6	42	51.2	19.5	51	5.3	-	14	4.3	0.7	15	4.3	1.0	25
discarded roundfish	0.0	-	0	1.1	0.1	2	0.4	0.4	1	5.9	1.9	6	2.5	-	7	0.4	0.1	1	0.3	0.1	2
polychaetes	0	-	0	0	0	0	0	0	0	0	0	0	0	-	0	1.2	0.6	4	1.4	0.8	8
crustaceans	1.0	-	2	1.8	-	4	1.6	-	3	2.6	0.8	3	6.6	-	17	1.8	0.6	6	1.5	0.4	9
echinoderms	40.3	-	80	21.8	-	44	23.6	-	44	28.1	7.1	28	21.7	-	56	16.1	10.8	56	3.6	0.2	21
molluscs	0	-	0	0	0	0	0	0	0	2.3	0.9	2	0	-	0	3.5	1.7	12	1.0	0.7	6
marketable fish	2.4	-	5	5.1	0.2	10	5.6	0.5	10	10.2	1.4	10	2.7	-	7	1.3	0.4	5	4.9	2.0	29
discarded fish	6.8	-	13	20.4	2.6	41	22.8	4.2	43	57.1	19.8	57	7.9	-	20	4.7	0.9	16	4.7	1.0	27
Invertebrates	41.3	-	82	23.7	10.2	48	25.2	6.9	47	33.1	7.6	33	28.3	-	73	22.5	12.3	79	7.6	1.6	44
total	50.5	-	100	49.2	13.0	100	53.5	11.5	100	100.4	28.8	100	38.9	-	100	28.5	13.6	100	17.1	4.8	100

AREA	4.4 (GERMAN BIGHT)																	
YEAR	1993			1994						1995								
SEASON	Autumn			Autumn						Spring								
GEAR (No.of observations)	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	%
marketable sole	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	0.7	-	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	0.2	-	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	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	0.0	-	0	0.8	0.4	1	2.3	0.8	36	0.1	0.0	4	1.8	0.3	1	3.7	0.8	6
polychaetes	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	-	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	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	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	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	2.8	-	22	31.3	7.6	48	3.5	0.8	53	1.6	0.2	47	17.6	5.8	15	27.4	7.0	44
Invertebrates	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	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	6.0	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	0.6	18	32.4	6.2	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	56.7	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	16.7	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	0.8	14
discarded fish	12.3	2.6	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	56.6	81	252.0	-	84	260.1	130.0	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)														
YEAR	1992			1994						1995					
SEASON	Spring			Spring						Spring					
GEAR (No.of observations)	4TBB (1)			12TBB (2)			4TBB (2)			12TBB (11)			4TBB (1)		
kg/hour	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
other marketable flatfish	3.9	-	3	38.1	2.3	8	14.8	1.2	8	48.9	1.0	3	1.9	-	1
marketable roundfish	0.9	-	1	2.1	1.1	0	0.3	0.3	0	6.2	3.9	0	6.4	-	4
discarded flatfish	20.1	-	13	189.3	25.8	39	73.0	15.4	42	536.0	200.0	37	23.6	-	14
discarded roundfish	0.0	-	0	10.3	0.6	2	1.3	1.3	1	62.7	17.4	4	11.2	-	6
polychaetes	0.0	-	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	-	0
crustaceans	3.1	-	2	17.6	-	4	5.2	-	3	52.6	34.2	4	29.4	-	17
echinoderms	119.3	-	80	213.1	-	44	77.0	-	44	650.7	422.8	45	95.8	-	56
molluscs	0.0	-	0	0.0	0.0	0	0.0	0.0	0	20.5	5.6	1	0.0	-	0
marketable fish	7.1	-	5	49.9	1.4	10	18.2	1.7	10	119.3	13.1	8	12.1	-	7
discarded fish	20.1	-	13	199.6	26.5	42	74.3	14.1	43	598.7	200.2	42	34.8	-	20
invertebrates	122.3	-	82	230.9	96.5	48	81.9	22.0	47	723.8	455.0	50	125.2	-	73
total	149.6	-	100	480.5	126.4	100	174.4	37.7	100	1441.8	668.3	100	172.1	-	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/hour	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%	mean	sem	%
marketable sole	13.3	4.6	1	14.1	6.1	3	64.3	-	11	34.0	1.6	5	0.0	0.0	0	0.4	0.2	0	180.2	34.0	5	16.6	3.3	7
other marketable flatfish	49.5	15.1	3	154.6	83.6	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	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	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	8.6	50	513.4	234.7	14	85.9	23.2	38
discarded roundfish	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	71.4	36.4	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	106.9	42.7	6	49.5	21.0	9	83.8	-	14	37.5	8.8	5	7.9	2.8	12	2.5	0.8	2	104.3	30.1	3	17.4	2.1	8
echinoderms	933.9	621.6	56	129.9	46.1	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	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	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	7.8	18
discarded fish	266.4	46.7	16	141.0	38.0	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	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	1656.4	788.2	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		catch composition (kg/ha)			
	p-value		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.

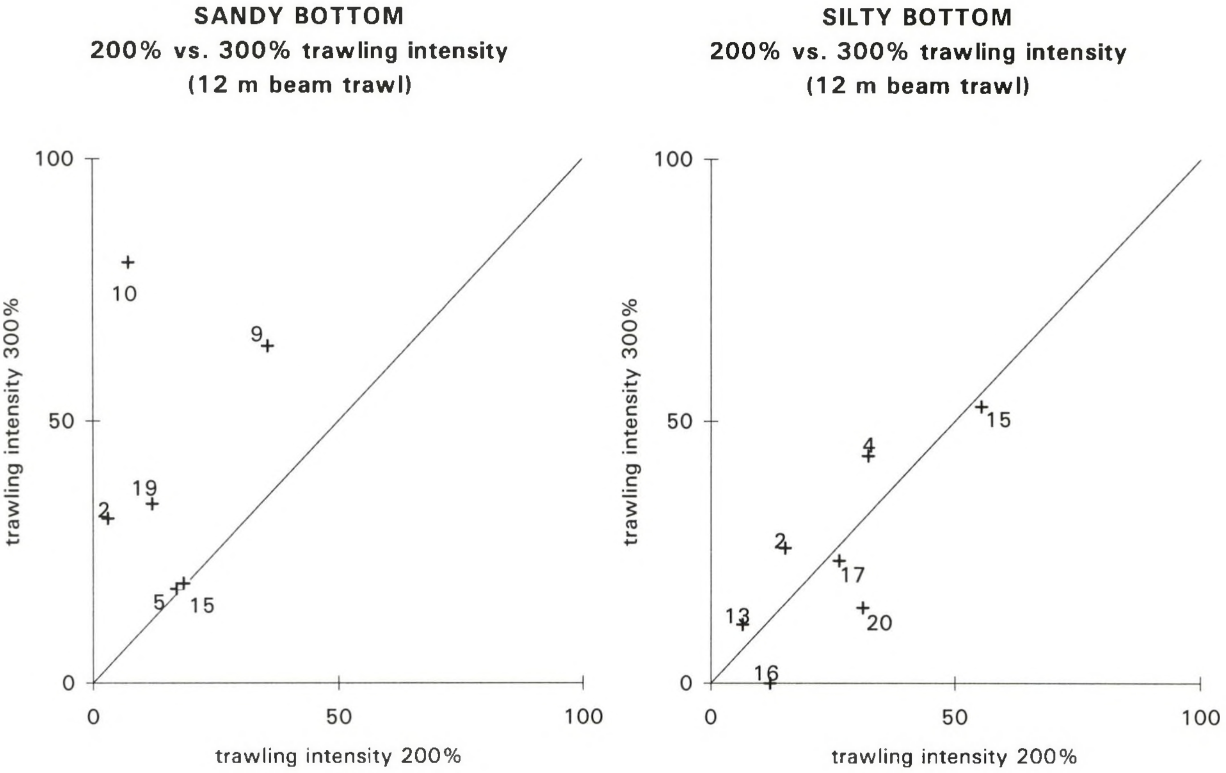
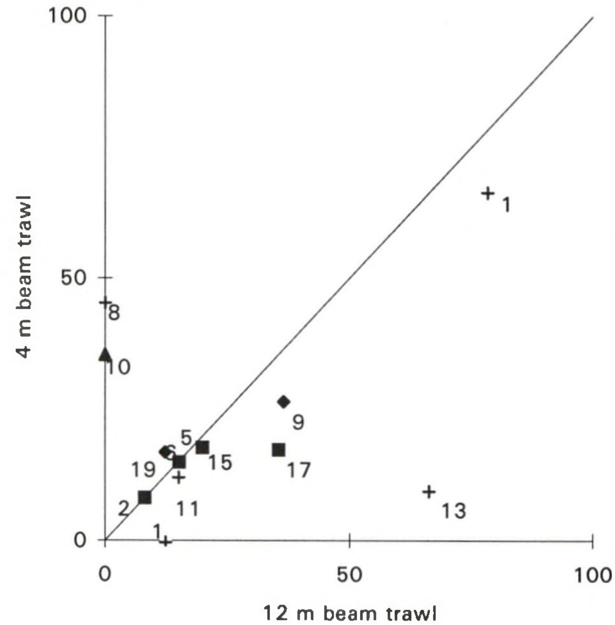
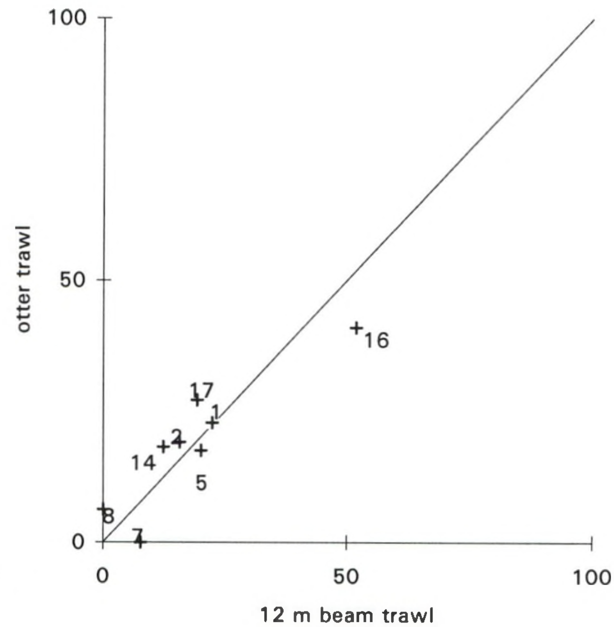


Fig. 3.5.1. Comparison of direct mortalities caused by different trawling intensities with 12m beam trawls in a sandy and a silty area (a 200% trawling intensity vs. a more heavily trawled 300% strip. All results are obtained from 1 study per sediment type. Only species with an initial abundancy of at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

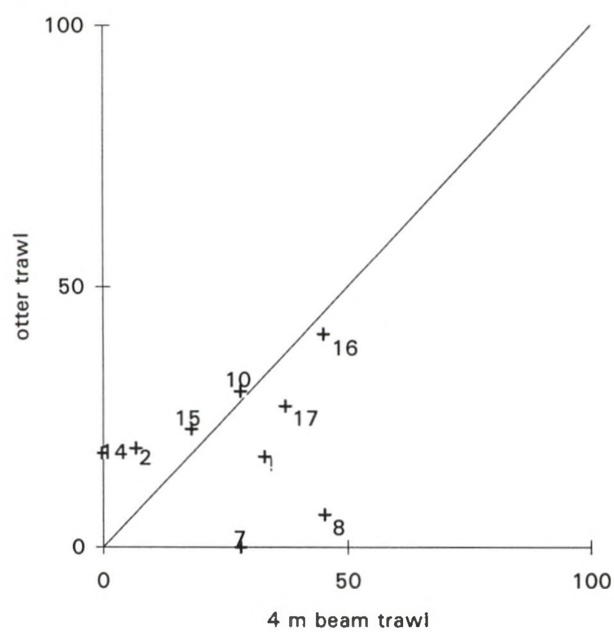
SANDY BOTTOM
12 m beam trawl - 4 m beam trawl



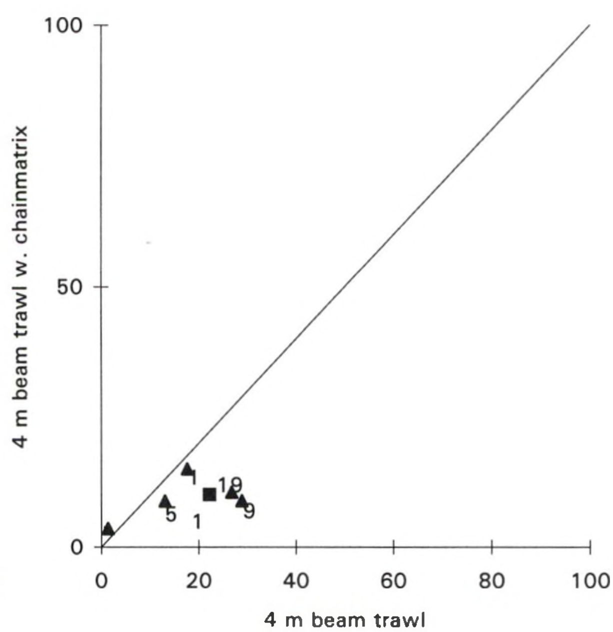
SANDY BOTTOM
12 m beam trawl - otter trawl



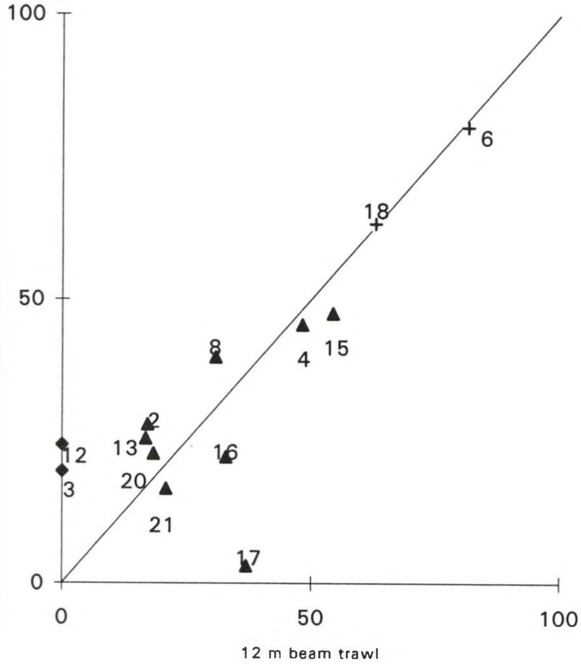
SANDY BOTTOM
4 m beam trawl - otter trawl



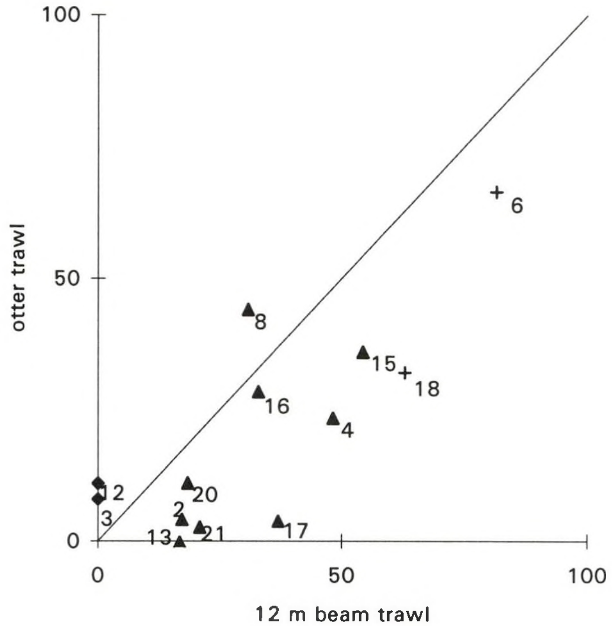
SANDY BOTTOM
4 m beam trawl - 4 m beam trawl w. chainmatrix



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

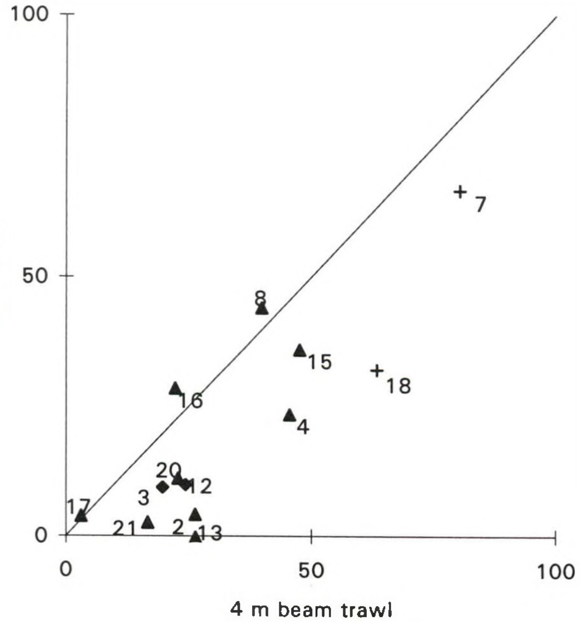


Fig. 3.5.2. Comparison of direct mortalities caused by different commercial gears, in sandy and silty areas. Symbols denote the number of studies from which the results are obtained:

+	=	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 m^2	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 m^2). 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		12 m beam trawl			4 m beam trawl			otter trawl			12 m beam trawl			4 m beam trawl			4 m b.tr. + chainmat			otter trawl		
SEDIMENT		SILTY			SILTY			SILTY			SANDY			SANDY			SANDY			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				

3.6. SCAVENGER RESPONSES TO TRAWLING

Introduction

This chapter investigates those scavengers which feed on animals killed or damaged by trawling. Firstly, we identified which are the important scavenger species found at the different study areas. We also describe changes in the diets of scavengers in response to trawling, and their behaviour. Finally, we attempt to assess the energetic importance of carrion produced by trawling to scavenger populations.

3.6.1. RESULTS OF FIELD INVESTIGATIONS

3.6.1.1. REPEATED TRAWLING

Eastern Irish Sea

At the Anglesey offshore site the hermit crab *Pagurus bernhardus* increased in numbers after fishing on the treatment wayline on both sampling occasions in April and October 1995 (Fig. 3.6.1), although the interaction between time and treatment was not significant in October 1995. The only other species to show a significant treatment * time effect in the ANOVA was the hermit crab *Pagurus prideaux* in October 1995. This response is attributed to an increase in the numbers of *P. prideaux* on the control wayline coinciding with a decrease in numbers on the treatment wayline.

At the Red Wharf Bay site there were no significant increases in numbers of scavengers after fishing the treatment wayline. However it should be noted that samples were collected for only one day after fishing which may not have allowed enough time for aggregation in sufficient numbers to show a significant response.

At the Walney Island site there were no significant increases in scavenger numbers sampled with the small beam trawl on any of the three days after fishing (Fig. 3.6.1). However, several species, including some of those observed scavenging in other experiments, decreased in density after fishing. The decrease in densities in these species after fishing resulted in a significant ANOVA interaction term for *Pagurus bernhardus, Liocarcinus depurator* and *Asterias rubens.*

Our results suggest that at the Anglesey offshore site hermit crabs *Pagurus bernhardus* aggregate in large numbers in trawled areas, increasing their abundance 2 and 3 days after fishing, by a factor of 10 times in April 1995. Elsewhere we have shown that *P. bernhardus* feeding in trawled areas consume more food than those feeding in adjacent control areas (Chapter 3.6.1.4; Ramsay *et al.* 1996). Therefore we conclude that hermit crabs are attracted into trawled areas where they feed on fauna damaged by the trawl.

However, the responses of scavenging species was not consistent between different localities. At the Red Wharf Bay and Walney Island site no migration of scavengers into the fished area was detected from trawl samples. At the Walney Island site scavengers were removed by fishing and apparently did not migrate back into the fished area for some time. Trawling may have removed a higher proportion of each population at the Walney site, if catch efficiency was higher in the softer sediment at this site (Bergman & van Santbrink 1994a; van Santbrink & Bergman 1994). Conversely, it is possible that the responses of scavengers to fishing disturbance reflects food availability both before and after trawling (Ramsay *et al.* in press).

Western Irish Sea

Catch composition: repeated trawling with the otter trawl

Whiting remained the dominant, but increasing, component of the samples obtained with the otter trawl both before and after creating the fishing disturbance in October 1994 (Fig. 3.6.2). Conversely, the percentage of *Nephrops norvegicus* (target species) declined in consecutive hauls after creating the fishing disturbance. The percentage of other invertebrate species increased in consecutive hauls. Of this component of the catch, crustaceans accounted for between 81 and 97%, consisting predominantly of shrimps (*Crangon allmanni),* prawns, *(Dichelopandalus bonnieri)* and swimming crabs (*Liocarcinus holsatus).* The catch weights of all three species increased in successive catches after the fishing disturbance (Fig. 3.6.3). After the experimental disturbance, a small proportion of the catch also included the prawn *Pasiphaea sivado* and the euphausid *Meganyctiphanes norvegica,* which were not captured prior to the disturbance.

Catch composition: sampling with 3m beam trawl (Table 3.6.1)

After creating the fishing disturbance with otter trawl in August 1995, the abundance of *D. bonneri* and *C. allmanni* decreased in the samples taken with fine-meshed 3m beam trawl after 24 h on both the control and fished transects, but increased after 48 h. Conversely, the abundance of *P. sivado, P. bernhardus* and *L. holsatus* followed a similar pattern on the control transect, but increased in consecutively 24 h intervals after the initial disturbance (Table 3.6.1). Interestingly, the numbers of infaunal molluscs *Abra alba* and *Abra nitida* increased in the samples from the fished line, probably because of increased penetration of the sampling gear after the surface sediments have been fluidised by the commercial otter trawl.

In April 1996, there was a decrease in the abundance of *Liocarcinus holsatus, Pagurus bernhardus* and *Asterias rubens.* Conversely, there was an observed increase in the abundance of *C. allmanni, D. bonnieri, L. holsatus* and *P. bernhardus* on the trawled transect after fishing with the commercial otter trawl (Table 3.6.1).

The results of this study suggest migration of some mobile predators and scavengers from adjacent undisturbed areas into the trawled transects.

Southern North Sea

During repeated trawling with otter trawl in August 1995 in the Weisse Bank area, there were no clear differences in the number of individuals per tow in either the treatment or control areas. However, during the sampling period up to 40 Eurocutters were observed fishing in the same area and the intensive beam trawl disturbance may have obscured any effects of the experimental otter trawling disturbance, confounding any attempt to detect scavenger responses in our experimental area.

In other areas repeated trawling with beam trawls yielded some evidence of the immigration of opportunistic scavenging species in the trawled area: in April 1993 the numbers of dab, plaice and whiting increased already about 3 hours after completing the fishing disturbance (Fig. 3.6.2). In September 1993 two tows were made 12 and 24 hours after the experimental area had been completely trawled. On this occasion the numbers of dab had increased nearly tenfold. Preliminary observations of the stomach contents of dab caught on the trawled lines, showed that they had been feeding on damaged or exposed bivalves, such as *Arctica* sp., *Acanthocardia* sp., *Spisula* sp. and *Donax* sp. (see also Chapter 3.6.1.4).

After trawling with commercial beam trawls, depleted mobile animals recolonise the trawled line by random movement and/or tidal transport, hence a gradual increase in their density, similar to that prior to trawling, is expected. Changes in relative abundance of some species that were common and regularly caught in most hauls are presented in Table 3.6.2.

The abundance of some species did not recover during the sampling period after fishing, e.g. solenette *(Buglossidium luteum)* and masked crab *(Corystes cassivelaunus),* but other species showed a gradual increase to levels similar to those in the untrawled areas, e.g. brittlestars *(Ophiura* spp.) and starfish *(Asterias rubens).* The densities of a few species increased to values much higher than the untrawled density, e.g. dab *(Limanda limanda)* and dragonets *(Callionymus lyra).* Responses of some species to trawling varied between locations (shallow coastal areas versus deeper offshore areas) and in different seasons (Spring or Autumn) (Table 3.6.2).

Dab *(Limanda limanda)* and dragonets *(Callionymus lyra* and *C. reticulata)* showed the most consistent increase in density in response to commercial trawling disturbance (Fig. 3.6.4). An increase in relative density was occasionally observed in gadoids (whiting, juvenile cod and bib), plaice and sole, which indicated that these fishes were also attracted to recently trawled areas (Table 3.6.2). Surprisingly, an increase in the density of lesser weever *(Echiichthys vipera)* was observed in response to trawl disturbance in June 1994. Weevers may have been attracted to the trawled line by the aggregations of scavenging shrimp and gobies which are their natural prey.

Shrimps and small fish like gobies sometimes showed increasing numbers, which suggested that they were also attracted to the trawled lines. This was particularly evident in September 1994 at Helgoland, where small red mullets (0-group *Mullus surmuletus)* appeared in the samples with 3m beam trawl only after trawling.

In September 1995, water temperature was higher than average at the studied coastal area west of Scheveningen (18-19° C) due to a particularly warm summer. Larger dab and starfish were scarce, but shrimp *(Crangon crangon)* were very abundant and about 30 small shrimp trawlers were fishing in the area. Samples taken with the 3-m beam trawl contained cooked shrimp (<1 ‰ of all shrimp caught) and dead fish remains, which were probably washed out during shrimp processing on board the trawlers. Hence, there was already a large amount of dead material on the seabed in the area of our experimental investigation. Consequently, our efforts to observe the immigration of scavenging species into the trawled areas were confounded. Shrimp were probably the most abundant potential scavenger in the area at that time.

In general, invertebrates rarely showed a consistent and clear response to the disturbed lines. Only on one occasion (September 1994, Helgoland) was a marked increase in the relative density of swimming crabs observed (Fig. 3.6.4).

3.6.1.2. BAITED TRAPS

Southern North Sea

Transparent pipe traps and Danish crab traps were used in the experiments in 1995. The traps caught large numbers of invertebrates (Table 3.6.3) but appeared to be less efficient in catching fish. Swimming crabs (*Liocarcinus holsatus)*, starfish (*Asterias rubens)* and hermit crab (*Pagurus bernhardus)* turned out to be strongly attracted by bait.

In general, the numbers of swimming crabs and starfish in the traps did not change very much after one or two days. The numbers of brittle stars (*Ophiura albida)* increased to a maximum after 3 days while the numbers of starfish (*Asterias rubens*) reached a maximum after 2 or 3 days. The numbers of amphipods declined after the first day. Most species were caught within 2 days and therefore the traps were generally exposed for 2 days.

Fish as bait was most attractive for swimming crabs, while crushed molluscs were very attractive for starfish and hermit crabs(Table 3.6.4). Several other species were particularly caught with molluscs as bait, such as whelks (*Buccinum undatum*), shrimps (*Crangon crangon*) and gadoid fish species, e.g. bib and poor cod (*Trisopterus luscus and T. minutus*). At some sites whelks were caught in large numbers, but only in traps exposed at locations far offshore.

Two species of amphipods (*Scopelocheirus hopei* and *Orchomene nanus*) were caught in amphipod traps baited with crustacean bait at all trap localities except close to the shore, usually in large numbers: hundreds in February up to thousands per trap in September. A scavenging isopod, *Natatolana* (=*Cirolana*) *borealis,* was caught in small numbers and only in traps baited with fish.

The swimming crab *Liocarcinus depurator* was more attracted by decaying fish whereas all other scavengers appeared to be indifferent for the quality of fish bait.

Swimming crabs, hermit crabs and shrimp (*Crangon crangon)* showed higher numbers in traps exposed close to the shore and somewhat lower numbers far off shore (8-14 nm). The common shore crab (*Carcinus maenas*) was only caught very close (2 nm) inshore.

Catches of different species in the traps were compared with the densities of the same species, estimated from catches with 3m beam trawl or benthos dredge (triple D) in the same areas, and the results are presented in Table 3.6.5.

Western Irish Sea

Returns of modified shrimp pots (Fig. 2.6.3j) were poor, consisting predominantly of pandalid shrimps (*Dichelopandalus bonnieri*) and the hermit crab *Pagurus bernhardus* (Table 3.6.6). No specimens were taken in the control traps. Interestingly no crangonids were returned, although trawl catches had shown that they were abundant in the area (see Table 3.6.1).

Returns from fyke nets and transparent pipes exposed in shallower areas are given in Table 3.6.7. Although returns are low, the main scavenging invertebrates on the shallower parts of the

Nephrops grounds appeared to be swimming crabs (*Liocarcinus holsatus),* hermit crabs (*Pagurus bernhardus)* and starfish (*Asterias rubens).*

Eastern Irish Sea

The baited traps caught several species, including the amphipods *Tmetonyx similis* and *Orchomene nanus* and the isopod *Natatolana (=Cirolana) borealis* (Table 3.6.8). The species caught varied according to the location of the experiment. *T. similis* and *N. borealis* only occurred at the Anglesey offshore site while *O. nanus* was found at both the Anglesey offshore site and the Red Wharf Bay site and only in pots baited with dead crabs.

At Walney Island the traps caught fairly large numbers of two species were which were not found at the other two sites: the shrimp *Processa nouveli holthuisi* and the mysid *Hemimysis lamornae.* However, these two species were caught in both the baited traps and the control traps and it is therefore possible that, rather than being attracted by the bait, these species are photophobic and hiding in the traps.

3.6.1.3. *IN SITU* OBSERVATIONS

Scavengers feeding on discards

Stills camera observations in the eastern Irish Sea

Observations using baited time-lapse cameras showed that the species and numbers of scavengers feeding on fisheries discards varied according to geographical location.

At the Anglesey offshore site the scavenger most commonly attracted to the bait was the hermit crab *Pagurus bernhardus* which aggregated in large numbers (Fig. 3.6.5).

At the Anglesey inshore site (Red Wharf Bay) several scavenging species were prevalent, including starfish, hermit crabs, whelks and swimming crabs. This camera deployment was considerably longer than the others and patterns of scavenger abundance through time were assessed (Fig. 3.6.6).

Far fewer scavengers were observed at the Walney Island site; the numbers observed on the bait never exceeded 5 (Fig. 3.6.7).

Video camera observations in the eastern Irish Sea

The baited video camera deployments were carried out at the Anglesey offshore site. For both periods of observation hermit crabs (*Pagurus bernhardus*) were the most abundant species that fed on the dead fish (Fig. 3.6.8). The intensity of competition increased both with increasing numbers of hermit crabs and decreasing size of food resource. Large hermit crabs were more successful at feeding than smaller ones when competition was more intense. For further details of these results see Ramsay *et al.* 1997a.

Consumption of dead fish exposed on the sea floor

Eastern Irish Sea

Scavengers consumed 448 g of fish (mean value) in 75 h at the Anglesey inshore site and 145 g in 24 h at Walney Island. When the cameras were retrieved from inshore Anglesey, the fish consisted of little more than skin and bones, the flesh having been almost completely consumed. More flesh was present on the fish from Walney Island but for several of the fish only the heads remained, the lower portion of the body having been completely removed. Video observations suggested that edible crab (*Cancer pagurus*) were able to remove large chunks of fish and then moved away from the camera.

The visual estimates of the amount of flesh remaining on the dead fishes (Anglesey inshore deployment) suggested that flesh was not consumed at a constant rate during the 75 h of the deployment (Fig. 3.6.9). There appeared to be a period between 28 h and 38 h when consumption of flesh was most rapid as approximately 60% was consumed.

Southern North Sea

Discard fish exposed on the seabed for some days were always partially consumed by scavengers. Some scavengers e.g. swimming crabs and hermit crabs left distinctive scars on the bait, whilst starfish (*Asterias rubens*) were sometimes found still clinging to the bait as it was retrieved.

Estimates of the decrease in weight of discard fish exposed for 1, 2 or 3 days on the sea floor in the Dutch coast in September 1995 are presented in Table 3.6.9. Assuming an exponentially decrease in weight, the mean daily *in situ* consumption per bait appeared to be relatively constant at about 13.2 g/day (S.D. 1.6). At this rate of consumption small fish lose 35-55% of weight per day and they will be completely consumed in about 3-4 days, whereas large fish lose 8% per day and will be consumed for about 50% in 8 days.

Scavengers feeding on trawl tracks - eastern Irish Sea

Diver observations of a line fished by a beam trawl

The damaged fauna observed by divers after trawling with 4m beam trawl is presented in Table 3.6.10. The scavengers most commonly observed by divers in the fished area were *Asterias rubens, Pagurus bernhardus, Buccinum undatum* and *Ophiura ophiura.* All of these species decreased in numbers on the treatment line directly after fishing and then generally increased to initial densities, although no significant differences were found (Fig. 3.6.10). A significantly higher percentage of *A. rubens* were observed feeding on the fished line 6 h and 25 h after fishing (Fig. 3.6.11). The three other species were rarely observed feeding before fishing or on the control line but did feed on damaged fauna on the treatment line after fishing had taken place (Table 3.6.11).

Divers observed that *Ophiura ophiura* was the most frequently damaged animal (but note that this species is extremely abundant at the experimental site) (Table 3.6.10). Also damaged were bivalves, including *Ensis* sp., and the sea urchin *Echinocardium cordatum.* Large numbers of tubes of the worm *Lagis koreni* (estimated at 770 per m^2) were observed on the surface of the sediment after trawling had taken place. When divers surveyed the area 2 h after beam trawling had taken place these tubes appeared to be empty.

Diver observations of an area fished by a scallop dredge showed that the effect of a scallop dredge was similar to that of a beam trawl.

3.6.1.4. STOMACH CONTENTS ANALYSIS

Eastern Irish Sea - beam trawl

Food intake of hermit crabs

Pagurus bernhardus. The relationship between ln (thorax length) and ln (dry weight of stomach contents) was linear (Fig. 3.6.12). Before fishing had taken place there were no significant differences between models for the control or treatment line (Ramsay *et al.* 1996). However, for 3 days following beam trawling there were significant differences between intercepts of the control and treatment samples, with the intercept on the fished line being higher than that for the control line (Fig. 3.6.12). On the final (4^{th}) day there were no significant differences in the intercepts or slopes.

Pagurus prideaux. There was no apparent effect of fishing on the relationship between ln (thorax length) and ln (dry weight of stomach contents) (Ramsay *et al.* 1996).

Hermit crab diets

The following groups were observed in the stomach contents: crustaceans, polychaetes, molluscs, hydroids, echinoderms, bryozoans and foraminiferans (Ramsay *et al.* 1996). In both species the most common groups were crustaceans, polychaetes and molluscs (Fig. 3.6.13).

Cluster analysis and subsequent multidimensional scaling (MDS) of the stomach contents data (percentage points) showed that the diets of *P. bernhardus and P. prideaux* fell into two significantly different groups (Fig. 3.6.14, ANOSIM R = 0.729, $p < 0.001$). All phyla observed were found in both species stomachs. *P. prideaux* appear to consume a larger proportion of molluscs and crustacea and a smaller proportion of polychaetes than *P. bernhardus* (Fig. 3.6.13). *P. bernhardus* also appeared to have a more diverse diet than *P. prideaux.*

The MDS ordination plot indicates that the diets of *P. bernhardus* collected on the trawled line the first day after fishing have the least similarity to those collected on the control lines (Fig. 3.6.14). This difference appears to be due to an increase in the proportions of crustacea and polychaetes in the diet (Fig. 3.6.13).

Western Irish Sea - otter trawl

Next to the target species *Nephrops norvegicus*, whiting and haddock dominated in repeated trawlings with *Nephrops* otter trawl. Whiting are well-known opportunistic scavengers (Kaiser & Spencer 1994), but haddock and *Nephrops* may also show feeding and disturbed benthos. Therefore stomach contents of all three species were analysed.

Whiting *(Merlangius merlangus)*
The mean total length of the whiting analysed during the course of the experiment tended to remain stable and was similar between surveys (Table 3.6.12). The stomach filling index (SFI) fluctuated. On the other hand, both mean stomach fullness and the gut content state increased after fishing disturbance in October 1994, but did not change in August 1995 (Table 3.6.12). Crustaceans dominated the diet of whiting and a gradual increase in the percentage of whiting stomachs containing crustacean prey items was observed in both surveys (Table 3.6.13) together with a decrease in the variety of prey items and a decrease in the % of empty stomachs.

Prior to trawling the crustacean prey items consisted mainly of euphausids, crangonids and some pandalid shrimps (Table 3.6.14). Seventy two hours following the initial disturbance in October 1994, an increased percentage of whiting stomachs containing crangonid shrimps was observed with euphausids now absent.

In August 1995, the percentage occurrence of crangonids and pandalids actually decreased following trawling (Table 3.6.14). The percentage occurrence of euphausids appeared to increase dramaticaly following trawling, while no specimens appeared in whiting stomach contents taken from the control waylines.

The mean numbers of crustacean prey items are shown in Table 3.6.15. Six hours following disturbance, little change in the mean number of prey items was observed. Seventy two hours following the start of the experiment the mean number of crangonids consumed had increased. In August 95 the opposite trend was observed.

Haddock *(Melanogrammus aeglefinus)*
The mean total length of the haddock also remained stable (Table 3.6.12). In both surveys the SFI increased, while mean stomach fullness and gut content state changed little. Crustaceans dominated the diet, with little change in percentage stomach content before and after trawling (Table 3.6.13). In October 1994 the variety of prey items increased, with both molluscs *(Abra* sp.) and annelids present following trawling. In the survey of August 95 the % stomachs containing molluscs and annelids decreased slightly after trawling while the % stomachs containing crustacea increased (Table 3.6.13). Among the crustacean prey in the stomachs (Table 3.6.14) crangonids increased, while amphipods and portunid crabs decreased. There was also a large increase in the percentage occurrence of *Nephrops* remains.

In October 1994 a substantial increase in the percentage of stomachs containing amphipods was observed (Table 3.6.14), together with an increase in numbers of amphipods per stomach (Table 3.6.15), while the % stomachs containing portunid crabs and *Galathea* sp. decreased.

Nephrops (Nephrops norvegicus).
The mean total length and weight of the *Nephrops* examined before and 48 hours after trawling tended to remain stable (see Table 3.6.12). The mean degree of fullness index increased on the fished line. Small molluscs (*Abra* sp.) appeared to dominate the diet both before and after trawling, although some small polychaetes were also present.

Southern North Sea - 12m beam trawl

Most of the investigated fish species collected in a recently trawled area showed clear evidence of opportunistic scavenging behaviour. Food intake increased while dietary composition also changed (Table 3.6.16). Small dab, whiting and dragonets in recently trawled areas switched their diets. Instead of a variety of prey items, they appeared to feed on the damaged remains (i.e. gonads and intestines) of heart urchins *(Echinocardium cordatum).* For comparison, an analysis of the stomach contents of sole *(Solea solea)* and the lesser weaver *(Echiichthys vipera)* showed no evidence of opportunistic feeding on damaged benthos.

During beam trawling with 12m beam trawls, dab fed approximately 5 times more on damaged bivalves and disturbed ophiuroids in the disturbed area than in a nearby reference area (Fig. 3.6.15). High values for stomach fullness were observed for a few hours after trawling, but rapidly decreased after 24 hours. Two days after trawling, a higher percentage of empty stomachs and a significantly lower median stomach fullness were observed in the trawled area compared to the reference area.

The actual composition of the diet of dab was seen to change during, and immediately following trawling (Table 3.6.17), with a greater variety of larger prey items present e.g. the soft parts of bivalves, including the quahog *(Arctica islandica)* and prickly cockle *(Acanthocardia echinata).* In addition, the incidence of deep burrowing bivalves and crustaceans (i.e. *Callianassa sp.)* in stomachs of fish from the trawled wayline also increased, whereas in stomachs of fish from the reference area only small bivalves or siphons were recorded together with the brittle star *Amphiura* (Table 3.6.17).

For dab and gurnards, it was noticed that amphipods (i.e. *Orchomene nana*, a scavenging species) and swimming crabs (*Liocarcinus* sp.) occurred most frequently in the stomach contents of fish from the trawled area, while the fraction of empty stomachs was also highest in fish from the trawled area.

Southern North Sea - 7m beam trawl

Repeated trawling over a transect with 7m beam trawl in an area W of Helgoland was carried out in June and September '92. Because returns in June were low, only the results of the September cruise are presented.

Grey gurnard *(Eutrigla gurnardus)*
Stomachs of gurnards contained predominantly the planctonic zoea larvae of *Corystes* and *Liocarcinus.* No conclusions on the effect of beam trawling on the uptake of benthic organisms can be drawn.

Dab *(Limanda limanda)*
The mean numbers of prey taxa in stomachs of dab are presented in Table 3.6.18 and the weight of prey taxa is presented in Fig. 3.6.16. Figure 3.6.17 shows an overall increase in the stomach fullness of dab collected from the repeated trawls. Echinoderms, amphipods, decapods and sessile polychaetes were the most frequent prey taxa in the stomachs, numbers of bivalves, fish and others were small.

Polychaetes decreased between the first and the last trawl, while decapods increased (Table 3.6.18). Two species of sessile polychaetes were found in the stomachs: *Owenia fusiformis* and *Lanice conchilega.* Numbers began to decline 3 h after trawling. The most frequent decapod species in the stomachs were swimming crabs *(Liocarcinus holsatus)* and hermit crabs *(Pagurus bernhardus).* Amphipods were found in all stomachs, but the mean number per stomach decreased 3 h after trawling (Table 3.6.18).

Plaice *(Pleuronectes platessa)*
The composition of stomach contents of plaice in September 92 is presented in Table 3.6.19. Polychaetes were the most abundant food, particularly the sessile species *Magelona papillicornis* and *Owenia fusiformis* and the mobile species *Nephthys hombergii.* The composition of stomach

contents changed in the course of the repeated trawling, showing a decrease in the numbers of sessile polychaetes with time while the numbers of mobile polychaetes remained the same.

Comparison of food composition

The degree of similarity of stomach contents of plaice and dab from the repeated trawling decreased during the course of the experiment (Fig. 3.6.18), whereas the similarity in species composition of decapods in the stomachs increased (Fig. 3.6.19).

North Sea - otter trawl

Comparison of stomach contents of fish collected during the three sampling days showed no differences between trawled and untrawled reference area, and no general trend was observed (Table 3.6.20). More than 50% of the larger carnivorous fishes fed on other fish (Fig. 3.6.20). As compared to the dab the stomachs of grey gurnard (*Eutrigla gurnardus)* contained more whole fish rather than fish remains.

Dab *Limanda limanda* were voracious scavengers, feeding mainly on fish tissue which comprised the entrails of gutted fish i.e. offal (Fig. 3.6.20). Larger dabs contained more fish and crustaceans in their stomachs, and less echinoderms and polychaetes, as compared to smaller dab (Table 3.6.20).

For gurnards no differences in composition of stomach contents between trawled and untrawled areas were observed (Table 3.6.20), but they possibly also fed on discarded fish. Out of 1800 investigated stomachs only 7 were empty and most of the prey species in the stomachs were undigested, indicating that the fish had fed recently. The presence of discarded materials in stomachs of fish from the untrawled control area suggests that other beam trawlers were operating in the same area at the same time.

3.6.2. RESULTS OF LABORATORY INVESTIGATIONS

3.6.2.1. FEEDING AND GROWTH OF SCAVENGERS

Daily food consumption of selected benthic predators

For some species measurements of daily food consumption at constant temperatures have been carried out over several weeks for animals of differing sizes, in order to estimate the relationship with body weight. An example of a double logarithmic plot of daily food consumption (mussel meat) against body weight of hermit crabs *(Pagurus bernhardus)* and dab *(L. limanda)* at 5° C is shown in Fig. 3.6.21. Similar measurements have been carried out for starfish and hermit crabs fed with fish flesh *(Callionymus lyra).* The relationships between food consumption and body weight for different species are presented in Table 3.6.21. The results show that daily food consumption of starfish, swimming crab, hermit crab and dab is exponentially correlated with body weight as is metabolism, with a weight exponent of approximately 0.8.

Growth rate

a. *Relation with size.* For some species growth rate was measured at constant temperature for series of animals of differing sizes. Double logarithmic plots of daily weight increment against (geometric) mean weight of dab *(L. limanda)* and starfish *(Asterias rubens),* growing at different temperatures with unlimited food, are shown in Fig. 3.6.22. The estimated parameters of the exponential relationship between daily weight increment and (geometric) mean body weight are summarized in Table 3.6.22. The results show that maximum daily weight increment is similarly proportional to the metabolic weight.
b. *Effect of temperature.* Growth rate of different species was measured at different constant temperatures over periods of 4-8 weeks. Growth rates in length or diameter and the growth rate in weight as % of metabolic weight (% $W^{0.8}$) of some common invertebrate species and fish, that may feed as scavengers on trawl tracks, are presented in Table 3.6.23. Measurements of growth rates and food consumption of some scavenging fish species are presented in Table 3.6.24. An example of the effect of temperature on growth rate of starfish *(Asterias rubens)* and

dab *(L. limanda)* is shown in Fig. 3.6.23, the general effect of temperature on growth rate of invertebrates and fish is illustrated in Fig. 3.6.24.

For most species a marked increase in growth rate is observed with temperatures from 5 to 15° C, which means that their food intake increases similarly with temperature.

Food conversion

For maximally feeding fish fed with unlimited rations the gross conversion efficiency of food into growth is usually about 25%. Hence, for fish growing with unlimited food the daily food consumption can be estimated as 4 times the daily weight increment. However, when food is limited the gross food conversion will decline and may even become negative when the fish lose weight.

Measurements of growth with different rations have been carried out with starfish *(Asterias rubens)*, hermit crabs *(Pagurus bernhardus)* and dab *(L. limanda)*. Mean values of daily food consumption and daily weight increment were divided by the metabolic weight ($W^{0.8}$) of the animals, in order to get size-independent parameters for feeding and growth. An example of a plot of growth against ration for starfish *(Asterias rubens)* and hermit crab *(Pagurus bernhardus)* at 15° C is shown in Fig. 3.6.25. Estimated parameters for the relationship between daily food consumption and growth are presented in Table 3.6.25. The "net" food conversion efficiency appears to be high for starfish, lower for dab and lowest for the hermit crab.

3.6.2.2. BEHAVIOUR OF SCAVENGERS IN THE LABORATORY

Video recording of feeding behaviour and competition

When dead fish were offered to starfish, hermit crabs, and swimming crabs, male swimming crabs were the first to arrive at the offered carrion and they usually tried to lift the bait and escape when other scavengers appeared. Starfish moved more slowly towards the bait, obviously following a trail of odour, and their speed at 15º C was estimated at about 8 meter per hour.

Aggressive interactions around the bait were often observed between swimming crabs males (*Liocarcinus)* and also between swimming crabs and large hermit crabs (*Pagurus bernhardus*) to the disadvantage of the latter. Other potential scavengers, such as sea urchins (*Psammechinus miliaris)*, sandstars (*Astropecten irregularis), whelks (Buccinum undatum)* and masked crab (*Corystes cassivelaunus),* showed little or no response to exposed fish carrion when they were kept together with swimming crabs, hermits and starfish. Avoidance reactions of whelks to starfish were observed, but when larger *Asterias* were removed whelks moved towards the bait immediately. This suggests that whelks show predator avoidance when they are kept together with starfish. When dab were included in multi species experiments it appeared that individuals of 15 cm competed for crushed bivalves more successfully than other species.

Food handling and food preferences

Swimming crabs were more successful at cutting pieces from fresh dead flatfish as compared to hermit crabs. Both swimming crabs and hermit crabs showed a clear pattern in the way of feeding on dead flatfish. Small hermit crabs (claw length < 15 mm) only succeeded in feeding on the skin between finrays or the soft parts of a dead fish. In the video experiments they preferred chopped bivalves if offered at the same time with dead fish. In general, crabs and starfish produced a different pattern of scars on the dead fish. Swimming crabs produced more cutting marks whereas starfish (and also sea urchins, *Psamechinus*) produced shallow round scars that were also observed on dead fish exposed on the sea floor.

3.6.2.3. ASSESSMENT OF THE IMPORTANCE OF FOOD PRODUCED BY TRAWLING FOR BENTHIC SCAVENGERS

Ash-free dry weight and length-weight relationships

Estimates of ash-free dry weight as % of wet weight of some benthic species, that can be found damaged in the trawl tracks, are presented in Table 3.6.26. The percentage ash-free dry weight is variable, depending on season, locality, and in general, on the condition of the animals. Percentage ash-free dry weight of starfish collected in Winter in the North Sea was comparable to the relatively low % afdw of starfish that had been starved for months in the laboratory. This suggests that starfish in the sea are food-limited and therefore discarded material is more likely to be important in their diet.

For estimation of the potential daily food consumption of scavenging species in an area, their density, biomass (Sum W) and "metabolic" biomass (Sum($W^{0.8}$)) have to be known. In many cases only densities and size distributions are available. Therefore the length - weight relationships of some common benthic predators in the southern North Sea have been estimated and the results are presented in Table 3.6.27.

For practical reasons the size of hermit crabs was measured by the length or height of the largest claw (chela). The relationship between chela-height and wet weight of hermit crabs shows a difference between the measurements at NIOZ and at the MAFF- laboratory Conwy, indicating that hermit crabs from the Irish Sea are about 25-35% heavier than hermits in the southern North Sea.

Food production by beam trawling in the southern North Sea

Benthic trawling produces two different kinds of food for opportunistic scavenging species:
a. The discard thrown overboard during sorting of the catch;
b. The damaged and exposed fauna that remains in the trawl track.

a. Discard production. The amount of discard produced by beam trawling for sole in the southern North Sea can be estimated from the general catch efficiency (chapter 3.4, Table 3.4.1) and the survival chances of discards (chapter 3.5, Table 3.5.3). The average catch and the amount of dead discard materials produced by 4m and 12m beam trawls are summarized in Table 3.6.28.
   The amount of by-catch and discard is variable, depending on season and area. The average total discard production varied between 0.17 and 0.19 gram afdw per m^2 per haul, while the discard production per kg sole is estimated at about 1.0-1.5 kg afdw per kg wet weight of marketable sole. With a mean value of 1.25 kg afdw discard per kg sole, and a total annual landing of 30 000 t sole (up to 1995), the annual discard production by sole fishery in the southern North Sea is estimated at about 37 500 ton afdw in an area of about 134 000 km^2, or a mean annual discard production of about 0.3 gram afdw $m^{-2}.year^{-1}$. Compared with the estimated mean value of 0.15 g afdw/m^2/haul this suggests that the whole southern North Sea is, on average, completely trawled twice each year. The estimates of trawling intensity in different ICES quadrants (chapter 4.1) indicate that some areas are trawled less intensively, about once each year, particularly protected coastal areas such as the plaice box, while other areas are completely trawled three times annually (see also Rijnsdorp *et al.* 1996).
   According to Van Beek (1990) the amount of discard fish produced by sole fishery was about 260 000 t wet weight per year. With a mean % ash-free dry weight of fish of 17% and a surface area of 134 000 km^2, this results in 0.33 g afdw/m^2/year, similar to our estimates.
b. Trawl track mortality. Density of infauna species and mortality due to beam trawling of animals that remain in the trawl tracks were estimated from the data presented in chapter 3.5. The numbers of dead animals in the trawl tracks were multiplied with their ash-free dry weight to estimate the production in g afdw/m^2/haul for two stations in the North Sea (Fig. 2.6.1): May 1995 on the Weisse Bank (silty bottom, site 9) and September 1995 on the Broad Fourteens off the Dutch coast (sandy bottom, site 10). The results are summarized in Table 3.6.29. In total, the amount of dead or damaged bottom fauna in the trawl tracks was estimated at about 1.1 gram ash-free dry weight per m^2, much more than the amount produced as discard. Sea

potatoes *(Echinocardium cordatum)* made up about 67% of the production in the trawl tracks, shellfish about 15-24%, crabs about 7-15%. In Summer all this material is rapidly consumed, usually within 2-3 days, by scavenging fish, starfish and crabs (see chapter 3.6.1).

Calculations of consumption of discards and damaged benthic fauna by scavengers in the southern North Sea

Discarded materials are partly consumed by sea birds (Camphuijsen *et al.* 1995). Birds particularly eat the (floating) roundfish, small fish, offal and a minor proportion of the invertebrates, comprising about 20% of all discard. Most of the discards are consumed on the sea bed, generally by crabs and starfish, while bacterial decay also occurs.

An example of the rate of decay of dab at 5, 10 and 15° C is shown in Fig. 3.6.26. Dead fish first increase in weight due to uptake of water, followed by enzymatic autolysis and finally decomposition by bacteria. They may remain available for scavengers for about one week in Summer (15-20° C) and about 2 weeks in Winter (5-10° C). All fish that are not rapidly consumed by scavengers will be ultimately consumed by bacteria.

The densities of scavenging epibenthic invertebrates and fish, and their length frequency distribution in our field trials (chapter 3.6.1) were used to calculate the metabolic (feeding) biomass: sum ($W^{0.8}$). Based on the laboratory measurements of maximum daily food consumption and growth, assuming that scavenging fish will eat particularly damaged molluscs while crabs and starfish will eat the dead fish, maximum daily food consumption of the most abundant species were estimated for a summer temperature of 15° C and the results are presented in Table 3.6.30.

The densities of other species were so low that they were not important as consumers of discards and damaged fauna in these calculations.

Based on the Tables 3.6.28, 29, 30 the production of a beam trawl can be summarized as follows: discards per haul about 0.15 g afdw.m^{-2}, damaged fauna about 1.1 g afdw.m^{-2}.$haul^{-1}$. Maximum daily food consumption by the most abundant epibenthic scavengers in Summer (15° C) was estimated at about 0.04-0.14 g afdw.m^{-2}.day^{-1} (Table 3.6.30). This means that in Summer in an area with many scavengers they can consume all food produced by beam trawling in about 9-14 days. The analysis of stomach contents have indicated that they do so in about 2-3 days, which suggests that scavengers from an area at least 3-4 times as large as the trawl track surface take part in the consumption of damaged fauna.

In Winter the daily food consumption of scavengers will be lower with the lower temperature. Most fish and invertebrates grow (and eat) at least 2.5-4.5 as much at 15° C than at 5° C. This means that, where they consume damaged fauna in Summer in about 2-3 days, they may feed on the same amount in Winter about 10 days.

Dead materials are also decomposed by bacteria, which are possibly the most important "scavengers" anyway. At 15° C the decay of dead fish takes about 8 days, at 5° C about 15 days (Fig. 3.6.26). Hence, in Summer the scavengers can eat for only one week from carrion generated from trawling, and in Winter only two weeks. Decaying fish are often found in areas with intensive beam trawling in the southern North Sea.

Annual production and consumption in the southern North Sea.

The production of damaged fauna in the trawl tracks consists for a large part (66%) of crushed sea potatoes. Several species are found in the North Sea *(Echinocardium cordatum, E. flavescens, Brissopsis lyrifera, Spatangus purpureus),* of which *Echinocardium cordatum* is the most abundant in sandy bottoms (Duineveld & Jenness 1984; Beukema 1985; Cramer 1991). In Winter these burying heart urchins become less active and a larger part of the population tends to stay at greater depth in the bottom, beyond the reach of beam trawls.

If *Echinocardium* are not damaged in Winter, the production of damaged fauna in the trawl tracks will be 66% less, in the order of magnitude of 0.4 g afdw/m^2/haul. Assuming that the southern North Sea is, on average, completely trawled twice each year, once in Summer and once in Winter, it follows that the total annual production of damaged fauna by beam trawling can not be much more than 1.5 g afdw/m^2/year, which can be compared with a total biomass of benthic infauna of approximately 4-14 g afdw/m^2 (Cramer 1991).

The maximum daily food consumption of the most abundant scavenging species (starfish, swimming crabs, hermit crabs, shrimp, dab, dragonets, whiting) was estimated to be in the order of magnitude of 0.04-0.14 g afdw.m^{-2} per day during Summer (Table 3.6.30). In Winter consumption will be approximately 3.5 times lower or 0.01-0.04 g afdw/m^2/day. Together this results in a total annual food consumption of about 183 * (0.05-0.18) = 9 to 33 g afdw/m^2/yr, on average about 21 g afdw/m^2/yr.

Compared with the estimate of total annual food production by beam trawling of approximately 1.5 g afdw/m^2 in the trawl tracks and 0.3 g afdw/m^2 as discard this suggests that beam trawling may provide an extra food supply of about 9% for benthic scavengers.

It is not clear yet whether this food source can be important for maintenance of scavenger populations, but it appears rather unlikely that it will promote larger populations. Many factors play a part in population regulation (e.g. predation, physical effects such as cold winters) and some of these may be more important than food supply to the adult stage.

3.6.3. GENERAL DISCUSSION

Our studies have demonstrated that benthic scavengers feed both on fisheries discards and on animals damaged in trawl tracks. At some sites scavengers migrated onto trawl tracks, although the responses of scavengers to carrion were very variable between sites. Various scavenging species increased their food intake when foraging within trawled areas and changes in dietary composition in response to trawling were also observed. Within trawled areas there may also be opportunistic feeding by some scavenging species on other species attracted by the disturbance effect. Competition for fisheries discards (both inter- and intraspecific competition) sometimes becomes intense and can affect feeding success. In the North Sea the total amount of carrion produced by fishing activities may only account for less than 10% of food consumption by scavenger populations in the benthic community. It appears unlikely that this will lead to larger populations of scavenging species.

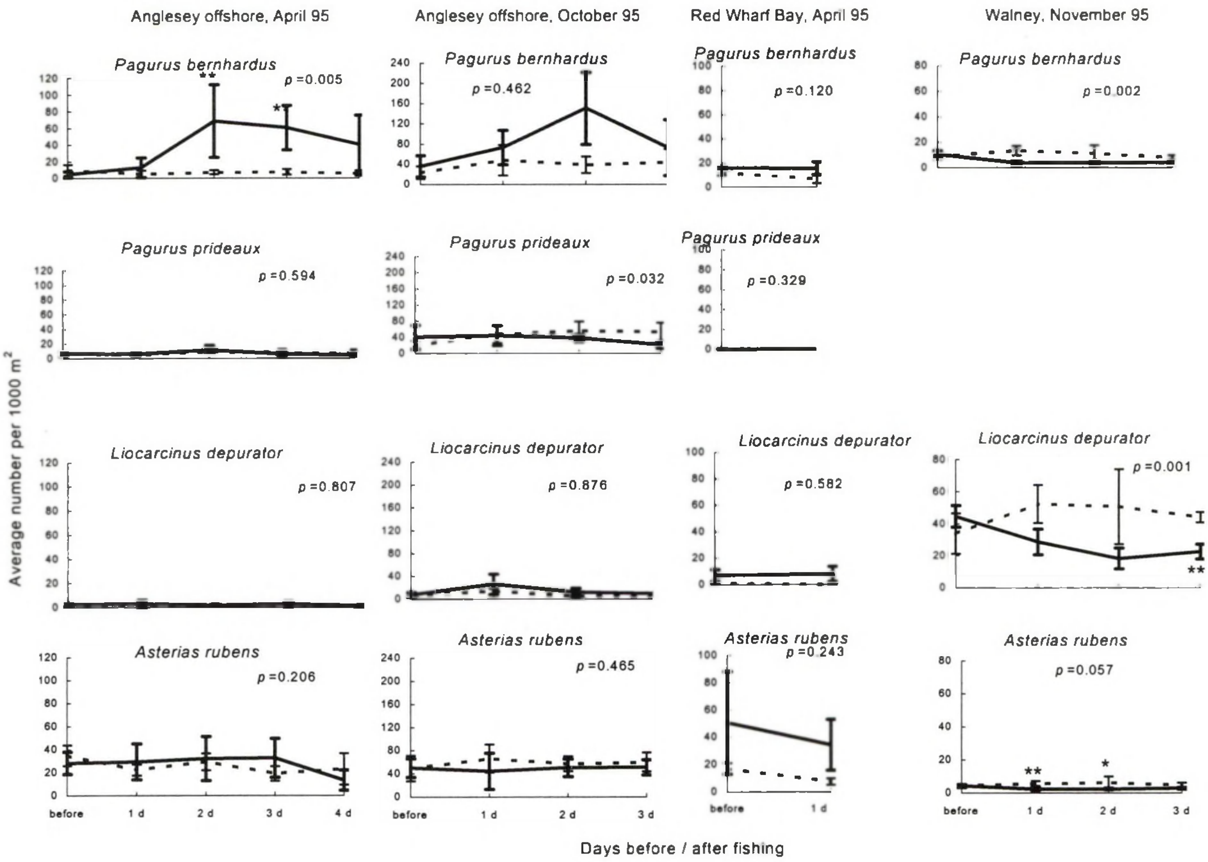


Fig. 3.6.1. Average numbers of animals per 1000 m^2 caught during 2.8 m beam trawl sampling. Only species where ANOVA has shown a significant time*treatment interaction term have been included (p value shown on graphs is significance of interaction term). Also showing results of Dunett's multiple comparison test between numbers on the treatment wayline before fishing and numbers at each time period after fishing (*** $p<0.001$, ** $p<0.01$, * $p<0.05$). Solid line = fished line, broken line = control lines.

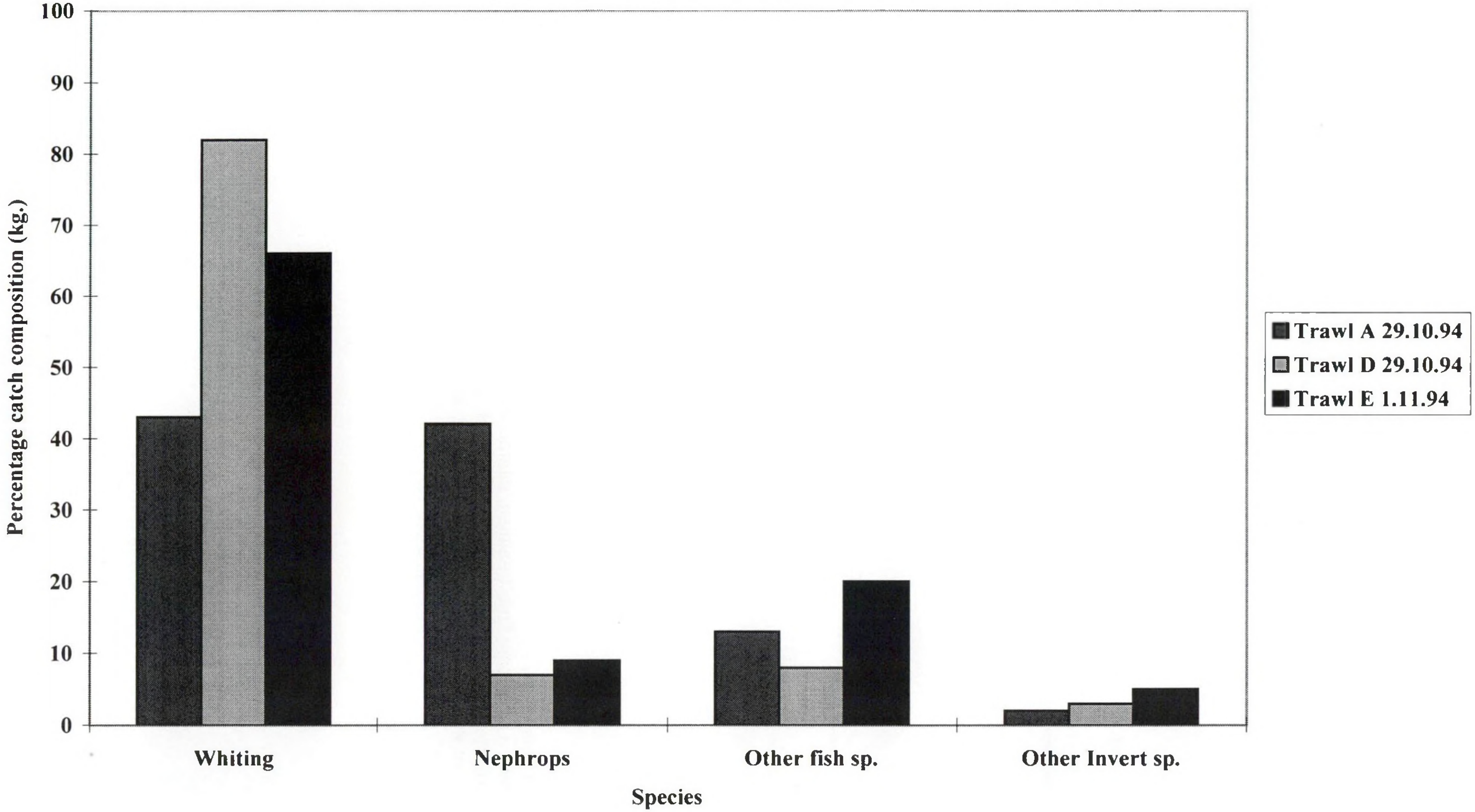


Fig. 3.6.2. Graph of the catch composition (by weight) of trawls taken at intervals (Trawl A = t0 h, Trawl D = t0 + 6 h, Trawl E = t0 + 72 h) along a transect located in the IMPACT II offshore station (NW Irish Sea).

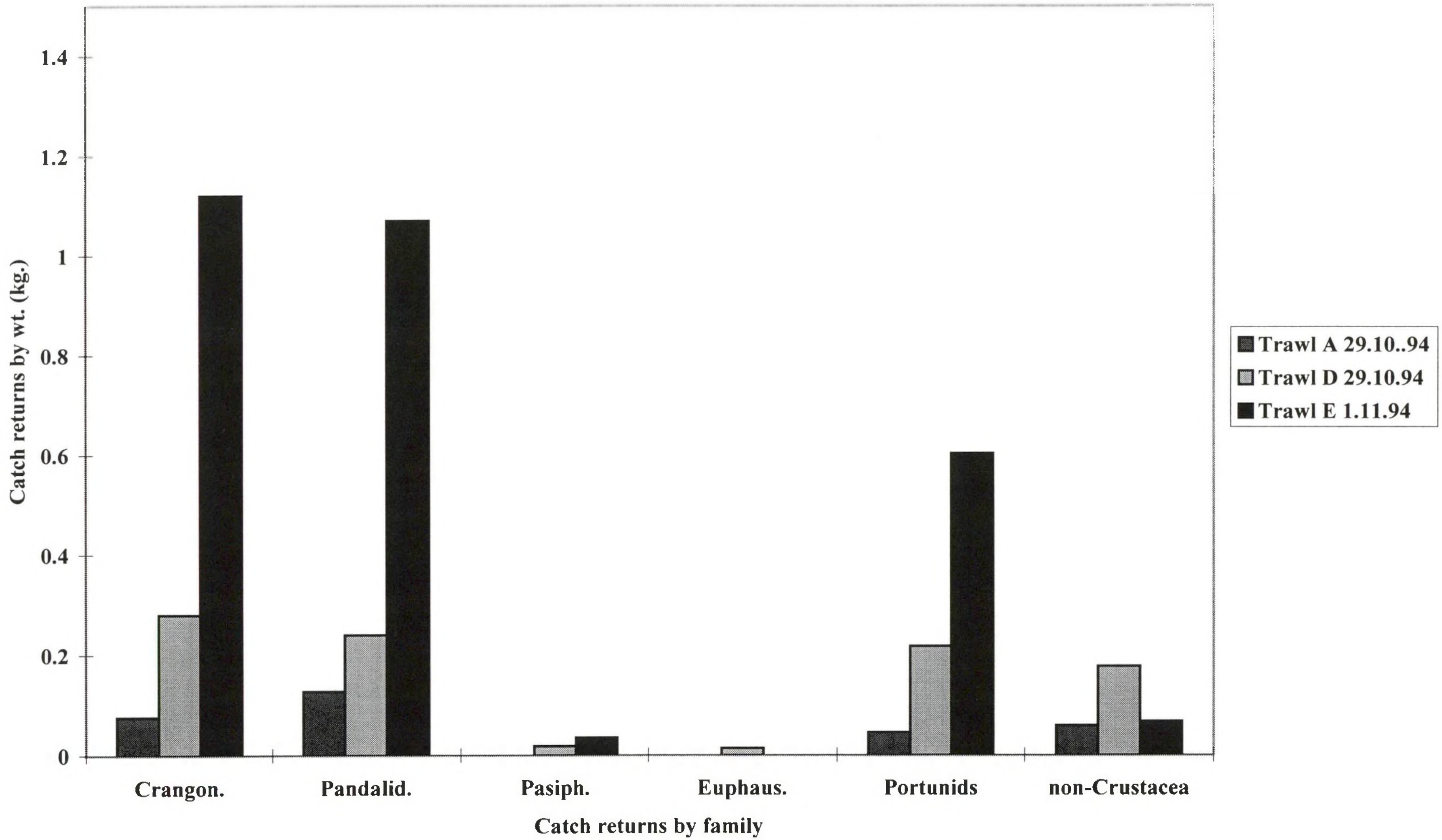


Fig. 3.6.3. Catch composition by weight of trawls taken taken on 29/10 - 1/11/1994 at intervals of 0, 6 and 72 h along a transect located in the IMPACT II offshore station, NW Irish Sea.

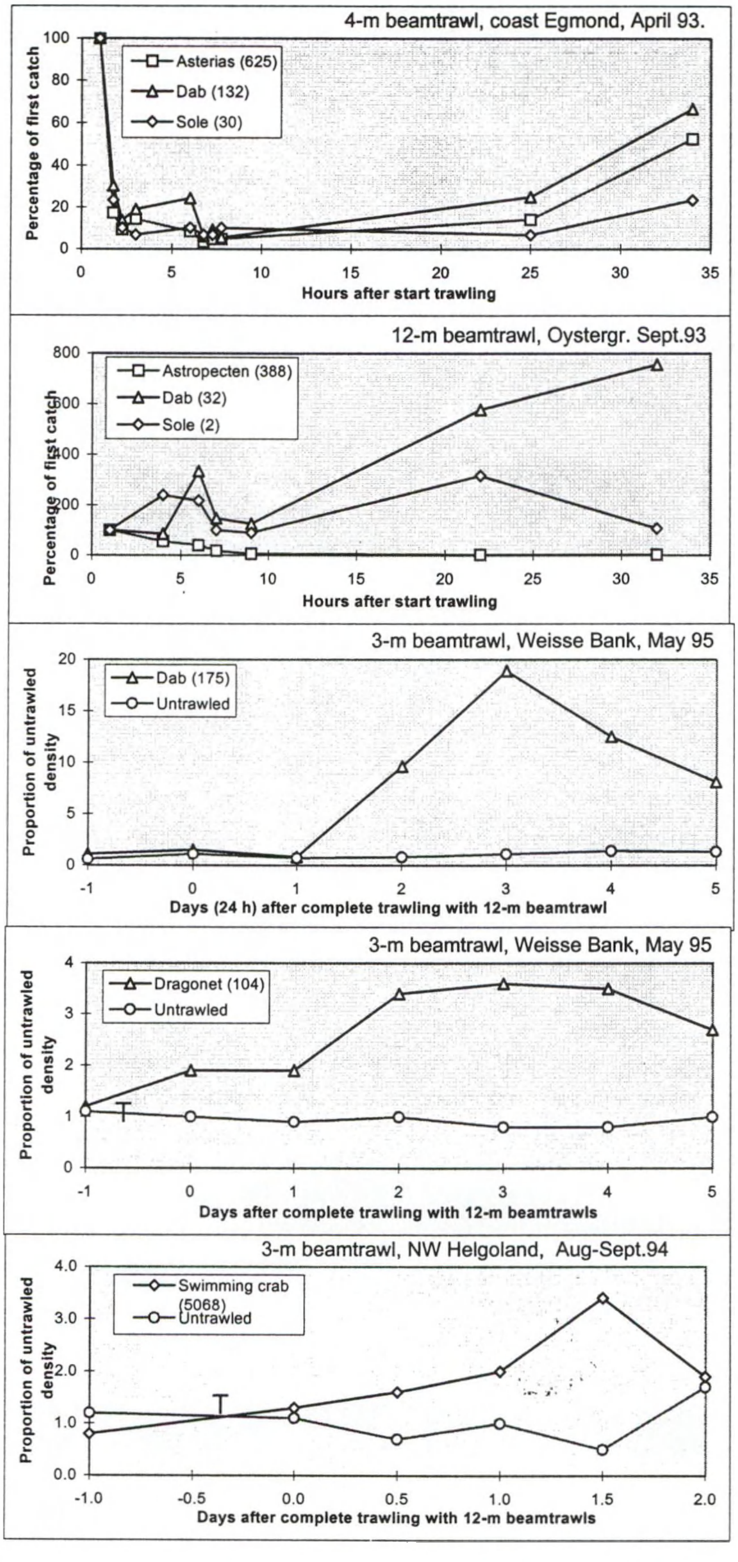


Fig. 3.6.4. Changes in densities of starfish, dab, dragonets and swimming crab, after complete trawling a transect with 12m beam trawls at time T. Relatieve densities estimated from catches with fine-meshed 3m beam trawl.

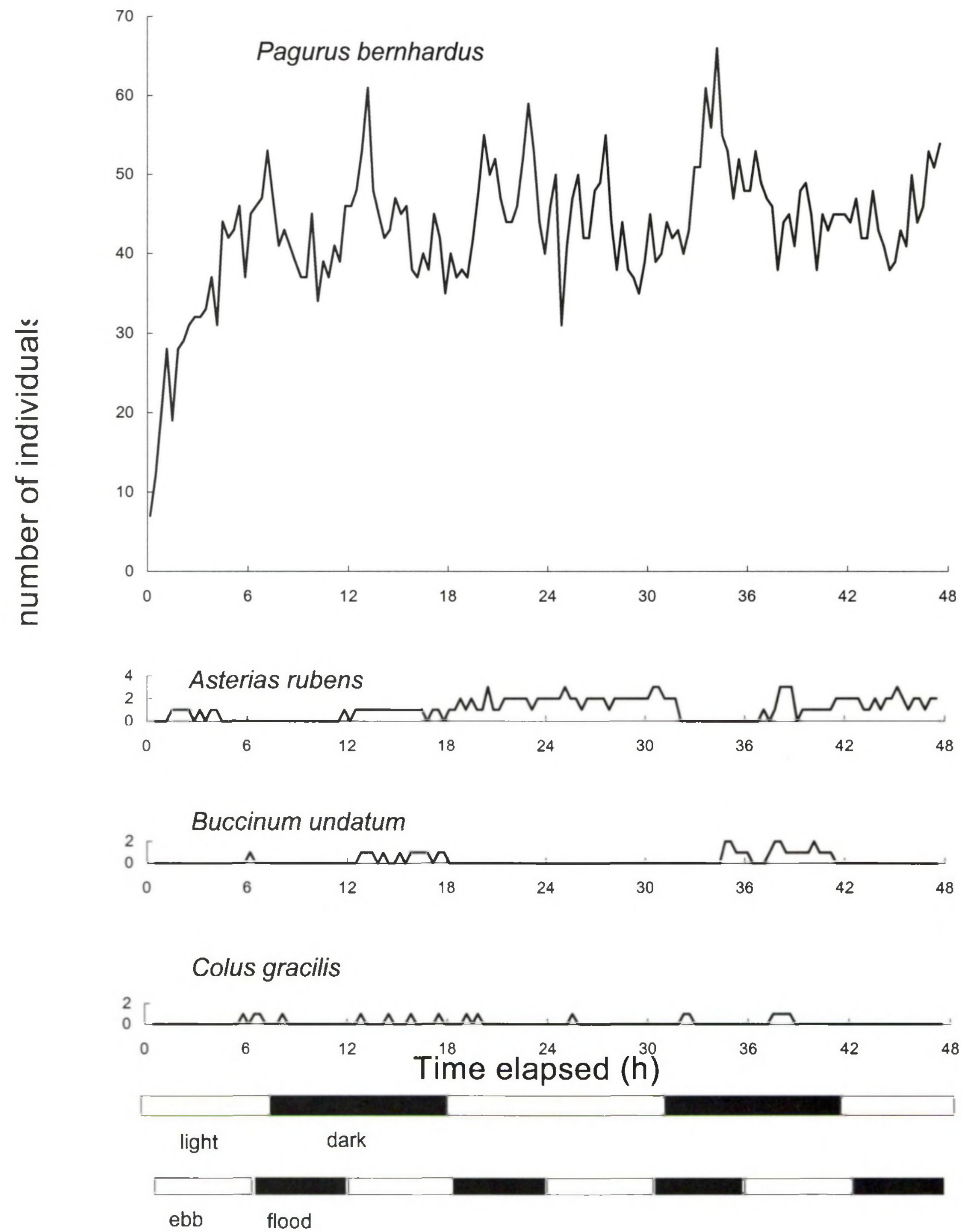


Fig. 3.6.5. Numbers of scavengers observed feeding on discarded fish at the Anglesey offshore site, September 1996.

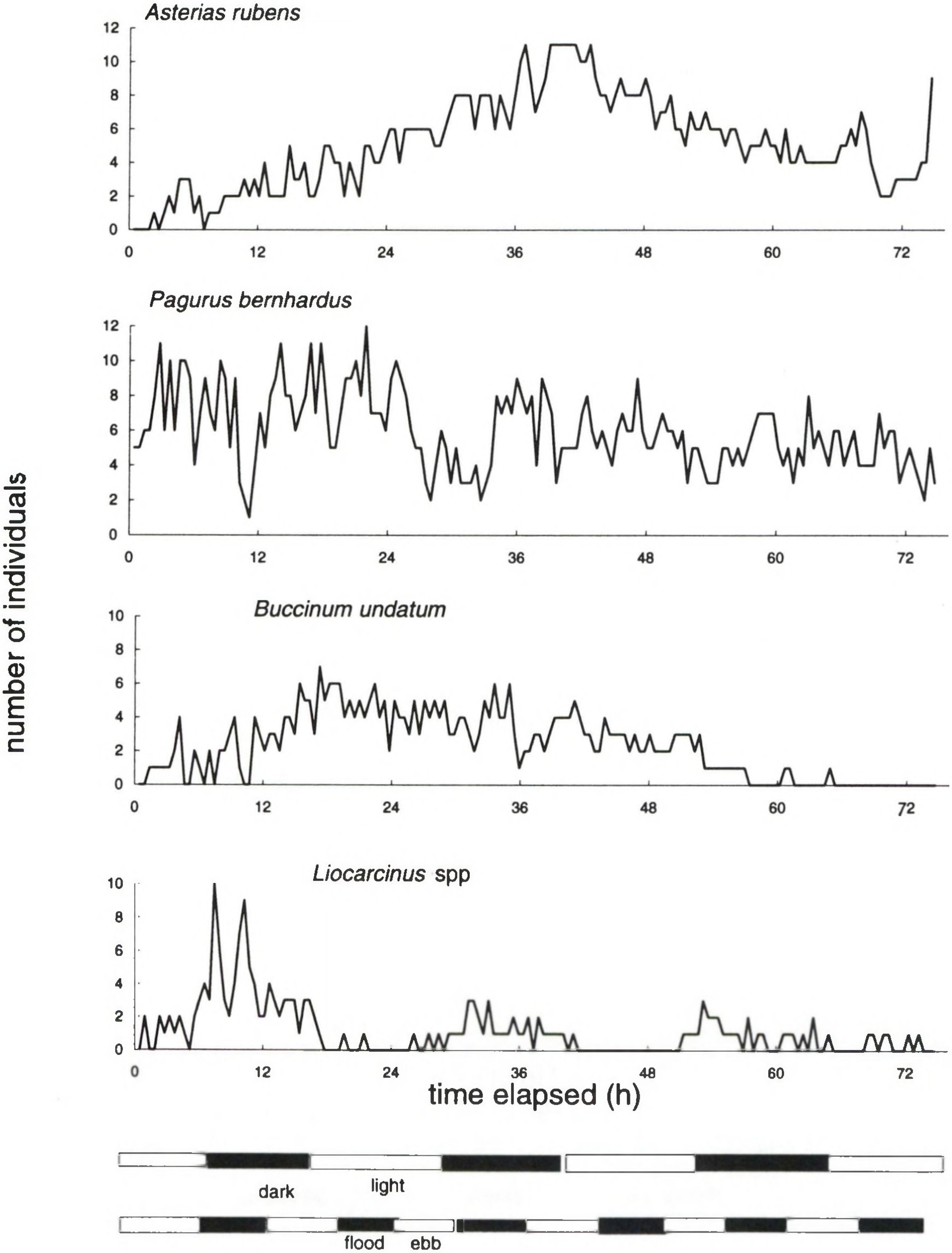


Fig. 3.6.6. Numbers of scavengers observed on the bait at Red Warf Bay, October 1995.

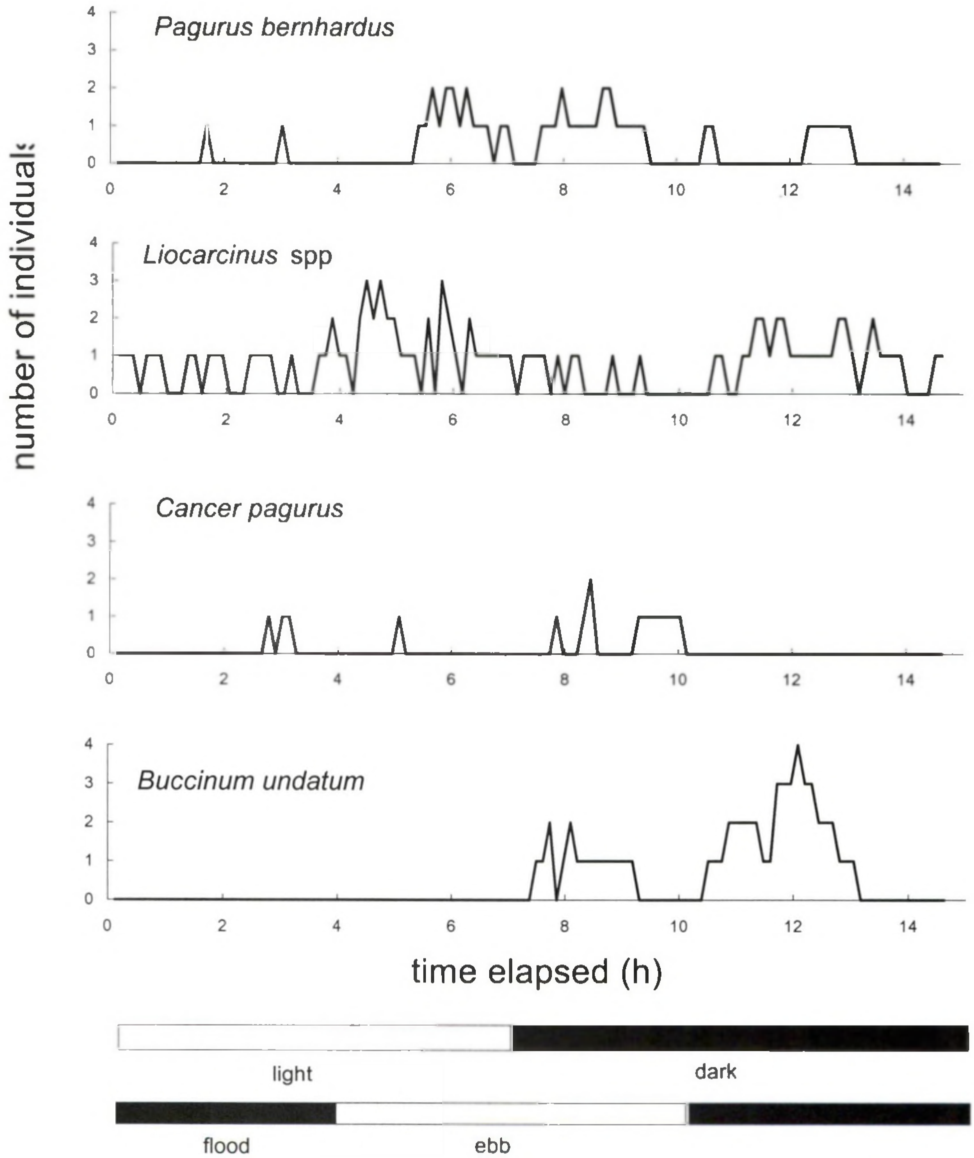


Fig. 3.6.7. Numbers of scavengers observed on the bait at the Walney Island site, November 1995 (deployment 2).

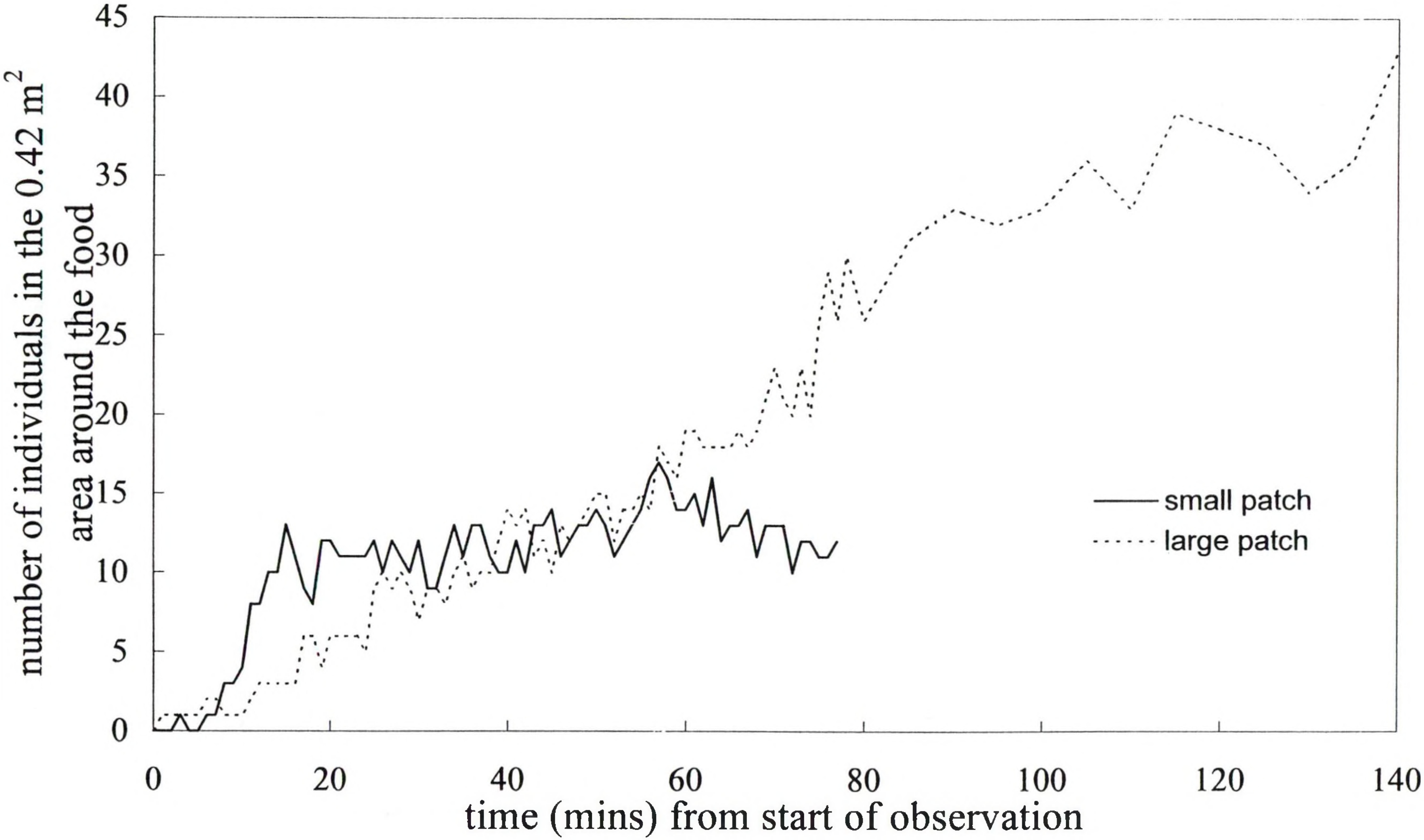


Fig. 3.6.8. Numbers of *P. bernhardus* present in the field of view (0.42 m^2) on the small food patch and large food patch. Durations of experiments were determined by onset of tidal flow (see text).

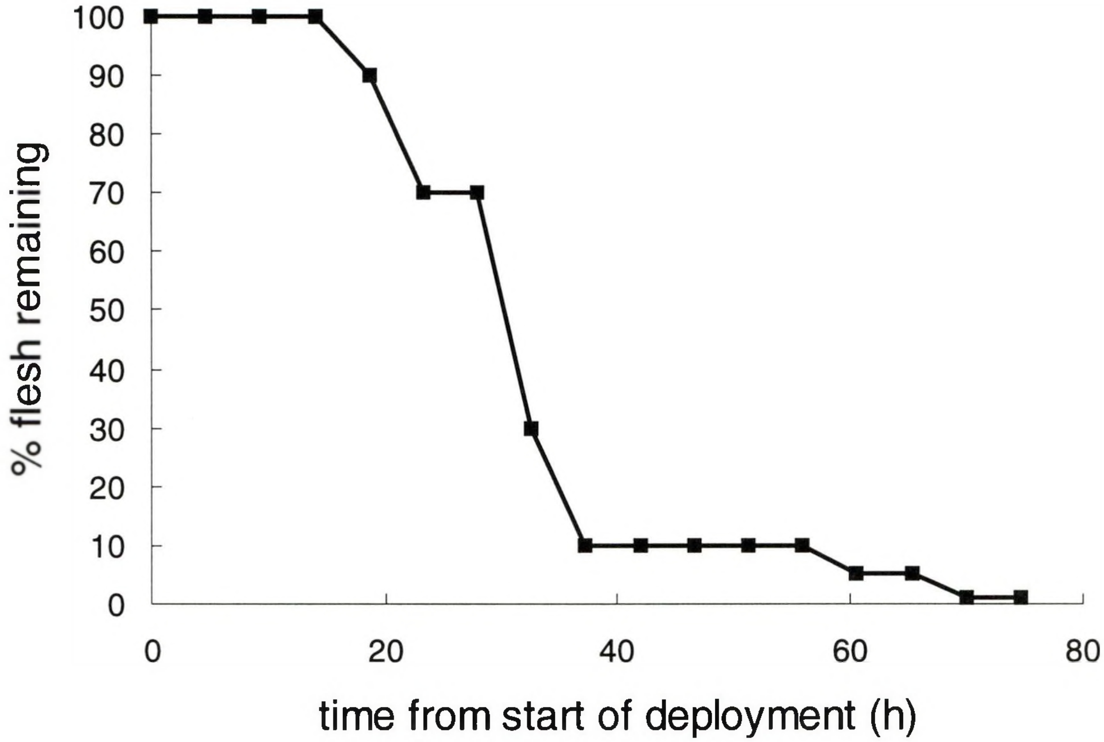


Fig. 3.6.9. Visual estimates of the percentage of flesh remaining on the bait (dragonets) during the Red Wharf Bay time-lapse camera deployment.

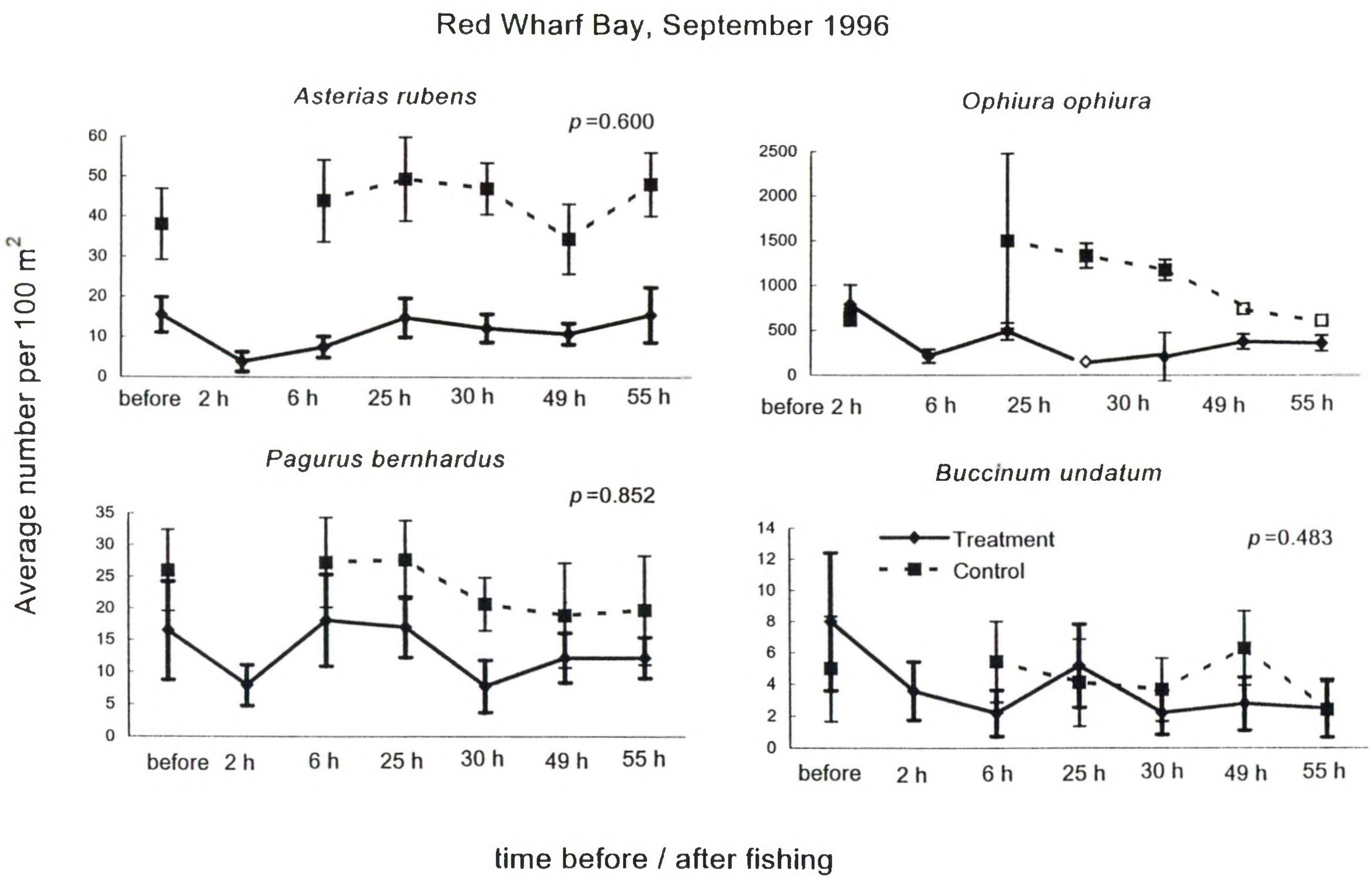


Fig. 3.6.10. Mean numbers (± 95% confidence intervals) of scavengers observed by divers before and after a line was fished with a beam trawl. p values are the significance of the interaction between time and treatment (repeated measures ANOVA on log transformed data).

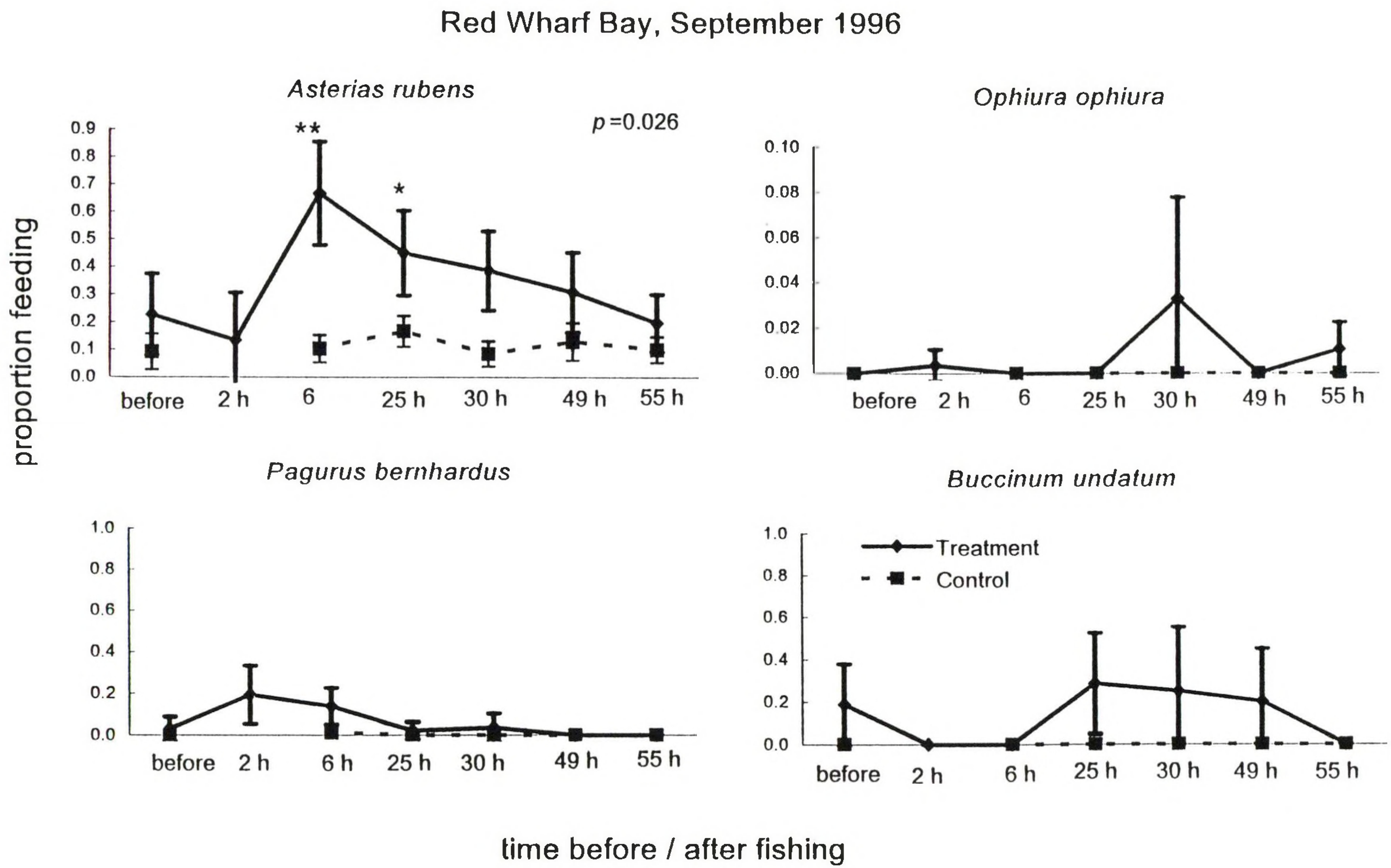


Fig. 3.6.11. Proportion of scavengers observed feeding before and after a line with a beam trawl. p values are the significance of the interaction between time and treatment (ANOVA specifying a binomial distribution). Where no p values if shown the model did not converge and therefore the validity of the model fit could be questionable. The comparison of numbers on the treatment wayline before fishing and numbers at each time period after fishing is also shown (*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$).

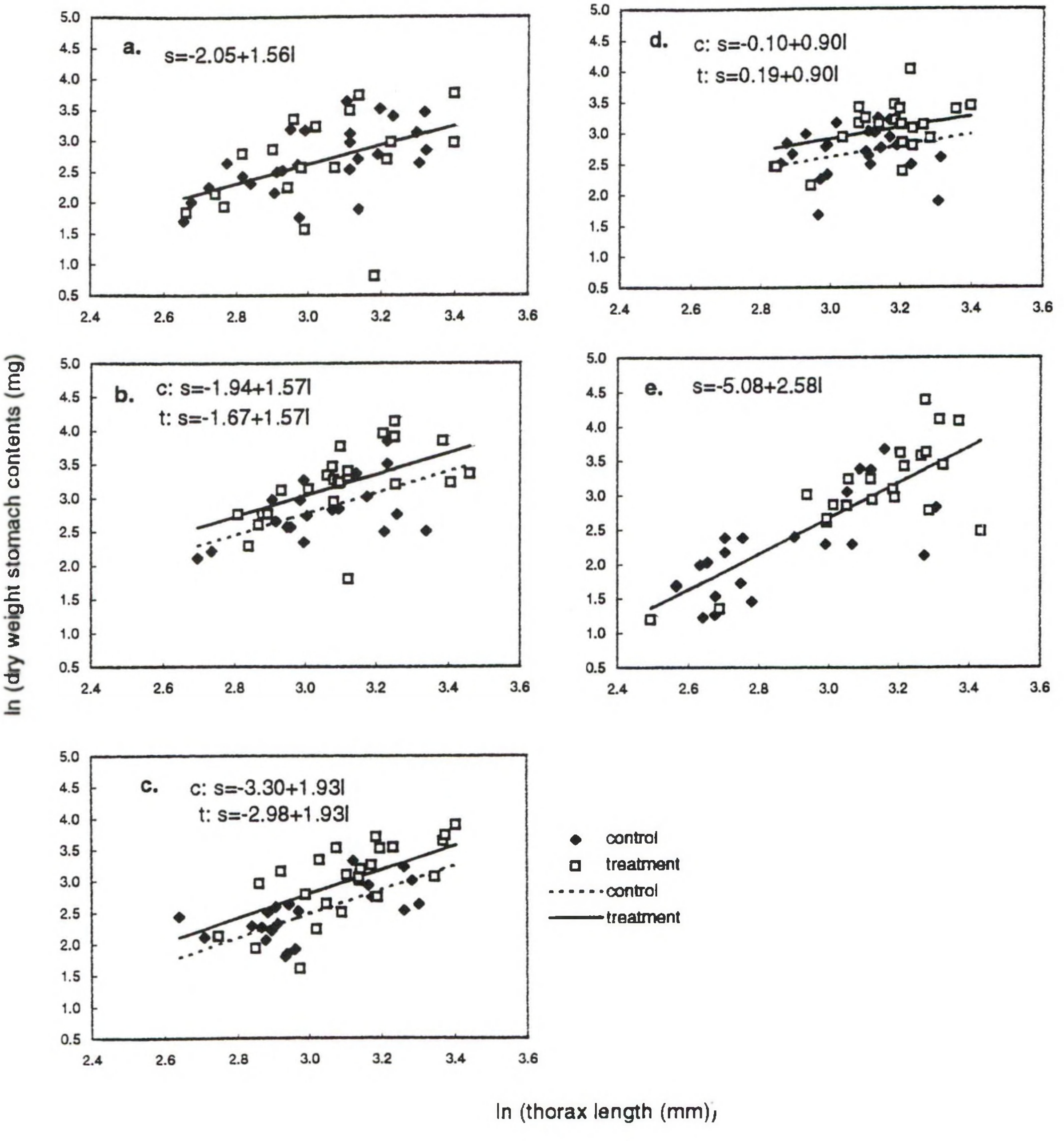


Fig. 3.6.12. *P. bernhardus*. Relationship between crab size and weight of stomach contents for treatment and control line (where only 1 line is shown this is a common line fitted to the whole dataset), also showing equations for the fitted line(s) where c = control line, t = treatment line, s = ln (dry weight of stomach contents (mg)) and l = ln (crab thorax length (mm)).

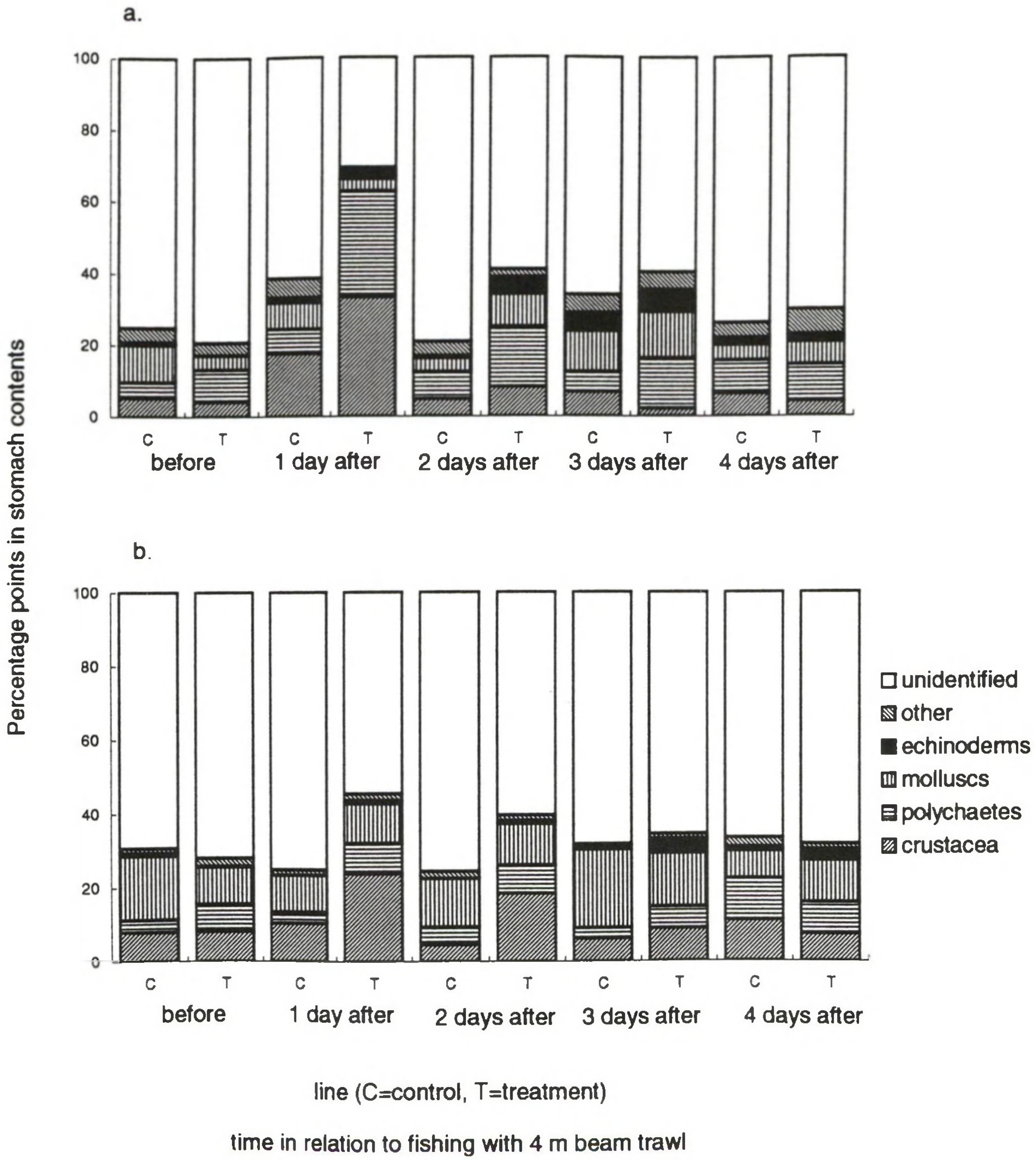


Fig. 3.6.13. Composition of the diet of a. *P. bernhardus*, b. *P. prideaux*, ("other" includes hydroids, bryozoans, eggs, fish scale).

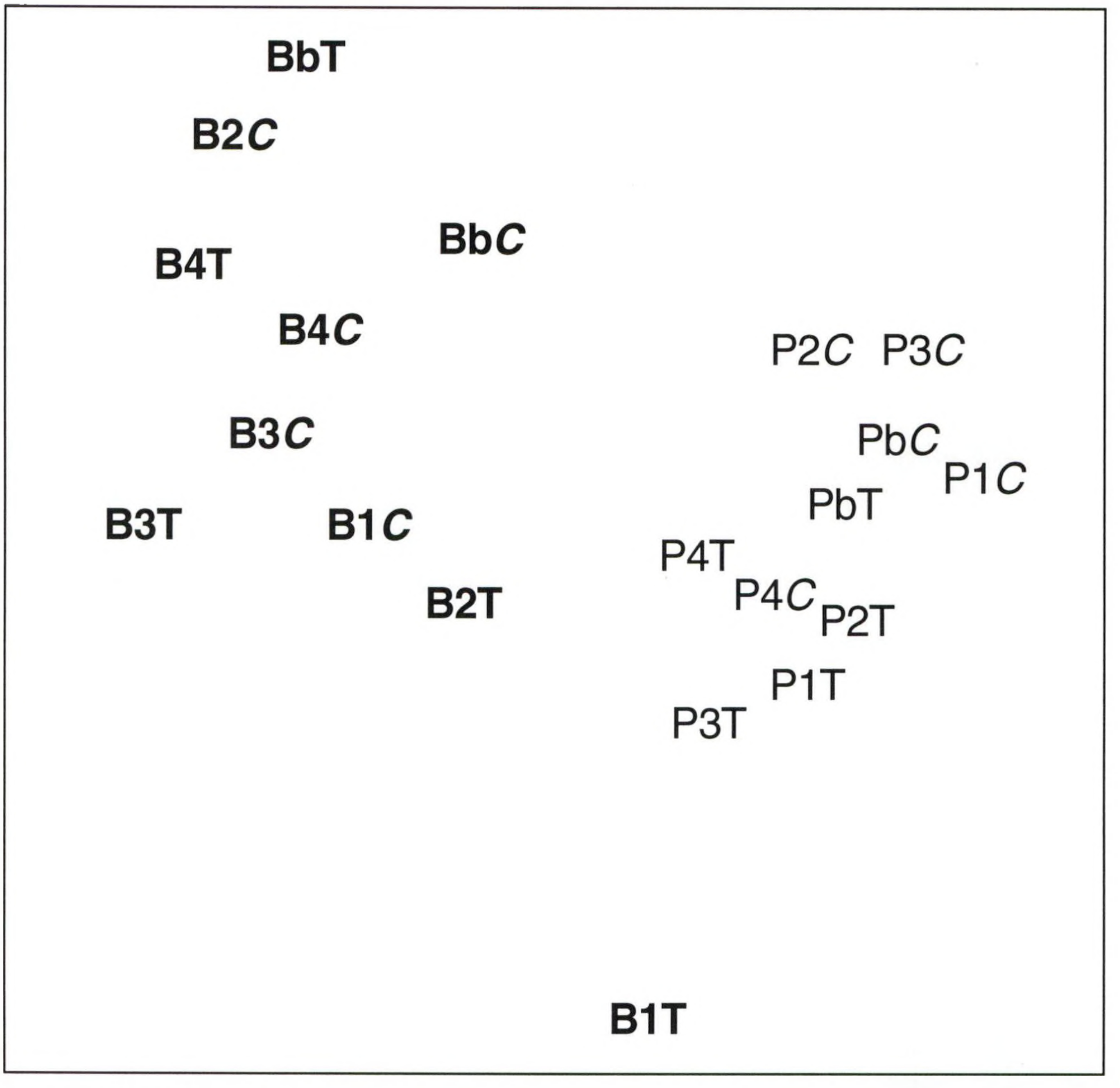


Fig. 3.6.14. MDS plot showing groupings based on stomach contents (stress value=0.14). Nomenclature as follows: XyZ - X = species (**B** *P. bernhardus*, P *P. prideaux*), y = days after fishing (b= before, 1= 1 day after etc.) , Z = line (C control, T treatment).

The distance between each point on the plot represents the similarity between each treatment on a particular date. The closer groups of points are clustered together the greater their similarity. Hence, it is clear that the stomach contents of *Pagurus bernhardus* are very different from all other sampling occasions on the first day after fishing (B1T).

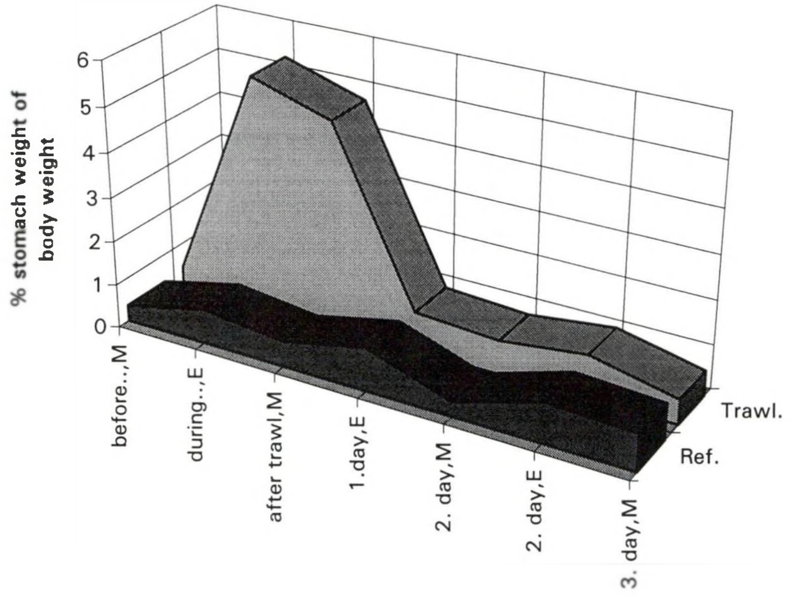


Fig. 3.6.15. The change of median stomach fullness of dab collected at 12 h intervals on a trawled area in comparison with an untrawled reference area. E = evening, M = morning.

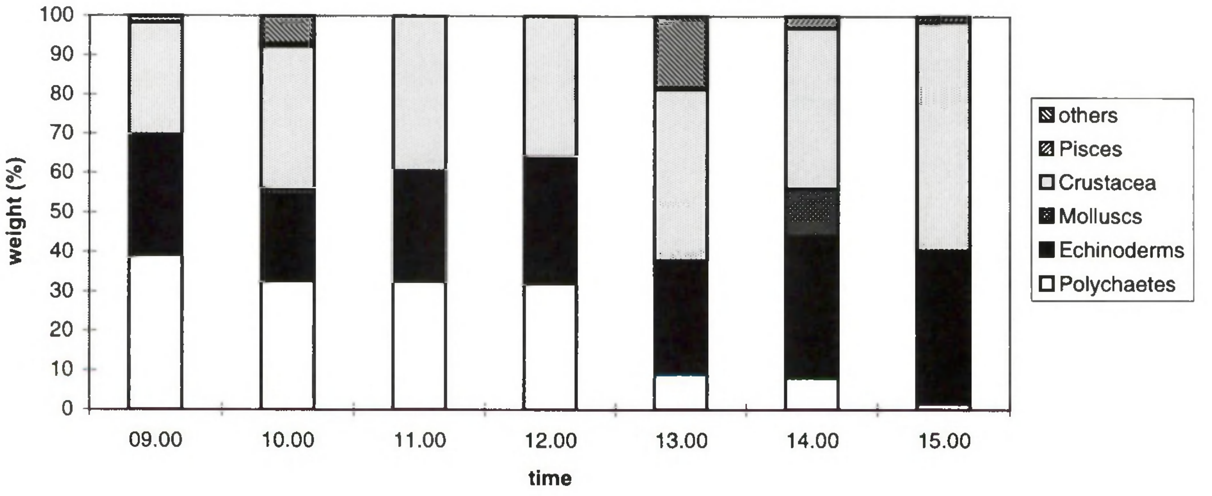


Fig. 3.6.16. The change in composition of stomach contents of dab during repeated trawling.

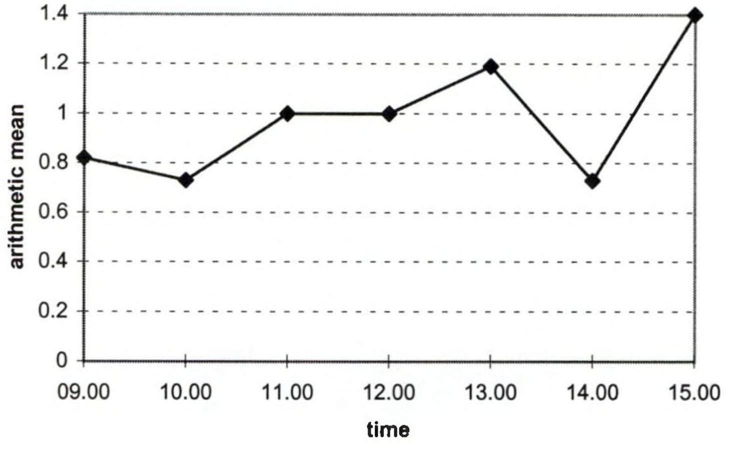


Fig. 3.6.17. The change in stomach fullness of dab during repeated trawling.

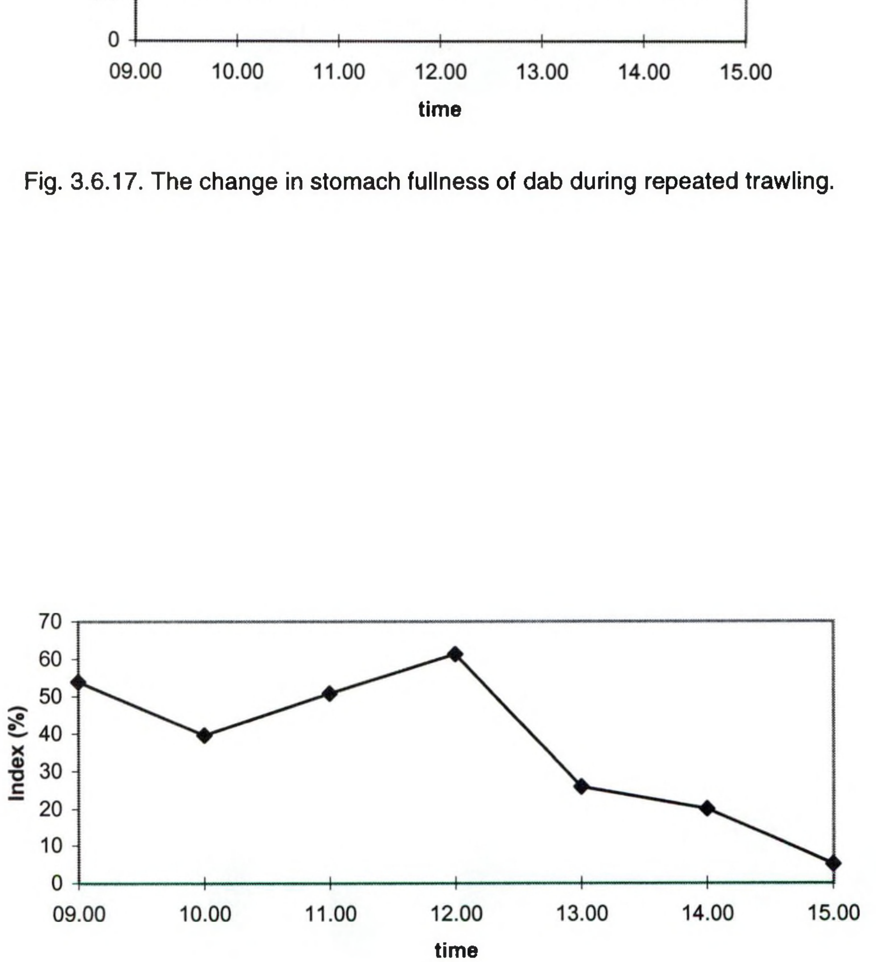


Fig. 3.6.18. The changing similarity index (%) of food composition in stomachs of dab and plaice during repeated trawling.

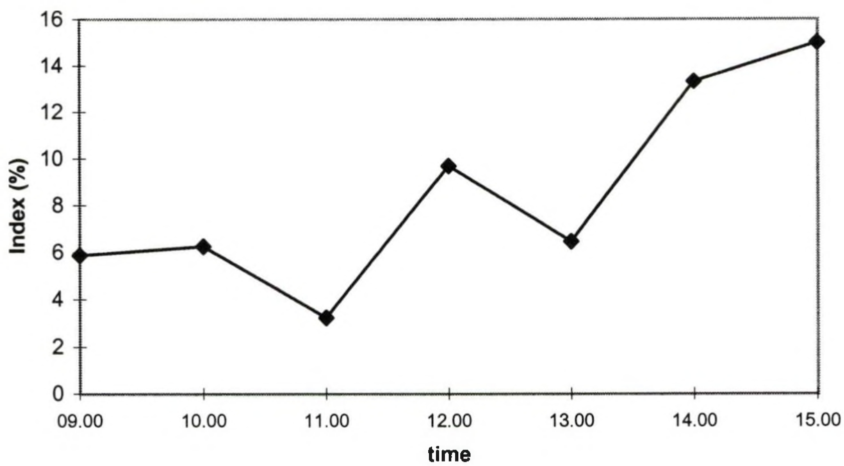


Fig. 3.6.19. The changing similarity index (%) for decapods in the stomachs of dab and plaice during repeated trawling.

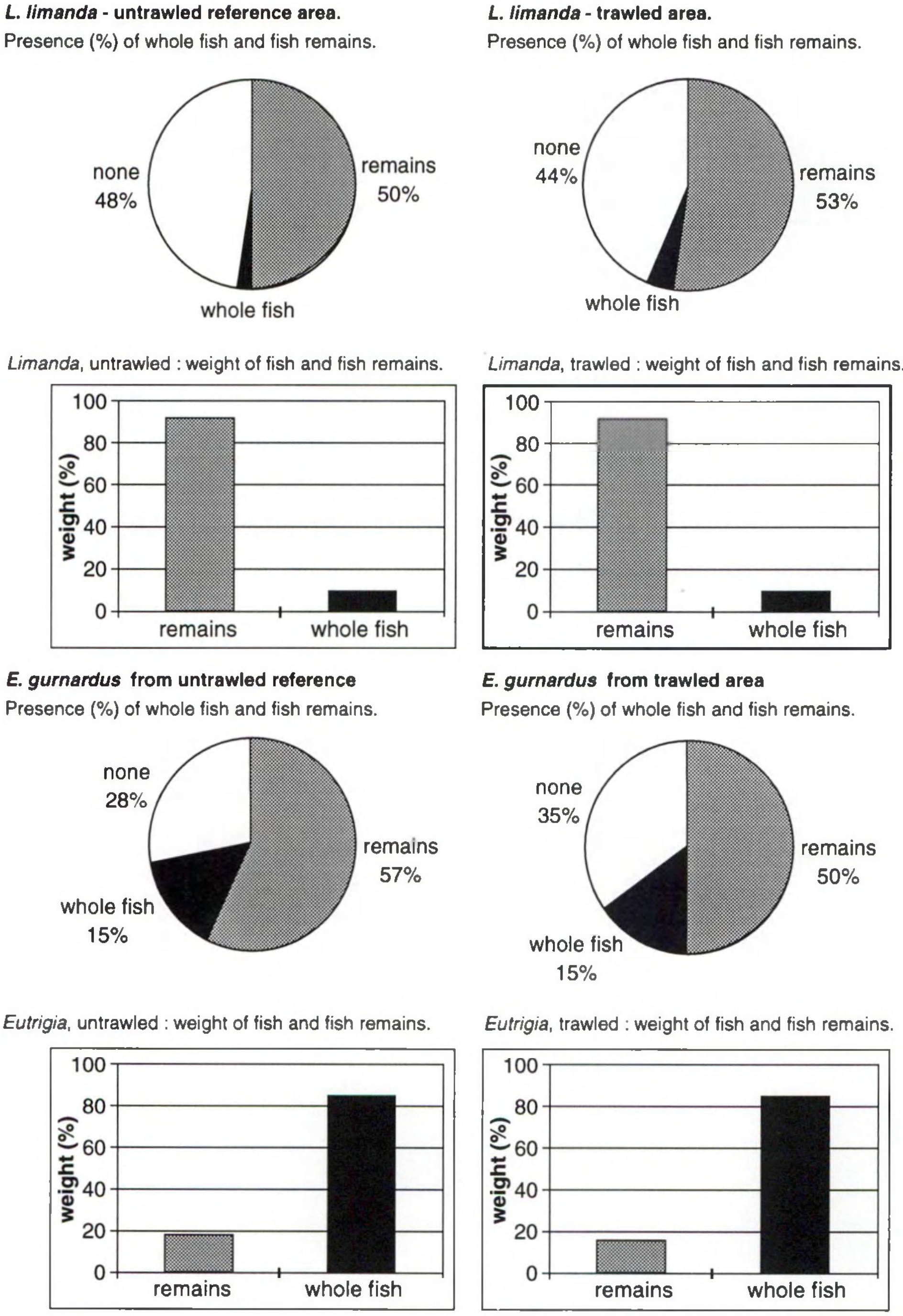
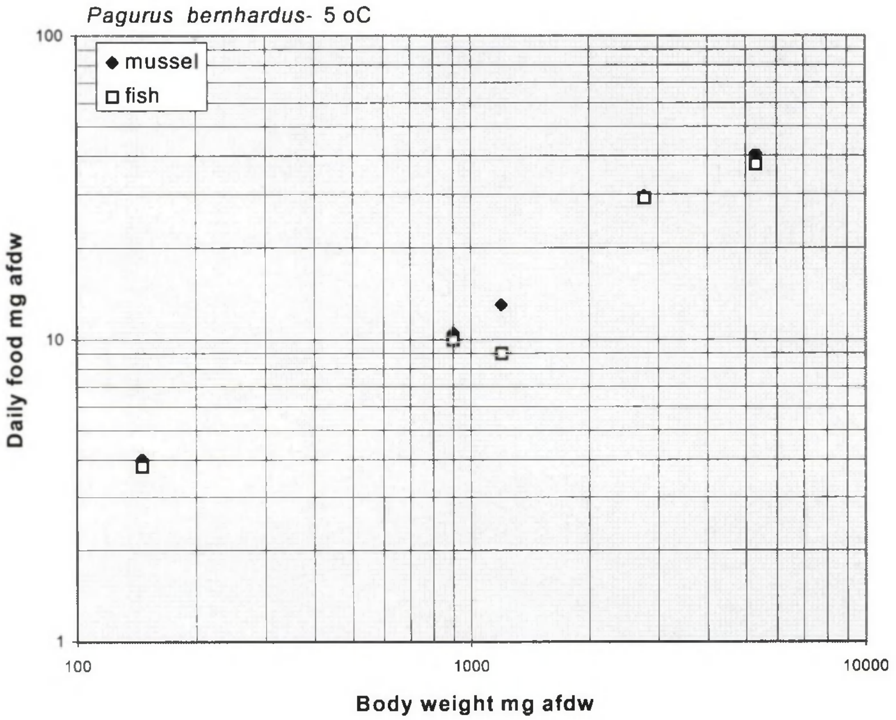


Fig. 3.6.20. The presence of fish in stomachs of dab (top) and grey gurnard (below) in an area trawled with otter trawl (right) as compared with an untrawled reference area (left).



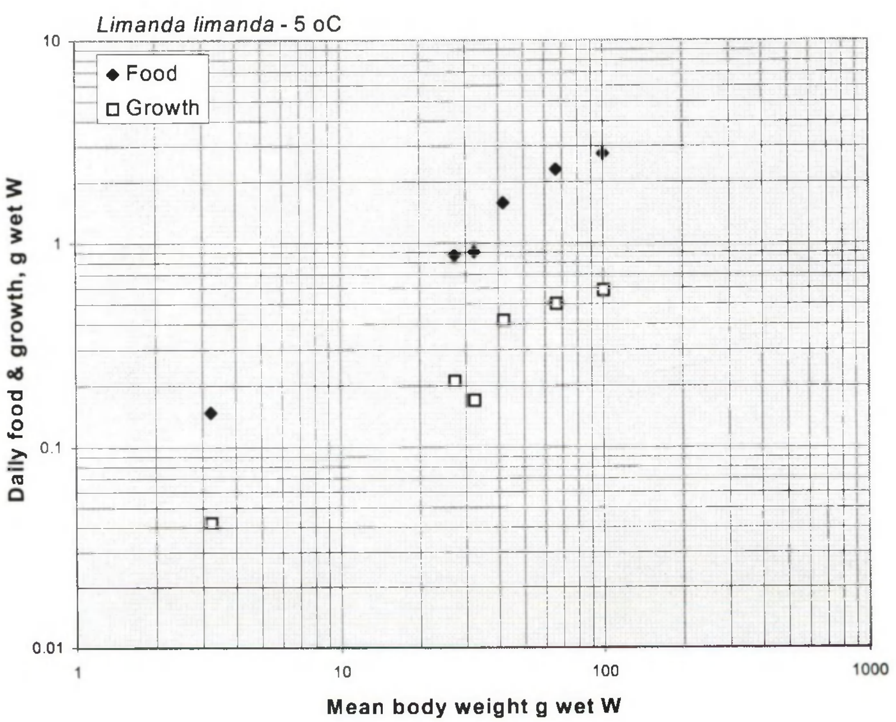
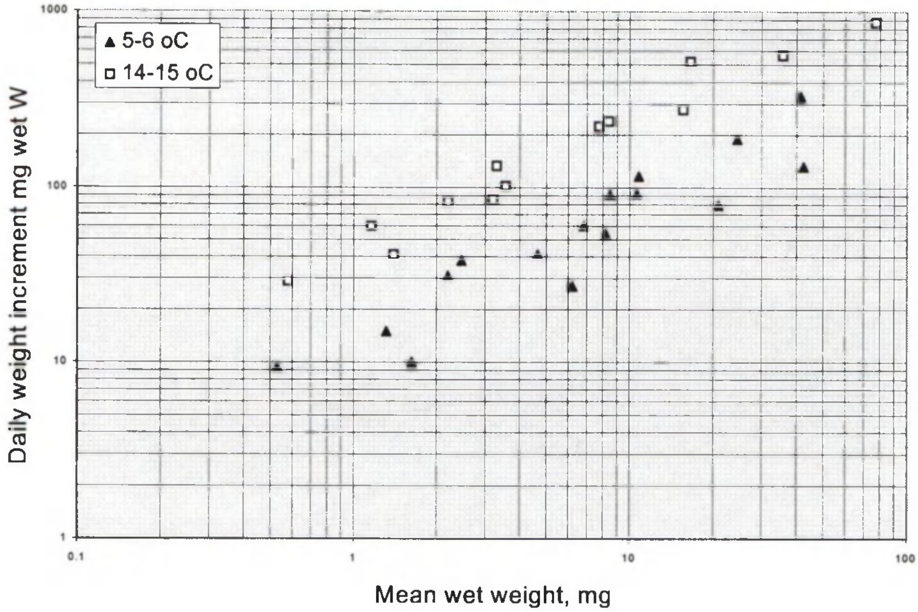


Fig. 3.6.21. A plot of daily food consumption against body weight for hermit crab (top: fed with mussel or fish at 5° C) and dab fed with mussel at 5° C).

Asterias rubens



Limanda limanda

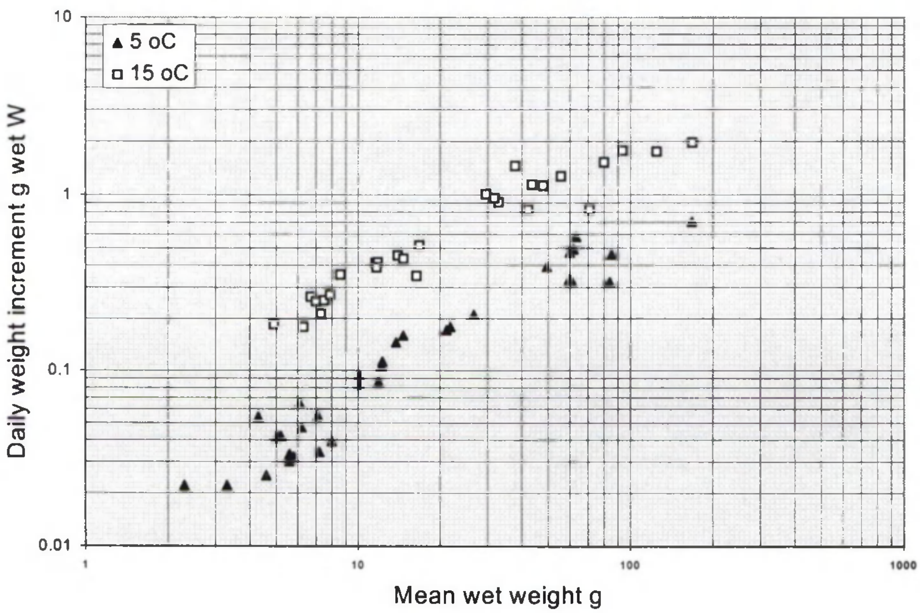
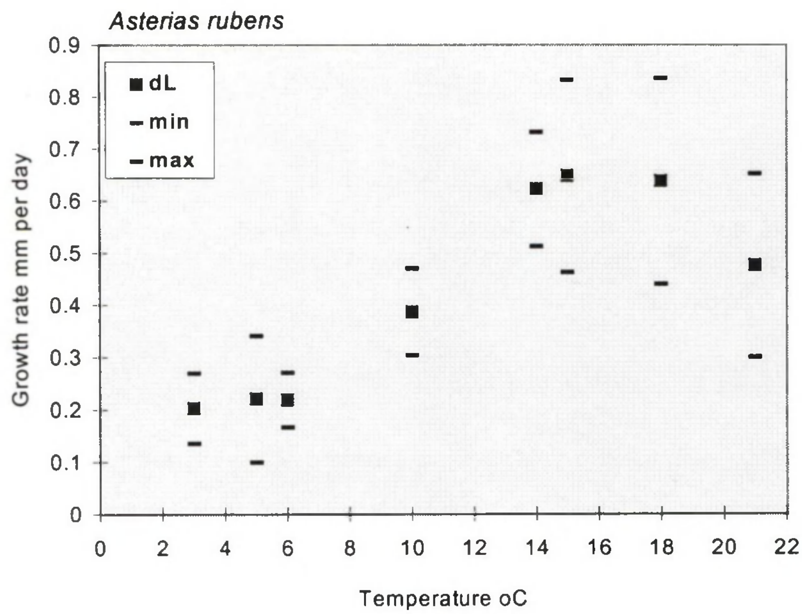


Fig. 3.6.22. A plot of daily growth in wet weight against mean weight of starfish (top) and dab (below), fed with unlimited rations at 5-6 and 14-15° C).



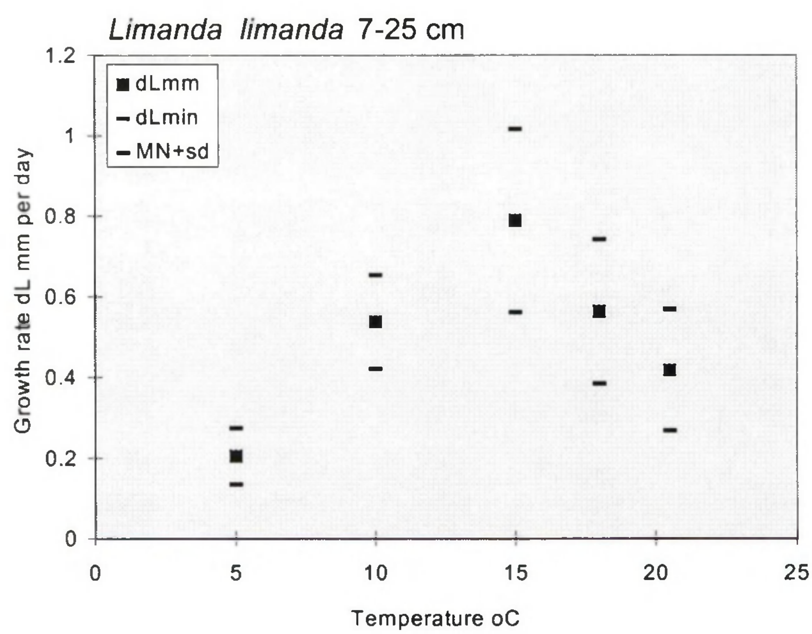
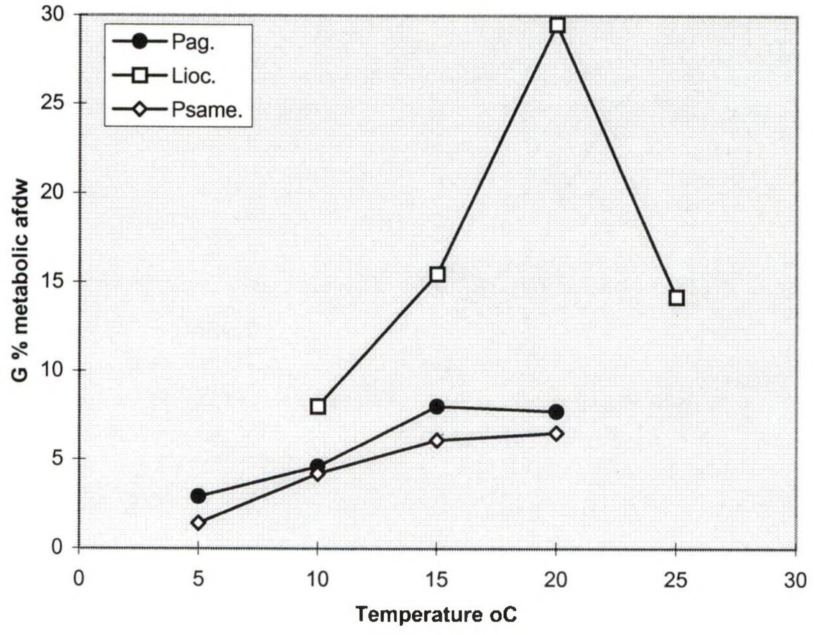


Fig. 3.6.23. The growth rate in length (dL, mm per day) of starfish (top) and dab (below) in the laboratory at constant temperatures. Mean values and the upper and lower limits of standard deviation.



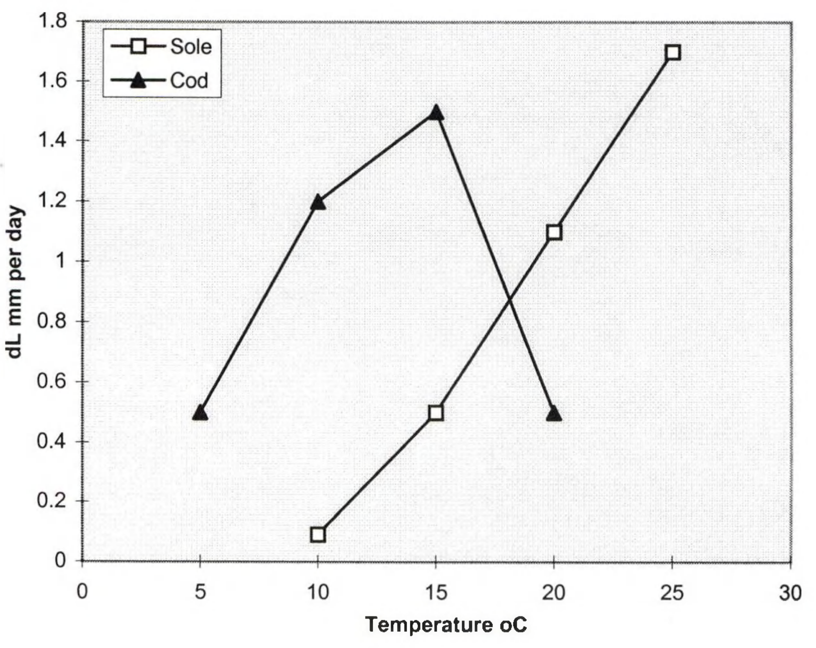


Fig. 3.6.24. The effect of temperature on daily weight increment as % of metabolic ash (top: hermit crab, swimming crab and sea urchin) and on growth rate in length (below: 0-group sole and cod).

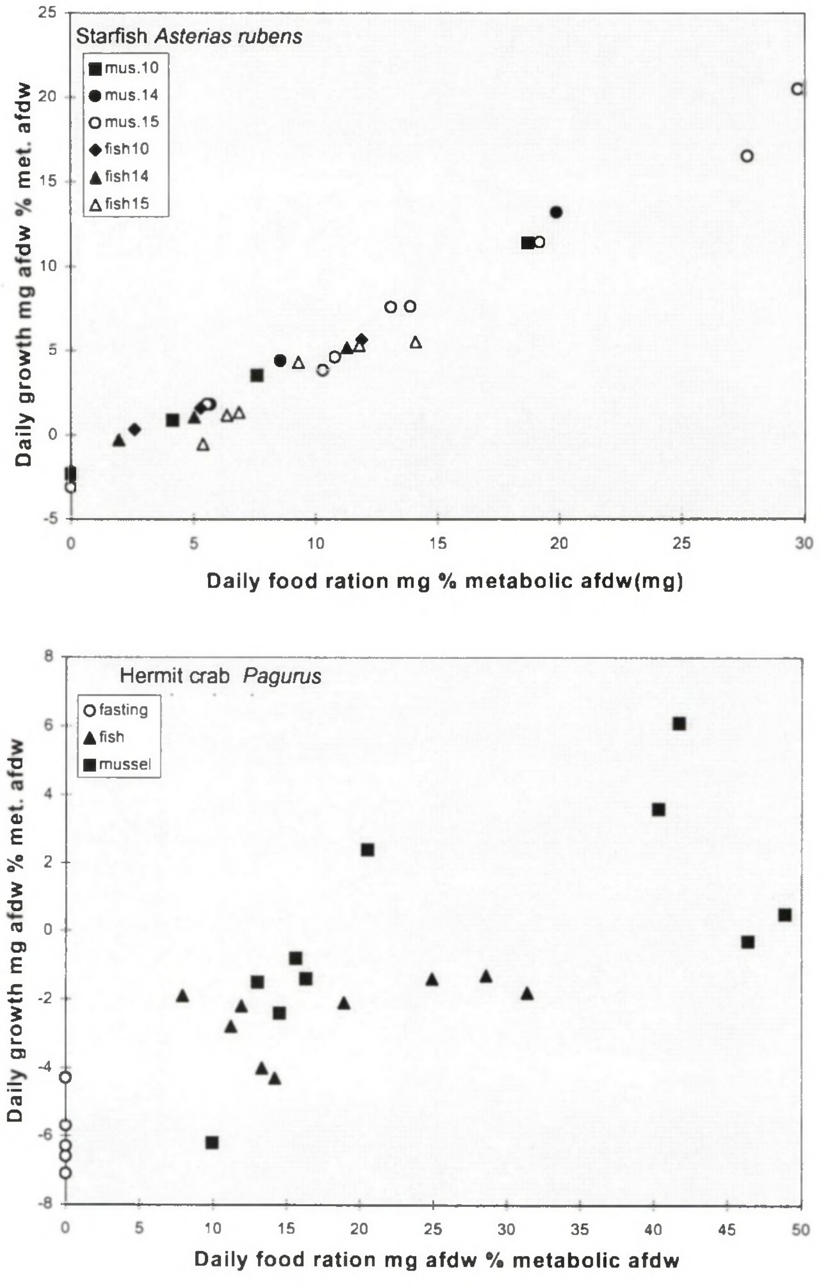


Fig. 3.6.25. The relationship between daily ration and growth, both in mg afdw as % metabolic afdw, of starfish (top: *Asterias rubens* 10-15° C) and hermit crab (below: *Pagurus bernhardus*, 15° C).

TABLE 3.6.1.

Returns of fine-meshed 3m beam trawl in numbers per hectare, from an area trawled with otter trawl in comparison with a nearby untrawled control area, in August 1995 and April 1996.

	August 1995						April 1996			
	Control To	Control To+24	Control To+48	Trawled To	Trawled To+24	Trawled To+48	Control To	Control To+48	Trawled To	Trawled To+48
SPECIES										
Crustacea										
D. bonneri	197	81	99	152	126	255	7	10	5	38
C. allmanni	250	23	45	155	76	120	6	9	8	25
P. sivado	37	11	39	6	9	26	6	2	12	2
L. holsatus	2	2	11	2	8	20	7	0	1	2
P. bernhardus	15	7	11	3	8	11	7	4	4	9
G. rhomboides	2	2	2	6	7	6	0	0	0	0
Echinodermata										
A. rubens	4	4	2	1	4	2	12	6	4	4
Polychaeta										
A. aculeata	1	1	0	2	3	3	4	2	5	4
Mollusca										
A. opercularis	3	0	3	4	2	2	1	1	2	4
H. arctica	1	2	2	4	1	0	0	0	0	6
A. alba	0	0	0	9	19	0	3	1	0	11
A. nitida	1	1	0	0	23	0	0	0	0	1
Total	515	133	211	344	285	444	53	34	40	105

TABLE 3.6.2.

Changes in the relative densities of demersal species in areas disturbed by commercial beam trawls, several days after trawling. Relative density as proportion of untrawled density.

Change in density after trawling :	**-1 = further decline; 0 = no change; 1 = 1-2 times as many animals; 3 = >3 times as many; 4 = >4 times as many.**								
Year	1993	1992	1993	1994	1994	1994	1994	1995	1995
Month	Apr.	Apr	Sep.	June	June	Sept	Sept	May	Sept.
Area	Egmond	Oystergr.	Oystergr.	North	South	Helgol.	Oystergr.	Weisse B.	South
Location map Fig. 2.6.1.	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Depth (m)	15	45	45	30	20	24	42	41	20
Commercial beam trawl	4	12	12	12	12	12	12	12	12
Area trawled	1100*32	1000*72	1800*72	1300*60	1200*60	1200*83	1200*65	2600*65	1200*65
Sampling beam trawl	4	12	12	3	3	3	3	3	3
Sampling period (days after trawling)	1	0.25	1	2	2.5	2	3	7	4
Species									
Sole *(Solea)*	**0**	**0**	**1**	**0**	**0**	**1**		**1**	**2**
Plaice *(Pleuronectes)*	**1**	**2**	**1**	**1**	**0**	**0**	**1**	**1**	**1**
Dab *(Limanda)*	**1**	**2**	**4**	**4**	**2**	**3**	**4**	**4**	**0**
Gadoids *(Merlangius e.o.)*	**0**	**3**	**0**	**0**	**3**	**0**	**4**	**0**	**0**
Gurnards *(Trigla)*		**0**	**0**	**4**	**1**	**0**	**0**	**0**	
Solenette *(Buglossidium)*				**0**	**0**	**0**	**0**	**0**	**0**
Scaldfish *(Arnoglossus)*				**1**	**0**	**0**	**0**	**1**	**2**
Dragonets *(Callionymus)*				**4**	**1**	**3**	**1**	**3**	**0**
Hooknose *(Agonus)*				**0**	**0**	**1**		**1**	**1**
Weever *(Echiichthys)*				**2**					**0**
Gobies *(Pomatoschistus)*				**0**	**1**	**1**	**0**	**0**	**1**
Red mullet *(Mullus)*						**2**			**0**
Starfish *(Asterias)*	**1**	**0**	**1**	**0**	**0**	**0**	**0**		**0**
Sandstar *(Astropecten)*		**0**	**0**	**0**			**1**	**-1**	
Brittle stars *(Ophiura)*	**1**			**0**	**0**	**0**	**0**	**0**	**0**
Sea urchin *(Psamechinus)*				**0**					
Masked crab *(Corystes)*		**0**	**0**	**0**	**0**	**0**	**0**	**0**	
Swim.crabs *(Liocarcinus)*	**1**	**0**	**1**	**0**	**1**	**3**	**0**	**1**	**1**
Hermits *(Pagurus)*	**1**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**
Shrimp *(Crangon)*					**2**	**0**		**0**	**1**
Sea mouse *(Aphrodyte)*		**0**	**0**				**0**	**1**	

TABLE 3.6.3.

Overview of all catches from all baited traps set in the North Sea. The species are sorted according to total catch numbers.

Site of exposure		1	2	3	4	5	6	7	8	9	10	11	SUM	
n traps	Clas.	15	6	35	35	15	17	16	45	45	15	114	**358**	**%**
Species	*													
Liocarcinus holsatus	C	48	17	183	53	78	79	5	55	66	258	1252	**2094**	**38.4**
Pagurus bernhardus	C	201	16	84	25	1	26	4	111	39	17	632	**1156**	**21.2**
Asterias rubens	E	165	14	633	33	1			3	231		16	**1096**	**20.1**
Crangon crangon	C		1			66	26	3	2	1	1	330	**430**	**7.9**
Buccinum undatum	M				1				19	84			**104**	**1.9**
Liocarcinus depurator	C	1	2								2	75	**80**	**1.5**
Carcinus maenas	C					64					7	1	**72**	**1.3**
Liocarcinus marmoreus	C											68	**68**	**1.2**
Ophiura ophiura	E	8		45									**53**	**1.0**
Ophiura albida	E	1		21	2		2		14				**40**	**0.7**
Ciliata mustela	F	1						17			1	12	**31**	**0.6**
Trisopterus luscus	F	10				4					2	14	**30**	**0.6**
Cirolana borealis	C						6		21				**27**	**0.5**
Cancer pagurus	C	2	1	12						2	2	3	**22**	**0.4**
Corystes cassivelaunus	C	13							9				**22**	**0.4**
Buglossidium luteum	F	15					1		1				**17**	**0.3**
Gadus morhua	F				3		1			13			**17**	**0.3**
Liocarcinus puber	C							1			4	5	**10**	**0.2**
Merlangus merlangus	F	2			2		1		1	3			**9**	**0.2**
Echinocardium cordatum	E	2	1						1	4			**8**	**0.1**
Macropodia sp.	C	6		1									**7**	**0.1**
Astropecten irregularis	E				5				1				**6**	**0.1**
Nemertini	W								6				**6**	**0.1**
Limanda limanda	F						5	1					**6**	**0.1**
Psammechinus miliaris	E	3								3			**6**	**0.1**
Ammodytes tobianus	F									5	1		**6**	**0.1**
Trisopterus minutus	F	1	1			1				1		2	**6**	**0.1**
Pomatoschistus minutus	F											5	**5**	**0.1**
Zoarces viviparus	F			4									**4**	**0.1**
Liocarcinus arcuatus	C							1			1	2	**4**	**0.1**
Myoxocephalus scorpius	F			2									**2**	**<0.1**
Callionymus lyra	F								1			1	**2**	**<0.1**
Nereis sp	W									1			**1**	**<0.1**
Solea solea	F						1						**1**	**<0.1**
Liparis montagui	F						1						**1**	**<0.1**
Lunatia catena	M								1				**1**	**<0.1**
Arnoglossus laterna	F	1											**1**	**<0.1**
Agonus cataphractus	F								1				**1**	**<0.1**
Trachinus vipera	F									1			**1**	**<0.1**
Gammarus sp.	C		1										**0**	**<0.1**
Orchomene & Scopeloche	C *			xxx	xxx		x	xxx	xx	xxxxx	xx	xx		
SUM		480	54	985	124	215	148	32	247	454	296	2418	**5453**	**100**

Classification :

* M=mollusc, E=echinoderm, C=crustacean, W=worm, F=fish.

TABLE 3.6.4.
Catches of scavengers in traps baited with different kinds of discard materials.

Period & area	February 1995 - Oystergrounds 39 m - 7 oC.					May 1995 - W. of Helgoland 35 m - 11 oC					
Bait : n traps	**Fish** 5	**Mollusc** 5	**Crustac.** 6	**No bait** 4	Sum %	**Fish** 15	**Mollusc** 15	**Crustac.** 15	**Echinod.** 15	**No bait** 15	Sum %
Liocarcinus	102	58	0	3	**56**	35	27	1	8	1	**15**
Pagurus	26	4	15	3	**17**	20	2	5	12	0	**8**
Asterias	0	0	0	0	**0**	62	90	72	25	5	**53**
Buccinum						4	46	16	17	0	**17**
Crangon	14	28	7	0	**17**						
Cirolana	12	0	0	0	**4**						
Ophiura	4	0	0	0	**1**	2	4	0	6	0	**3**
Cancer						2	0	0	0	0	**1**
Gadoid fish	0	0	2	3	**2**	0	14	0	1	0	**3**
Flatfish	2	4	2	0	**3**						
Amphipods *	0	0	300	0	*	12	0	19000	8200	0	*
Sum % :	**55**	**33**	**9**	**3**	100	**26**	**38**	**20**	**15**	**1**	100

(* amphipods not included in the sum).

TABLE 3.6.5.
The area of attraction for some species of scavengers caught in baited traps. Numbers caught in the traps divided by the densities in the surrounding area. For some species the two highest values are shown.

Species	**Area**	**Date**	**Density** n/100 m^2	**Area of attraction** m^2
Cirolana borealis	Weisse Bank	Feb-95	< 1	**429**
Cirolana borealis	Weisse Bank	May-95	3	**87**
Pagurus bernhardus	Dutch coast W	Sep-95	6	**93**
Pagurus bernhardus	Helgoland	Sep-94	5	**46**
Liocarcinus holsatus	Weisse Bank	Feb-95	7	**59**
Liocarcinus holsatus	Dutch coast W	Jun-94	5	**56**
Asterias rubens	Dutch coast W	Jun-94	4	**55**
Asterias rubens	N Oystergrounds	Sep-94	2	**43**
Buccinum undatum	Weisse Bank	May-95	1	**37**
Crangon crangon	Weisse Bank	Feb-95	5	**30**
Ophiura ophiura	Dutch coast N	Jun-94	3	**21**
Ophiura albida	Weisse Bank	May-95	2	**14**
Ophiura albida	N Oystergrounds	Jun-94	2	**3**
Corystes cassivelaunus	Dutch coast N	Jun-94	68	**1**

TABLE 3.6.6.
Trap returns from modified shrimp pots for 24 h offshore at 70 m depth in September 1995 (cruise IMPII/LB4).

Bait :	no bait		Nephrops		Fish	
Number of traps :	4		5		7	
Catch :	n	W, g	n	W,g	n	W,g
Species						
Dichelopandalus bonnieri	1	3	146	154	133	112
Pagurus bernhardus	0	-	3	11	7	41
Liocarcinus holsatus	0	-	1	5	0	-
Calocaris macandreae	0	-	0	-	1	1

TABLE 3.6.7.
Catch composition of baited traps in shallow water NW Irish Sea. April 1996 (cruise IMPII/LB4).

Trap :	**Crab Fyke nets**			**Transparant pipes**			**Amphipod pipe**		
Bait :	no bait	Nephrops	Fish	no bait	Nephrops	Fish	no bait	Nephrops	Fish
Number of traps	6	6	6	6	6	6	6	6	6
Species									
Asterias rubens	0	4	3	0	5	3	0	1	4
Liocarcinus holsatus	0	4	0	0	0	11	0	0	0
Pagurus bernhardus	0	2	0	0	1	3	1	0	0
Crangon allmanni	0	0	0	0	0	0	1	0	0
Pandalids juv.	0	0	0	0	0	0	1	0	0

TABLE 3.6.8.

Mean numbers of animals caught per trap in the eastern Irish Sea. Only species with average number per trap above 5 have been included, species associated with other species caught have been excluded.

Bait :	**no bait**	**fish**	**crab**	**mollusc**
Anglesey offshore, 7-9 April 1996, small entrance				
Buccinum undatum	0	0	5	2
Cirolana borealis	0	5	0	0
Tmetonyx similis	5	0	24	17
Orchomene nana	0	0	12	0
Anglesey offshore, 27-28 April 1995, large entrance				
Buccinum undatum	1	2	14	10
Colus gracilis	0	6	7	3
Pagurus bernhardus	1	69	27	32
Tmetonyx similis	0	35	9	11
Orchomene nana	0	0	7	0
Red Wharf Bay, 29-31 October 1995, large entrance.				
Buccinum undatum	0	1	2	0
Lysianassid indet.	4	0	7	11
Walney Island, 3 November 1995, large entrance.				
Buccinum undatum	0	0	3	0
Processa nouveli-h.	4	8	3	6
Hemimysis lamornae	3	10	15	6

TABLE 3.6.9.

Mean *in situ* consumption of dead discard fish exposed in September 1995 on the North Sea floor for 1, 2 or 3 days at 18-20 m depth and 18° C.

Duration days	n fish baits	Species discarded fish	Weight at start g	Weight at end g	Rate of discard consumption % / day	Rate of discard consumption g / day
1	5	mixed	73.2	60.5	17.4	11.6
2	5	mixed	69.7	38.8	25.4	13.2
3	5	mixed	69.1	28.0	26.0	11.4
2	5	dab	55.7	11.1	55.4	13.8
2	5	dragonet	69.3	29.5	34.6	15.7
2	4	plaice	187.7	159.2	7.9	13.7

TABLE 3.6.10.

Numbers of damaged animals per 1000 m^2 observed by divers on a treatment line after fishing with a 4m beam trawl. September 1996, Red Wharf Bay.

Hours after fishing:	2	6	25	30	49	55
ECHINODERMS						
Ophiura ophiura	164	53	15	3	14	11
Echinocardium cordatum	31	16	41	25	22	17
Asterias rubens	3	0	0	0	0	0
Astropecten irregularis	3	3	0	3	3	0
CRUSTACEA						
Corystes cassivelaunus	3	3	7	17	0	0
Liocarcinus spp.	0	0	4	3	3	0
MOLLUSCS						
Buccinum undatum	3	6	0	0	0	0
Ensis sp.	6	6	19	6	6	11
unidentified bivalves	3	13	0	8	14	3

TABLE 3.6.11.
Numbers of scavengers per 1000 m^2 observed feeding on different food items before fishing and on the control line and on the treatment line after fishing with a 4m beam trawl. September 1996, Red Wharf Bay.

Scavenger :	***Asterias rubens***		***Pagurus bernhardus***		***Ophiura ophiura***		***Buccinum undatum***	
	Before & control	After fishing	Before & control	After fishing	Before & control	After fishing	Before & control	After fishing
Damaged prey								
MOLLUSCS								
unidentified bivalves	5.6	5.3		0.5			0.5	
Ensis sp.	2.5	3.4				9.8		1.0
Mactra stultorum	1.5	1.0						
Buccinum undatum				3.4				
CRUSTACEA								
Corystes cassivelaunus	0.5			0.5		4.9		0.5
ECHINODERMS								
Echinocardium cordatum	5.1	9.2					1.0	0.5
POLYCHAETES								
Lagis koreni	1.0	3.9		1.0				1.0
ANTHOZOA								
Cyanea lamarckii	5.1		0.5					

TABLE 3.6.12.

Means and standard deviations of length, weight, Stomach Filling Index (SFI, % of weight), Stomach Fullness and gut content state of whiting and haddock taken at intervals along a trawled transect at different times (t1, t2, t3) and from an untrawled control transect in the IMPACT II offshore station at 75 m depth in the NW Irish Sea, in October 1194 and August 1995. Mean carapace length and degree of fullness for the foregut of *Nephrops* are presented for August 1995.

	Number fish	Length, cm		Weight, g		Stomach Filling Index		Stomach fullness		Gut content state	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Whiting											
October 94											
Trawled wayline											
t1 at 0 hrs	61	**18.9**	4.2	**64.3**	39.5	**4.3**	3.5	**1.7**	1.6	**1.2**	1.0
t2 after 6 hrs	60	**22.2**	3.4	**104.5**	46.8	**2.7**	1.6	**2.2**	1.6	**1.5**	0.9
t3 after 72 hrs	60	**17.0**	4.7	**49.7**	44.2	**4.0**	1.8	**2.8**	1.8	**1.7**	0.9
August 95											
Trawled wayline											
t1 at 0 hrs	60	**22.9**	5.0	**114.2**	74.5	**3.3**	2.0	**2.4**	1.5	**1.5**	0.8
t2 after 48 hrs	60	**22.8**	3.8	**106.7**	46.8	**2.2**	0.9	**2.1**	1.2	**1.5**	0.7
untrawled control											
t1 after 48 hrs	60	**20.6**	6.6	**95.9**	79.9	**3.6**	1.4	**1.8**	0.8	**1.4**	0.7
Haddock											
October 94											
Trawled wayline											
t1 at 0 hrs	60	**17.1**	1.4	**46.2**	12.3	**3.1**	1.3	**2.1**	2.1	**1.0**	0.9
t2 after 6 hrs	0	-		-							
t3 after 72 hrs	60	**15.9**	4.5	**45.7**	69.4	**3.8**	1.6	**1.8**	1.6	**1.3**	0.9
August 95											
Trawled wayline											
t1 at 0 hrs	60	**26.7**	4.5	**201.2**	75.9	**2.0**	0.6	**2.4**	1.2	**1.5**	0.8
t2 after 48 hrs	60	**26.8**	4.3	**226.8**	136.7	**2.9**	2.4	**2.6**	1.4	**1.5**	0.8
untrawled control											
t1 after 48 hrs	60	**27.5**	4.4	**232.5**	109.6	**2.3**	0.5	**2.9**	0.8	**1.9**	0.4
Nephrops		(carapace)						(foregut)			
August 95											
Trawled wayline											
t1 at 0 hrs	60	**3.5**	0.2					**27.5**	26.3		
t2 after 48 hrs	60	**3.4**	0.01					**42.0**	17.9		
untrawled control											
t1 after 48 hrs	60	**3.4**	0.4					**37.5**	25.0		

TABLE 3.6.13.
Percentage occurrence of major groups in the gut contents of whiting and haddock taken before (t1 at 0 h) and following trawl disturbance (t2, t3) along a trawled wayline and an untrawled control transect located in IMPACT II offshore station (75 m depth) in the NW Irish Sea, in October 1994 and August 1995.

	October 94			**August 95**		
Haul nr.	t1	t2	t3	t1	t2	Control
time	0 hrs	6 h	72 h	0 h	48 h	48 h
	%	%	%	%	%	%
Whiting						
Crustacea	59	66	85	59	74	43
Mollusca	0	0	0	0	0	0
Annelida	5	3	2	1	0	0
Pisces	11	17	2	22	17	15
Others/unidentif.	3	0	0	0	0	0
Empty	31	20	14	18	8	42
Haddock						
Crustacea	63	-	57	39	49	26
Mollusca	0	-	5	33	27	47
Annelida	0	-	15	18	16	13
Pisces	0	-	0	3	0	6
Others/unidentif.	0	-	0	1	6	0
Empty	38	-	23	6	2	8

TABLE 3.6.14.
Percentage occurrence of major groups of Crustacea in the gut contents of whiting and haddock taken before (t1 at 0 h) and following trawl disturbance (t2, t3) along a trawled wayline and an untrawled control transect located in IMPACT II offshore station (75 m depth) in the NW Irish Sea, in October 1994 and August 1995.

	October 94			August 95		
Haul nr.	t1	t2	t3	t1	t2	Control
time	0 hrs	6 h	72 h	0 h	48 h	48 h
	%	%	%	%	%	%
Whiting						
Crangonidae	33	35	72	71	42	77
Pandalidae	6	5	6	18	3	7
Euphausidae	44	45	0	2	42	0
Portunidae	0	0	4	5	0	3
Nephropidae	0	0	0	3	0	7
Others/unidentif.	17	15	18	1	13	7
Haddock						
Crangonidae	29	-	26	31	41	23
Pandalidae	0	-	0	4	0	3
Amphipoda	14	-	58	39	21	37
Portunidae	14	-	0	20	11	14
Nephropidae	0	-	0	2	21	14
Galathea	14	-	5	-	-	-
Others/unidentif.	29	-	11	4	7	9

TABLE 3.6.15.

Mean numbers of Crustacea in the gut contents of whiting and haddock taken before (t1 at 0 h) and following trawling disturbance (t2, t3) along a trawled wayline and an untrawled control transect located inIMPACT II offshore station (75 m depth) in the NW Irish Sea in October 1994 and August 1995.

	October 94						**August 95**					
Haul nr.	t1 (0 h)		t2 (6 h)		t3 (72 h)		t1 (0 h)		t2 (48 h)		Control (48 h)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Whiting												
Crangonidae	**1.4**	0.8	**1.1**	0.4	**1.9**	1.0	**3.0**	0.5	**1.5**	0.2	**1.6**	0.4
Pandalidae	**1.0**	0	**1.0**	0	**1.0**	0	**1.5**	0.2	**1.0**	0	**0.5**	0.7
Euphausidae	**1.8**	0.9	**2.2**	1.8	**0**		**0.6**	1.3	**2.2**	1.5	**0**	
Portunidae	**0**		**0**		**1.0**	0	**0.8**	0.5	**0**		**0.5**	0.7
Nephropidae	**0**		**0**		**0**		**1.0**	0	**0**		**0.5**	0.7
Haddock												
Crangonidae	**1.0**	0	-		**1.2**	0.5	**1.5**	0.3	**1.8**	0.4	**1.3**	0.4
Pandalidae	**0**		-		**0**		**0.9**	1.0	**0.5**	0.7	**0.5**	0.7
Amphipoda	**1.0**	0	-		**8.8**	11	**2.4**	0.6	**2.4**	0.1	**1.5**	0.2
Portunidae	**1.0**	0	-		**0**		**1.9**	1.4	**1.4**	0.3	**1.0**	0
Nephropidae	**0**		-		**0**		**1.4**	0.4	**1.3**	0.1	**0.7**	1.0
Galathea	**1.0**	0	-		**1.0**	0						

TABLE 3.6.16.

Overview of stomach contents of selected fish from trawled areas and untrawled reference areas. Only prey taxa with 25% occurence or more are shown. Feeding intensity in trawled areas is the change in stomach fullness after trawling, compared to the reference area: 0 = no increase, X = increase, XX = strong increase.

Species	Area (Fig. 2.6.2)	Season year	Diet in reference areas	Number of fish	Diet after trawling	Number of fish	Feeding intensity
Dab	Dutch coast W	May-93	*Ensis, Lanice,* other polychaetes	31	*Spisula, Ensis, Tellina*	46	XX
Plaice	Dutch coast W	May-93	*Ensis* , Neriidae	25	*Spisula, Neriidae*	38	XX
Sole	Dutch coast W	May-93	*Lanice* , juv. *Spisula*	12	*Spisula, Lanice*	26	0
Dab	Oyster grounds	Jun-94	*Lanice, Pectinaria* , siphons	67	*Donax, Mactra*	72	XX
Dragonet	Oyster grounds	Jun-94	*Lanice, Pectinaria* , juv. bivalves	19	*Echinocardium*	15	XX
Whiting	Oyster grounds	Jun-94	empty	3	*Mactra, Crangon, Echinocardium*	8	XX
Lesser Weaver	Oyster grounds	Jun-94		0	*Crangon*	9	
Dab	Weisse Bank	Jun-94	juv. *Liocarcinus* , siphons,*Nephtys*	92	*Nephtys, Echinocardium, Ensis*	180	XX
Dragonet	Weisse Bank	Jun-94	juv. *Liocarcinus*	21	juv. *Liocarcinus, Echinocardium*	16	XX
Whiting	Weisse Bank	Jun-94	*Crangon* ,juv. & ad., *Liocarcinus*	12	*Crangon* ,juv. & ad. *Liocarcinus, Corystes*	20	X
Tub gurnard	Weisse Bank	Jun-94	*Crangon* ,juv., *Liocarcinus*	15	*Crangon* ,ad. & juv. *Liocarcinus*	17	XX
Sole	Weisse Bank	Jun-94	empty, polychaetes	9	empty	4	0
Dab	Dutch coast W	Jun-94	*Lanice* , *Crangon,* empty	55	*Ophiura, Lanice* , small bivalves	51	X
Plaice	Dutch coast W	Jun-94	*Lanice, Tellina* , empty	67	*Lanice, Tellina, Nephtys*	40	X
Dragonet	Dutch coast W	Jun-94		0	*Echinocardium*	6	
Tub gurnard	Dutch coast W	Jun-94	*Crangon*	10	*Crangon, Liocarcinus*	25	XX
Whiting	Dutch coast W	Jun-94	*Crangon, Liocarcinus*	13	*Crangon, Liocarcinus* , gobies	10	X
Bull rout	Dutch coast W	Jun-94	*Liocarcinus, Crangon* , gobies	16	*Liocarcinus,* gobies	12	0
Dab	Weisse Bank	Sep-94	*Amphiura*	74	*Amphiura, Chamelea, Phaxas, Callianassa*	97	XX
Grey gurnard	Weisse Bank	Sep-94	*Crangon*	18	*Crangon*	9	X
Cod	Weisse Bank	Sep-94	*Corystes*	5	*Callianassa*	7	X
Whiting	Weisse Bank	Sep-94		0	*Callinassa, Chamelea*	24	
Dab	Dutch coast N	May-95	*Amphiura, Nephtys*	26	*Amphiura, Callianassa*	54	X
Grey gurnard	Dutch coast N	May-95	*Crangon*	8	*Crangon* ,empty	16	X
Dragonet	Dutch coast N	May-95	*Amphiura, Echinocardium*	45	*Amphiura, Tellina, Callinassa*	69	XX
Whiting	Dutch coast N	May-95	*Crangon*	10	*Crangon*	7	X
All fish	all sites			**653**		**878**	

TABLE 3.6.17.

Stomach contents of dab from a trawled area, N of Oyster grounds, 5-8 September 1994. Occurrence (% fish containing the prey item) and Dominance (% of prey item in the stomachs) before and after trawling.

Date & time : Time after trawling :	Density	Untrawled 6/9/22 To evening		Before 5/9/11 T - 10 morning		Trawling 5/9/21 T evening		After trawling 6/9/09 T + 12 morning		48 hrs later 7/9/21 T + 48 evening		60 hrs later 8/9/21 T + 60 morning	
	n per 100 m^2	Occ. %	Dom. %	Occ. %	Dom. %	Occ. %	Dom. %	Occ. %	Dom. %	Occ. %	Dom. %	Occ. %	Dom. %
Prey species													
MOLLUSCS													
Dosinia sp.	109					5	1	5	0	5	1	6	2
Chamelea	365					40	16	75	6	5	1	6	2
Phaxas	24					30	3	40	4				
Acanthocardia	<1					5	1						
Arctica	2					5	1						
Abra	6	5	3	6	2			5	0				
ECHINODERMS													
Echinocardium	56	5	1	6	2	15	3					6	2
Amphiura	2154	67	95	89	93	85	63	100	86	90	59	65	70
CRUSTACEANS													
Amphipoda	unknown	5	1	6	2	5	9			47	30	12	15
Callianassa	unknown	10	3			30	6	75	6	5	1	12	6
Natantia	43					5	1			16	3		
Liocarcinus	6											6	2
Corystes	64									5	1		
POLYCHAETES													
Nephtys	350					15	3			11	2		
Lanice	182					5	1						
FISH													
Pomatosch.	17					5	1			5	1		
EMPTY		5	0							5	0	18	0
Total number of dabs		21		18		20		20		19		17	
Total number of preys		77		45		106		251		110		47	
n species in stomach		5		4		13		6		9		7	
Stomach fullness													
in trawled area		**0.9**		**0.4**		**5.3**		**4.7**		**0.9**		**0.6**	
in reference area		0.8		0.4				0.6		1.0		0.8	

TABLE 3.6.18.
Average numbers of prey in stomachs of dab (*L. limanda*) during repeated trawling with 7m beam trawl on 22 September 1992, NW of Helgoland.

Haul nr	1	2	3	4	5	6	7
Time of day (hr)	9	10	11	12	13	14	15
Prey species							
Polychaetes							
- mobile	0.1	0.1	0.1	0.1	0.1	<0.1	0.1
- sessile	0.3	0.2	0.3	0.3	0.2	0.1	0
Bivalves	0.1	0.1	0.1	0.0	<0.1	<0.1	0.0
Decapods	0.2	0.3	0.4	0.6	0.7	0.6	0.8
Amphipods	7.3	3.6	8.5	5.6	5.7	2.9	0.9
Echinoderms	0.6	0.7	1.0	0.7	0.9	0.7	1.1
Others	2.2	<0.1	0.0	0.0	<0.1	0.0	0.0
Fish	0.0	<0.1	0.0	0.0	0.1	0.1	0.2

TABLE 3.6.19.
Average numbers of prey in stomachs of plaice (*P. platessa*) during repeated trawling with 7m beam trawl on 22 September 1992, NW of Helgoland.

Haul nr	1	2	3	4	5	6	7
Time of day (hr)	9	10	11	12	13	14	15
Prey species							
Polychaetes							
- mobile	0.8	0.6	0.9	1.5	0.8	0.8	1.6
- sessile	12.2	8.4	14.9	12.0	8.0	4.8	6.5
Bivalves	0.2	0.2	0.3	1.3	0.7	0.6	0.8
Decapods	0.1	0.1	<0.1	0.2	0.1	0.2	0.2
Amphipods	0.0	0.0	0.1	0.1	<0.1	0.1	0.0
Echinoderms	0.2	0.1	0.1	0.3	0.1	0.0	0.0
Others	0.0	0.0	0.0	0.0	0.1	0.0	<0.1
Fish	<0.1	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 3.6.20.

Stomach content composition of dab and grey gurnard in an area trawled with otter trawl on August 1995, Weisse Bank 40 m depth.

Fish	Small dab		Large dab		Grey gurnard	
Size, L cm	12-15 cm		19-25 cm			
Treatment	Control	Trawled	Control	Trawled	Control	Trawled
% in stomachs	%	%	%	%	%	%
Echinoderms	42	43	14	19		
Crustaceans	17	15	29	20	31	34
Molluscs	4	6	7	7	0	1
Polychaetes						
sessile	12	12	2	2		
mobile	9	12	3	7	10	8
others	5	2	2	3		
Hydrozoa	4	3	5	2		
Fish	7	7	38	40	59	57

TABLE 3.6.21.

Daily food consumption (F, g wet weight or afdw) in relation to bodyweight (W, g wet or g afdw) of hermit crab, swimming crab, dab and whiting at different constant temperatures.

Species	Temp. oC	Food type	F = a * W ^ b a	b	Correll. coeff. r2	n	Size W g	Season (m/yr)
			F & W in mg afdw				afdw, g	
Hermit crab	5	mussel	**0.0520**	**0.785**	0.994	6*	0.1-6.2	5/96
Pagurus bernhardus	5	fish	**0.0450**	**0.787**	0.98	6	,,	,,
,,	10	mussel	**0.3380**	**0.651**	0.978	6*	,,	6/96
,,	10	fish	**0.4480**	**0.579**	0.975	4	,,	,,
,,	15	mussel	**1.8450**	**0.607**	0.984	5*	,,	7/96
					(* = groups)			
			F & W in g wet				wet W,g	
Starfish	10	fish	**0.22**	**0.750**	p0.0001	26	0.9-52.8	Conwy
Asterias rubens	15	,,	**0.24**	**0.680**	0.003	27	0.6-22.6	,,
Hermit crab	10	fish	**0.09**	**0.780**	0.15	15	3.7-48.9	,,
Pagurus bernhardus	15	,,	**0.13**	**0.790**	0.0001	24	1.8-11.9	,,
Pagurus prideaux	10	,,	**0.78**	**0.270**	0.21	13	3.9-7.9	,,
	15	,,	**0.49**	**-0.06**	0.91	26	2.4-14.6	,,
Hermit crab *Pagurus bernhardus*	15	fish	**0.063**	**0.851**	0.85	24		NIOZ
Swimming crab *Liocarcinus holsatus*	15	fish	**0.097**	**0.761**	0.84	14		,,
Dab *Limanda limanda*	5	mussel	**0.051**	**0.879**	0.986	6	3-66	8/84
Whiting *Merlangius merlangus*	5	mussel	**0.036**	**0.701**	-	2	84-106	11-12/82
	10	,,	**0.246**	**0.586**	-	2	42-80	11/84
	15	,,	**0.187**	**0.676**	0.95	4	35-106	2-3/83

TABLE 3.6.22.

Estimates of the relationship between daily growth (G) and body weight (W) from laboratory measurements with starfish (1988/1990) and dab ('8-9/1984) fed with excess food at constant temperatures.

	Temp. oC	Growth in weight G = a * W ^ b		Correll. coeff.		Number animals	Size range	
		a	b	r2	n		L,cm	W, gwet
		G & W in mg afdw						
Starfish	6	**0.040**	**0.837**	0.95	8	74	4-12	1-42
Asterias rubens	10	**0.123**	**0.784**	0.97	12	77	4-13	1-67
,,	14	**0.177**	**0.790**	0.96	6	43	4-7	1-8
,,	18	**0.286**	**0.716**	0.89	5	20	5-8	3-9
		G & W in g wet						
Starfish	5 - 6	**0.013**	**0.764**	0.84	18	154	2-12	0.5-43
Asterias rubens	10	**0.027**	**0.764**	0.92	18	132	2-13	0.2-57
,,	14-15	**0.042**	**0.777**	0.96	16	133	2-16	0.2-77
,,	18	**0.033**	**0.972**	0.95	8	36	2-8	0.1-9
,,	20 - 22	**0.036**	**0.818**	0.88	7	47	2-7	0.1-7
Dab								
Limanda limanda	5	**0.016**	**0.796**	0.94	6	14	8-21	3-100

TABLE 3.6.23.

The effect of temperature on growth rates in length or diameter (mm per day) and in wet weight (%W,$g^{0.8}$) of scavenging invertebrates kept at constant temperatures and unlimited food.

Species	Temp.	Daily growth			Size range		Days	Period
	oC	Diam. or L mm/day	wet weight % met.W,g	n	D or L cm	wet W g		
Sea urchin								
Psamechinus miliaris	5	**0.02**	**0.19**	20	1.5-2.5	1-4	56	5/96
,,	10	**0.09**	**1.86**	10	1.5-2	1-2.5	,,	,,
,,	15	**0.12**	**2.42**	10	1.5-2	1.5-4	,,	,,
,,	20	**0.09**	**1.96**	10	1.5-2	1-3	,,	,,
Brittle star	5	**0.00**	**0.01**	7		6.59	56	5/96
Ophiura ophiura	15	**0.01**	**0.22**	6		5.34	,,	,,
Starfish	5	**0.22**	**1.59**	9	2-12	0.3-43	30-40	(88-90)
Asterias rubens	10	**0.39**	**2.83**	17	2-13	0.2-56	..	..
	15	**0.64**	**4.50**	12	2-9	0.2-17	..	..
	21	**0.48**	**3.93**	7	2-7	0.4-6	..	..
Sandstar	5	**< 0**	**0.82**	4		41.5	56	5/96
Astropecten irregularis	15	**0.08**	**0.73**	5		37.34	,,	,,
Hermit crab		Claw L,mm			(Claw,mm)			
Pagurus bernhardus	5	**0.02**	**0.72**	19	7-8	0.1-0.2	56	5/96
,,	10	**0.04**	**1.92**	19	7-9	0.1-0.2	,,	,,
,,	15	**0.05**	**2.36**	19	7-9	0.1-0.2	54	,,
,,	20	**0.07**	**1.80**	15	7-10	0.1-0.6	,,	,,
		CarapaxW			Carap.cm			
Shore crab	5	**0.00**	**0.00**	10	1.4	0.675	33	6/96
Carcinus maenas	10	**0.14**	**2.68**	8	1.4	0.693	,,	,,
,,	15	**0.29**	**5.87**	7	1.5	0.839	35	,,
,,	20	**0.41**	**9.45**	2	1.3	0.671	,,	,,
		CarapaxW			Carap.cm			
Swimming crab	10	**0.05**	**0.58**	10	2.4	3.02	30	8/96
Liocarcinus holsatus	15	**0.64**	**8.07**	10	2.9	4.86	22	,,
,,	20	**0.54**	**7.29**	6	2.6	3.63	20	,,
,,	25	**0.48**	**5.07**	4	2.4	2.88	19	8/96
		L, mm/d			L,cm			
Brown shrimp	5	**0.13**	**0.95**	24	1.9	0.247	33	6/96
Crangon crangon	10	**0.34**	**3.01**	25	2.2	0.363	,,	6/96
,,	15	**0.50**	**6.57**	30	2.4	0.588	35	6/96
,,	20	**0.67**	**7.35**	22	2.6	0.634	,,	6/96

TABLE 3.6.24.

The effect of temperature on daily food consumption and growth (both % metabolic wet weight) and growth rate in length (mm/day) of scavenging fish species at constant temperatures.

	Temp. oC	Daily food wet w % met.W,g	Daily growth Length mm/day		Daily growth wet weight % met.W,g	n	Size range L cm	Size range wet W g	Period
Dab *Limanda limanda*	5	6.9	0.18		1.35	30	7-19	2-63	6/90
	10	13.0	0.54		3.68	23	7-19	3-67	,,
	15	18.7	0.83		5.54	24	8-20	5-80	,,
	18	39.0	0.67	O	4.73	10	11	16	,,
	18	19.0	0.46	I	3.10	10	20	77	,,
Dragonet *Callionymus lyra*	5	-	0.05		0.28	3	11-12		,,
	10	-	0.41		2.68	13	9-15		,,
	15	-	0.62		3.90	11	10-14		,,
		%W^0.7			%W^0.7				
Whiting *Merlangius merlangus*	5	4.0	0.12		<0	6	22-26	83-145	2/83
	10	15.0	0.49		3.82	20	17-24	34-123	3/84
	15	15.0	0.77		4.65	16	15-26	29-165	11/82
Bib *Trisopterus luscus*	5	5.3	0.08		0.51	5	15-17	42-61	3/83
	15	13.0	0.47		4.65	3	14-15	32-40	11/82

TABLE 3.6.25.
The food conversion efficiency for starfish, hermit crab and dab fed with different rations of either mussel meat or fish. Daily food consumed and daily growth as % metabolic wet weight ($W, g^{0.8}$).

	Temp. oC	Food type	**G% = - a + c* F%** G & F in mg afdw **a**	**c**	Correl. coeff. r2	n	Range wet W g	Yr
Starfish	10	mussel	**-2.21**	**0.730**	0.999	4	3.2-6.7	1988
Asterias rubens	10	fish	**-2.03**	**0.637**	0.988	4	3.1-4.8	,,
,,	14	mussel	**-2.34**	**0.777**	0.999	4	2.8-7.2	,,
,,	14	fish	**-1.80**	**0.633**	0.987	4	2.3-3.9	,,
,,	15	mussel	**-3.14**	**0.758**	0.988	9	1.4-7.0	1994
,,	15	fish	**-3.06**	**0.636**	0.907	9	1.4-12.8	,,
Hermit crab	15	mussel	**-1.79**	**0.301**	0.936	14	0.6	1996
Pagurus bernhardus	15	fish	**-1.51**	**0.229**	0.823	13	0.6	,,
Dab *Limanda limanda*	5	mussel	**-0.251**	**0.446**	0.983	7	3-100	1984

TABLE 3.6.26.
Ash-free dry weight as % of wet weight of some common species of benthic invertebrates.

		% ashfree-dry weight Mean	st.dev.	Numbers n	animals	Range wet W,g	source	Period
ECHINODERMS								
Ophiura ophiura		**11.1**	3.45	8	33	0.4-7	North Sea	Apr.96
,,		**10.2**	0.82	9	57	0.04-7	,,	Oct.96
Ophiura albida		**7.5**	0.59	10	82	0.1-0.8	,,	,,
Astropecten irregularis		**8.4**	0.59	8	32	0.04-3	,,	Oct.96
,,		**12.7**	1.64	4	7	4.8-43	Laboratory	,,
Asterias rubens		**7.9**	0.67	10	72	3.5-71	Lab.-starved	88
,,		**10.6**	0.87	31	158	1.3-249	Lab.-wellfed	,,
,,		**8.6**	1.63	7	63	0.2-150	North Sea	Febr.91
,,		**11.3**	0.93	23	61	0.3-13	,,	Mrch.94
Luidia sarsi		**9.1**	1.71	18	31	1.8-75	,,	Apr.90
Echinocyamus pusillus		**6.7**		1	14	0.2	,,	,,?
Psamechinus miliaris		**4.6**	0.41	7	43	0.4-20	Laboratory	May-96
,,		**5.2**	0.97	13	66	0.4-20	North Sea	Apr. 96
Echinocardium cordatum		**2.7**	0.30	3	22	12-38	,,	Febr.96
,,		**3.0**	0.25	6	44	0.2-56	,,	Oct.96
Trackythyone elongata		**7.7**	0.30	6	30	1.7-3.5	,,	Apr.96
CRABS								
Pagurus bernhardus		**23.0**	1.32	5	61	0.1-0.5	Laboratory	Jul-96
,,		**24.7**	1.73	50	50	0.4-6	,,	,,
,,		**22.4**	1.42	44	122	0.04-61	North Sea	Mar-96
Liocarcinus holsatus		**16.5**	1.70	29	104	0.6-14	,,	Apr-96
Liocarcinus depurator		**18.6**	2.59	10	46	2.5-13	,,	,,
Liocarcinus marmoratus		**13.9**	1.36	3	22	0.3-0.6	,,	?
Thia polita		**15.3**	0.65	4	31	0.2-2	,,	?
SHRIMP								
Crangon crangon		**21.7**	1.43	8	34	2.5-7	,,	,,
,,		**20.1**	0.73	9	74	0.06-2	Wadden Sea	Aug.96
Crangon allmanni		**24.6**		2	50	0.45	North Sea	May-96
Processa sp.		**25.2**		1	10	0.2	,,	,,
Nephrops norvegicus		**9.6**	1.46	4	4	14-68	,,	Oct.96
POLYCHAETS								
Lagis koreni	+	**3.7**		1	10	0.6	,,	Apr.96
Nephthys sp.		**15.0**		1	6	0.9	,,	,,
MOLLUSCS								
Angulus tenuis	+	**19.4**		1	30	0.5	,,	May-96
Abra alba	+	**16.2**		1		0.2	,,	May-96
Phaxas pellucidus	+	**17.5**		1	15	0.9	,,	May-96
Ensis directus	+	**12.3**		1	20	10.2	,,	Apr.93
Ensis sp.	+	**10.4**		1	15	5.6	,,	May-96
Nucula nitidosa	+	**10.4**	0.10	3	23	0.3-0.4	,,	May-96
Corbula gibba	+	**11.0**	2.60	4	40	0.6-0.8	,,	May-96
Dosinia lupinus	+	**8.4**		1	4	0.9-8	,,	May-96
Chamaelea sp.	+	**7.2**	0.97	4	12	1.1-7	,,	May-96
Mactra corallina	+	**9.4**		1	3	5.3	,,	May-96
Spisula subtruncata	+	**9.7**		1	20	4.7	,,	Apr.93
Spisula subtruncata	+	**10.4**		1	15	5.6	,,	May-96
Turritella communis	+	**6.6**	0.2	4	22	0.5-2	,,	

(+ = % afdw from wet weight with shell or tube)

TABLE 3.6.27.
The relationship between size (length or diameter) and weight (W) of some common species of benthic scavengers. Size and weight in cm and g wet weight, or in mm and mg ash-free dry weight.

	wet W, g W = a * L ^ b a	L, cm b	Afdw, mg W = a * L ^ b a	L, mm b	Correl. coeff. r2	(*) n	Size L or D	Period	Source
ECHINODERMS	Disc diameter		Disc, mm						
Ophiura albida	**0.508**	**2.700**	**0.038**	**3.016**	0.985	12	3-12	10/1996	Oystergr.
Ophiura ophiura	**0.540**	**2.619**	**0.096**	**2.754**	0.997	24	5-27	10/1996	Oystergr.
	Total diameter		Diameter, mm						
Astropecten irregularis	**0.041**	**2.649**	**0.005**	**2.811**	0.994	16	10-59	10/1996	Oystergr.
,,	**0.055**	**2.637**			0.964	16	50-120		Laboratory
Asterias rubens	**0.025**	**2.980**	**0.003**	**3.000**	0.996	28	40-210	1988	Laboratory
,,	**0.037**	**2.855**	**0.006**	**2.772**	0.986	23	40-160	1990	Laboratory
Luidia sarsi	**0.022**	**2.590**	**0.001**	**2.988**	0.995	17	54-225	4/1990	Oystergr.
CRABS	Chela length, cm		Chela L, mm						
Pagurus bernhardus	**1.499**	**2.606**	**0.558**	**2.724**	0.979	48	3-44	3/1996	North Sea
,,	**1.197**	**2.641**	**0.725**	**2.601**	0.872	63	7-19	5-6/1996	Laboratory
	Chela height, cm								
Pagurus bernhardus	**5.886**	**2.415**			0.855	63		NIOZ	Laboratory
Pagurus bernhardus	**7.947**	**2.520**			0.960	95		CONWY	Irish Sea
Pagurus prideauxi	**9.034**	**2.200**			0.870	63		CONWY	Irish Sea
	Carapax width		Carapax, mm						
Liocarcinus holsatus	**0.296**	**2.769**	**0.203**	**2.504**	0.967	30	1.3-3.8	1996	Laboratory
Cancer pagurus	**0.139**	**3.030**			0.980	37	9-18	9/1996	North Sea
FISH	Total length								
Limanda limanda	**0.0074**	**3.089**			0.980	75	11-28	9/1993	North Sea
Eutrigla gurnardus	**0.0064**	**3.040**			0.960	49	10-42	,,	
Merlangius merlangus	**0.0056**	**3.108**			0.997	33	8-38	,,	
Gadus morhua	**0.0083**	**3.000**			0.997	21	9-27	1983	Laboratory
Trisopterus luscus	**0.0057**	**3.260**			0.995	17	6-25	,,	,,
Callionymus lyra	**0.0100**	**2.840**			0.999	9	11-22	8/1990	North Sea

TABLE 3.6.28.

Estimates of the total discard production for scavengers by 4m and 12m beam trawling for sole in the southern North Sea.

	4m Kg/ha	**12m** Kg/ha
In wet weight :		
Sole	1.1	1.9
Total market fish	4.1	5.2
Discard fish	8.3	9.8
Invertebrates	25.3	15.9
Dead invertebrates	3.1	2.2
In ash-free dry weight :		
Discard fish	1.4	1.7
Dead invertebr.	0.3	0.2
Total discard	1.7	1.9
In wet weight / kg sole :		
Discardfish	7.5	5.2
Dead invertebrates	2.8	1.2
In ash-free dry weight:		
Dead discard / kg sole	1.5	1.0

TABLE 3.6.29.

The amount of damaged fauna in gram afdw per 100 m^2 in beam trawl tracks, estimated for two locations in the southern North Sea.

	Weisse Bank May-95 **g afdw / 100 m2**	Dutch coast Sept.1995 **g afdw / 100 m2**
All bottomfauna	379	1007
Echinocardium	143	396
Damaged fauna		
Echinocardium	**77**	**79**
Molluscs	**17**	**29***
Crustaceans	**17***	**8**
Others	**5**	**2**
Total damaged	**116**	**118**
	*13 g Corystes	*21 g Ensis

TABLE 3.6.30.
Estimates of the maximum daily food consumption of some common scavengers in the southern North Sea at 15° C.

Period	Area (map 2.6.2)	Species	Density per 100 m^2	Biomass g wet W /100 m^2	**Daily food cons. g afdw per m^2** fish	mollusc	Sum g afdw m^2
Sept. 93	N of Oystergr.	Sandstar	21	90		**0.002**	
		Dab	3	150		**0.016**	} 0.034
		Whiting	1	37		**0.016**	
Jun-94	Dutch coast N	Starfish	63	4300	**0.02**	**(0.04)**	
		Dab	11	300		**0.04**	} 0.11
		Dragonet	2	40		**0.01**	
Jun-94	Dutch coast N	Starfish	338	2300	**0.11**	**(0.23)**	
		Dab	3	100		**0.01**	
		Plaice	1	90		**0.01**	} 0.14
		Dragonet	4	80		**0.01**	
Sept. 94	Weisse Bank	Swimming crab	89	940	**0.09**		
		Hermit crab	14	195		**0.02**	} 0.11
Sept. 94	Dutch coast S	Swimming crab	33	275	**0.03**		
		Hermit crab	2-3	15		**0.01**	} 0.04
Sept.95	Dutch coast S	Shrimp	1000	600		**0.08**	
		Dragonet	20	50		**0.01**	} 0.09

3.7. COMPARISON OF UNDISTURBED AND DISTURBED AREAS

Introduction

The three studies comparing undisturbed and disturbed areas to investigate the longer term effects of fishing disturbance, utilised two essentially different methodologies. While the Gareloch study exploited the unique opportunity offered by a previously unfished area to carry out a manipulative disturbance experiment, the West Gamma and Iron Man/41 Fathom Fast studies made use of areas of the seabed surrounding wrecks as protected areas, adapting the approach of Hall *et al.* 1993a. The West Gamma site was initially investigated during the IMPACT I study (Arntz *et al.* 1994; Schroeder 1995), and this work is also included below.

3.7.1. LOCH GARELOCH STUDY

Sediment Particle Size and Organic Carbon

Throughout each of the surveys, the sediment in both areas of the loch was very similar, being classified as poorly sorted fine silt (approx 95% silt & clay), with a mesokurtic (nearly normal) distribution (Folk 1974). Grab penetration into the sediment was high at all times and did not vary between sites on any survey ($P = 0.535$). Two-way ANOVA of median particle diameter identified a significant difference between sites ($P < 0.001$), but neither the date ($P = 0.089$) or interaction ($P = 0.402$) terms were significant. A significant interaction term implies that the trend over time differed between sites, and therefore suggests a treatment effect. The sediment in the treatment area was consistently finer (median diameter 109 µm) than that in the reference area (median diameter 119 µm), although the differences between sites in individual surveys were not always significant, and trawling disturbance did not appear to have any longer term effect. Median sediment diameter in each area for each survey is provided in Table 3.7.1.

Organic carbon varied significantly between treatment ($P < 0.001$) and date ($P < 0.0001$), but the interaction term was not significant ($P = 0.389$). Organic carbon levels varied between dates and were consistently higher in the treatment area than in the reference area, although not always significantly so. Mean% organic carbon in each area for each survey is provided in Table 3.7.1.

TABLE 3.7.1
Median diameter and mean organic carbon in each experimental area for each survey.

	Treatment area		Reference area	
	Median dia. (µm)	% C	Median dia. (µm)	% C
Nov 1993	110	4.82	123	4.24
May 1994	104	4.75	120	4.14
Oct 1994	114	4.96	123	4.11
May 1995	103	4.61	120	4.30
Oct 1995	104	4.43	119	3.88
May 1996	106	4.92	120	4.47
Oct 1996	103	4.96	121	4.61

Biological analysis - infauna

Box plots of number of species, number of individuals, biomass, two diversity measures and Pielou's evenness for the treatment and reference sites for each sampling occasion are shown in Fig. 3.7.1. (lower panels), along with the time-series for the median values for each survey (upper panels). Box-plots are arranged in pairs in time (survey) order, with the reference plot on the right for each pair.

It would appear that while changes over time occurred at both sites, the changes differed between sites for a number of these parameters. Two-way ANOVA of the number of species identified significant site and date effects ($P < 0.0001$), along with a significant interaction term ($P < 0.0001$).

The number of species became significantly different between sites after 16 months of disturbance (species numbers greater at treatment site), and remained so throughout the monitored recovery period (Fig. 3.7.1a). The numbers of individuals also showed significant site, date and interaction effects ($P < 0.0001$). The numbers of individuals were higher at the treatment site before the experiment (Fig. 3.7.1a), and although the numbers were not significantly different after 5 months disturbance, they became significantly different between sites after 10 months of disturbance (numbers greater at treatment site), only returning to similar levels after 18 months of recovery. The disturbance appeared to have no effect on infaunal biomass, since neither site, date or interaction terms were significant.

The measures of diversity and evenness also showed treatment effects. Two-way ANOVA of Shannon's exp *H'* identified significant effects for site and interaction ($P < 0.0001$), and date term ($P = 0.001$). Both Simpson's reciprocal *D* and Pielou's evenness measure showed similar changes in the community, with significant site, date ($P < 0.0001$ and interaction terms ($P < 0.001$). Each of the indices showed a similar temporal pattern between sites (Fig. 3.7.1b), showing significantly higher values for the reference site after only 5 months of disurbance, returning to similar levels between sites after 12 months of recovery. Since all three measures show a significant treatment effect, the trawling disturbance can be seen to have had an effect on both rare (measured by Shannon's exponential *H'*) and more abundant (measured by Simpson's reciprocal *D*) species in the community, along with the dominance structure (measured by Pielou's evenness). The changes shown in Fig. 3.7.1b indicate that when compared to the temporal changes at the reference area, the trawling disturbance reduced diversity and reduced evenness (increased dominance) at the treatment area.

Changes in the abundance (ln x+1 transformed) of the twenty commonest species in relation to site and date were examined using two-way ANOVA. The results of these analyses are summarised in Table 3.7.2.

The species which appear to be the best indicators of physical disturbance through increasing in abundance belong to the cirratulid (*Chaetozone setosa* & *Caulleriella zetlandica*) and capitellid (*Mediomastus fragilis*) families, which are generally considered to be resistant to disturbance and opportunistic in nature. These species are able to reproduce rapidly to increase population size when resources become available (if environmental conditions change and species less able to survive are killed, for example).

Table 3.7.2. Summary of two-way ANOVA of abundance in relation to site and date for twenty commonest infaunal species. P values are provided for site, date and interaction effects (n.s. - not significant at 5% level.). Densities provided are averages from all samples collected throughout the experiment. Where significant interactions were found, the change indicated represents change in abundance (relative to the reference site) associated with the disturbance of the treatment site (ie +ve - increase in abundance following disturbance, -ve - decrease in abundance following disturbance, ? - change variable and unclear). Those species showing consistent effects, and which may probably therefore be considered indicator species for physical disturbance in this habitat, have been highlighted in bold type.

Species	Density (.1 m^{-2})	Phylum	Site	Date	Interaction	Change
Chaetozone setosa	79.06	Polychaeta	<0.0001	<0.0001	<0.05	+ve
Mediomastus fragilis	68.24	Polychaeta	<0.0001	<0.0001	<0.05	+ve
Caulleriella zetlandica	47.54	Polychaeta	<0.0001	<0.0001	<0.0001	+ve
Pseudopolydora pauchibranchiata	39.45	Polychaeta	n.s.	<0.0001	<0.0001	+ve
Abra alba	34.62	Mollusca	n.s.	<0.0001	<0.05	?
Lagis koreni	23.11	Polychaeta	<0.0001	<0.0001	n.s.	
Melinna palmata	17.96	Polychaeta	n.s.	<0.0001	<0.001	+ve
Thyasira flexuosa	15.36	Mollusca	n.s.	<0.0001	n.s.	
Scalibregma inflatum	12.06	Polychaeta	n.s.	<0.0001	<0.05	?
Nucula nitidosa	11.66	Mollusca	<0.005	<0.001	<0.005	-ve
Scolopolos armiger	10.19	Polychaeta	<0.0001	<0.05	<0.01	-ve
Pholoe inornata	9.64	Polychaeta	n.s.	<0.0001	n.s.	
Nephtys cirrosa	9.42	Polychaeta	<0.0001	<0.0001	<0.001	-ve
Terebellides stroemi	9.07	Polychaeta	<0.01	<0.0001	<0.005	-ve
Nuculoma tenuis	6.45	Mollusca	<0.005	<0.0001	n.s.	
Corbula gibba	6.03	Mollusca	<0.0001	<0.0001	<0.001	-ve
Nemertea sp.	5.75	Nemertea	<0.0001	<0.0001	n.s.	
Aphelochaeta marioni	5.36	Polychaeta	n.s.	<0.0001	<0.05	?
Abra nitida	5.18	Mollusca	n.s.	<0.01	n.s.	
Goniada maculata	5.11	Polychaeta	<0.05	<0.001	<0.05	-ve

Box plots of abundance for selected species are shown in Fig. 3.7.2a & b. Species that increased in abundance relative to the reference area in response to the disturbance are shown in Fig. 3.7.2a. The cirratulids *C. setosa* and *C. zetlandica* show a similar pattern, with density becoming greater at the treatment site after 10 months disturbance. *C. setosa* appears to be a longer term indicator, however, since median density was still significantly higher at the treatment site following 18 months recovery (although the whiskers extend well below the box, indicating some samples with low density), while the density of *C. zetlandica* was not significantly different between sites by this time. *M. fragilis* showed a strong seasonal effect (densities greater in the autumn than in the spring) and was significantly more abundant at the treatment site throughout the disturbance period, with differences in densities becoming non-significant after 12 months recovery. The density of *Pseudopolydora pauchibranchiata* remained similar between the two sites until immediately after the end of the disturbance programme. After 6 months recovery the density at the treatment site had increased dramatically, remaining significantly greater than the density at the reference site until 18 months recovery. While the density of this species did not change relative to the reference area during the period of physical disturbance, it was able to rapidly take advantage of the disturbed habitat once the trawling had finished.

Species which reduced in density relative to the reference area are shown in Fig. 3.7.2b. The density of the nutshell, *Nucula nitidosa* reduced in the treatment area after only 5 months disturbance, and remained significantly lower than that in the reference area for the first 10 months of disturbance. The densities of both *Scolopolos armiger* and *Nepthys cirrosa* declined in the treatment area during the disturbance period, while at the same time increasing in the reference area. The density of *Terebellides stroemi* remained similar between areas throughout the disturbance period (although densities declined slightly in the treatment area), but increased relative to the reference area during the recovery period, becoming significantly greater after 18 months recovery. The slight decline with disturbance and gradual increase with recovery of this less resistant species contrasts with the rapid short term increase in numbers shown by the opportunistic spionid *P. pauchibranchiata* (Fig. 3.7.2a), after the disturbance period.

MDS plots of the reference and treatment areas are shown in Fig. 3.7.3. Software limitations mean that a maximum of 125 stations can be plotted on any one figure. The data are therefore shown on two plots, the first displaying the preliminary to 6 months recovery survey (Fig. 3.7.3a), and the second displaying the 16 months disturbance to the 18 months recovery survey (Fig. 3.7.3b). Stations which are more similar to one another in their infaunal community occur closer together on the figure, which shows that although the treatment and reference areas were not greatly separated in the preliminary survey, they became distinct once the experimental trawling commenced (Fig. 3.7.3a). During the recovery period the infaunal communities at the two sites remained distinct, although they appeared to be becoming more similar, particularly in the final survey (Fig. 3.7.3b). These subjective impressions were confirmed by an analysis of similarities (one-way ANOSIM test; Clarke & Green 1988) with adjusted probabilities for multiple comparisons, which showed that while the communities were not significantly different before the experiment started, both sites differed significantly over time and were significantly different after 5 months disturbance, remaining so throughout the experiment.

The SIMPER test (Clarke 1993) was used to identify which species contributed most to the similarity or dissimilarity between the two sites. In the preliminary survey the cirratulids *C. zetlandica* and *C. setosa*, the capitellid *M. fragilis*, the pectinariid *Lagis koreni* and the bivalve *Abra alba* were common at both sites and contributed most to the inter-site similarity. Although both sites showed seasonal fluctuations in the abundance of certain species, consistent patterns were evident, particularly while the disturbance was ongoing. During this time the main differences between the sites (contributing most to the dissimilarity) were the greater abundance of *M. fragilis, C. setosa* and *C. zetlandica* at the treatment site and greater abundance of *S. armiger*, *N. cirrosa* and *P. pauchibranchiata* at the reference site. During the recovery period the largest contribution to the dissimilarity arose from greater abundances of certain opportunist species at the treatment site, with *C. setosa* remaining important throughout the period, *P. pauchibranchiata* being important only during the 6 month recovery survey, and *C. zetlandica* and *M. fragilis* declining in importance as the recovery period progressed. This supports the results of the analysis of individual species abundances using two way ANOVA, finding the same species responsible for differences between the communities of the two areas between surveys.

ABC curves (Warwick 1986) are shown for the reference and treatment areas for selected surveys in Fig. 3.7.4. These figures plot cumulative dominance curves for abundance and biomass on the same graph, allowing comparison of the forms of these curves. In undisturbed communities the biomass curve would be expected to lie above the abundance curve throughout its length, with the reverse for grossly disturbed communities (Warwick 1986). In moderately disturbed areas the two curves are closely coincident and may cross each other one or more times.

It can be seen that prior to disturbance both sites were in a moderately disturbed condition. The SIMPER test found that in the preliminary survey, cirratulids and a capitellid (opportunistic species generally considered indicators of disturbance) contributed most to the inter-site similarity, thus also suggesting both sites may have been disturbed at this time. While the reference site had recovered 6 months later, the treatment site remained in a moderately disturbed condition throughout the period of experimental trawling (Fig. 3.7.4), only becoming undisturbed after 12 months recovery (plot not shown). Analysis of the W statistic (a measure of the difference between the two curves, standardised to a common scale; Clarke 1990) for each area and survey indicate that while the values of the statistic were not significantly different between sites in the preliminary survey, the W statistic was significantly greater at the reference site after 5 months disturbance (ie. the ABC curve for the treatment site was significantly more disturbed) and remained so until 18 months recovery (Fig. 3.7.5).

Biological analysis - epifauna

The densities of epifaunal organisms were calculated from video counts and known TV sledge tow distances. Unfortunately, underwater visibility was very poor (often <1 m) throughout the experimental period, and some of the video data could not be used. Our preliminary survey found the visibility to be very poor, and we therefore do not think it was associated with our experimental disturbance. Densities were very low and there was no interaction effect on number of species or total number of individuals. For the species commonly identified from the TV survey, two-way ANOVA were also carried out for individual species densities, and are summarised in Table 3.7.3. While most species showed no significant site:date interaction, and therefore no identifiable treatment effect, the brittle star *Ophiura* sp. appeared to increase with disturbance, while long rough dab *Hippoglossoides platessoides*, the large anemone *Metridium senile* and the whelk *Buccinum undatum* declined in density relative to the reference area. These effects were noted during the 16 months disturbance (for *Ophiura*, *Hippoglossoides* and *Metridium*) and 6 months recovery (*Buccinum*) surveys. Although the data showed the same trend, none of the effects were significant 6 months later. Lindley *et al.* (1995) suggested that fisheries may have contributed to an increase in echinoderm populations in the North Sea, and the changes noted in the density of *Ophiura* sp. may also support this theory. No effect was noted for *Asterias rubens* in the present study, however. It is unclear why the density of long rough dab decreased in association with disturbance, but the plumose anemone was probably damaged or killed by physical impact with the fishing gear, thus reducing its density in disturbed areas. The other common cnidarian found, *Virgularia mirabilis*, was not affected by the disturbance. However, this species is able to withdraw into the mud very rapidly, and would therefore avoid damage from a trawl. While *Buccinum undatum* appears quite robust, recent studies (section 3.5.4 have shown this species to be sensitive to discarding, and Cadée *et al.* (1995) suggested fishing disturbance may have influencial in the decline of whelk stocks in the coastal areas of the North Sea. Kaiser & Spencer (1994) found that benthic disturbance by fishing gear caused an increase in the density of epifaunal scavengers, in response to an increase in food availability in the form of damaged and disturbed organisms. Such responses to disturbance are generally short term in nature (Hall *et al.* 1994), however, and may be dependent on tidal conditions (Hall *et al.* 1996). The effects on epifauna appear to have been quite short lived, the densities being indistinguishable 6 months after they were noted, but the epifaunal species assemblage appears to be quite poor in Loch Gareloch, with no fragile sponges or corals, which might be more susceptible to such damage.

TABLE 3.7.3

Summary of two-way ANOVA of density from TV survey in relation to site and date for commonest epifaunal species. P values are provided for site, date and interaction effects (n.s. - not significant at 5% level.). Densities provided are averages from surveys collected throughout the experiment. For further details see Table 3.7.2.

Species	Density (.m^{-2})	Phylum	Site	Date	Interaction	Change
Asterias rubens	0.071	Echinodermata	n.s.	<0.05	n.s.	
Virgularia mirabilis	0.054	Cnidaria	<0.05	<0.01	n.s.	
Hippoglossoides platessoides	0.020	Pisces	n.s.	<0.01	<0.01	-ve
Liocarcinus depurator	0.014	Crustacea	n.s.	n.s.	n.s.	
***Ophiura* sp.**	0.013	Echinodermata	<0.01	<0.001	<0.01	+ve
Metridium senile	0.009	Cnidaria	<0.001	<0.001	<0.001	-ve
Pagurus bernhardus	0.009	Crustacea	n.s.	n.s.	n.s.	
Buccinum undatum	0.007	Mollusca	<0.01	<0.05	<0.05	-ve
Other fish	0.007	Pisces	n.s.	<0.01	n.s.	

3.7.2. WEST GAMMA STUDY

Sediment Characteristics

The sediment of the area shows a gradient from well sorted very fine silty sands in the SW to poorly sorted medium to coarse sands in the NE (Table 3.7.4; Fig. 2.4.4).

TABLE 3.7.4
Sediment distribution in the West-Gamma-Area.

Area	medium grain size	% silt & clay	Sorting
S/W	<85 µ	> 20%	well sorted
middle area (incl. wreck)	85 - 125 µ	10 - 20%	moderately to poorly sorted
N/E	>125 µ, some 500-1000 µ	< 10%	poorly sorted

There were no detectable differences in the median particle size between the areas inside and outside the buoys, and the organic carbon content was only dependent on the silt content of the sediment. However, on all cruises the penetration of the grab in the area surrounding of the wreck was generally higher than outside the buoys. In 1992 and 1994 this difference was clearly visible (Fig. 3.7.6a & b) being more significant in the later year. In 1995 the area of higher penetration was restricted to the closer vicinity of the wreck (< 50 m). Samples from somewhat further away from the wreck but inside the former position of the buoys showed the highest variation in penetration depth but the same median as the samples from "outside" (Fig. 3.7.6c). This difference was also noted during the initial processing of the samples during cruises, as the sediment in grabs from "outside" appeared to be much more compact and solid than the sediment in grabs taken closer to the wreck (personal observations on cruises in 1995 and 1996).

The differences in penetration depth of the grab and the more compact sediment on the "outside" stations may reflect some physical effects of bottom fishery. The natural sediment is structured by the influence of infaunal organisms (Buchanan 1984), that not only mix the upper layers, but also construct tubes and hollows that reduce the compactness of the sediment. This improves the oxygen supply in the lower layers and thus allows more organisms to find adequate living conditions and protection from epibenthic predators. Frequent disturbance of these biogenic structures by heavy bottom fishing gear rearranges the upper sediment layers (Becker 1990, BEON 1991) and thus makes them more compact. This also indirectly affects the infaunal community by reducing the available living areas.

Benthic infauna

The results of this study confirm that the macrozoobenthos around the West-Gamma-wreck belongs to the *Amphiura-filiformis*-association (*sensu* Salzwedel *et al.* 1985) with a tendency to the *Tellina-fabula*-association in the eastern parts of the area. An analysis of samples from one station showed that 2 grabs are sufficient to catch about 64% of the species caught with 10 grabs (Schroeder 1995). 2 grabs also proved to be adequate to reduce the variation between single grabs as far as to make the formation of meaningful groups by Cluster analysis and MDS plots possible. Therefore in all subsequent analyses 2 grabs were combined to form 1 sample.

Development from 1992 to 1995

Large differences in species composition and abundances were found between the samples taken in April and August 1994, representing considerable seasonal effects. In April an average of 1250 individuals.m^{-2} were found belonging to a total of 92 species. In August an average of 9500 individuals.m^{-2} and a total of 125 species were found with a few dominating species which consisted mainly of juvenile specimens.

Apart from these seasonal differences, some clear changes of the faunal community become obvious from 1992 to 1995 from comparison of the autumn samples from each year. There was a significant increase in the number of species from 1992 to 1995. However, as this increase was shown in both the protected and fished areas, this reflects a general trend, which was also found in other studies (see section 3.8). It is interesting to note the relatively high number of species in April 1994 in the protected area, approaching the values for the August samples, while the number of species in the surrounding area were much lower. This may indicate more stable conditions in the protected area. There was also a significant increase in the number of organisms from 1992 to 1994, while the values for 1994 and 1995 were similar. The extremely high values for 1994 and 1995 were mostly due to high densities of *Phoronis* spp., small polychaetes (*Owenia fusiformis)* and juvenile bivalves and echinoderms.

Subsequently the diversity and evenness reduced significantly between 1992 and 1994. Since the number of species increased between 1994 and 1995, while the number of individuals remained constant, the diversity and evenness in 1995 were much higher again. This drop in diversity caused by the mass occurrence of juvenile specimen indicates some kind of disturbance of the whole area prior to August 1994. This could possibly be due to catastrophic events such as an oxygen deficiency, which have been previously recorded in this part of the German Bight, causing mass occurrences of opportunistic species (Niermann *et al.* 1990; Ziegelmeier 1970). However these general trends were the same for the protected area and the surroundings and thus allow no statements about a differing development of the protected area.

Biomass values vary considerably between samples due to the patchy distribution of larger organisms and a general trend in the development of the overall biomass between 1994 and 1995 could not be identified. (In 1992 no biomass data were recorded).

Analysis of separate cruises

Temporal variability in benthic communities between cruises meant that a combined analysis of all cruises only served to separate the data by date. In order to better separate the samples within these groups, the subsequent analysis was carried out for each separate cruise.

Cluster analysis (using group average and complete linkage) generally showed similar groups to those shown on the following MDS plots. However, because of the small distances between the groups, samples were sometimes included in the neighbouring group. We therefore regard the MDS plots as a better mean to show coherent groups of relatively small differences. Thus in the following only the MDS plots are presented.

1992

In August 1992 only one station from the "outside" area was sampled. On the MDS plot (Fig. 3.7.8a) it is positioned at the right edge of the group of stations, but not far enough away to indicate stronger differences than those between the other samples. Otherwise no meaningful groups are discernible. A comparison of the characteristics of this station showed that the number of species and individuals, and measures of diversity and evenness were below the median of the other stations, but well within the normal variation.

In September 1992 two groups were separable (Fig. 3.7.8b). On the left the stations lie inside the buoys, while the stations on the right lie outside. The number of species appeared to be generally higher "inside" (Fig. 3.7.7a), while there was no difference in the number of organisms between areas (Fig. 3.7.7b).

Subsequently the diversity was higher "inside" (Fig. 3.7.7c), while the evenness was only slightly higher (Fig. 3.7.7d). However these differences were not big and consistent enough to be statistically significant.

Several species showed differences in abundance between the area inside the buoys and the surrounding area (Table 3.7.5).

TABLE 3.7.5

September 1992. Species with differences in abundance between in- and outside the wreck area, * = statistically significant; ^ = only found here; () = slightly more abundant.

More abundant inside	More abundant outside	Phylum
(Amphiura filiformis)	*Ophiura* spp. juv.	Echinodermata
Trachythyone elongata^		Echinodermata
Leptosynapta inhaerens		Echinodermata
*Phaxas pellucidus**	*Thyasira flexuosa**	Mollusca
(Mysella bidentata)		Mollusca
*Chamelea gallina**		Mollusca
(Cylichna cylindracea)		Mollusca
Upogebia sp. juv.*	*(Amphipoda)*	Crustacea
	(Ampelisca spp.*)*	Crustacea
	Harpinia spp. *	Crustacea
Lanice conchilega^	*Ophelina accuminata*	Polychaeta
Pectinaria spp.*	*(Spiophanes bombyx)*	Polychaeta
Enipo kinbergi^		Polychaeta
Nemertini spp.		Nemertini

In 1992 no biomass data were recorded.

1994

Cluster analysis and MDS-plots showed clearly distinguishable groups in both months. They corresponded to the position of the sample inside or outside the enclosed area and to the sediment characteristics (Fig. 3.7.9a & b). In April the samples from "inside" had significantly higher species number, and higher abundance and diversity than those from "outside", while the values for evenness were about the same between areas (Fig. 3.7.7). In August the high number of juvenile specimens, whose distribution was strongly related to sediment characteristics, blurred the picture and prevented similarly clear results. Thus no remarkable differences in the station characteristics between in- and outside could be found (Fig. 3.7.7). This high potential for recolonization by juveniles reduced differences in the distribution of many species each year. The higher densities of several mollusc and other species "outside" were mostly present as juvenile individuals (*Spisula subtruncata*, *Ophiura* spp. juv.) which suggests a higher recruitment in this area. The disturbed community in this area with lower densities of adult organisms may facilitate the settlement of juveniles.

Nevertheless some species were obviously more numerous either inside or outside of the enclosed area in both months (Table 3.7.6).

In April a significantly higher biomass of all groups was found "inside" (Fig. 3.7.7e). The heart urchin, *Echinocardium cordatum,* showed a high variation in biomass between stations and was excluded from the echinoderm group in the above analysis. In August only the mollusc group showed a higher biomass "inside", although the difference was not significant, and the other groups showed no discernible trend (Fig. 3.7.7e).The high variation resulting from a patchy distribution of *Echinocardium cordatum* is likely to be the cause for the contradictory results for this species in the different sampling periods, although this species is known to be susceptible to destruction by trawling (van Santbrink & Bergman 1994; Bergman & van Santbrink 1994a).

TABLE 3.7.6

April and August 1994. Species with differences in abundance between in- and outside the wreck area, names printed bold indicate a similar distribution in 9´92, 4´94 and 8´94. Phylum abbreviations: E = Echinodermata; M = Mollusca; C = Crustacea; P = Polychaeta; Further details as for Table 3.7.5. ➔Indicates contrasting distribution in April and August.

More abundant inside	April	August	More abundant outside	April	August	Phylum
Amphiura filiformis	*	()	***Ophiura* spp. juv.**	o		E
Trachythyone elongata		()				E
Echinocardium cordatum	()	➔	*Echinocardium cordatum*		*	E
Abra nitida	o	()	***Spisula subtruncata***	o	()	M
Mysella bidentata	()					M
Thyasira flexuosa	()	*				M
Chamelea gallina		*				M
Cylichna cylindracea	()	*				M
Callianassa subterranea	*	o	**(Amphipoda)**			C
Pseudione borealis	()	o	***Ampelisca* spp.**	()	*	C
			Harpinia crenulata		()	C
Exogone hebes	*	*	***Spiophanes bombyx***		*	P
Lanice conchilega	*	➔	*Lanice conchilega*		()	P
Magellona spp.	*	()				P
Enipo kinbergi	o	o				P
Nemertini spp.	*	*				

Several of those species found consistently in higher densities in the protected area may be regarded as sensitive to bottom trawling effects. It is well known that beam trawl fishery, especially if equipped with numerous tickler chains, severely damages many delicate infaunal and epifaunal species (Fonds 1994). Species may be vulnerable to damage either because they are fragile and thus are easily hurt by the tickler-chains (*Amphiura filiformis, Callianassa subterranea,* Nemertini spp., *Trachythyone elongata*) or because they are dug out of the sediment and thus are exposed to predators (*Thyasira flexuosa, Cylichna cylindracea, Mysella bidentata*).The results of this study from September 1992 and April and August 1994 show clear differences in the macrozoobenthic community of the area enclosed by the buoys and the surrounding. The fact that these differences were more pronounced in 1994 shows a differing development of the fauna in the protected area.

1995

In 1994 the buoys marking the wreck were removed, and by the 1995 cruise much of the previously "inside" area had been open to fishing for a year. Only the area in close proximity to the wreck was protected from fishing by this time.

In 1995 the samples from the former "inside" were no longer discernible from the other stations on the MDS plot. Only those stations that are closest to the wreck form a group, while the rest of the "inside" stations are mixed with the stations from "outside" (Fig. 3.7.10). The number of species was somewhat lower around the wreck, although there was no difference in the number of individuals. However, as the numbers of *Phoronis* spp. in some of the "outside" samples were extremely high, the abundance values mostly reflect the distribution of *Phoronis* spp. The abundance of *Phoronis* spp. was significantly lower near the wreck than "outside", with intermediate values at the "inside" stations. Subsequently the diversity and the evenness tended to be higher near the wreck, while none of these differences was big enough to be significant (Fig. 3.7.7).

The biomass of the stations close to the wreck were higher than those of the other stations. This was mostly due to the significantly higher biomass of the polychaetes and to some extent non significant differences in the crustaceans. This trend is also visible in the distribution of several species whose abundance was much higher near the wreck than "outside", with intermediate numbers at the stations previously "inside" (Table 3.7.7).

TABLE 3.7.7
August 1995. Species with differences in abundance between the close vicinity of the wreck and the surrounding, names printed bold indicate a similar distribution in the other sampling periods. Further details as for Table 3.7.5.

More abundant near the wreck	More abundant outside	Phylum
Amphiura filiformis	***Ophiura* spp. juv.**	Echinodermata
(Asterias rubens)		Echinodermata
*Echinocardium cordatum**		Echinodermata
(Leptosynapta inhaerens)		Echinodermata
(Tellimya ferruginosa)	*Nucula* spp.*	Mollusca
Mysella bidentata	*Spisula subtruncata* (juv.)*	Mollusca
Thyasira flexuosa* juv.	*Lunatia nitida**	Mollusca
*Cingula vitrea**		Mollusca
Liocarcinus holsatus juv.*	**Amphipoda**	Crustacea
Callianassa subterranea*		Crustacea
***Upogebia* spp.^**		Crustacea
Pectinaria* spp.	*Ophelina accuminata*	Polychaeta
Enipo kinbergi*	***Spiophanes bombyx****	Polychaeta
	*Spio filicornis^*	Polychaeta
	Phoronis spp. *	Tentaculata
Anthozoa spp.*		Cnidaria
Nemertini spp.		Nemertini

The data suggest that the area that was formerly enclosed by the buoys may have been in a transitory state in 1995, probably being influenced by fishery again. Only the area directly adjacent to the wreck, which would still have been unaffected by trawling, showed clear differences from the "outside" area. However, in samples taken close to the wreck it becomes difficult to separate the changes caused by the absence of disturbance by fishing gear from those caused by the direct influence of the wreck.

The wreck acts as an artificial reef and thus causes an aggregation of fishes (Davis *et al.* 1982; Russel 1975) It also increases the input of organic material to the surrounding sediment community due to dead or alive organisms falling from the wreck as well as faeces of those organisms living on the wreck. This produces an increase in density of many organisms feeding on this organic material such as starfishes and many polychaetes (Davis *et al.* 1982; Wolfson *et al.* 1979). Such increases can be observed in the samples from 1995 that are closest to the wreck, which show a significant increase in polychaete and crustacean biomass. It may also affect the densities of several species that were found to be more abundant near the wreck and may be the cause of the higher densities of Anthozoans and predatory and scavenging species like *Asterias rubens* and *Liocarcinus holsatus* that were not found to be more abundant "inside" in 1992 or 1994. The abundance of some species may also be reduced in the vicinity of the wreck due to increased predation by fish aggregations and starfish (Davis *et al.* 1982). This may explain the lower numbers of juvenile molluscs (*Nucula nitidosa, Spisula subtruncata, Lunatia nitida*), ophiuroids, small tube building worms (*Phoronis* spp., *Spiophanes bombyx, Spio filicornis*) and of amphipods around the wreck (Table 3.7.6). These effects are limited to the direct surroundings of the wreck up to 20 to 100 m distance (Davis *et al.* 1982) and thus should not affect the samples from 1992 and 1994 which were taken further away than this.

Despite this complication, species found to be more abundant “inside” in 1992 and 1994 were found in higher densities near the wreck in 1995, indicating that the protection of this area from bottom fishery is still one factor influencing the benthic faunal composition.

Comparison of the separate results

Several species showed a similar distribution in a number of the sampling periods. In particular, the investigations from September 1992, April and August 1994 provide useful results. The results from August 1995 must be looked at more critically, as in 1995 only the stations from the close vicinity of the wreck could be separated from the rest. These samples, however, may be directly influenced by the presence of the wreck and its epifauna in several ways. The following species show consistent differences between the protected area and the surrounding and might be proposed as indicators for disturbances by bottom trawling (Tab. 3.7.8):

TABLE 3.7.8
Species showing consistent differences in abundance between the protected area and the surrounding.

More abundant in protected areas	More abundant in disturbed areas	Phylum
Amphiura filiformis	juvenile ophiuroids	Echinodermata
Thrachythyone elongata		Echinodermata
Leptosynapta inhaerens		Echinodermata
Echinocardium cordatum		Echinodermata
Tellimya ferruginosa	*juvenile bivalves*	Mollusca
Mysella bidentata		Mollusca
Thyasira flexuosa		Mollusca
Cylichna cylindracea		Mollusca
Cingula vitrea		Mollusca
Callianassa subterranea	Amphipoda	Crustacea
Upogebia spp.		Crustacea
Pectinaria spp.	*Ophelina accuminata*	Polychaeta
Enipo kinbergi	*Spiophanes bombyx*	Polychaeta
	Spio filicornis	Polychaeta
	Phoronis spp.	Tentaculata
Anthozoa spp.		Cnidaria
Nemertini spp.		Nemertini

Benthic epifauna: Dredge samples

The dredge samples from 1992 indicated “inside” a somewhat higher abundance of the starfish *Asterias rubens* and *Astropecten irregularis* and the molluscs *Buccinum undatum* and *Corbula gibba*. However the abundance of the ophiuroids *Ophiura albida* and *O. ophiura* seemed to be lower than “outside”. In 1994 the dredge samples indicated a higher abundance of a few epibenthic species "inside" (the gastropod *Buccinum undatum,* the crustaceans *Ebalia cranchii*, *Pagurus bernhardus* and *Pandalus montagui* and the ophiuroids *Ophiura albida* and *O. ophiura*). These data can not be analysed quantitatively as it is impossible to exactly determine the sampling area for several reasons (Holme & McIntyre 1984). However because of the larger sampling area it is possible to make qualitative statements about the larger, more widely dispersed and the more mobile species. Most species that were more abundant in the dredge samples from “inside” were mobile epibenthic predators (*Asterias rubens, Buccinum undatum, Pagurus berhardus, Ophiura* spp.), that are not greatly affected by trawling (Fonds 1994). The distribution of these species is often related to the availability of food and they are generally more abundant in recently trawled areas (van Santbrink & Bergman 1994; Kaiser & Spencer 1994). The distibution of these species in this study contradicts these previous studies however, as density was higher in the unfished area. The only explanation for this fact is the higher biomass and abundance of food species in the protected area that also means more prey for epibenthic predators. The higher density of these species in recently trawled areas is a rather short term and localised phenomenon. Under undisturbed conditions the abundance of epibenthic predators should be limited by prey availability and thus should be the highest in those areas with the highest density of prey organisms.

3.7.3. IRON MAN/41 FATHOM FAST STUDIES

Sediment Particle Size and Organic Carbon

The study from both the shallow (35 m) and deep (75 m) sites showed no particularly clear change in sediment as one moves from the vicinity of either wreck along the transects into the prawn grounds. The sediment at both sites was a poorly sorted silt. Grab penetration was always high with full grabs on all occasions. Organic carbon varied between sites but showed no obvious pattern.

Benthic infauna

Iron Man wreck and Impact II Inshore station

The study from the shallow (35 m) site showed no particularly clear change in fauna as one moves from the vicinity of the Iron Man wreck along transects into the prawn grounds. Table 3.7.9 shows the community parameters (number of species, number of individuals, biomass, species richness, Shannon's diversity, and Pielou's evenness) from three positions along a transect from the wreck (Near 125 m, Middle 260 m, Far 400 m) and from the nearby fished grounds before and after experimental trawling. With the exception of biomass, which showed a decrease as one moved away from the wreck, there was no significant difference between the Near, Middle and Far sites along the transect. However, the number of individuals and biomass showed a significant decrease between the wreck sites and the fished ground, prior to experimental trawling. Within the fishing grounds, 24 hours after experimental trawling, there was a significant decrease in number of species, biomass, species richness, and Shannon's diversity.

TABLE 3.7.9

Mean community parameters measured at three locations (Near, Middle, Far) along transects sampled in the vicinity of the Iron Man wreck and from nearby *Nephrops* trawling grounds before (Control) and 24 hours after (Impact) experimental trawling.

Inshore *Nephrops* Fishing Grounds					
	Fishing Grounds		Iron Man wreck		
Parameter	Control	Impact	Near	Middle	Far
Total Species	113	72	96	100	96
Total Individuals	1551	1578	3009	2572	3413
Biomass (g/m^2)	61	36	119	243	66
Species Richness	10.6	6.68	8.22	8.74	7.84
Shannon's Diversity	5.09	4.53	4.75	4.97	4.59
Evenness	0.746	0.735	0.721	0.748	0.702

Table 3.7.10 lists the species which were more abundant at the wreck site and those more abundant in the inshore fishing grounds. Fifty eight (58) of the species found at the wreck site were not found at the inshore site. These included Phyllodocidae and Ampharetidae, as well as a number of bivalves and echinoderms. By comparison, 18 species were found at the inshore site, which were not found at the wreck site. These were predominantly polychaetes, including *Glycera rouxi* (a large predator) and *Mediomastus fragilis* (typical of enriched/disturbed muds). In addition, large specimens of some molluscs (*Turritella communis, Dosinia lupinus, Azorinus chamasolen*) and echinoderms (*Amphiura chiajei, Brissopsis lyrifera, Echinocardium cordatum*) were quite common along the transects. While large specimens of these molluscs and of *Amphiura chiajei* were also found at the inshore station in small numbers, the spatangid echinoids *Brissopsis lyrifera* and *Echinocardium cordatum* were never found.

TABLE 3.7.10

List of species occurring at the Iron Man wreck or the inshore fishing grounds at a density of ≥10 individuals per m^2. Species with differences in abundance between the two locations, *=statistically significant; ^=only found here; ()=slightly more abundant.

More abundant near wreck	More abundant in fished ground
Annelida	
Chaetozone setosa	*Levinsenia gracilis**
Cirratulus spp.	*Nephtys incisa**
*Diplocirrus glaucus**	*Abyssoninoe hibernica*
Ophiodromus flexuosus	*Exogone hebes*
Nephtys hombergii	Oligochaeta
(Nephtys kersivalensis)	*Magelona minuta*
Glycera alba	*Synelmis klatti*
*Prionospio fallax**	*Glycera rouxi^*
Spiophanes kroyeri	*Laonice cirrata*
*Minuspio cirrifera^*	*(Scolelepis tridentata)*
(Glycinde nordmanni)	*Notomastus latericeus**
*Antinoella sarsi**	
*Ampharete falcata^*	
*Amphictene auricoma**	
Myriochele spp.*	
(Praxillella cf. affinis)	
Crustacea	
Harpinia antennaria	(Amphipoda)
(Harpinia crenulata)	*Harpinia pectinata*
(Ampelisca tenuicornis)	*(Protomedia fasciata)*
*Eudorella truncatula**	
Tanaidae*	
Isopoda*	
(Ostracoda)	
Copepoda*	
*Abludomelito obtusata**	
Echinodermata	
Amphiura spp.*	
Mollusca	
Abra spp.	*(Nuculoma tenuis)*
Thyasira flexuosa	
Corbula gibba	
Cylichna cylindracea	
*Dosinia lupinus**	
*Turitella communis**	
*Tellimya ferruginosa^*	

MDS plots of the fauna from the wreck and inshore station areas are shown in Fig. 3.7.11. It is clear that stations from along the wreck transects (Near, Middle, Far) showed no clear pattern with distance from the wreck (Fig. 3.7.11a). This lack of change along the transects may be due to not extending them far enough. It is possible that in this shallow, dawn and dusk fishery, boats do not risk trawling within 400 m of the wreck. However, there was a clear separation (with the exception of station C14) between these wreck stations and those from the inshore station prior to experimental trawling. Both sets of stations did, however, show a widely scattered distribution (Fig. 3.7.11b). The separation was much more clearly shown when one compares the wreck sites with the samples from the inshore station 24 hours following experimental trawling (Fig. 3.7.11c).

41 Fathom Fast wreck and Impact II Offshore station

The study from the deeper (75 m) site showed some indication of change in fauna as one moves from the vicinity of the 41 Fathom Fast wreck along transects into the prawn grounds. Table 3.7.9 shows the community parameters (number of species, number of individuals, biomass, species richness, Shannon's diversity, and Pielou's evenness) from three positions along a transect from the wreck (Near 50 m, Middle 250 m, Far 500 m) and from the nearby fished grounds before and after experimental trawling. Number of species, number of individuals and biomass, all showed a decrease as one moved away from the wreck, along the transect from Near to Far sites. All of the parameters measured showed a significant decrease between the wreck sites and the fished ground, prior to experimental trawling. Within the fishing grounds, 24 hours after experimental trawling, there was further decrease in most of these parameters (Table 3.7.11).

TABLE 3.7.11

Mean community parameters measured at three locations (Near, Middle, Far) along transects sampled in the vicinity of the 41 Fathom Fast wreck and from nearby *Nephrops* trawling grounds before (Control) and 24 hours after (Impact) experimental trawling.

Offshore *Nephrops* Fishing Grounds					
	Fishing Grounds		41 Fathom Fast wreck		
Parameter	Control	Impact	Near	Middle	Far
Total Species	50	37	71	71	62
Total Individuals	687	513	3463	2847	2850
Biomass	21	19	40	189	30
Species Richness	5.2	4	5.95	6.1	5.32
Shannon's Diversity	3.62	3.88	4.5	4.31	4.31
Evenness	0.642	0.745	0.732	0.701	0.724

Table 3.7.12 lists the species which were more abundant at the 41 Fathom Fast wreck and those more abundant in the offshore fishing grounds. Sixty nine (69) of the species found at the wreck site were not found at the offshore site. These included polychaetes, crustaceans, bivalves, gastropods and echinoderms. In particular, large specimens of some molluscs (*Phaxas pellucidus, Cylichna cylindracea*) and echinoderms (*Amphiura chiajei, Brissopsis lyrifera, Echinocardium cordatum*) were quite common along the transects. By contrast, while juveniles of some of these species were very rarely taken at the offshore trawling station, large specimens were never found. By comparison, only 5 species (all small sized polychaetes) were found exclusively at the offshore site, but not near the wreck.

MDS plots of the fauna from the wreck and offshore station areas are shown in Fig. 3.7.12. It was clear that stations from along the wreck transects (Near, Middle, Far) showed no pattern with distance from the wreck (Fig. 3.7.12a). However, there is a very clear separation between these wreck stations and those from the offshore station prior to experimental trawling (Fig. 3.7.12b). The separation is even clearer when one compares the wreck sites with the samples from this offshore station 24 hours following experimental trawling (Fig. 3.7.12c).

ABC curves (Warwick 1986) are shown for the Near, Middle and Far stations along the transects from the wreck to fished grounds (Fig. 3.7.13).

The station closest to the wreck (Near) showed an undisturbed pattern with the biomass curve above the abundance curve (Fig. 3.7.13a). The middle station showed an even clearer undisturbed pattern (3.7.13b). This result is somewhat influenced by the presence of a single large echinoid (*Brissopsis lyrifera*), which accounted for 25% of the total biomass at this location. The station furthest from the wreck (Far) showed some indication of disturbance, with the two curves lying close together throughout their length and the abundance curve crossing over the biomass curve at one point (3.7.13c).

TABLE 3.7.12

List of species occurring at the 41 Fathom Fast wreck and the offshore fishing grounds at a density of ≥10 individuals per m^2. Species with differences in abundance between the two locations, *=statistically significant; ^=only found here; ()=slightly more abundant.

More abundant at wreck	More abundant in fished ground
Annelida	
*Diplocirrus glaucus**	*Abyssoninoe hibernica*
Terebellides stroemi^	*(Prionospio fallax)*
(Levinsenia gracilis)	*Nephtys incisa**
*Chaetozone setosa**	*Laonice cirrata*
Monticellina dorsobranchialis^	*Glycera rouxi*
*Capitomastus minimus**	
Notomastus latericeus	
Nereis longissima^	
Ampharete falcata^	
Praxillella cf. *affinis*^	
Gyptis propinquua^	
Eulalia bilineata^	
*Scolelepis tridentata**	
Spiophanes kroyeri	
Glycera lapidum^	
Oligochaeta*	
Crustacea	
Ampelisca brevicornis	
Ampelisca macrocephala	
*Harpinia antennaria**	
Harpinia pectinata	
Harpinia laevis	
Harpinia crenulata	
Harpinia spp.^	
Eudorella truncatula^	
(Copepoda)	
Tanaidae*	
Pseudorachna hirsuta^	
Diastylis lucifera^	
Protomedia fasciata^	
Echinodermata	
Amphiura spp.^	
Mollusca	
Cylichna cylindracea^	
Abra spp.*	
*Nucula tenuis**	
Thyasira flexuosa^	
Corbula gibba^	
Mysella bidentata^	

The results of this study allow observations to be made on both the short term (24 hours after experimentral trawling) and apparent long term impacts of *Nephrops* trawling on the benthos of the North Western Irish Sea. The fauna at the inshore trawling grounds showed some indication of disturbance, (e.g. the disappearance of *Brissopsis lyrifera* and the reduced number of individuals and mean infaunal biomass) when compared with the 'unfished' wreck site, but with a benthic infauna almost as diverse as that found at the wreck site. However, the trawling grounds still contained some large molluscs, and the number of species and Shannon's diversity did not vary significantly, suggesting the continued presence of a diverse and species rich benthic infauna. It is possible that in this shallow, dawn and dusk fishery, there is insufficient fishing pressure to cause observable long-term changes. However, there is cause for concern when one observes the immediate short-term effects of fishing on this species rich area. The numbers of species, species richness and biomass were all seen to drop within 24 hours of experimental trawling.

At the deeper offshore location, the results are more dramatic and appear to suggest a more worrying long-term trend. All of the parameters measured, number of species, number of individuals, biomass, species richness and Shannon's diversity, showed a reduction in the main fishing grounds when compared with the 'unfished' wreck site. In particular, there was a complete absence of large benthic infauna (with the exception of the fishery target species, *Nephrops norvegicus*). The short-term fishing effects were less obvious, with a smaller decrease in number of species and biomass following experimental trawling. There was also no clear pattern between trawled and untrawled stations from the MDS plots. This appears to reflect the very low initial species and biomass numbers in the trawling grounds, and the composition of the fauna comprising mainly small opportunistic polychaetes (adapted to disturbance).

3.7.4. DISCUSSION

All three studies found considerable evidence of longer term effects of fishing disturbance on benthic communities. Some of the fine details of the effects appeared to differ, however, between study areas.

Gareloch

At the sheltered sealoch study area, trawling disturbance had a clear effect, increasing the numbers of species and numbers of individuals, and decreasing diversity. Certain opportunistic species (mainly small polychaetes), considered to be indicators of disturbance, became more abundant in the treatment area when compared to the reference area, both during and following the disturbance period. The densities of some species declined relative to the reference area, suggesting these species may be sensitive to physical disturbance. Community structure measures of disturbance indicated that relative to the reference area, the community at the treatment site became more disturbed during the trawling period, and only became comparable to the reference area after an 18 month recovery period. Measures of numbers of species, numbers of individuals and diversity also indicated the sites were indestinguishable after 12 months recovery, but multivariate analysis of the community data found significant differences between the areas after 18 months recovery. Longer term effects were noted for some epifaunal species, with brittle stars increasing in density, while long rough dab and anenomes decrease in density in association with disturbance.

West Gamma

The results of the West Gamma study show clear differences in the macrozoobenthic community of the area enclosed by the buoys and the surrounding unprotected area. The fact that these differences were more pronounced in 1994 shows a differing development of the fauna in the protected area. Several of those species that were found to be more abundant in the quasi protected area may be regarded as vulnerable to bottom fisheries, either because they are fragile and thus are easily damaged by the tickler-chains or particularly because the smaller species are dug out of the sediment and thus are exposed to predators.

Following removal of the buoys marking the wreck, the area formerly enclosed became open to fishing. Only the area adjacent to the wreck, which was still unaffected from fisheries, showed clear differences with the surrounding area. However it became more difficult to separate the changes caused by the absence of disturbance by fishing gear from those caused by the direct influence of the wreck. The reduction of detectable effects to the immediate vicinity of the wreck following removal of the buoys underlines that the differences detected earlier were related to the protection of the area by the buoys.

Iron Man & 41 Fathom Fast

At the lower intensity fishing area, the species rich fauna of the "unfished" wreck site may resemble the natural undisturbed fauna characteristic of the region, prior to commencement of the *Nephrops* fishery. In comparison to this protected area the fauna at the inshore station showed some indication of disturbance (reduction in number of species and biomass, disapearance of some fragile bodied species), but still included some large molluscs and had a similar diversity to the wreck site. Multivariate analysis showed clear differences between the fished and unfished areas. At the heavily fished site the biomass and diversity and average size of individuals all appeared greater in the protected area than the surrounding ground. Large fragile bodied species were completely absent from the fished area.

While both sites showed considerable disturbance effect, this effect appeared to be greater at the higher intensity fishing area, and impact may therefore be related to intensity of fishing.

All three studies found a change in the infaunal community in responce to trawling disturbance. These changes were commonly due to greater numbers of either opportunist species in disturbed areas or vulnerable species in protected areas. In the studies examining sites over time, these effects were identifiable despite considerable seasonal and longer term community changes. Differences in effects were shown between areas of different fishing effort, suggesting benthic impact is related to fishing intensity. Effects on the epifaunal community were less obvious, but showed an increase in a scavenger and a decrease in a fragile anenome. Increases in the density of scavengers are generally considered to be short term in nature (Hall *et al.* 1994; Kaiser & Spencer 1994), however, and are not always present (Hall *et al.* 1996). The work shows that trawling clearly has a longer term effect on infaunal communities, with recovery rates from the sealoch site suggesting that, at least for fine muddy sediment habitats, areas may fail to recover before further disturbance occurs. While previous studies have identified longer term effects of fishing on selected groups of species (see Rumohr & Krost 1991), these are the first studies to detect longer term effects of fishing on benthic communities.

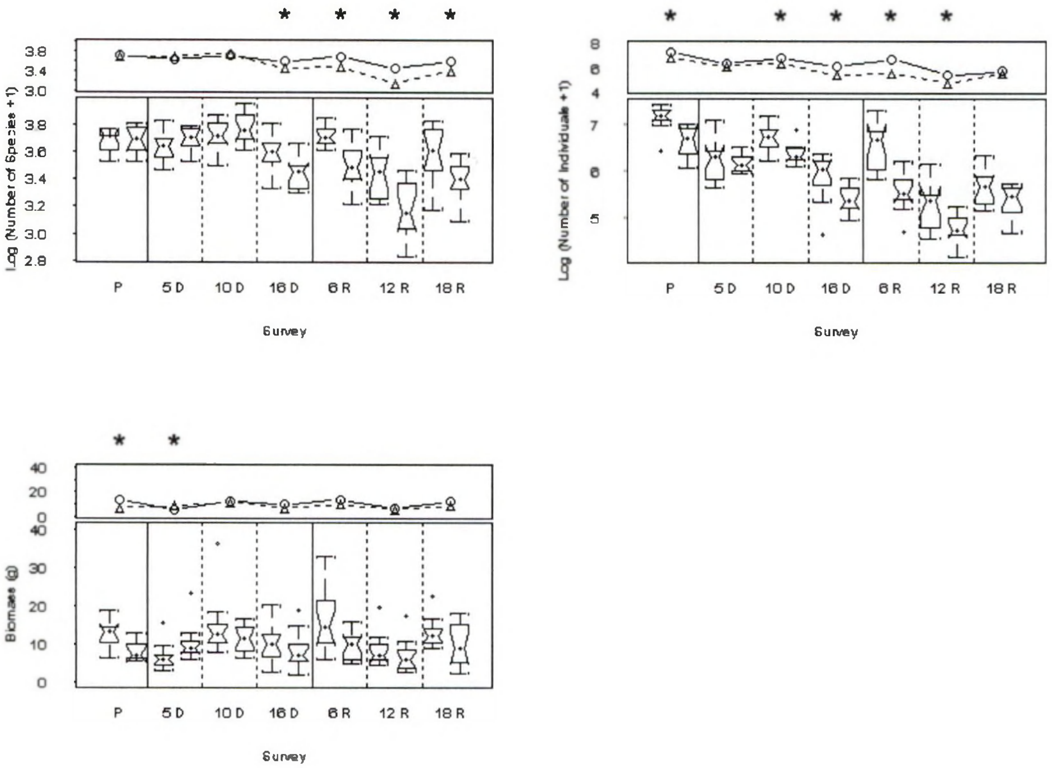


Fig. 3.7.1a. Box plots of number of species, individuals and biomass (.1 m^{-2}) (lower panels), along with the time-series for the median values for each survey (upper panels). Box-plots are arranged in pairs in time (survey) order, with the reference plot on the right for each pair. Surveys in which medians of two sites were significantly different are marked by an asterisk. Surveys labelled as follows: P - Preliminary survey, 5D - 5 months disturbance, 10D - 10 months disturbance, 16D - 16 months disturbance, 6R - 6 months recovery, 12R - 12 months recovery, 18R - 18 months recovery.

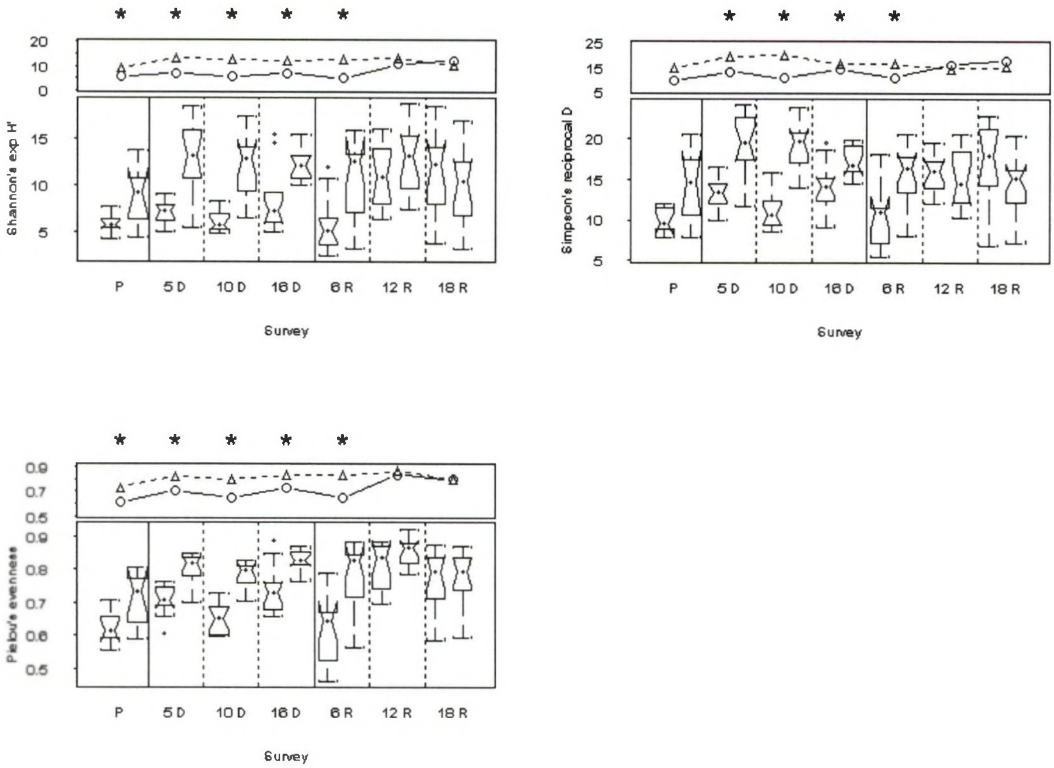


Fig. 3.7.1b. Box plots and time series for median values of Shannon's exponential *H'*, Simpson's reciprocal *D* and Pielou's evenness. Further details as for Fig. 3.7.1a.

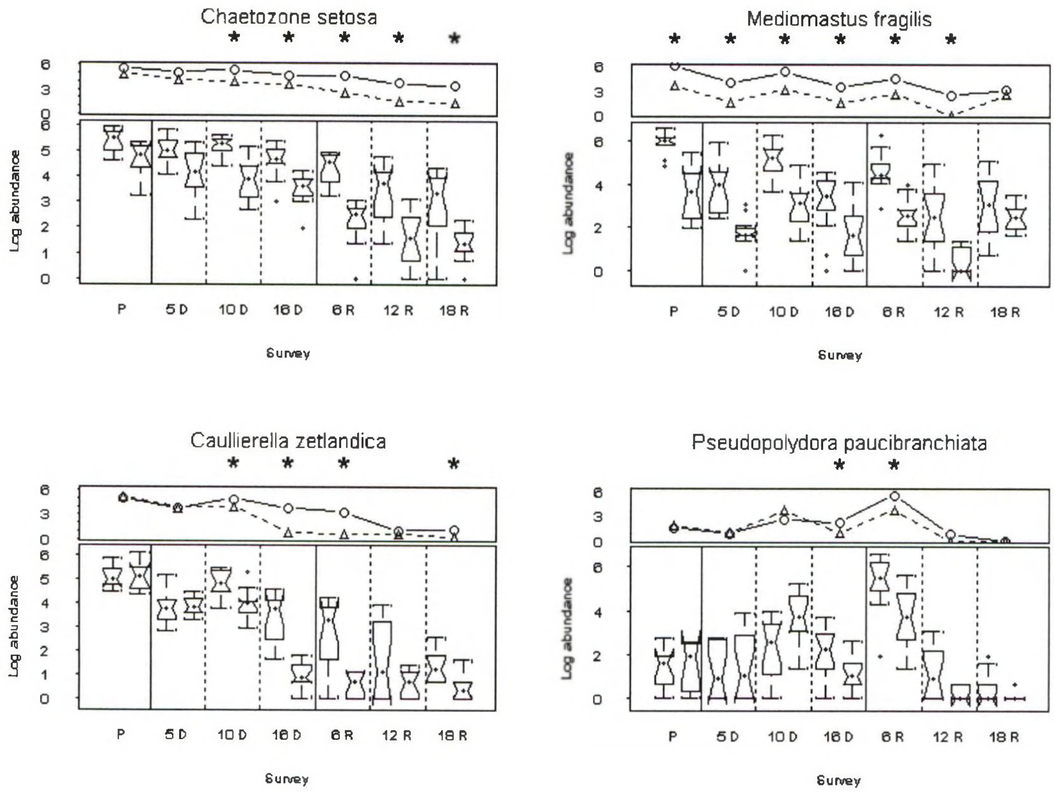


Fig. 3.7.2a. Box plots and time series for median values of abundance of four species showing an increase in abundance in responce to physical disturbance. Further details as for Fig. 3.7.1a.

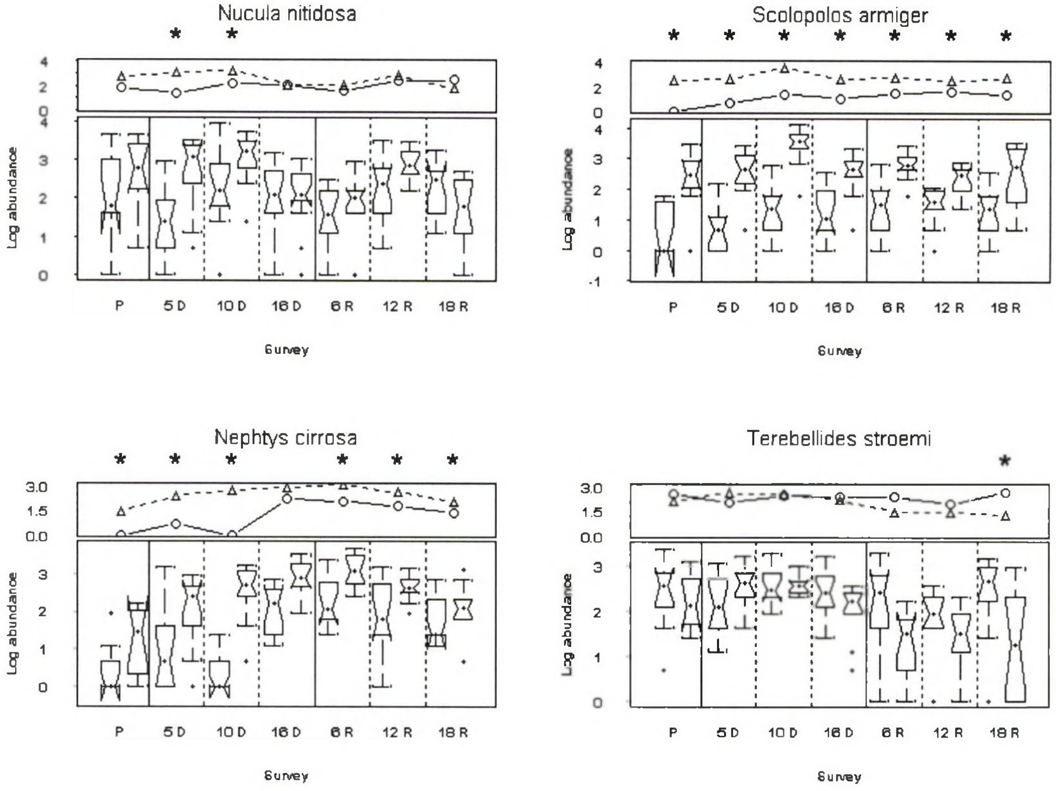


Fig. 3.7.2b. Box plots and time series for median values of abundance of four species showing a decrease in abundance in responce to physical disturbance. Further details as for Fig. 3.7.1a.

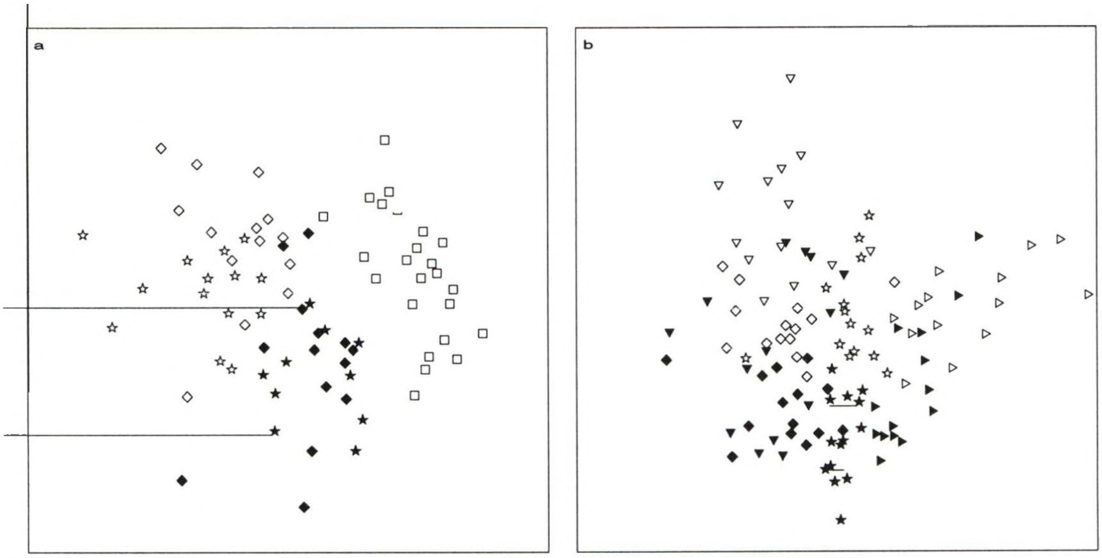


Fig. 3.7.3. MDS plots of infaunal data for reference and treatment areas from preliminary to 6 months recovery survey (a) and 16 months disturbance to 18 months recovery survey. Surveys depicted as follows; O - preliminary survey, Δ - 5 months disturbance, □ - 10 months disturbance, ◊ - 16 months disturbance, ★ - 6 months recovery, ∇ - 12 months recovery, ▹ - 18 months recovery. On the plot, reference and treatment areas are represented by hollow and filled symbols, respectively. Both plots have a stress of 0.21.

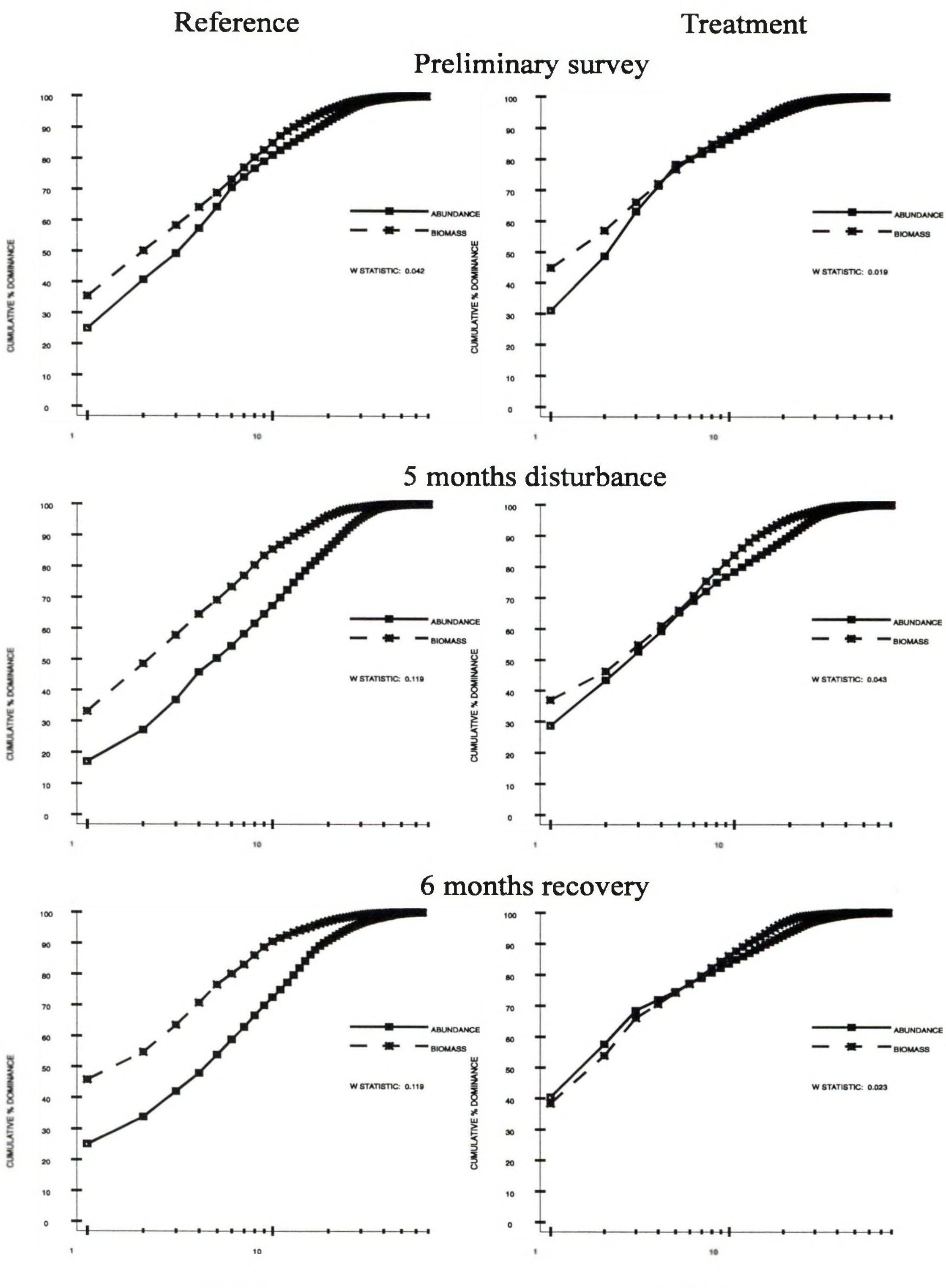


Fig. 3.7.4. ABC curves for selected surveys.

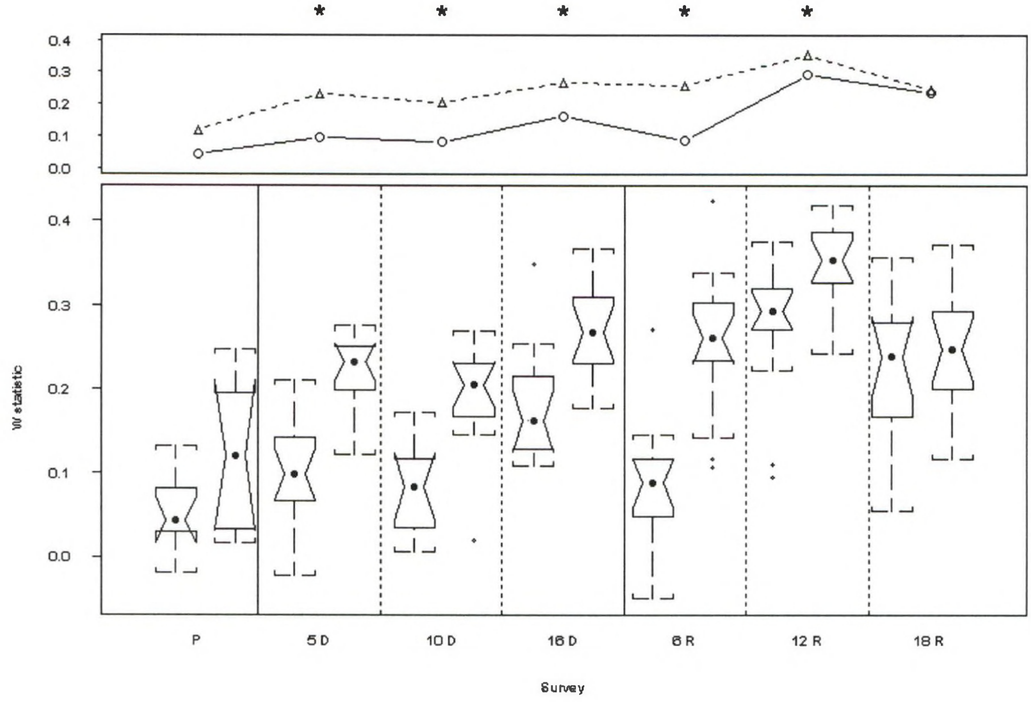


Fig. 3.7.5. Box plots and time series for median values of the W statistic for each site through the experiment. Further details as for Fig. 3.7.1a.

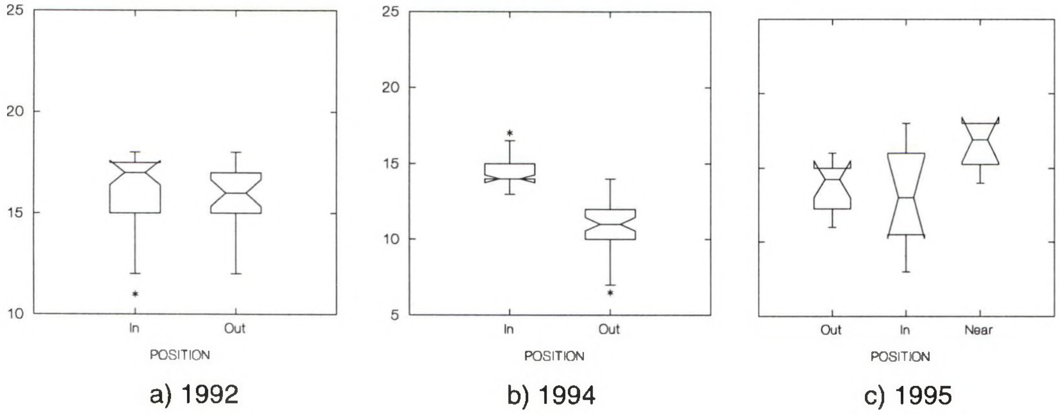


Fig. 3.7.6. Penetration of the Van Veen grab [cm] in the different sampling periods.

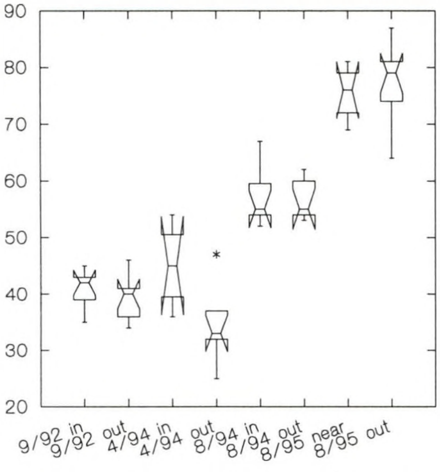


Fig. 3.7.7a. Number of species (.0.2 m⁻²)

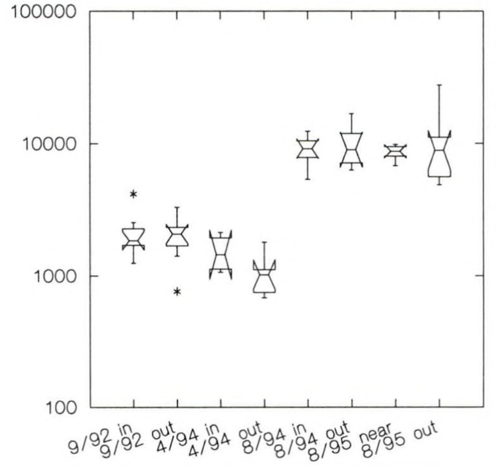


Fig. 3.7.7b. Number of individuals (.m⁻²)

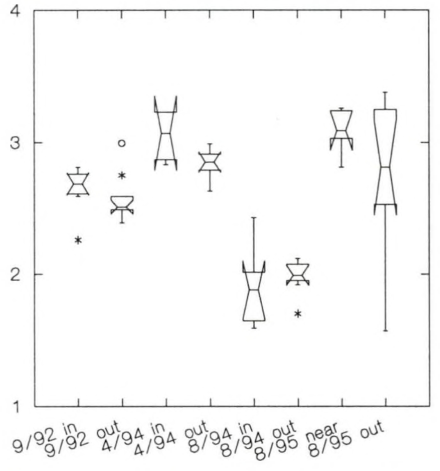


Fig. 3.7.7c. Diversity H' (Shannon-Wiener)

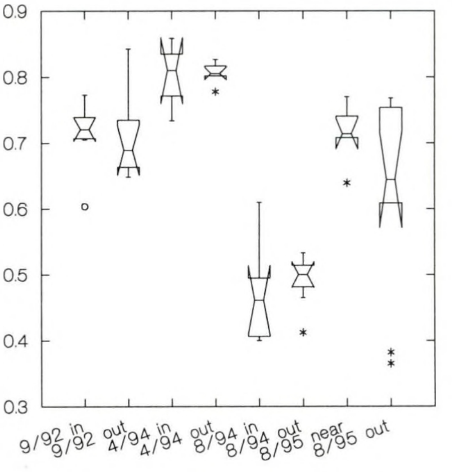


Fig. 3.7.7d. Evenness E (Pilou)

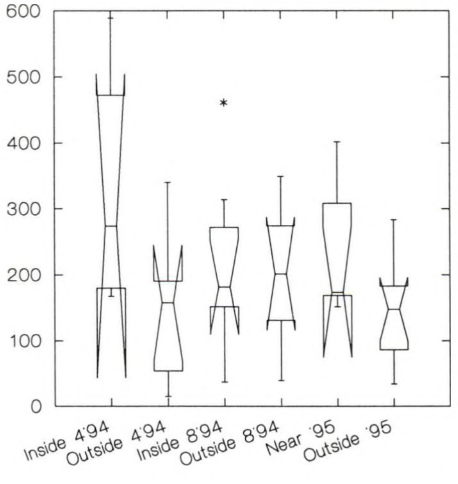
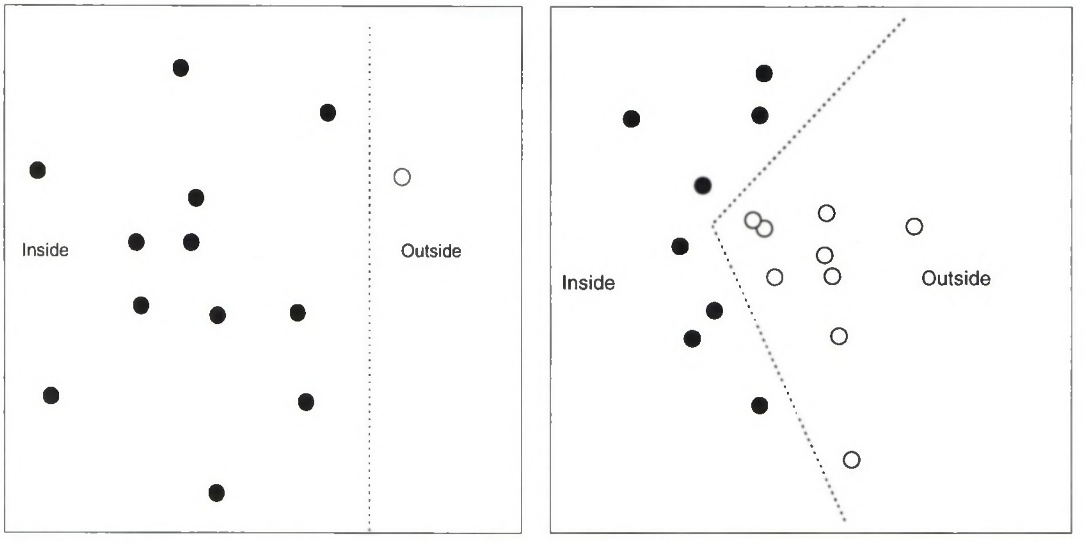


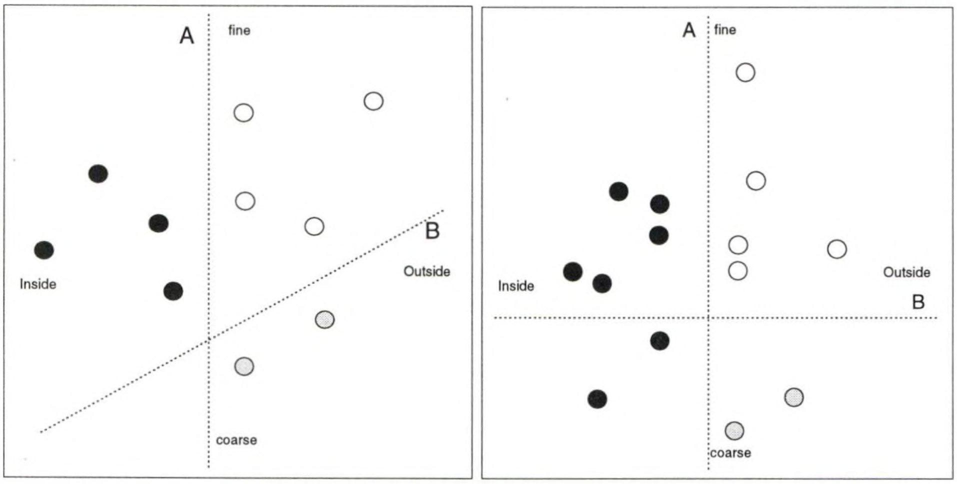
Fig. 3.7.7e. Biomass (wet weight g.m⁻²)



stress = 0.14 overall similarity: 63% stress = 0.15 overall similarity: 63%

a) August 1992 b) September 1992

Fig. 3.7.8. MDS-plots of the August- (a) and September- (b) samples 1992. Overall similarity as minimal similarity between all pairs of samples. ● = samples from "inside"; ○ = samples from "outside"; The line separates stations from inside the buoys from those outside.



a) stress: 0.11 overall similarity: 60% b) stress: 0.14 overall similarity: 68%

Fig. 3.7.9. MDS-plots of the April- (a) and August- (b) samples 1994. ● = samples from "inside"; ○ = samples from "outside"; Line A separates samples from inside the enclosed area from those taken outside; Line B separates samples with fine sediments from those with coarser sediments.

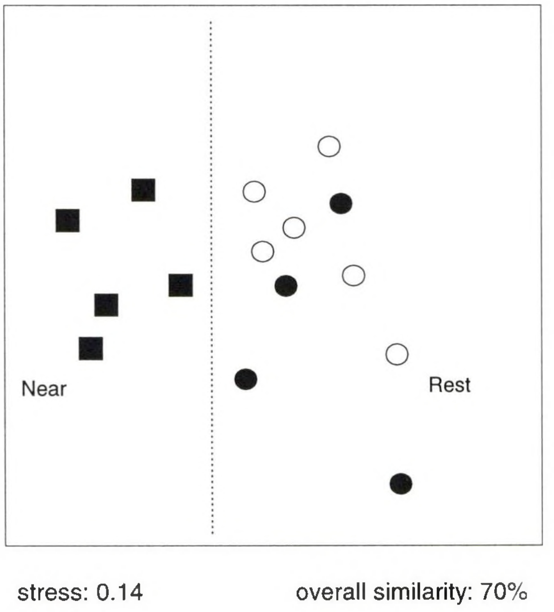


Fig. 3.7.10. MDS-plot of the 1995 samples. ■ = samples from near the wreck; ● = samples from "inside"; ❍ = samples from "outside"; The line separates the samples from the close vicinity of the wreck from the rest.

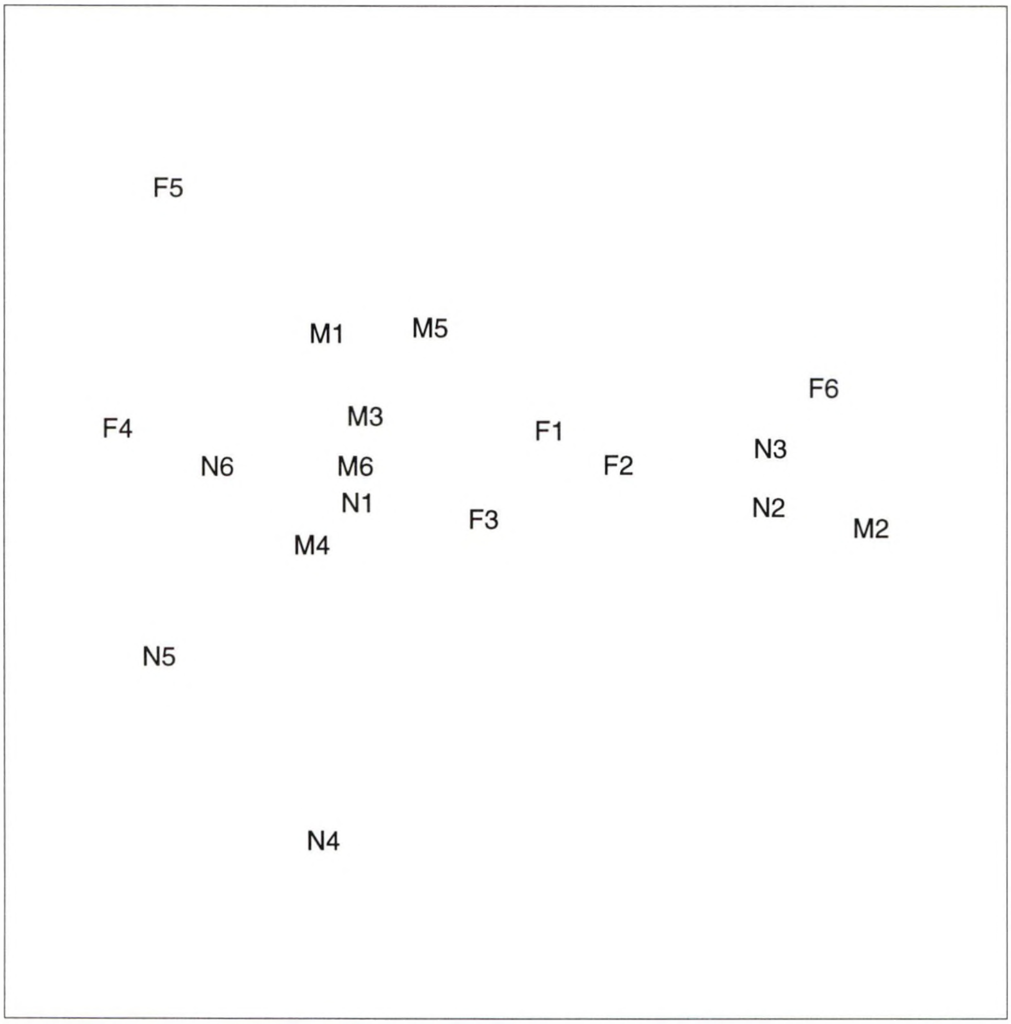


Fig. 3.7.11a. Shallow wreck site - MDS, Comparison of Iron Man wreck fauna (N=Near, M=Middle, F=Far) with near by fishing grounds: a. along the wreck transect.

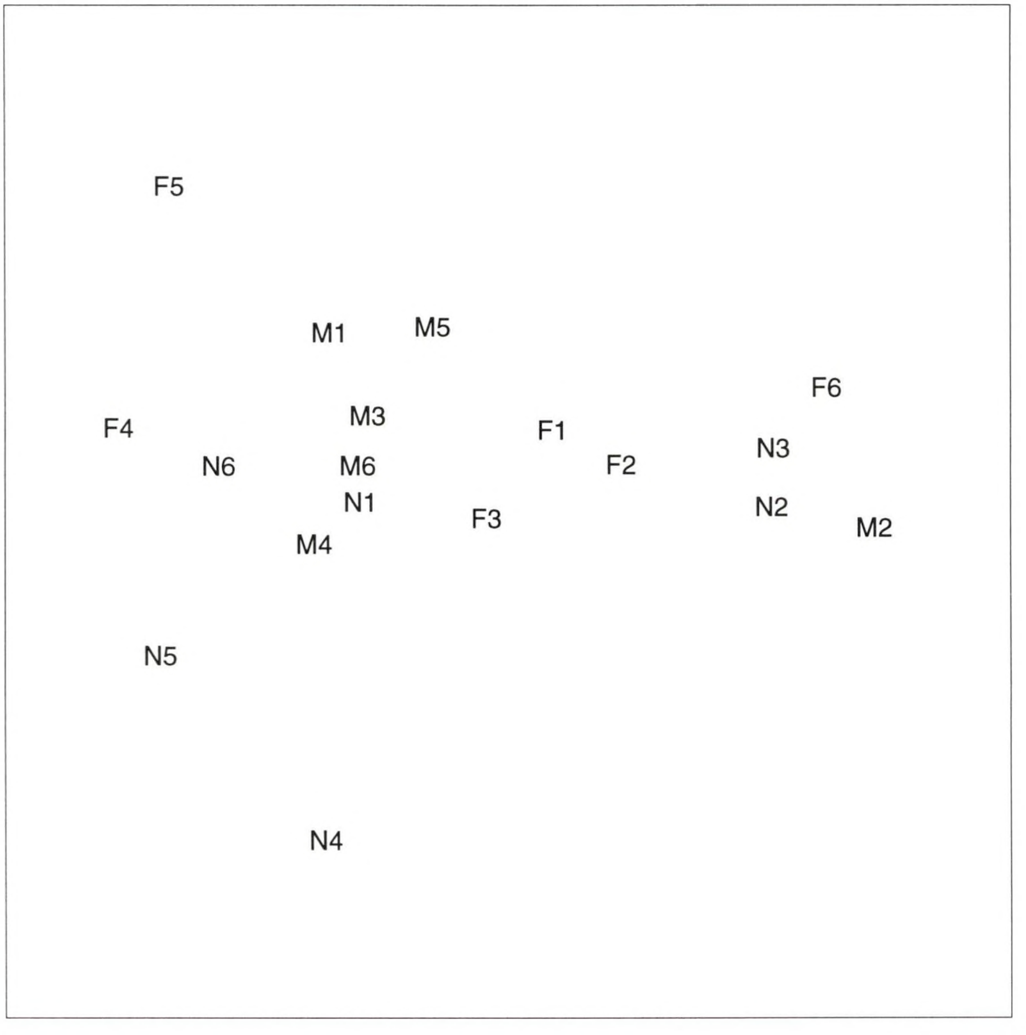


Fig. 3.7.11b. Shallow wreck site - MDS, Comparison of Iron Man wreck fauna (N=Near, M=Middle, F=Far) with near by fishing grounds: b. before experimental fishing (C=fishing ground).

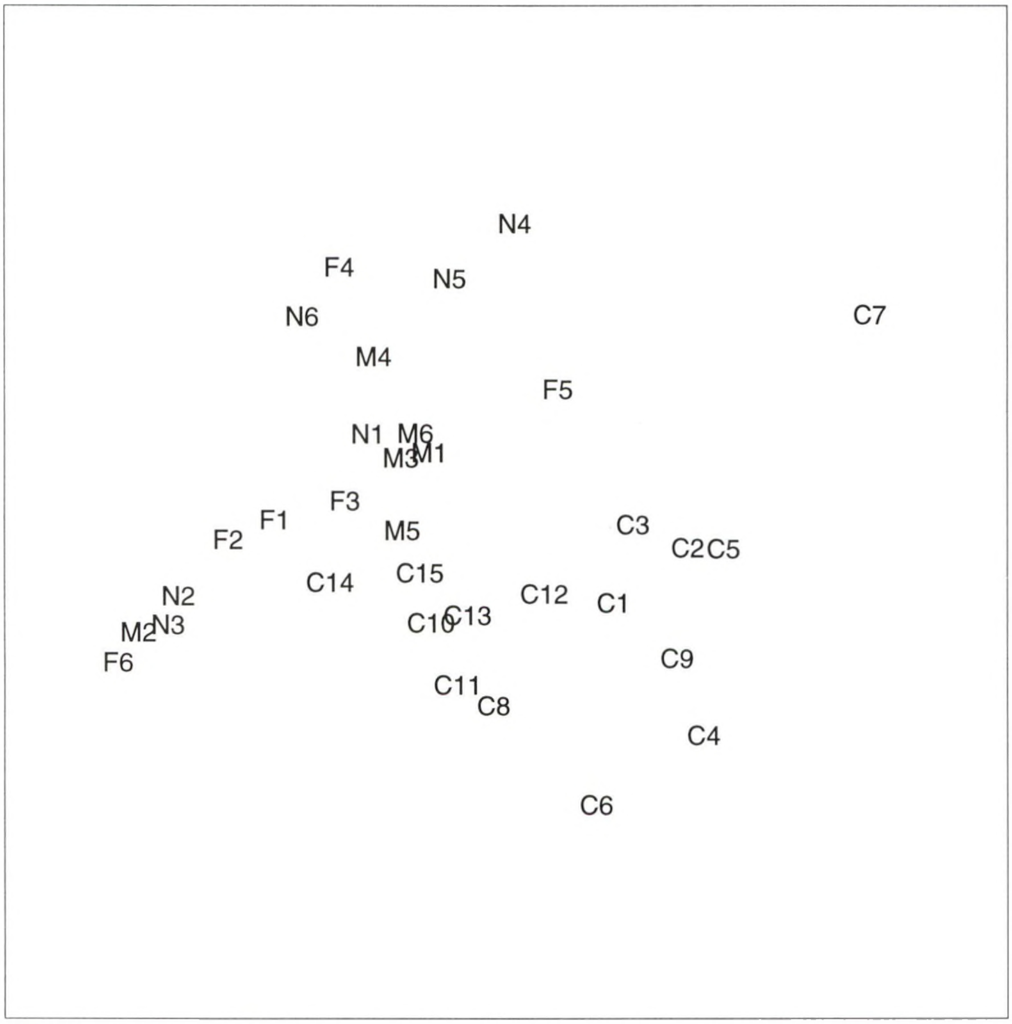


Fig. 3.7.11c. Shallow wreck site - MDS, Comparison of Iron Man wreck fauna (N=Near, M=Middle, F=Far) with near by fishing grounds: c. 24 hours after experimental fishing (I=fishing ground).

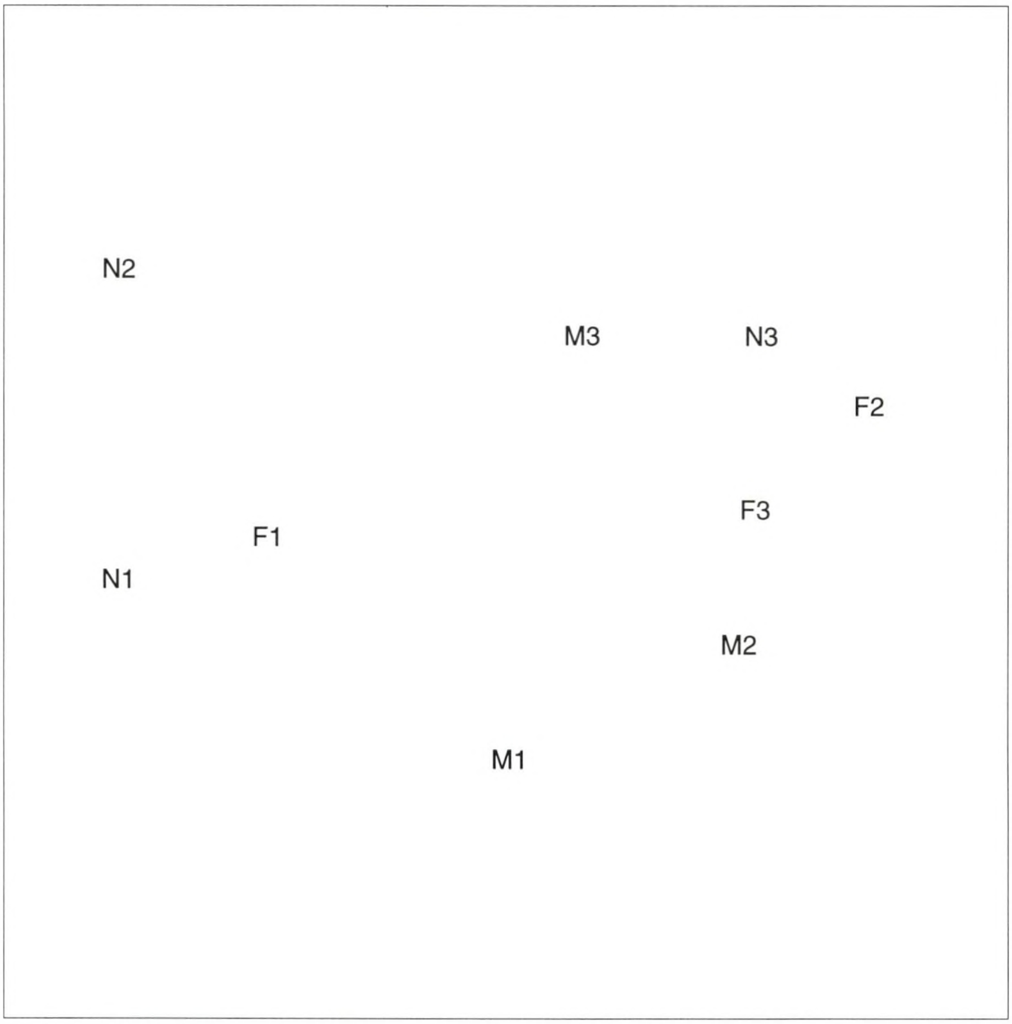


Figure 3.7.12a. Deep wreck site - MDS, Comparison of 41 Fathom Fast wreck fauna (N=Near, M=Middle, F=Far) with near by fishing grounds. a. along the wreck transect.

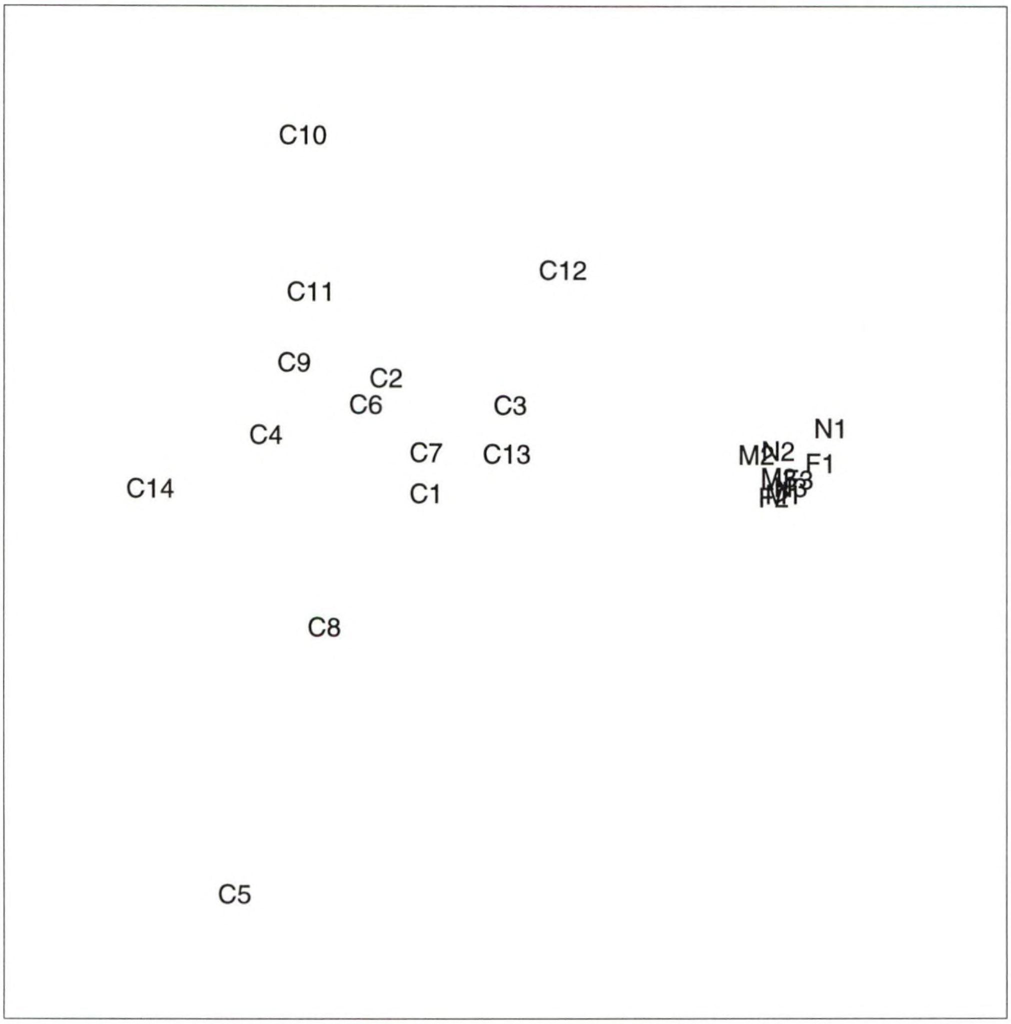


Figure 3.7.12b. Deep wreck site - MDS, Comparison of 41 Fathom Fast wreck fauna (N=Near, M=Middle, F=Far) with near by fishing grounds. b. before experimental fishing (C=fishing ground).

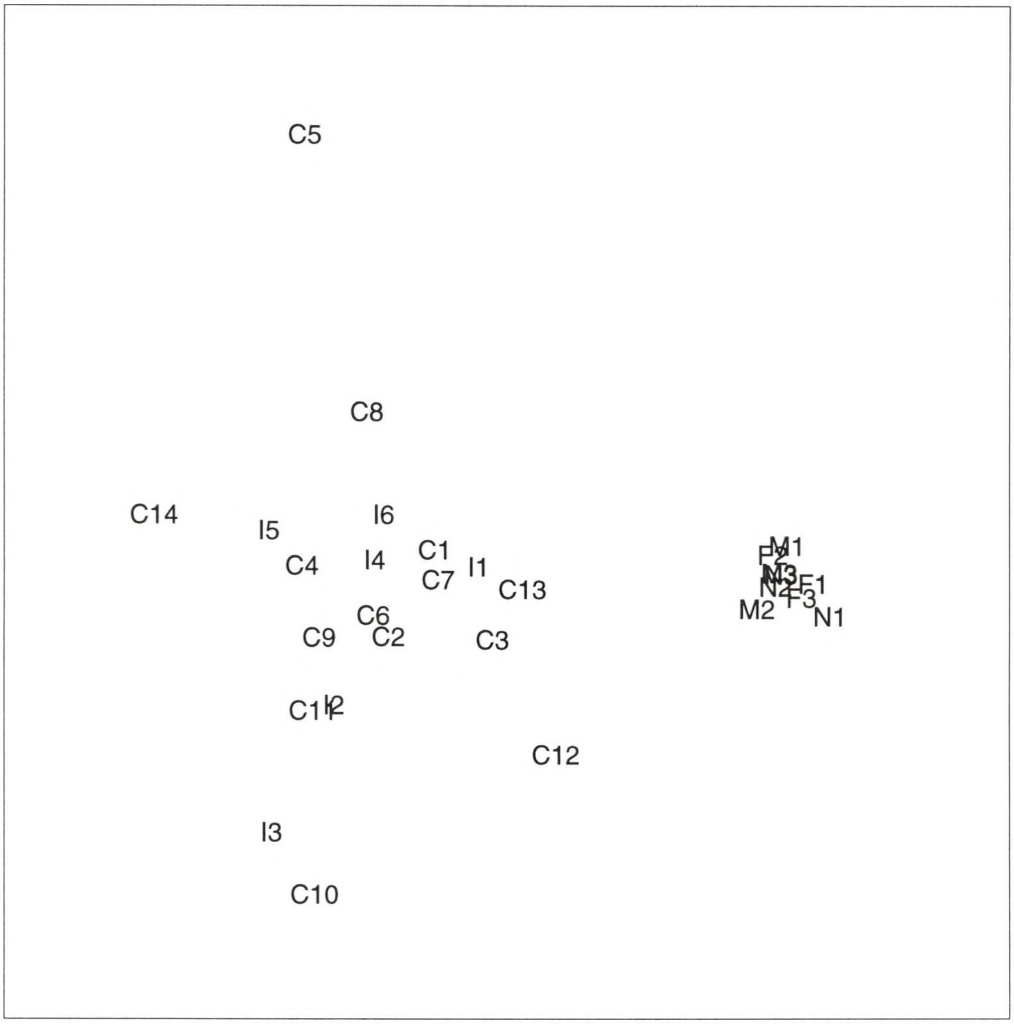


Figure 3.7.12c. Deep wreck site - MDS, Comparison of 41 Fathom Fast wreck fauna (N=Near, M=Middle, F=Far) with near by fishing grounds. c. 24 hours after experimental fishing (I=fishing ground).

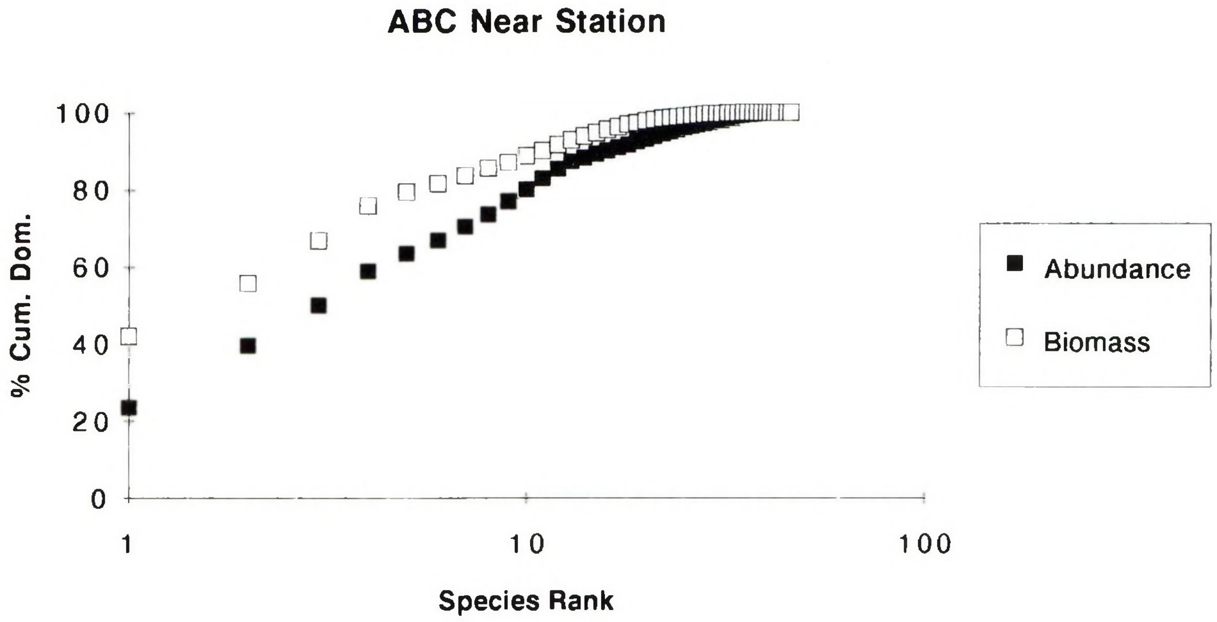


Fig. 3.7.13a. ABC curves from the 41 Fathom Fast wreck site: Near - 50 m from wreck.

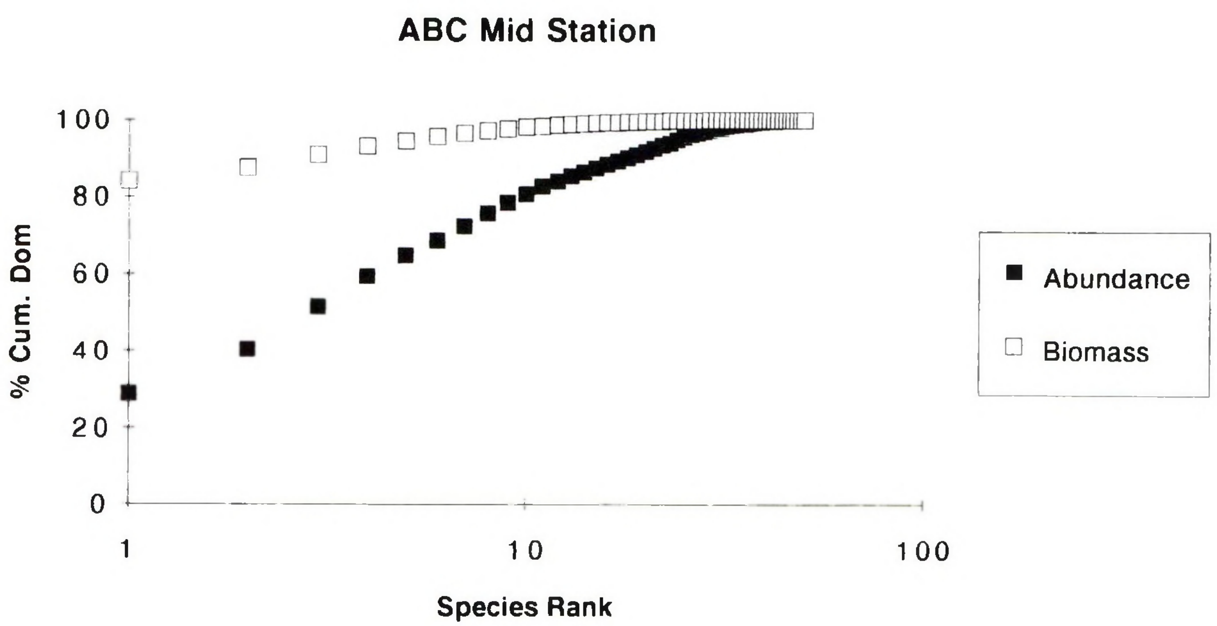


Fig. 3.7.13b. ABC curves from the 41 Fathom Fast wreck site: Middle - 250 m from wreck.

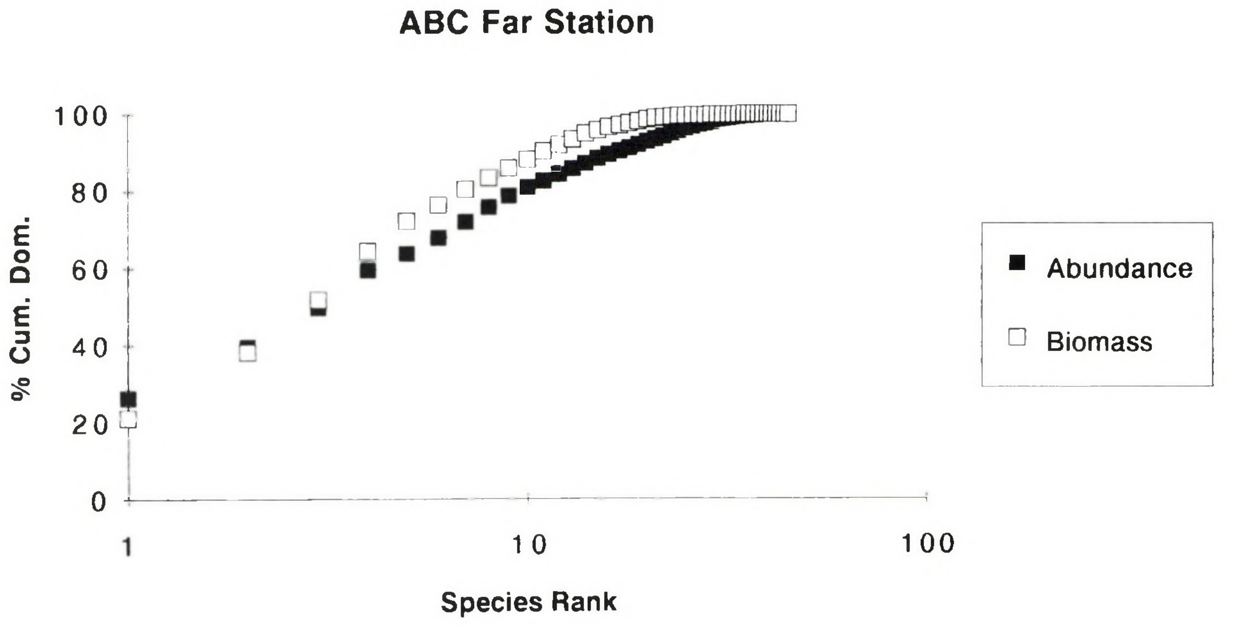


Fig. 3.7.13c. ABC curves from the 41 Fathom Fast wreck site: Far - 500 m from wreck.

3.8. LONG TERM TRENDS IN DEMERSAL FISH AND BENTHIC INVERTEBRATES

Introduction

The activities described in this chapter have been performed along two ways:

i) in dealing with qualitative/quantitative historical benthos data in comparison with recent data to unveil possible changes introduced by the developing trawl fishery and
ii) in collecting and analysing quantitative catch and by-catch data and relate their changes to possible fishery induced effects.

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

Reconstructed historical epifauna data from 1902-1912 collected during ICES routine cruises in the North Sea are compared with epifauna data from the ICES-Benthos Survey 1986.

3.8.1.1. SPECIES NUMBERS

The comparison of historical species numbers from different faunal groups with recent ones (Fig. 3.8.1.1.1) reveales distinct changes especially with the bivalves where 11 species were not found again in 1986 wheras 3 species seem to be new. Within the group of decapods 4 species were not found again whereas 8 new species appeared on stage.

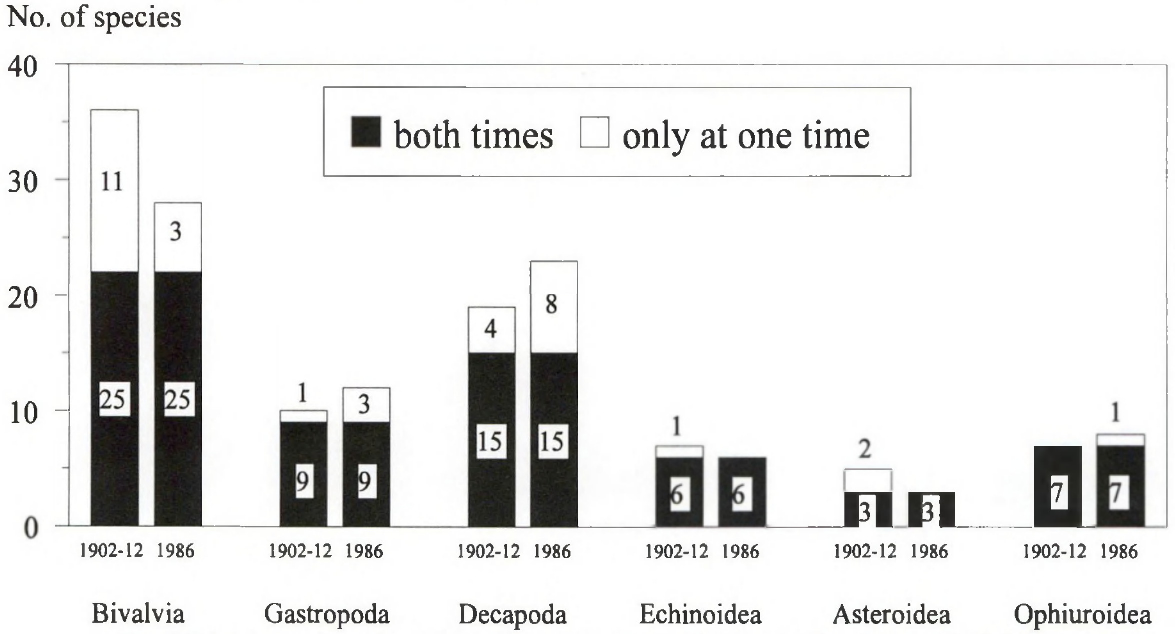


Fig. 3.8.1.1.1. number of species in the selected area for the six chosen taxonomic level.

In general are species which are only found in one dataset occur only on 15% of the stations (mainly under (10%). Exceptions are *Lunatia pulchella* with 47.4%, *Spirontocaris liljeborgii* with 22.5% and *Macropipus dupurator* with 20% (all in 1986). Since the stations in both data sets differ significantly according to their species composition (PRIMER ANOSIM) it follows that this must have taken place within the species occurring at both sampling times. The same holds true for higher taxonomic levels such as genus family and order. The differences become increasingly weaker with increasing taxonomic level but stay nevertheless significant. This statement holds true for both data sets as a whole but also for the different stations in the different depth strata. In the following we describe changes within the chosen taxonomic level but only species, that were found at least at 50% of the stations.

3.8.1.2. SPECIES COMPOSITION

Asteroidea (Fig. 3.8.1.2.1)
The starfish *Astropecten irregularis* and *Asterias rubens* were found in 1986 in depth down to 30 m at almost all stations, in 1902-12 they occurred only on stations deeper than 30 m resp. at 33% of the stations with a depth of more than 30 m. Looking at all stations there is an increase from 52% to 93% resp. from 75% to 95%. While *Leptasterias muelleri* and *Henricia sanguinolenta* were found 1902-12 at 40% resp.20% of all stations deeper than 50 meters (only there) they were not found in the 1986 survey.

Ophiuroidea (Fig. 3.8.1.2.1)
The brittle star *Amphiura filiformis* was 1986 only at 5% of the stations whereas it was found in 1902-12 at 82% of the stations. The counts of *Ophiura albida* increased from 55% to 87.5% in 1986. In this year *Ophiura sarsi* appears as a new species at the deeper stations (> 50 m) with 35%. *Ophiura ophiura* that was found in the early days at 55% of the stations > 50 m was not found in 1986 at that depth level.

Echinoidea (Fig. 3.8.1.2.2)
In 1986 the small sea urchin *Echinocyamus pusillus* is almost extinct compared to the beginning of the century. The percentage of stations where the green sea urchin *Psammechinus miliaris* was found increases from 7% in 1902-12 to 70% in 1986. There is also an increase in *Brissopsis lyrifera* at stations > 50 m (from 10% to 64%). The largest changes -however- occur in *Echinocardium cordatum* which increases especially in the shallower waters (< 50 m) from 33% to100% and over the whole depth range from 23% to 75% when comparing the beginning of the century with the year 1986.

Gastropoda (Fig. 3.8.1.2.3)
The occurrence of common whelk *Buccinum undatum* nearly doubled in the years compared from 23% to 57% of the stations visited. Also the rare *Colus gracile* was found at an increased number of stations (9% to 25%). In the general the largest increase was found in the Genus *Lunatia* that was found in 1902-12 as one species (*L. pallida*) at only 11% of the stations. This species was not found again in 1986 but three other species of this genus. *Lunatia montagui* at 50% of the stations > 50 m (and only there), *Lunatia catena* at 22% of the stations in the 30-50 range (only there) and *Lunatia pulchella* at 47% of all stations but pronounced at the shallow stations (0-30 m) with 62%.

Bivalvia (Fig. 3.8.1.2.4)
In this group we find a drastic decrease of all species found originally in 1902-12. The following species are only found at 20-30% of all stations from 1986: *Phaxas pellucidus* (earlier 70%), *Nucula nitidosa* (earlier 53%), *Arctica islandica* (earlier 45%). At more than 70% of all stations *Spisula solida* was found in the early century (now only 5%) and also *Nuculoma tenuis* (1986: 27.5%). The following species have been recorded in 1902-12 at 30-40% of the stations: *Hiatella arctica* (1986: 0% although there may be a mixing up with *H.rugosa* 21%), *Tridonta montagui* (1986: 7.5%), *Abra prismatica* (1986: 2.5%) *Aequipecten opercularis* (1986: 12.5%). Occurrences of 40-50% such as in *Chamelea gallina* decrease to 12.5% in 1986, *Acauthocardia echinata* (1986: 22%), and *Varicorbula gibba* (12.5%).

Decapoda (Fig. 3.8.1.2.5)
All species of this group were found in 1986 at more stations than in 1902-12. The genus *Crangon* (with *C. allmanni* and *C. crangon*) was found at a significantly higher numbers of stations overall, especially in the depth stratum of 30-50 m. The swimming crab *Liocarcinus holsatus* increased from 16% to 82% whereas the strongest increase can be found in the depth zone > 30 m. The generally abundant hermit crab *Pagurus bernhardus* showed only a slight increase from 66% to75%. Further drastic changes occur in *Hyas coarctus* (29% to 62.5%) and in the masked crab *Corystes cassivelaunus* (18% to 57.5%).

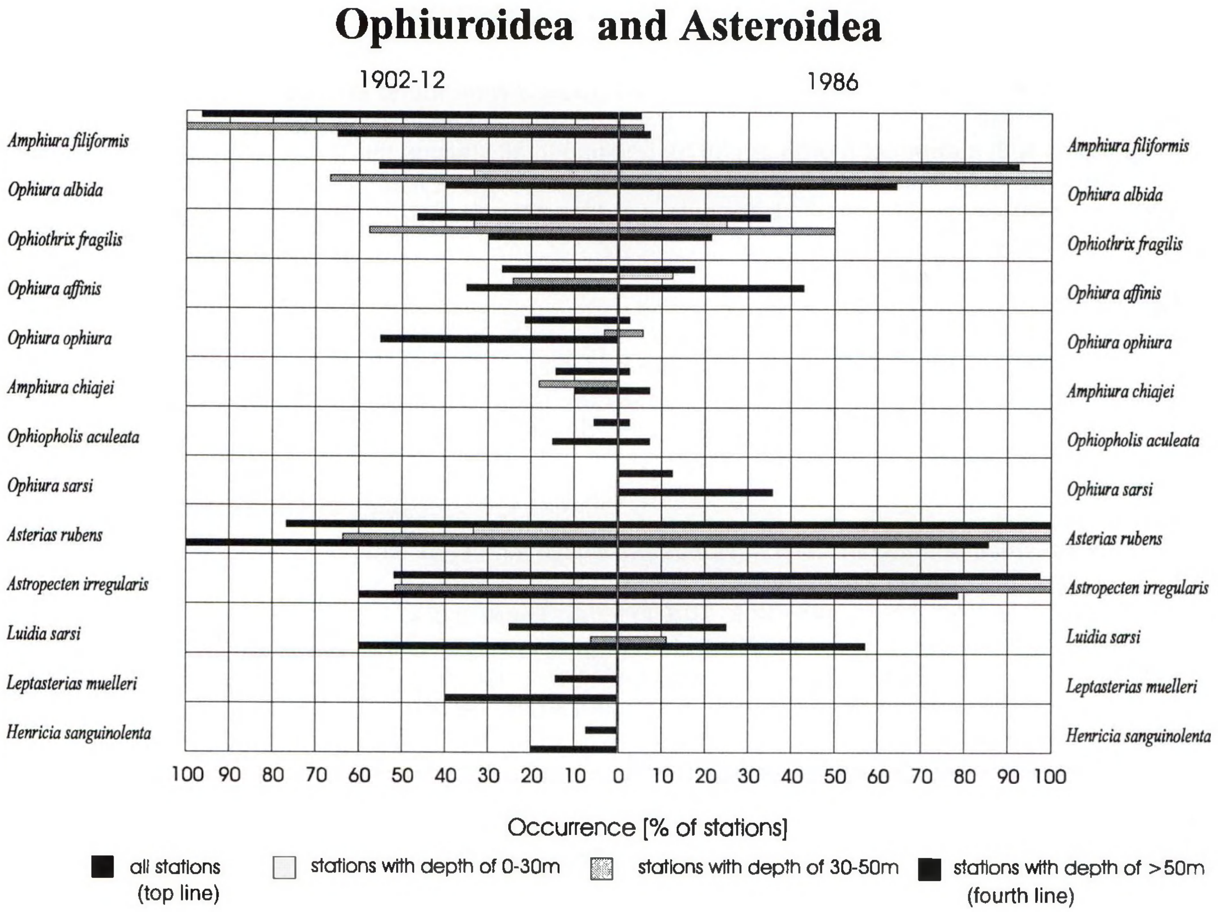


Fig 3.8.1.2.1. Occurrence [% of stations] of Asteroidea and Ophiuroidea.

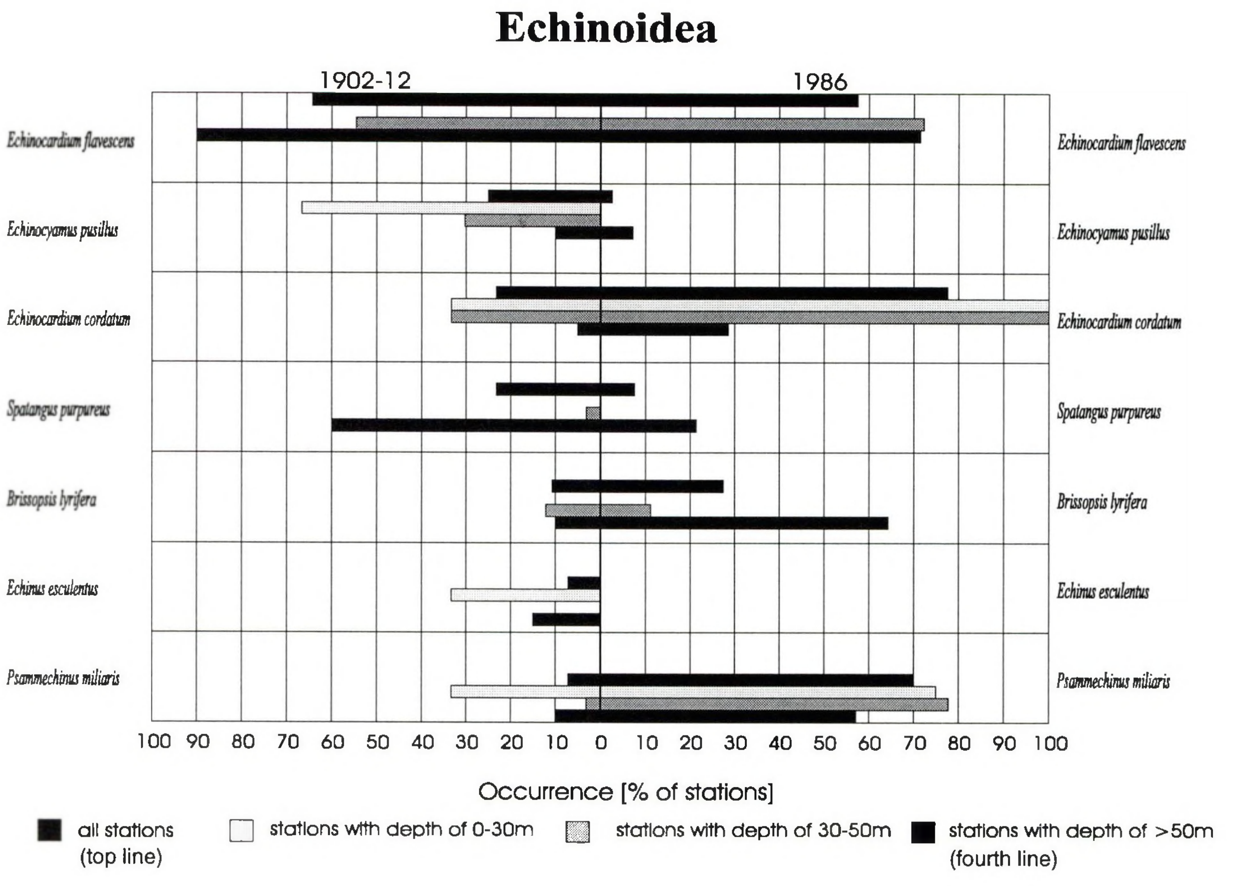


Fig 3.8.1.2.2. Occurrence [% of stations] of Echinoidea.

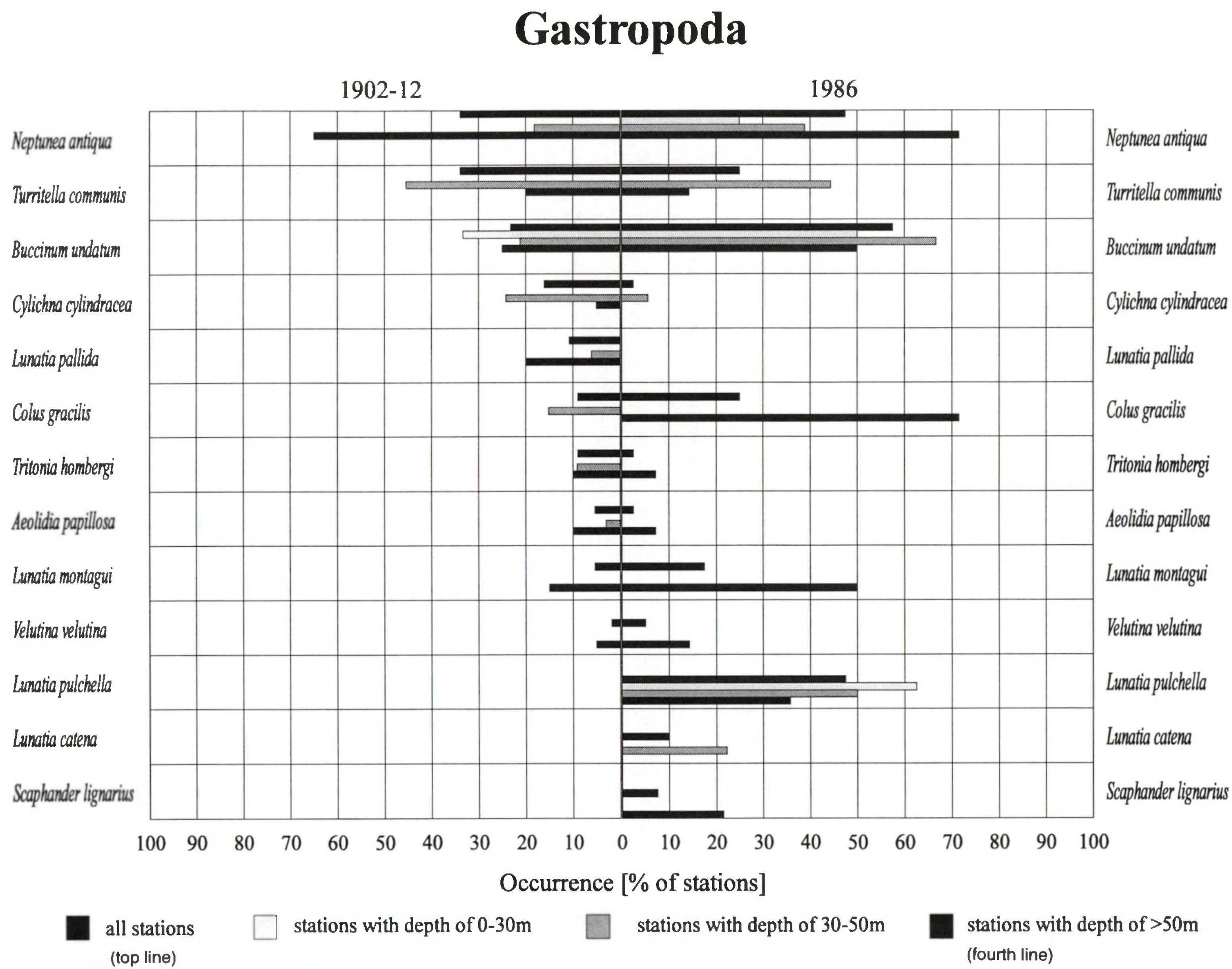


Fig. 3.8.1.2.3. Occurrence [% of stations] of Gastropoda.

Bivalvia

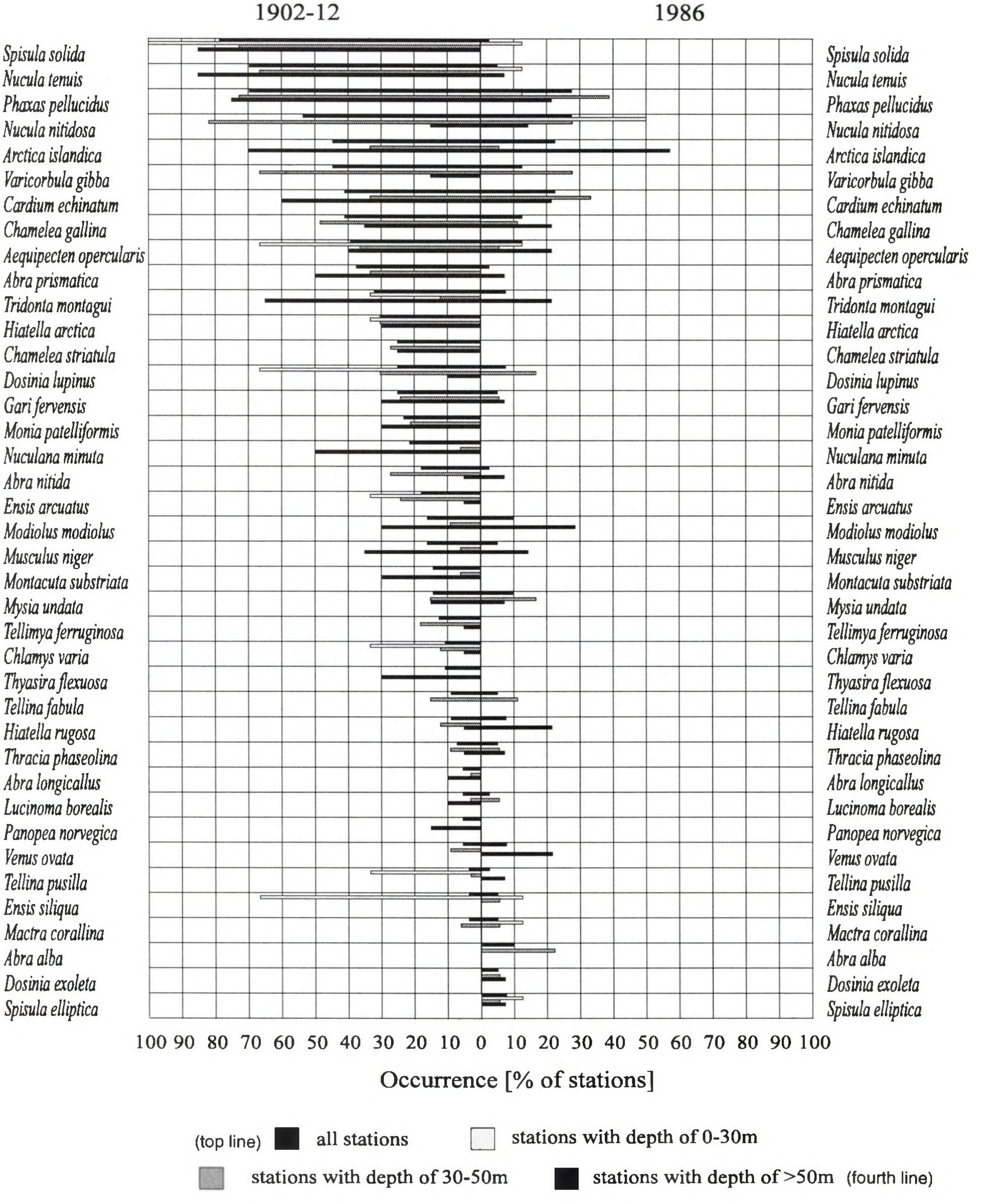


Fig 3.8.1.2.4. Occurrence [% of stations] of Bivalvia.

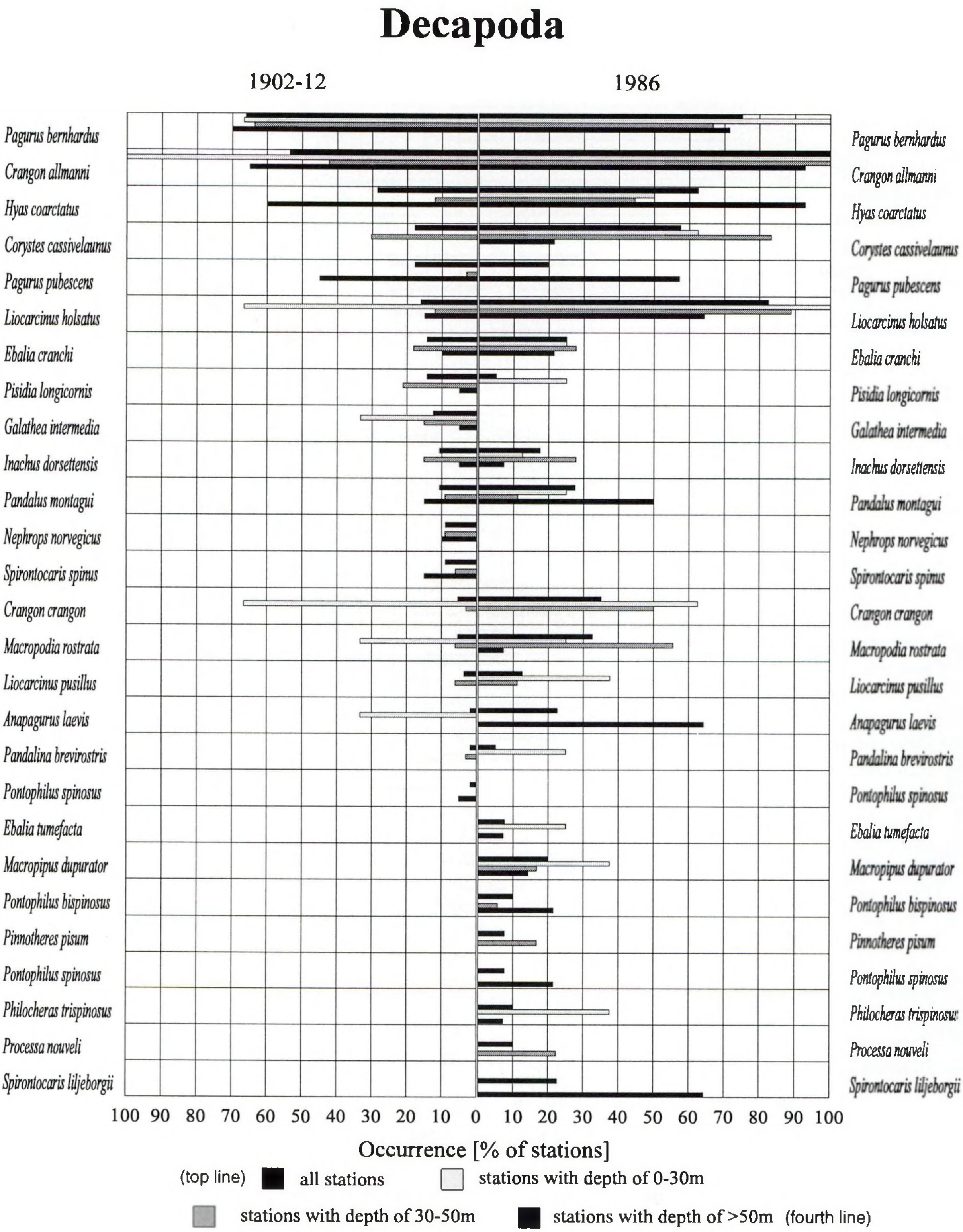


Fig 3.8.1.2.5. Occurence [% of stations] of Decapoda.

Discussion

When dealing with historical data the question of comparability with more recent data automatically arises. The historical data used in this comparison have been reconstructed from museum specimens. In order to judge the value of these data some information is included about the way of reconstruction historical dredge protocols.

No direct quantitative conclusions can be drawn from the material presented, since it is not certain with regard to the museum's material whether all collected animals were kept and as there is only little evidence of individual numbers in the available literature. These data can be used only as presence data since the reasons for the absence in the records are unclear. Also the attempt to investigate temporal changes in the 10 consecutive years of sampling had to be abandoned since the input-rate of data records drastically declined from more than hundred in the first years to less the fifty in the last years. Therefore we lumped the whole dataset to one set and assume that the whole species list represents the largest and almost complete part of the species sampled in that period. This seems justified since there was high interest from taxonomists in the Kiel and Helgoland Laboratories to receive interesting and new material and their approach was to get an complete overviev over the species spectrum. The reduction of the species list to almost only epifaunal species or taxa (except for the bivalves and some echinoderms) makes a comparison more realistic, since in the infauna data of the ICES survey in 1986 many more small species appear (especially polychaetes) which could not have caught with the gears used in the early part of the century (quantitative sampling of benthos was not possible in those days).

The comparability of sampling gears is one of the main questions that cannot be answered satisfactorily. In both cases towed gear was used (see Table 2.8.1) with some penetration into the upper sediment layers that resulted in a certain share of infauna in the samples. There is no information about the width of the meshes used. Is the disappearance of the small echinoderm *Echinocyamus pusillus* due to the different gears (or mesh width) in use (similar with small bivalves *Abra* and *Nucula*)? When looking at the patterns found it is likely that they are comparable since the changes found are quite robust and also detectable on higher taxonomic (and thus coarser) levels.The evaluation of a likely increase of some species (i.e. *Asterias rubens*) at shallow water stations is hard since too few stations have been sampled to make general statements (1902-12: 3; 1986: 8). It seems, however, that the observed tendencies are more pronounced in the depth stratum < 50 m.

The analysis of animal distributions according to the sediments was not possible since not enough sediment data were available for both data sets. Nevertheless we assume this to be of minor importance since the sediment distribution follows in general the depth zonation.

In general the tendencies stated are robust despite some taxonomic problems for example in the genera Hiatella (mollucs) and Lunatia (gastropods). Despite the possibility of misidentification or confusion of species belonging to the echinodermata the general increase in this group can be illustrated when we lump all echinoderms species into the large groups of Spatangoidae and Echinoidae (percentage of occurrence on all stations):

	1902-1912	1986
Spatangoidae	67.9%	97.5%
Echinoidea	12.5%	65.0%

This is also true for the strong decline in occurrence of *Amphiura filiformis*, under the assumption that a possible confusion only with other *Amphiura* species is possible but not with species of the genus Ophiura that increases in occurrence (% of stations):

	1902-1912	1986
Amphiura spec.	62.5%	7.5%
Ophiura spec.	82.1%	92.5%

In general a decline in the occurrence of bivalves can be stated whereas scavengers and predators such as crustaceans, gastropods and star fish have been found more frequently in 1986. This can be clearly attributed to the fishery impact which produces by means of the discards and by-catch together with the destroyed animals at the sea floor a large amount of additional possible food material for scavenging species. In general a decline in the occurrence of bivalves can be stated whereas scavengers and predators such as crustaceans, gastropoda and sea stars have been found more frequently in 1986. This can be clearly attributed to the fishery impact which produces by means of the discards and by-catch together with the destroyed animals at the sea floor additional possible food material for scavenging species. This stimulating factor for the populations may even overrule the deleterious effect of the physical damage through the fishing process to the same vulnerable species.

Putting our findings into the general developement of the demersal fishery in the southern North Sea we cover the span after the initial onset of a widespread trawl fishery that skimmed off the surplus of the virgin stocks in the 19th century (Fig 3.8.1.2.6). The ICES routine investigation where started in the general care about the state of the fish populations which seemed to severely crash after the first strong fishery impact in the last century. However, parts of the off-coast regions might have been still close to a pristine status with regards to the benthic invertebrates that may have been found before the onset of the trawl fishery. In 1986, almost 100 years of trawling impact have certainly re-structured the benthic system and so this comparison from close to a pristine situation to a long term disturbed situation may be the most what we can achieve despite all the mentioned problems with the historical data.

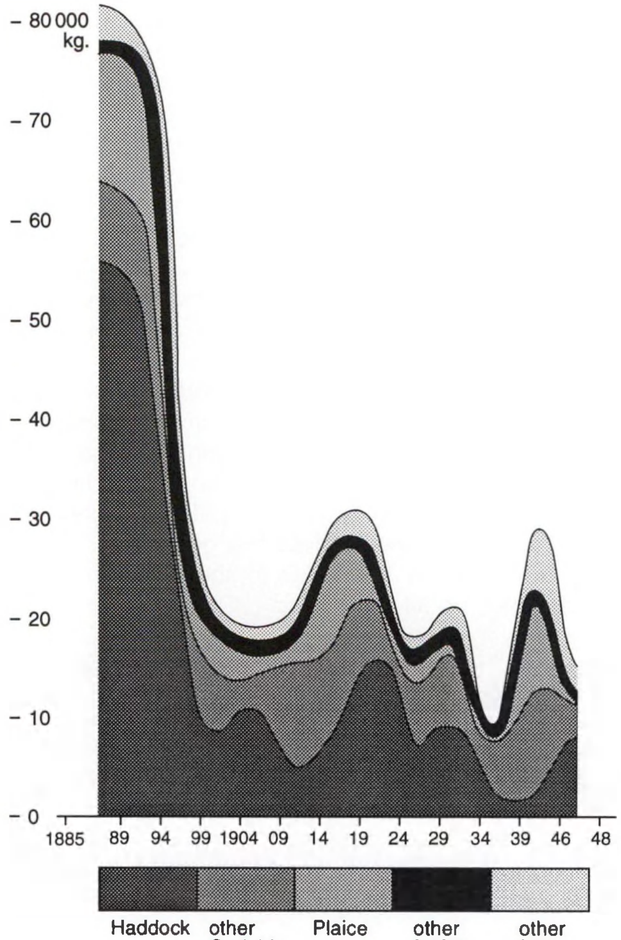


Fig. 3.8.1.2.6. Corrected yields (catch/10 d trip) of a unit trawler as a relative measure for the population density of commercial fish in the North Sea under the impact of fishing (after Hempel 1978).

3.8.2. HISTORICAL AND RECENT DATA ON MACROINFAUNA IN THE GERMAN BIGHT

Spatial distribution of benthic associations in the German Bight

For the description of the benthic fauna of the German Bight, the area is divided into regions that are characterised by benthic associations according to their species spectrum and dominance structure.

To analyse possible changes in the borders between them, the areas characterised by these associations are plotted on three maps of the German Bight (Fig. 3.8.2.1; Fig. 3.8.2.2; Fig. 3.8.2.3). For the comparison, the names of the associations given by Salzwedel *et al.* (1985) are adopted, as they are based on presently used species names.

1923/24:

The distribution of the communities according to Hagmeier is shown on the map in Fig. 3.8.2.1.

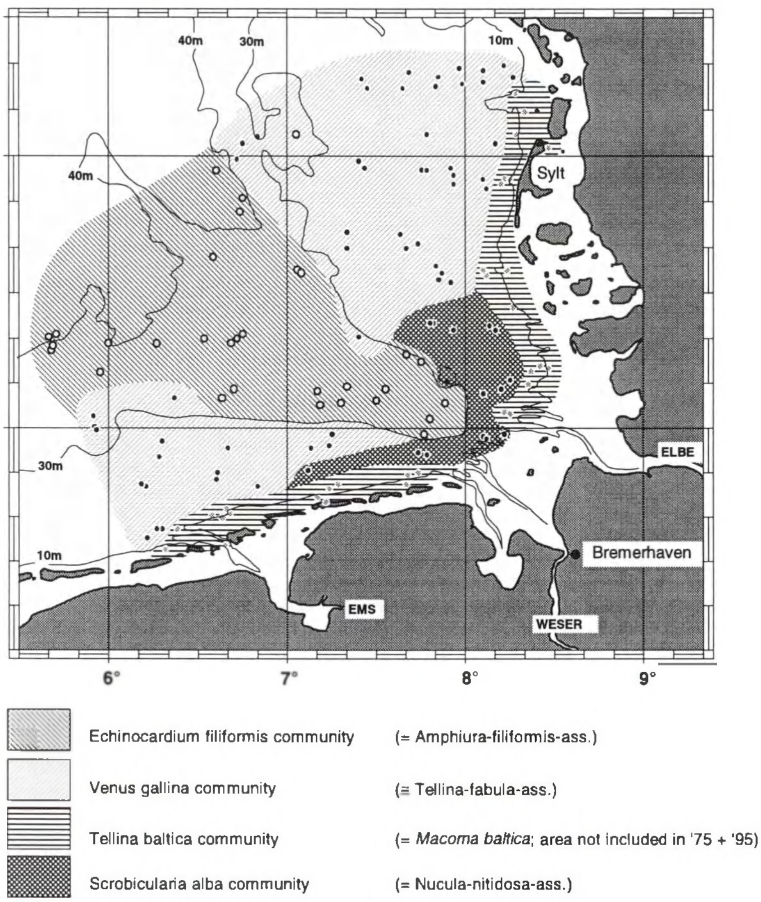


Fig. 3.8.2.1. Distribution of the communities according to Hagmeier (1925). Association names in brackets are the new names for the associations after Salzwedel *et al.* (1985).

Hagmeier distinguished four communities, depending on the depth of the area and the sediment type. However many of the stations lying close to the borders depicted in Fig. 3.8.2.1 are of a transitional character between two asociations, especially those attributed to the *Amphiura filiformis* association.

The coastal area up to a depth of 10-15 m is characterised by the *Macoma-baltica*-association (= "*Tellina baltica* community" Hagmeier 1925) on patchily distributed sediments. The area of clean sand in the north-eastern and south-western parts from 10 m up to a depth of 27-40 m are inhabited by the "*Venus gallina* community", (≈ *Tellina-fabula*-association including also areas of coarse sand: *Goniadella-Spisula*-association; see detailed description later on). The deeper areas north-west of Helgoland (over 30 m) with fine silty sand are attributed to the *Amphiura filiformis* association (= "*Echinocardium filiformis* community" Hagmeier 1925) and the area in front of the Elbe and Weser estuaries as well as the surrounding of Helgoland is characterised by the so-called *Scrobicularia alba* community, which resembles the *Nucula nitidosa* association (see detailed description later on).

1975:

Analysing the data from 1975 with today's computational methods produces a slightly different but similar grouping of the stations compared to the original results from Salzwedel *et al.* (1985) (Fig. 3.8.2.2).

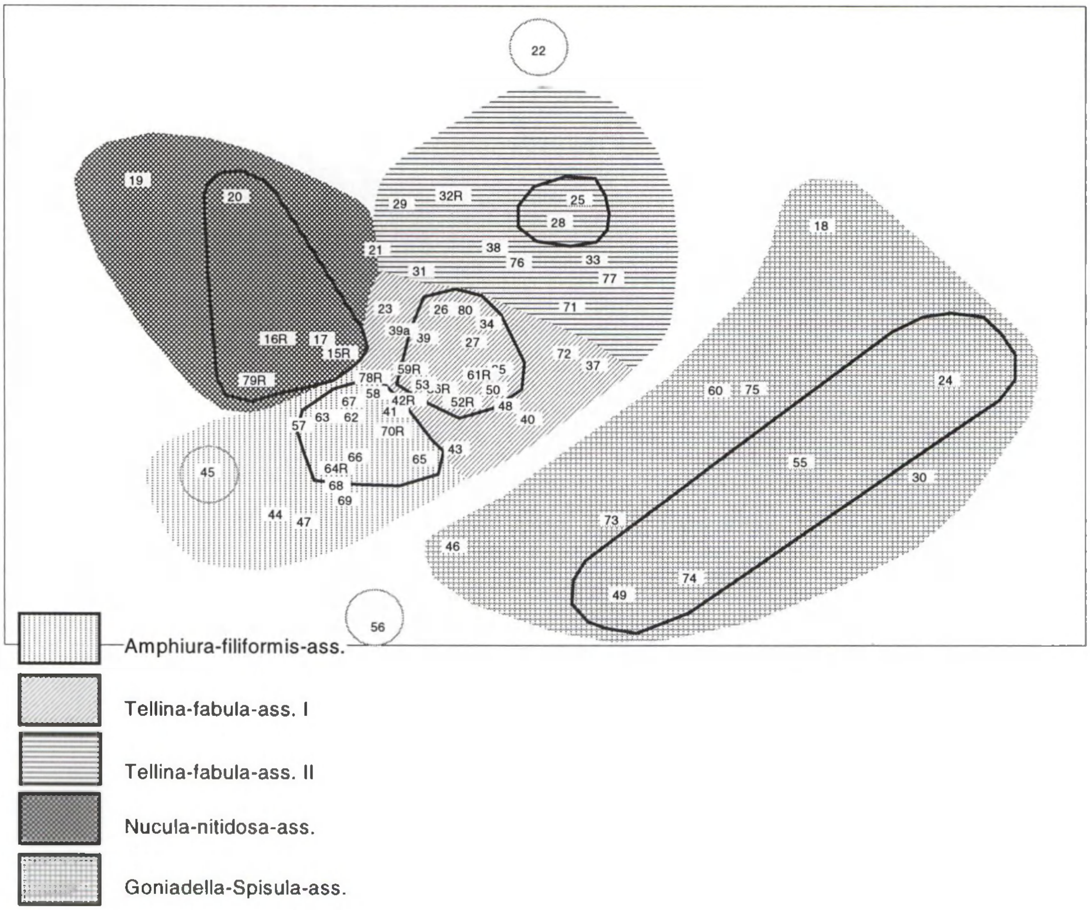


Fig. 3.8.2.2. MDS plot for all data from 1975 (Salzwedel *et al.* 1985) (stress = 0.14) (using Bray-Curtis index, 4th root transformation). Associations as joint by clusteranalysis (Complete linkage) are marked. Lines encircle the stations that were also sampled in 1995 and thus were used for the comparison of the development of the faunal communities. The leading '4' of the station numbers has been omitted for better graphical resolution (e.g. 56 corresponds to 456 in Salzwedel *et al.* 1985).

The separation of the north-western parts into a separate *Spio-filicornis*-association could not be confirmed. The resulting spatial distribution is shown in Fig. 3.8.2.3. This map closely resembles the map from Fig. 9 in Salzwedel *et al.* (1985) after omitting the "somewhat doubtful" (Salzwedel *et al.* 1985) *Spio-filicornis*-assocations.

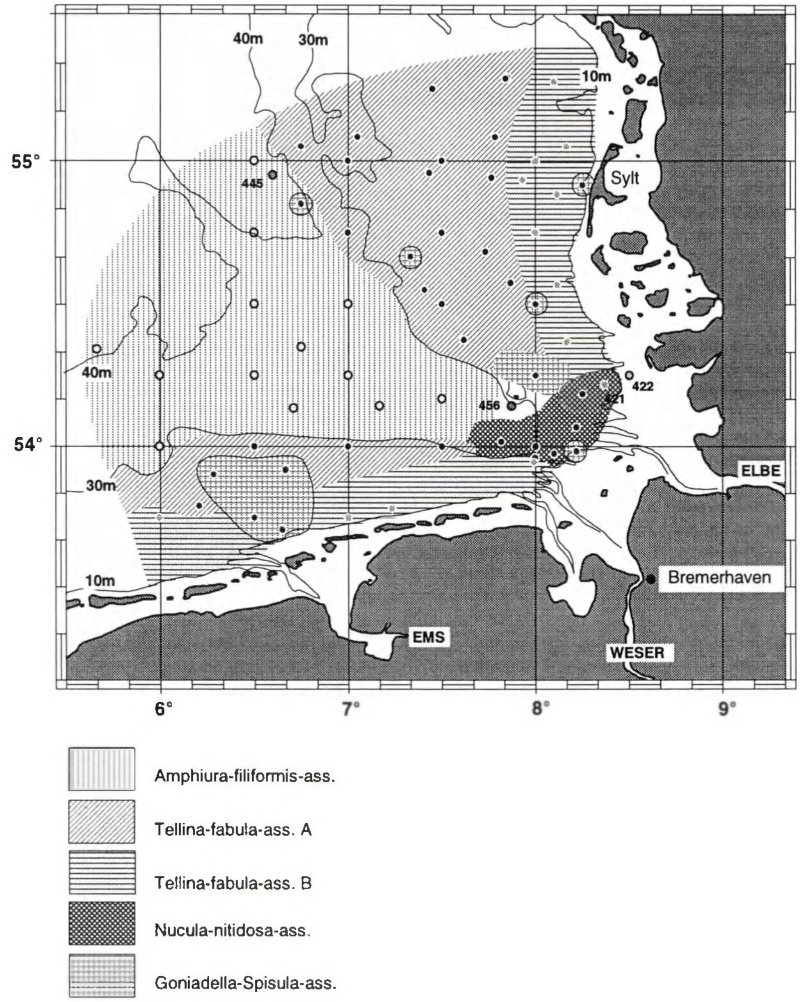


Fig. 3.8.2.3. Spatial distribution of benthic macrofauna association in the German Bight 1975 (Data from Salzwedel *et al.* (1985) reanalysed).

The *Tellina-fabula*-association is subdivided into a shallow (B) and a deeper part (A) and a few stations have been assigned to other associations.

Station 446, formerly included in the *Amphiura-filiformis*-association, now belongs to the *Goniadella-Spisula*-association, station 465, formerly *Tellina-fabula*-association, was now included in the *Amphiura-filiformis*-association, station 422, the shallowest station, was separated from the *Nucula-nitidosa*-association and station 456, located in the " Helgoländer Tiefe Rinne", was also put separately between the *Amphiura-filiformis*-association and the *Goniadella-Spisula*-association (Fig. 3.8.2.2).

This change in the number of stations assigned to the benthic associations, combined with the reduction of the stations for the comparison of the faunal communities to those that had also been sampled in 1995, produces results for the characterisation of the communities that differ from the result from Salzwedel *et al.* (1985). The ranks of the dominant species and the species fulfilling the requirements for characteristic species are different for these new groups. The comparison of the faunal communities from 1975 and 1995 is based only on these new groups, thus the results presented here differ from those from Salzwedel *et al.* (1985).

1995

The dominance structure and species spectrum of most associations has changed and some of the characteristic species from 1975 do not fulfil the requirements in 1995 (see following chapter). Nevertheless the names from Salzwedel *et al.* have been adopted to make a comparison of the associations easier.

The associations on fine and silty sediments (*Amphiura-filiformis-* and *Nucula-nitidosa*-association) are clearly discernible also from the 1995 data (Fig. 3.8.2.4, Fig. 3.8.2.5).

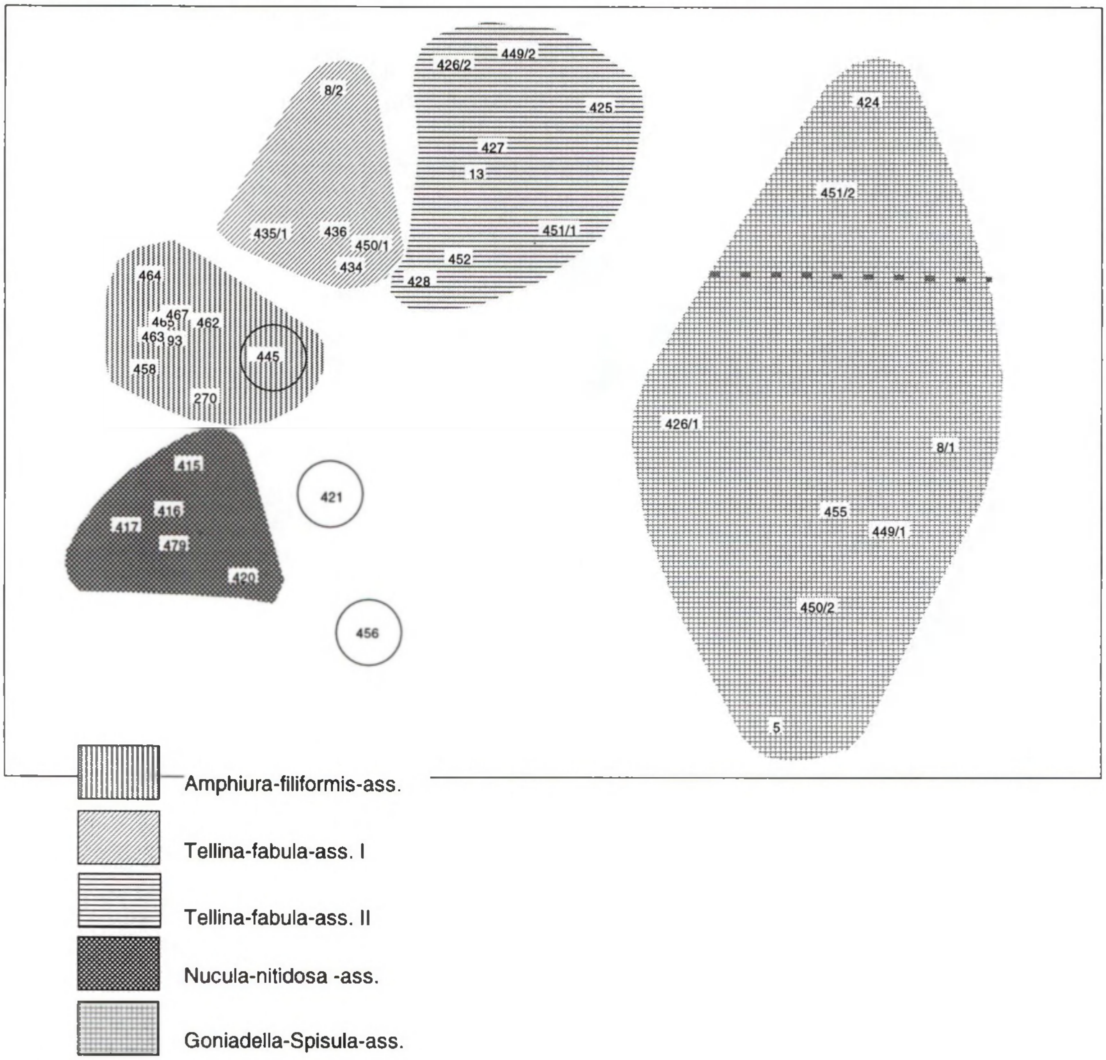


Fig. 3.8.2.4. MDS plot for the data from 1995 (Richter 1996; Bischoff 1996) (stress = 0.15) (using Bray-Curtis index, 4th root transformation). Associations as joint by clusteranalysis (Complete linkage) are marked.

Other associations (especially those located north of Helgoland on variable sediment types) show a slightly different spatial distribution (Fig. 3.8.2.5). Especially the stations that were in 1995 assigned to the (coarse sand) *Goniadella-Spisula*-association differ from those from 1975 (Fig. 3.8.2.4, Fig. 3.8.2.5).

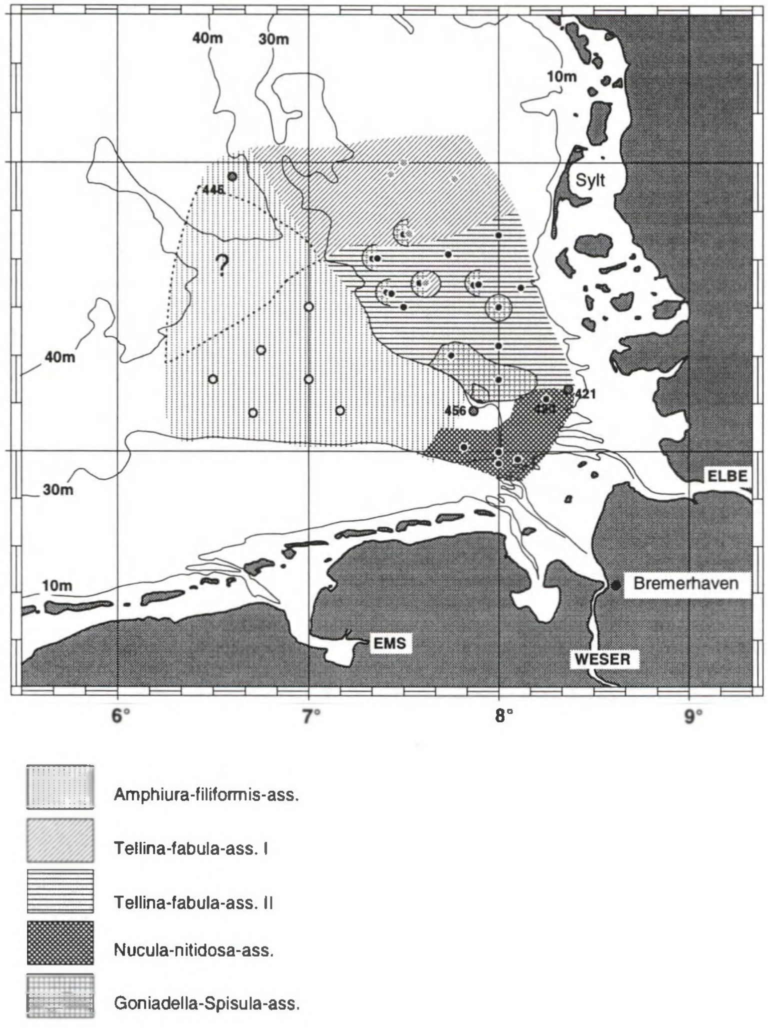


Fig. 3.8.2.5. Spatial distribution of benthic macrofauna associations in the German Bight 1995 (Data from Richter 1996; Bischoff 1996).

The area of the *Tellina-fabula*-association has been divided into a richer *Tellina-fabula*-association I in the northern part and a poorer *Tellina-fabula*-association II in the southern part. In the area directly north of Helgoland, only stations with coarse sediments were found, thus it was assigned to the *Goniadella-Spisula*-association

The different spatial distribution of the *Goniadella-Spisula*-association within the area of the *Tellina-fabula*-association between the 1975 and 1995 data is caused by the fact that the results from these areas are highly depending on the exact position of the grab. As could often be seen from the sediment in two successive grabs at one station, the sediments in these areas are very patchy and small patches of fine silty sand are located only metres away from others with coarse sand and pebbles. The benthic fauna is highly dependent on the sediment type (Gray 1984; Jones 1950; Kingston & Rachor 1982) thus the corresponding associations also show a patchy distribution.

Comparison of the main characteristics of the benthic fauna between 1925, 1975 and 1995

The different methods used by Hagmeier permit only a very general comparison of the recent data with the data from 1923/24. The abundances and presence of single species are difficult to compare between Hagmeier's data and the recent data, as the small numbers or the absence especially of small species in 1923/24 may only be caused by the methodical differences. Conclusions are mostly only possible about those species that were present in 1923/24 or that are big enough so that he would have found them, had they been present. The development of the biomass should be more reliably analysable, as the exclusion of very small organisms in 1923/24 should not affect the overall biomass that much. However the samples from 1923/24 were taken in May and July, when the biomass is always lower than in autumn due to seasonal variability.

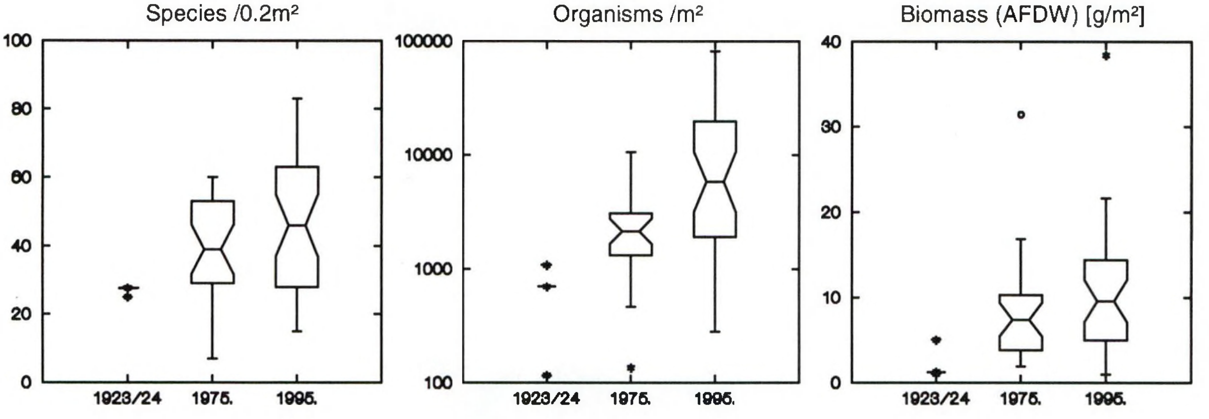


Fig. 3.8.2.6. Main characteristics of the macro benthic fauna 1923-1995. Values from 1923/24 are average values for the communities and are marked by a line with an asterisk. The number of species is expressed for the actually sampled area because extrapolation to m^2 is not possible.

The number of species, the abundances and the biomass of nearly all species groups in all associations were in 1975 already much higher than the average values from 1923/24 (Fig. 3.8.2.6). This may be partly caused by methodical differences especially for the numbers of species and organisms, but, as mostly small organisms should have been missed by Hagmeier (1925), the values for the biomass, showing a significant increase since 1923/24, should be more reliable (Fig. 3.8.2.6).

In general the number of organisms, the number of species as well as the biomass increased again from 1975 to 1995 (Fig. 3.8.2.6). This is mostly caused by an increase of small opportunistic species like polychaetes and *Phoronis* spp. while the density of adult bivalves and echinoderms decreased.

The fact that Hagmeier only found very small numbers of amphipods, cumaceans and small polychaetes may not really reflect an increase in their abundance. However for some species some general trends can be detected:

In general in all associations the numbers of polychaetes have increased since 1923/24, as Hagmeier mentions only very low numbers of polychaetes, while in 1975 and 1995 even the number of tube building polychaetes and bigger species were so high, that he could not have missed them. This trend continues in the development from 1975 to 1995, where the abundance of some species, especially *Phoronis* spp. and *Owenia fusiformis*, as well as some other small polychaetes increased significantly in most areas of the German Bight.

A detailed description of the development follows for the separate associations.

Development of the benthic fauna for separate associations

The Tellina-fabula-association

(sensu Salzwedel *et al.* 1985), named *Venus gallina*-(= *Chamelea gallina)* community by Hagmeier (1925; Stripp 1969), on fine to medium sands north of Helgoland.

In 1975 the area was divided into two subareas, one in the deeper part (*Tellina-fabula*-association A) and one in the shallower parts (*Tellina-fabula*-association B) (Fig. 3.8.2.3). The stations in the shallower part show lower numbers of individuals and species and also differ in the rank of the dominating species, as there were no *Phoronis* spp. and much less juvenile *Ophiura* spp. than in the deeper part.

Only two stations from the shallow part were also sampled in1995 and thus were included in the analysis of the faunal composition (425 + 428). As these two stations were not sufficient for a statistical comparison with the other stations, the description of the development of the *Tellina-fabula*-association is based on the stations from the deeper *Tellina-fabula*-association B from 1975.

The data from 1995 show a different picture, as the area of the *Tellina-fabula*-association is divided into two other subareas: The stations in the northern parts (*Tellina-fabula*-association I) differ from those in the central and southern areas (*Tellina-fabula*-association II).

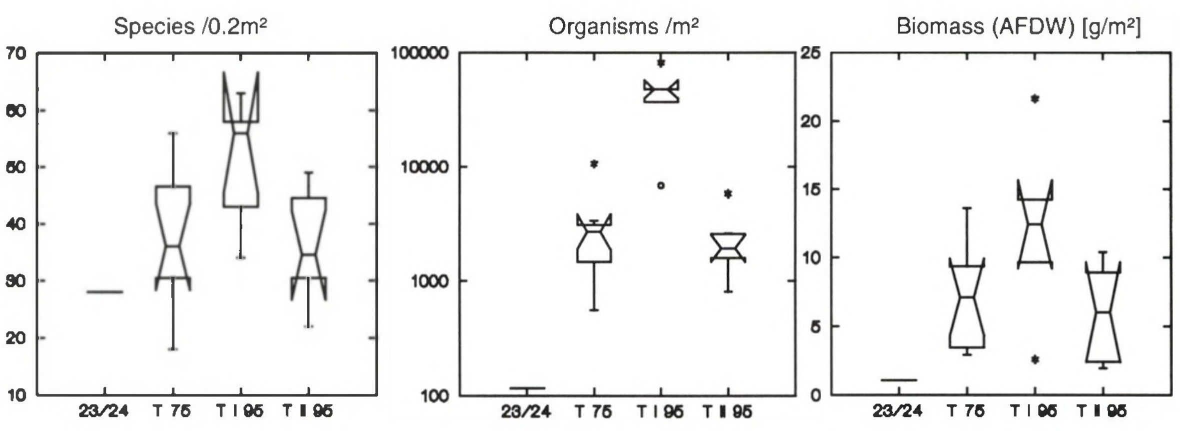


Fig. 3.8.2.7. Development of main characteristics of the *Tellina-fabula*-association 1923-1995. In 1995 this association was divides into two parts: T I and T II.

In the southern part the number of species, the abundances and the biomass are slightly lower than the values from 1975 (Fig. 3.8.2.7). This southern area represents a poorer *Tellina-fabula* association with less organisms and thus also less species (*Tellina-fabula*-association II). The species spectrum however did not differ that much. Seven out of the ten most dominant species of the northern *Tellina-fabula*-association I were also amongst the ten most dominant species in the southern *Tellina-fabula*-association II .

In 1995 in the northern area the number of species, the abundances and the biomass is significantly higher than in the southern area and also significantly higher than the values from 1975 (Fig. 3.8.2.7).

However in the "richer"*Tellina-fabula*-association I the biomass of molluscs is somewhat lower than in the southern *Tellina-fabula*-association II (Fig. 3.8.2.8).

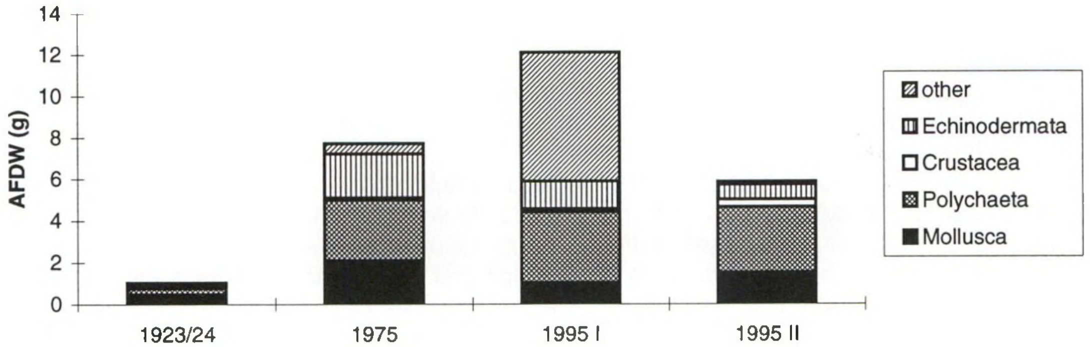


Fig. 3.8.2.8. Development of average biomass of the *Tellina-fabula*-association

The high biomass in the northern part is mostly caused by extremely high numbers of *Phoronis* spp., while in the southern part the biomass of „others" was very low. Compared to 1975 the biomass of molluscs and echinoderms has slightly decreased, while that of polychaetes and „others" increased (Fig. 3.8.2.8). These results however must be looked with caution, as the average values from 1975 were based on 33 stations from a wider area than the study area of 1995, including stations from further north as well as some from the south-western part of the German Bight. Nevertheless, as the trends of the overall biomass shown in these plots are consistent with the results from Fig. 3.8.2.7, that was based on stations from the same area in 1975 and 1995, the findings from Fig. 3.8.2.8 might be accepted (after all they are the only available data for biomass by species-group from 1975).

There are no species in 1995 that are characteristic for this association, which is mostly due to the fact that especially the northern area was dominated by the quite common *Phoronis* spp. and *Owenia fusiformis* and some other small polychaetes, that were also found in other associations. However the species that were characteristic in 1975 were also quiet common in 1995, but did not fulfil the requirements put up by Salzwedel *et al.* (1985).

TABLE 3.8.2.1
Characteristic species for the *Tellina-fabula* association.

1923/24 (after Hagmeier)	1975 (after Salzwedel *et al.*)	1995 (new analysis)
Tellina fabula	*Tellina fabula*	----
Venus gallina	*Magellona papillicornis*	
Spisula solida	*Urothoe grimaldii*	

Only *T. fabula* was named a characteristic species by Hagmeier (1925) and Salzwedel *et al.* (1985). *C. gallina* was not included by Salzwedel *et al.* (1985) as it also appeared in reasonable numbers in other associations. *M. papillicornis* and *U. grimaldii* are rather small species and may not have been conspicuous enough to be called characteristic by Hagmeier (1925). The characterisation of *Spisula solida* as characteristic species in 1923/24 may be caused by the incorporation of coarse sand stations into this community, while in the later studies *S. solida* was named a characteristic species for the (coarse sand-) *Goniadella-Spisula*-association (see following chapter).

The changes in the abundance of single species are listed Table 3.8.2.5 A & B. Because the quantitative data from 1923/24 are not statistically comparable to the more recent data (as mentioned above), for each separate association the changes in the abundance of single species are listed in two separate tables. The changes from 1923/24 to 1975/95, are listed in the first table (I), showing only those species whose abundance obviously changed, while in the second table (II) species are listed that clearly changed in abundance between 1975 and 1995, based on statistical analyses of the data (except for the *Goniadella-Spisula*-association, which was not described in 1925).

The most interesting changes are the disappearance of two larger bivalve species *Arctica islandica* and *Venus gallina* and the strong increase of the tube building worms *Owenia fusiformis* and *Phoronis* spp.

The Goniadella-Spisula-association

is strongly connected to coarse sediments. The stations with this association were found in the area of the *Tellina-fabula*-association (southern part) wherever medium to coarse sediments appeared, therefor the results of these samples were included in the *Venus-gallina*-community by Hagmeier (1925).

The number of species is much lower even than that of the poorer *Tellina-fabula*-association II, while the number of organisms is about the same (Fig. 3.8.2.7, Fig. 3.8.2.9). The biomass is even slightly higher, but this is mostly caused by the large number of *Branchiostoma lanceolatum* in the *Goniadella-Spisula*-association.

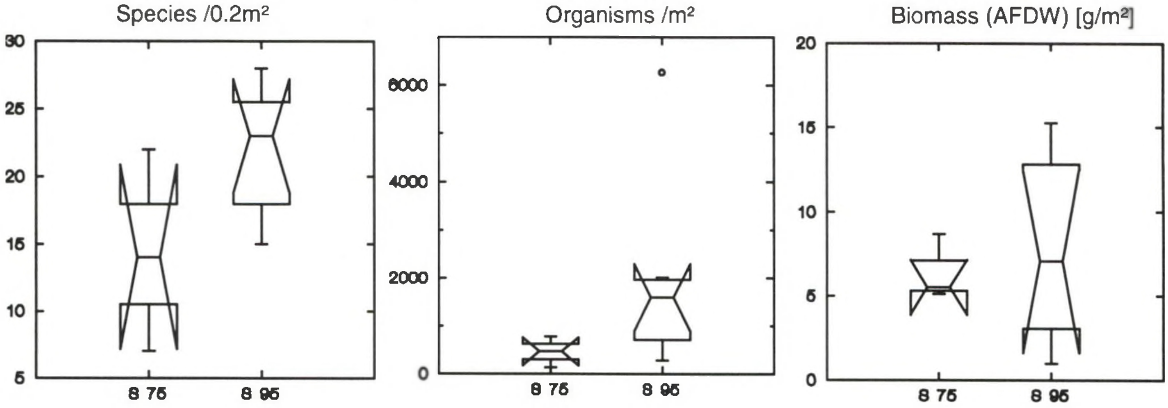


Fig. 3.8.2.9. Development of main characteristics of the *Goniadella-Spisula*-association 1975-1995.

Compared to 1975, in 1995 a significantly higher number of species, a clearly higher number of organisms and a somewhat higher, though very variable biomass were found (Fig. 3.8.2.9). This increase in biomass is caused by the high biomass of *Branchiostoma lanceolatum* and the increase in polychaetes (Fig. 3.8.2.10).

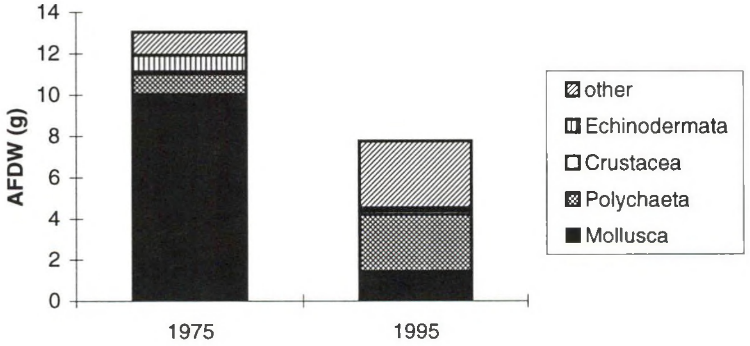


Fig. 3.8.2.10. Development of average biomass of the *Goniadella-Spisula*-associaiton.

The biomass of molluscs probably rather decreased, but the extreme decrease visible in Fig. 3.8.2.10 is an artefact caused by the inclusion of four stations from the "Borkum Reef" into the *Goniadella-Spisula*-association in 1975, an area which was not sampled in 1995 and which is characterised by relatively high numbers of large bivalves. Also in 1975 high numbers of bivalves were found at these stations, but detailed biomass data are not available. This inclusion of "Borkum Reef" is also the cause for the contradiction between Fig. 3.8.2.9 showing a slight increase in median biomass and Fig. 3.8.2.10 showing a steep decline in the average overall biomass.

TABLE 3.8.2.2
Characteristic species for the Goniadella-Spisula-association.

1923/24 (after Hagmeier)	1975 (after Salzwedel *et al.*)	1995 (new analysis)
Community not separated	*Goniadella bobretzkii* *Spisula spp.* *Polygordius sp.*	*Pisione remota* *Protodorvillea kefersteinii* *Polygordius sp.* *Aonides paucibranchiata* *(Branchiostoma lanceolatum)*

As also indicated by the high variation in biomass (Fig. 3.8.2.9) and by relatively low similarity indices (visible as distances on Fig. 3.8.2.2 & Fig. 3.8.2.4) between the faunal composition of the stations that are grouped in this association, there are strong variations and fluctuations in the abundances and dominances of the species. This makes it rather difficult to characterise this association by a few characterising species.

The changes in the abundance of single species are listed Table 3.8.2.5 B (Annex).

The Amphiura-filiformis-association

(sensu Salzwedel *et al.* 1985) was named „*Echinocardium-filiformis*-community" by Hagmeier (1925), but renamed because *E. cordatum* also appears in high numbers in other associations and thus can not be called characteristic. It is situated in the area west and north-west of Helgoland on silty fine sands.

While in 1975 none of the stations showed extremely high or low abundances or species numbers, in 1995 these values were extremely high (Fig. 3.8.2.11).

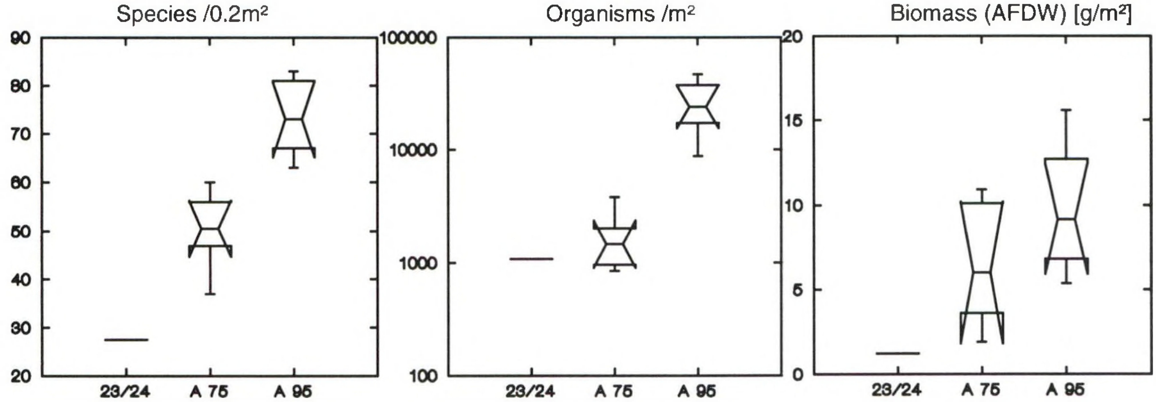


Fig. 3.8.2.11. Development of main characteristics of the *Amphiura-filiformis*-association 1923-1995.

Especially *Phoronis* spp. and *Owenia fusiformis* showed very high abundances, both tube building suspension feeders, that did not belong to the 10 dominating species in 1975. Compared to the average densities of the last 70 years (1923/24, 1966, 1975, 1984; as listed in Rachor 1990), it becomes evident that the numbers of individuals per m² have never been as high as in 1995. An interesting point is the fact that in the years when *Phoronis* spp. were dominant (1966, 1984 and 1995) also *Owenia fusiformis* was noted amongst the 12 most dominant species, while in the years where *Amphiura filiformis* was the dominant species, neither *Phoronis* spp. nor *O. fusiformis* were amongst the dominant ones.

The biomass was also clearly higher in 1995 than in 1975 but not significantly so, as the values varied too much between stations (Fig. 3.8.2.11).

As for the *Tellina-fabula*-association and the *Goniadella-Spisula*-association, the average biomass of bivalves and echinoderms decreased, while that of polychaetes and "others" (here mainly *Phoronis* spp.) increased (Fig. 3.8.2.12).

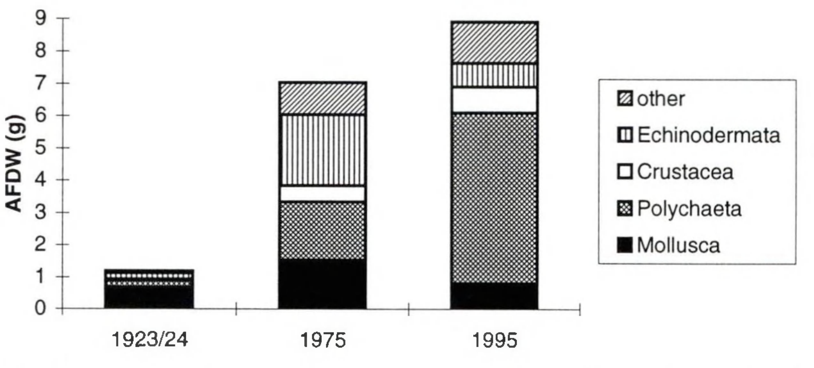


Fig. 3.8.2.12: Development of average biomass of the *Amphiura-filiformis*-association.

As mentioned for the *Tellina-fabula*-association, these results from the average values must be treated with care, because in 1995 only the inner part of the area was sampled.

TABLE 3.8.2.3
Characteristic species for the *Amphiura-filiformis*-association.

1923/24	1975	1995
Echinocardium cordatum	*Amphiura filiformis*	*(Magellona alleni)*
Amphiura filiformis	*(Magellona minuta)*	*(Thracia phaseolina)*
Cylichna cylindracea	*(Diplocirrus glaucus)*	*(Acteon tornatilis)*
Ophelina accuminata		*Aonides paucibranchiata*

( ) = species with low dominance

Amphiura filiformis, which was identified as characteristic species in 1923/24 and 1975, was not as abundant in 1995, but juveniles of *Amphiura* spp. were one of the most abundant organisms. The most dominant species in 1995 (*Phoronis* spp., *Owenia fusiformis*) can not be called characteristic as they were abundant in the whole study area.

The changes in the abundance of single species are listed Table 3.8.2.5 A & B.

The most interesting changes are the increase in the abundance of polychaetes and *Phoronis* spp. and the decreasing abundance of the bivalve *Venus striatula* and of the gastropod *Turritella communis* which was not found in 1995.

According to the species spectrum there is a close relation to the *Nucula-nitidosa*-association and some similarities with the *Tellina-fabula*-association as had also been stated by Hagmeier (1925) and Salzwedel *et al.* (1985)

Station 445 in the north-western corner of the area of investigation differs from all other station of the *Amphiura-filiformis*-association for several reasons: The species spectrum resembles the one of the northern *Tellina-fabula*-association while some of typical species of silty sediments like *Abra nitida* and *Nucula nitidosa* were also found.

It also is the deepest Station of the *Amphiura-filiformis*-association with finer sediments than the rest and may be closer to the typical *Amphiura-filiformis*-association as Hagmeier (1925) called it. In addition to this, this station is relatively close to the area of the *Tellina-fabula*-association and may have a transitional character between these two associations (Fig. 3.8.2.3, Fig. 3.8.2.5).

Station 456 differs from the rest as it is the deepest station of this study (53 m), lying in the „Helgoländer Tiefe Rinne" on sediment that is dominated by shell fragments (Fig. 3.8.2.3, Fig. 3.8.2.5). It shows a very special species spectrum. Nine species were only found here, amongst them species that normally appear on stony ground like *Pomatoceros triqueter*, *Polyplacophora* spp. and *Pantopoda* sp. On the other hand several species of fine and silty sediments were found here like *Scalibregma inflatum* and *Callianassa subterranea*, indicating a relation to the *Amphiura-filiformis*-association With the exception of juvenile ophiuroids and the amphipod *Photis longicaudatum* that appeared in very high numbers in 1975, the abundance of most species and the overall biomass was higher in 1995.

The Nucula-nitidosa-association

(sensu Salzwedel *et al.*1985) is situated in the area south of Helgoland on silty sediments. It has been named *Scrobicularia-(Abra-)alba* community (Hagmeier 1925, Stripp 1969) and *Echiurus echiurus* coenosis (Dörjes 1968; Dörjes *et al.* 1970) but was renamed by Salzwedel *et al.* because of the higher dominance and presence of *Nucula nitidosa*. It is a typical association on silty sediments with a high content of organic matter (Stripp 1969). In a more detailed analysis of the fauna of the area surrounding Helgoland, Stripp (1969) distinguished a central area south-east of Helgoland and a southern and an eastern fringe zone. While it is not exactly the area of the *Scrobicularia-alba*-community from Hagmeier (1925) (Fig. 3.8.2.1), this central area is also clearly visible from the data from 1975 and 1995 and the eastern stations (421 and 422) correspond to the eastern fringe zone (Fig. 3.8.2.3 & Fig. 3.8.2.5).

The species spectrum from 1995 resembles the one from 1975 and the median number of species is higher in 1995 but does not differ significantly (Fig. 3.8.2.13). However, the number of organisms was significantly higher in 1995 (Fig. 3.8.2.13), which was mostly caused by a few species (especially *Owenia fusiformis, Mysella bidentata*).

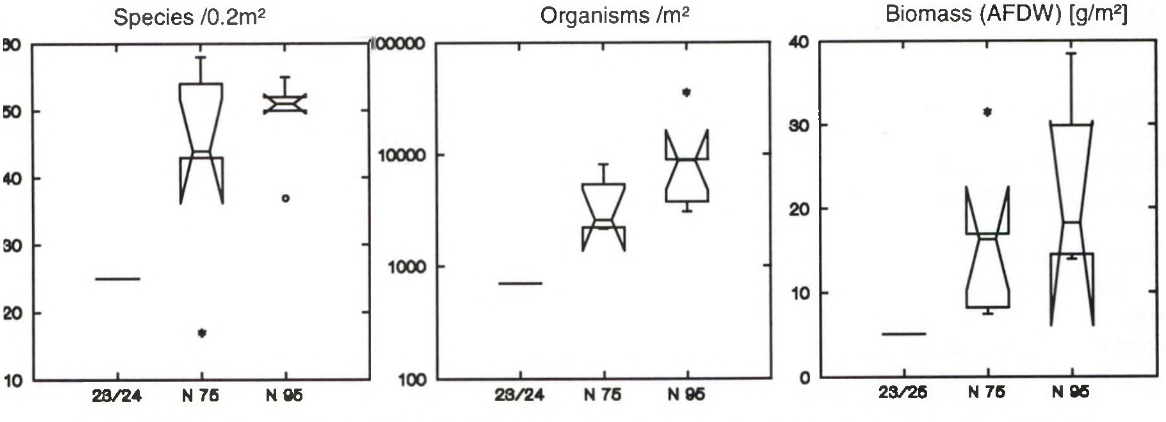


Fig. 3.8.2.13. Development of main characteristics of the *Nucula-nitidosa*-association 1923-1995.

The overall biomass was generally higher in 1995, but as it varied too much between stations, this increase was not significant (Fig. 3.8.2.13). Unlike the other associations, the *Nucula-nitidosa*-association includes the same area in 1975 and 1995 and thus the average values are better comparable.

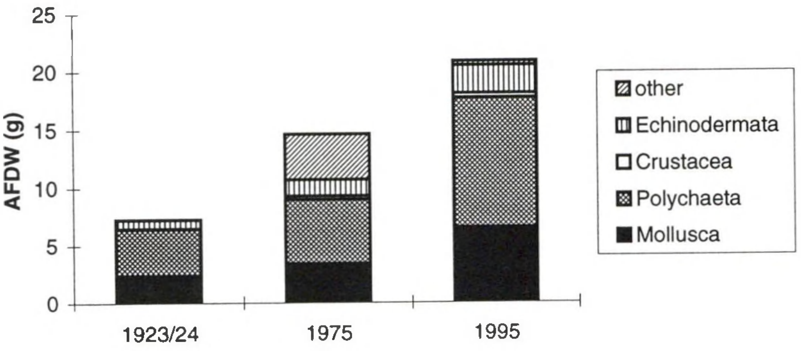


Fig. 3.8.2.14. Development of average biomass of the *Nucula-nitidosa*-association

There is a consistent increase in biomass of molluscs, polychaetes and echinoderms from 1925 over 1975 to 1995, while crustaceans and "others" only play a minor role (Fig. 3.8.2.14).

TABLE 3.8.2.4
Characteristic species for the *Nucula-nitidosa*-association

1923/24 (after Hagmeier)	1975 (after Salzwedel *et al.*)	1995 (new analysis)
Abra alba	*Nucula nitidosa*	*Nucula nitidosa*
Corbula gibba	*Diastylis rathkei*	*Mysella bidentata*
Ophiura albida		*(Ampharete finmarchica)*
Ophiura ophiura		
(Nucula nitidosa)		

( ) = species with low dominance

Only *N. nitidosa* was consistently characteristic for this association. The other species that were called characteristic by Hagmeier (1925) also frequently occur in other associations and showed only very low dominance values in 1975 and/or 1995. *Owenia fusiformis*, the most dominant species in 1995, is for the first time amongst the 10 most dominating species of this association (Salzwedel 1985; Rachor 1990).

This area is an area of high organic input of organic matter due to the input from several rivers and from high primary production, Additionally the area is characterised by strong fluctuations in salinity and temperature and is subjected to low near-bottom oxygen levels under certain conditions (Rachor 1990). Therefore it is an ecologically sensitive area where species may settle or disappear rather rapidly (Rachor 1990). Thus the abundance of single species may under certain conditions increase very rapidly and become numerically dominant as for example *O. fusiformis* in 1995. The changes in the abundance of single species are listed Table 3.8.2.5 A & B.

The most interesting changes are the increase in the abundance of polychaetes, especially *O. fusiformis,* of *Phoronis* spp. and of the small bivalve *Mysella bidentata*.

The species spectrum of the stations 420 and 421 resembles this association but the fauna differs by their low number of organisms and species and the presence of *Macoma baltica* and some other species indicating a transition to the *Macoma-baltica*-association of shallow areas, which were not included in this investigation. There were also some species that are characteristic for the *Tellina-fabula*-association (e.g. *Tellina fabula, Magellona papilicornis*), indicating that these stations represents a transition between these three associations.

Discussion and conclusion

Development of the benthic fauna of the entire German Bight

The geographic borders between the faunal association in the German Bight are relatively stable and have remained relatively unchanged, while the faunal composition of these associations is less stable (Rachor 1990) and has changed considerably since 1923/24. Strong fluctuations not only of seasonal character, but also between the years, as well in the abundance of the species as in the biomass, have been documented frequently (Rachor & Gerlach 1978; Rachor 1990; Niermann *et al.* 1990; Duineveld *et al.* 1991). Due to the highly unstable living conditions of these shallow water associations, these communities probably never reach a stable and balanced climax situation (Rachor & Gerlach 1978) and every study will find different successional stages.

On the one hand this is caused by the relatively high natural variability of the communities of the North Sea and their elasticity against short-term and localised disturbances (Rachor & Gerlach 1978; Niermann *et al.* 1990; Rachor 1990). On the other hand it is often not possible to distinguish the influence of fisheries from the multiple influences of pollution and eutrophication (Rachor 1990; Duineveld *et al.* 1991).

The benthic communities in the North Sea show a significant increase in biomass and a change in community structure with a dominance of opportunistic short-lived species and a decrease of long-living sessile organisms like several bivalve species (Rachor 1990; Duineveld *et al.* 1987; Kröncke 1992; Witbaard & Klein 1993; Kröncke & Knust 1995). These trends have been confirmed by this investigation showing higher abundances and biomass of these opportunistic species in most areas than all preceding investigations.

For many species whose distribution is concentrated in certain association, a long term trend can only be seen for these separate associations. However there is a general trend which is similar for all associations.

Increasing trend	Decreasing trend
abundance & biomass of Phoronis spp.	
abundance & biomass of suspension feeding polychaetes:	
e.g. *Owenia fusiformis*	
Lanice conchilega	
Magellona spp.	
Spionidae	
abundance of some predatory polychaetes:	
Nepthys spp.	
Nereis spp.	
Abundance of brittle stars:	**overall biomass of echinoderms**
Amphiuridae	
Ophiuridae	
abundance of cumaceans:	
Pseudocuma longicornis	
Eudorella emarginata	
abundance of smaller bivalves:	**abundance of larger long-lived bivalves**:
Abra spp.	*Arctica islandica*
Tellimya ferruginosa	*Chamelea gallina*
Tellina fabula	**overall biomass of molluscs**
(mainly juvenile specimen)	

The only exception to this rule is the especially muddy and nutrient rich area of the *Nucula-nitidosa*-association, where the biomass of all groups increased, including those of the echinoderms and molluscs.

Frequent disturbances favour the establishment of small, opportunistic species, while the densities of larger long lived species are reduced (Rachor & Gerlach 1978; Riesen & Reise 1982; Kröncke 1992). Apart from the influence of eutrophication, which generally induces a similar effect, this may be seen as an indication for an increase in the frequency of disturbance from the increased fishing pressure (Chapter 3.1). This may contribute to the explanation of the extremely high numbers of *Phoronis* spp., *Magelona* spp., *Owenia fusiformis*, *Spiophanes bombyx* and other opportunistic species. These species can colonise disturbed areas very quickly and they are not very dependent on the exact type of sediment, leading to a wide spread dominance of this group. Mostly the increased eutrophication had been used to explain this trend (Rachor 1990), but a general increase in the supply of organic matter within certain limits should also result in better conditions for filter and suspension feeders like most bivalves and several echinoderms. However the numbers and especially the biomass of these species declined, while that of the above mentioned opportunistic species increased. This provides evidence for an increased frequency of disturbance, stronger affecting longer lived species and putting the faunal communities back to an earlier successional stage. Although there are natural factors of disturbance like oxygen deficiencies situations, strong storms causing sediment movements or extremely cold temperatures, fishery today has become one very important disturbing factor. Mechanical disturbances caused by natural events (sediment movements) may expose or bury organisms, but will rarely result in mechanical damage or destruction of animals. None of the naturally occurring events produces the same effects as bottom fisheries, physically crushing or damaging many benthic species (see Chapter 3.5). Thus the additional disturbance caused by bottom fishery not only increases the frequency of disturbances but also adds a different quality. The direct effects are quite different from those caused by water current driven sediment movements, by oxygen deficiencies or by temperature anomalies.

Comparing the observed long term changes in benthic communities to the direct effects of bottom fisheries (Chapter 3.5 and 3.6) and to the differences found between fished and unfished areas (Chapter 3.7) shows clear parallels. This leads to the conclusion that demersal fishery has become a keyfactor causing the detected changes of the benthic fauna of the North Sea.

TABLE 3.8.2.5A
Species with obvious changes in abundance from 1923/23 to 1975/95 (details: Table 3.8.2.6).

Association	'75/'95 more abundant	'75/'95 less abundant	'75/'95 new	'75/'95 disappeared
Telina-fabula-ass.	*Tellina fabula** *Chamelea gallina*		*Cylichna cylinddracea* *Lunatia poliana* *Phaxas pellucidus* *Mactra corallina* *Tellimya ferruginosa* *Corystes cassivelaunus* *Branchiostoma lanceolatum* *Edwardsia* spp. *Phoronis* spp.	*Arctica islandica* *Nucula nitidosa*
Amphiura-filiformis-ass.	Polychaeta *Ophiura* spp.	*Turritella communis* *Chamelea gallina* *Asropecten* spp.	*Phaxas pellucidus* *Corbula gibba* *Mactra corallina* *Tellimya ferruginosa* *Phoronis* spp.	*Ebalia cranchii*
Nucula-nitidosa-ass.	Polychaeta Amphiurids	*Aphrodita aculeata*	*Cylichna cylindracea* *Lunatia poliana* *Mysella bidentata* *Venus striatula* *Phoronis* spp.	

* new name is *Fabulina fabula*.

TABLE 3.8.2.5B
Species with obvious changes in abundance from 1975 to 1995 (details: Table 3.8.2.6).

Association	'95 more abundant	'95 less abundant	'95 new	'95 disappeared
Tellina-fabula ass. *=only in the rich Tellina-ass. I °=only in the poor Tellina-ass. II	*Anaitides maculata* *Owenia fusiformis** *Branchiostoma lanceolatum** *Pseudocuma longicornis** *Phoronis spp.**	*Capitella capitata*	*Eumida bahusiensis* *Diastylis rathkei* *Aonides paucibranchii* *Sigalion mathildae** *Parvicardium ovale* *Abra alba*	*Chamelea gallina* *Eumida punktifera* *Diastylis bradyi* *Glycinde nordmannii°* *Anaitides groenlandica* *Cerianthus lloydii°* *Capitella capitata**
Goniadella-Spisula-ass.	*Pisione remota* *Eumida sp. 1* *Spio filicornis*	*Synchelidium haplocheles* *Ensis sp.*	*Protodorvillea kefersteinii* *Lanice conchilega* *Hesiunura augeneri* +45 rare species	*Iphinoe trispinosa* *Lutraria lutraria* + 14 rare species
Amphiura-filiformis-ass.	*Pseudocuma longicornis* *Orchomenella nana* *Eudorella emarginata*	*Amphiura filiformis*	*Phtisica marina* *Acrocnida brachiata*	*Edwardsia spp.* *Cerianthus lloydii* *Turritella communis*
Nucula-nitidosa-ass.	*Owenia fusiformis* *Mysella bidentata* *Pariambus typicus* *Eudorella emarginata* *Amphiura filiformis* *Amphiura spp. juv.*	*Scoloplos armiger* *Eumida punktifera* *Diastylis rathkei*	*Acrocnida brachiata* *Nuculoma tenuis* *Nucula nitidosa*	*Edwardsia sp.*

TABLE 3.8.2.6
Species list with semiquantitative abundances per association.

	Nucula-nitidosa			Amphiura-filiformis			Tellina-fabula				Goniadella-Spisula	
	23/24	75	95	23/24	75	95	23/24	75	95 I	95 II	75	95
Gastropoda												
Actaeon tornatilis	-	X	X	-	X	X	X	X	-	X	-	-
Hyala vitrea	-	1	-	-	-	X	-	-	-	-	-	-
Cylichna cylindracea	-	X	XX	X	X	X	-	X	X	X	-	-
Lunatia poliana	-	XX	XX	X	XX	XX	-	XX	XX	X	-	X
Chrysallida obtusa	-	-	-	-	-	1	-	-	-	-	-	-
Retusa umbilicata	-	-	-	-	-	XX	-	-	-	-	-	-
Trophonopsis muricatus	-	-	-	-	-	-	-	-	X	-	-	-
Turritella communis	-	-	-	XX	X	-	-	-	-	-	-	-
Hydrobia ulvae	X	-	-	-	-	-	-	-	-	-	-	-
Vitreolina philippi	-	-	X	-	-	X	-	-	-	-	-	-
Bivalvia												
Abra alba	XX	XXX	XXX	-	XX	XX	-	-	XX	XX	-	X
Abra nitida	-	XX	XX	X	1	X	-	-	-	X	-	-
Acanthocardia echinata	-	-	X	-	-	XX	-	-	X	-	-	-
Arctica islandica	-	X	1	-	X	1	X	-	-	-	-	-
Tridenta montagui	-	-	-	-	-	1	-	-	-	-	-	-
Goodallia triangularis	-	-	-	-	-	-	-	-	-	-	-	XX
Corbula gibba	XX	-	XX	-	X	XX	-	-	-	-	-	-
Phaxas pellucidus	X	XX	X	-	XX	XXX	-	XX	X	X	1	-
Dosinia sp.	-	-	-	X	-	-	-	X	-	-	-	1
Ensis sp.	-	-	X	-	-	-	X	1	X	X	XX	X
Lutraria lutraria	-	-	X	-	1	-	-	-	-	-	XX	-
Macoma balthica	X	XX	-	-	-	-	-	-	-	-	1	-
Mactra corallina	X	-	1	-	X	X	-	XX	XX	X	1	-
Montacuta ferruginosa	X	XX	XX	-	X	XX	-	X	X	1	-	-
Mya arenaria	-	-	-	-	-	1	-	-	-	-	-	-
Mya sp.	-	XX	-	-	-	-	-	1	-	-	-	-
Mysella bidentata	-	XXX	XXXX	XX	XX	XX	-	X	-	-	-	-
Mysia undata	-	-	-	-	1	-	-	1	-	-	-	-
Nucula nitidosa	XXX	XXXX	XXXX	XXX	XX	XX	X	1	-	-	-	-
Nuculoma tenuis	-	-	XX	-	-	XX	-	-	-	-	-	-
Petricola pholadiformis	X	-	X	-	-	XX	-	-	-	-	-	-
Parvicardium ovale	-	-	-	-	-	-	-	-	XX	X	-	-
Saxicavella jeffreysi	-	XX	-	-	-	-	-	-	-	-	-	-
Spisula juv.	-	-	-	-	-	-	-	-	-	-	-	1
Spisula solida	-	-	-	-	-	-	X	-	-	X	X	X
Spisula subtruncata	-	XX	XX	-	XX	XX	1	X	-	-	-	1
Fabulina fabula	X	XX	XX	X	X	XX	X	XXX	XXX	XX	-	X
Moerella pygmea	-	-	-	-	-	-	-	-	-	-	1	-
Angulus tenuis	-	-	-	-	-	-	-	-	-	X	-	-
Thracia juv.	-	-	-	-	-	-	-	-	-	X	-	-
Thracia phaseolina	-	-	-	-	XX	XX	-	1	-	-	X	-
Thyasira flexuosa	X	XXX	XX	X	XX	XX	-	-	X	-	-	X
Thyasira subtrigona	-	-	-	-	-	1	-	-	-	-	-	-
Venerupis pullastra	-	-	-	-	-	X	-	-	-	-	-	-
Clawinella fascicata	-	-	-	-	-	-	-	-	1	X	-	-
Timoclea ovata	-	-	-	-	-	-	-	-	1	-	-	-
Chamelea gallina	-	X	X	XX	X	X	X	XX	-	-	-	-

Average abundances: - = 0; 1 = 1; X = < 10; XX = < 100; XXX = < 1000; XXXX = < 10 000; XXXXX = > 10 000

Cont. TABLE 3.8.2.6

	Nucula-nitidosa			Amphiura-filiformis			Tellina-fabula				Goniadella-Spisula	
	23/24	75	95	23/24	75	95	23/24	75	95 I	95 II	75	95
Polychaeta												
Ampharete acutifrons	-	-	X	-	X	-	-	-	-	-	-	-
Ampharete finmarchica	-	-	XX	-	-	-	-	-	-	-	-	X
Ampharete sp.	-	XX	-	-	-	-	-	-	-	-	-	-
Anaitides groenlandica	-	X	-	-	X	X	-	XX	XX	-	1	X
Anaitides maculata	-	X	-	-	-	-	-	1	XX	XX	-	-
Anaitides mucosa	-	X	1	-	1	X	-	X	-	-	-	-
Anaitides subulifera	-	XX	-	-	X	XX	-	XX	XX	X	-	-
Aonides paucibranchiata	-	-	-	-	1	-	-	-	-	X	XX	XXX
Aphrodita aculeata	X	1	1	-	X	X	-	-	-	-	-	-
Aricidea minuta	-	-	-	-	-	-	-	-	-	X	-	-
Autolytus prolifera	-	1	X	-	X	X	-	X	-	-	-	-
Capitella capitata	-	X	-	-	-	-	-	XX	-	1	-	-
Capitomastus minimus	-	XX	X	-	1	-	-	-	-	-	-	-
Chaetopterus variopedatus	-	-	-	-	-	-	-	1	-	-	-	X
Chaetozone setosa	-	-	-	-	X	XX	-	XX	XXX	XX	-	-
Chone duneri	-	1	-	-	X	1	-	X	-	-	-	-
Chone infundibuliformis	-	-	-	-	X	-	-	-	-	-	-	-
Diplocirrus glaucus	-	1	-	-	XX	X	-	-	-	-	-	-
Eteone flava	-	X	-	-	-	-	-	1	X	X	-	-
Eteone foliosa	-	-	-	-	-	-	-	1	-	-	-	-
Eteone longa	-	X	X	-	X	XX	-	X	XX	X	-	X
Eteone spitsbergensis	-	-	-	-	1	-	-	X	-	-	-	-
Eumida spp.	-	XX	XX	-	XX	XX	-	XX	XX	XX	X	XX
Phylodocidae spp.	-	-	-	-	-	-	X	-	-	-	-	-
Exogone hebes	-	-	-	-	-	-	-	-	-	-	-	X
Fabriciola baltica	-	-	-	-	-	X	-	-	-	-	-	-
Gattyana cirrosa	-	X	-	-	-	X	-	-	-	-	-	-
Glycera alba	-	-	-	-	-	-	-	-	-	X	-	X
Glycera lopidum	-	-	-	-	-	-	-	-	-	-	X	X
Glycera juv.	-	-	-	-	-	-	-	-	X	X	-	XX
Glycinde nordmanni	-	X	X	-	XX	XX	-	XX	XX	-	X	XX
Goniada maculata	-	XX	X	-	XX	XX	-	XX	XX	X	-	X
Goniadella bobretzkii	-	-	-	-	-	-	-	X	1	-	XXX	XX
Gyptis helgolandica	-	X	XX	-	X	X	-	X	X	1	-	-
Harmothoe imbricata	-	-	-	-	-	X	-	-	-	-	-	-
Harmothoe lljungmani	-	-	-	-	-	-	-	-	-	XX	-	XX
Harmothoe glabro	-	X	-	-	X	-	-	X	X	X	-	X
Harmothoe lunulata	-	XX	XX	-	X	XX	-	X	-	X	-	XX
Eunoe nodosa	-	-	1	-	-	-	-	-	-	-	-	X
Harmothoe sarsi sarsi	-	1	-	-	X	-	-	-	-	-	-	-
Heteromastus filiformis	-	1	-	-	-	-	-	-	-	-	-	-
Hauchiella tribullata	-	-	-	-	-	-	-	-	-	-	-	X
Hesionura augeneri	-	-	-	-	-	-	-	-	-	-	-	XX
Lanice conchilega	-	XXX	XX	-	XX	XX	-	XX	XX	XXX	-	XXX
Lysilla loveni	-	-	1	-	-	-	-	-	-	-	-	-
Terebellidae spp.	-	-	-	-	-	-	X	-	-	-	-	-
Magelona aleni	-	-	-	-	XX	XX	-	X	1	-	-	-
Magelona minuta	-	-	-	-	XX	XXX	-	XX	XXX	X	-	-
Magelona papillicornis	-	X	X	-	XX	XXX	-	XXX	XXXX	XXX	-	X
Maldanidae spp.	X	-	-	-	-	-	-	-	-	-	-	-
Mediomastus fragilis	-	-	X	-	-	-	-	-	-	-	-	-

Average abundances : - = 0; 1 = 1; X = < 10; XX = < 100; XXX = < 1000; XXXX = < 10 000; XXXXX = > 10 000

Cont. TABLE 3.8.2.6

	Nucula-nitidosa			Amphiura-filiformis			Tellina-fabula				Goniadella-Spisula	
	23/24	75	95	23/24	75	95	23/24	75	95 I	95 II	75	95
Nephtys caeca	-	X	-	-	1	1	-	X	-	XX	-	X
Nephtys ciliata	-	-	-	-	-	-	-	-	-	1	-	-
Nephtys cirrosa	-	-	-	-	-	-	-	XX	-	XX	XX	XX
Nephtys hombergii	-	XXX	XXX	-	XX	XX	-	XX	XX	XX	-	X
Nepthys sp.	XX	-	-	X	-	-	X	-	-	-	-	-
Nephtys longosetosa	-	-	-	-	-	-	-	X	X	X	X	-
Nephtys juv.	-	XX	XXX	-	XX	XX	-	X	XX	XXX	-	XX
Nereis longissima	-	X	X	-	-	X	-	X	-	1	-	-
Nereis virens	X	-	-	-	-	-	-	-	-	-	-	-
Nereis juv.	-	-	-	-	-	X	-	-	XX	XX	-	-
Notomastus latericius	-	XX	XX	-	X	-	-	X	-	X	X	XX
Ophilia limacina	-	-	-	-	-	-	X	X	-	XX	X	X
Ophelina acuminata	-	X	-	-	-	X	-	-	-	-	-	-
Ophiodromus flexuosus	-	-	-	-	1	X	-	-	-	-	-	-
Orbinia sertulata	-	-	-	-	-	-	-	-	-	-	1	-
Owenia fusiformis	-	XX	XXXX	X	XX	XXXX	-	X	XXXX	XX	X	X
Lagis auricoma	-	X	-	-	X	-	-	-	-	-	-	-
Lagis koreni	X	XXX	XX	-	X	X	-	XX	X	X	-	-
Lagis sp.	-	-	-	X	-	-	-	-	-	-	-	-
Pherusa plumosa	-	-	-	-	-	-	-	-	-	-	-	-
Pholoe inornata	-	XXX	XXX	-	XXX	XXX	-	XX	XX	X	-	X
Pisione remota	-	-	-	-	-	-	-	-	X	1	1	XXX
Poecilochaetus serpens	-	1	1	-	X	XX	-	X	XX	X	X	XX
Pseudopolydora pulchra	-	XX	XX	-	1	XX	-	X	XX	X	-	-
Enipo kinbergi	-	-	1	-	-	-	-	-	-	-	-	X
Protodorvillea kerfersteini	-	-	-	-	-	-	-	-	X	-	-	XXX
Pygospio elegans	-	-	-	-	-	-	-	-	X	-	-	X
Scalibregma inflatum	XX	XX	XX	-	1	X	-	-	-	-	-	-
Scolelepis foliosa	-	-	-	-	-	-	-	-	-	-	-	X
Scolelepis bonnieri	-	-	-	-	X	XX	-	XX	XX	XX	1	X
Scoloplos armiger	X	XX	XX	-	X	X	XX	XX	XX	XX	-	X
Sigalion mathildae	-	-	-	-	X	X	-	-	XX	1	-	-
Sphaerodorum flavum	-	X	X	-	-	-	-	-	-	-	-	-
Spio filicornis	-	X	-	-	XX	XX	X	XXX	XXXX	XX	X	XXX
Spiophanes bombyx	-	XXX	XX	-	XX	XXXX	-	XXX	XXX	XXX	1	X
Sthenelais limicola	-	1	X	-	X	XX	-	1	X	-	-	-
Sthenelais zetlandica	-	-	-	-	1	-	-	1	-	-	-	-
Tomopteris septentrionalis	-	-	-	-	-	X	-	-	-	-	-	-
Polychaeten spp.	X	-	-	XX	-	-	-	-	-	-	1	-
Amphipoda												
Acidostoma obesum	-	-	-	-	X	-	-	-	-	-	-	-
Ampelisca brevicornis	-	XX	X	-	XX	XX	-	X	-	X	-	-
Ampelisca diadema	-	-	-	-	-	X	-	-	-	-	-	-
Ampelisca tenuicornis	-	-	X	-	-	X	-	-	-	-	-	-
Ampelisca typica	-	-	-	-	-	-	-	1	-	-	-	-
Ampelisca sp.	-	-	-	-	-	-	X	-	-	-	-	-
Amphilochoides boecki	-	-	-	-	-	1	-	-	-	-	-	-
Amphilochus neapolitanus	-	-	X	-	-	X	-	-	-	-	-	-
Amphilochus manudens	-	1	-	-	-	-	-	-	-	-	-	-
Aora typica	-	-	-	-	X	XX	-	1	-	-	-	-
Apherusa cirrus	-	-	-	-	-	X	-	-	-	-	-	-
Apherusa ovalipes	-	-	-	-	-	X	-	-	-	-	-	-
Argissa hamatipes	-	-	X	-	-	X	-	1	X	X	-	-
Bathyporeia tenuipes	-	-	-	-	-	X	-	-	-	-	-	-
Bathyporeia elegans	X	-	-	-	X	-	XX	XX	XX	XX	-	-
Bathyporeia guillamsionana	-	-	-	-	-	-	XX	XX	XX	XX	-	-
Corophium crassicorne	-	-	-	-	-	-	-	1	-	-	-	-

Average abundances : - = 0; 1 = 1; X = < 10; XX = < 100; XXX = < 1000; XXXX = < 10 000; XXXXX = > 10 000

Cont. TABLE 3.8.2.6

	Nucula-nitidosa			Amphiura-filiformis			Tellina-fabula				Goniadella-Spisula	
	23/24	75	95	23/24	75	95	23/24	75	95 I	95 II	75	95
Gitanopsis inermis	-	-	-	-	1	-	-	-	-	-	-	-
Gammaropsis maculata	-	-	-	-	-	1	-	-	-	-	-	-
Gammaropsis palmata	-	-	-	-	-	1	-	-	-	-	-	-
Harpinia antennaria	-	-	-	-	-	X	-	-	-	-	-	-
Harpinia pectinata	-	-	-	-	X	-	-	-	-	-	-	-
Hippomedon denticulatus	-	-	-	-	-	-	-	X	-	-	-	-
Ingolfiellidae	-	-	-	-	-	-	-	-	-	X	-	-
Iphimedia obesa	-	-	-	-	1	-	-	-	X	-	-	-
Leucothoe incisa	-	-	-	-	-	XX	-	-	-	-	-	-
Megaluropus agilis	-	-	X	-	-	X	-	XX	XX	XX	1	-
Melita aculeata	-	-	-	-	1	-	-	-	-	-	-	-
Melita dentata	-	-	-	-	1	-	-	1	-	-	-	-
Abludomelita obtusata	-	X	1	-	1	X	-	X	-	-	-	-
Metopa pusilla	-	-	-	-	-	1	-	-	-	-	-	-
Microprotopus maculatus	-	X	-	-	-	X	-	X	XX	X	-	X
Microdeutopus propincuus	-	-	-	-	-	-	-	-	X	-	-	-
Monuculodes carinatus	-	-	-	-	-	-	-	-	XX	-	X	-
Nototropis falcatus	-	-	1	-	-	-	-	-	-	-	X	-
Atylus swammerdami	-	X	-	-	X	X	-	X	X	X	-	XX
Orchomenella minuta	-	-	-	-	-	-	-	X	-	-	1	-
Orchomenella nana	-	-	-	-	X	XX	-	1	X	-	-	-
Orchomenalla sp.	-	-	-	-	-	-	-	X	-	-	-	-
Paratylus sp.	-	-	-	-	-	-	1	-	-	-	-	-
Pariambus typicus	-	X	XX	-	X	XXX	-	X	XXX	XX	-	X
Perioculodes longimanus	-	X	-	-	X	XX	-	XX	XX	X	X	-
Photis longicaudata	-	-	X	-	XX	X	-	-	-	-	-	-
Photis rheinhardii	-	1	1	-	-	1	-	-	-	-	-	-
Phtisica marina	-	-	-	-	-	XX	-	-	-	-	-	-
Pontocrates arenarius	-	-	-	-	-	-	-	-	-	X	-	-
Stenothoe marina	-	X	XX	-	X	XX	-	X	-	-	-	-
Synchelidium haplocheles	-	-	-	-	X	X	-	XX	XX	XX	XX	X
Urothoe elegans	-	-	-	-	-	-	-	-	XX	-	-	-
Urothoe grimaldii	-	-	-	-	-	-	X	XXX	XX	XX	-	-
Westwoodilla caecula	-	-	-	-	-	-	-	-	-	1	-	-
Amphipoden spp.	-	X	-	XX	1	-	-	XX	X	-	-	-
Cumacea												
Bodotria arenosa	-	-	-	-	-	-	-	-	XX	X	-	-
Diastylis bradyi	-	-	X	-	X	X	-	X	X	-	1	-
Diastylis laevis	-	-	-	-	-	X	-	-	-	-	-	-
Diastylis rathkei	-	XX	X	-	-	1	-	-	XX	XX	-	-
Diastylis rugosa	-	-	-	-	-	-	-	1	-	-	-	-
Eudorella emarginata	-	1	X	-	1	XX	-	-	-	-	-	-
Eudorella truncatula	-	1	-	-	-	-	-	-	-	-	-	-
Iphinoe trispinosa	-	-	-	-	-	-	-	XX	XX	X	X	-
Lamprops fasciata	-	-	-	-	-	-	X	-	-	-	-	-
Pseudocuma longicornis	-	-	1	-	1	XX	-	1	XX	-	-	-
Pseudocuma similis	-	-	-	-	X	X	-	X	XX	XX	1	-

Average abundances : - = 0; 1 = 1; X = < 10; XX = < 100; XXX = < 1000; XXXX = < 10 000; XXXXX = > 10 000

Cont. TABLE 3.8.2.6

	Nucula-nitidosa			Amphiura-filiformis			Tellina-fabula				Goniadella-Spisula	
	23/24	75	95	23/24	75	95	23/24	75	95 I	95 II	75	95
Decapoda												
Callianassa subterranea	-	X	X	-	X	XX	-	-	1	-	-	-
Corystes cassivelaunus	-	-	-	X	X	X	-	1	X	X	-	-
Crangon allmanni	-	-	X	-	-	-	-	-	-	-	-	-
Crangon crangon	-	-	-	X	-	-	X	-	-	-	-	X
Ebalia tuberosa	-	-	-	-	-	1	-	-	-	-	-	-
Ebalia cranchii	-	-	-	X	-	-	-	-	-	-	-	-
Liocarcinus holsatus	-	-	-	-	-	1	-	-	XX	1	-	X
Liocarcinus marmoreus	-	-	-	-	-	X	-	-	-	-	-	-
Pagurus bernhardus	-	-	-	-	-	X	X	-	-	-	-	-
Pontophilus trispinosus	-	-	-	-	-	1	-	-	-	-	-	-
Processa nouveli holthuisi	-	-	-	-	-	X	-	-	-	-	-	-
Thia sculellata	-	-	-	-	-	-	-	-	-	-	-	1
Upogepia deltaura	-	-	-	-	-	1	-	-	-	-	-	1
Mysidacea												
Praunus sp.	-	-	X	-	-	-	-	-	-	-	-	-
Mesopodopsis slabberi	-	-	X	-	-	-	-	-	-	-	-	-
Gastrosaccus spinifer	-	-	X	-	-	1	X	-	-	-	-	-
Schistomysis spiritus	-	-	XX	-	-	-	-	-	-	-	-	-
Mysidacea spp.	-	-	X	-	-	-	-	-	X	X	-	XX
Isopoda												
Pseudione borealis	-	-	1	-	-	-	-	-	-	-	-	-
Echinodermata												
Acrocnida brachiata	-	-	XXX	-	-	XX	-	1	-	-	-	-
Amphipolis squamata	-	-	-	-	-	-	-	X	-	-	-	-
Amphiura chiajei	-	-	-	-	-	-	X	-	-	-	-	-
Amphiura filiformis	1	X	XXX	XX	XXX	XX	-	-	X	X	-	-
Amphiura juv.	-	X	XX	-	XX	XXX	-	-	X	X	-	X
Asterias juv.	-	-	-	-	-	-	-	-	1	-	-	-
Asterias rubens	-	-	-	-	-	X	-	-	-	-	-	-
Astropecten irregularis	-	-	-	XXX	-	X	-	-	X	-	-	-
Echinocardium cordatum	X	XX	XX	XX	XX	XXX	1	XX	XXX	XX	1	X
Echinocardium pennatifidum	-	-	-	-	-	-	-	-	-	-	X	-
Echinocyamus pusillus	-	-	-	-	-	-	-	1	-	-	-	X
Psammechinus miliaris	-	-	-	-	-	-	-	1	-	-	-	-
Ophiotrix fragilis	-	-	-	-	1	-	-	-	-	-	-	-
Ophiura albida	XX	XXX	XXX	-	XX	X	X	XX	X	X	-	-
Ophiura ophiura	XX	XX	XX	-	1	X	1	X	-	-	-	-
Ophiura juv.	XX	XX	XXX	X	XXX	XX	-	XXX	XXX	XXX	XXX	XX
Acrania												
Branchiostoma lanceolatum	-	-	-	X	-	XX	-	1	XX	X	XX	XXX
Cnidaria												
Cerianthus lloydii	-	-	-	-	X	-	-	X	-	-	-	-
Edwardsia sp.	-	-	-	-	XX	-	-	XX	XXX	XX	-	X
Tentaculata												
Phoronis spp	-	XXX	XXX	-	XX	XXXX	-	XXX	XXXXX	XX	-	X
Archeannelida												
Polygordius sp.	-	-	-	-	-	-	-	-	-	-	-	XXX
Oligochaeten												
Grania sp.	-	1	X	-	-	X	-	-	-	X	-	XX

Average abundances : - = 0; 1 = 1; X = < 10; XX = < 100; XXX = < 1000; XXXX = < 10 000; XXXXX = > 10 000

3.8.3. LONG-TERM IMPACT OF BOTTOM FISHERIES ON SEVERAL BYCATCH SPECIES OF DEMERSAL FISH AND BENTHIC INVERTEBRATES IN THE SOUTH-EASTERN NORTH SEA

The fish catchability model explained well the relation between gear-specific and species-specific fishery pressure and the number of bycatch species as delivered to the Dutch Zoological Station at Den Helder between 1947 and 1981 for most demersal fish and benthic invertebrates with the exception of one species. Furthermore, the model results of three other species are thought to be unreliable because the correlations between the parameter estimates were high, i.e. > 0.9 (Table 3.8.3.1). The variation in numbers of bycatch, appears therefore to be related to the variation in gear and effort of bottom trawlers for most bycatch species considered.

TABLE 3.8.3.1

Parameter estimates (and 95% confidence intervals between brackets) for the data presented in Fig. 3.8.3.1. The value of the parameter q_1 is the otter trawl catch efficiency, i.e. the probability that an animal in the path of the otter trawl is captured per unit otter trawling effort per year. The value of the parameter q_2 is the beam trawl catch efficiency, i.e. the probability that an animal in the path of the beam trawl is captured per unit beam trawling effort per year. The value of the parameter N_1 is the total exploitable population size in the sampling area during the first year of the study period. The correlation coefficients *r* indicate how dependent the parameter estimates are of each other, e.g. high values imply that different values of the parameter estimates are possibly with a similar goodness-of-fit of the catchability model.

	q_1	q_2	N_0^*	correlation coefficients		
Species	($n \cdot n^{*-1} \cdot e^{-1} \cdot y^{-1}$)	($n \cdot n^{*-1} \cdot e^{-1} \cdot y^{-1}$)		$q_2\ q_1$	$q_2\ N_0^*$	$q_1\ N_0^*$
Smooth hound	0.15 (0.03)	0.40 (0.87)	558 (69)	0.33	-0.29	-0.75
Small spotted cat shark	0.09 (0.02)	0.00 (0.04)	4267 (635)	0.32	-0.33	-0.86
Roker	0.24 (0.06)	0.47 (2.60)	639 (122)	0.05	-0.01	-0.68
Common skate	0.12 (0.00)	0.00 (0.00)	805 (225)	-0.60	0.11	-0.86
Stingray	0.07 (0.01)	0.44 (0.31)	435 (54)	0.37	-0.41	-0.41
Greater weever	0.31 (0.07)	1.53 (9.52)	445 (71)	-0.01	0.01	-0.74
Angler	0.14 (0.04)	0.23 (0.82)	129 (30)	0.22	-0.19	-0.68
Common whelk	0.04 (0.02)	1.37 (1.15)	3822 (1060)	0.47	-0.58	0.23
Red whelk	0.04 (0.01)	0.36 (0.12)	627 (75)	0.23	-0.44	-0.01
Slender spindle shell	0.00	0.20 (0.10)	405 (126)	-	-0.65	-
Common european squid	0.02 (0.01)	0.18 (0.07)	21287 (3671)	0.20	-0.69	0.12
Lesser octopus	0.02 (0.01)	0.33 (0.12)	399 (69)	0.11	-0.43	0.22
European lobster	0.06 (0.01)	3.26 (1.45)	143 (17)	0.07	-0.27	0.06
Norway lobster[a]	0.01 (0.00)	0.05 (0.04)	34814 (16487)	0.93	-0.99	-0.91
Edible crab	0.06 (0.01)	1.12 (0.53)	1956 (264)	0.23	-0.15	0.04
Velvet swimming crab	0.00	0.21 (0.07)	3274 (667)	-	-0.62	-
Masked crab[a]	0.06 (0.07)	0.04 (0.29)	6183 (5828)	0.82	-0.85	-0.95
Green sea urchin	0.02 (0.00)	0.28 (0.08)	19092 (2367)	0.16	-0.60	-0.06
Purple heart urchin[b]	-	-	-	-	-	-
Dahlia anemone	0.01 (0.01)	0.28 (0.08)	19092 (2367)	0.16	-0.60	-0.06
Sea mouse[a]	0.00	0.01 (0.05)	194070 (13836)	-	-1.00	-

[a] correlation coefficient parameter estimates > 0.9
[b] no fit

Otter trawl catchability was set to zero for the slender spindle shell (*Colus gracilis*) and velvet swimming crab (*Liocarcinus puber*). These invertebrates were hardly delivered to the Zoological Station by commercial fishermen before 1960 (Fig. 3.8.3.1) which implies that they were not caught in the otter trawls. The otter trawl catchability estimates were higher for fish than for invertebrate species. According to the model results, otter trawling resulted in an almost 95% decline of roker (*Raja clavata*) and greater weever (*Trachinus draco*) in the sampling area between 1947 and 1960. smooth hound (*Mustelus mustelus*), common skate (*Raja batis*) and angler (*Lophius piscatoris*) decreased by more than 75%, whilst the small spotted cat shark (*Scyliorhinus caniculus*), stingray (*Dasyatis pastinaca*), european lobster (*Homarus gammarus*) and edible crab (*Cancer pagurus*) decreased by more than 50% within this 14 year period (Fig. 3.8.3.1).

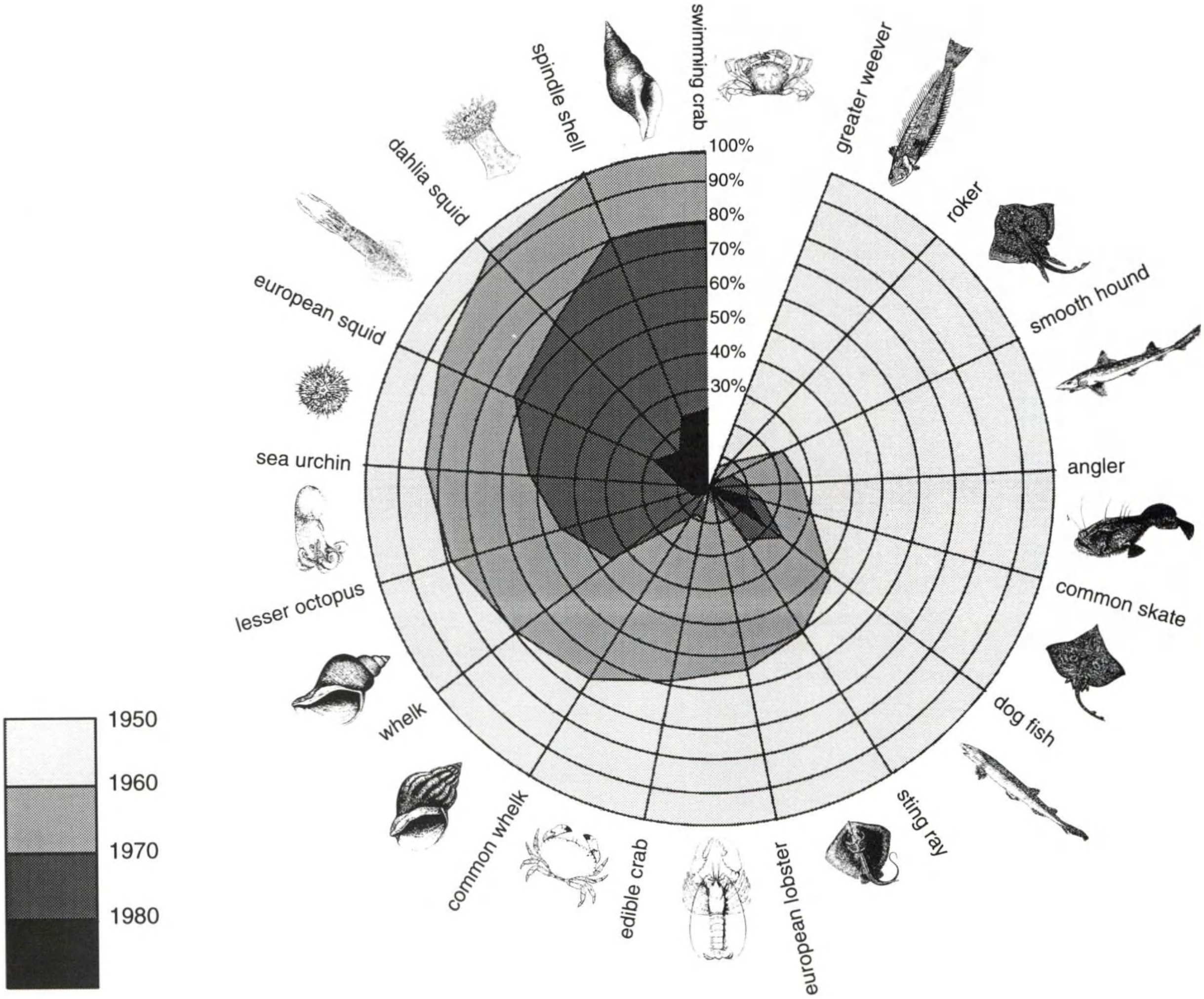


Fig. 3.8.3.1. Results from the model of long-term trends in relative abundance of demersal fish and benthic invertebrates in the south-eastern North Sea between 1947 and 1981. The relative abundance in 1960, 1970 and 1980, respectively, is expressed as a percentage of the original relative abundance in 1950 as estimated by means of the catchability model (i.e. N_0 in table 3.8.3.1). Furthermore, the species are ranked from greater weever to swimming crab (clockwise) based on their estimated decline due to otter and beam trawling, respectively.

For small spotted cat shark and common skate, the estimate of the beam trawl catchability was almost zero (Table 3.8.3.1). These bycatch fish species appear to have mainly been caught by otter trawls, or at least during the period when otter trawls were the main fishing gear in the southeastern North Sea. For several other bycatch species (greater weever, common whelk, european lobster, edible crab) the estimate of the beam trawl catchability exceeded 1 $n^{*} \cdot n^{*-1} \cdot e^{-1} \cdot y^{-1}$ (Table 3.8.3.1). This high value implies that the populations of these particular species were reduced to zero before maximum beam trawl effort occurred in the sampling area, i.e. before 1988. With the exception of the common whelk, these species were indeed scarcely delivered from the mid-1970s onwards. According to the model results, the slender spindle shell, velvet swimming crab and dahlia anemone (*Tealia felina*) were hardly affected by otter trawling but rapidly declined from 1960 onwards to less than 20% of the original population size at the end of the study period (Fig. 3.8.3.1). The increase in beam trawling coincided also with a further reduction of smooth hound, roker, stingray, angler, red whelk (*Neptunea antiqua*) and lesser octopus (*Eledone cirrosa*) to less than 5% of their original abundance in 1947 (Fig. 3.8.3.1).

In conclusion, for most species under consideration, the observed variation in annual numbers of fish and invertebrates delivered to the Zoological Station were found to be related to the changes in gear and fishing effort of bottom trawlers. Otter trawlers caught relatively more fish than invertebrates, whilst beam trawlers caught some invertebrate species (i.e. velvet swimming crab, slender spindle shell) that were hardly delivered by otter trawlers before. On average, the catchability of beam trawling appeared to be ten times as high than that of otter trawling for all species considered. Furthermore, the model results imply that bottom fisheries had a considerable impact on the marine ecosystem by reducing several demersal fish and benthic invertebrate species to very low levels of abundance within 35 years.

3.8.4. SHIFTS IN THE BENTHIC COMMUNITY OF THE SOUTH-EASTERN NORTH SEA DURING EXTENSIVE BOTTOM TRAWLING FISHERY

The relative species composition has changed in the south-eastern North Sea during the last decades as derived from the 3 selected surveys, i.e. the International Bottom Trawl Survey, the Sole Net Survey and the Demersal Fish Survey of 10 selected species including 2 target flatfishes, 1 non-target flatfish, 2 non-target roundfish, and 5 epifaunal invertebrates (Tables 3.8.4.1 and 3.8.4.2). The observed changes in the abundance of demersal fish and benthic invertebrates appear to be related to fisheries, i.e. to increased mortality on the one hand and to increased possibilities for scavenging on the other hand.

Dragonets (*Callionymus lyra*) appear to have increased in several areas within the south-eastern North Sea during the last decades. All surveys reveal an increase of dragonet numbers off the Dutch west coast. Several series show an increase of this fish species north of the Wadden. According to the IBTS survey, dragonets also increased in the German Bight. Rapid increase of this species was observed around the most extensively fished areas, i.e. off the Dutch west coast and in off the coastlines of the German Bight. No increasing trend, however, was observed in the extensively fished inner part of the German Bight.

Based on the IBTS survey, grey gurnards (*Eutrigla gurnardus*) appear to have increased in several areas within the south-eastern North Sea, i.e. north of the eastern Dutch Wadden Sea and in the German Bight. No significant trends were observed in the other ICES quadrants nor in time series originating from other surveys (i.e. SNS and DFS). The increase was observed for moderate extensively fished areas but not for the most extensively fished areas. Based on the IBTS and SNS surveys, the flatfish dab (*Limanda limanda*) appears to have increased off the Dutch west coast. The IBTS surveys furthermore indicate an increase in this fish species in the German Bight, an area moderately fished by the German trawling fleet.

TABLE 3.8.4.1
Results from trend analysis of log-transformed relative abundance of demersal fish as derived from different surveys in the south-eastern North Sea. The IBTS survey was performed between 1980 and 1995, the SNS survey between 1969 and 1990, and the DFS survey between 1980 and 1993. Significant trends are expressed as the slope of the time series of the log-transformed relative abundances (* $p < 0.05$; ** $p<0.01$; *** $p<0.001$). Non-significant trends were considered to be the result of an absence of change, and subsequently noted as 0.00 $n \cdot n^{-1} \cdot y^{-1}$.

Survey area	Dragonet	Grey gurnard	Dab	Plaice	Sole
IBTS-33F4	0.00	0.00	0.00	0.00	n.a.
IBTS-34F3	0.00	0.00	0.13*	0.00	n.a.
IBTS-34F4	0.09*	0.00	0.06*	0.00	n.a.
IBTS-35F3	0.00	0.00	0.00	0.00	n.a.
IBTS-35F4	0.00	0.00	0.00	0.00	n.a.
IBTS-36F4	0.00	0.00	0.00	0.00	n.a.
IBTS-36F5	0.13**	0.12*	0.00	0.00	n.a.
IBTS-36F6	0.10*	not caught	0.00	0.00	n.a.
IBTS-36F7	0.00	not caught	0.00	0.00	n.a.
IBTS-37F6	0.00	0.12**	0.07**	0.00	n.a.
IBTS-37F7	0.00	0.00	0.00	0.00	n.a.
IBTS-37F8	0.00	0.00	0.00	0.00	n.a.
IBTS-38F6	0.13**	0.09*	0.08**	0.00	n.a.
IBTS-38F7	0.11*	0.00	0.12***	0.00	n.a.
IBTS-38F8	0.00	0.00	0.00	0.00	n.a.
IBTS-39F6	0.13**	0.10*	0.00	0.00	n.a.
IBTS-39F7	0.00	0.00	0.08*	0.00	n.a.
SNS-1	0.05*	0.00	0.00	n.a.	n.a.
SNS-2	0.00	0.00	0.06***	n.a.	n.a.
SNS-3	0.00	0.00	0.05**	n.a.	n.a.
SNS-4	0.00	0.00	0.00	n.a.	n.a.
DFS-401	0.25*	0.00	0.00	-0.20**	-0.32**
DFS-402	0.50***	0.00	0.00	0.00	-0.33**
DFS-403	0.33*	0.00	0.00	0.00	0.00
DFS-404	0.18*	0.00	0.00	-0.09*	-0.23**
DFS-405	0.00	0.00	0.00	-0.09**	-0.21*
DFS-406	0.00	0.00	0.00	0.00	-0.25*

According to the results of the DFS surveys, the commercial flatfish species decreased in the study area between 1980 and 1993. Plaice (*Pleuronectes platessa*) appears to have decreased in a part of the south-eastern North Sea, i.e. in the southern part of the study area and north of the Wadden Sea. These are extensively and moderately fished areas, respectively. Sole (*Solea solea*) appears to have decreased in most areas within the south-eastern North Sea.

Based on the SNS surveys, the abundances of hermit crab (*Pagurus bernhardus*) and swimming crab (*Liocarcinus holsatus*) showed no trends within the study area between 1972 and 1991. Starfish (*Asterias rubens*) papered to have increased in several parts of the study area, i.e. in the transects in the southern part of the study area and north of the Wadden Sea. Heart urchin (*Echinocardium cordatum*) and the common whelk (*Buccinum undatum*) decreased considerably in the areas north of the Wadden islands. For the sea potato, no significant trends were observed for other areas within the south-eastern North Sea. The common whelk, however, significantly increased in the SNS-Cleaver Bank transect between 1972 and 1991.

TABLE 3.8.4.2
Results from trend analysis of log-transformed relative abundance of benthic invertebrates as derived from the SNS survey between 1969 and 1990 in the south-eastern North Sea. Significant trends are expressed as the slope of the time series of the log-transformed relative abundances (* $p < 0.05$; ** $p<0.01$; *** $p<0.001$). Non-significant trends were considered to be the result of an absence of change, and subsequently noted as 0.00 $n \cdot n^{-1} \cdot y^{-1}$.

Survey-transect	Hermit crab	Swimming crab	Starfish	Sea potato	Common whelk
SNS-Scheveningen	0.00	0.00	0.16*	0.00	0.00
SNS-IJmuiden	0.00	0.00	0.00	0.00	0.00
SNS-Texel	0.00	0.00	0.00	0.00	not caught
SNS-Cleaver Bank	0.00	0.00	0.00	0.00	0.13*
SNS-Terschelling	0.00	0.00	0.08*	-0.22*	-0.11*
SNS-Norderney	0.00	0.00	0.00	-0.24*	-0.22*
SNS-Borkum	0.00	0.00	0.10**	-0.16*	0.00
SNS-Helgoland	0.00	0.00	0.00	0.00	0.00
SNS-Sylt	0.00	0.00	0.00	0.00	0.00
SNS-Esbjerg	0.00	0.00	0.00	0.00	0.00

On average, the relative species composition appeared to have changed in the south-eastern North Sea during the last decades. We observed a decrease of several flatfish species such as plaice and sole and benthic invertebrates such as sea potato and common whelk, whilst other species increased in numbers such as grey gurnard, dab and starfish and in particular dragonet. The changes were most pronounced in areas which were moderately to extensively fished. This observed change is in agreement with our hypothesis that fisheries mainly affects commercial flatfish species and vulnerable (epibenthic) species. The increase in dragonet could be due to its low catch efficiency and its ability to scavenge. Although starfish has a high catch efficiency, its increase may be explained by its low catch mortality. When publications about fish mortality experiments and field observations (are compared with the long term changes, the results are corresponding. An investigation on scavenger behaviour (Fonds & Groenewold 1996) assents the same. Although we cannot exclude other influences on the populationsizes and distributions in the North Sea, like a raise in temperature, eutrophication, windforce and -direction and intra- and interspecific interactions, the observed changes could be very well explained by increased fisheries mortality on the one hand and increased possibilities for scavenging on the other hand.

3.8.5. 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 number of fish recruits is not very strongly related to hydrographical conditions, water temperature and primary and secondary production.

Due to missing values of chlorophyll in 1972 and 1973, the period for the PCA was restricted to the years between 1974 and 1994. The first two principal components (PCs) of the PCA of the environmental data accounted for 73% of the total variance of the untransformed and standardized values of the NAO index, the water temperature, the chlorophyll concentration and the crustacean abundance. From the biplot, the NAO index and the winter temperature are positively correlated, but no correlation seems to exist between winter temperature and crustacean abundance (Philippart *et al.* 1996). These conclusions from the biplot are in agreement with the correlation structure between the four environmental factors for the entire study period (with the exception of chlorophyll concentrations): only a significant linear correlation was found between the NAO index and water temperature in winter ($n = 23$, $r = 0.71$, $p < 0.05$). In general, high recruit numbers for most species but in particular herring, flounder, sole, plaice and whiting were observed in years characterized by low values of the NAO index and by severe winters, i.e. 1979 and 1985-1987 (Fig. 3.8.5.1). Recruits of whiting, cod, plaice, sole, flounder and herring were abundant in periods when chlorophyll levels were above average and in years with low densities of predatory crustaceans.

The relatively low value of the explained variance in the fish abundance biplot indicates that the interannual variation in recruits cannot be explained by one or two common environmental factors. Due to the strong correlation between the NAO index and winter temperature, as also found for other locations in Europe (Hurrell 1995), no distinction can be made between the effects of these two variables. Coinciding high recruit numbers of herring, flounder, sole, plaice and whiting in years with a low NAO index and low water temperatures in winter can, therefore, be caused by an enhancement of eastward transport of fish larvae across the North Sea (Corten & van de Kamp 1992) as well as a decrease in mortality of recruits after severe winters (Rijnsdorp *et al.* 1992; van der Veer 1986; Zijlstra & Witte 1985). Recruits of whiting, cod, plaice, sole, flounder and herring seem to prosper in years with high chlorophyll concentrations and low numbers of predatory shrimps and crabs. High abundances of flatfish recruits at low predation pressure is in agreement with the predation hypothesis for flatfish (van der Veer *et al.* 1990, 1991). For cod and whiting, crustacean predation was not expected to be an important factor for recruit survival. However, these are demersal roundfish and may, therefore, also be affected by benthic predators.

In conclusion, our results suggest that recruit numbers in the Wadden Sea are influenced by a combination of density-dependent processes in the nurseries and year-to-year variations in the estuarine environment. However, based on the low covariability between the species it is expected that no single environmental factor caused the observed interannual variability in recruits in the Dutch coastal zone.

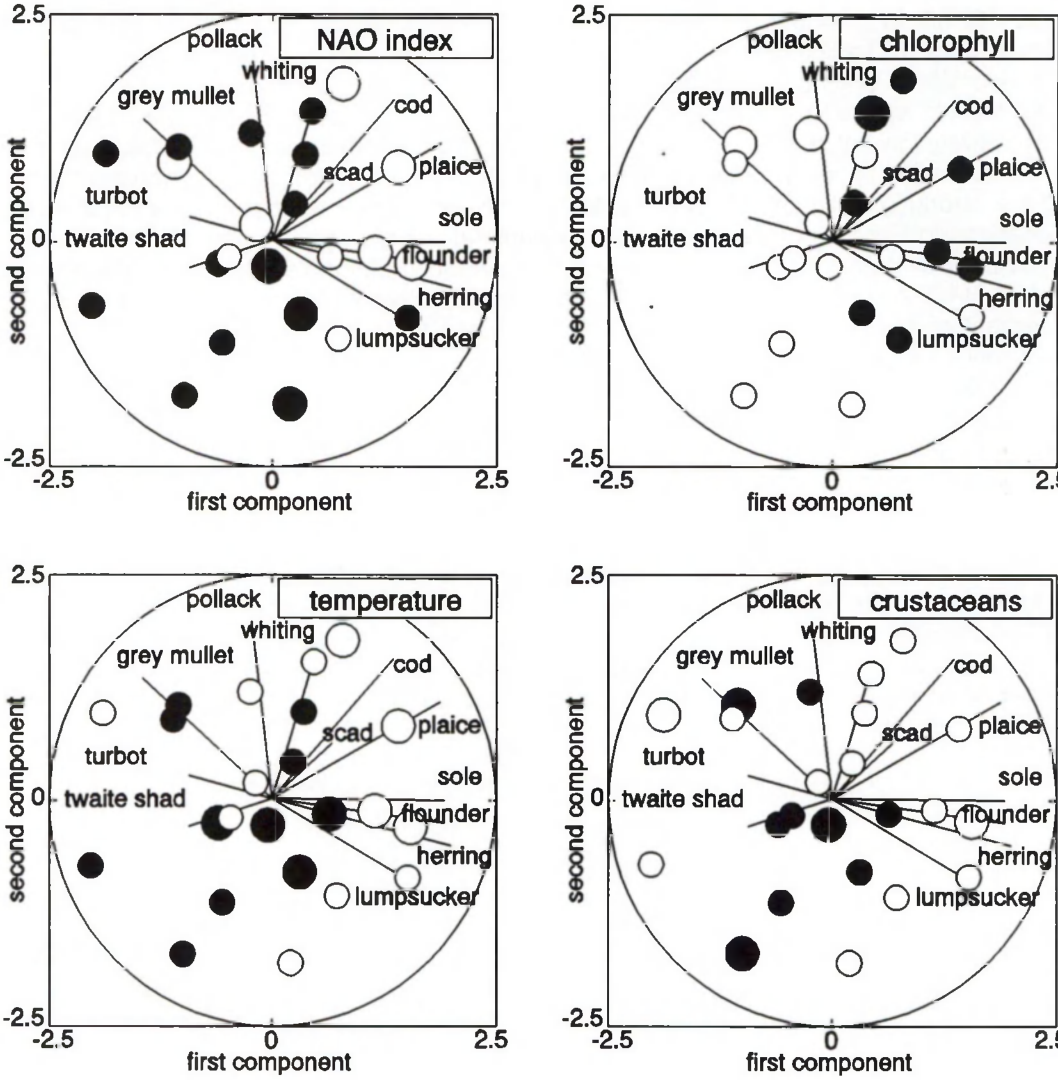


Fig. 3.8.5.1 Covariance biplots based on principal component analysis (1st and 2nd axis) of fish recruit abundance, including indications of the NAO index (Dec-Feb), the water temperature in winter (Dec-Feb), the annual chlorophyll concentration (Jan-Dec), and the predation pressure by crustaceans in late winter (Feb/Mar) between 1972 and 1994. Open circles refer to values below average and closed circles to values above average of the environmental variable. The size of the circle indicates the deviation from the average value. For 1972 and 1973, no data on chlorophyll concentrations were available.

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

Introduction

The scope of this investigation was to correlate historical data on fishing effort with the abundance of those fish species which are effected by fishing gear. 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 rectangle 37F7 off the island of Helgoland.

Results

Since the implementation of the Plaice-Box in 1989 the effort of beam trawlers has nearly doubled in ICES rectangle 37F7 as compared to the period before 1983, whereas the effort of otter and pair trawlers has only slightly increased in recent years as shown in Figs. 3.8.6.1a to 3.8.6.1c.

The inter-annual variability of the abundance of dab and grey gurnard as well as the trawlable biomass of the GOV-trawl within this area is high. Significant trends during the last decade to lower or higher values in abundance and biomass are not to be detected in spite of the increasing fishing effort (Figs. 3.8.6.1a to 3.8.6.1c).

Discussion

The rectangle 37F7 (Box A) is a heavily fished area since it is situated just outside the Plaice-box. This is indicated by a figure of the micro-distribution of large (> 300 hp) Dutch beam trawlers in 1994/95 (Rijnsdorp *et al.* 1996). It may be hypothesised that such intensive fishing could have a measurable influence on the abundance indices of dab and grey gurnard, which are highly vulnerable to the beam trawl, and moreover to the fish biomass near the bottom.

The high inter-annual variability of the catch rates could be attributed to the relative small size of the investigated box and the mobility of the fish, which migrate into the area from the surroundings. In roundfish-area 6, which includes the German Bight, the abundance of dab and grey gurnard has increased significantly during this period inspite of heavy fishing. The increasing trend in abundance for both species is also true for the whole North Sea, as shown in Chapter 3.8.7 and also for the trawlable biomass in the North Sea (Ehrich, in preparation).

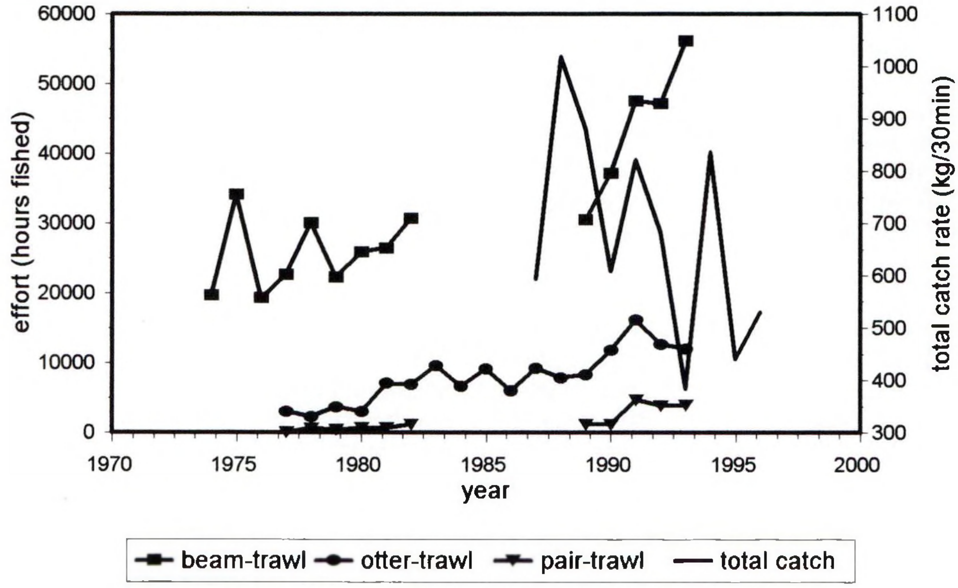


Fig. 3.8.6.1a. Trawlable biomass and fishing effort in ICES retangle 37F7 (German Bight).

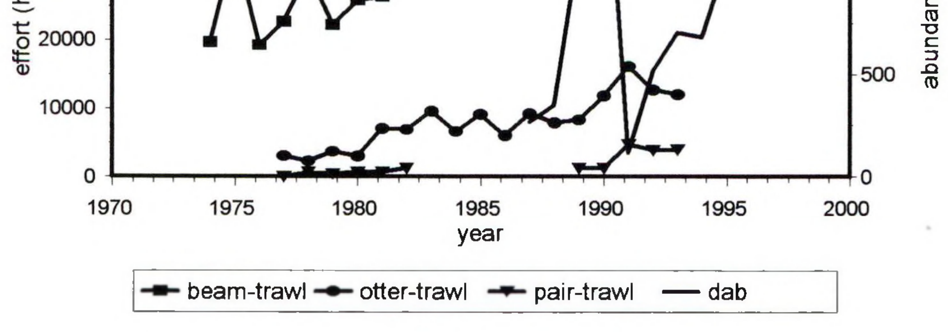


Fig. 3.8.6.1b. Dab. Abundance and fishing effort in ICES retangle 37F7 (German Bight).

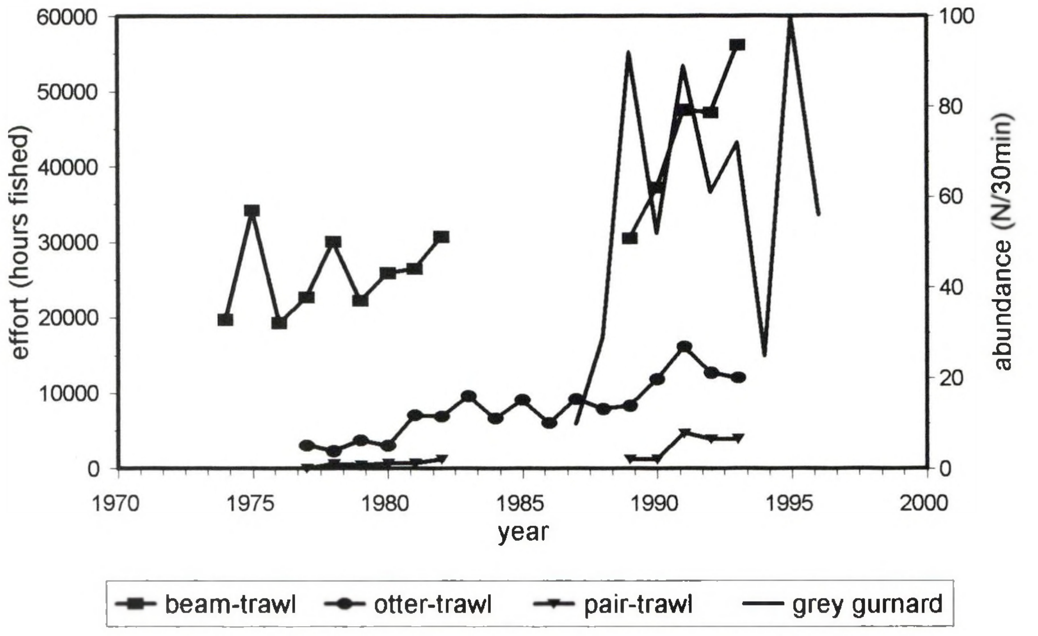


Fig. 3.8.6.1c. Grey gunard. Abundance and fishing effort in ICES retangle 37F7 (German Bight).

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

In this investigation an attempt was made to indicate trends in the abundance and in the length of these eight species over the last decades back to 1958, during a period with increasing effort in the beam trawl fishery, which is responsible for severe impacts on the benthos as well as on the demersal fish assemblages.

The annual values of abundance in quarter 1 (winter) and quarter 3 (summer) for the eight species in the entire North Sea are summarised in Fig. 3.8.7.1a and b. Furthermore, the values of the spatial, seasonal and inter-annual variability were separated into RA's (= Roundfish Area) of the North Sea (Figs. 3.8.7.2a to 3.8.7.9b).

The annual changes in the proportions of the 3 length classes per species were calculated only for quarter 1 in the RA's are given in Figs. 3.8.7.2c to 3.8.7.9c. The changes in mean length over the period in quarter 1 for the entire North Sea are summarised for the 8 species in Fig. 3.8.7.10a and 3.8.7.10b.

The spatial, seasonal and inter-annual variability (percentual coefficient of variance) of the abundance and the results of the calculations of overall trends in abundance (restricted to the first quarter of the year and to the period from 1980 till 1995, when the total North Sea was covered) and length for each species are given in Table 3.8.7.1.

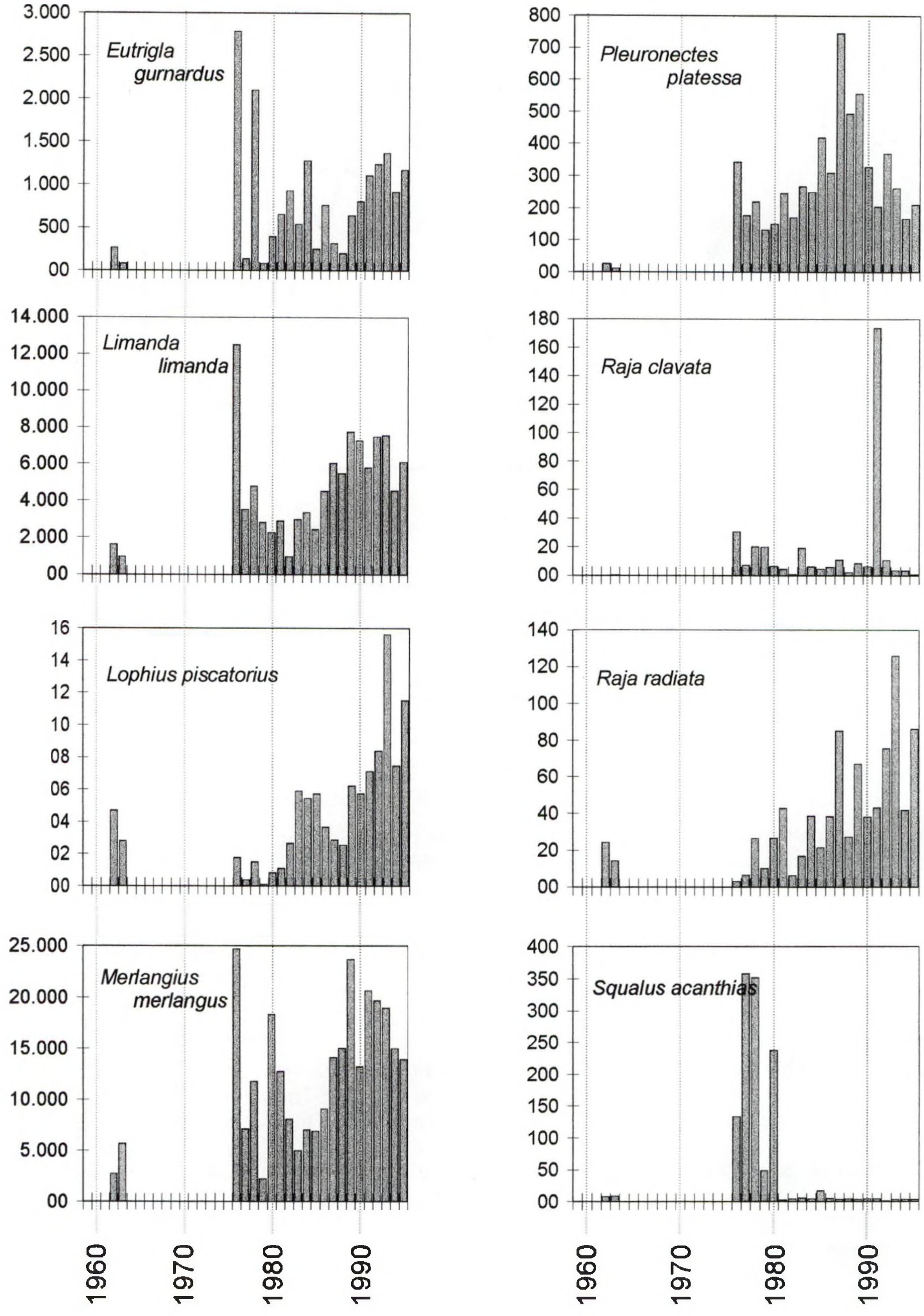


Fig. 3.8.7.1a. Mean abundance (N/10h) of species in the North Sea during Winter (quarter 1) (1962-1963, 1976-1995).

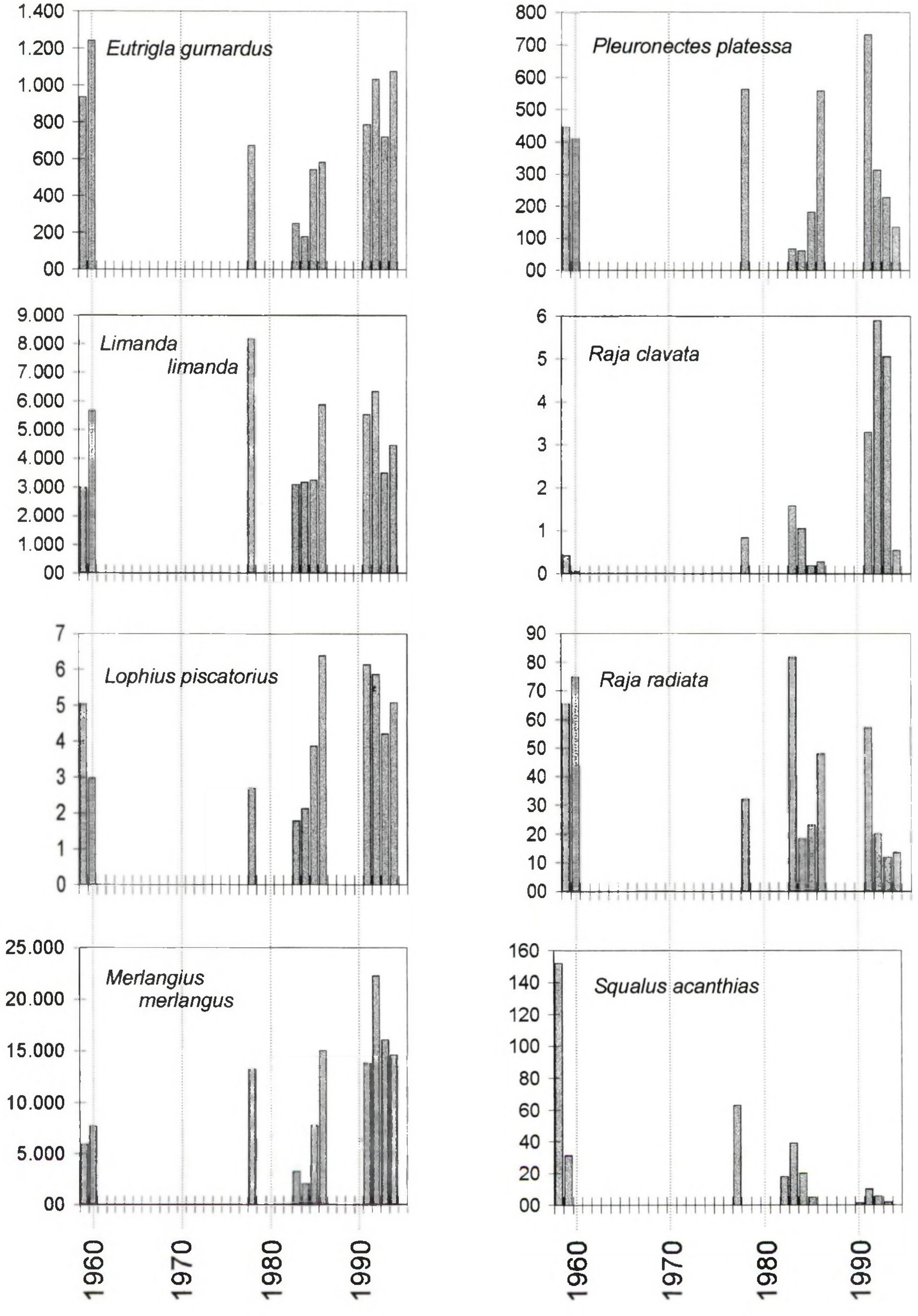


Fig. 3.8.7.1b. Mean abundance (N/10 h) of species in the North Sea during Summer (quarter 3) 1959-1960, 1978, 1983-1986 and 1991-1994.

The spurdog (*Squalus acanthias;* Figs. 3.8.7.2a to 3.8.7.2c) is unevenly distributed within the North Sea. The seasonal and inter-annual differences are very high as compared to the other species. From the data of quarter 1a significant overall trend in abundance could not be detected for the period since 1980, but the catches are very low since 1981 compared to the preceding 5 years period of uncertain data. The catches in 1962 and 63 are also very low and comparable to recent years. This points at a periodical pattern of higher abundance of spurdog in the North Sea. The mean length of spurdog shows an overall significantly increasing trend (Fig. 3.8.7.10a).

The North Sea is the northern boundary of the distribution area of the Lusitanian ray *Raja clavata* (roker or thornback ray; Figs. 3.8.7.3a to 3.8.7.3c). This explains the relatively high variability in the spatial, seasonal and annual distribution patterns. The high abundance in 1991 for the total North Sea during winter (quarter 1) is caused by only one extreme big catch in roundfish area 5 and the figure therefore is not representative. There are no trends in abundance and length. This is confirmed by Walker & Heessen (1996) who also found no trend in abundance of this ray in the North Sea over the period from 1925 to 1995.

A different situation was found for the widely distributed boreal species *Raja radiata* (starry ray; Figs. 3.8.7.4a to 3.8.7.4c) with low spatial and medium seasonal and inter-annual changes. From the data of quarter 1 highly significant increasing trends in abundance and length can be detected for the entire North Sea. This trend in abundance is also shown by Walker & Heessen (1996), but not supported by the data of quarter 3.

The angler *Lophius piscatorius* (Figs. 3.8.7.5a to 3.8.7.5c) is more abundant in the central, north-western and northern part of the North Sea than in southern and south-eastern areas. The seasonal variability is relatively low and the inter-annual variability of medium order. The positive trend in abundance is highly significant for the winter series but not so obvious in summer. Since 1980 an increasing proportion of the smallest length class in RA 1 and 3 dominates the significant trend of decreasing length (Fig. 3.8.7.10a).

During the 5 years before 1981 nearly exclusively specimen of the biggest length class were caught. Since than the development seems to go back to the sixties, related to the proportion of length classes.

In the North Sea the angler is only a by-catch species in the fishery, but of considerable economic importance.

The grey gurnard (*Eutrigla gurnardus;* Figs: 3.8.7.6a to 3.8.7.6c) undertakes seasonal migrations within the North Sea, therefore the spatial and seasonal variability of the catches are high, whereas the annual variability was estimated to be of low magnitude. A general increasing trend in abundance was found only in the data for quarter one. Since 1990 the abundance indices are on a very high level in both data sets. Looking at the development of the fish length, no trend can be noticed. Grey gurnard is a by-catch species in demersal fisheries. Only the largest individuals are landed. Nearly 100% of the discards are dead or have no chance to survive after being thrown back into the sea (Fonds 1994).

Dab (*Limanda limanda;* Figs. 3.8.7.7a to 3.8.7.7c) is the most abundant species in the beam trawl fishery and is evenly distributed in the whole North Sea. The seasonal and the inter-annual variability is also low. An increasing trend in abundance since 1980 is significant. No trend in mean length can be observed. Dab is only a by-catch species in the flatfish fishery and less than 10% of the catch are considered to be large enough for human consumption. More than 90% are discarded at sea and less than 20% of them survive (Craeymeersch 1994; Fonds 1994).

The interannual and seasonal variability of plaice (*Pleuronectes platessa;* Figs. 3.8.7.8a to 3.8.7.8c) is low, whereas the spatial variability is of medium size. With increasing age the juvenile plaice migrates from the most important nursery area, the Wadden Sea, into the deeper parts of the North Sea. Therefore, the proportion of plaice smaller than 15 cm is the largest in roundfish area 6. An overall trend in abundance over the period since 1980 does not exist, but there is a significant decreasing trend in mean length (Fig. 3.8.7.10b), for the proportion of the lowest length class is bigger throughout the recent 10 years compared to the former decade. Together with sole, the target species plaice belongs to the most important species in the flatfish fishery.

For whiting (*Merlangius merlangus;* Figs. 3.8.7.9a to 3.8.7.9c) the spatial and annual variability is low and the seasonal variability of medium magnitude. There is no overall trend in abundance as well as in the mean length. The winter series of whiting abundance shows high values from 1989 to 1993, but the abundance of whiting decrease in the recent years. Whiting of more than 30 cm in length, corresponding to a mean age of about 4, are very scarce in the catches since the beginning of the time series.

Whiting is one of the 4 most important target species in the North Sea roundfish fishery, being exploited on a very high level.

Summarising the results listed in Table 3.8.7.1, it can be stated that no decreasing trend could be detected in the abundance of the eight fish species as expected during a period (1980-1995) of increasing fishing effort. For only two of the eight species a decrease and for two an increase in mean length over the time period (quarter 1) was observed.

Additional information on spatial distribution, on life history, on population structure and exploitation of these eight species is available in the Atlas of North Sea Fishes (Knijn *et al.* 1993).

TABLE 3.8.7.1
Criteria of variabilitv and trends for the 8 species.

species	variability (CV(%))			trends in abundance		trends in fish length	
	spatial	seasonal	inter-annual	quarter 1 (1980-95)	F	quarter 1 (1976-95)	F
Spurdog	104.9	56.8	292.8	no trend	0.093	increasing trend	0.045 *
Thornback ray	175.3	59.6	245.8	no trend	0.522	no trend	0.749
Starry ray	95.4	45.7	62.1	increasing trend	0.007 **	increasing trend	0.001 **
Angler	125.6	38.4	64.1	increasing trend	0.000 **	decreasing trend	0.001 **
Grey gurnard	145.4	60.0	46.9	increasing trend	0.047 *	no trend	0.914
Dab	79.4	26.6	43.3	increasing trend	0.000 **	no trend	0.695
Plaice	105.7	37.8	49.0	no trend	0.807	decreasing trend	0.025 *
Whiting	87.0	44.2	38.7	no trend	0.054	no trend	0.879

* significant
** highly significant

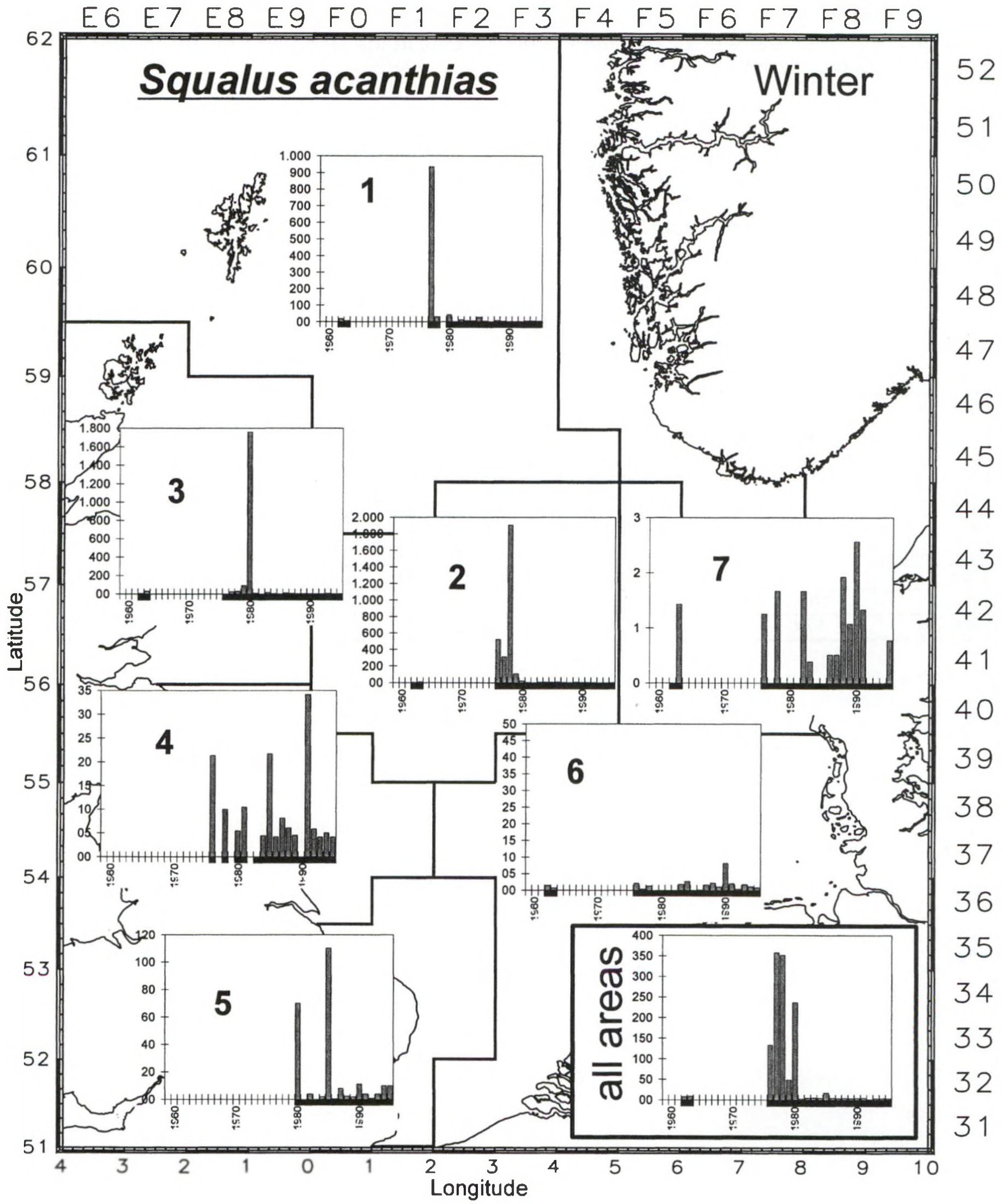


Fig. 3.8.7.2a. Spurdog: Mean catch rate (quarter 1; N/10 h) per roundfish area and in the total North Sea during the periods 1962-1963 and 1976-1995.

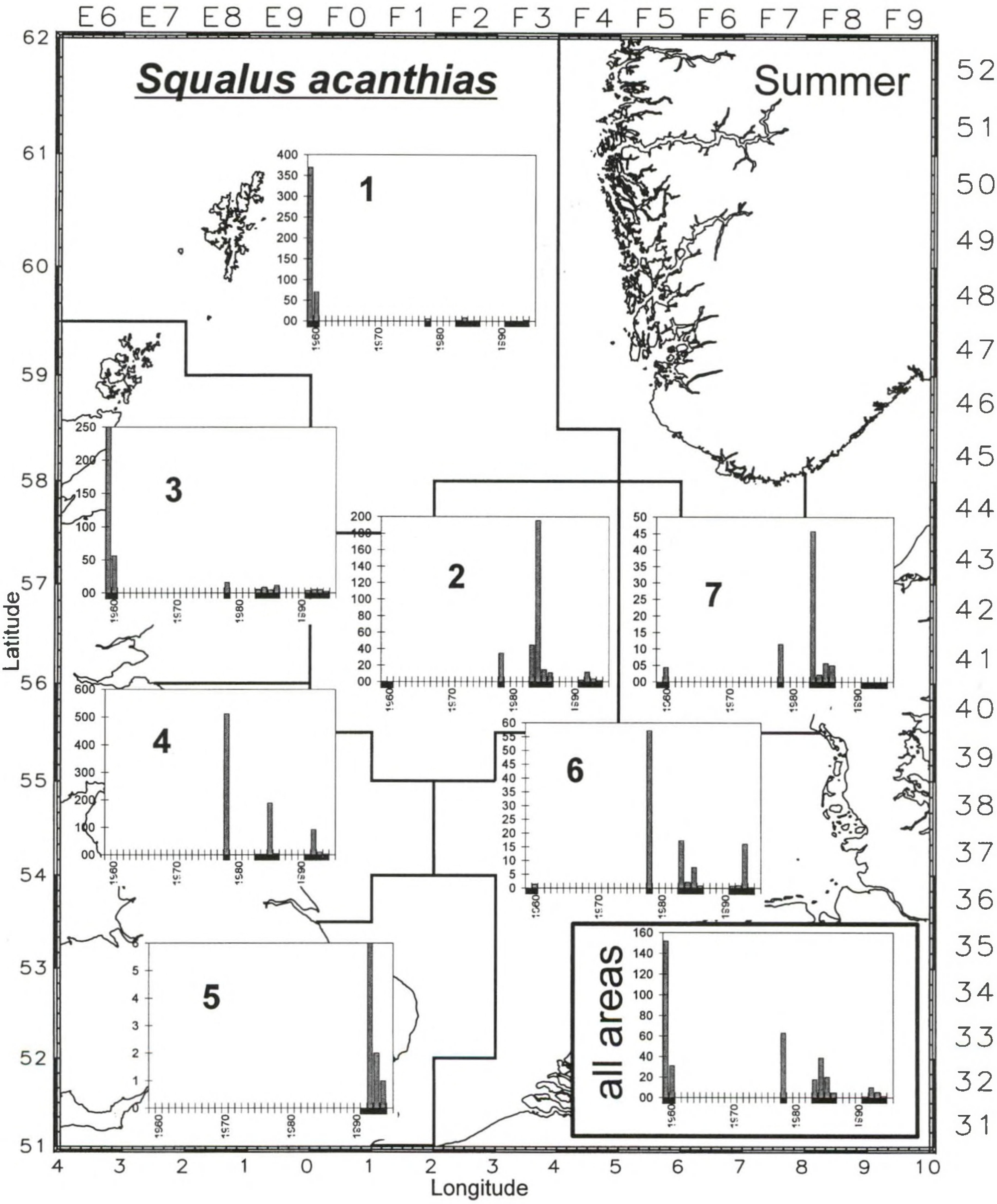


Fig. 3.8.7.2b. Spurdog: Mean catch rate (quarter 3; N/10 h) per roundfish area and in the total North Sea during the periods 1959-1960, 1978, 1983-1986 and 1991-1994.

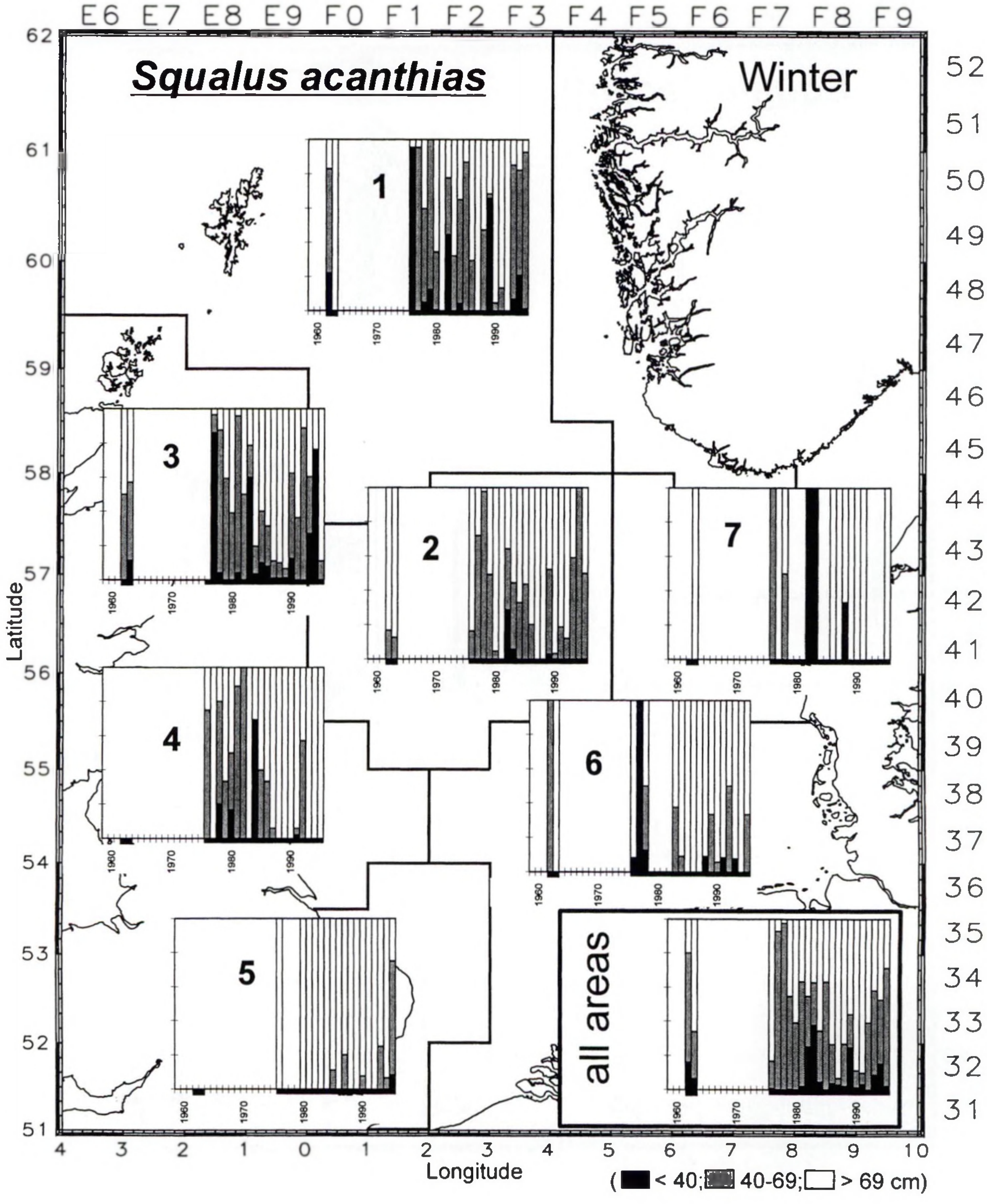


Fig. 3.8.7.2c. Spurdog: Percentage of the size classes in the mean catch rate (quarter 1).

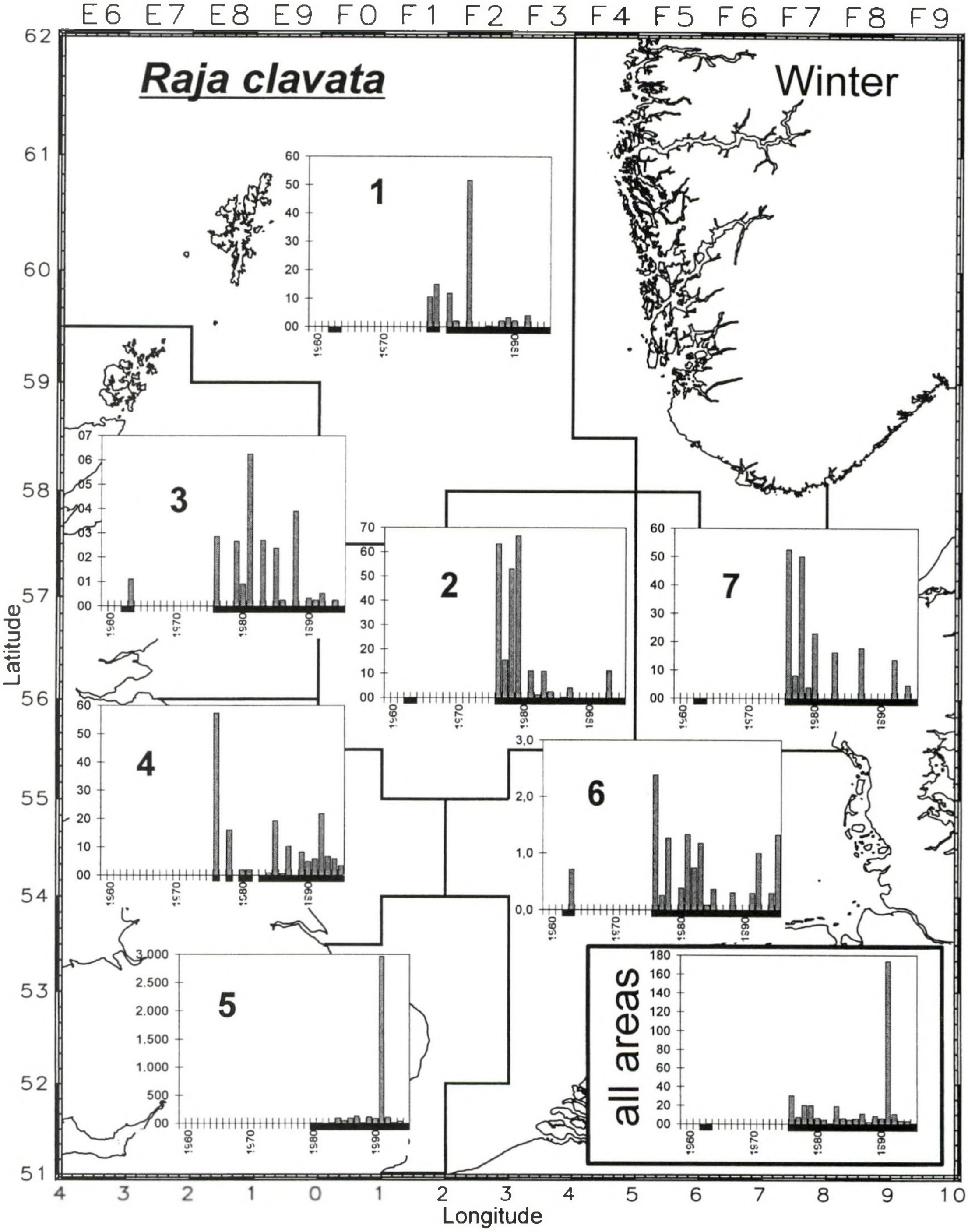


Fig. 3.8.7.3a. Thornback ray: Mean catch rate (quarter 1; N/10 h) per roundfish area and in the total North Sea during the periods 1962-1963 and 1976-1995.

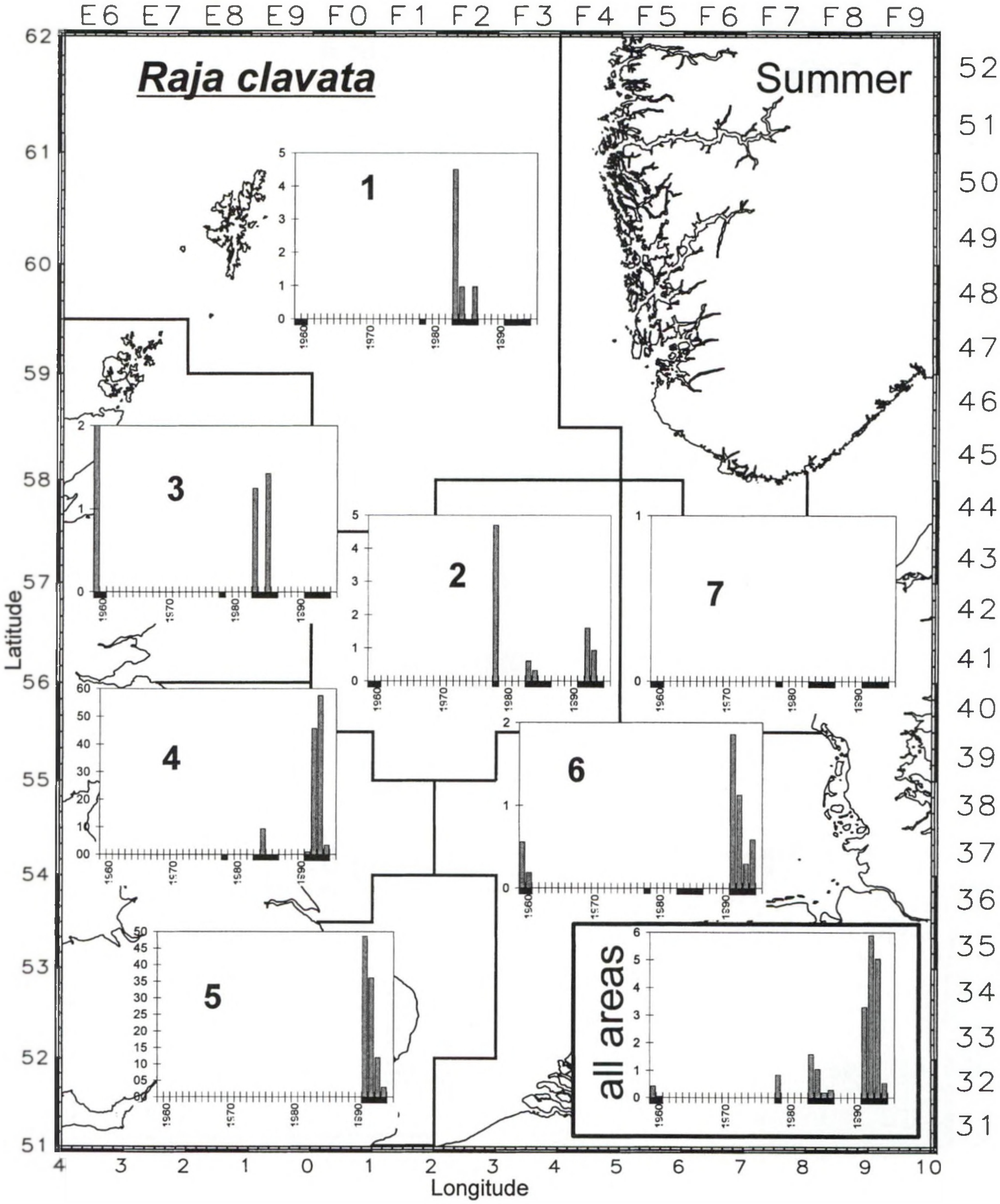


Fig. 3.8.7.3b. Thornback ray: Mean catch rate (quarter 3; N/10 h) per roundfish area and in the total North Sea during the periods 1959-1960, 1978, 1983-1986 and 1991-1994.

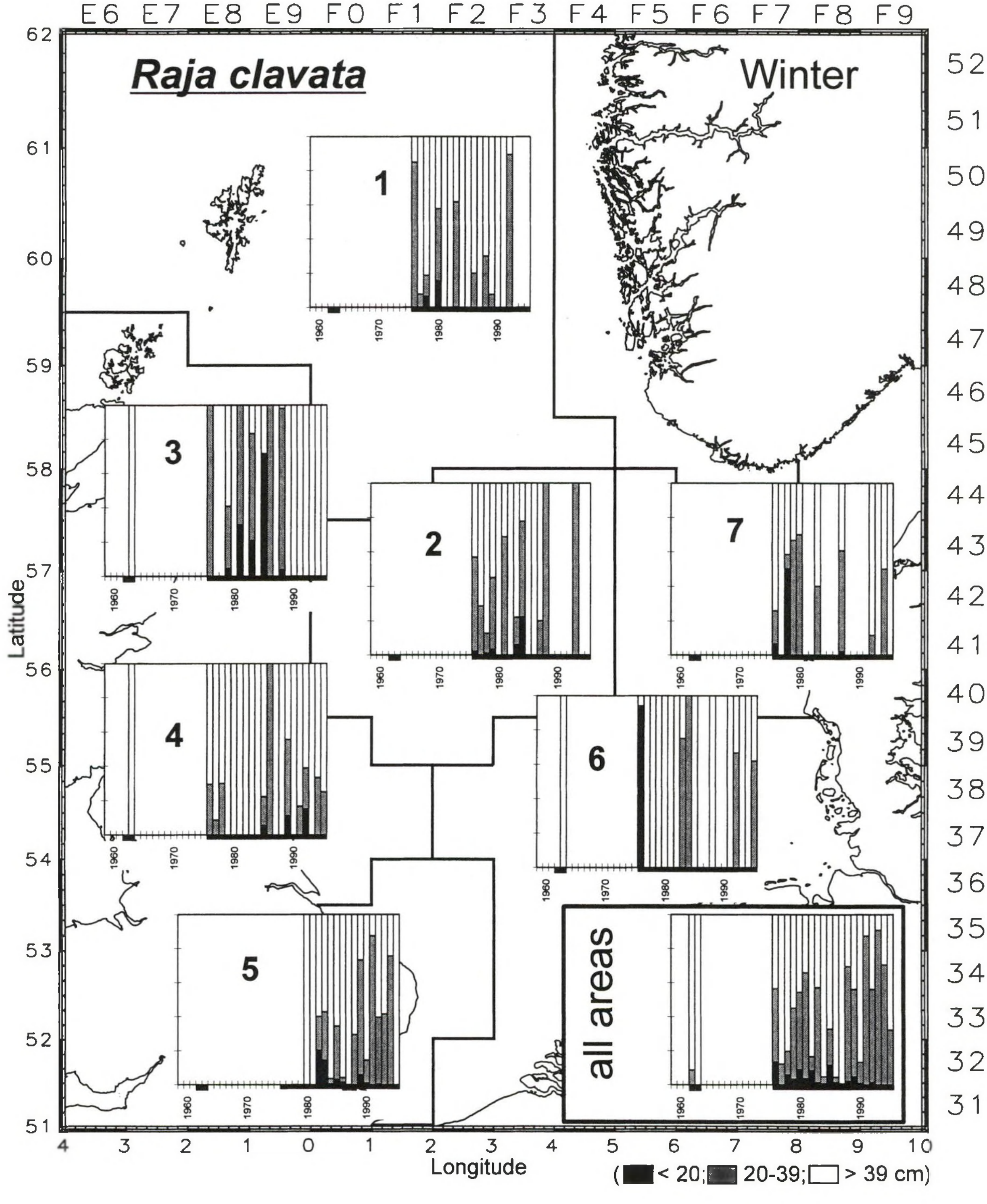


Fig. 3.8.7.3c. Thornback ray: Percentage of the size classes in the mean catch rate (quarter 1).

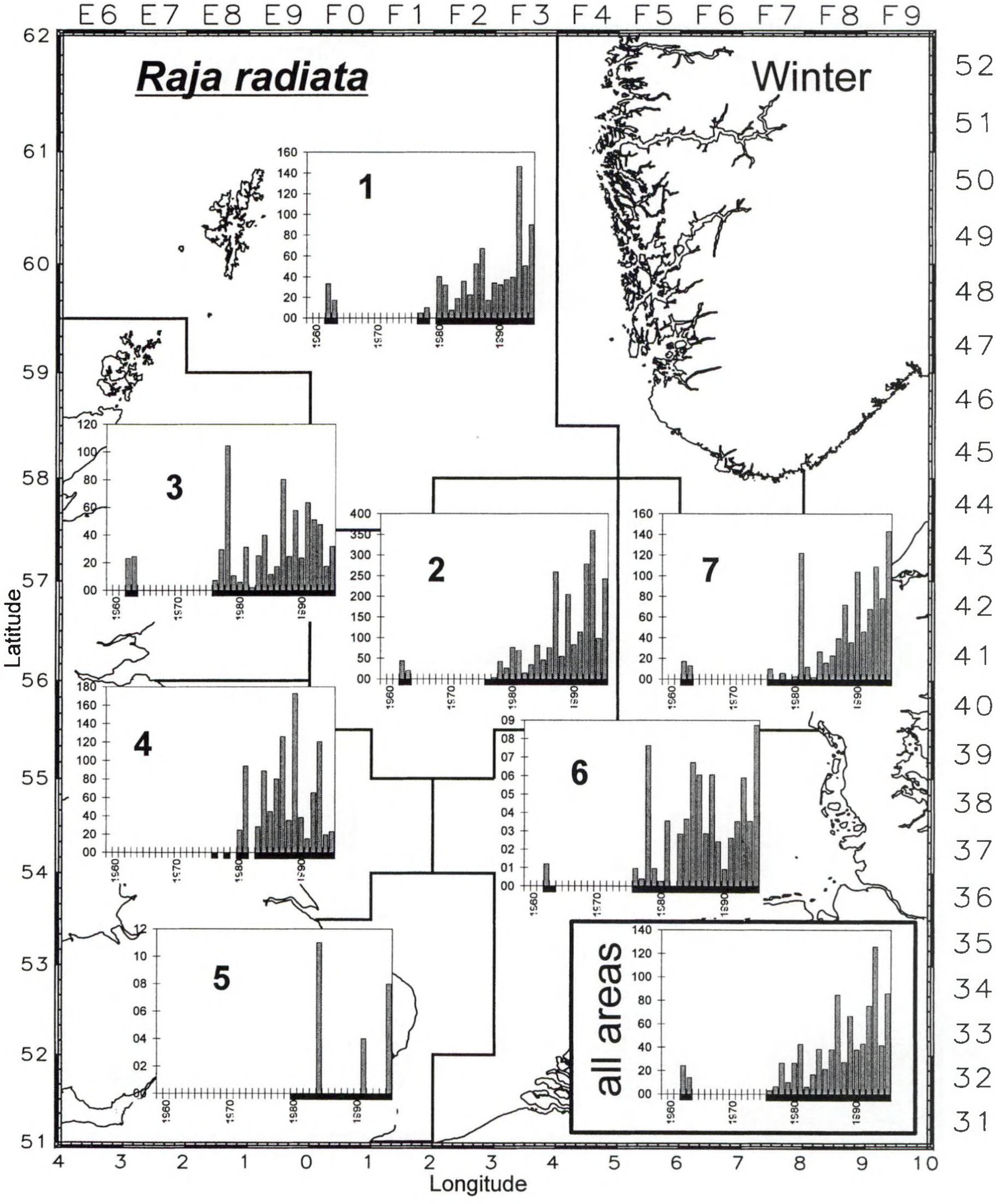


Fig. 3.8.7.4a. Starry ray: Mean catch rate (quarter 1; N/10 h) per roundfish area and in the total North Sea during the periods 1962-1963 and 1976-1995.

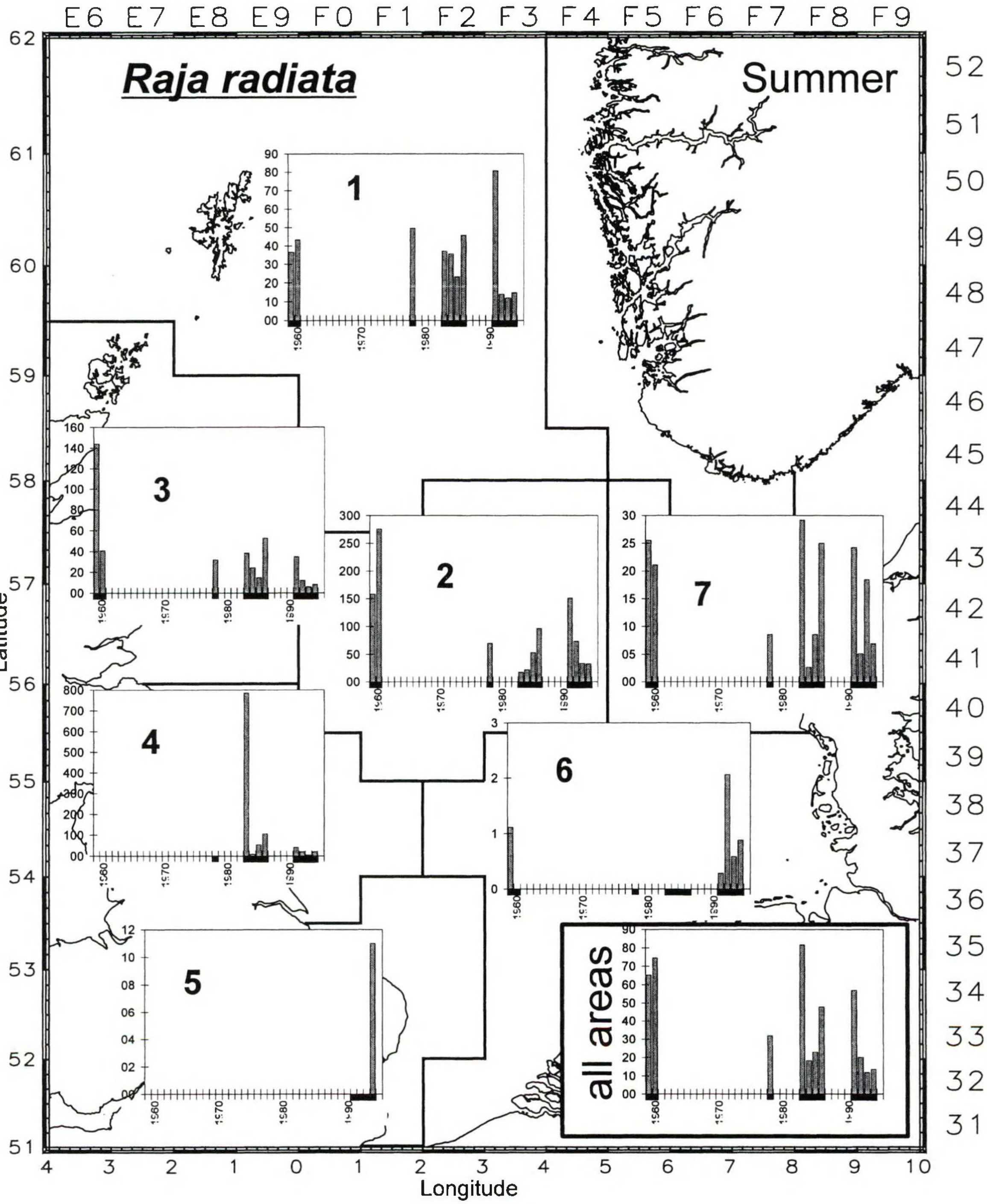


Fig. 3.8.7.4b. Starry ray: Mean catch rate (quarter 3; N/10 h) per roundfish area and in the total North Sea during the periods 1959-1960, 1978, 1983-1986 and 1991-1994.

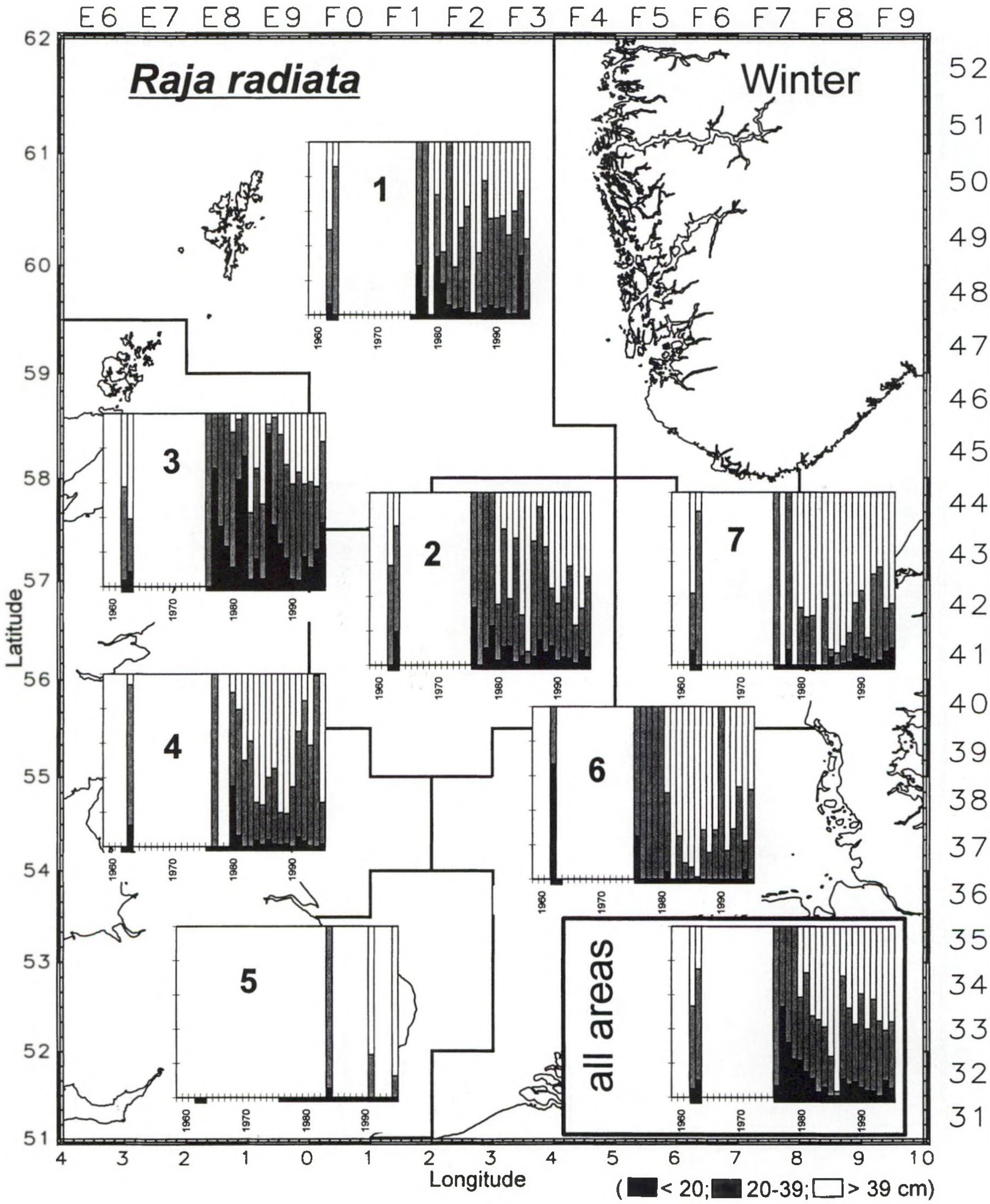


Fig. 3.8.7.4c. Starry ray: Percentage of the size classes in the mean catch rate (quarter 1).

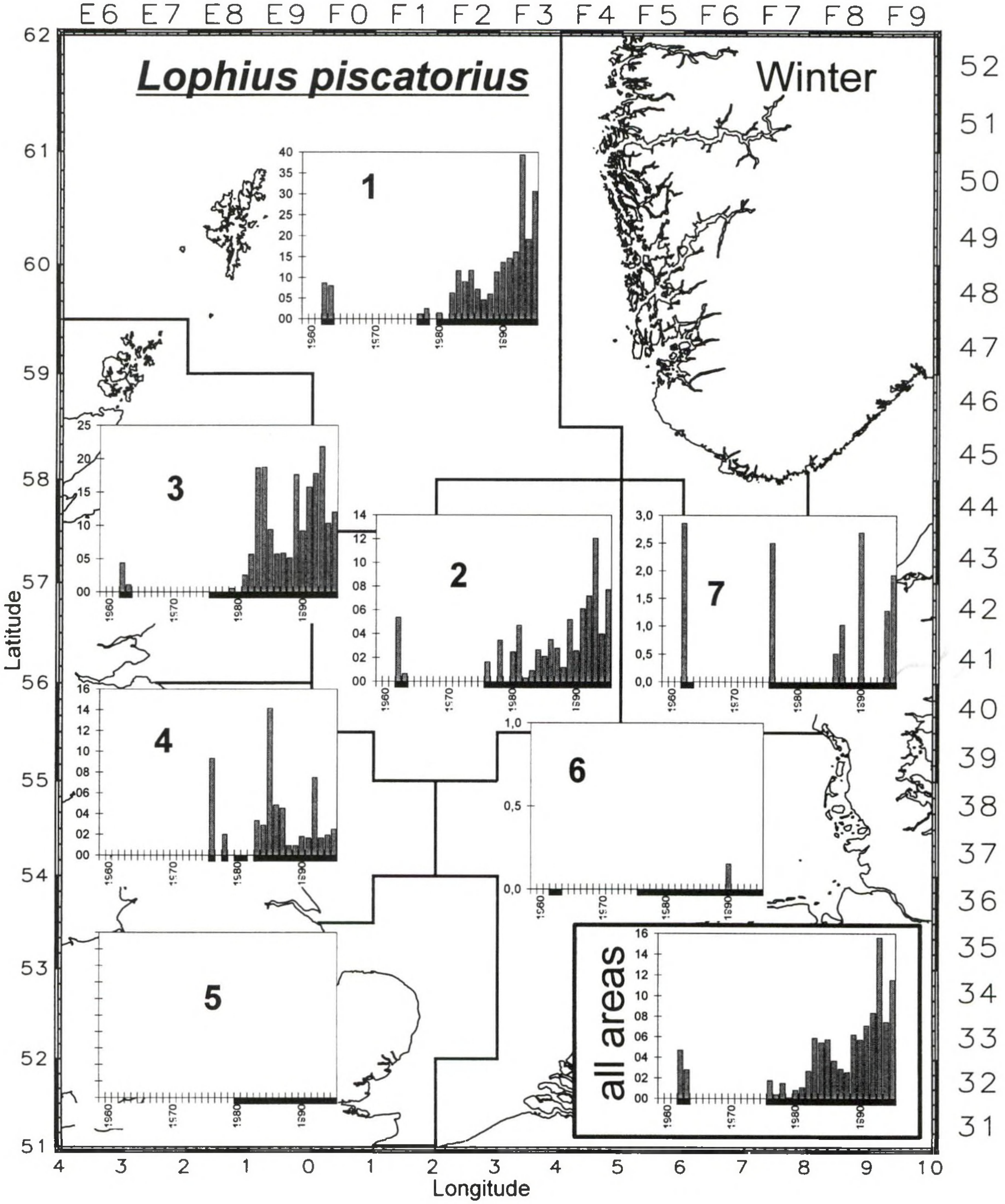


Fig. 3.8.7.5a. Angler: Mean catch rate (quarter 1; N/10 h) per roundfish area and in the total North Sea during the periods 1962-1963 and 1976-1995.

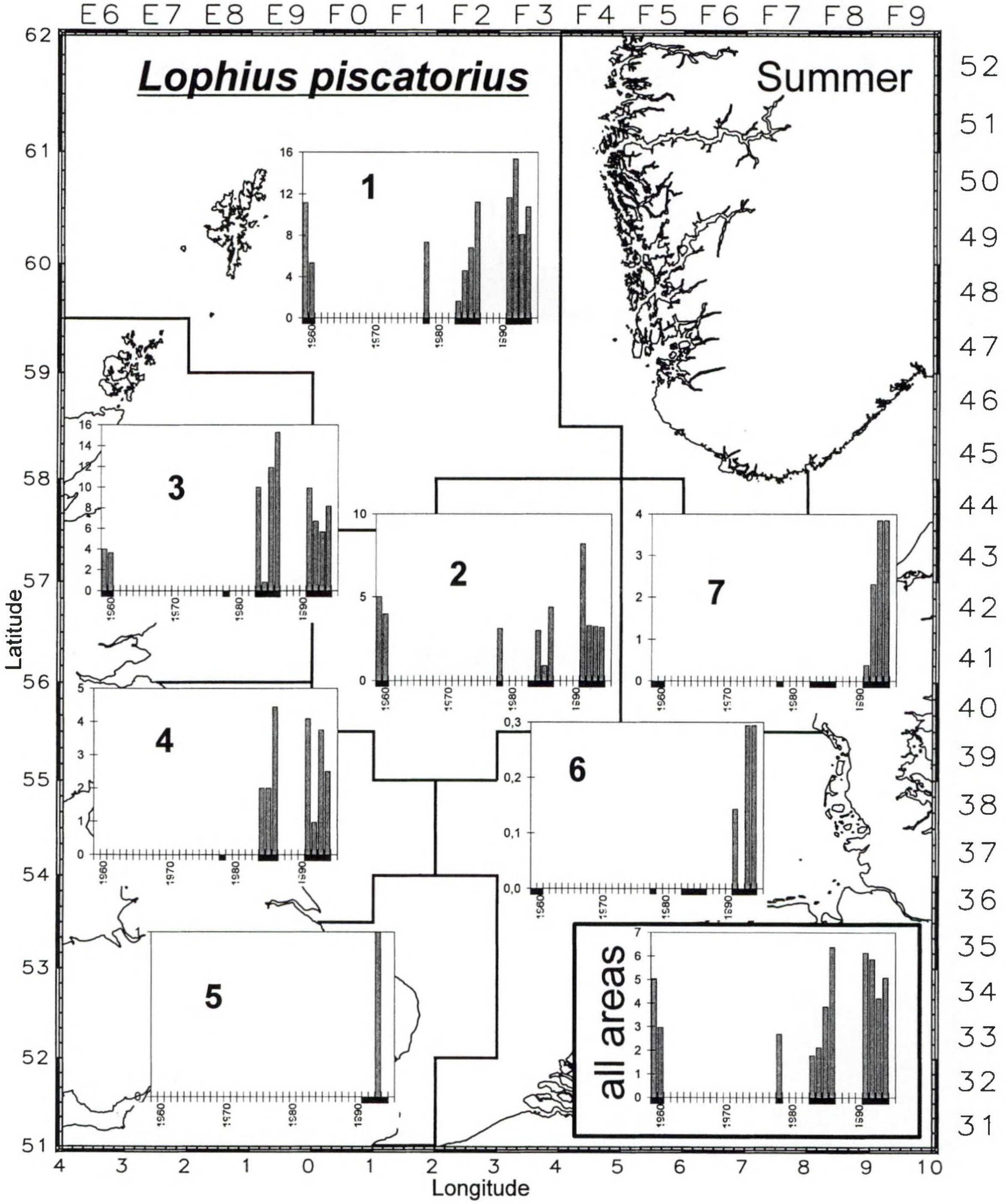


Fig. 3.8.7.5b. Angler: Mean catch rate (quarter 3; N/10 h) per roundfish area and in the total North Sea during the periods 1959-1960, 1978, 1983-1986 and 1991-1994.

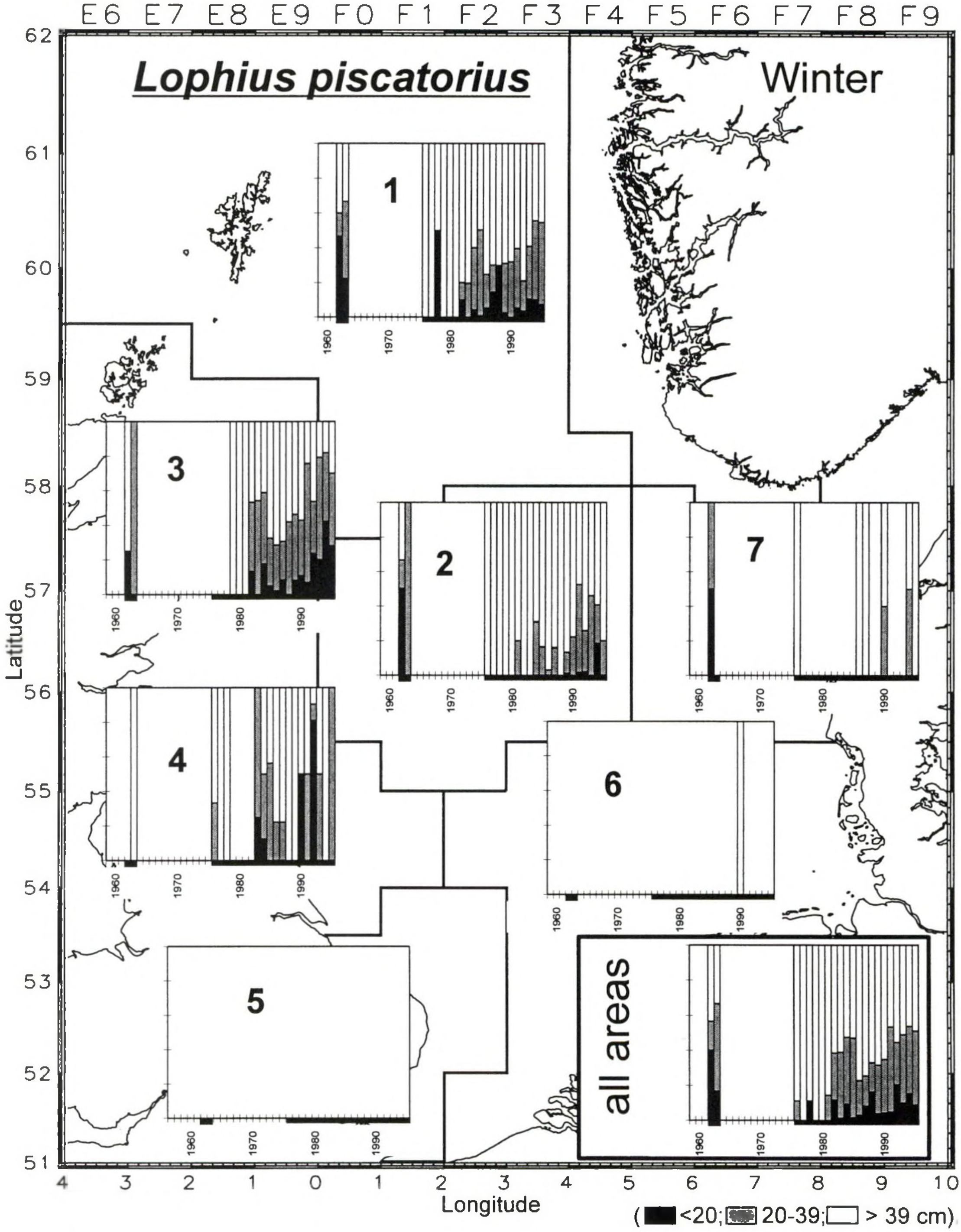


Fig 3.8.7.5c. Angler: Percentage of the size classes in the mean catch rate (quarter 1).

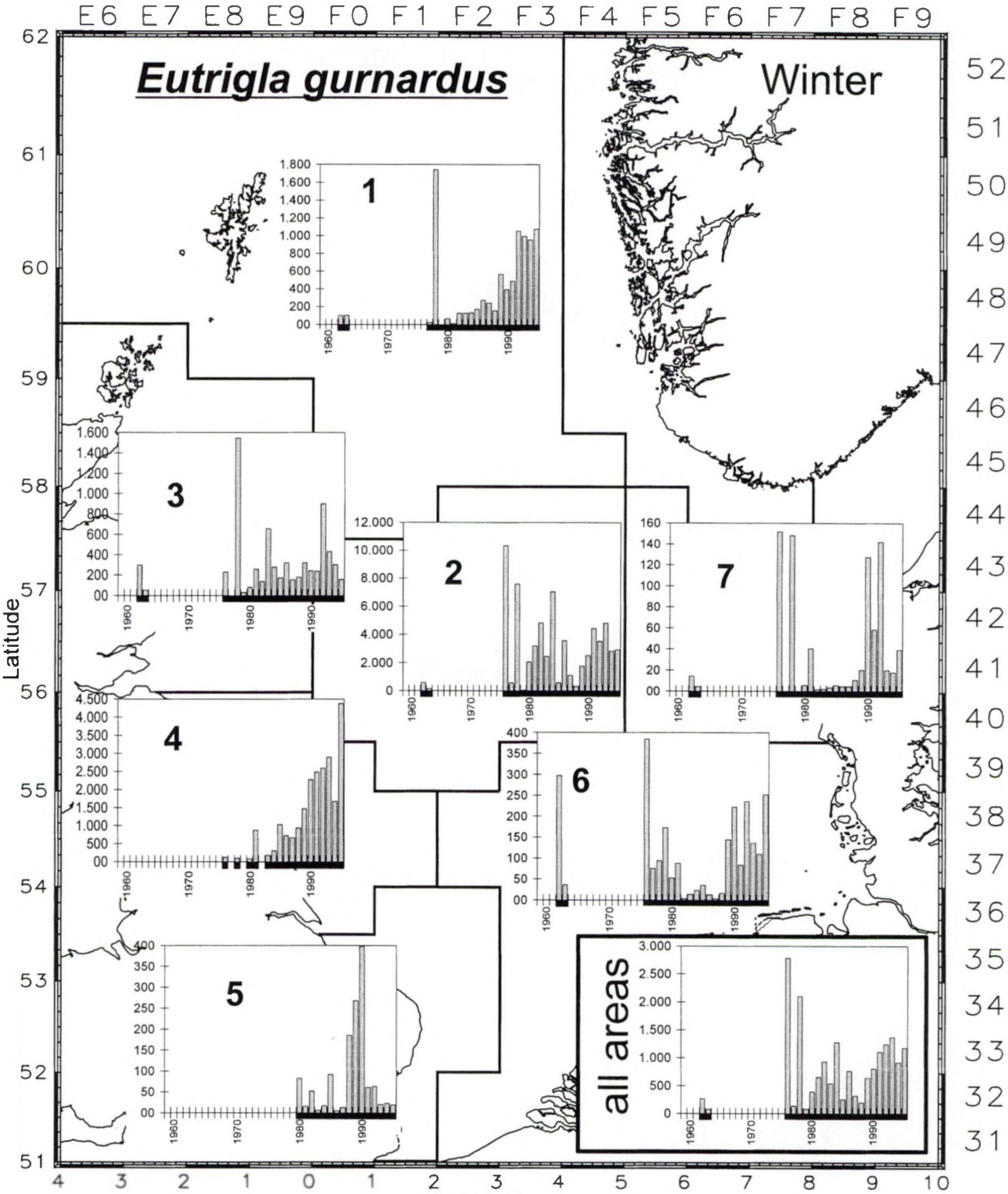


Fig. 3.8.7.6a. Grey gunard: Mean catch rate (quarter 1; N/10 h) per roundfish area and in the total North Sea during the periods 1962-1963 and 1976-1995.

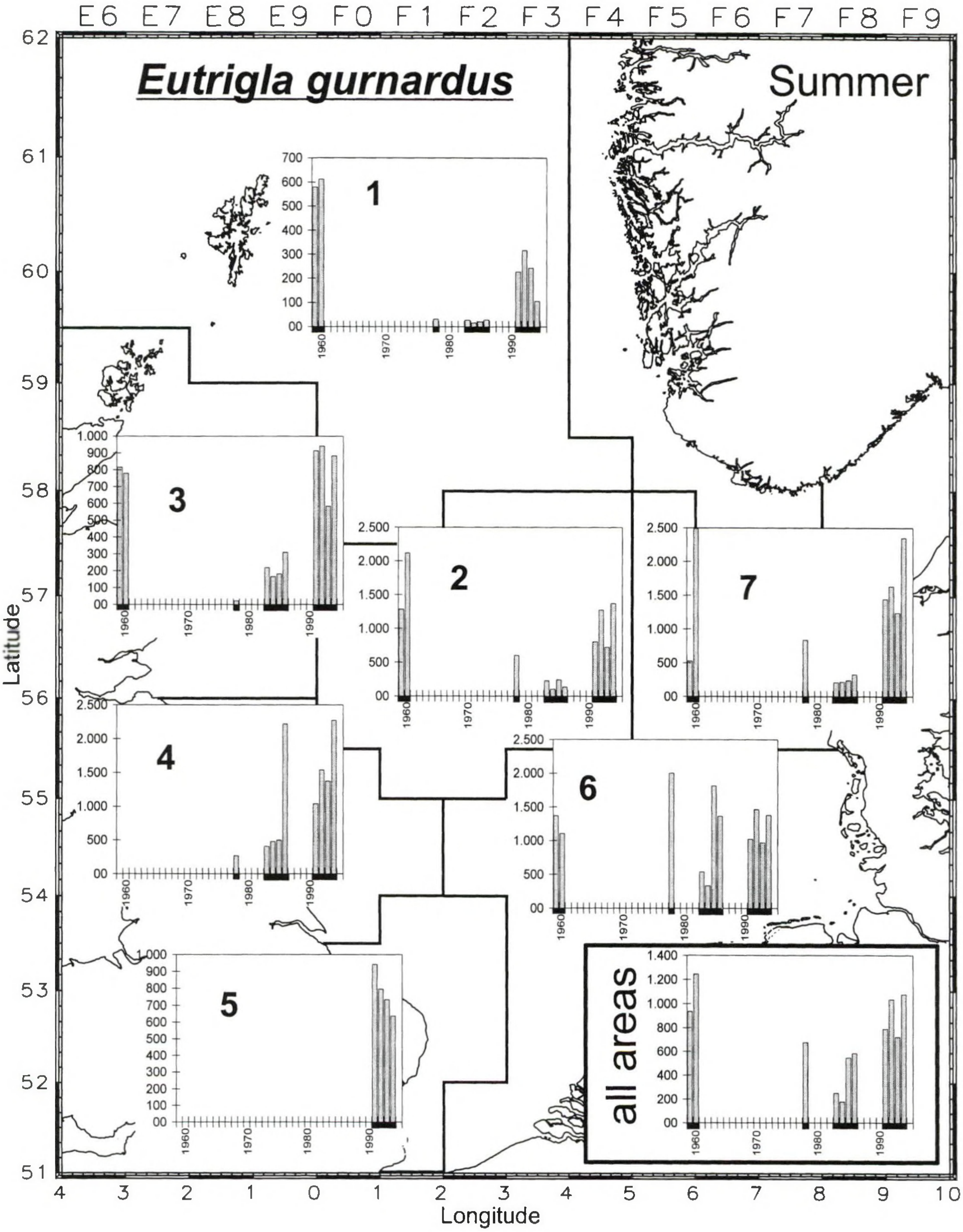


Fig. 3.8.7.6b. Grey gunard: Mean catch rate (quarter 3; N/10 h) per roundfish area and in the total North Sea during the periods 1959-1960, 1978, 1983-1986 and 1991-1994.

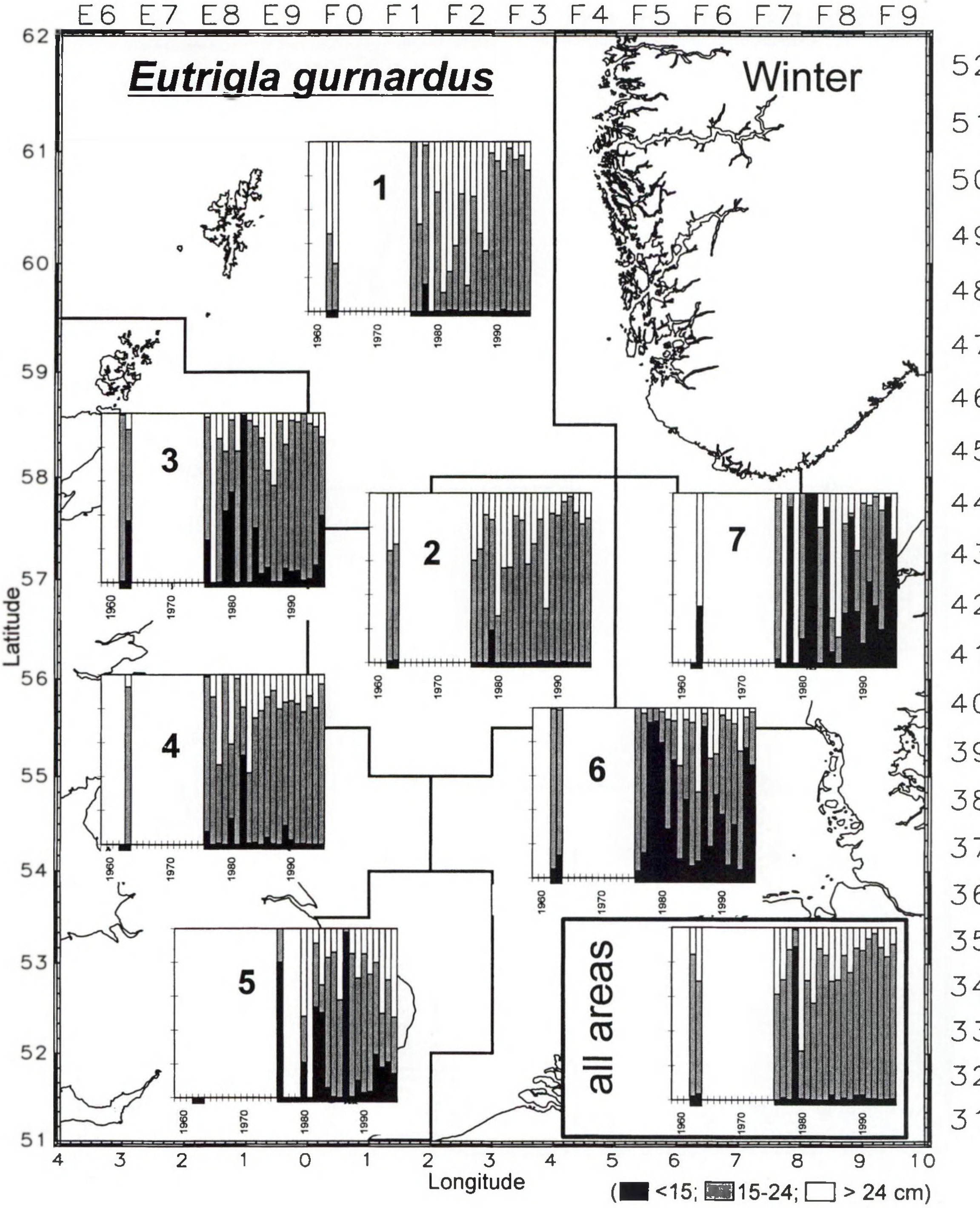


Fig. 3.8.7.6c. Grey gunard: Percentage of the size classes in the mean catch rate (quarter 1).

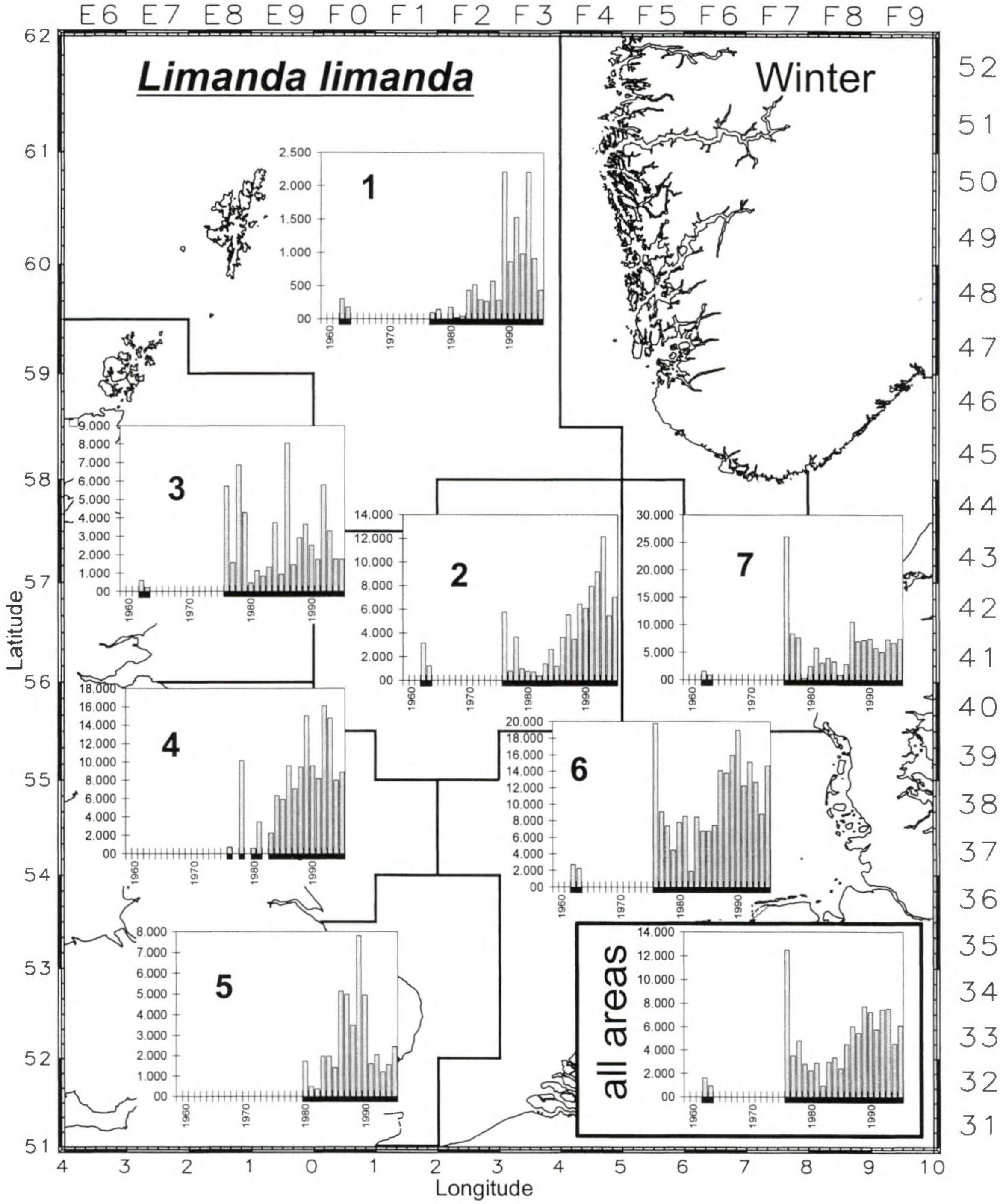


Fig. 3.8.7.7a. Dab: Mean catch rate (quarter 1; N/10 h) per roundfish area and in the total North Sea during the periods 1962-1963 and 1976-1995.

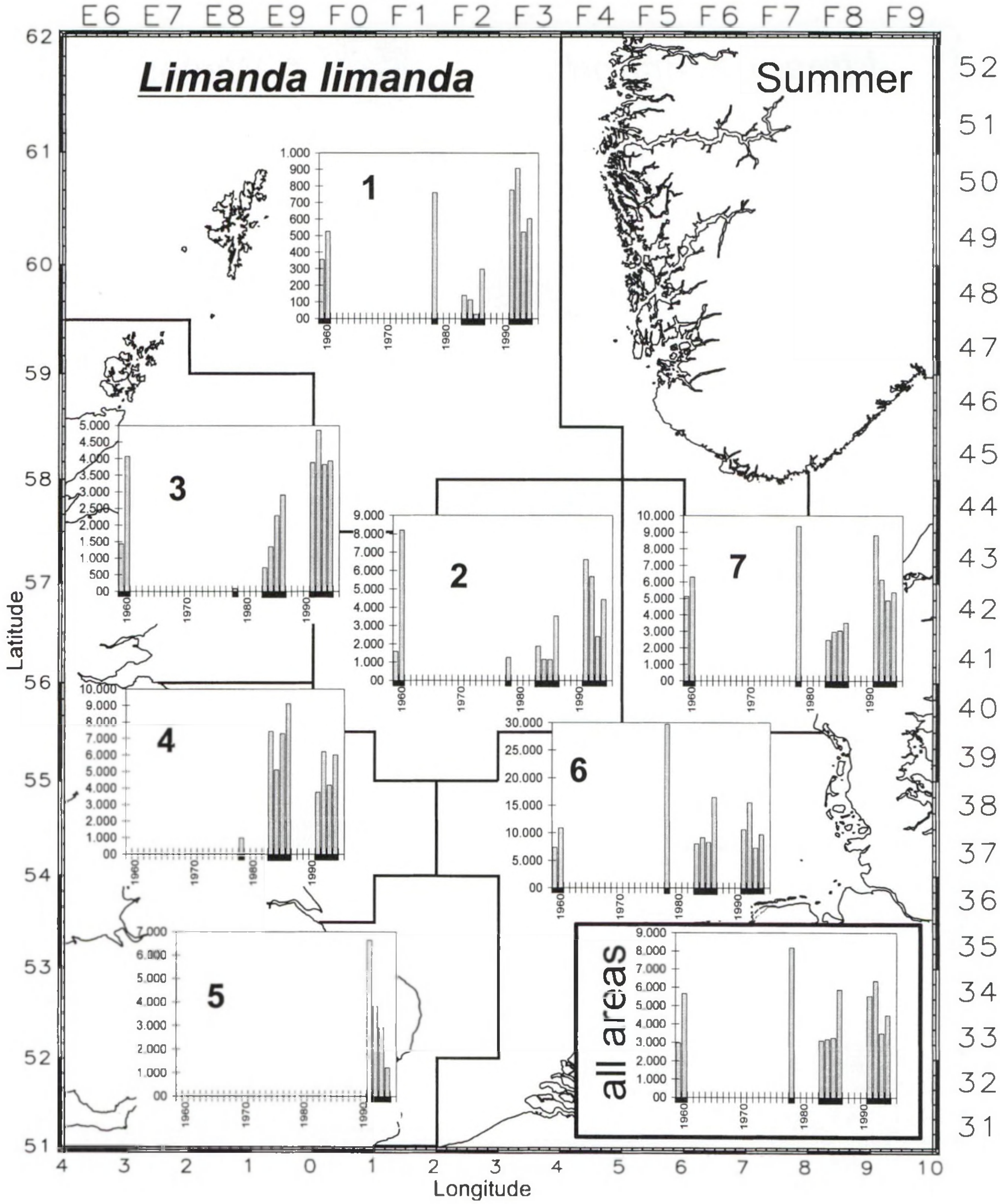


Fig. 3.8.7.7b. Dab: Mean catch rate (quarter 3; N/10 h) per roundfish area and in the total North Sea during the periods 1959-1960, 1978, 1983-1986 and 1991-1994.

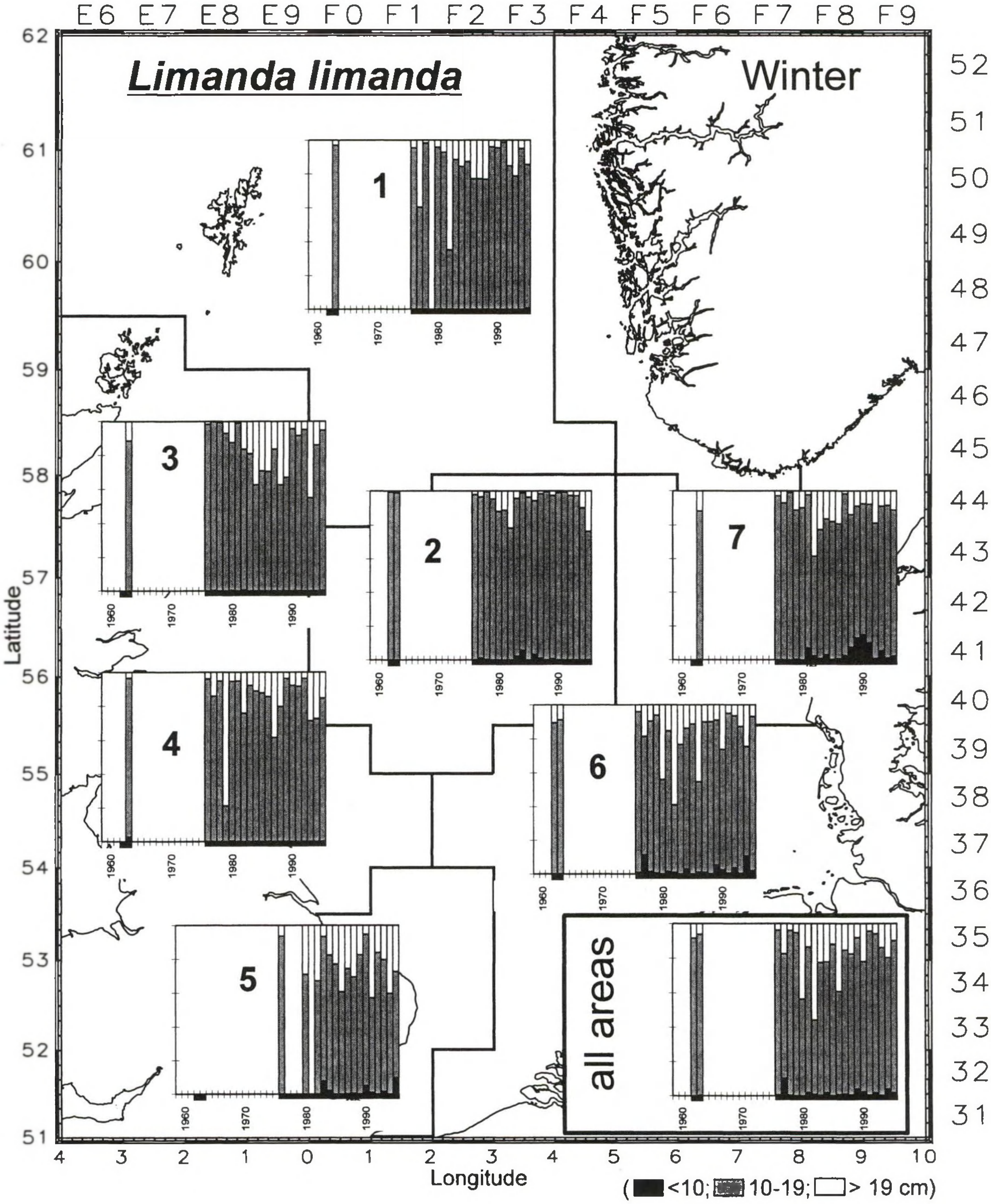


Fig. 3.8.7.7c. Dab: Percentage of the size classes in the mean catch rate (quarter 1).

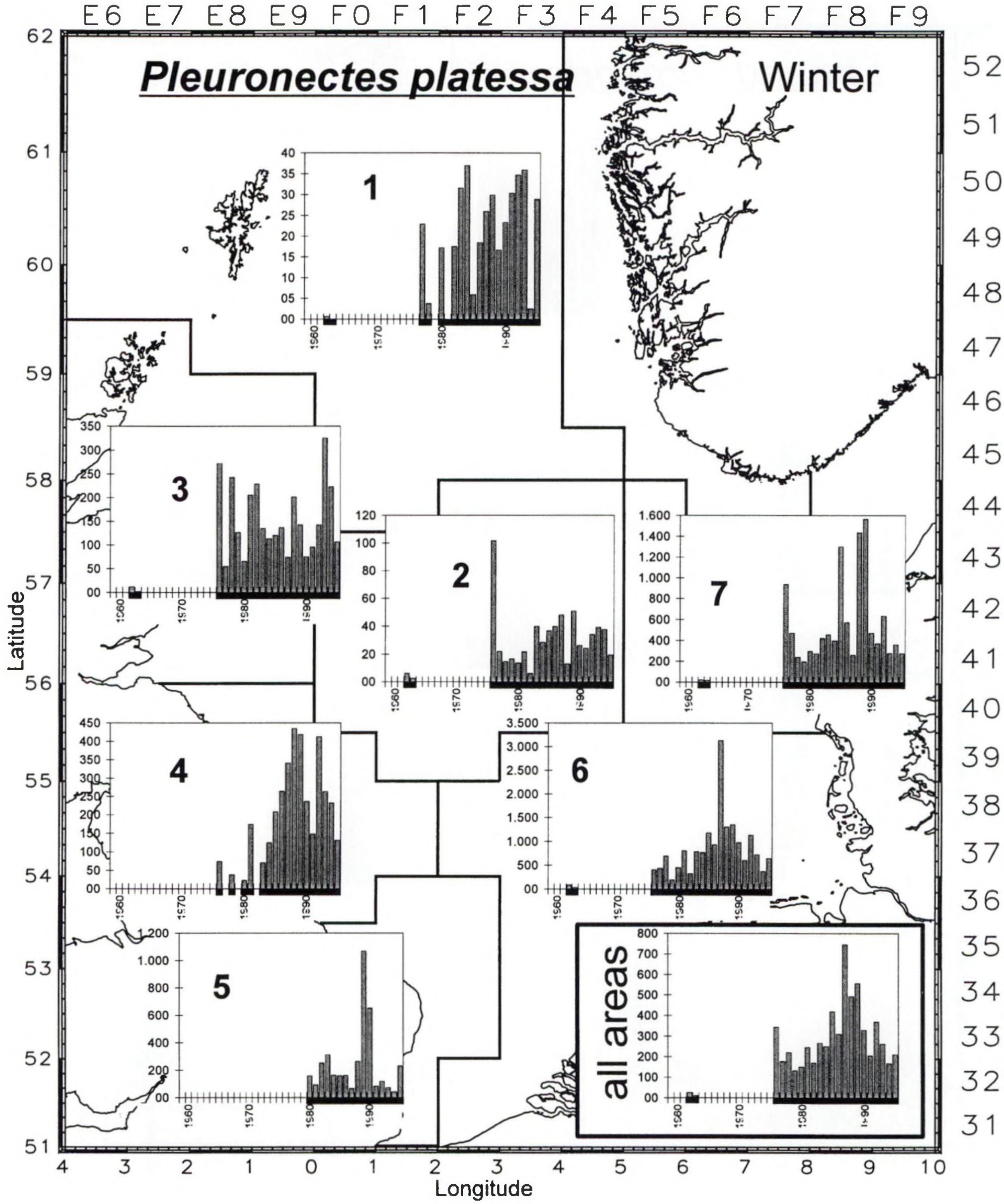


Fig. 3.8.7.8a. Plaice: Mean catch rate (quarter 1; N/10 h) per roundfish area and in the total North Sea during the periods 1962-1963 and 1976-1995.

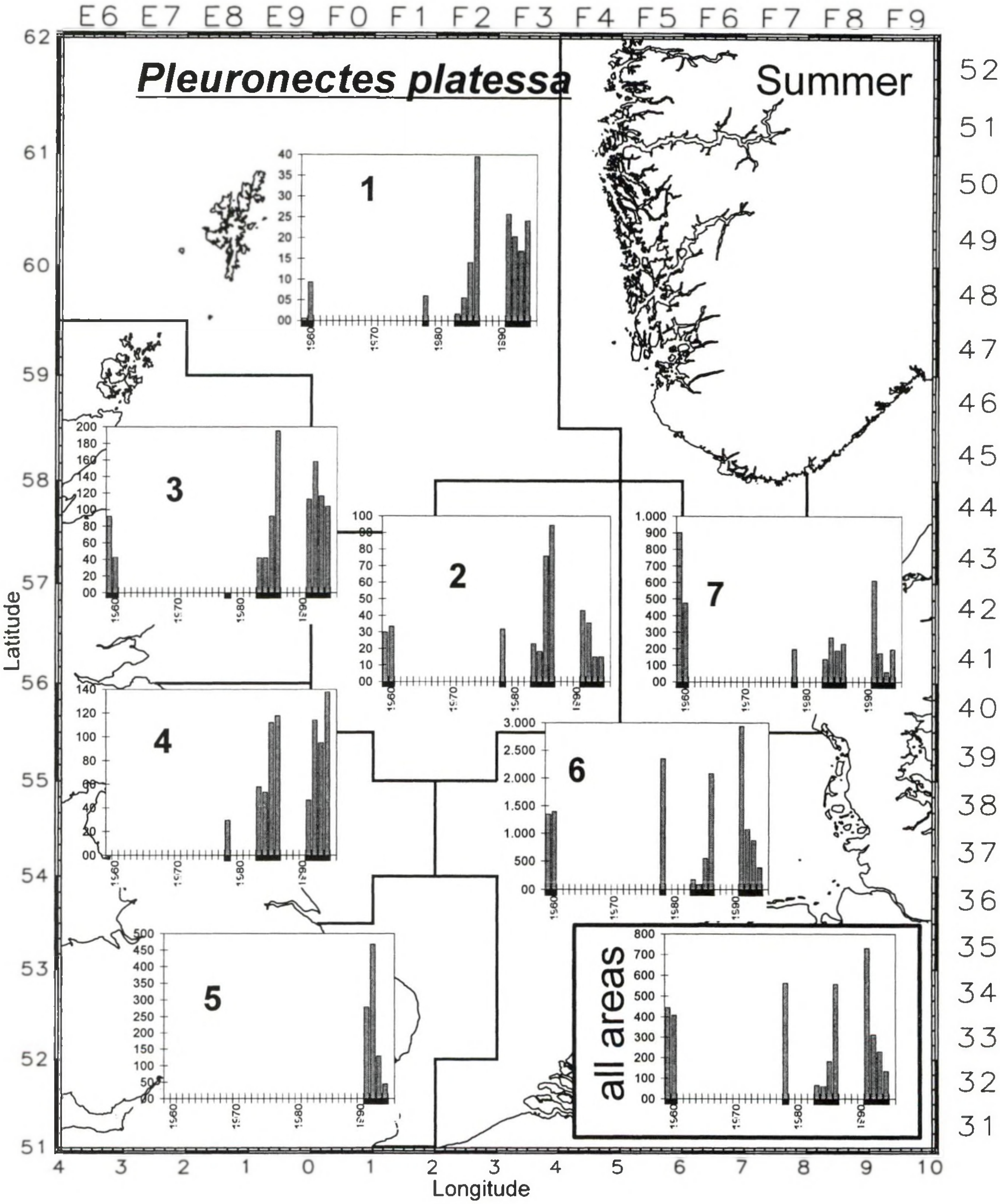


Fig. 3.8.7.8b. Plaice: Mean catch rate (quarter 3; N/10 h) per roundfish area and in the total North Sea during the periods 1959-1960, 1978, 1983-1986 and 1991-1994.

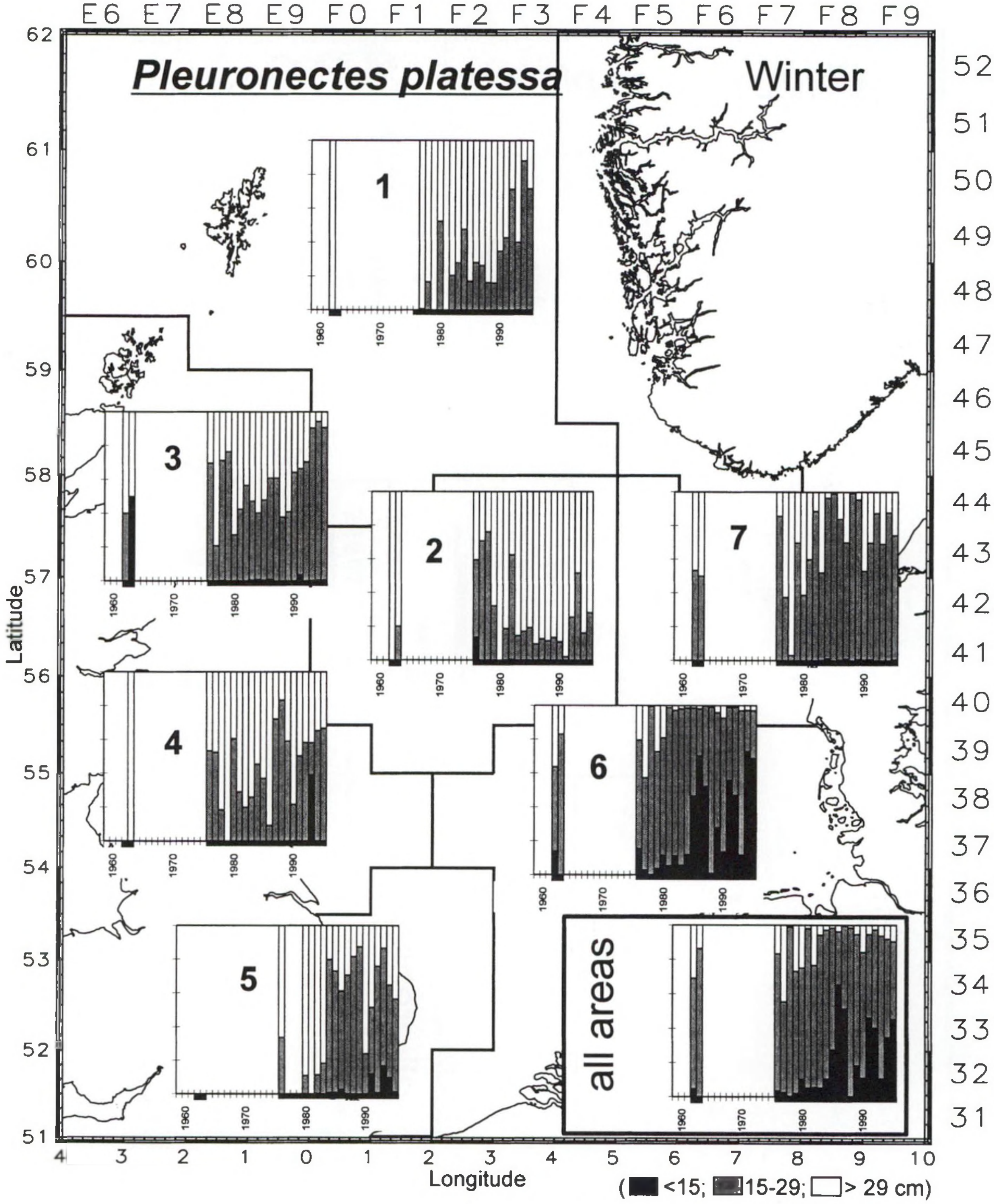


Fig. 3.8.7.8c. Plaice: Percentage of the size classes in the mean catch rate (quarter 1).

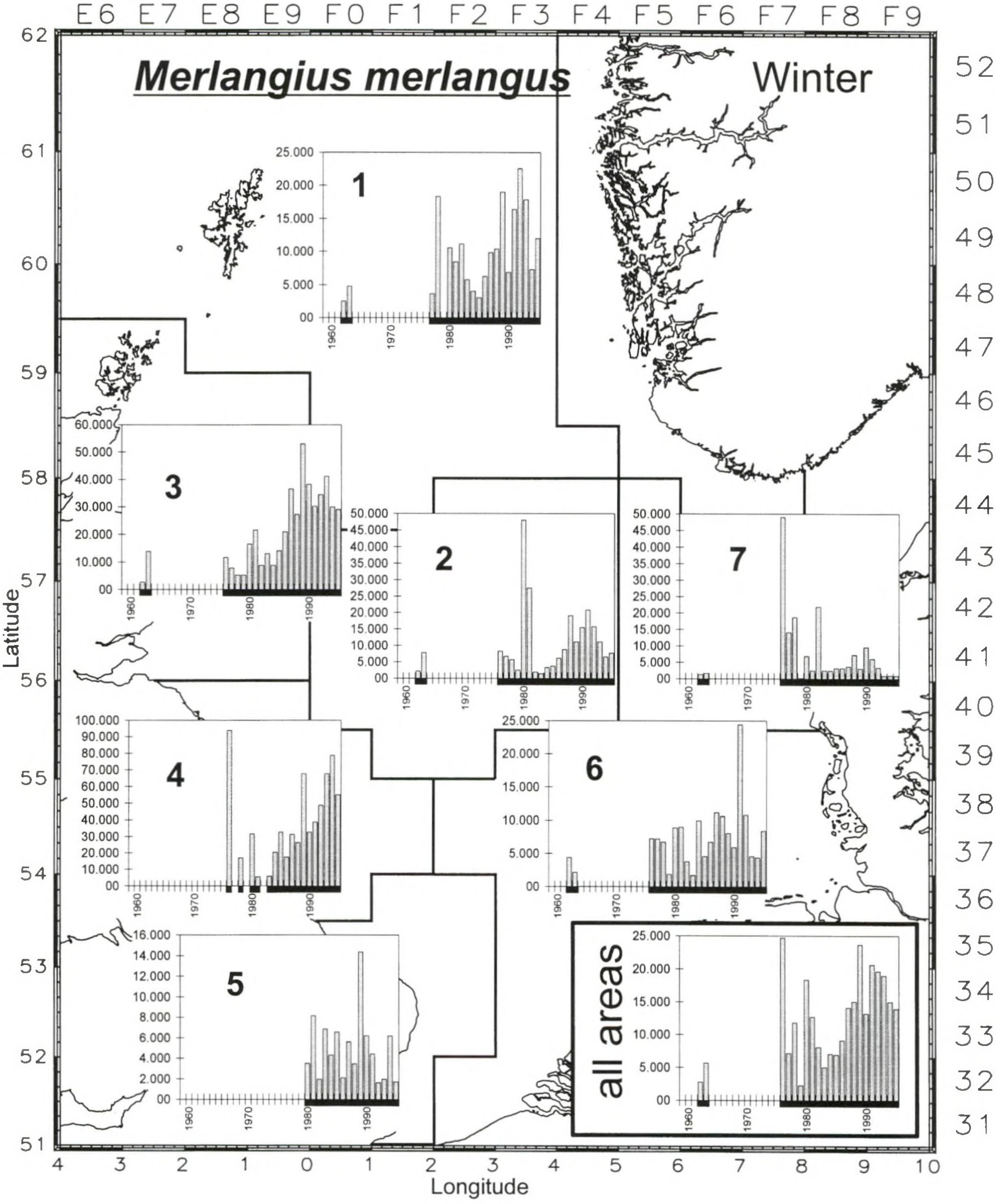


Fig. 3.8.7.9a. Whiting: Mean catch rate (quarter 1; N/10 h) per roundfish area and in the total North Sea during the periods 1962-1963 and 1976-1995.

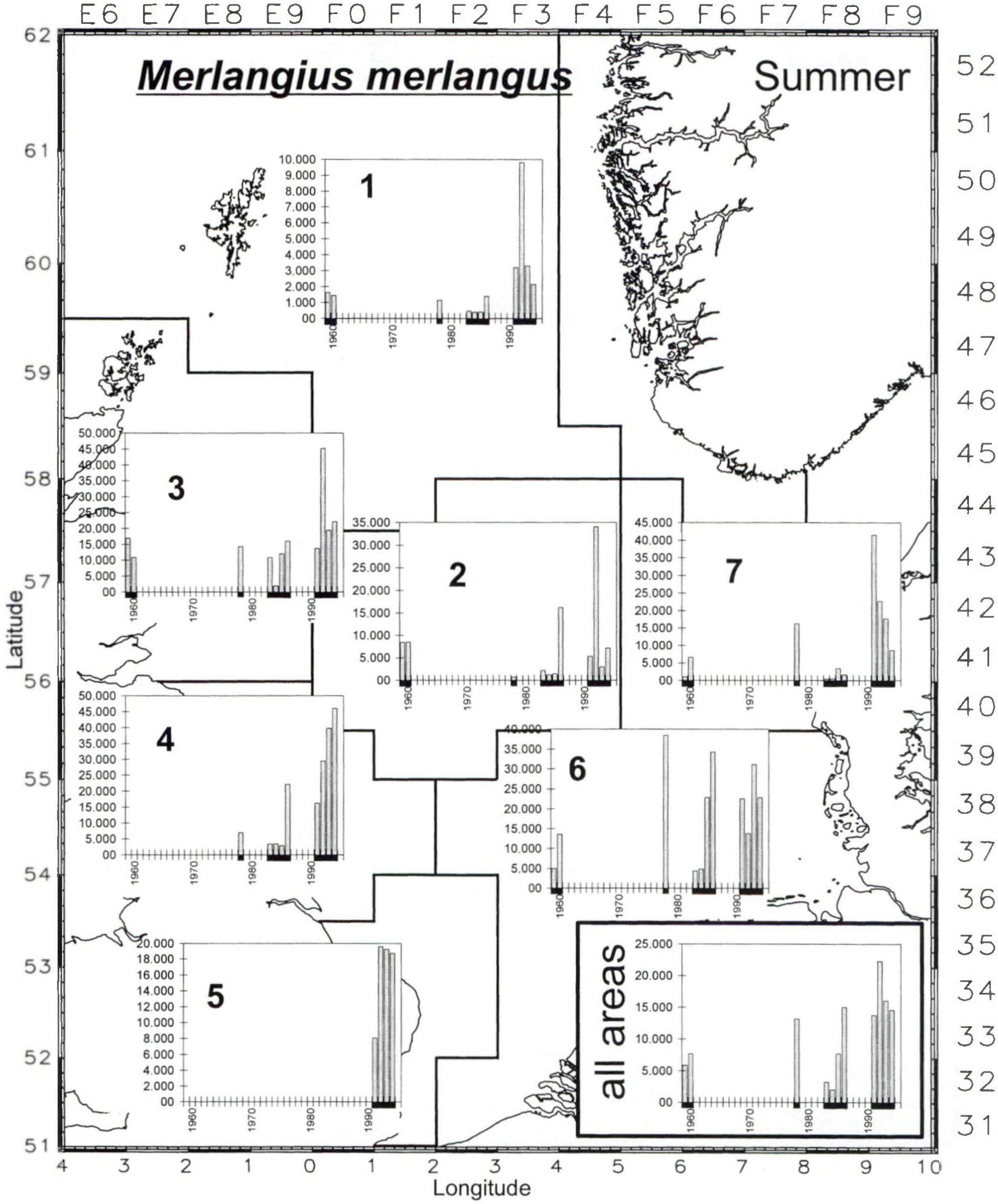


Fig. 3.8.7.9b. Whiting: Mean catch rate (quarter 3; N/10 h) per roundfish area and in the total North Sea during the periods 1959-1960, 1978, 1983-1986 and 1991-1994.

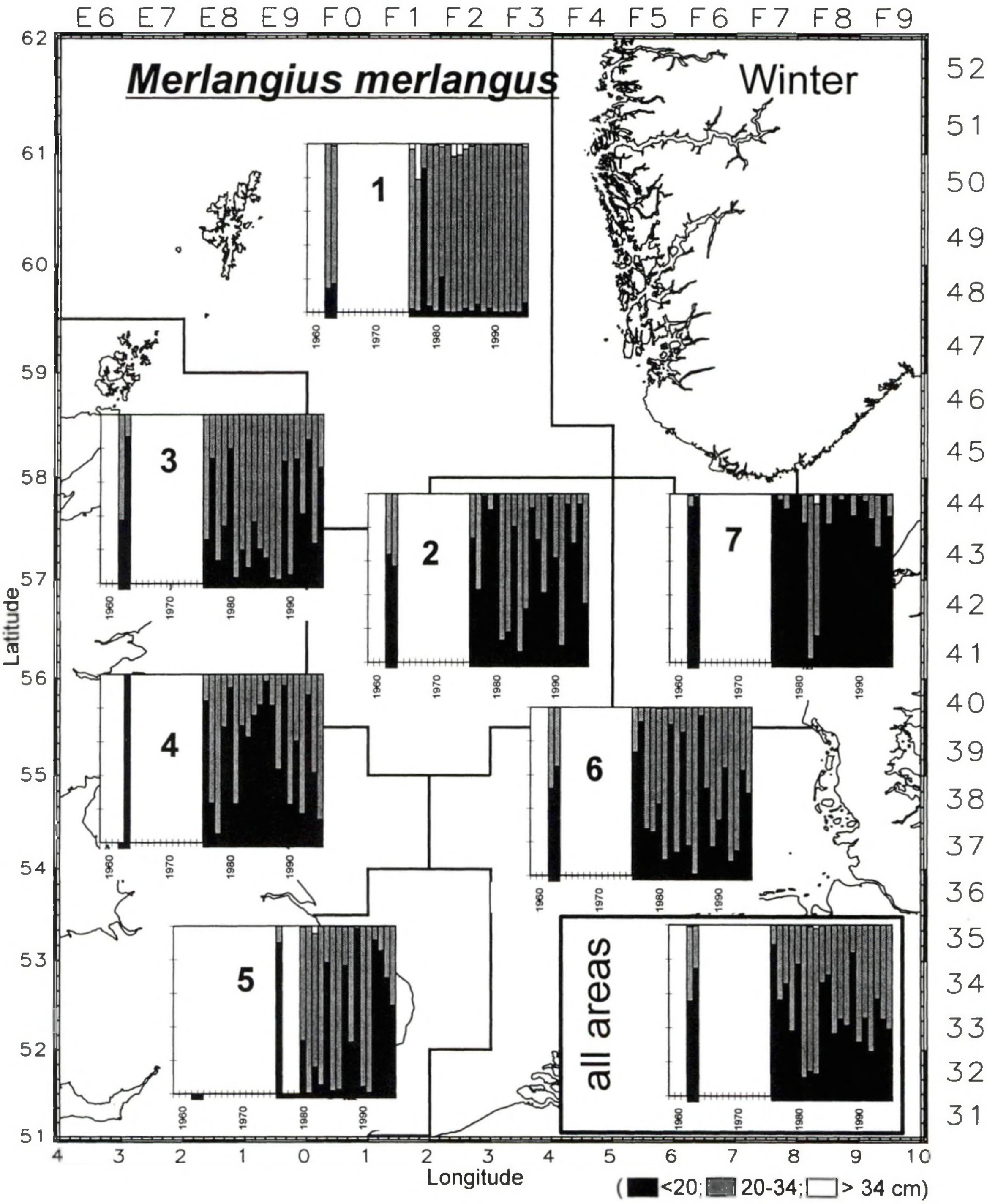


Fig. 3.8.7.9c. Whiting: Percentage of the size classes in the mean catch rate (quarter 1).

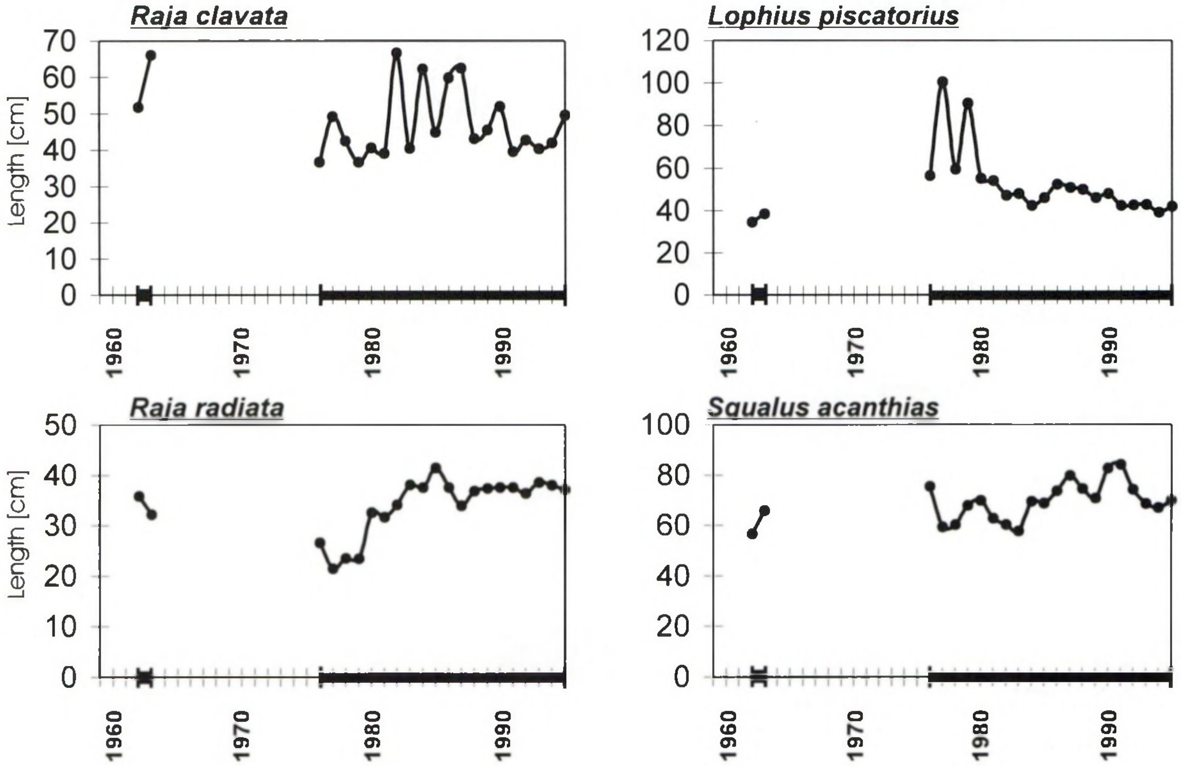


Fig. 3.8.7.10a. Changes in mean length per species during the periods 1962-1963 and 1976-1995.

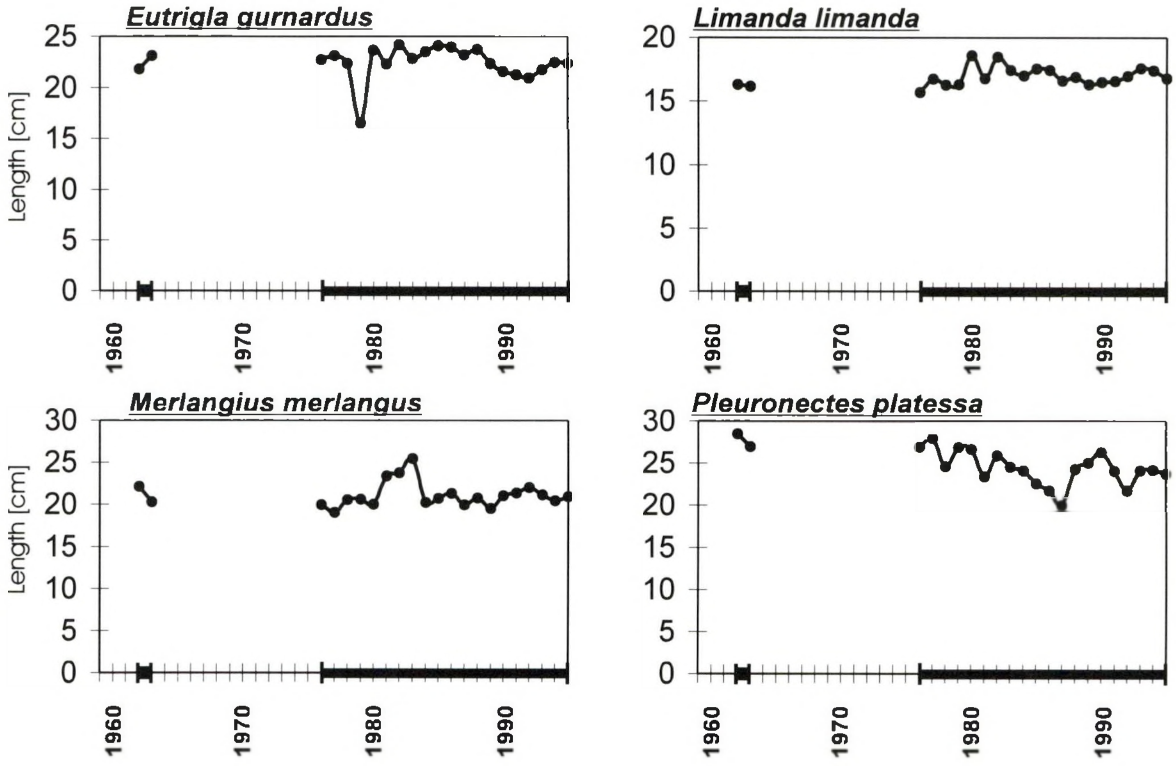


Fig. 3.8.7.10b. Changes in mean length per species during the periods 1962-1963 and 1976-1995.

Discussion

As a result, the recurrent hypothesis that „the strong and increasing effort in the demersal fishery results in a permanent decrease in the abundance of non-target fish and invertebrate species within the ecosystem North Sea" - cannot be maintained for these fishes. This is shown by Heessen (1996) and Heessen & Daan (1996) and in the present investigation. Dab and grey gurnard are widely and evenly distributed species, which live close to the bottom and are therefore highly vulnerable to beam and otter trawls. Therefore decreasing trends rather than the observed increasing trends should be expected.

How to explain this discrepancy?

1. The distribution and number of hauls may not be sufficient to obtain data, which are representative for the real development of abundance.
2. The increasing fishery may have caught the large predators (cod) of dab and gurnard and reduced the natural mortality of both species.
3. The beam and otter trawl fishery may have a positive effect on the food availability by digging out or damaging the invertebrate prey species. This could improve the conditions for dab and gurnard.

4. Large-scale changes in the North Sea ecosystem have taken place in earlier times. The hypothesis of an ecosystem switch between demersal and pelagic species is discussed in Jones (1992); Lindeboom *et al.* (1995) and Steele (1996). The actual state of such regime has an inherent stability and significant forces are necessary to shift the regime from one level of stabile imbalance into the alternative state.

In the „North Sea ecosystem" the recent high level of fishing effort is integrated as an externally driving factor. The fish species could have reacted with higher productivity like increase in growth (Hempel 1976), decrease in mean length at first maturity and possibly an increase in fecundity, that the effect of the fishery to the abundance of the species are compensated.

Also for the abundance in weight (biomass) no negative trend can be observed in the total catch rate in the data series of the IBTS (Ehrich, unpublished data) over the last 2 decades.

Finally some remarks about the recent very low abundance of spurdog. The ecosystems of the North Sea and the Georges Bank in the North West Atlantic have some similarities. Both areas are heavily fished and the gadoids, especially haddock played a dominant role in both systems in former decades. Now in both areas the gadoids are of minor importance, but in the North Sea the pelagic species dominate, whereas spurdog and skates constitute over 50% of the demersal biomass on Georges Bank, in spite of the fishery. This indicates that the recent low abundance of spurdog in the North Sea is probably more caused by other factors than fishery.

3.8.8. GENERAL DISCUSSION

It is important to note that the findings in this chapter are only valid for certain areas and time „windows" in which and for which they have been investigated. It is also true that other factors than fisheries may cause similar effects which may be hard to distinguish (e.g. eutrophication). Also the length of the observation time (as shown in figure 2.8.1) may have some influence on the validity of the results since the major shifts in the ecosystem may have already occurred before the onset of the time series presented here.

BENTHIC INVERTEBRATES

Relating the results from the epifauna and parts of the infauna to the general development of the demersal fishery in the southern North Sea the analyses cover the span after the initial onset of a widespread trawl fishery that skimmed off the surplus of the virgin stocks in the 19th century. The ICES routine investigations were started in the general care about the state of the fish stocks. The populations appeared to have severely crashed after the first strong fishery impact in the last century, i.e. at the end of the last century. At the beginning of this century, however, parts of the off-coast regions might have been still close to a pristine status with regard to benthic comunities that would have been found before the onset of the trawl fishery. In 1986, almost 100 years of trawling impact have certainly re-structured the benthic system and so this comparison from close to a pristine situation to a long term disturbed situation may be the most that we can achieve despite the mentioned problems with the historical data.

For the longest time span observed (1902/'12-1986) a decline in the spatial occurrence of bivalves can be stated whereas scavengers and predators such as crustaceans, gastropods and sea stars have been found more frequently in 1986. This can be clearly attributed to the fishery impact which reduces the spatial heterogeneity of the habitat, directly damages and destroys vulnerable species and produces by means of the discards together with the destroyed animals at the sea floor a huge amount of additional possible food material for scavenging species. This stimulating factor for the populations may even overrule the deleterious effect of the physical damage through the fishing process to the same vulnerable species.

For another long time span (1923-1995), the geographic borders between the association of infauna in the German Bight were relatively stable and remained relatively unchanged suggesting that the sediment type may be the masterfactor. The composition within these associations, however, was less stable and changed considerably during the last 70 years. The benthic communities of the German Bight show a significant increase in biomass and a change in community structure with a dominance of opportunistic short-lived species (r-selected) and a decrease of long-living sessile organisms (K-selected) like several bivalve species. The 1995 investigation shows higher abundances and biomass of these opportunistic species in most areas than all preceeding investigations.

Even for shorter time spans (1980-1993), long-lived species such as *Buccinum* decreased in abundance whilst those organisms which benefit from the discarded organic material from fisheries increased (e.g. *Asterias*) in the southeastern North Sea. Results of an analysis of a historical by-catch data set suggested that catch mortality of epifauna and infauna increased significantly after the introduction of beamtrawling in the beginning of the sixties. Beam trawlers caught some invertebrate species (i.e. velvet swimming crab, slender spindle shell) that were hardly delivered by ottertrawlers before.

Our observations are in agreement with other observations for North Sea benthic communities (e.g. Rachor 1990; Duineveld *et al.* 1987; Kröncke 1992; Witbaard & Klein 1993; Kröncke & Knust 1995). Combined with the results from other chapters on the immediate effects of bottom fisheries on the benthos and the comparison between fished and unfished areas, it has to be concluded that the observed trends in benthic invertebrates were to a great extent caused by the direct and indirect effects of fisheries and not solely by eutrophication and/or pollution as interpreted in previous studies (e.g. Rachor 1990; Kröncke & Knust 1995).

DEMERSAL FISH

Due to the direct extraction of fish from the ecosystem, bottom fisheries should also have effected the abundances, the biomass and the population structure of the target and non-target species of demersal fish.

The observed variation in annual numbers of fish and invertebrates delivered to the Zoological Station in Den Helder were found to be related to the changes in gear and fishing effort of bottom trawlers. Otter trawlers caught relatively more fish than invertebrates and, on average, the catchability of beam trawling appeared to be an order of magnitude higher than that of otter trawling for all species considered.

On average, the relative species composition appeared to have changed in the south-eastern North Sea during the last decades. We observed a decrease of several flatfish species such as plaice and sole, whilst other species increased in numbers such as grey gurnard, dab and in particular dragonet. High trawling intensity may cause this increase on abundance by several effects which can work synergistically, such as lower catchabilityof small-sized fish, lower perdation pressure due to higher catchability of predating larger fishes, higher productivity of small-sized fast growing prey species and opportunistic scavenging behaviour by the mentioned fish species. Although we cannot exclude other influences on the population sizes and distributions in the North Sea, like a raise in temperature, eutrophication, windforce and -direction and intra- and interspecific interactions, the observed changes could be very well explained by increased fisheries mortality on the one hand and improved circumstances for growth and survivalon the other hand.

Small scale investigations have their drawbacks when analysing this kind of problems, as shown by the investigation in Box A in the German Bight. In contrast to the findings from the entire German Bight (roundfish area 6) no trend in abundance could be detected for dab and grey gurnard. The high inter-annual variability of the catch rates of these two species could be attributed to the relative small size of the investigated box and the mobility of these fish species, which might have migrated into the study area from the surrounding waters.

Large scale investigations also gave conflicting results. For the North Sea as a whole and for the ICES roundfish areas within the North Sea, we observed an increase in dab, grey gurnard, starry ray and angler between 1976 and present. These demersal fish species were expected to be highly vulnerable to beam and/or otter trawling and subsequently hypothesised to show a negative instead of a positive trend in abundance.

The recurrent hypothesis that „the strong and increasing effort in the demersal fishery results in a permanent decrease in the abundance of non-target fish and invertebrate species within the ecosystem North Sea" - is not supportet by all analyses. The discrepancy in results might be explained by the following factors:

1. The distribution and number of hauls may not be sufficient to obtain realistic data, which are representative for the actual trends in abundance.
2. The increasing fishery may have diminished the large predators of dab and gurnard such as cod and subsequently reduced the natural mortality of both species.
3. The beam and otter trawl fishery may have had a positive effect on the food availability by digging out or damaging the invertebrate prey species. This could have improved the conditions for dab and gurnard.
4. Large-scale temporal changes in the North Sea ecosystem due to fisheries may have already taken place in earlier times. It is possible that from the beginning of the time series, we were already looking at heavily exploited fish communities where large changes in effort now only cause small and hardly visible changes in species composition of demersal fish communities.
5. Natural temporal large-scale changes in the North Sea ecosystem may have counteracted the effects of fisheries. The hypothesis of an ecosystem switch between demersal and pelagic species is discussed in Jones (1992); Lindeboom *et al.* (1995) and Steele (1996). The actual state of such regime has an inherent stability and significant forces are necessary to shift the regime from one level of stabile imbalance into the alternative state.
6. The effect of fisheries can only be observed by looking at a particular spatial scale. The abundance of vulnerable species may have decreased in heavily fished areas such as the coastal zones, whilst the stock as a whole may not have been affected when looking at a broader range of distribution.

4. GENERAL DISCUSSION

4.1. FISHING MORTALITY IN INVERTEBRATE POPULATIONS DUE TO DIFFERENT TYPES OF TRAWL FISHERIES IN THE DUTCH SECTOR OF THE NORTH SEA IN 1994

Introduction

In this section an estimate is given for the fishing mortality, *i.e.* the total direct mortality in the populations of invertebrate species generated by the trawl fisheries over a certain time period, due to (i) the different trawl fleets and (ii) the combined trawling activities of the fleets in the southern North Sea in 1994.

Calculations

The fishing mortality in the populations was calculated using three variables: (i) the spatial distribution of benthic invertebrate species, (ii) the trawling frequency of the different demersal fleets in 1994, and (iii) the estimates of the total direct mortality due to experimental trawling with commercial trawls.

(i) Since only for the Dutch sector the population densities of larger sized invertebrates were reliably estimated (data 1996 in Bergman & van Santbrink 1997), calculations on fishing mortality in these populations were limited to this sector. It was assumed that the distribution patterns in 1996 were roughly similar with those in 1994 and that the distribution of a species within an ICES statistical rectangle was homogeneous. For the analysis, only species were selected for which a reliable total direct mortality estimate for at least two different types of trawls was available, and for which this estimate was >10% due to at least one type (chapter 3.5, Table 3.5.5). In Fig. 4.1.1 some characteristic distribution patterns of species over the ICES rectangles in the Dutch sector are shown.

(ii) The trawling frequencies per ICES rectangle by the Dutch, Belgium, German and British fleets in 1994 were calculated from the numbers of fishing hours (chapter 3.2) and the surface area of the ICES quadrants, for 4m and 12m beam trawls with ticklers, 4m beam trawls with chain matrices, and otter trawls (Fig. 4.1.2). Trawling frequencies with beam trawls of intermediate lengths, and with 12m beam trawls rigged with chain matrices were not included, since direct mortality estimates were not available for these trawl types. However, their use is much less than the types included in this section. In a recent study, Rijnsdorp *et al.* (1997) analysed the activities of a representative selection of trawlers (13% of the Dutch 12m beam trawl fleet) and showed that the trawling effort was clustered. To simulate a similarly clustered distribution, each ICES rectangle was divided in nine subrectangles, over which the total trawling effort of a fleet in that ICES rectangle was distributed, in terms of percentages, as 0.1, 0.2, 0.6, 1.1, 2.2, 5.6, 11.1, 22.2 and 56.9%. Although the fishing mortality calculated in this way might slightly differ from the actual fishing mortality generated by the fishery, the differences in fishing mortality between the various fleets will not deviate greatly from the actual situation, assuming that all types of trawling showed the same degree of heterogenity in the spatial distribution within ICES rectangles.

(iii) The total direct mortality in invertebrate species due to experimental trawling with different types of trawls was calculated in chapter 3.5. Since it was concluded that the mortality estimate for 12m and 4m beam trawls with ticklers did not differ greatly, the mean estimate for these beam trawls was used in the calculations below, to reduce erroneous variation in the results.

In the calculations, the invertebrate populations were assumed to decline due to the trawling activities during 1994, as recruitment and growth parameters were not included. The survival rate S of a species *x* in a subrectangle *r* after trawling that subrectangle with a particular gear *g* is described by the following power function:

$$S_{x,r,g} = (1\text{-}Md_{g,x}/100)^{f(r,g)}$$

with:
$Md_{g,x}$ = the direct mortality estimate of species x for a gear g expressed as a percentage of the initial density; $Md_{g,x}$ depends on the sediment type (sandy or silty) as described in chapter 3.5
$f(r,g)$ = the trawling frequency in subrectangle r (r = 1,...,9) with gear g

The fishing mortality of a species x in a subrectangle r due to a gear g is then given by 1- $S_{x,r,g}$. The fishing mortality F in an ICES rectangle R is the average of the fishing mortalities in the nine subrectangles. This fishing mortality is multiplied by 100 to express it as a percentage of the initial density:

$$F_{x,R,g}\ (\%) = 100 * (\Sigma_r(1-S_{x,r,g}))/9$$

Based on the calculation of $F_{x,R,g}$, the fishing mortality for a species in the entire Dutch sector ($F_{x,g}$) was calculated for the different types of fisheries, by dividing the sum of the specimens killed due to a particular fishery in each ICES rectangle by the sum of the actual numbers of specimens present in those rectangles:

$$F_{x,g}\ (\%) = \Sigma_R (n_{x,R} * F_{x,R,g}) / \Sigma_R n_{x,R}$$

with:
$n_{x,R}$ = the initial numbers of specimens of species x in ICES rectangle R.

When calculating the fishing mortalities due to each particular type of fisheries, the other types of fisheries, also leading to mortalities in the same area, were not accounted for. Because the actual decline in numbers of specimens due to the combined action of the different types of trawl fleets is faster than in the calculation, the fishing mortality due to individual fisheries was slightly overestimated. Therefore, the overall fishing mortality $F_{overall}$ for a species (*i.e.* due to the four types of fisheries considered) was calculated using the overall survival rate, instead of using the sum of individual fishing mortalities. This overall survival rate was calculated as the product of the survival rates within each type of fishery. If *e.g.* the survival rate due to a certain fishery is 0.4 and due to another 0.5, the total survival rate is 0.4 *0.5 = 0.2. The overall fishing mortality is then, when expressed as a percentage of the initial density, given by:

$$F_{overall,x}\ (\%) = 100 * (1 - \Pi_g (1-F_{x,g}/100))$$

For each species, the fishing mortality per type of fishery and the overall fishing mortality, *i.e.* due to the four types of fisheries, are presented in Table 4.1.1.

Discussion

Figure 4.1.2 illustrates the distribution of the fishery effort due to the different fleets over the ICES rectangles of the Dutch sector in 1994. The 12m beam trawl fishery was the dominant type of trawling, with an average frequency for the Dutch sector of 1.23 (in contrast to frequencies of 0.13, 0.01 and 0.06 for the 4m beam trawl fishery with ticklers, with chain matrices and the otter trawl fishery respectively). Obviously, the different types of fisheries were not distributed homogeneously over this sector. The 12m beam trawl fishery occurred predominantly offshore. The 4m beam trawl fishery was mainly restricted to the coastal zone, where the trawling intensity of this fishery was as high as the 12m beam trawl fishery. The 4m beam trawls rigged with chain matrices were used exclusively in the mobile, medium-grained sandy areas in the two southernmost rectangles. Otter trawls were used throughout the Dutch sector, but it should be noted that the otter trawl effort data included the otter trawl fishery for roundfish, which still is a widely practised type of trawling. The effort of the flatfish otter trawl fishery has declined dramatically during the last decades and is nowadays very low.

For all invertebrate species considered, the 12m beam trawl fishery caused the highest fishing mortality (Table 4.1.1). It appeared that the fishing mortality in invertebrate populations largely depends on the spatial distribution of both the effort of trawling fleets and of the species. Especially for species living predominantly in silty offshore areas (*e.g. Dosinia lupinus*) and for those occurring in all types of sediments (*e.g. Echinocardium cordatum*), the fishing mortality due to the 12m beam trawl fisheries was much higher than due to the 4m beam trawl fisheries, mainly due to the spatially limited distribution of this last mentioned fishery. For species that are restricted to sandy areas, in which the highest efforts of the 4m beam trawl fisheries are found, this difference in fishing mortality was less pronounced (*e.g. Spisula solida* and *Ensis* spp., dominated by the coastal species *Ensis americanus).*

Although the 12m beam trawl fisheries generally caused higher fishing mortalities in all invertebrate species, this was not valid for all individual rectangles. For example, in rectangles 33F4 and 35F5, situated in the coastal 12 miles zone and in the Plaice Box - where the use of 12m beam trawls was forbidden and restricted respectively - the effort of 12m beam trawls is lower than of 4m beam trawls. Because the same total direct mortality estimate (Table 3.5.5) was used for these two fisheries, fishing mortality due to 12m beam trawl fishery was, in these two rectangles, lower than due to 4m beam trawl fishery. Also within the other coastal ICES rectangles restrictions for the12 m beam trawl fleet existed, and although the mean effort of 12m beam trawls in these rectangles was still higher than of the 4m beam trawl fisheries (Fig. 4.1.2), in the closed subareas the effort (and thus fishing mortality) of 12m beam trawlers was nihil. This implies that for predominantly coastal species like *Thia scutellata*, *Spisula* spp., *Lunatia catena*), 4m beam trawl fisheries probably caused higher fishing mortalities in the entire Dutch sector, relative to those caused by the 12m beam trawl fleet, than is mentioned in Table 4.1.1. Especially for species like *Spisula subtruncata* and *Ensis americanus*, that mainly occur within the 12 miles zone, it is likely that the fishing mortality in the entire Dutch sector due to the 4m beam trawl fishery even exceeds that of the 12m beam trawl fleet.

The fishing mortality due to the fleet using 4m beams rigged with chain matrices was much lower than that due to the fleet using 4m beams with tickler chains, as trawling with chain matrices was only carried out in the two southernmost rectangles in the Dutch sector (Fig. 4.1.2).

In silty areas, the otter trawl fisheries caused fishing mortalities generally similar to 4m beam trawl fleet fishing with tickler chains. Apparently, the lower total direct mortality estimate for otter trawls (Table 3.5.5) was compensated by the higher trawling effort (Fig. 4.1.2). However, fishing mortalities due to otter trawl fisheries might be overestimated, as the otter trawl effort included roundfish otter trawling, whereas the total direct mortality estimate was based solely on flatfish otter trawling (which is assumed to have more impact on the seabed). In sandy areas, the fishing mortality due to otter trawl fisheries tended to be lower than due to 4m beam trawl fisheries, mainly because of the lower otter trawling effort in the coastal zone.

The fishing mortality in the invertebrate populations in the Dutch sector due to trawl fisheries in 1994 varied from 7 to 48%. However, despite the high fishing mortality for most of the species considered, these species were still present in densities sufficiently high to estimate the total direct mortality. Apparently, these species were able to maintain a certain population density despite this fishery induced mortality. Other species, showing higher direct mortalities or population characteristics less suited to resist this pressure, were not able to withstand the fishing mortality and have become rare, as was indicated for many bivalve species in chapter 3.8. Long term impact of trawl fisheries on invertebrate populations depends on both the fishing mortality and other population dynamics. To understand these long term impacts, more information on population parameters of invertebrate species (recruitment, natural mortality, succession) should be collected.

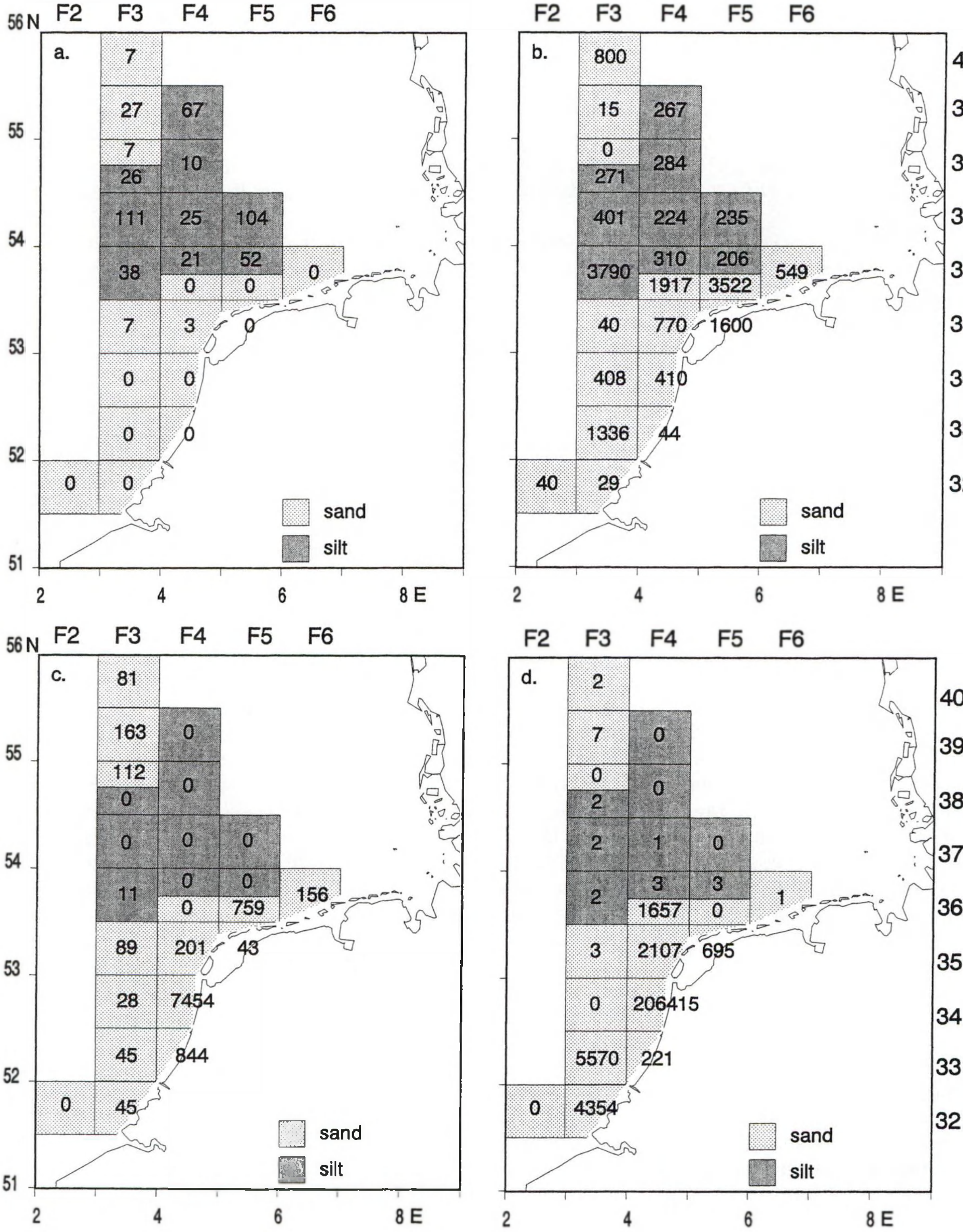


Fig. 4.1.1. Distribution of some invertebrate species over the Dutch sector. Densities were calculated per ICES rectangle in numbers per 100 m^2. Results were based on a sampling programme carried out with the Triple-D, in 1996 (Bergman & van Santbrink 1997). a. *Dosinia lupinus*, a species with a main distribution in offshore, silty sediments; b. *Echinocardium cordatum*, present in all sediment types; c. *Ensis* spp. and d. *Spisula subtruncata*, species with a main distribution in sandy area's, along the Dutch coast.

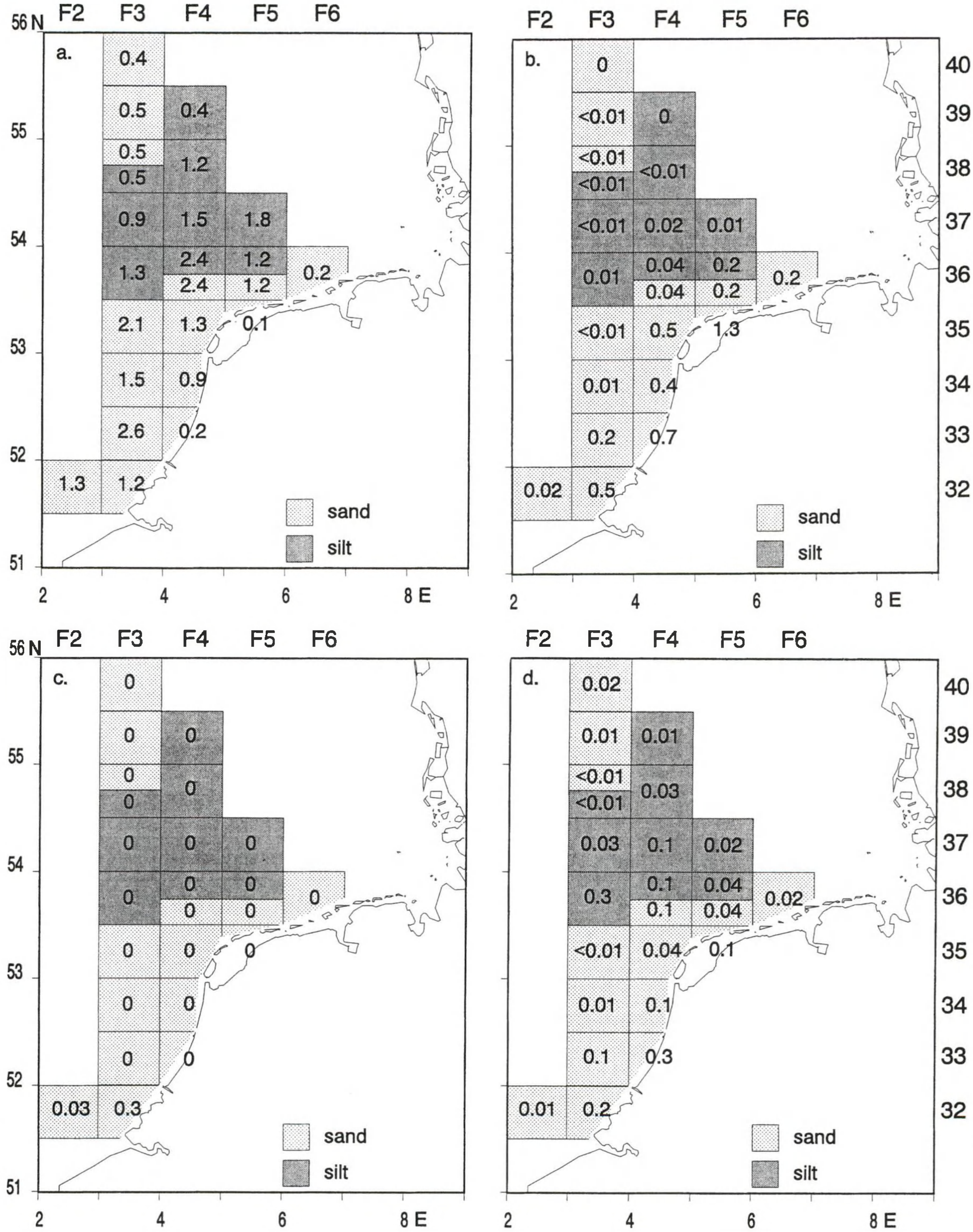


Fig. 4.1.2. Distribution of the trawling effort in 1994, for four types of trawl fisheries, over the Dutch sector. The mean yearly trawling frequency was calculated per ICES rectangle from the results in chapter 3.2.
a. 12m beam trawl fisheries using tickler chains;b. 4m beam trawl fisheries using tickler chains;c. 4m beam trawl fisheries using chain matrices;d. otter trawl fisheries (flatfish and roundfish).

TABLE 4.1.1

Fishing mortality (%) in the total population of a number of species in the Dutch sector due to different bottom trawl fisheries in 1994. For some species the mortalities have been calculated only for silty or sandy sediments, when (i) this species occurred only in this sediment or (ii) when only for this sediment type a total direct mortality estimate (Table 3.5.5) is available. - = no total direct mortality estimate availabe for this species. [blank] = no overlap in trawling and species distribution. 12TBB = 12m beam trawl fishery using tickler chains; 4TBB = 4m beam trawl fishery using tickler chains; 4TBBm = 4m beam trawl fishery using chain matrices; OTB = otter trawl fishery.

species	size	Fishing mortality (%) in the Dutch sector in 1994				
	(cm)	12TBB fishery	4TBB fishery	4TBBm fishery	OTB fishery	total fisheries
ALL SEDIMENTS						
Chamelea gallina	<2	7	0	0	0	7
Chamelea gallina	>2	28	1	0	2	30
Corystes cassivelaunus - female	>1.5	21	1	0	1	23
Corystes cassivelaunus - male	>1.5	32	1		3	35
Echinocardium cordatum	>3	25	3	0	4	30
Ensis spp.	>20	10	5	0	1	16
Mactra corallina	<5	17	2	-	1	20
Phaxas pellucidus	<3	21	0		2	22
SANDY SEDIMENTS						
Lunatia catena	<1	33	22	-	-	48
Ophiura texturata	<3	7	1	0	1	9
Spisula solida	<5	21	11	1	-	31
Spisula subtruncata	<3	16	8	0	3	25
Thia scutellata	<2	21	4	0	-	25
SILTY SEDIMENTS						
Abra alba	<3	30	2		0	31
Aphrodita aculeata	>7	25	1		1	27
Arctica islandica	>8	15	0		1	15
Astropecten irregularis	<6	18	0		0	18
Corystes cassivelaunus - juv	<1.5	35	1		2	37
Dosinia lupinus	<4	29	1		1	31
Gari fervensis	>3	39	0		4	42
Pelonaia corrugata	<7	18	0		0	19
Turritella communis	<5	16	2		0	18

4.2. AN ASSESSMENT OF THE IMPACT OF TRAWLING ON THE ECOSYSTEM OF THE SOUTHERN NORTH SEA AND THE IRISH SEA

Bottom fishing gears have both a physical and biological impact on the seabed. In this chapter we will assess both the short- and long-term impacts of trawling on the studied ecosystems.

Trends in trawling fleets

Throughout the last century the composition and range of fishing fleets have changed dramatically. (Fig. 4.2.1). Before 1884, fishing vessels were either rowing-boats or sailing vessels. Between 1910 and 1920, the number of sailing vessels reached a maximum of over 6000 for the combined Dutch, Belgium and German fleets, but although the numbers of sailing vessels were high, the effort exerted (area swept per 100 h fishing effort) was low and passive fishing methods were the principal techniques employed.

The number of sailing vessels decreased drastically with the development of the diesel engine after 1920. Together with steam-powered vessels, which were introduced in 1884, diesel powered boats caused a boost in effort, which, together with the introduction of the otter trawl, increased the overall disturbance of the seafloor compared with non-motorised boats. Motorised trawlers were not limited in their choice of fishing ground and were less dependent upon weather conditions, hence the overall areas fished increased greatly.

Diesel powered boats replaced all other types of vessels by the 1950s, and in the early 1960s the beam trawl was re-introduced in the Dutch, Belgian and German fishery. This gear was previously constructed of wood, but was now replaced by heavy steel gear frequently equipped with tickler chains and in later years chain mats for use in areas of rough ground. It became obvious that the catch efficiency of this gear increased with increasing numbers of tickler chains and that higher towing speed had no negative effect on catches, hence a trend started for vessels to increase engine powers. Consequently, smaller vessels disappeared in favor of larger vessels. By the mid 1980s total engine power deployed peaked and this is now decreasing slowly.

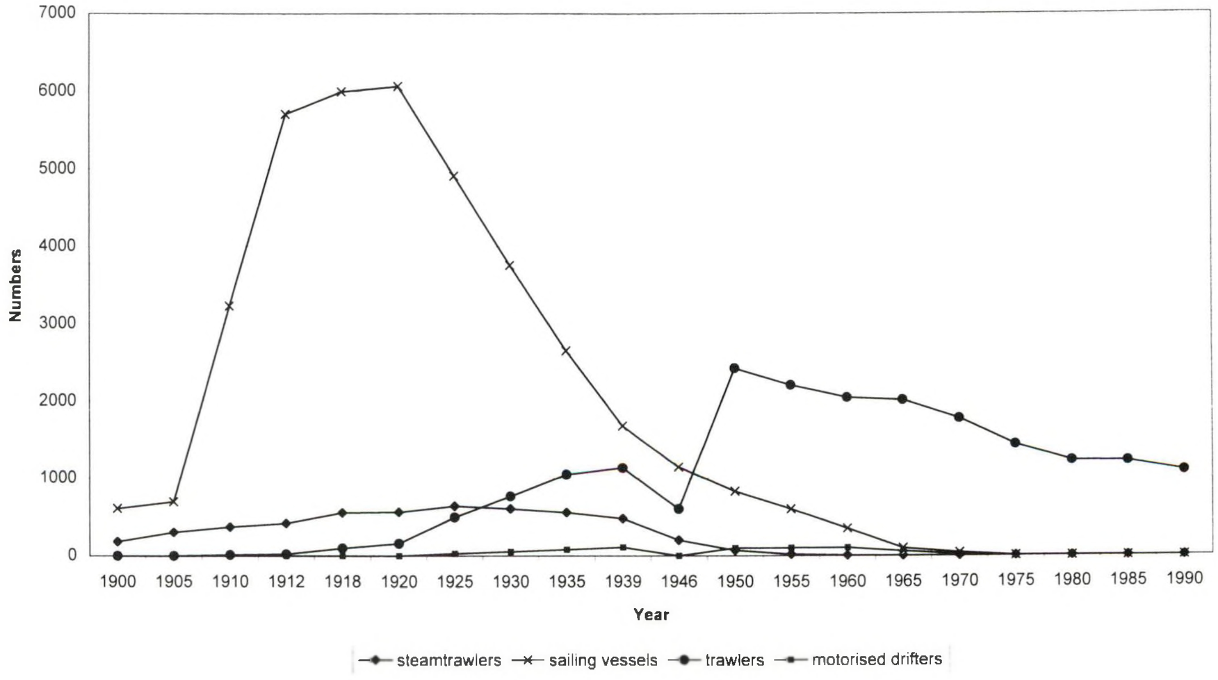


Fig. 4.2.1. Numbers of fishing vessels in the Belgian, Dutch and German fishing fleets since 1900.

Physical impact

The pressure force exerted on the sea floor by trawls is strongly related to the towing speed. As the speed increases the lift of the gear increases and the resultant pressure force decreases. At higher speeds the weight of the gear is fully compensated by the greater upwards pull and the trawl will lift of the bottom.

For the 4m beam trawl the pressure exerted by the sole plates varies from 1.7 to 3.2 N/cm^2 at towing speeds of 4 to 6 kt. Bottom contact is lost at 7 kt. Although 12m beam trawls use heavier equipment, this is compensated for by larger sole plate dimensions and higher towing speeds, hence the pressure exerted is more or less the same as for 4m beam trawls.

The sole plates of beam trawls and of boards for otter trawls leave detectable marks on the sea floor. Depending on local circumstances these marks disappear after a period of between 37 hours (in areas with fine sediments and exposed to tidal currents) to 18 months (otter trawls in muddy sediment in a very sheltered area). Using REMOTS photography it was estimated that heavy beam trawls remove at least the upper 1 cm of the sediment. The actual penetration depth of a beam trawl could not be determined, but earlier studies estimate that, depending on sediment characteristics and the rigging of the gear, beam trawls penetrate the sea bed to a depth of between 1 to 8 cm (BEON 1991).

In general the passage of towed demersal fishing gears flattens contours on the sediment surface and may severely damage the delicate and complex burrow or tube systems of epifauna and infauna. The movement of a trawl over the seabed causes the suspension of the lighter sediment fraction. The changes are most pronounced in areas with a lot of fine and very fine sand. The suspended particles, however, settle down within hours.

Catch efficiency and by-catch

For beam trawls the catch efficiency (percentage of animals present on and in the seabed that is actually caught in one haul of the trawl) was low (< 10%) or nil for small fish. For most invertebrate species the catch efficiency was < 10%, and even < 5% for half the number of species. Only the largest length classes of starfish, hermits and seamouse were caught with efficiencies >10%. For otter trawls, the catch efficiencies for invertebrates were < 2%.

As percentage of the total catch, by-catch by weight was high. For beam and otter trawls used in the North Sea, the by-catch of flatfish (mostly dominated by dab and plaice) was at least as high as the marketable catch and the by-catch of invertebrates (dominated by starfish, heart urchins, swimming crabs or masked crabs) was several times the amount of marketable fish. However, the by-catch of roundfish was relatively low (< 5% of the total catch).

In the *Nephrops* trawl in the Irish Sea studies, the by-catch by weight of roundfish (mainly whiting) was roughly similar to the amount of marketable prawns, the by-catch of non-target invertebrates was relatively low (< 5%) and dominated by crustaceans and molluscs.

Direct mortality due to trawling

Mortality in discards (non target organisms returned into the sea) from commercial flatfish trawls was species-dependent and varied for invertebrates from < 10% of the individuals caught (starfish, brittle stars) to almost 90% (the bivalve *Arctica islandica*), with most crustacean species showing intermediate values (about 50-70%). Discarded fish showed mortalities ranging from 50% to 100% (flatfish) from 80 to 100% (roundfish), with 100% mortality for gadoids.

Total direct mortality of invertebrates (mortality of discards plus mortality in the trawl track, both as % of initial density) was species dependent and varied from 10-40% for some gastropods, starfish, crustaceans, annelid worms and seamouse, from 10-50% for *Echinocardium cordatum* and *Corystes cassavelaunus*, and from 30-80% for a number of bivalves. For all these invertebrate species, the mortality mainly occurred in the trawl path, possibly as a direct result of physical damage inflicted by the passage of the trawl or indirectly from disturbance and subsequent predation.

Most species showing high total direct mortalities are very fragile (e.g.*Echinocardium cordatum, Phaxas pellucidus*), or live in the uppermost layers of the seabed (e.g. *Spisula* spp.). Species showing relatively low total mortalities are generally robust (e.g. *Astropecten irregularis, Chamelea gallina, Corbula gibba*) or burrow deeply into the sediment, where they evade the damaging effects of the trawl (e.g. *Lutraria lutraria, Mya truncata, Nucula nitidosa* and some anemones). In general, small sized species showed relatively low total mortalities: probably small individuals are dispersed more easily by the bow wave of the trawl.

Considering the high fishing mortality (7-45%) in the invertebrate species it can be expected that commercial bottom trawling has already affected the composition of the benthic community. Direct mortalities could only be estimated for species that were still abundant after twenty years of intensive bottom trawling in the North Sea. Populations of vulnerable species with more sensitive life history strategies have probably decreased to low levels and/or locally restricted distributions. The composition of benthic fauna at the offshore station in the Irish Sea may reflect the effect of long-term, intensive *Nephrops* trawling. The present species-poor and low-biomass fauna may represent an artificial man-made community adapted to the regular fishing disturbance experienced at this site.

Comparing catch efficiency, by-catch and mortality of different trawls

A comparison of catch and by-catch in the different gears revealed that in the sandy area more marketable fish was caught per ha trawled by 12m beam trawls than by 4m beam trawls. Neither the amount of invertebrate by-catch, nor the catch efficiency differed between these trawls. The 4m beam trawls fitted with tickler chains, caught more marketable fish and invertebrates than 4m beam trawls rigged with a chain matrix. The catch, by weight, of 4m and 12m beam trawls was several times higher than that for otter trawls (more than seven times for marketable fish, ten times for all discards). This was reflected in higher catch efficiencies for all invertebrates of these beam trawls.

The mortalities of discards caught in the commercial gears generally did not vary much between the different gears, for the majority of fish and invertebrate species.

In contrast to the mortality of discards, the total direct mortality was found to be dependent upon the type of trawls. In areas of the North Sea with a silty seabed, otter trawling clearly caused lower direct total mortality than beam trawling for most of the burrowing invertebrate species. For the majority of the species considered, little difference was observed in the total direct mortality due to trawling with 4m or 12m beam trawls. For some species, total direct mortality in 4m beam trawls fitted with tickler chains was slightly higher than in 4m beam trawls rigged with chain mats. The total direct mortality of invertebrates due to beam trawling was higher in silty areas than in sandy areas. All these differences in total mortality are probably due to differences in penetration depth: deeper penetration leeds to higher mortality.

Scavengers

Seabirds that feed around trawlers eat only a proportion of the discards and offal produced (Camphuysen *et al.* 1995; Garthe *et al.* 1996). In total, approximately 20% (mainly gadoids and offal) of the discards are consumed by seabirds, while the remaining 80% presumably sink to the seabed. In chapter 3.6.2.3 the total annual food production in the northern North Sea by beam trawling was estimated at about 1.5 g afdw/m^2 in the trawl tracks and 0.3 g afdw/m^2 as discards.

As yet, we have no way of knowing whether any of this component of the discards are consumed in midwater by fish or marine mammals. Catches with baited traps have shown differences in scavenger preferences for different discarded species and the general attraction of scavengers by discard materials. For example, swimming crabs move quickly towards fish carrion and will probably consume a large proportion of dead fish. Hermit crabs also eat fish, but their claws are either too weak or unsuitable for cutting into fresh dead fish and they eat mainly the softer parts or partly decomposed fish or molluscs.

In the Irish Sea, the common hermit crab *(Pagurus bernhardus)* rapidly aggregated in trawled areas and they were also attracted in large numbers to fish carrion. In contrast, a closely related species, *Pagurus prideaux*, was not attracted to carrion in the field, although it would eat dead fish in the laboratory. Starfish and whelks also eat carrion, but aggregate more slowly, and are unable to gain access to carrion when they occur in low numbers, as they are competitively excluded by dense aggregations of hermit crabs. *In situ* diver observations from a trawled area have shown that disturbed whelks were attacked and consumed by starfish. Furthermore, laboratory observations indicate that whelks avoid aggregations of starfish. Hence, whelks and starfish are in strong competition for the same food resource.

In the North Sea, gadoids feed on discarded crustaceans and molluscs, as shown by stomach contents analyses. However, dead crustaceans were consumed preferentially by scavenging amphipods that were caught in large numbers (>1000) in special amphipod traps baited with crustacean carrion. A large isopod, *Cirolana borealis*, was caught in small numbers in traps baited with fish carrion, but its importance may have been underestimated.

Experiments with baited traps in shallow coastal areas of the Irish Sea revealed similar patterns as found in the southern North Sea; starfish, hermit crabs and swimming crabs were the main scavenging species. In addition, a large number of scavenging amphipod species were also trapped.

Damaged and exposed benthos found in trawled areas is consumed by many fish species. In the southern North Sea dab *(Limanda limanda)* and dragonets *(Callionymus* spp.) were the most conspicuous scavengers. In some cases plaice and gobies (*Pleuronectes platessa* and *Pomatochistus* spp.) displayed similar behaviour. The results of stomach contents analyses indicated that fish on a line trawled with 12m beam trawls switched to feeding on molluscs, polychaetes, small crustaceans *(Callianassa* spp.) and the remains of *Echinocardium* spp. All of these organisms are known to be damaged or disturbed by trawling. In the deeper parts of the Irish Sea gadoids (whiting and haddock) were the most obvious scavengers on the soft bottom *Nephrops* grounds, feeding mostly on damaged crustaceans, and on crustaceans attracted to trawled areas.

Analysis of stomach contents of fish sampled from areas disturbed by trawling indicated that they fed on disturbed and damaged benthos for approximately two days after the initial disturbance. The stomachs of most fish were consistently empty by the third day. Even when we assume that the same area is trawled at least twice each year, this will result in food for scavengers for less than one week. Fish may be able to capitalise on this food source more than other species because they migrate quickly into recently trawled areas (within 10 minutes) and can be observed in densities 3-10 times higher than prior to disturbance. This means that trawling may also provide food for fish from a much larger surrounding area.

These additional food sources are consumed or degraded within a few days in summer, but less rapidly in winter when it may support scavenging species for at least 2 weeks. Compared to the total food demand of the benthic ecosystem in the southern North Sea the additional food supplied by fisheries may amount to about 9% per annum.

Laboratory measurements of the food conversion efficiency for some selected species have shown that starfish are very efficient (75% conversion), followed by fish (c. 50% conversion), while hermit crabs have a low food conversion efficiency of c. 30%. Crustaceans have lower efficiencies because growth requires the exoskeleton to be shed, thereby discarding part of their accumulated energy in the exuva.

An addition of 9% to the annual food consumption of the most abundant scavengers in the North Sea is probably insufficient to promote a significant increase in population numbers, although it may be a substantial addition to the maintenance food requirements.

Effects of disturbance on benthic communities; fished compared with unfished areas

Previous studies have shown that it is difficult to find completely unfished areas in the open North Sea. To compare fished with unfished areas one has to find special places where, due to legal regulations, no fishing has occurred for many years. Such an area was found in Loch Gareloch, Scotland, where the presence of a naval base has prohibited fishing in the past. Other areas were found near the wreck of the “West Gamma” in the German Bight and the wrecks of the “Iron Man” and the “41 Fathom Fast” in the Irish Sea. In the first area the effect of fishing was studied though experimental trawling disturbance, while in the other areas the communities in the ‘protected area’ were compared with the communities in nearby fished areas.

All three studies found changes in the infaunal community in responce to trawling disturbance. These changes were associated with greater numbers of either opportunistic species in disturbed areas or vulnerable species in protected areas.

In Loch Gareloch, trawling had a clear effect, increasing the numbers of species and individuals, and decreasing diversity. Community structure measures (diversity indices) of disturbance indicated that the community at the treatment site was only comparable to the reference area after a 12 month recovery period. However, more sensitive multivariate analysis of the community data found significant differences between these areas after 18 months of recovery. Some epifaunal effects were also detectable but recovery was rapid (6 months). Examinig the wreck sites, both in the North Sea and Irish Sea, clear differences were found in macrofaunal community of the area close to the wrecks compared with the surrounding unprotected area. Several of the species that were more abundant in the *quasi* protected area may be regarded as vulnerable to bottom fisheries, either because they are fragile and thus easily damaged by the tickler-chains or because smaller species are dug out of the sediment and thus exposed to predators. Differences in these effects were found between areas of different fishing effort, suggesting that benthic impact is related to fishing intensity.

All studies show that trawling clearly has a long term effect on infaunal communities that were previously undisturbed, with recovery rates from the sealoch site suggesting that, at least for muddy sediment habitats, areas may fail to recover before further disturbances occurs. With the high trawling intensity in the North Sea and some areas of the Irish Sea, it is likely that the benthic community has changed significantly in most of the area as a result of bottom fisheries.

Long term trends in demersal fish and benthic invertebrates

The findings of this part of the project are only valid for certain areas and time „windows" in which and for which they have been investigated. It is also true that other factors than fisheries may cause similar effects which may be hard to distinguish (e.g. eutrophication). Also the length of the observation time (as shown in figure 2.8.1) may have some influence on the validity of the results since the major shifts in the ecosystem may have already occurred before the onset of the time series investigated.

Relating the results from the epifauna and parts of the infauna to the general development of the demersal fishery in the southern North Sea the analyses cover the span after the initial onset of a widespread trawl fishery that skimmed off the surplus of the virgin stocks in the 19th century. The ICES routine investigations were started in the general care about the state of the fish stocks. The populations appeared to have severely crashed after the first strong fishery impact in the last century, i.e. at the end of the last century. At the beginning of this century, however, parts of the off-coast regions might have been still close to a pristine status with regard to benthic communities that would have been found before the onset of the trawl fishery. In 1986, almost 100 years of trawling impact have certainly re-structured the benthic system and so this comparison from close to a pristine situation to a long term disturbed situation may be the most that we can achieve despite the mentioned problems with the historical data.

For the longest time span observed (1902/'12-1986) a decline in the spatial occurrence of bivalves can be stated whereas scavengers and predators such as crustaceans, gastropods and sea stars have been found more frequently in 1986. This can be clearly attributed to the fishery impact which reduces the spatial heterogeneity of the habitat, directly damages and destroys vulnerable species and produces by means of the discards together with the destroyed animals at the sea floor a huge amount of additional possible food material for scavenging species. This stimulating factor for the populations may even overrule the deleterious effect of the physical damage through the fishing process to the same vulnerable species.

For another long time span (1923-1995), the geographic borders between the association of infauna in the German Bight were relatively stable and remained relatively unchanged suggesting that the sediment type may be the masterfactor. The composition within these associations, however, was less stable and changed considerably during the last 70 years. The benthic communities of the German Bight show nevertheless a significant increase in biomass and a change in community structure with a dominance of opportunistic short-lived species (r-selected) and a decrease of long-living sessile organisms (K-selected) like several bivalve species.

Combined with the results from other chapters on the immediate effects of bottom fisheries on the benthos and the comparison between fished and unfished areas, it has to be concluded that the observed trends in benthic invertebrates were to a great extent caused by the direct and indirect effects of fisheries and not solely by eutrophication and/or pollution as interpreted in previous studies (e.g. Rachor 1990; Kröncke 1995).

Testing the hypotheses

Starting from the general working hypothesis of the IMPACT project (see Chapter 1.3): "Demersal fishing activities and increased trawling intensity (effort per unit area) has a direct effect and induces long term effects on the seabed and benthic communities", the following more specific hypotheses can be formulated and tested using the results of the IMPACT studies.

1. *Fishing practice has changed and trawling intensity has increased over the past century.*
   This is supported by the following findings: Installed horse power increased until the 1980's, and leveled off since then, and has been associated with an increase in the weight and size of fishing gears. This has led to an increased demersal fishing intensity over the last century, partly due to the replacement of the otter trawl by the large beam trawl. Our estimates indicate that presently the southern North Sea is, on average, trawled 1.5 - 2 times per year.

2. *Demersal trawling results in measurable direct mortality of benthic invertebrates and demersal fish.*
   Significant mortalities were observed for most non-target species and all fish species caught in the nets. For invertebrates direct mortality mainly occurred in the trawl path. Fragile or superficial living species showed the highest mortalities, robust or deeply burrowing species low or even no mortalities. Small sized species showed relatively low mortalities. A decline in standing stock of several target species has also been observed, which is attributed to the effect of overfishing.

3. *Demersal trawling results in food production for scavengers.*
   Benthic scavengers gain additional food by feeding on fisheries discards, animals damaged in trawl tracks or attracted by the disturbance effect. However, it seems unlikely that these additional food sources as such will lead to long term large scale changes in scavenger populations, as these food sources contribute less than 10% of the annual food requirement.

4. *High demersal trawling intensity results in long term changes in benthic communities (fish and invertebrates).*
   Greater numbers of opportunistic species were found in disturbed (heavily trawled) areas whilst the relative abundance of vulnerable, large, long-lived sessile species was greater in protected areas (wreck sites and closed areas). Increased demersal trawling pressure, led ultimately to decreased diversity and changes in community structures and habitats (e.g. loss of *Sabellaria* reefs). The population structure in many target and non target species has also changed, with a decline in adults and an associated increase in juveniles.
   This study demonstrated that trawling has long term effects on the benthic communities and if trawling intensity remains high, these communities may never recover.

Finally, during the last century fishing fleets and techniques have changed enormously. Considering catch efficiency, direct mortality and trawling intensity, it is clear that demersal fisheries have an impact on the marine ecosystem. A major problem of the present study is that most of the experiments were carried out in areas where bottom fisheries have taken place for decades or even centuries. This means that we have been studying the impact on a previously perturbed system. Therefore, we may have missed or underestimated the effects of fishing on the most vulnerable species, because they disappeared already.

In general, there are clear indications that the benthic ecosystem in the eastern part of the North Sea has changed significantly. This may be partly due to natural variation in birth and death rates and migration, climate change (colder or warmer winters, storm frequencies, warmer summers, etc.), contamination or increased eutrophication, but as this study has shown, present day demersal fisheries have become a very important form of disturbance in the North Sea and some areas of the Irish Sea, and it is certainly one of the key factors causing the detected changes.

5. SUMMARY AND CONCLUSIONS

SUMMARY

THE IMPACT II PROJECT

The EU funded research project AIR 94 1664 "The effects of different types of fisheries on the North Sea and Irish Sea benthic ecosystem" was set up to investigate the short-term and long-term effects of bottom trawl gear on benthic invertebrates and fish. As a follow-up to the IMPACT I (FAR MA 2-549) project an extensive study of the relative physical and biological effects of different trawl types on the benthic ecosystem was executed at different sites in the southern North Sea and Irish Sea. The effects of fisheries upon scavengers was assessed, while the long-term impacts were studied by comparing fished and unfished areas and by collating nine different long-term data sets which might indicate possible changes in the marine ecosystem during the last decades and the last century.

An historical review of fishing fleets and gears used in the study area was made, being a clear indication of the rapid development from a large sailing fleet at the end of the previous century towards a smaller but much more efficient engine powered beam and otter trawl fleet nowadays. An inventory was made of the present numbers of Belgian, Dutch, German, Irish and UK fishing vessels active in the North Sea and Irish Sea. The gears in use per vessel size class in the different fleets is described, indicating that beam trawling is the most important fishery in Belgium and the Netherlands, while for England and Wales otter trawling is the most significant fishing method. The distribution of the fishing effort of the different fleets and gears is given for the North Sea.

The physical impact of the fleets on the seafloor was determined by direct pressure measurements, side scan sonar observations, RoxAnn surveys, sediment profile imaging (REMOTS/SPI) and video and stills photography.

Trawling programs to further study the effects on benthic communities and to compare the impact of the different gear types were carried out in the southern North Sea and the Irish Sea. The catch efficiency of the different gears, and the mortality both of the discards and of organisms in the trawl path was assessed. A comparison was made between the impact of the 4m beam trawl rigged with chain matrices or with tickler chains, the 12m beam trawl and the otter trawl. Before, and after, experimental trawling both in- and epifauna were sampled using various pieces of equipment including; box corers, Van Veen grabs, Day grabs, 3m beam trawls, and the specially developed Triple-D dredge.

The responses to trawling of sub-surface scavengers was investigated both in the field and the laboratory. Repeated trawling over the same fishing strip, the use of baited traps, video and stills camera observations, and stomach content analyses all hinted at a very active response of possible scavengers to fishing activities. Using the results of the field surveys, and the outcome of feeding experiments under controlled conditions in the laboratory, the importance of fisheries as food source for selected scavenging species was assessed. A comparison was made between these effects in the southern North Sea and the Irish Sea.

To assess the longer term impact of fisheries at three study sites (Loch Gareloch, Firth of Clyde, Scotland; Iron Man/41 Fathom Fast in the Irish Sea, and West Gamma in the North Sea), areas disturbed by fishing were compared with undisturbed areas. In Loch Gareloch, the effect of experimental fishing was measurable. At the other two sites a difference in the benthic fauna was detected between these areas.

The long term trends in demersal fish and benthic invertebrates was assessed by analyzing seven different data sets. On average, the relative species composition appeared to have changed in the research area. Almost all benthic communities show a significant increase in biomass and a change in community structure with a shift towards dominance by opportunistic short-lived species and a decrease in long-living sessile organisms such as bivalves. A model describing fishing types and efforts implied that between 1947 and 1981, bottom fisheries has a considerable impact on the marine ecosystem by reducing several demersal fish and benthic invertebrate species to very low

levels of abundance. Especially during the last decades not all data series show expected trends. This and possible other causes for the observed changes, e.g. climate change and eutrophication are discussed.

The actual impact of the different gears used in the southern North Sea was estimated by combining the fishing efforts, the estimated mortalities and the actual distribution of a number of selected species.

The project was undertaken by the following contractors:

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The University of Wales (UWB), Bangor, Wales (UK) and the Fisheries Research Centre (FRC), Dublin, Ireland acted as subcontractors.

CONCLUSIONS[1]

- Fishing has been an important industry since the beginning of this century. The high numbers of sailing fishing vessels and steam trawlers demonstrate that in the early 1900s the North Sea was already intensely fished. The fishery at that time mainly used passive fishing gears but trawl nets were already in use by steam trawlers and larger sailing vessels. Technological advances have led to an increase in the impact, with the introduction of the diesel engine, otter trawls able to fish rough grounds, the beam trawl and modern navigation equipment, as the main steps (3.1).
- Beam trawls are the most common demersal fishing gears in Belgium, the Netherlands and Germany at present. Otter trawling has a minor importance and its use is still decreasing. For the UK and Ireland the otter trawl is the most frequently used fishing gear. In the U.K. however, beam trawling has gained an increasing importance over recent years (3.2).
- The pressure exerted by a beam trawl on the sea bed is relatively low and does not increase considerably with the size of the gear. The reason is that the higher weight of the larger gears is compensated by larger contact surfaces and higher towing speeds, leading to a greater vertical lift (3.3).

[1] Between ( ) the chapter to which the conclusions refer.

- Trawls leave visible marks on the sea floor. Depending on the local circumstances these marks will disappear in a period of 37 hours (beam trawl in an area with fine sediments and exposed to tidal currents) to 18 months (otter trawl on a muddy sediment in a very sheltered area) (3.3).
- The passage of towed demersal fishing gears flattens the contours on the sediment surface. Former studies estimate the penetration depth of a beam trawl as 1 to 8 cm, depending on sediment characteristics and rigging of the gear. Due to the passage of the trawl over the seabed the smaller sediment particles are suspended, but they settle out within hours (3.3).
- The catch efficiency of beam trawls was generally low (0-10%) for small sized fish and invertebrate species. In otter trawls, the catch efficiencies for invertebrates were even lower than 3%. Only in beam trawls the largest length classes of starfish, hermits and seamouse were caught with efficiencies higher than 10% (3.4).
- In North Sea flatfish beam and otter trawls, the by-catch by weight of flatfish (mostly dominated by dab and plaice) was at least as high as the marketable catch. The by-catch of invertebrates (dominated by starfish, heart urchins, crabs) was several times the amount of marketable fish. The by-catch by weight of roundfish was relatively low (< 5% of the total catch) (3.4).
- In the Irish Sea *Nephrops* studies, the by-catch by weight of roundfish (mainly juvenile whiting) was roughly similar to the amount of marketable prawns. The by-catch of non-target invertebrates was relatively low (< 5% of the total catch) and dominated by crustaceans and molluscs. However, the recent implementation of legislation governing the insertion of square mesh panels in *Nephrops* nets will increase the quantity of fish escaping from the net, and thus reduce the quantities of juvenile whiting discarded (3.4).
- The catch efficiency for invertebrates did not differ between 4m and 12m beam trawls both rigged with tickler chains. In 4m beam trawls with tickler chains, more marketable fish and invertebrates (by weight) were caught than in 4m beam trawls rigged with a chain matrix. The total catch by weight in 12m beam trawls was several times higher than in otter trawls: for marketable fish at least seven times, for all discards more than ten times (3.4).
- Mortality of discards from flatfish beam trawls was species-dependent and varied for invertebrates from < 10% of the individuals caught (starfish, brittlestars) to almost 90% (the bivalve *Arctica islandica*), with most crustaceans showing intermediate values (about 50-70%). Discarded fish showed mortalities ranging from 50 to 100% (flatfish), from 80 to 100% (roundfish), with 100% mortalities for gadoids (3.5).
- For the majority of fish and invertebrate species, no clear differences were found in discard mortalities between the different trawls tested (3.5).
- Despite the high mortality of discarded small fish and most invertebrate species, this mortality is still very low (a few %) when expressed as percentage of the initial density of these animals on the seabed. This is due to the low catch efficiency of the commercial trawl for these species which mostly pass through the meshes or do not even enter the net. For all invertebrate species, direct mortality mainly occurred in the trawl path, possibly as a result of direct physical damage inflicted by the passage of the trawl or indirectly from disturbance and subsequent predation (3.5).
- Total direct mortality of invertebrates (both discard mortality and mortality in the trawl path as % of initial density) varied for various species of gastropods, starfish, small and medium sized crustaceans, and annelid worms from 10 to 50%. For a number of bivalves species, mortalities were found of 30-80%. Fragile or superficial living species showed high mortalities, robust or deeply burrowing species low or even no mortalities. In general, small sized species and specimens showed relatively low total mortalities (3.5).
- Otter trawling in silty areas caused less total direct mortality in many burrowing invertebrate species as compared to beam trawling; otter trawls apparently penetrate less deeply into the seabed. Differences in total direct mortalities of benthic fauna due to trawling with 4m and 12m beam trawls were generally not obvious. For some species, total direct mortality for 4m beam trawls with tickler chains was slightly higher than for 4m beam trawls with chain matrices, probably because chain matrices penetrate less deeply into the sediment (3.5).

- In silty sediments in the North Sea a trend was found for higher total direct mortalities of invertebrates due to beam trawling than in sandy areas. This points to a deeper penetration of beam trawls into a softer seabed (3.5).
- The species-poor and biomass-poor fauna at the offshore station in the Irish Sea illustrates the possible impact of a longterm, high *Nephrops* trawling effort leading to a species composition that is adapted to regular fishing disturbance (3.5 and 3.7).
- Benthic scavengers and predators feed both on fisheries discards and on animals damaged in trawl tracks. The responses of scavengers to carrion varies between different sites depending on environmental and physical factors (3.6).
- In some trawled areas there is opportunistic feeding by a number of predatory species on scavenging species attracted by the disturbance effect. Scavengers can increase their food intake when migrating into and foraging in trawled areas and also alter dietry composition in response to trawling (3.6).
- Competition for fisheries discards between benthic scavengers sometimes becomes intense and can affect feeding success (3.6).
- In the North Sea the annual amount of carrion produced by fishing activities accounts for a maximum of 10% of annual food consumption by scavenger populations (3.6).
- Experimental disturbance of a previously unfished site showed clear long term effects on both epi- and infauna. Comparison of fished and protected sites within fishing grounds also showed clear differences, suggesting that fishing disturbance has significant long term effects on benthic communities (3.7).
- Comparison of the two Irish Sea sites showed an increasing effect of fishing with greater fishing intensity. At the heavily fished site the fauna already acclimated to intense fishing disturbance and no short term effects could be detected with the sampling methods used (3.7).
- In general, opportunistic (small size, fast reproducing) species increased in abundance while sensitive (large size, fragile) species declined in numbers due to trawling disturbance. Longer term disturbance effects on epifauna were less easy to quantify, and results were contradictory for some species. The results from the Loch Gareloch study did, however, suggest that fragile sessile species such as *Metridium senile* are adversely affected by trawling disturbance. The ability of mobile scavengers to migrate in and out of disturbed areas makes the detection of trawling effects on these species difficult (3.7).
- Measures of diversity and evenness were consistently higher in unfished areas when compared to adjacent disturbed areas (3.7).
- Results from the Loch Gareloch study suggest that in sheltered muddy sites, recovery following disturbance may take over 18 months. In regularly fished area, communities may never fully recover before being redisturbed (3.7).
- Almost 100 years of trawling impact have certainly re-structured the benthic system. For the longest time span observed (1902-1986), a decline in the frequency of occurrence of bivalves can be seen, whereas scavengers and predators such as crustaceans, gastropods and sea stars have increased (3.8).
- The observed variation in annual numbers of fish and invertebrates delivered to the Zoological Station in Den Helder, The Netherlands, were found to be related to the changes in gear and fishing effort of demersal trawlers. Otter trawlers delivered relatively more fish than invertebrates and, on average, the catch efficiency of beam trawling appeared to be an order of magnitude higher than that of otter trawling for all species considered (3.8).
- The benthic communities in the German Bight show a significant increase in biomass and a change in community structure with a dominance of opportunistic short-lived species (r-selected) and a decrease of long-living sessile organisms (K-selected) like several bivalve species (3.8).
- Combined with the results from other chapters on the direct effects of bottom fisheries on the benthos and the comparison between fished and unfished areas, it has to be concluded that the observed long term trends in benthic communities were to a great extent caused by the direct

and indirect effects of fisheries and not solely by eutrophication, climatic fluctuations and/or pollution (3.8).

- In the Dutch sector in 1994, the 12m beam trawl fishery was the dominant type of trawling offshore, with an average frequency of 1.23. The average frequency of the 4m beam trawl fishery with ticklers was 0.13 mainly in the coastal zone, that of 4m beam trawl fishery with chain matrices was 0.01 exclusively in the southernmost areas, and that of the otter trawl fishery was 0.06 (4.1).
- The annual fishing mortality in the larger sized invertebrate populations varied from 7 to 48% due to trawl fisheries in the Dutch sector in 1994, with half the number of species showing values of > 25%. The 12m beam trawl fisheries caused higher fishing mortalities than 4m beam trawl and otter trawl fisheries. Only in species restricted to the coastal zone, where 4m beam trawl fishery is much more intensive than in offshore areas, fishing mortalities due to this fishery were relatively higher and might even exceed that due to the 12m beam trawl fishery (4.1).

RECOMMENDATIONS FROM THIS STUDY

- Mortality in invertebrate populations due to commercial trawl fisheries depends on (i) the spatial distributions of species and trawling effort of the different fleets, and (ii) the total direct mortality estimate. Management measures to reduce this fishing mortality have to be centred on reduction of trawling effort, on spatial restriction (e.g. zonation) of a particular trawling effort and on reduction of the direct mortality rate (e.g. alternative gear design)
- The use of sampling gears suitable for specific fractions of the benthic fauna in monitoring studies of invertebrate populations in the North Sea, will provide more appropriate data for the analysis of long term changes.Traditional gears such as boxcorers and grab samplers are appropriate for small sized in- and epifauna, fine meshed small beam trawls for fish and larger epifauna, and the Triple-D benthos dredge for larger sized in- and epifauna in sandy sediments. More attention should be devoted to the development of appropriate sampling gears for other types of sediments like stony and (very) silty areas.
- To understand the long term impact on the occurrence of individual species, more information on population dynamics of these species (effects on recruitment and size distribution, recovery time, succession patterns, etc.) should be collected.
- The extraction of more detailed information on the long term effects from the presented and other historical data series should be continued.

GENERAL RECOMMENDATIONS

- Studies on the direct effects of fishing in areas which have been continually trawled in the last decades are inconclusive. Rare and long-lived species may already have disappeared, while the relatively resistant species may predominate present-day fauna. More conclusive evidence for the long-term effects of beam trawling on the benthic ecosystem can only be obtained by studying relatively <u>large areas closed to fisheries for many years</u>.
- Research should be encouraged to reduce the destruction of potentially valuable undersized fish, of benthos and of habitats. Alternative fishing methods should be developed.
- Studies on commonly overlooked parts of the benthic fauna, i.e. large and rare in- and epifauna that may be vulnerable to fisheries, should be encouraged.
- For future studies examining the effects of fishing more detailed information on the distribution of fishing effort in time and space is needed. It should be considered to equip all vessels with "black boxes" to independently register their fishing activities.
- The development and application of indirect methods to estimate fishing intensity (marks in the shells of bivalves, lost arms of echinoderms) should be encouraged.
- Fisheries management should not only be based on management of fish stocks with commercial value, but also on ecosystem management.

6. GLOSSARY

6.1. GLOSSARY OF TERMS AND ABBREVIATIONS

ABC (Abundance Biomass Curve) plots and the *W* statistic. *k* -dominance curves plot cumulative ranked abundances against species rank (Lambshead *et al.* 1983). ABC plots display the *k* -dominance curves for abundance and biomass of the species in a community on the same plot (Warwick 1986). The advantage of such plots is that the distribution of abundances and biomasses among individuals can be compared on the same terms.

Agassiz trawl — Fine meshed benthic trawl designed to sample small fish and invertebrates.

Annelida (Annelids) — Phylum of segmented worms, many freshwater and marine species (also terestrial species). The nervous system, the excretory organs, the vessels the the coelom follow the segmentation (not the gut). The phylum Annelida (Annelids) comprises the classes Polychaeta (Polychaets), Oligochaeta (Oligochaetes) and Hirudinea (Hirudinids), the Leeches.

ANOVA — Analysis of variance.

AWI — Alfred-Wegener Institut für Polar- und Meeresforschung, Bremerhaven, Germany (04).

Beam — Steel spar which holds the net of a beam trawl open.

Beam length — The length of the beam of a beam trawl.

Beam trawl — The horizontal opening of this trawl is provided by a beam, made of metal or wood (old fashioned), which may be between 3-12 m long. Beam trawls are used mainly to catch flatfish and shrimp fishing (Fig. 3.2.1, 3.2.2).

Beam trawl shoe; trawlhead; beam head; sledge. A strong half-heart shaped iron frame fitted at each end of a trawl beam. It is this part of the rigid metal frame of the beam trawl that slides over the ground and that assures the net remains open (Fig. 3.2.1, 3.2.2).

Beam trawl with chain matrix. See beam trawl. To enable fishing on rough ground, a chain matrix is rigged between beam and ground rope enable the trawl to slide over stony ground.

Benthos — Animals living in or on the seabed.

BEWG — ICES Benthos Ecology Working Group.

BFA-ISH — Bundesforschungsanstalt für Fischerei - Institut für Seefischerei, Hamburg, Germany (10).

Biomass — The overall amount in weight of organic matter.

Bivalvia (Bivalves) — A class of the phylum Mollusca (Molluscs), also known as Lamellibranchia (Lamellibranches). Contains all the common bivalves like mussels, cockles, clams, etc. The animal is protected by two shell valves which are joined dorsally by a ligament and closed vertically by one or two adductor muscles.

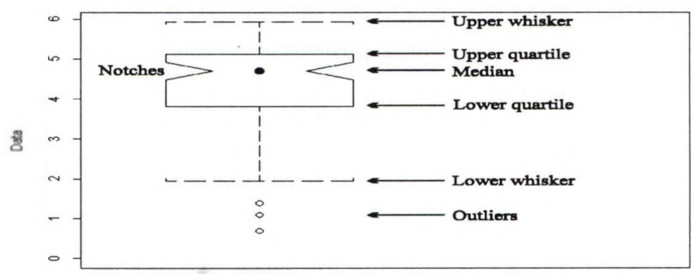
Bobbin(s); roller — A number cylinders which are threaded on wire of specified length to form part of a groundrope (Fig. 3.2.2).

Bottom fishing gear — Towed fishing gear fished in close contact with the seafloor (Fig. 3.1.14, 15, 16, 17).

Boxcorer — Benthos sampling device retangular box, pushed into the sediment and closed by means of a spade. Sampling depth 15-20 cm, sampling size 0.06 m^2, mesh size 1 mm, for small in-/epifauna.

Box plot — A box plot provides a simple graphical summary of a batch of data. They display the distribution of a variable and can be very useful when used as group plots showing a single variable stratified across multiple groups.
The method of summary is illustrated on the next page. The filled circle (or horizontal line) within the box represents the median, a measure of the centre of the distribution. The upper and lower ends of the box are the upper and lower quartiles. The distance between these two values, the *interquartile range*,

is a measure of the spread of the distribution. The relative distances of the upper and lower quartiles from the median provide information about the shape of the distribution of the data. If the box is notched, then the notches represent confidence intervals on the median. If the intervals (notches) around two medians do not overlap, you can be confident at about the 95% level that the two population medians are different. The dashed appendages of the box plot are the *whiskers*. The upper whisker represents the largest observation that is less than or equal to the upper quartile plus 1.5*interquartile range. The lower whisker represents the smallest observation that is greater than or equal to the lower quartile minus 1.5*interquartile range. Whiskers also provide summaries of spread and shape, but do so further in the extremes of the distribution. Outliers, observations beyond the whiskers, are graphed individually, and provide further information about the spread and shape of the data.



Bridle (sweep)	The rope usually of wire, between otter board and net or danleno or legs (Fig. 3.2.5).
BRT	Dutch for GRT, stands for Gross Register Tonnage.
By-catch	The catch of non-target species, still with a commercial value, e.g. plaice caught by the shrimp fishery or cod and whiting in the plaice fishery.
Carapace	Shield of exoskeleton covering part of the body (several segments) of some Arthropoda e.g. crabs, shrimps.
Catchability	The capability of a fishing gear to catch fish during a fishing operation.
Catch efficiency	The ratio between caught animals and those actually present. It shows the efficiency of a sampling gear, e.g. trawl, grab or core.
CEFAS	Centre for Environmental, Fisheries and Aquaculture Sciences, Conwy Laboratory, North Wales, U.K. (09).
Chain matrix	See beam trawl with chain matrix.
Codend	The rearmost part of the trawl where the catch accumulates (Fig. 3.2.1, 3.2.5).

Coelenterata (Coelenterates). Phylum of animals containing hydroids, jelly fish, sea-anemones, corals, comb-jellies. All aquatic, most marine. Body built on a fairly simple plan; more or less radially symmetrical; body jelly-like consistency; gut (coelenteron) has one opening only; nervous system diffuse; no excretory system; no blood system. The body wall is usually described as having only two layers of cells.

Controllable pitch (propeller), adjustable pitch. A propeller with blades that can be controlled hydraulically to vary the pitch, making it possible to alter the vessel's speed or to provide astern thrust without reversing the direction of rotation.

Copepoda (Copepods). Class of the sabphylum Crustacea (Crustaceans). The largest class of small crustaceans over 7500 mainly marine species. They often dominate the zooplankton.

Crustacea — A subphylum of the phylum Arthropoda. A phylum of segmented animals of which the body is entirely covered with a chitinous exoskeleton. To the crustacea belong crabs, hermit crabs, shrimps and lobsters. About 42000 species belong to the crustaceans (Fig. 6.2a).

Cuidaria (Cuidarians). Synonym for Coelenterata (Coelenterates).

Danleno — Large hollow steel sphere that prevents the wings of the trawlnet from becoming caught up on small obstacles.

Day grab — Bottom sampling gear for benthos. Sampling depth 8-15 cm, sampling size 0,1 m^2, mesh size 1 mm, for small in-/epifauna.

Demersal — Found near the sea-bottom (as opposed to pelagic).

DFS — Demersal Fish Survey.

DGPS — Differential Global Positioning System. A world wide positioning system to be used on land, in air and at sea giving the position by determining its relative position to geostationay satellites. Primarily developed for military use (highest accuracy) for commercial use made available with less accuracy. Improvement on GPS.

Direct mortality — Mortality within 0-3 days due to trawling with a particular gear.

Discard — All the animals not targeted by trawlers that are rejected.

Discard mortality — Mortality within 3 hours (immediate) to 3 days (secundary) among discarded animals.

Diversity — See Shannon-Wiener diversity index.

Door — See otter boards.

Drifter — A fishing vessel fishing with a passively fishing net that is moving in the direction of the wind or current.

Driftnet; drifting gillnet. Net kept on the surface, or at a certain distance below it, by numerous floats. It drifts freely with the current, separately or, more often, with the boat to which the net is attached. This is a passive fishing gear (Fig. 3.1.13).

Echinodermata (Echinoderms). The phylum Echinodermata contains species as the starfish, brittle stars, sea urchins, sea lilies and sea cucumbers. The echinoderms are exlusively marine. The body has a radial symmetry (in principle five sided), they have an internal skeleton formed by calcareous plates (Fig. 6.3).

Echo sounder (acoustic sounder). An apparatus used on a fishing boat for the detection and identification of fish and the determination of depth of water and nature of the seabed.

Endofauna (Infauna) Organisms living in the bottom sediment for the greater part of their lives, e.g. most worms and bivalves (as opposed to epifauna).

Epifauna — Bottom animals that live on the surface of the sea floor, e.g. most crabs, shrimps, starfish (as opposed to endofauna).

Fish — Flatfish and roundfish (Fig. 6.4).

Fishing effort — A measure of the activity of fishing boats. Fishing effort is strictly defined in terms of "total standard hours fishing per year" but is often described less rigorously in terms of numbers of vessels, fishing time or fishing power for instance.

Fishing intensity — Fishing effort per unit area.

Fishing mortality — Total direct mortality in the population of a benthic species, generated by a trawl fishery over a certain time perios, expressed as % of initial population.

Fishing net — A fishing implement comprised mainly of netting. An open-work fabric forms meshes of suitable size for catching fish.

Fish track — The geographical positions where the fishing operation has been carried out; the fishing operation.

Flip-up-rope — Arrangement of ropes forming squares. Fitted on top of the bobbin rope in order to prevent stones from entering the net.

FRC — Fisheries Research Centre, Dublin, Ireland (11[a]).

FRS-MLA — Fisheries Research Services, Marine Laboratory Aberdeen (08). An executive agency of the Scottish Office, formerly known as SOAEFD-MLA.

FRV — Fisheries Research Vessel.

Gastropoda (Gastropods). Class of Mollusca, including snails, slugs, sea-hares. Marine, freshwater, and terrestrial. Head distinct, with eyes and tentacles; often a single shell.

GOV — Grand Ouverture Vertical, spatial designed trawl for juvenile fish studies.

GPS — Global Positioning System (see DGPS).

Groundrope — Rope or bobbin rope attached to the front of the belly of a net used to help the net over obstacles on the seafloor (Fig. 3.2.2).

GRT — Gross Register Tonnage.

GT — Gross Register.

Haul — A single fishing operation.

Hectare — 10 000 m^2.

HELCOM — Helsinki Commission, Baltic Marine Environment Protection Commission, members from all Baltic States, including the European Community (founded 1974).

hp — Horse power; 1 hp = 0.7355 kW.

Hyball ROV — The video system used was a JVC TK-885E colour video camera head housed in a HYBALL versatile remotely operated vehicle (ROV). The ROV is manouvered using four 250 W thruster motors, with an individual thrust of 5.5 Kg. Maximum speed is 2.5 knots. Illumination is by means of two 100 Watt variable intensity quartz halogen lamps aiming forward, and two 75 Watt variable intensity quartz halogen lamps moving with the camera.

IBTS — International Bottom Trawl Survey. Sampling programme of ICES.

ICES — International Council for Exploration of the Sea (founded 1902, Copenhagen). All nations bordering the North Atlantic are members.

ICES Statistical-retangle. A retangular grid of approximately 30x30 Nm used by the ICES in their study area.

IfM — Institut für Meereskunde, Kiel, Germany (03).

IMR — Institute of Marine Research, Bergen, Norway.

Infauna — See endofauna.

Intensity — Effect per unit effort.

Invertebrate — Sometimes called evertebrate. The 95% of the animal kingdom not possessing a backbone (vertebral column).

Kelly's eye — 8-Shaped steel forging, the smaller ring for attachment to packstop, the larger through which passes the bridle, to arrest the stopper at the fore end of the bridle.

Kieler Kinderwagen — Type of benthos dredge developed by the Institut für Meereskunde, University of Kiel (partner 03). Sampling depth < 1 cm, for large epifauna (1 m wide, 5 mm mesh).

Kort nozzle — To increase thrust at low speeds a propeller may be enclosed in a cylinder (the nozzle).

kW — Kilo Watt; 1 kW = 1.3596 hp.

Lift — Of a net, hydrodynamic of hydrostatic force, directed vertically upwards.

LOA (length overall) The total length from the foremost to the aftmost points of a vessel's hull.

Loess — A statistical technique using locally weighted regression to fit a smooth line through bivariate data.

Loess smooth — Loess smoothing is a non-parametric (not reliant on the data being distributed in any particular way) regression technique to examine trends in data. A smoothed line is fitted through the data, with each value along the line calculated as a locally weighted average, with these values joined to produce the trend line.

Lower panel — Comprises all the net section of the lower part of the trawl net, i.e. lower wings, belly, lower extension piece.

Macrofauna — Bottom living organisms retained on a 1 mm meshed sieve.

MAFF — Ministry of Agriculture, Fisheries and Food, Fisheries Laboratory, Conwy, UK (09) (see CEFAS).

Mesh
- * Mesh opening: the distance between two opposite knots in the same mesh when fully extended in the N-direction (= normally the length axis of the trawl.
- * Mesh side-half mesh: the distance between two sequential knots, measured from centre to centre when the yarn between those points is fully extended.
- * Length of mesh-full mesh: a) for knotted netting, the distance between the centres of two opposite knots in the same mesh when fully extended in the N-direction; b) for knotless netting, the distance between the centres of two opposite joints in the same mesh when fully extended along its longest possible axis.

MHWS — Mean High Water Spring.

Mobile species — Invertebrate animals who have the power to move over or in the bottom, e.g. crabs, shrimps, queen scallop, starfish.

Mollusca (Molluscs) — The Mollusca form one of the largest phyla of the animal kingdom. About 50000 living species. The unsegmented soft-bodied animals are characterized by a muscular foot, a calcareous shell secreted by two lobes of skin called the mantle. The Molluscs are divided in Gastropoda (snails), Polyplacophora (chitons), Aplacophora (solenogasters), Bivalvia, Scaphopoda (tusk shells), Cephalopoda (squids, cuttle-fish and octopods) (Fig. 6.1).

Mollusc dredger — Water jets dislodge mollusc from the seabed ahead of the dredge. The catch may be transferred to the boat by a conveyor belt device or by pump.

MRI — The Martin Ryan Marine Science Institute, Galway, Ireland (11). Belongs to University College Galway (UCG).

Nemertea (Nemerteans). Formerly known as Nemertini. A phylum of mostly marine worms (also called Rhynchocoela). Typical of the phylum is a well developed proboscis (tubular process of the head used in feeding, burrowing or locomotion).

Nephrops trawl — Demersal trawl specially designed for the *Nephrops* fishery. *Nephrops* trawl have often separator panels to reduce the unwanted by-catch e.g. fish or invertebrates.

Net wings — Net section extending forward from one side of the main body of the net.

NIOO-CEMO — Netherlands Institute of Ecology - Centre for Estuarine and Coastal Ecology, Yerseke, The Netherlands (07).

NIOZ — Netherlands Institute for Sea Research, Texel, The Netherlands (02).

Non-target species — All animals and plants not directly fished for. If no commercial value at all they will be discards (see discards).

Offshore — At a distance from the shore, but within the offing.

Otter board — Trawl board; trawl door; board; door. Shearing device, two of which hold open horizontally the wings and mouth of a trawl (Fig. 3.2.5).

Otter trawl — A large conical net supplied with two otter boards which keep the mouth at the net open horizontally. Single boat operation only (Fig. 3.2.5).

Outrigger boom — Strong boom to spread the fishing gear. The outrigger is usually fastened to the mast and extends out from the sides of the vessel towing two or more trawls by means of ways passing through blocks at the ends of the outrigger (Fig. 3.1.17).

PA — Polyamide, here netting yarn material.

Pair trawl (bull trawl) — Trawl towed by two boats whose separation controls the horizontal opening of the net. Otter boards are not used (Fig. 3.1.16).

PARADOX — Computer data base programme.

PC — Principle Components.

PCA — Principle Component Analysis, a mathematical technique to analyse statistical data.

PE — Poly Ethylene, here netting yarn material.

Pelagic — Of or in the main water-mass of sea or lake.

Pelagic fishing gear — Towed fishing gear used on the near-surface and middle depths of the open sea (midwater).

Pielou's Evenness measure. Evenness expresses how evenly individuals are distributed among the different species, and is essentially the reverse of dominance. The most commonly used measure of evenness is Pielou's evenness index:

$$J' = \frac{H'(\text{observed})}{H'_{max}}$$

where J' is the index of evenness, H' is the Shannon-Wiener function and H'_{max} is the maximum possible diversity which would be achieved if all species were equally abundant:

$$H'_{max} = \log_2 S$$

where S is the number of species.

Polychaeta (Polychaetes). A class in the phylum Annelida (worms). The bristle worms can be free-moving or errant, or sedimentary living in tubes, some are pelagic. The polychaetes are a vast class, more than 5000 species, containing most of the marine annelids (segmented worms) (Fig. 6.2b).

PP — Poly Propylene, here netting yarn material.

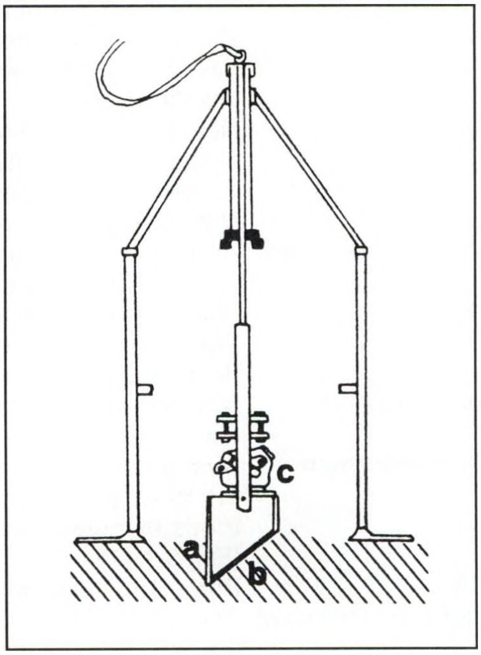
PRIMER — Plymouth Routines In Multivariate Ecological Research.

Recruits — The instreaming juveniles of the species under consideration, the offspring, the new year classes (fish).

Redox-potential discontinuity. That depth below the sediment-water interface marking the transition from chemically axidative to reducing processes.

Reineck boxcorer — A bottom sampler especially designed to obtain undisturbed, still stratified, sediments. Designed by Reineck in 1958.

REMOTS — Remote Ecological Monitoring Of The Seafloor. Special type of profile gear to obtain photographs of the undisturbed superficial bottom sediment, based on the principal of an upside down periscope drilled into the sediment. Photographs are made with a camera of slices of sediment with a depth of about 20 cm (the penetration depth of the prism).
See figure: a) sediment profile photographed, b) reversing mirror, c) camera (based on Rhoads & Germano 1982.



Research vessel The following research vessels (RV) were used during the IMPACT experiments.

Name	Nationality	LOA M	GRT tons	Engine Power kW/hp	Positioning system	Gears
BELGICA	B	50.9	765	1154/1576	DGPS	4M TBB m
BUTENDIEGK*	D				-	OTB
CORYSTES	GB	53			DGPS	3M, 4M TBB
ISIS	NL	28	180	588/800	DGPS	4M TBB, OTB
LOUGH BELTRA	IRL	21.1	115	311/425	DGPS	OTB n
MITRA	NL	56.3	991	1090/1380	DGPS	
NAVICULA	NL	23		110/150	DGPS	3M TBB
PELAGIA	NL	66	1615	1000/1360	DGPS	3M TBB
SOLEA	D	35.4				OTB
TRIDENS	NL	73.5	2199	3200/4400	DGPS	4M, 12M TBB
VICTOR HENSEN	D	39.2				
WALTHER HERWIG III	D	27.4				
ENDRICK II	GB	15.3	48	221/300	DGPS	Sampling gear
JEANNIE STELLA*	GB	12.2	15	89/121	DGPS	OTB n

* commercial trawler, used as RV

LOA = length overall; DGPS = differential GPS; TBB = beam trawl; OTB = otter trawl, bottom; M = meter; m = chain matrix; n = *Nephrops*

RIVO-DLO Netherlands Institute for Fisheries Research, IJmuiden, The Netherlands (01).

Rockhopper groundrope. Type of groundrope consisting of rubber discs for fishing on medium stony grounds.

Roller See bobbin.

RoxAnn Processes the information from a conventional echo-sounder to determine the nature of different substrates. The system is combined with an accurate positioning system (DGPS). The display is e.g. via coloured charts.

RDP Redox Potential Discontinuity. The boundary between the coloured ferri-hydroxide surface sediments and underlying grey to black sediment.

RSZV Rijksstation voor Zeevisserij, Oostende, Belgium (05).

RV Research Vessel.

RWS-DNZ Rijkswaterstaat - North Sea Directorate, Rijkswijk, The Netherlands (06).

Sampling gear Device to sample benthic fauna. Gears used in this project: Van Veen grab, Reineck boxcorer, Day-grab, Kieler Kinderwagen, Triple-D and finemeshed 3m beam trawl. Main characteristics are given in Table 2.5.2 (Fig. 6.5).

Scavenger Those animals which feed (not necessarily exclusively) on dead organic matter. They range from fish species to echinoderms and crustaceans.

Sedentary Not migratory.

Semi-pelagic fishing gear. Towed fishing gear fished close to the seafloor with a higher vertical net opening than a bottom fishing gear.

Sessile/sedentary species. Invertebrate animals who have no or only for a short period during their development the power of movement. They stay were they are settled, e.g. hydroids, sea anemones, barnacles, bryozoans.

Shackles U-shaped steel forging with a pin through an eye on each end of the "U" which serves as connecting links for rigging components.

Shannon-Wiener diversity Index. The Shannon-Wiener function is a commonly used type I (mose sensitive to changes in rare species in the community) diversity measure. It is calculated as:

$$H' = -\sum_{i=1}^{S}(p_i)(\log_2 p_i)$$

where H' is the index of species diversity, S is the number of species and p_i is the proportion of the total sample belonging to the ith species. The index may also be expressed as Shannon's exponential H' (N_1: Hill 1973):

$$N_1 = e^{H'}$$

Peet (1974) recommends N_1 as the best type I heterogeneity measure.

Side-scan sonar — An acoustic imaging device to provide pictures of the bottom. It consists of a recording device, an underwater towed body ("fish") and a cable connection between the two.

Silt — Deposit of fine sediment in water.

Simpson's Diversity index. Simpson's index is a commonly used type II (more sensitive to changes in abundant species in the community) diversity measure. It is calculated as:

$$D = \sum p_i^2$$

where D is Simpson's index and p_i is the proportion of the total sample belonging to the ith species. It is commonly expressed as Simpson's reciprocal index (N_2: Hill 1973):

$$N_2 = \frac{1}{D}$$

In this form, Simpson's diversity can be most easily interpreted as the number of equally common species required to generate the observed heterogeneity of the sample.

SNS — Sole Net Survey.

Stern trawler — A fishing vessel designed for trawling, in which the nets are hauled in over the stern, up a ramp or over a roller or the bulwark, with the aid of a derrick or gantry.

Stow net (swing net) Net in the form of a cone or pyramid held open by one or more horizontal beams below an anchored boat. This is a passive fishing gear (not towed) (Fig. 3.1.11).

SPI — Sediment Profile Imaging is a formal standardized technique for imaging and analysis of sediment structure in profile.

SPI (REMOTS) — Special type of profile gear to obtain photographs of the undisturbed superficial bottom sediment. Penetration depth of the prism about 10-15 cm.

Square Mesh Panel — The square mesh panel incorporated in the nets of the Irish Sea *Nephrops* fishery must have:

a) a minimum mesh size of at least 75 mm per side,
b) be constructed in knotless netting material,
c) be at least 3 m in length
d) be constructed such that, at any point along the length of the panel, the number of meshes widthways across the panel is no greater than half the number of meshes widthways across the sections of the net of which the panel is attached, and
e) when installed be at least 90 per cent of the stretched width of the top sheet at its rearmost part.

Sweep(s), bridle — The rope usually of wire, between otter board and net or the danleno or legs. One of two ropes usually of combination rope connecting danleno to the head line or fishing line (Fig. 3.2.5).

Target species	All the animal or plant species a fishing vessel tries to collect in as high as possible numbers. Gears are adapted to the various species e.g. flatfish trawl, shrimp trawl, *nephrops* trawl, oyster dredge, cockle dredge.
Tentaculata	(Tentaculates). Class of the subphylum Ctenophora (phylum Cuidaria) with retractile tentacles. Most Ctenophora belong to this group.
Tickler chain	A chain rigged in front of the groundrope of a beam trawl to disturb flatfish from the bottom and to increase the fishing efficiency (Fig. 3.2.2).
Total direct mortality.	Sum of discard mortality and mortality of animals in the trawl path due to the passage of trawl, expressed as % of initial density in the seabed.
Track path	Is the reflection of the track on the bottom, caused by the penetration of various gear parts in the bottom. Especially the iron parts of the gear e.g. trawl shoes, trawl doors, chained ground rope, ticklers, chain matrix.
Trackpoint II	The ORE International Inc. Model 4410C Trackpoint II is an integrated, ultra-short baseline acoustic tracking system designed to operate with up to six targets. It is used for a wide range of subsea navigation and relocation tasks. The target type consists of Multibeacon transponders, responders or free running pingers. The system is microprocessor-based, and consists of a hydrophone assembly, interconnecting deck cable and command/display module. Trackpoint II presents the user with a video display of the underwater position of the target, or targets, relative to a chosen reference point on the surface vessel. In addition to the graphic display of the target position, Trackpoint II displays digital values for azimuth and range to each target.
Trawl head; beamhead; sledge.	A strong heart-shaped iron frame filled at each end of a trawl beam. The after side is straight and slopes upward of each head to stake the ropes or wires by which the trawl is towed. The sides of the net are seized or lashed at a point close to the ground.
Trawl head height	The height of the trawl head of a beam trawl.
Trawl net	Towed net consisting of a cone-shaped body, closed by a bag or codend and extended at the opening by wings. It can towed by one or two boats and, according to the type, is used on the bottom or in midwater (pelagic).
Trawl path	See track path.
Trawl warp; warp	Long flexible steel rope connecting the fishing gear to the vessel (Fig. 3.2.5).
Triple-D-dredge	Type of benthos dredge developed by the Netherlands Institute for Sea Research (NIOZ, 02). For full description see Bergman & van Santbrink (1994b). The gear was developed for the IMPACT-I programme. Sampling depth 10 cm, mesh size 14 mm, for large in-/epifauna.
Upper panel	Comprises all the net sections of the upper part of the trawl net, including the upper wings.
UWB	University of Wales, Bangor, UK (09[a]).
Van Veen grab	A bottom sampler, designed in the mid-thirties in by Van Veen, for sampling bottom sediments and benthic organisms. Sampling depth 8-15 cm, sampling size 0,1-0,4 m^2 (sometimes 0,2 m^2), for in-/epifauna.
Vertebrates	The animals possessing a backbone.
Wayline, track	The navigational course steered by a vessel between two points plotted on the navigational plotter.
Wings	See otter board.
3m beam trawl	See beam trawl. Only in use as sampling gear.

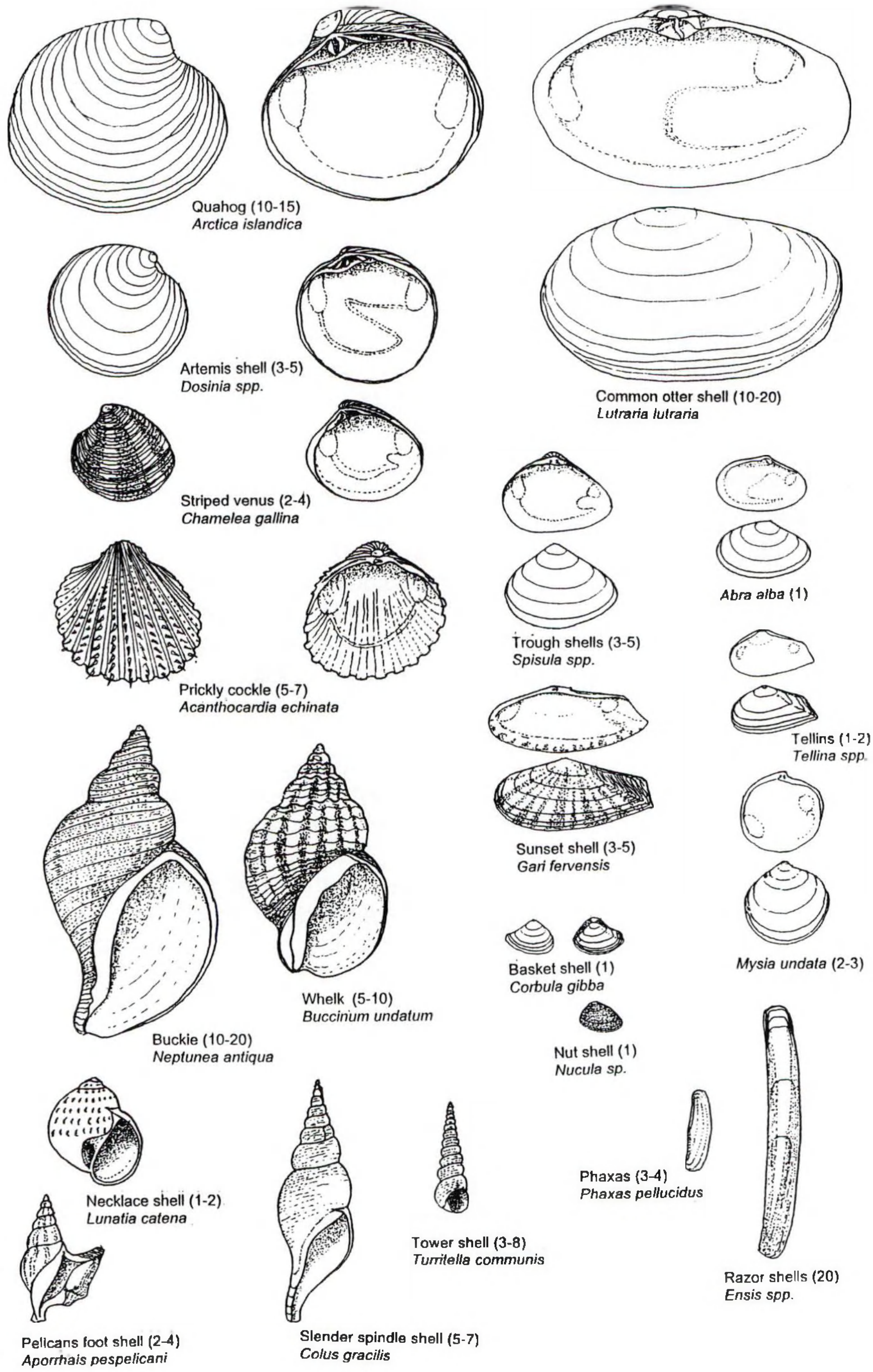
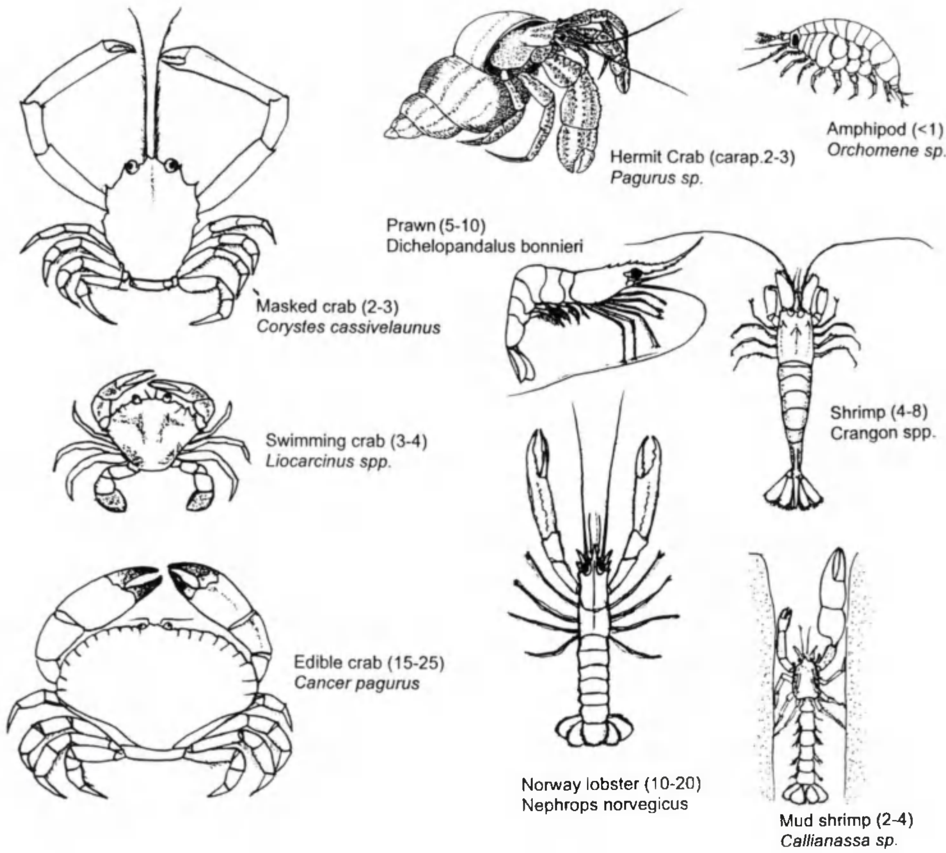


Fig. 6.1. Some of the mollusc species mentioned in the report.
In brackets: adult and maximum size in cm (bivalves: length; gastropods: height).

a



b

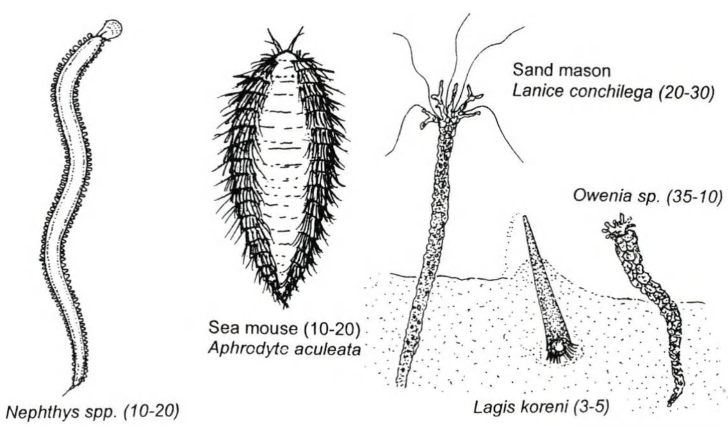


Fig. 6.2. **a**: Some of the crustacean species mentioned in the report. In brackets: adult and maximum size in cm (carapax width). **b**: Some of the polychaete species mentioned in the report. In brackets: adult and maximum length in cm.

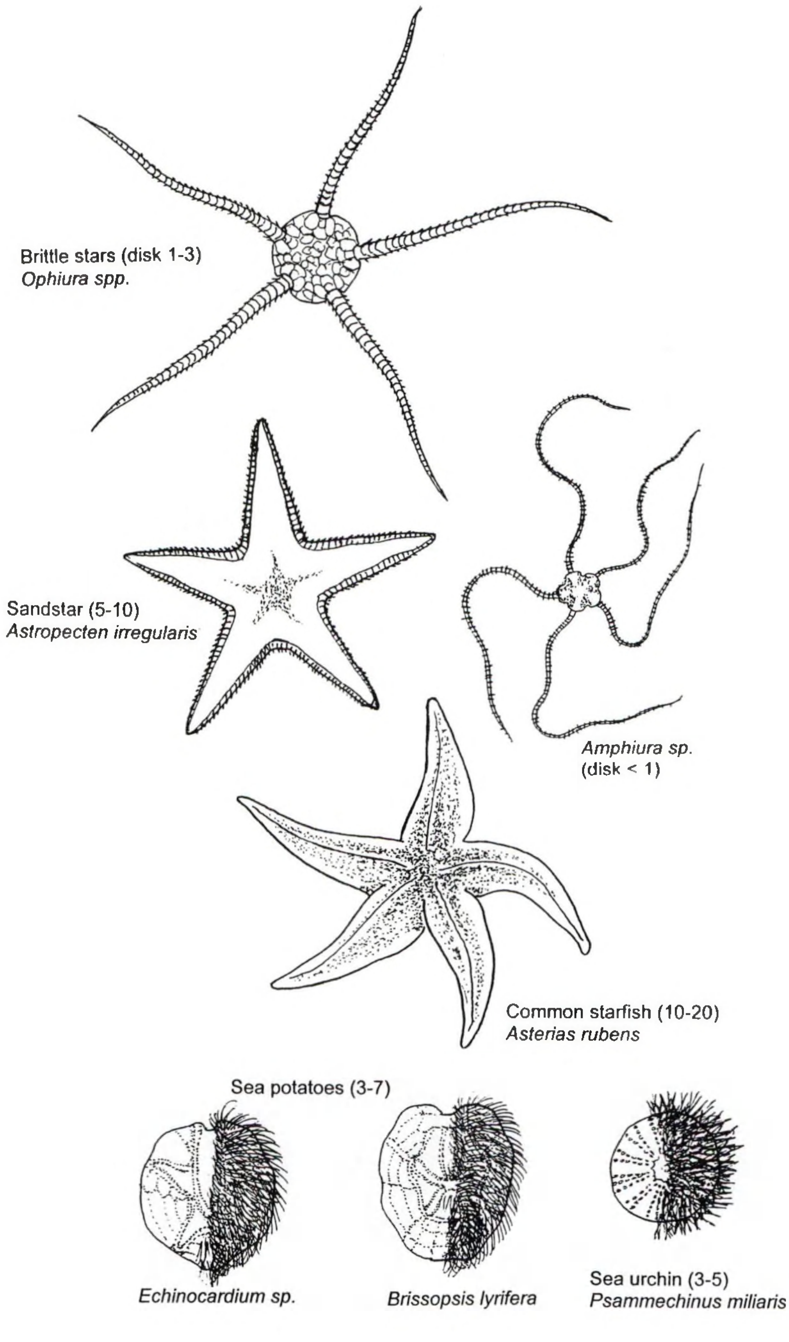


Fig. 6.3. Some of the echinoderm species mentioned in the report.
In brackets: adult and maximum size in cm (diameter or disc diameter (*Ophiura* and *Amphiura*)).

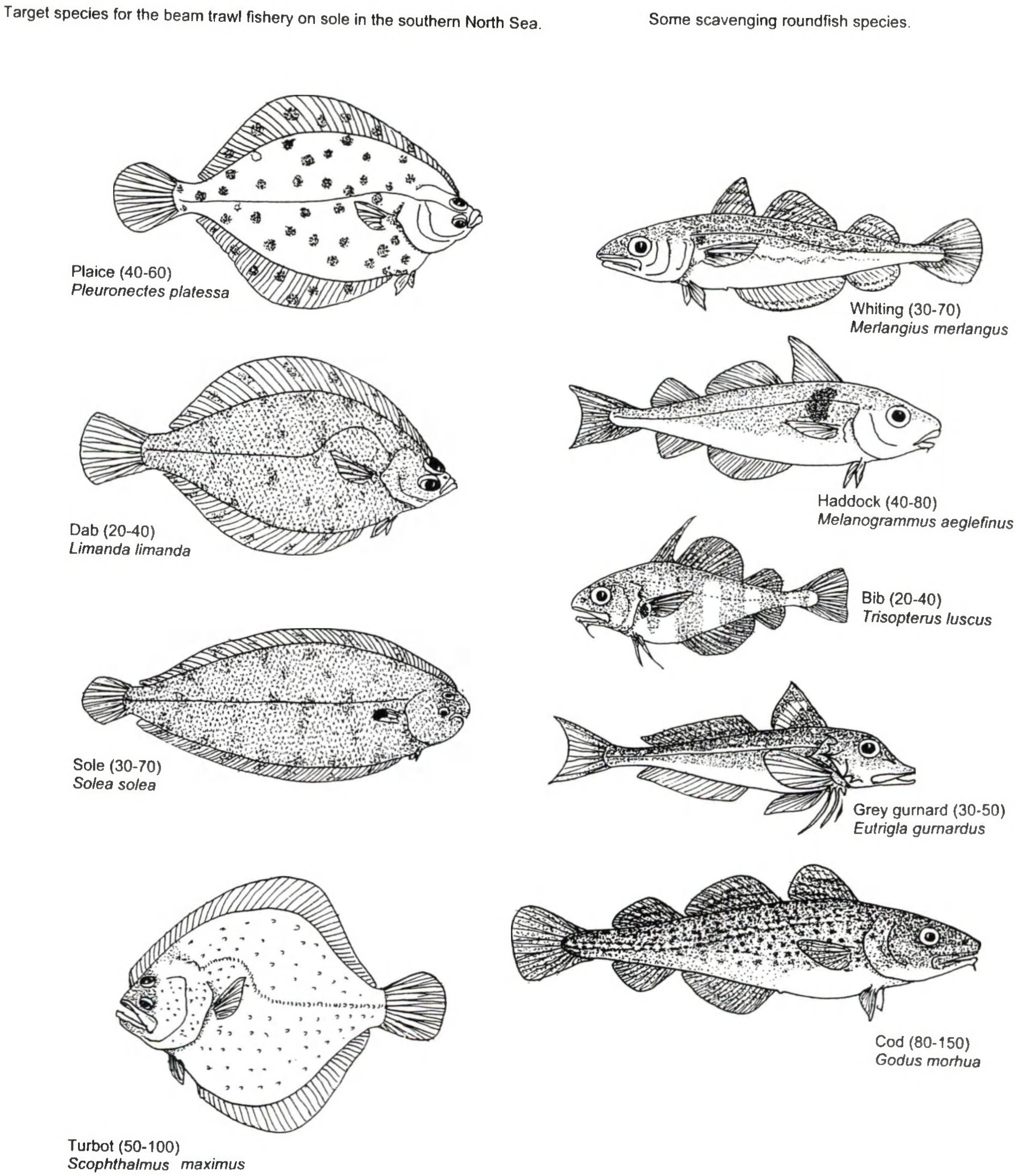
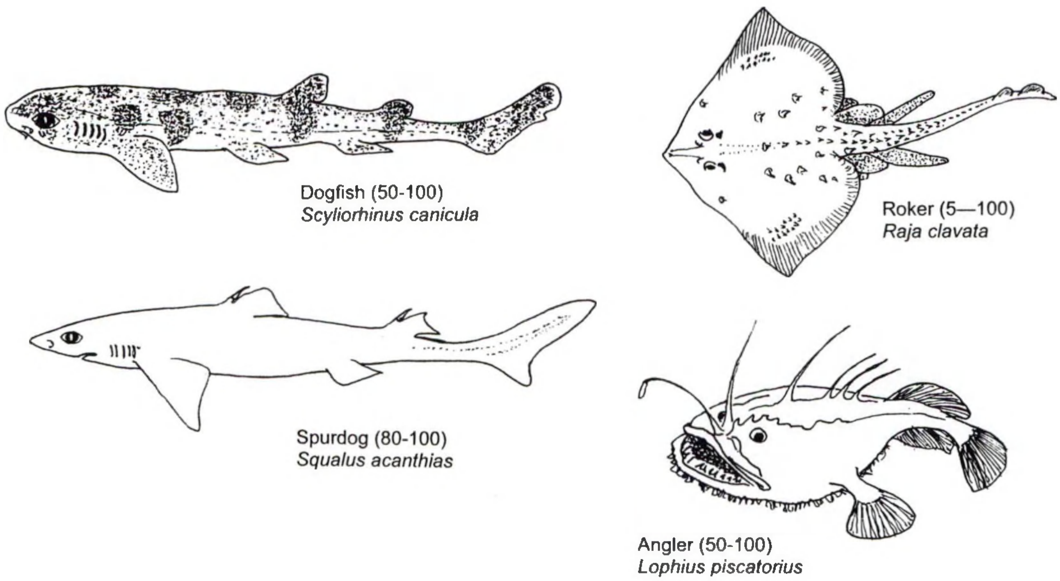


Fig. 6.4. Some of the fish species mentioned in the report.
In brackets: adult and maximum length in cm.

Large fish species that have become very rare in the southeastern North Sea.



Small demersal fish species that pass through the 8 cm meshes of sole nets.

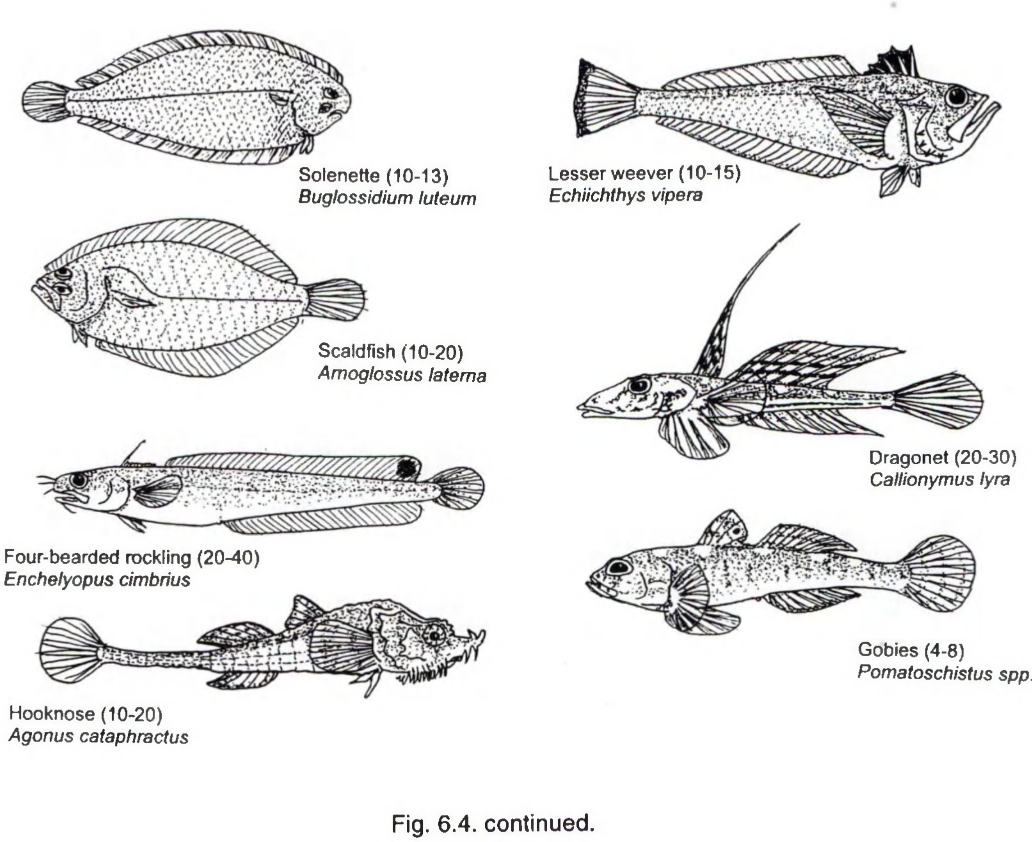


Fig. 6.4. continued.

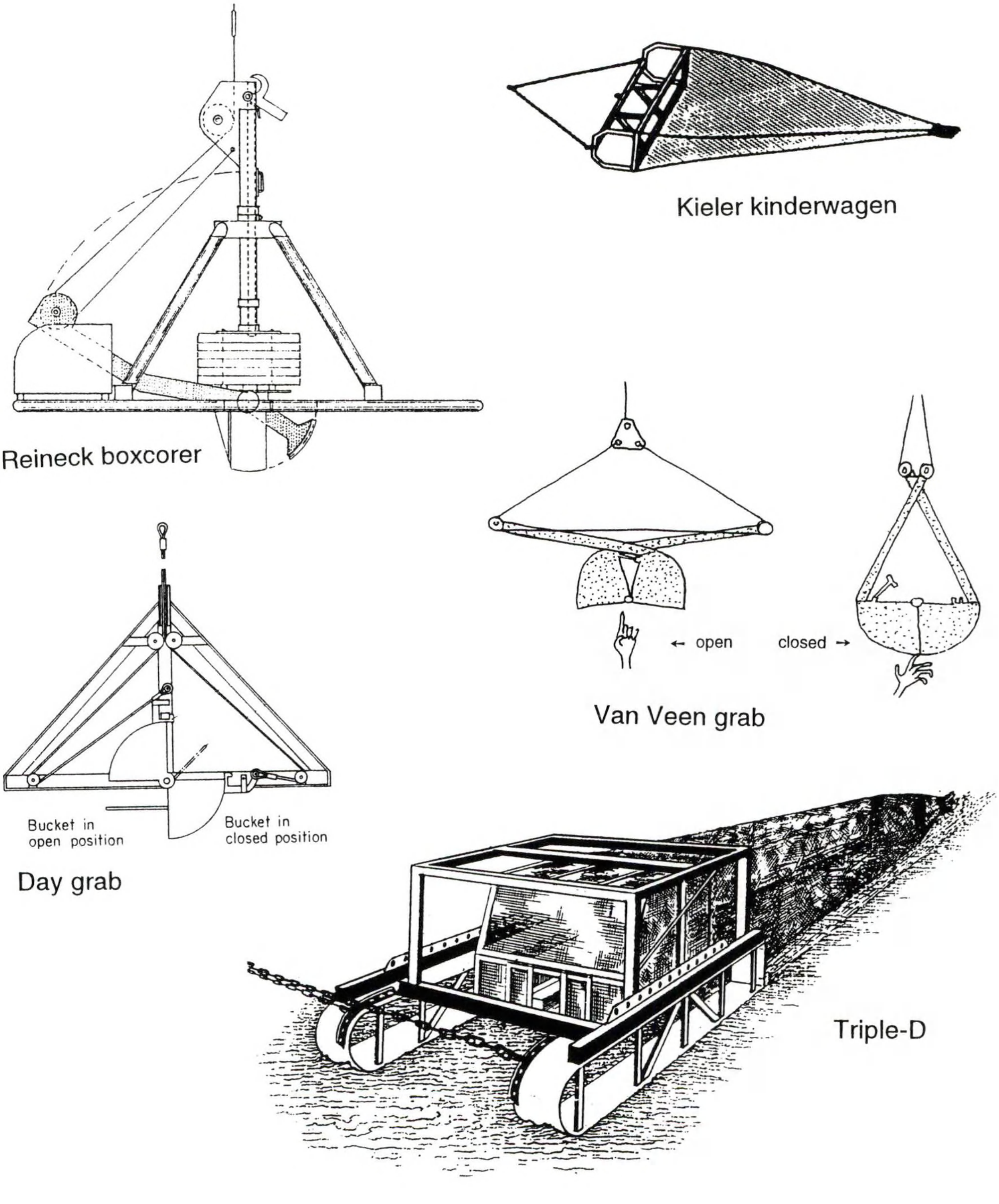


Fig. 6.5. Some of the sampling gears mentioned in the report.

6.2. LIST OF SPECIES MENTIONED IN THE REPORT

Phylum	Scientific name	English name	German name	Dutch name	French name
Annelida	*Aphrodita aculeata*	Sea mouse	Seemaus	Fluwelen zeemuis	Aphrodite
Annelida	*Nephtys hombergii*	Cat worm		Zandzager	
Arthropoda	*Callianassa subterranea*	Mudshrimp	Maulwurfskrebs sp		Taupe de Mer
Arthropoda	*Callinectes sapidus*	Blue crab	Blaukrabbe	Blauwe zwemkrab	Crabe bleu
Arthropoda	*Cancer pagurus*	Edible crab	Taschenkrebs	Noordzeekrab	Tourteau
Arthropoda	*Carcinus maenas*	Shore crab	Strandkrabbe	Strandkrab	Crabe vert
Arthropoda	*Corystes cassivelaunus*	Masked crab	Maskenkrabbe	Helmkrab	
Arthropoda	*Crangon crangon*	Brown shrimp	Garnele	Garnaal	Crevette grise
Arthropoda	*Dichelopandalus bonnieri*	Prawn			
Arthropoda	*Goneplax rhomboides*	Angular crab			
Arthropoda	*Hemimysis lamornae*	Mysid			
Arthropoda	*Homarus gammarus*	European lobster	Hummer	Kreeft	Homard
Arthropoda	*Hyas*	Spider crab	Seespinne	Spinkrab	
Arthropoda	*Liocarcinus*	Swimming crab	Schwimmkrabbe	Zwemkrab	Etrille
Arthropoda	*Liocarcinus depurator*	Blue-leg swimming crab	Schwimmkrabbe	Blauwpootzwemkrab	Etrille a pattes bleues
Arthropoda	*Liocarcinus holsatus*	Swimming crab	Schwimmkrabbe	Gewone zwemkrab	
Arthropoda	*Liocarcinus marmoreus*	Swimming crab	Schwimmkrabbe	Gemarmerde zwemkrab	
Arthropoda	*Liocarcinus puber*	Velvet swimming crab	Schwimmkrabbe	Fluwelen zwemkrab	Etrille commune
Arthropoda	*Liocarcinus pusillus*	Dwarf swimming crab	Schwimmkrabbe	Kleine zwemkrab	Crabe nageur
Arthropoda	*Macropodia rostrata*	Long legged spider crab		Hooiwagenkrab	Macropode
Arthropoda	*Macropodia tenuirostris*	Slender spider crab			
Arthropoda	*Meganyctiphanes norvegica*	Euphausid			
Arthropoda	*Nephrops norvegicus*	Norway lobster	Kaisergranat	Noorse kreeft	Langoustine
Arthropoda	*Pagurus bernhardus*	Hermit crab	Einsiedlerkrebs	Gewone heremietkreeft	Bernard l'ermite
Arthropoda	*Pasiphaea sivado*	Ghost shrimp			Sivade blanche
Arthropoda	*Thia scutellata*	Thumb-nail crab		Nagelkrab	

Phylum	Scientific name	English name	German name	Dutch name	French name
Coelenterata	*Actiniaria*	Beadler anemone			
Coelenterata	*Tunicata*	Sea squirt			
Coelenterata	*Urticina felina*	Dahlia anemone			
Echinodermata	*Asterias rubens*	Common starfish	Seestern	Gewone zeester	
Echinodermata	*Astropecten irregularis*	Starfish species	Kammsterne	Kamster	
Echinodermata	*Echinidae*	Sea urchins		Zeeëgel	Oursins
Echinodermata	*Echinocardium cordatum*	Sea potato	Herzseeigel	Zeeklit	
Echinodermata	*Echinus esculentus*	Common sea urchin	Essbares seeigel		
Echinodermata	*Spatangus purpureus*	Purple heart urchin	Violetter Herzseeigel		Oursin violet
Mollusca	*Acanthocardia echinata*	Prickly cockle	Dornige Herzmuschel	Gedoornde hartschelp	Bucarde a papilles
Mollusca	*Acteon tornatilis*	Actaeon shell		Spoelhoren	
Mollusca	*Aequipecten opercularis*	Queen scallop	Gedeckter Kammuschel	Wijde mantel	Vanneau
Mollusca	*Angulus tenuis*	Thin tellin	Plattmuschel	Tere platschelp	Telline papillon
Mollusca	*Aporrhais pespelicani*	Pelican's foot shell	Pelikansfuss	Pelikaansvoet	Pied de pelican
Mollusca	*Arctica islandica*	Quahog	Island Muschel	Noordkromp	Cyprine d' Islande
Mollusca	*Buccinum undatum*	Whelk	Wellhornschnecke	Wulk	Buccin commun du Nord
Mollusca	*Cerastoderma edule*	Common edible cockle	Herzmuschel	Kokkel	Coque bugarde comestible
Mollusca	*Chamelea gallina*	Striped venus	Venusmuschel	Venusschelp	Venus poule
Mollusca	*Chlamys*	Scallop			Petoncles
Mollusca	*Colus gracilis*	Slender spindle shell		Slanke noordhoren	
Mollusca	*Corbula gibba*	Common basket shell	Korbmuschel	Korfschelp	
Mollusca	*Dendronotus frondosus*	Nudibranch			
Mollusca	*Donax vittatus*	Banded wedge shell	Sägezahn	Zaagje	Donax des canards fliot
Mollusca	*Dosinia lupinus*	Smooth artemis		Gladde artemisschelp	Dosine
Mollusca	*Eledone cirrhosa*	Lesser octopus, Curled octopus		Oktopus	Poulpe blanc
Mollusca	*Ensis*	Razor shell	Swertmuschel	Mesheften en zwaardschedes	Couteau
Mollusca	*Ensis directus*	American razor shell	Amerikanische Schwertmuschel	Amerikaanse zwaardschede	
Mollusca	*Ensis ensis*	Razor shell	Swertmuschel	Slanke kleine zwaardschede	Couteau sabre
Mollusca	*Fabulina fabula*	Tellin	Plattmuschel	Rechtgestreepte platschelp	

Phylum	Scientific name	English name	German name	Dutch name	French name
Mollusca	*Gari fervensis*	Farce sunset shell		Geplooide zonneschelp	Psammobie boréale
Mollusca	*Gibbula tumida*	Topshell	Kreiselschnecke	Tolhoren	
Mollusca	*Loligo vulgaris*	Squid	Kalmar	(Gewone) Pijlinktvis	Encornet
Mollusca	*Lunatia*	Necklace shell	Nabelschnecke	Tepelhoren	Natices
Mollusca	*Lunatia catena*	Large necklace shell	Nabelschnecke	Grote tepelhoren	Natice a collier
Mollusca	*Lunatia poliana*	Common necklace shell	Nabelschnecke	Glanzende tepelhoren	Natice belle
Mollusca	*Mactra stultorum*	Rayed trough shell	Trogmuschel	Grote strandschelp	Mactre coralline
Mollusca	*Modiolus modiolus*	Horse mussel	Pferdemuschel	Paarde mossel	Grande moule
Mollusca	*Mya arenaria*	Sand gaper	Gemeine Klaffmuschel	Strandgaper	Mye des sables
Mollusca	*Mytilus edulis*	Edible mussel		Mossel	Moule bleue
Mollusca	*Neptunea antiqua*	Buckie, Red Whelk	Gemeine Spindelschnecke	Noordhoren	
Mollusca	*Nucula nitidosa*	Nutshell	Nussmuschel	Driehoekige parelmoerneut	
Mollusca	*Sepia*	Cuttlefish	Sepia	Zeekat	Seiche
Mollusca	*Sepiola atlantica*	Little cuttlefish		Dwerginktvis	
Mollusca	*Spisula*	Trough shell	Trogmuschel	Strandschelp	Mactres
Mollusca	*Spisula solida*	Thick trough shell	Dickschalige Trogmuschel	Stevige strandschelp	Mactre solide
Mollusca	*Spisula subtruncata*	Cut trough shell	Dreieckige Trogmuschel	Halfgeknotte strandschelp	Mactre tronquee
Mollusca	*Thracia villosiuscula*	Thrasia shell			
Mollusca	*Turritella communis*	Tower shell	Turmschnecke	Penhoren	Turitelle commune
Pisces	*Agonus cataphractus*	Hooknose	Steinpicker	Harnasmannetje	Souris de mer
Pisces	*Alosa alosa*	Allis shad	Maifish	Elft	Alose vraie
Pisces	*Alosa fallax*	Twaite shad	Fint	Fint	Alose feinte
Pisces	*Ammodytes lanceolatus*	Greater sandeel		Smelt	Lançon
Pisces	*Ammodytes tobianus*	Sand eel	Kleiner Sandaal	Zandspiering	Équille
Pisces	*Anguilla anguilla*	Eel	Aal	Paling	Anguille
Pisces	*Arnoglossus laterna*	Scaldfish	Zammzunge	Schurftvis	Fausse limande
Pisces	*Aspitrigla cuculus*	Red gurnard	Seekuckuck	Engelse poon	Grondin rouge
Pisces	*Barbus barbus*	Barbel	Barbe	Barbeel	
Pisces	*Belone belone*	Garfish	Hornhecht	Geep	Orphie

Phylum	Scientific name	English name	German name	Dutch name	French name
Pisces	*Buglossidium luteum*	Solenette	Zwergzunge	Dwergtong	Petite sole jaune
Pisces	*Callionymus lyra*	Dragonet	Gestreifter Leierfisch	Pitvis	Dragonet lyre
Pisces	*Caranx trachurus*	Scad	Stöcker	Horsmakreel	Saurel, Chinchard
Pisces	*Ciliata mustela*	Five-bearded rockling	Funfbärtelige Seeguappe	Vijfdradige meun	Motelle a cinq barbillons
Pisces	*Ciliata septentrionalis*	Northern rockling		Noorse meun	Motelle Nordique
Pisces	*Clupea*	Herring\Sprat		Haring/Sprot	Clupes
Pisces	*Clupea harengus*	Herring	Hering	Haring	Hareng
Pisces	*Conger conger*	Conger	Meeraal	Zeepaling	Congre
Pisces	*Cyclopterus lumpus*	Lumpsucker	Seehase	Snotdolf	Lompe
Pisces	*Dasyatis pastinaca*	Stingray	Stechrochen	Pijlstaartrog	Pastenague commune
Pisces	*Enchelyopus cimbrius*	Four-bearded rockling	Vierbärtelige Seeguappe	Vierdradige meun	Motelle a quatre barbillons
Pisces	*Engraulis encrasicolus*	Anchovy	Anchovis	Ansjovis	Anchois
Pisces	*Eutrigla gurnardus*	Grey gurnard	Grauer Knurrhahn	Grauwe poon	Grondin gris
Pisces	*Gadus morhua*	Cod	Kabeljau	Kabeljauw	Cabillaud, Morue
Pisces	*Gaidropsarus vulgaris*	Three-bearded rockling	Dreibärtelige Seeguappe	Driedradige meun	Motelle commune
Pisces	*Galeorhinus galeus*	Tope	Hundshai	Ruwe haai	Requin hâ
Pisces	*Glyptocephalus cynoglossus*	Witch	Hundszunge	Witje	Plie cynoglosse
Pisces	*Gobiidae*	Gobies	Grundel	Grondels	Gobies
Pisces	*Hippoglossoides platessoides*	Long rough dab	Scharbenzunge	Lange schar	Faux fletan
Pisces	*Hippoglossus hippoglossus*	Halibut	Heilbutt	Heilbot	Flétan
Pisces	*L. friesii*	Fries goby			Gobie a grandes ecailles
Pisces	*Labridae indet.*	Wrasse	Lippfisch	Lipvis	Labres
Pisces	*Lepidorhombus whiffiagonis*	Megrim	Flügelbutt	Scharretong	Cardine (franche)
Pisces	*Limanda limanda*	Dab	Kliesche	Schar	Limande
Pisces	*Lophius piscatorius*	Angler	Seeteufel	Zeeduivel	Lotte, Baudroie
Pisces	*Lumpenus lumpretaeformis*	Snake blenny			
Pisces	*Maurolicus muelleri*	Pearl-side	Lachshering	Lichtend sprotje	
Pisces	*Melanogrammus aeglefinus*	Haddock	Schellfisch	Schelvis	Églefin
Pisces	*Merlangius merlangus*	Whiting	Wittling	Wijting	Merlan

Phylum	Scientific name	English name	German name	Dutch name	French name
Pisces	*Merluccius vulgaris*	Hake	Seehecht	Heek	Merlu
Pisces	*Micromesistius poutassou*	Blue whiting	Blauer Wittling	Blauwe wijting	Poutassou
Pisces	*Microstomus kitt*	Lemon sole	Echte Rotzunge	Tongschar	Limande sole
Pisces	*Molva molva*	Ling	Leng	Leng	Grande lingue
Pisces	*Mullus surmuletus*	Striped red mullet	Streifenbarbe	Mul	Rouget de roche
Pisces	*Mustelus mustelus*	Smooth hound	Glatthai	Gladde haai	Émissole lisse
Pisces	*Myoxocephalus scorpius*	Bull-rout	Seeskorpion	Zeedonderpad	Chaboisseau de mer commun
Pisces	*Osmerus eperlanus*	Smelt	Stint	Spiering	Éperlan d'Europe
Pisces	*Pholis gunnellus*	Butterfish	Butterfisch	Botervis	Gonnelle
Pisces	*Pisces indet.*	Fish	Fische	Vis	Poissons
Pisces	*Platichthys flesus*	Flounder	Flunder	Bot	Flet
Pisces	*Pleuronectes platessa*	Plaice	Scholle	Schol	Plie
Pisces	*Pleuronectiformes indet.*	Flatfish		Platvis	Poisson plats
Pisces	*Pollachius pollachius*	Pollack	Pollack	Witte koolvis	Lieu jaune
Pisces	*Pollachius virens*	Saithe	Kohler	Zwarte koolvis	Lieu noir
Pisces	*Pomatoschistus*	Goby	Grundel	Grondel	Gobies
Pisces	*Raja batis*	Common skate	Glattrochen	Vleet	Pocheteau gris
Pisces	*Raja clavata*	Roker\Thornback ray	Nagelrochen	Stekelrog	Raie bouclée
Pisces	*Raja naevus*	Cuckoo ray	Kuckucksrochen	Grootoogrog	Raie fleurie
Pisces	*Raja radiata*	Starry ray	Sternrochen	Sterrog	Raie radiée
Pisces	*Raniceps raninus*	Tadpole-fish	Froschdorsch	Vorskwab	Trident
Pisces	*Salmo salar*	Salmon	Lachs	Zalm	Saumon atlantique
Pisces	*Salmo trutta trutta*	Sea trout	Meerforelle	Zeeforel	Truite de Mer
Pisces	*Sardina pilchardus*	Pilchard	Sardine	Sardien	Sardine
Pisces	*Scomber scombrus*	Mackerel	Makrele	Makreel	Maquereau
Pisces	*Scophthalmus maximus*	Turbot	Steinbutt	Tarbot	Turbot
Pisces	*Scophthalmus rhombus*	Brill	Glattbutt	Griet	Barbue
Pisces	*Scyliorhinus canicula*	Dogfish	Kleingeflecter Katzenhai	Hondshaai	Petit roussette
Pisces	*Scyliorhinus caniculus*	Small spotted cat shark			

Phylum	Scientific name	English name	German name	Dutch name	French name
Pisces	*Solea lascaris*	Sand sole	Sandzunge	Franse tong	Sole pole
Pisces	*Solea solea*	Common sole	Seezunge	Tong	Sole commune
Pisces	*Sprattus sprattus*	Sprat	Sprotte	Sprot	Sprat
Pisces	*Squalus acanthias*	Spurdog	Dornhai	Doornhaai	Aiguillat commun
Pisces	*Syngnathus*	Pipefish sp	Seenadel	Zeenaald	Syngnathes
Pisces	*Trachinus*	Weever		Pieterman	Vive
Pisces	*Trachinus draco*	Greater weever	Petermänchen	Grote pieterman	Grande vive
Pisces	*Trachinus vipera*	Lesser weever	Vipergneise	Kleine pieterman	Petite vive
Pisces	*Trigla*	Gurnard	Knurrhahn	Poon	Grondins
Pisces	*Trigla lucerna*	Tub gurnard	Roter Knurrhahn	Rode poon	Grondin perlon
Pisces	*Trigloporus lastovitza*	Streaked gurnard	Gestreifter Knurrhahn	Gestreepte poon	Grondin camard
Pisces	*Trisopterus luscus*	Bib	Fransozenfisch	Steenbolk	Tacaud
Pisces	*Trisopterus minutus*	Poor cod	Zwerchdorsch	Dwergbolk	Capelan
Pisces	*Zeugopterus punctatus*	Topknot	Haarbutt	Gevlekte griet	Targeur, Sole de roche

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