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.

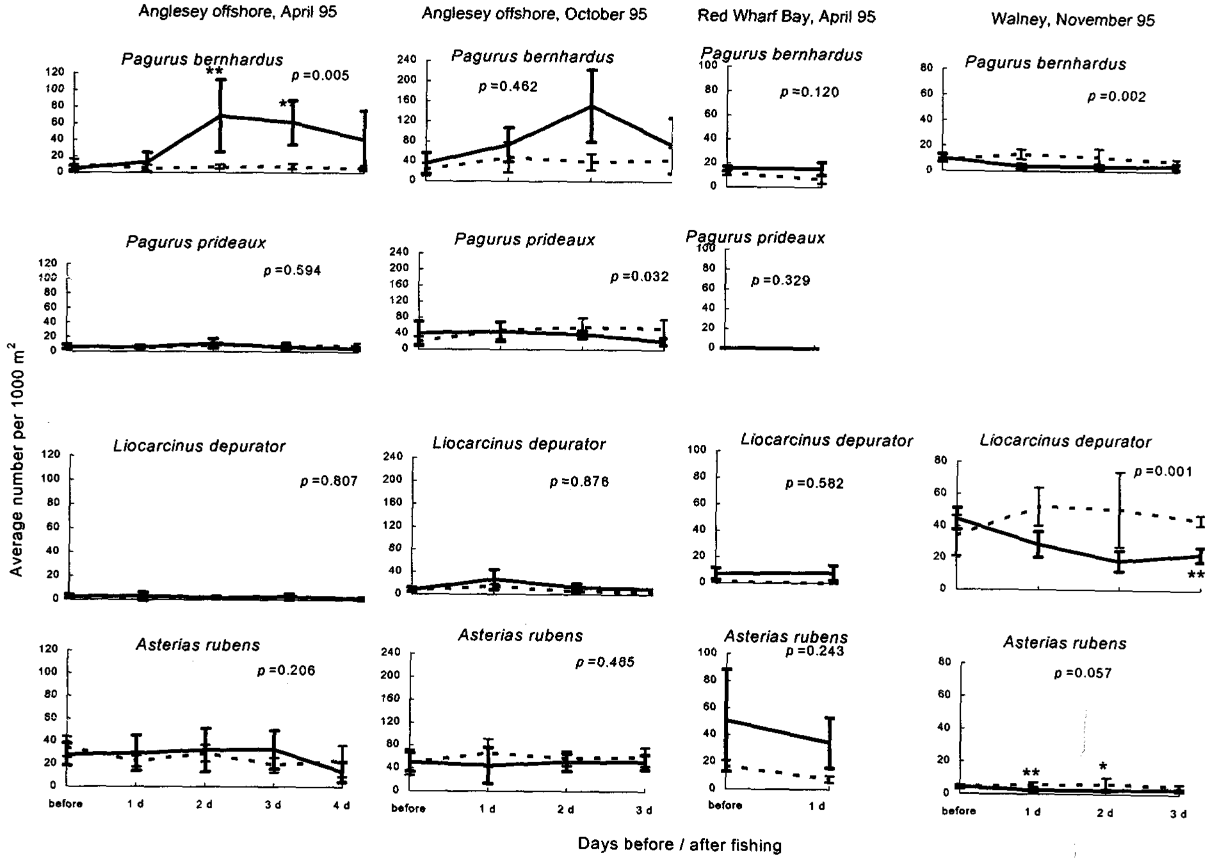


Fig. 3.6.1. Average numbers of animals per 1000 m^2 caught during 2.8 m beam trawl sampling. Only species where ANOVA has shown a significant time*treatment interaction term have been included (p value shown on graphs is significance of interaction term). Also showing results of Dunett's multiple comparison 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.

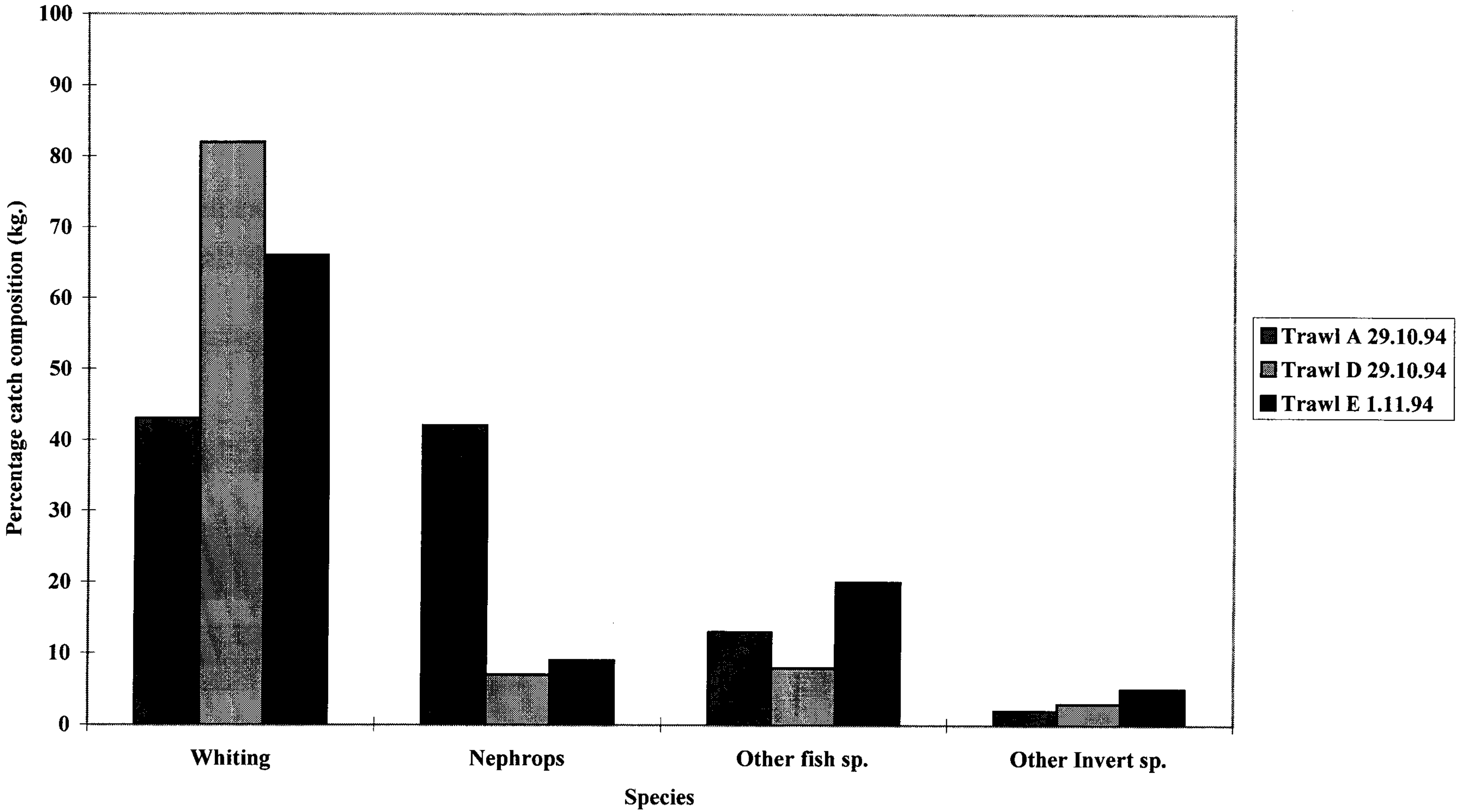


Fig. 3.6.2. Graph of the catch composition (by weight) of trawls taken at intervals (Trawl A = t0 h, Trawl D = t0 + 6 h, Trawl E = t0 + 72 h) along a transect located in the IMPACT II offshore station (NW Irish Sea).

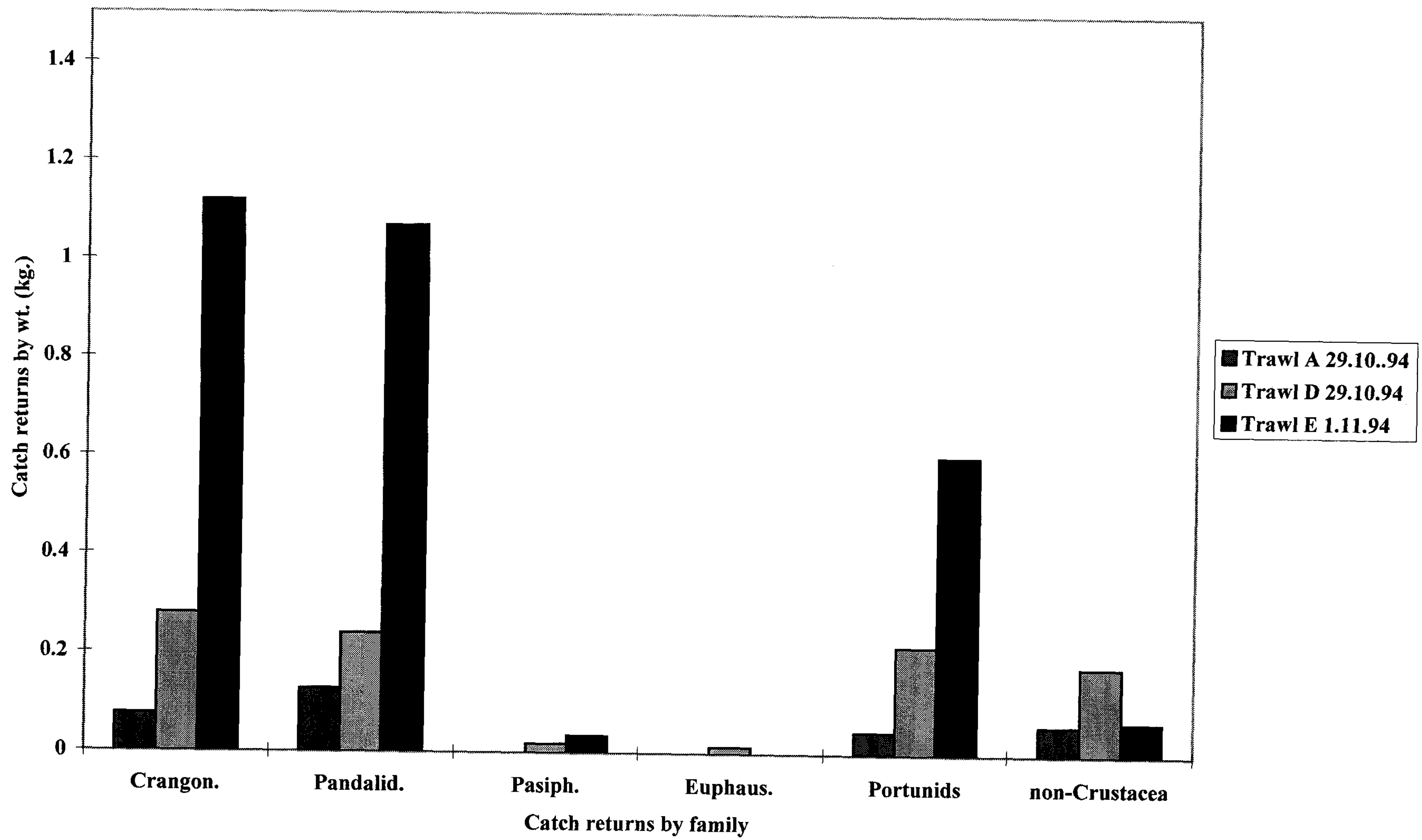


Fig. 3.6.3. Catch composition by weight of trawls taken taken on 29/10 - 1/11/1994 at intervals of 0, 6 and 72 h along a transect located in the IMPACT II offshore station, NW Irish Sea.

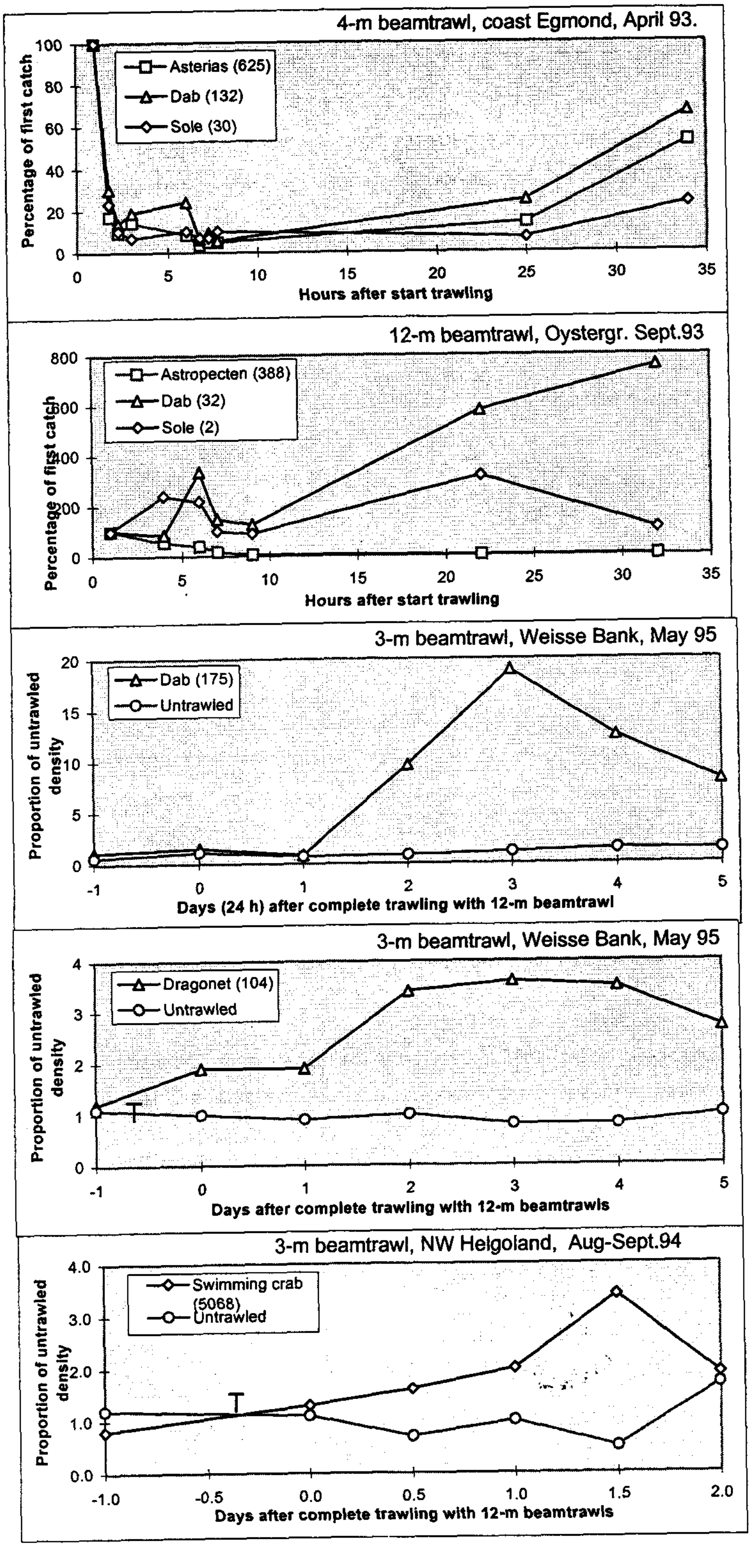


Fig. 3.6.4. Changes in densities of starfish, dab, dragonets and swimming crab, after complete trawling a transect with 12m beam trawls at time T. Relatieve densities estimated from catches with fine-meshed 3m beam trawl.

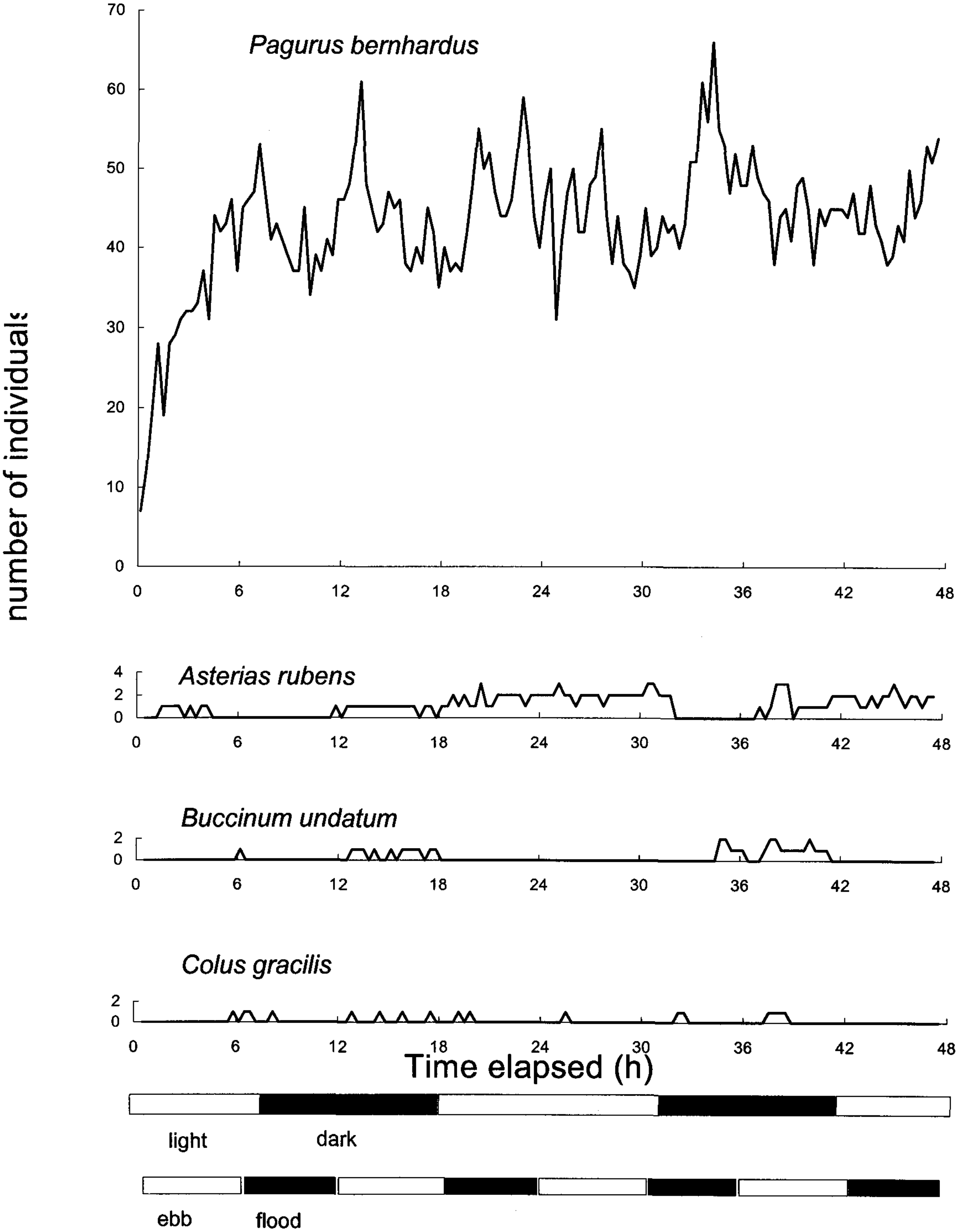


Fig. 3.6.5. Numbers of scavengers observed feeding on discarded fish at the Anglesey offshore site, September 1996.

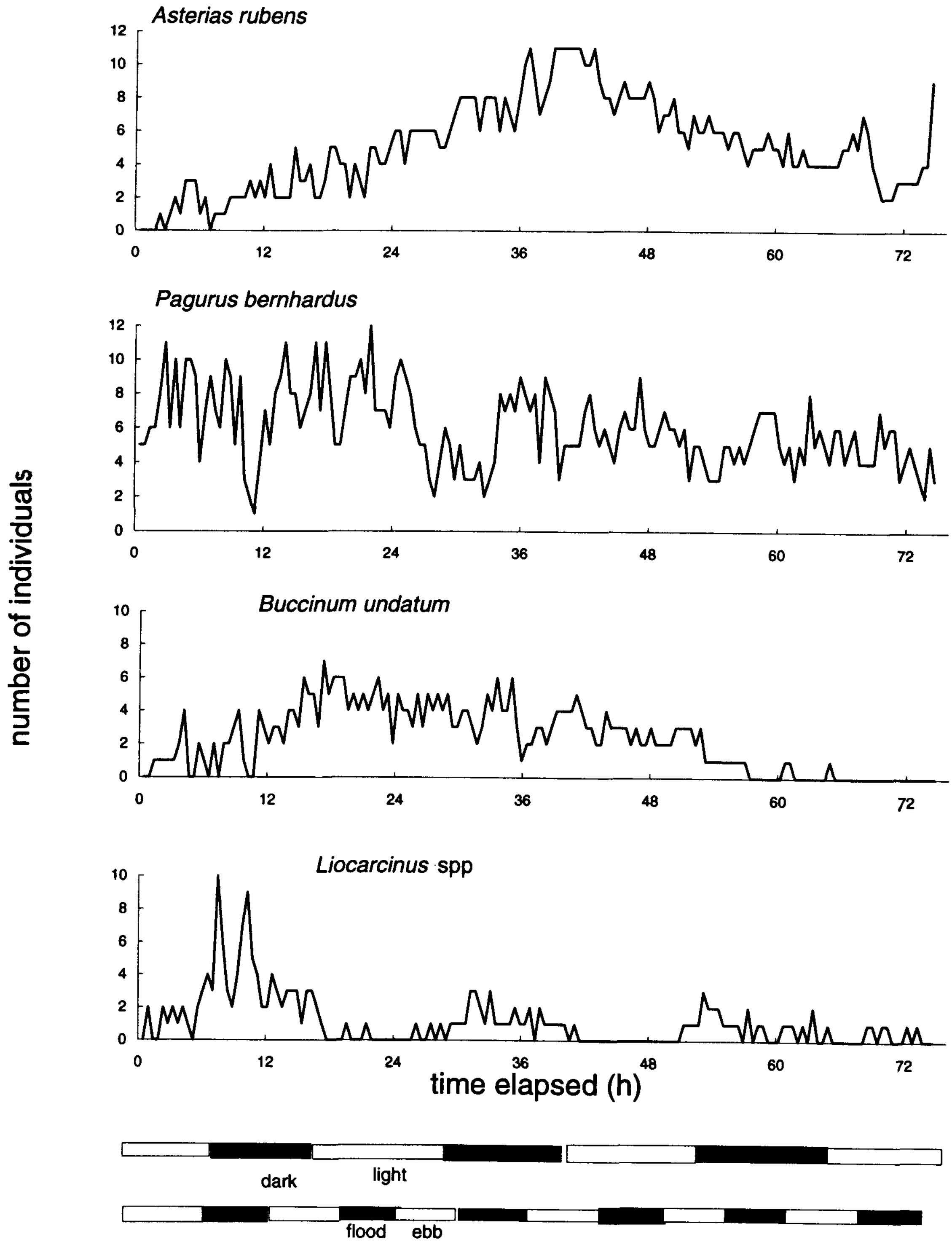


Fig. 3.6.6. Numbers of scavengers observed on the bait at Red Warf Bay, October 1995.

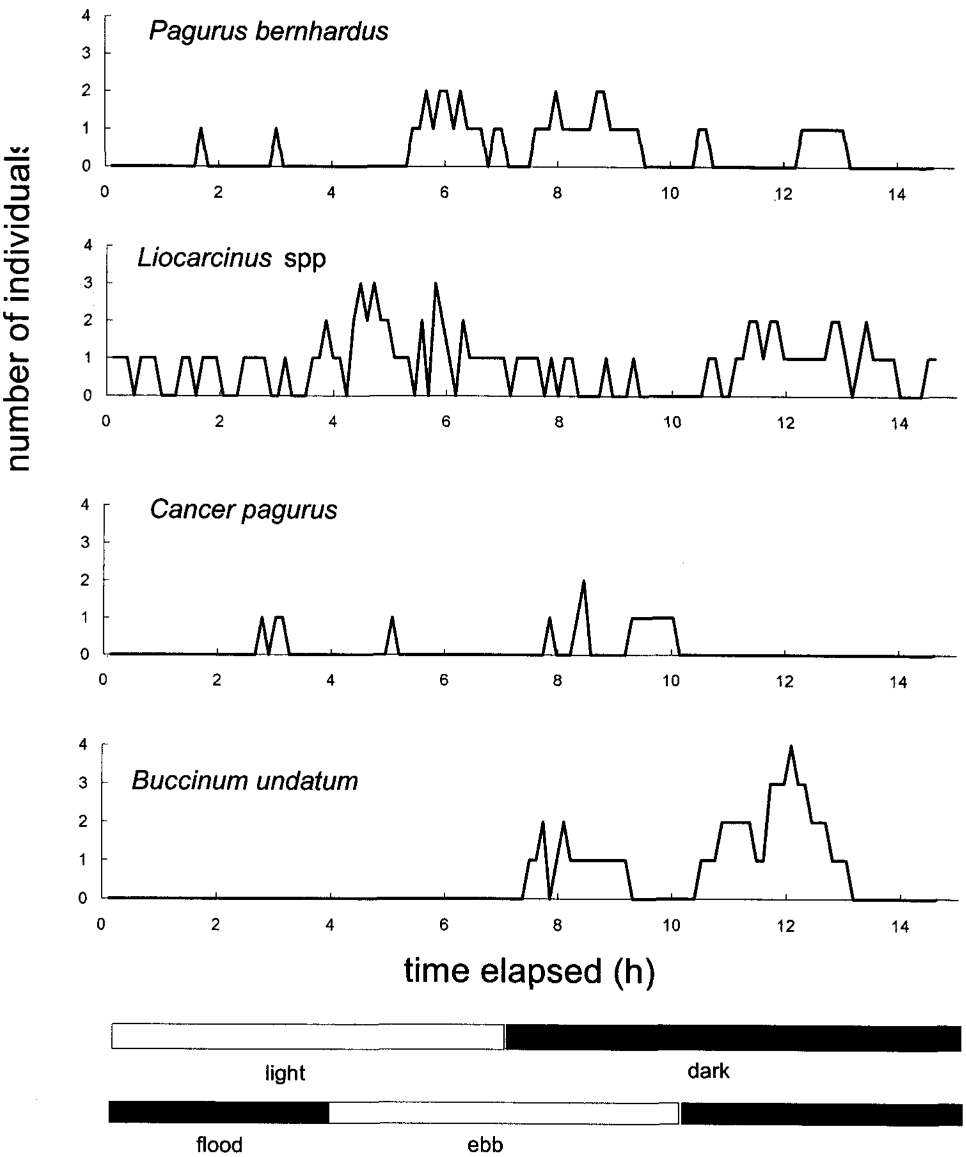


Fig. 3.6.7. Numbers of scavengers observed on the bait at the Walney Island site, November 1995 (deployment 2).

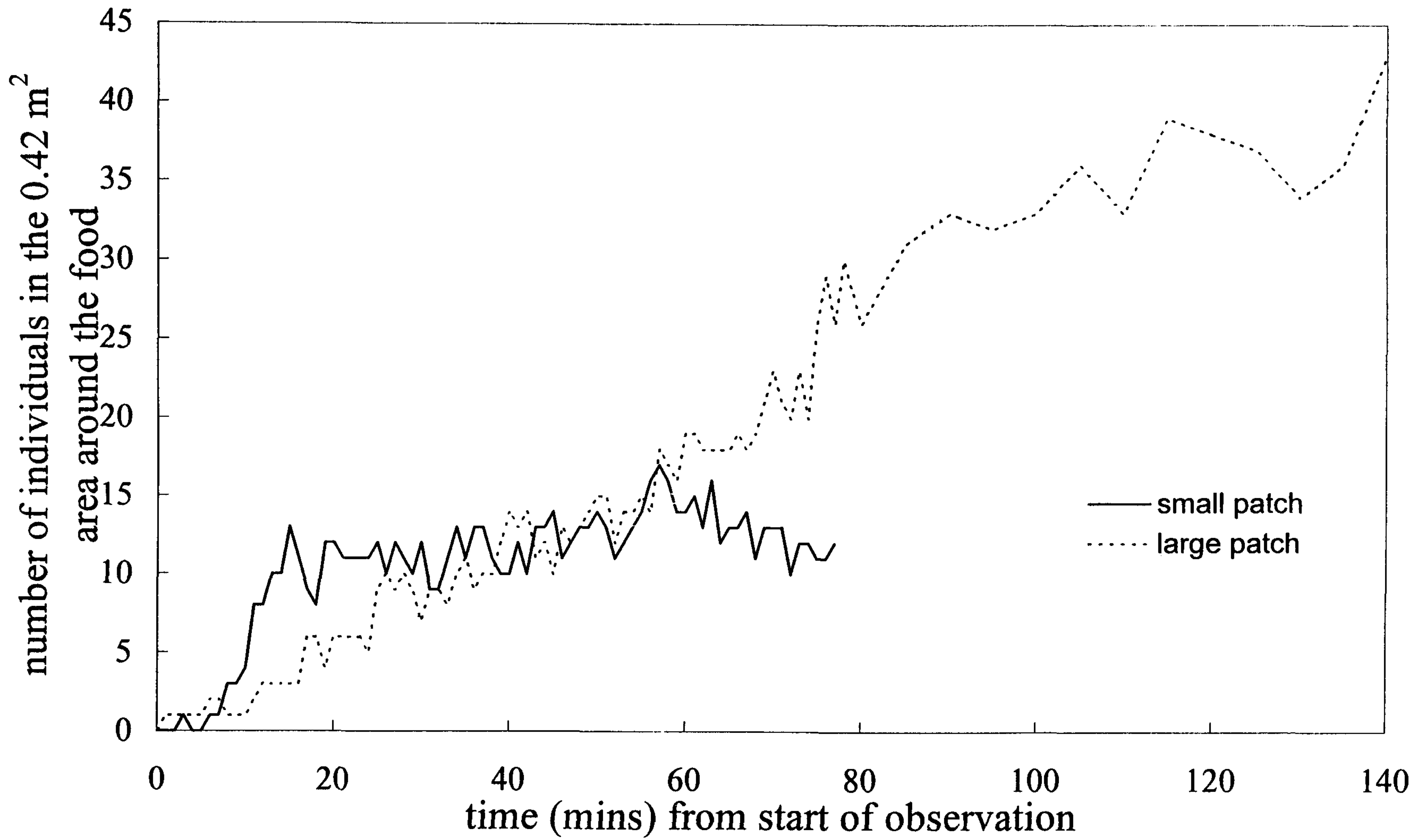


Fig. 3.6.8. Numbers of *P. bernhardus* present in the field of view (0.42 m^2) on the small food patch and large food patch. Durations of experiments were determined by onset of tidal flow (see text).

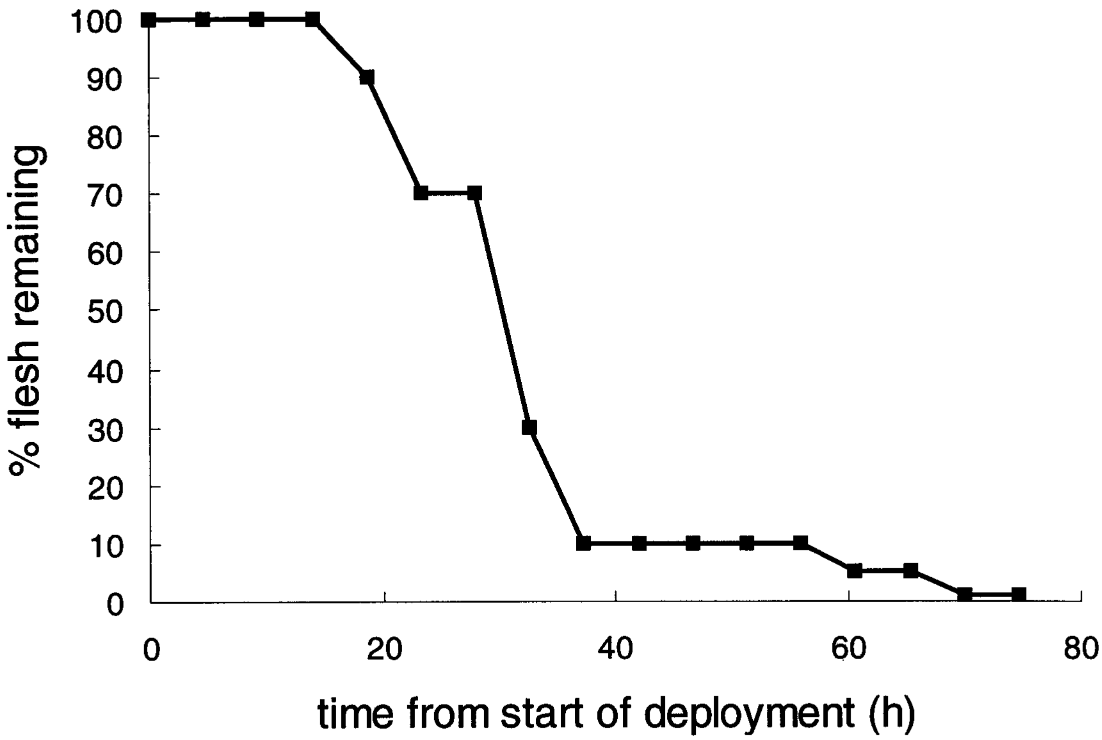


Fig. 3.6.9. Visual estimates of the percentage of flesh remaining on the bait (dragonets) during the Red Wharf Bay time-lapse camera deployment.

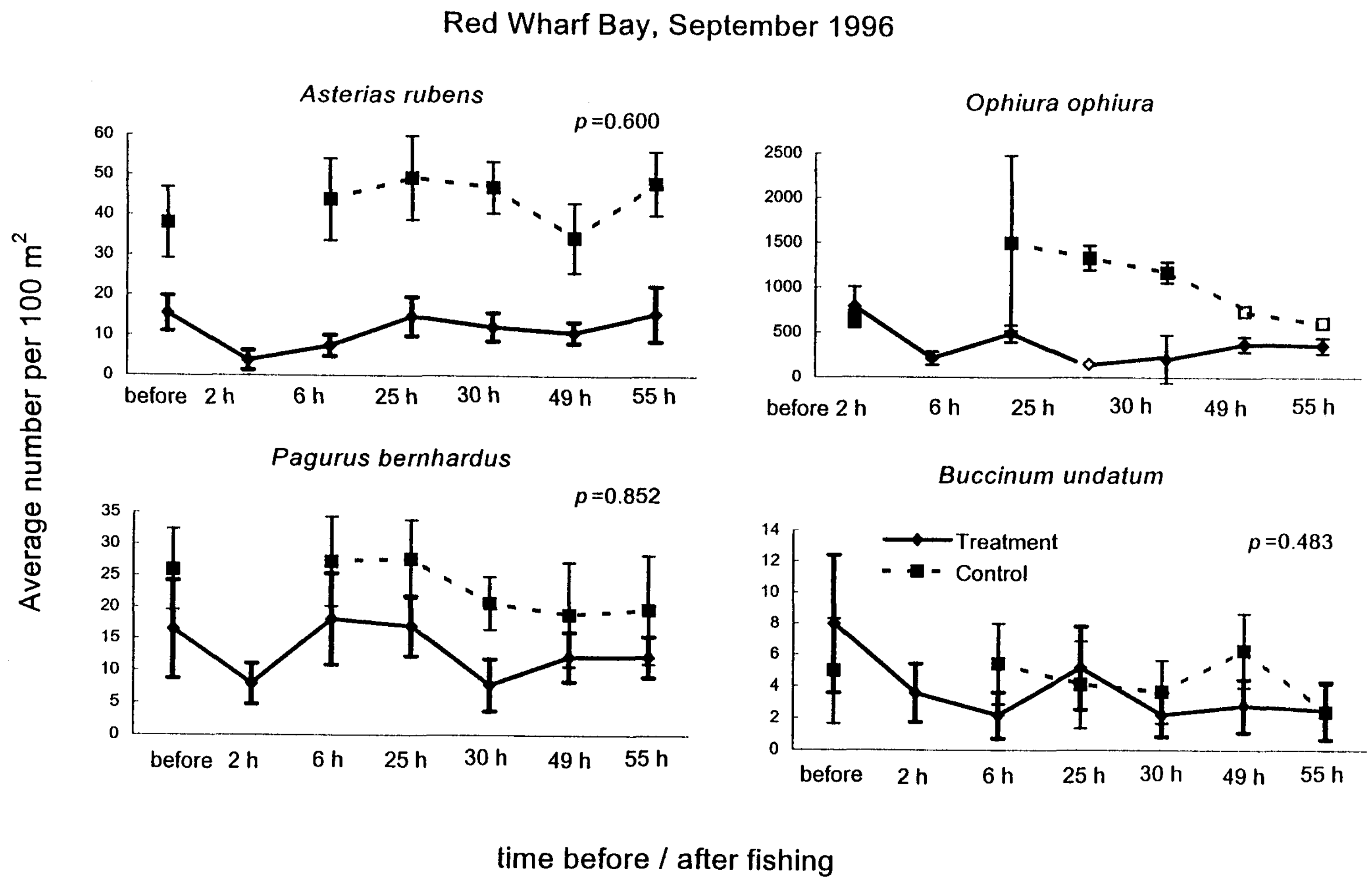


Fig. 3.6.10. Mean numbers (± 95% confidence intervals) of scavengers observed by divers before and after a line was fished with a beam trawl. p values are the significance of the interaction between time and treatment (repeated measures ANOVA on log transformed data).

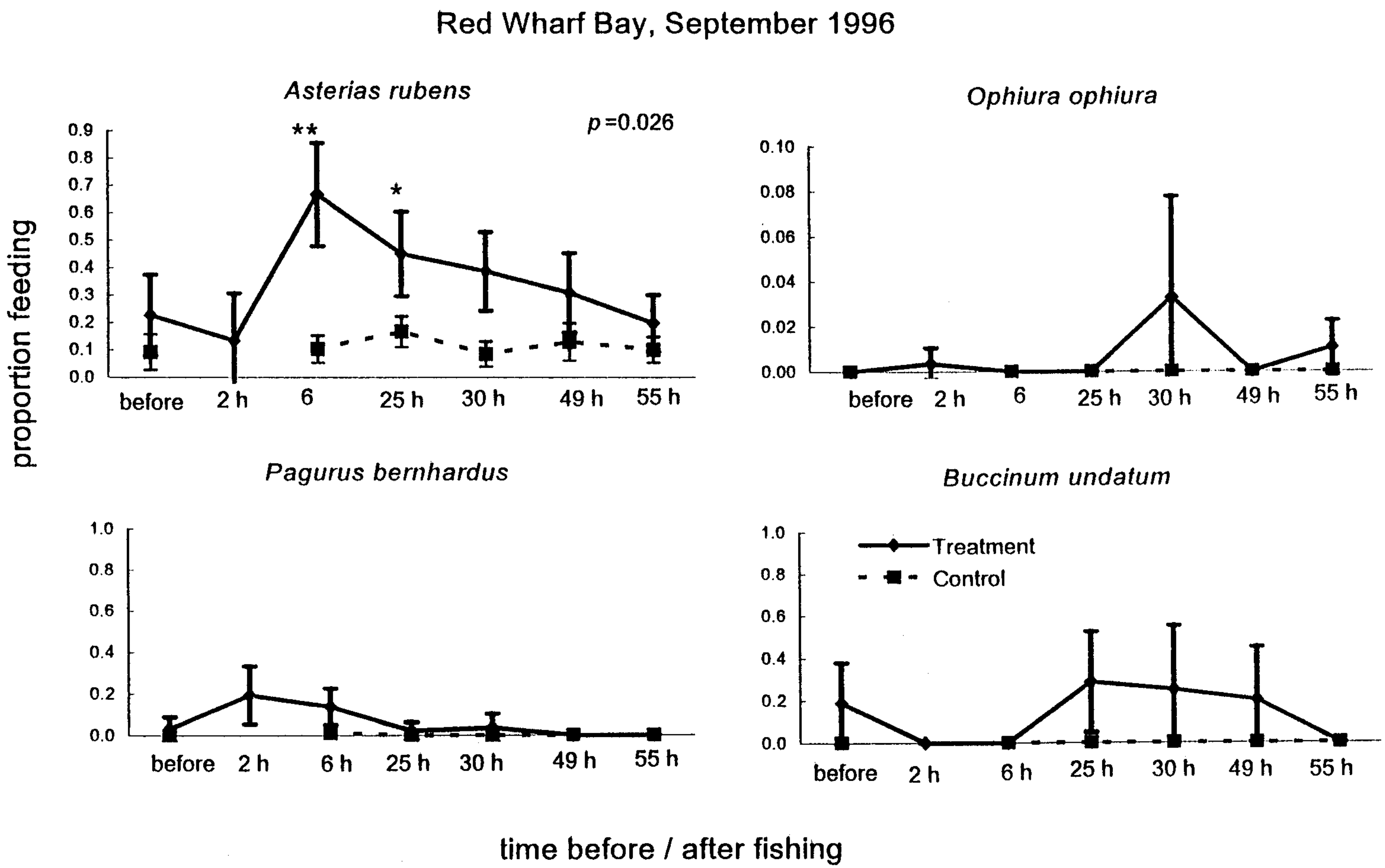


Fig. 3.6.11. Proportion of scavengers observed feeding before and after a line with a beam trawl. p values are the significance of the interaction between time and treatment (ANOVA specifying a binomial distribution). Where no p values if shown the model did not converge and therefore the validity of 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).

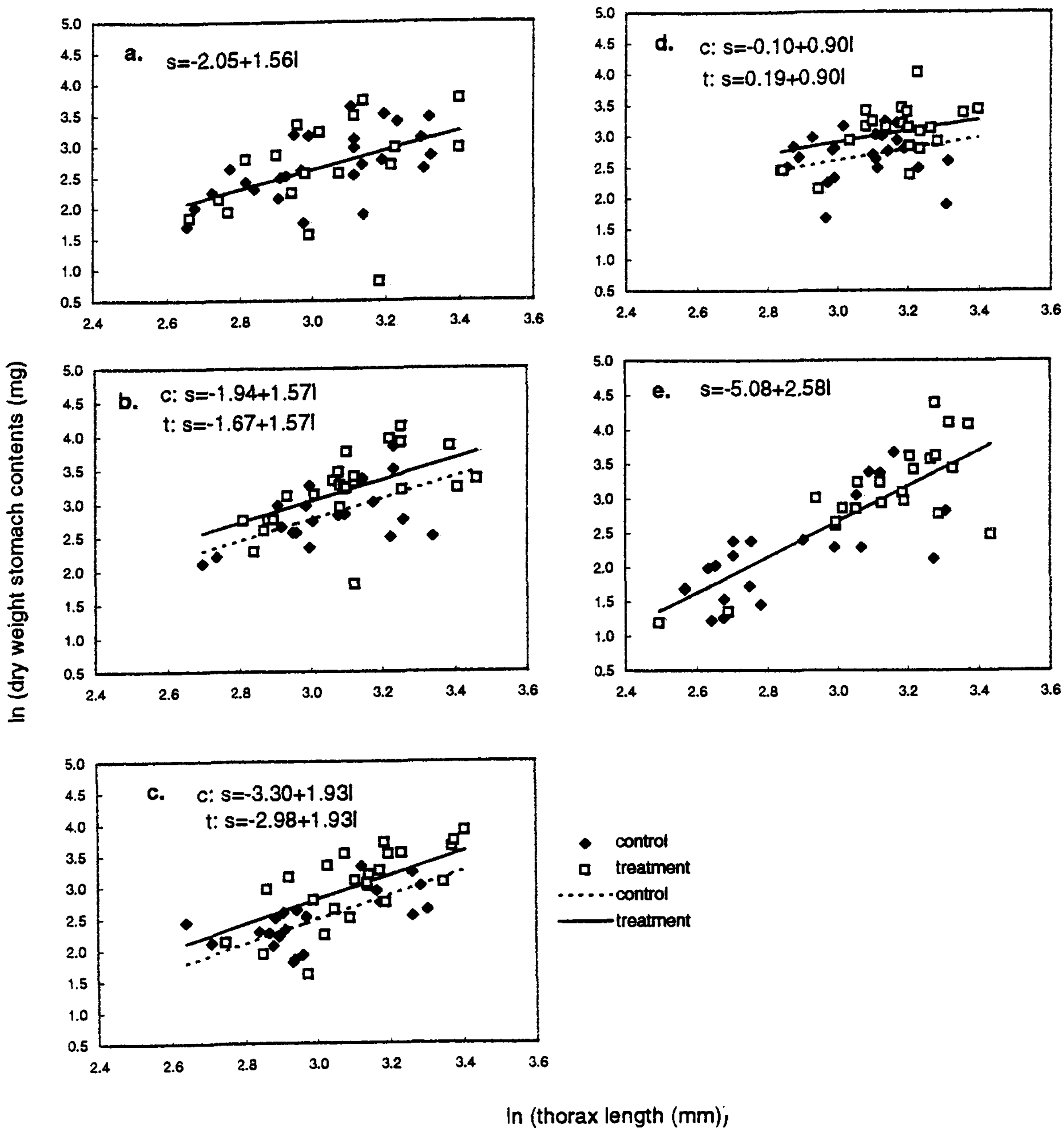


Fig. 3.6.12. *P. bernhardus*. Relationship between crab size and weight of stomach contents for treatment and control line (where only 1 line is shown this is a common line fitted to the whole dataset), also showing equations for the fitted line(s) where c = control line, t = treatment line, s = ln (dry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

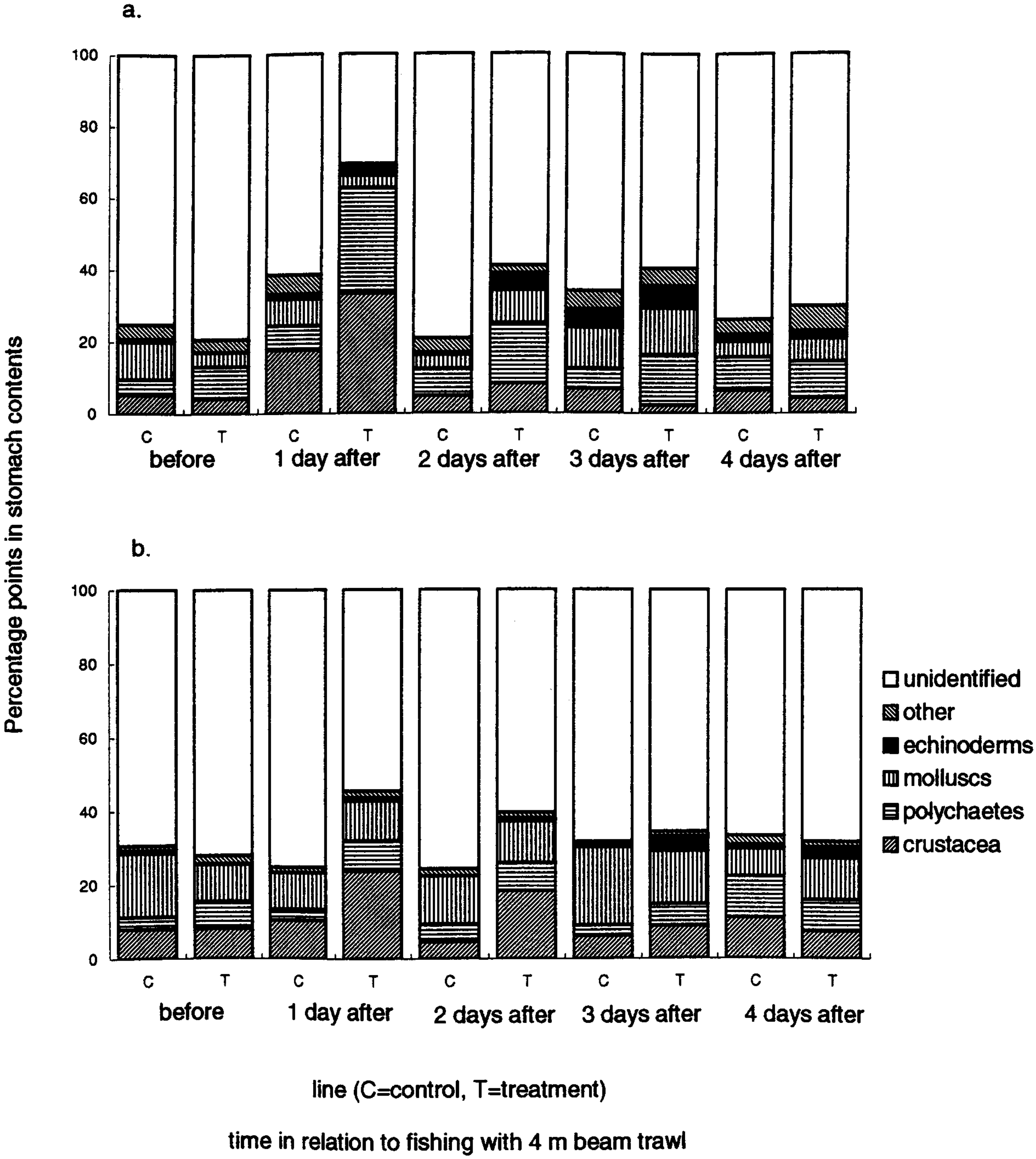


Fig. 3.6.13. Composition of the diet of a. *P. bernhardus*, b. *P. prideaux*, ("other" includes hydroids, bryozoans, eggs, fish scale).

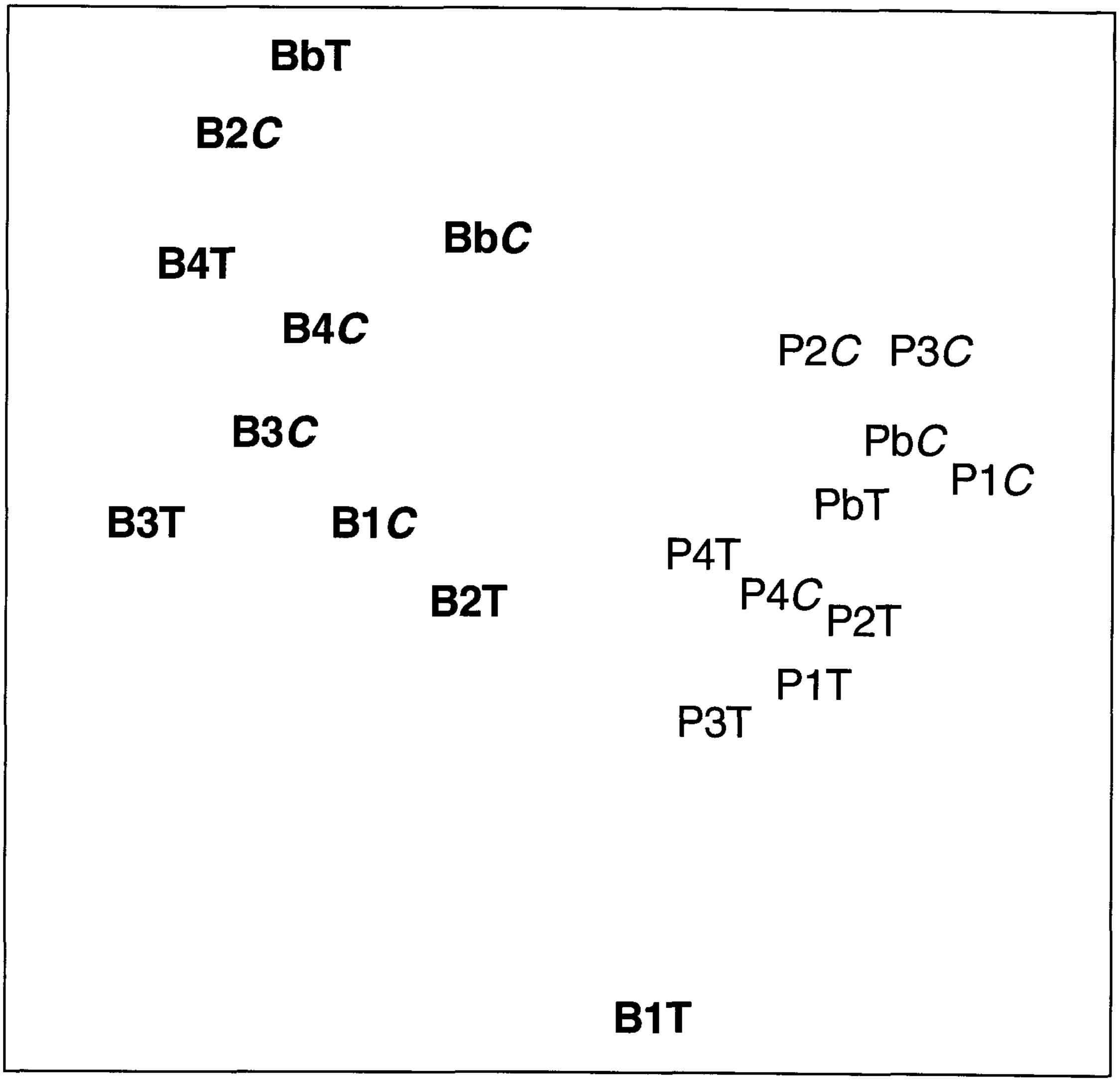


Fig. 3.6.14. MDS plot showing groupings based on stomach contents (stress value=0.14). Nomenclature as follows: XyZ - X = species (**B** *P. bernhardus*, P *P. prideaux*), y = days after fishing (b= before, 1= 1 day after etc.) , Z = line (C control, T treatment).
The distance between each point on the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

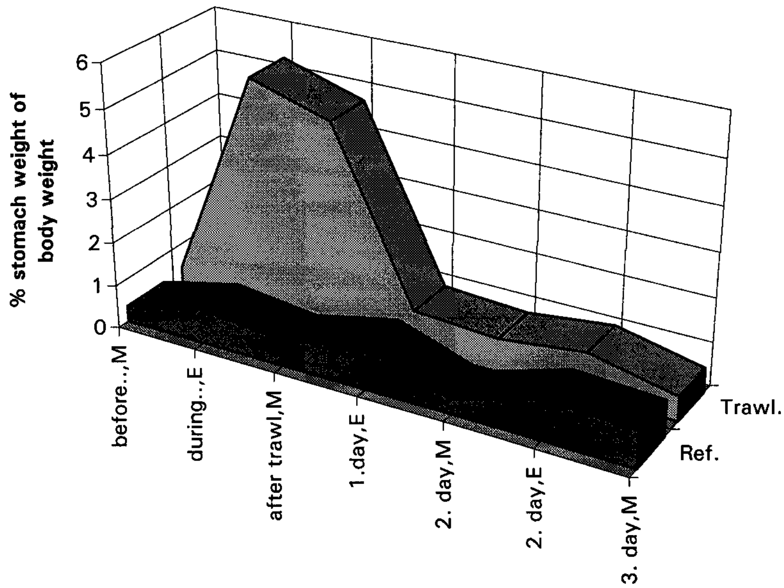


Fig. 3.6.15. The change of median stomach fullness of dab collected at 12 h intervals on a trawled area in comparison with an untrawled reference area. E = evening, M = morning.

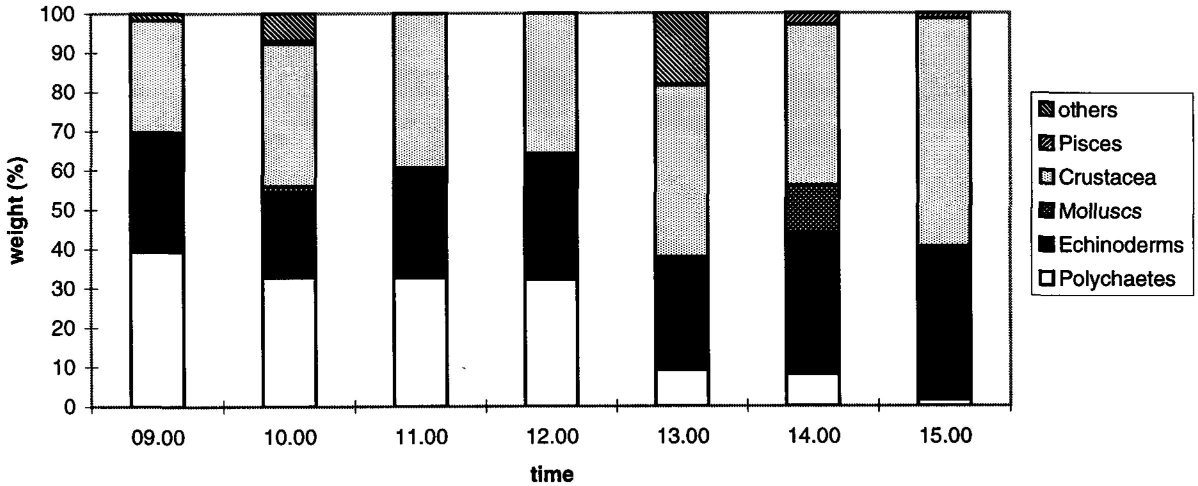


Fig. 3.6.16. The change in composition of stomach contents of dab during repeated trawling.

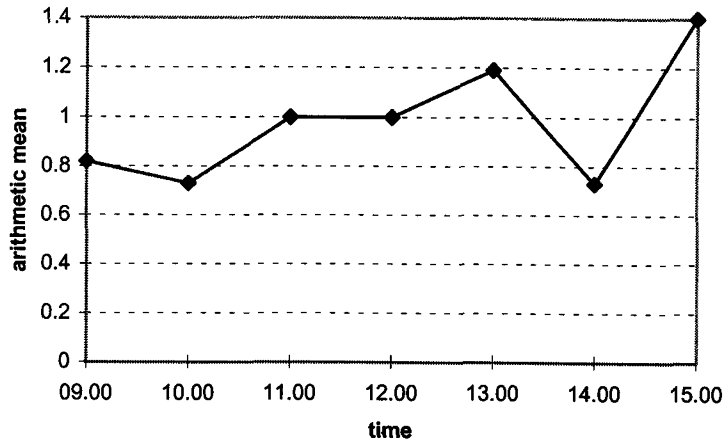


Fig. 3.6.17. The change in stomach fullness of dab during repeated trawling.

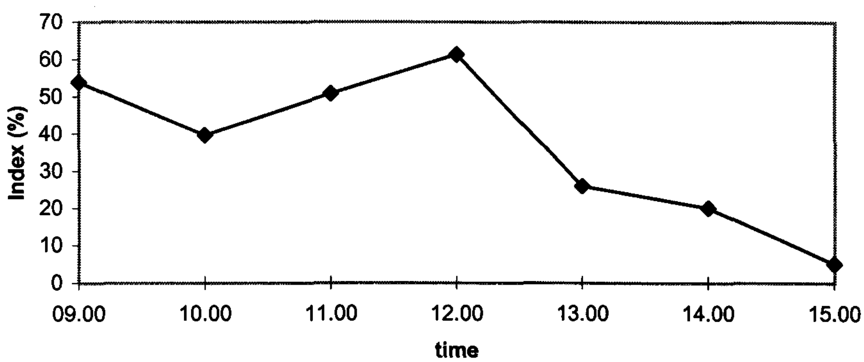


Fig. 3.6.18. The changing similarity index (%) of food composition in stomachs of dab and plaice during repeated trawling.

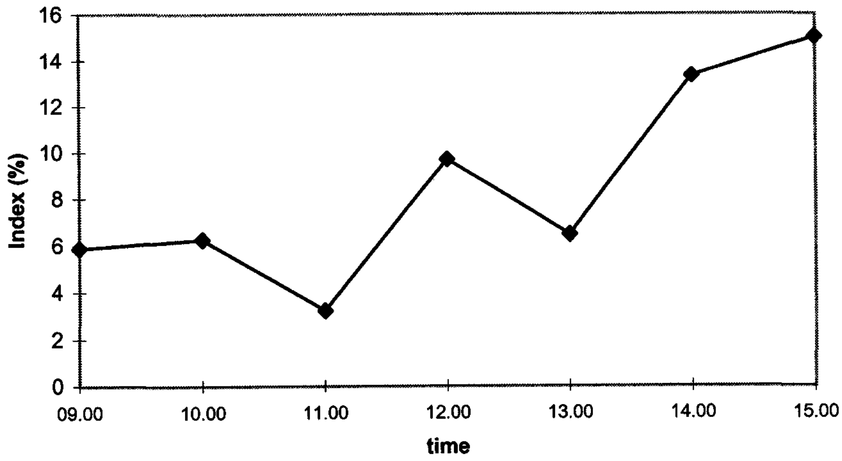
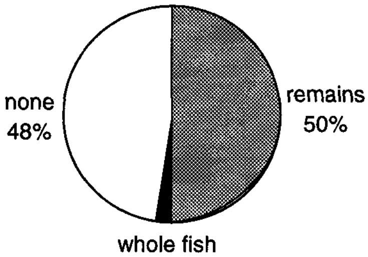
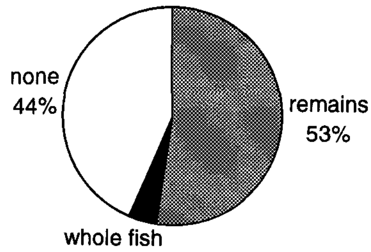


Fig. 3.6.19. The changing similarity index (%) for decapods in the stomachs of dab and plaice during repeated trawling.

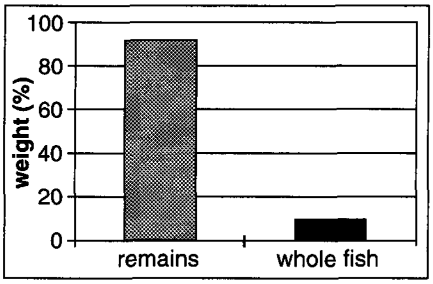
L. limanda **- untrawled reference area.**
Presence (%) of whole fish and fish remains.



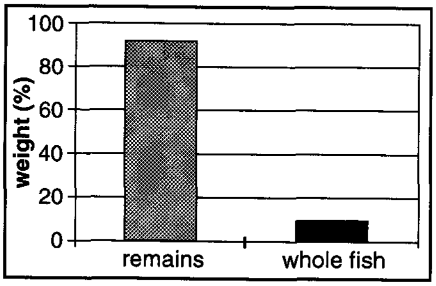
L. limanda **- trawled area.**
Presence (%) of whole fish and fish remains.



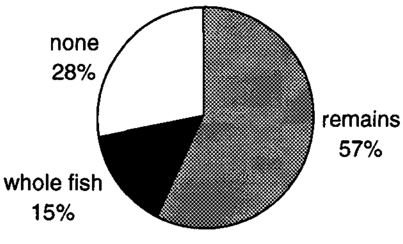
Limanda, untrawled : weight of fish and fish remains.



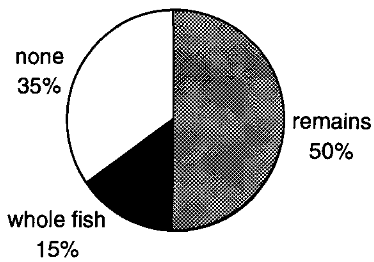
Limanda, trawled : weight of fish and fish remains.



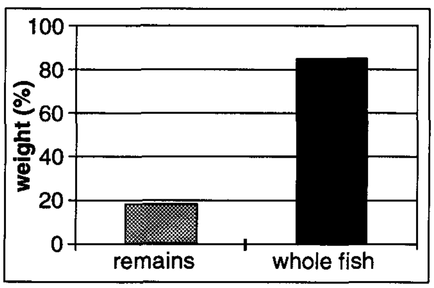
E. gurnardus **from untrawled reference**
Presence (%) of whole fish and fish remains.



E. gurnardus **from trawled area**
Presence (%) of whole fish and fish remains.



Eutrigia, untrawled : weight of fish and fish remains.



Eutrigia, trawled : weight of fish and fish remains.

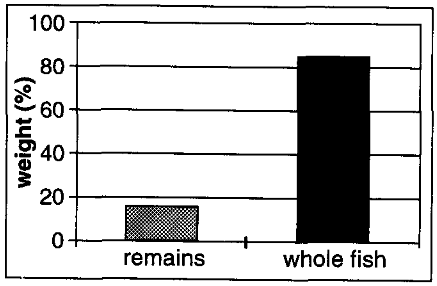
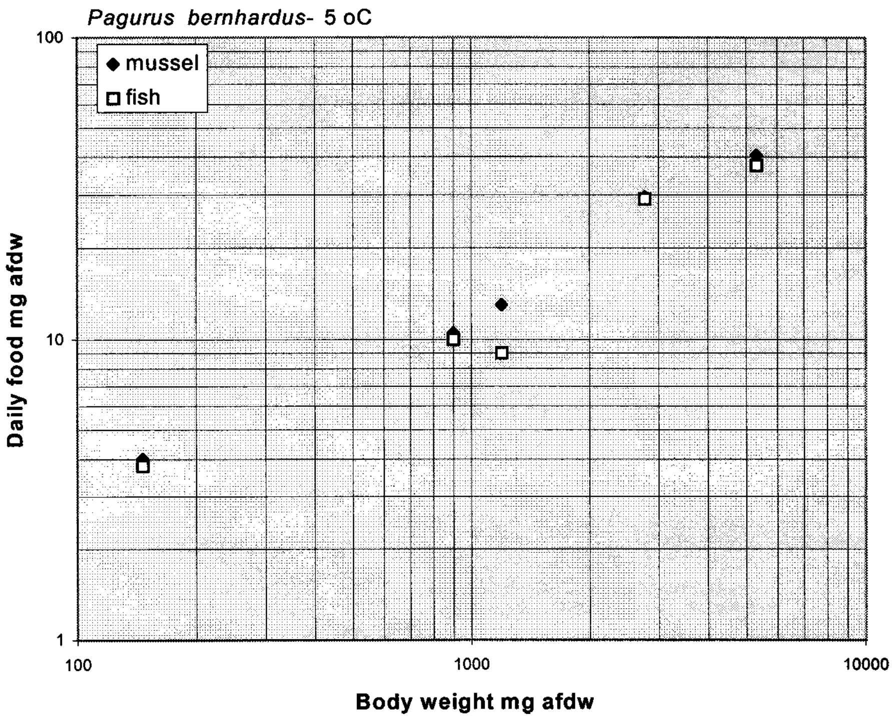


Fig. 3.6.20. The presence of fish in stomachs of dab (top) and grey gurnard (below) in an area trawled with otter trawl (right) as compared with an untrawled reference area (left).



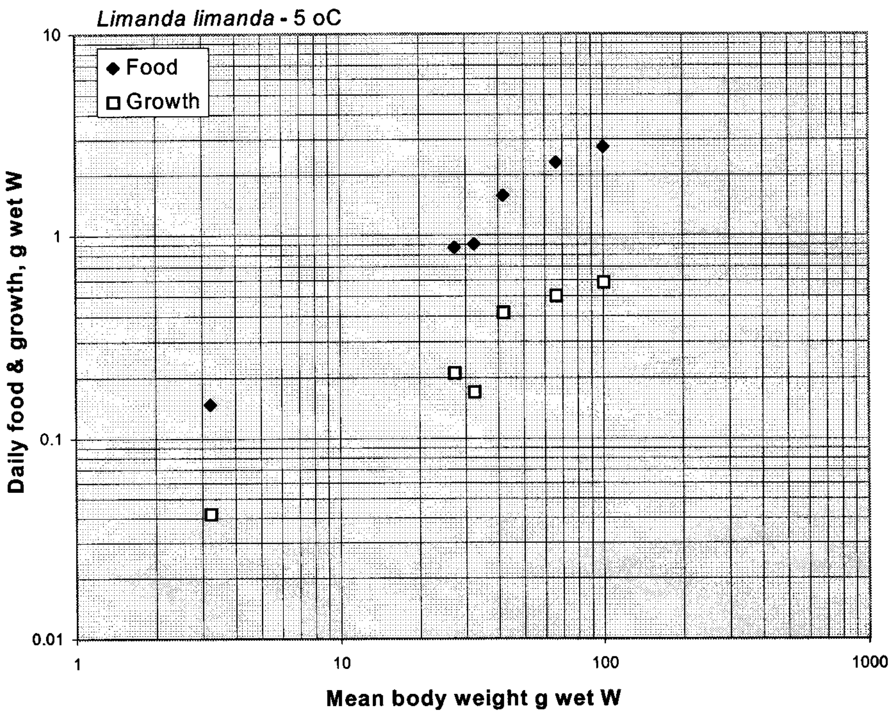


Fig. 3.6.21. A plot of daily food consumption against body weight for hermit crab (top: fed with mussel or fish at 5° C) and dab fed with mussel at 5° C).

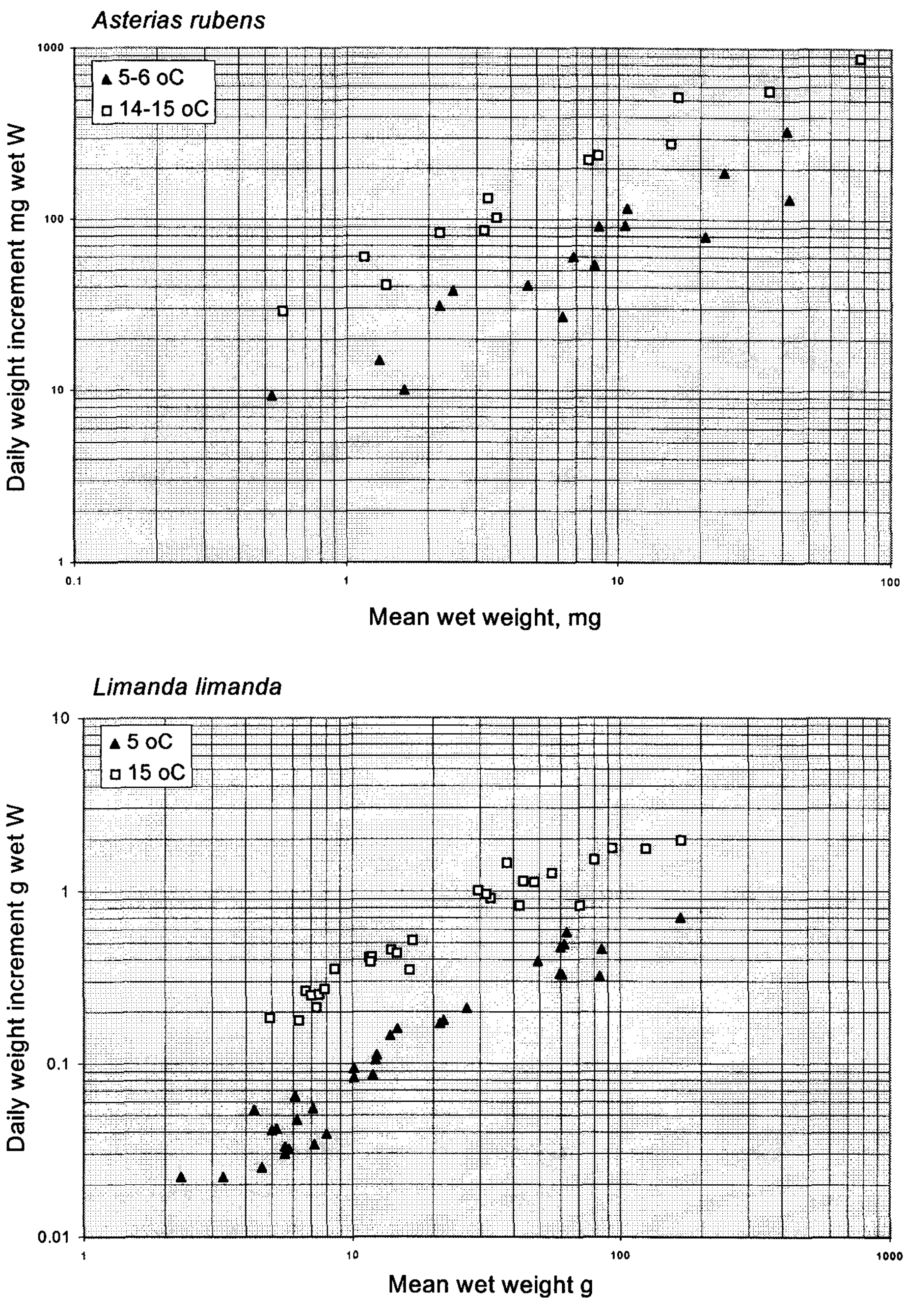
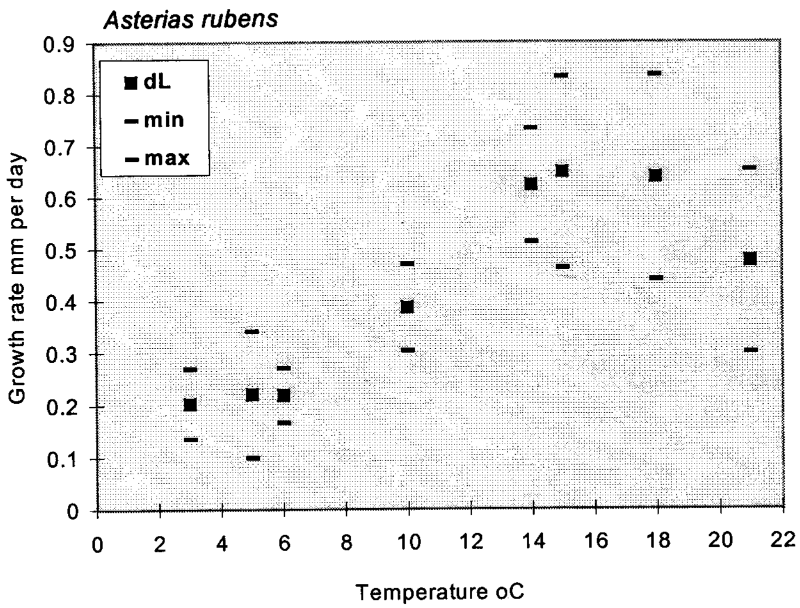


Fig. 3.6.22. A plot of daily growth in wet weight against mean weight of starfish (top) and dab (below), fed with unlimited rations at 5-6 and 14-15° C).



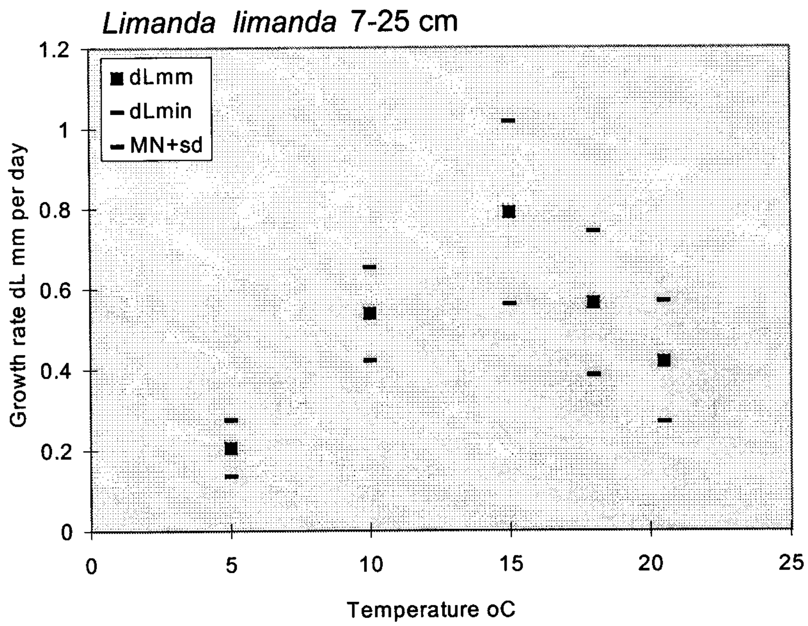
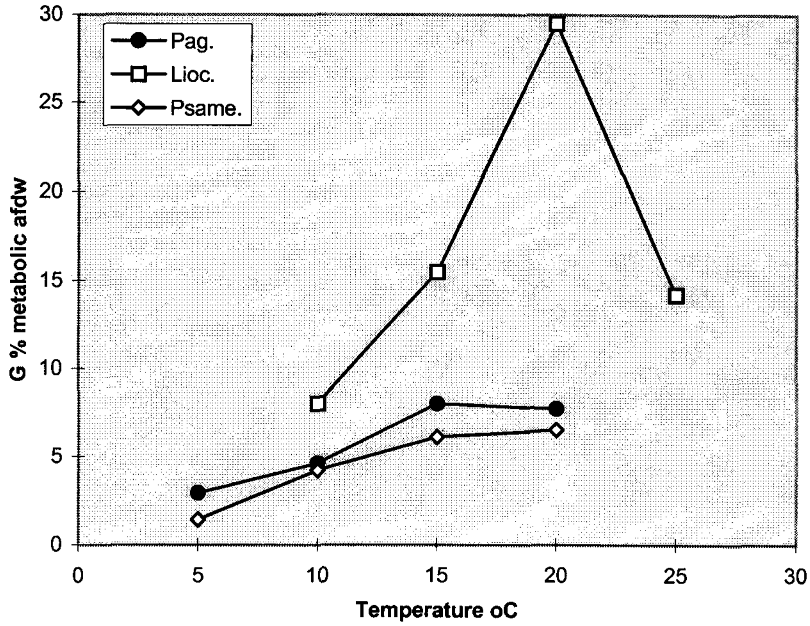


Fig. 3.6.23. The growth rate in length (dL, mm per day) of starfish (top) and dab (below) in the laboratory at constant temperatures. Mean values and the upper and lower limits of standard deviation.



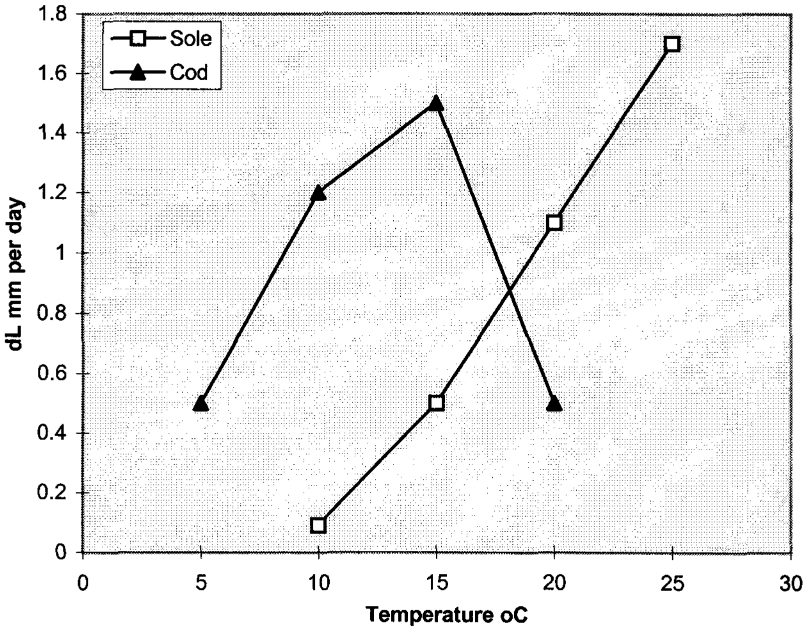
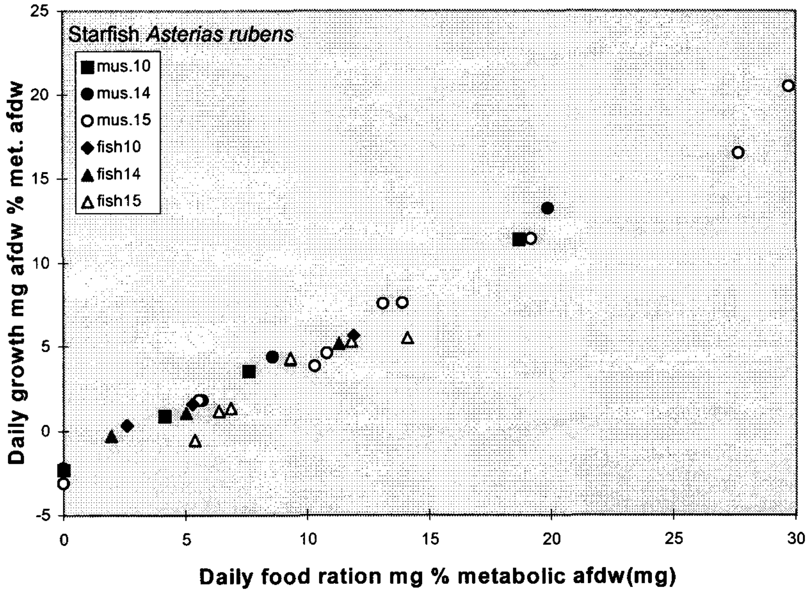


Fig. 3.6.24. The effect of temperature on daily weight increment as % of metabolic ash (top: hermit crab, swimming crab and sea urchin) and on growth rate in length (below: 0-group sole and cod).



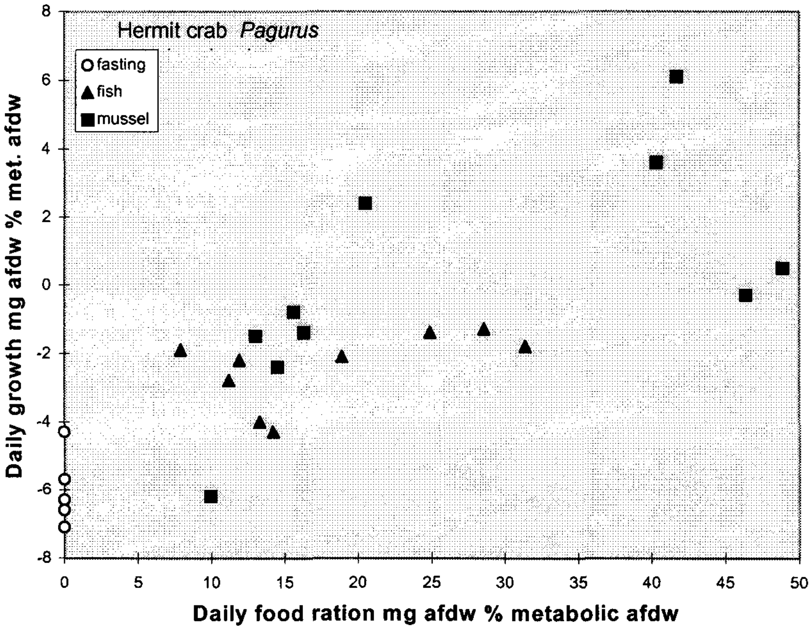


Fig. 3.6.25. The relationship between daily ration and growth, both in mg afdw as % metabolic afdw, of starfish (top: *Asterias rubens* 10-15° C) and hermit crab (below: *Pagurus bernhardus*, 15° C).

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 :	**Fish**	**Mollusc**	**Crustac.**	**No bait**	Sum	**Fish**	**Mollusc**	**Crustac.**	**Echinod.**	**No bait**	Sum
n traps	5	5	6	4	%	15	15	15	15	15	%
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 Mean	Length, cm S.D.	Weight, g Mean	Weight, g S.D.	Stomach Filling Index Mean	Stomach Filling Index S.D.	Stomach fullness Mean	Stomach fullness S.D.	Gut content state Mean	Gut content state 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. oC	Daily growth Diam. or L mm/day	wet weight % met.W,g	n	Size range D or L cm	wet W g	Days	Period
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	**L, cm**	**Afdw, mg**	**L, mm**	Correl.		Size	Period	Source
	W = a * L ^ b		**W = a * L ^ b**		coeff.	(*)	L or D		
	a	**b**	**a**	**b**	r2	n			
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 coherrent 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.

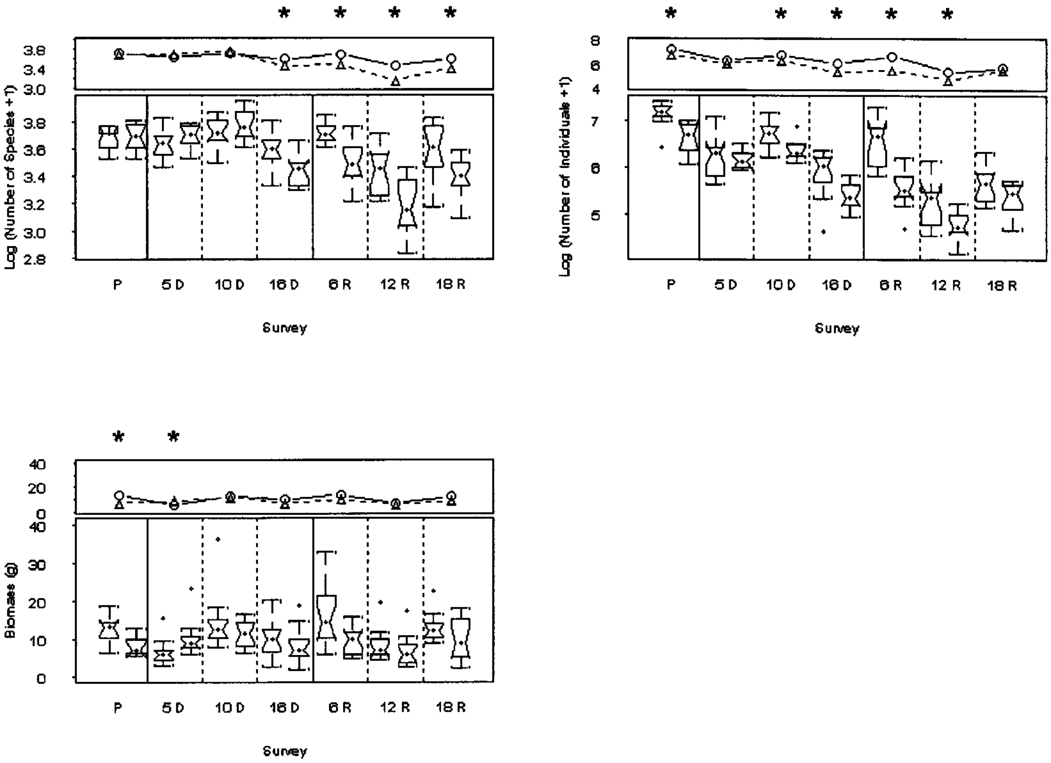


Fig. 3.7.1a. Box plots of number of species, individuals and biomass (.1 m^{-2}) (lower panels), along with the time-series for the median values for each survey (upper panels). Box-plots are arranged in pairs in time (survey) order, with the reference plot on the right for each pair. Surveys in which 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.

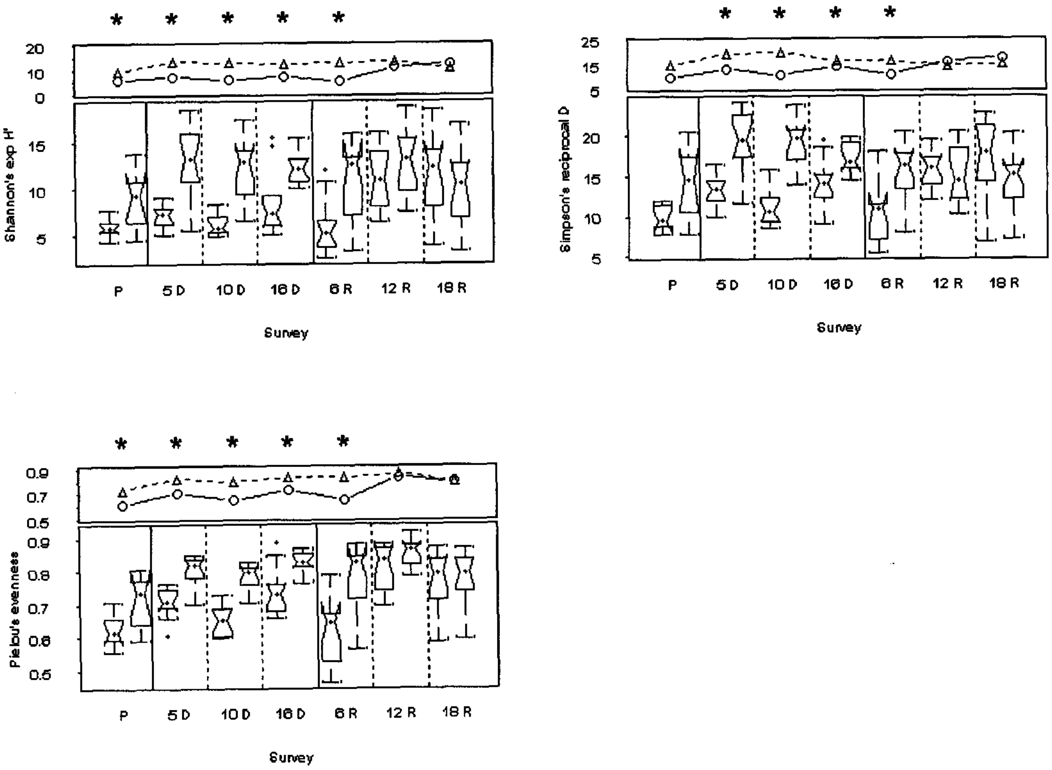


Fig. 3.7.1b. Box plots and time series for median values of Shannon's exponential *H'*, Simpson's reciprocal *D* and Pielou's evenness. Further details as for Fig. 3.7.1a.

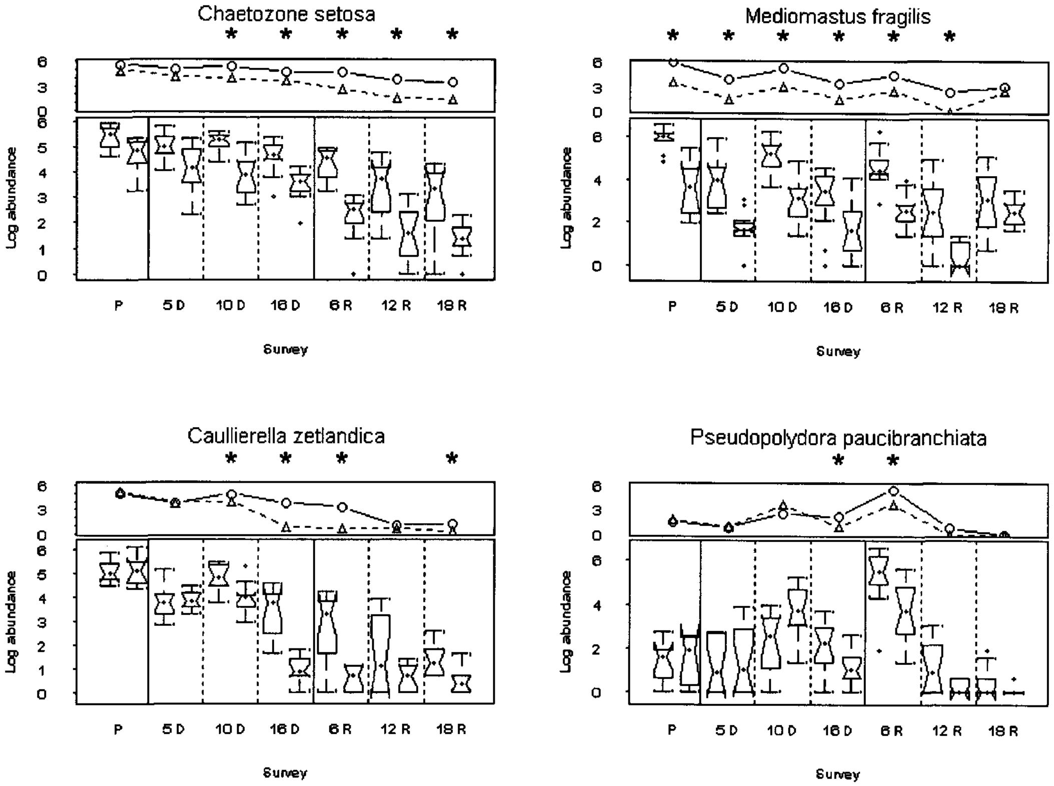


Fig. 3.7.2a. Box plots and time series for median values of abundance of four species showing an increase in abundance in responce to physical disturbance. Further details as for Fig. 3.7.1a.

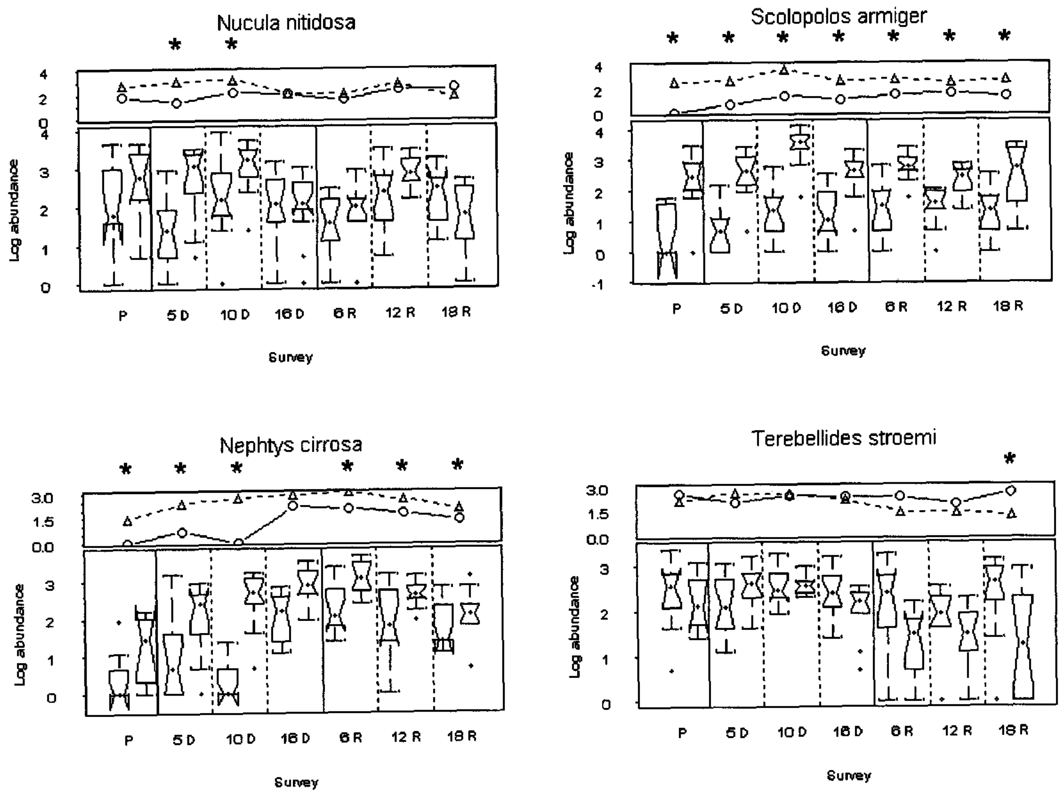


Fig. 3.7.2b. Box plots and time series for median values of abundance of four species showing a decrease in abundance in responce to physical disturbance. Further details as for Fig. 3.7.1a.

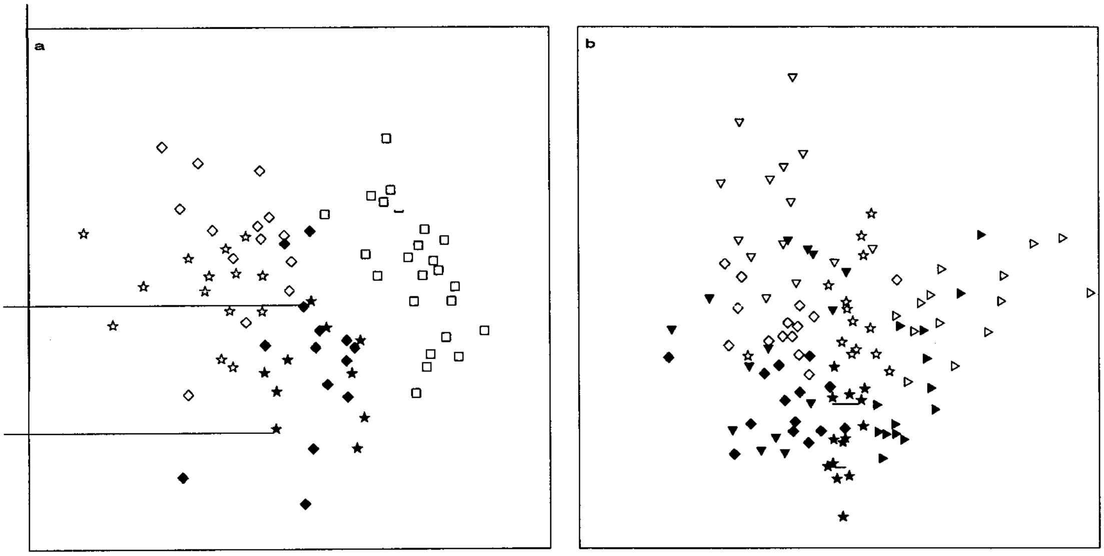


Fig. 3.7.3. MDS plots of infaunal data for reference and treatment areas from preliminary to 6 months recovery survey (a) and 16 months disturbance to 18 months recovery survey. Surveys depicted as follows; O - preliminary survey, Δ - 5 months disturbance, □ - 10 months disturbance, ◊ - 16 months disturbance, ★ - 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.

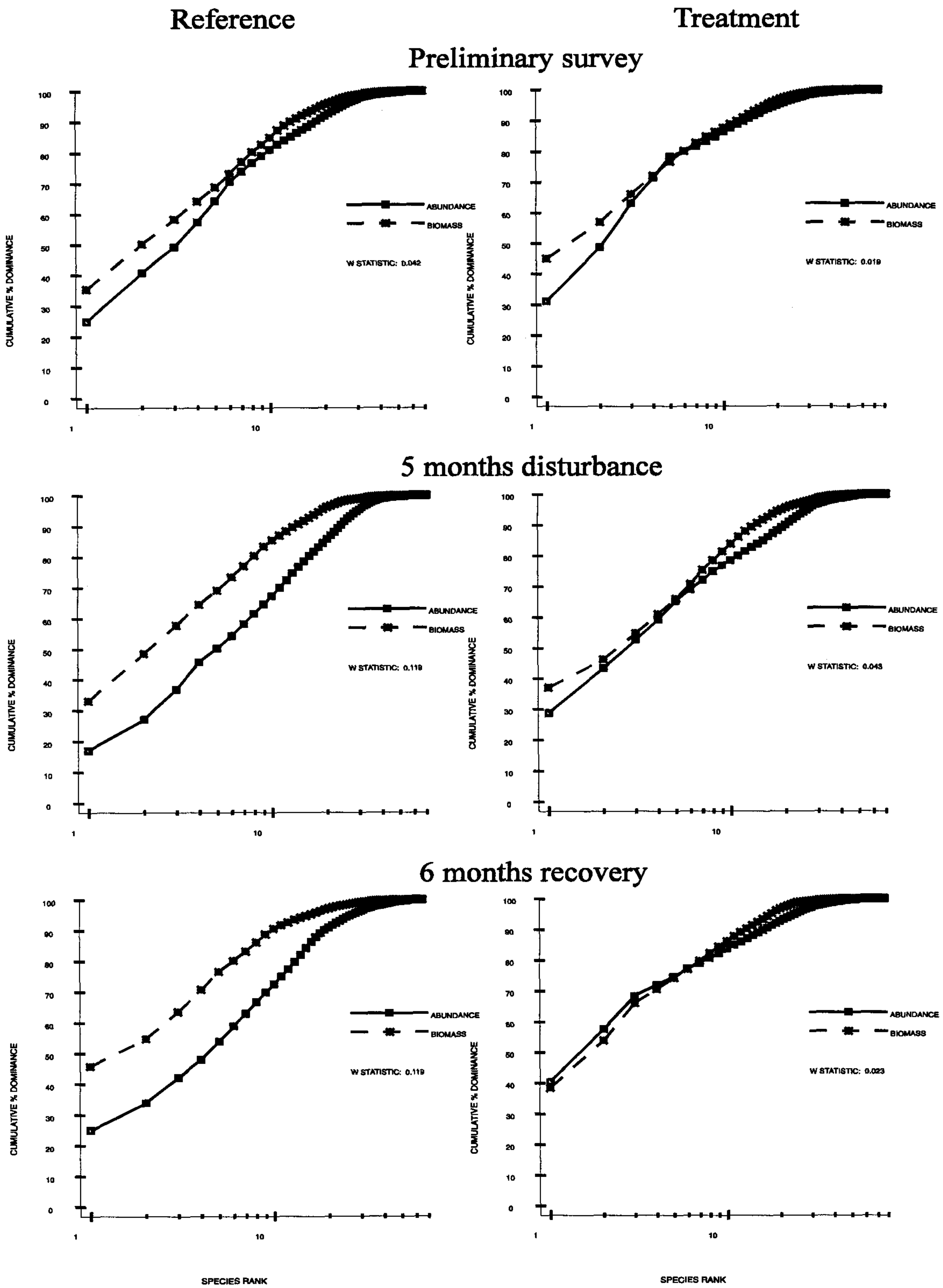


Fig. 3.7.4. ABC curves for selected surveys.

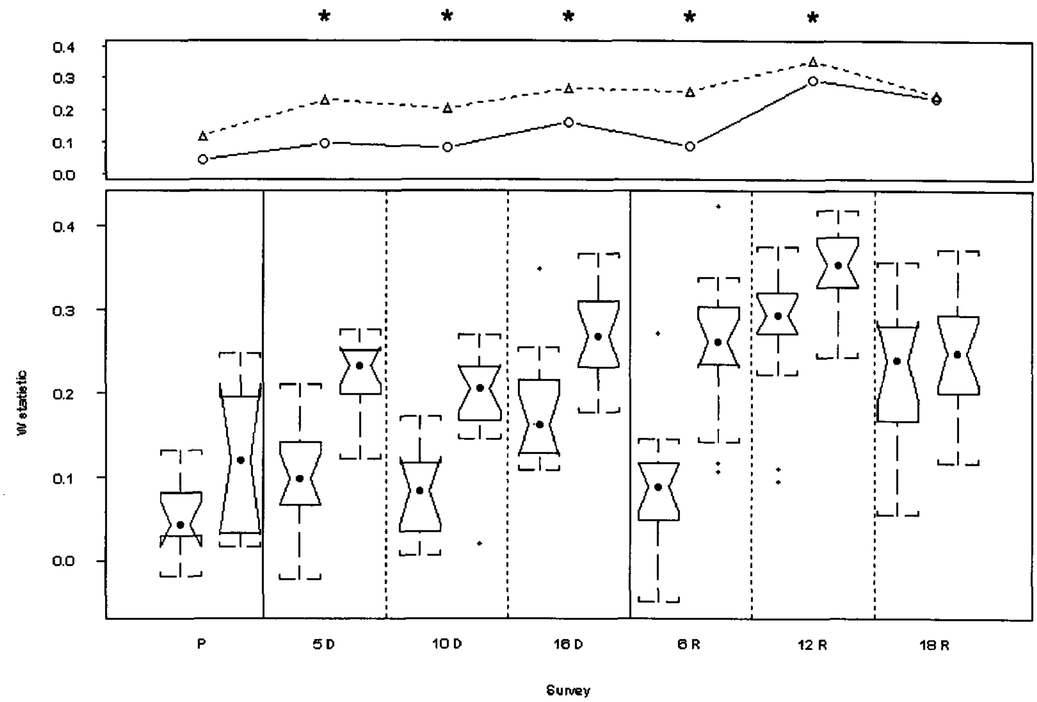


Fig. 3.7.5. Box plots and time series for median values of the W statistic for each site through the experiment. Further details as for Fig. 3.7.1a.

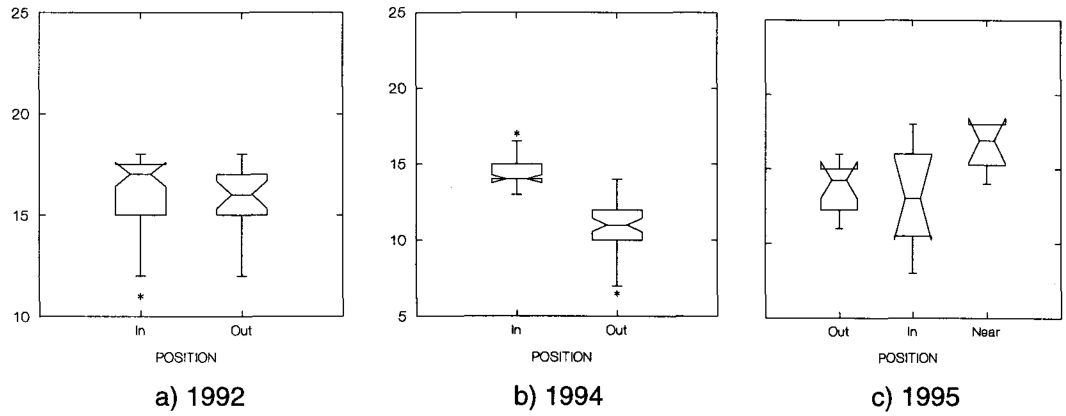


Fig. 3.7.6. Penetration of the Van Veen grab [cm] in the different sampling periods.

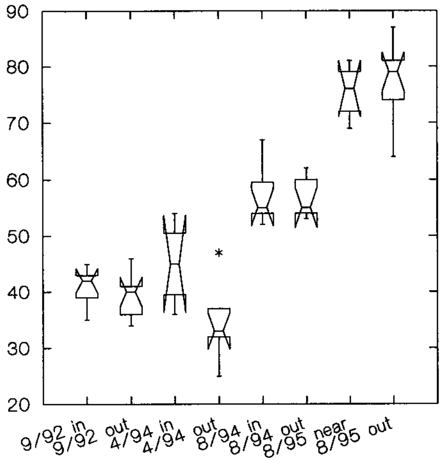


Fig. 3.7.7a. Number of species (.0.2 m⁻²)

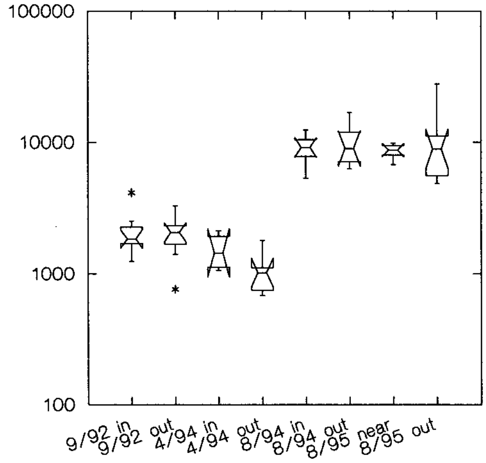


Fig. 3.7.7b. Number of individuals (.m⁻²)

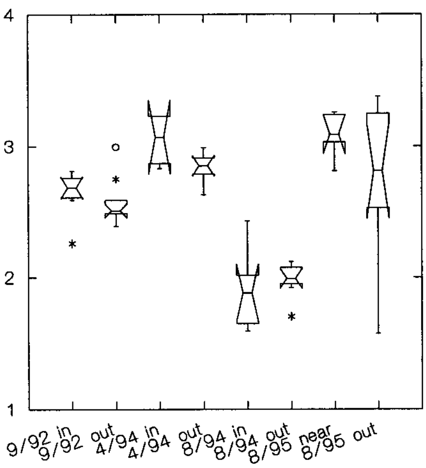


Fig. 3.7.7c. Diversity H' (Shannon-Wiener)

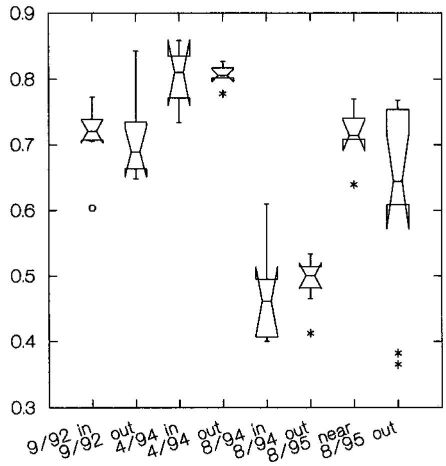


Fig. 3.7.7d. Evenness E (Pilou)

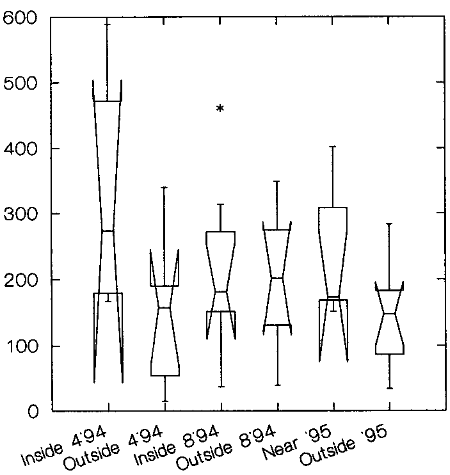


Fig. 3.7.7e. Biomass (wet weight g.m⁻²)

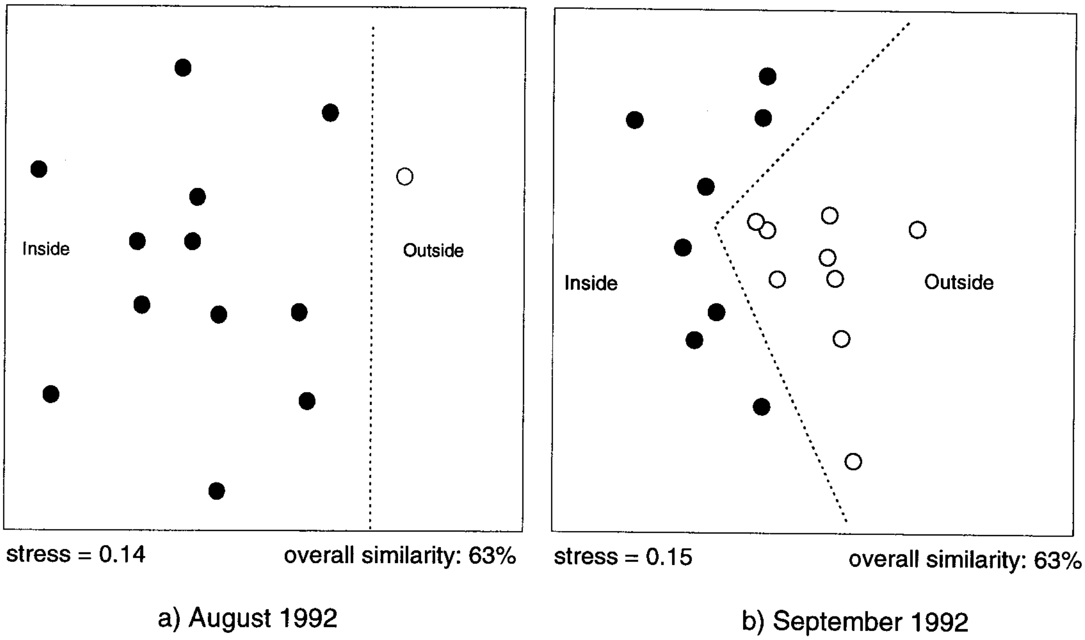


Fig. 3.7.8. MDS-plots of the August- (a) and September- (b) samples 1992. Overall similarity as minimal similarity between all pairs of samples. ● = samples from "inside"; ○ = samples from "outside"; The line separates stations from inside the buoys from those outside.

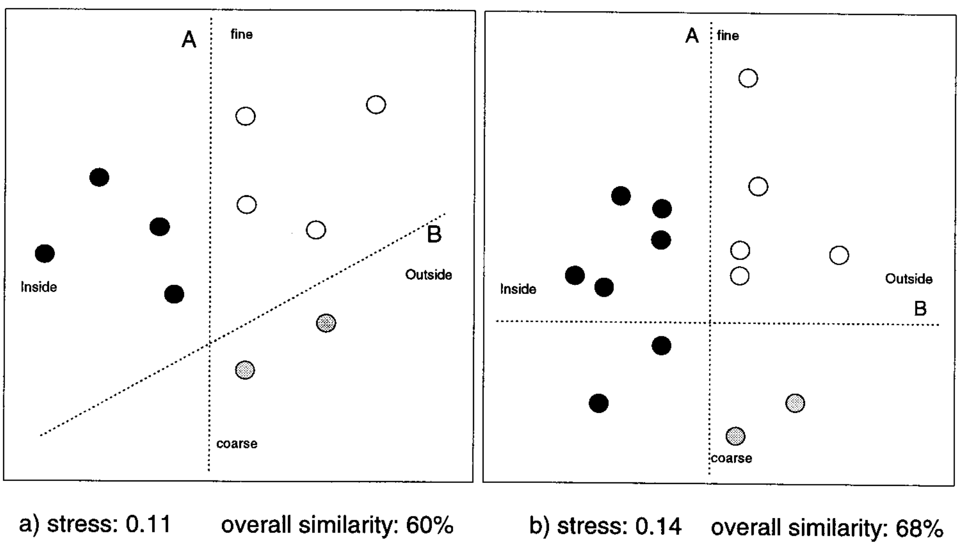
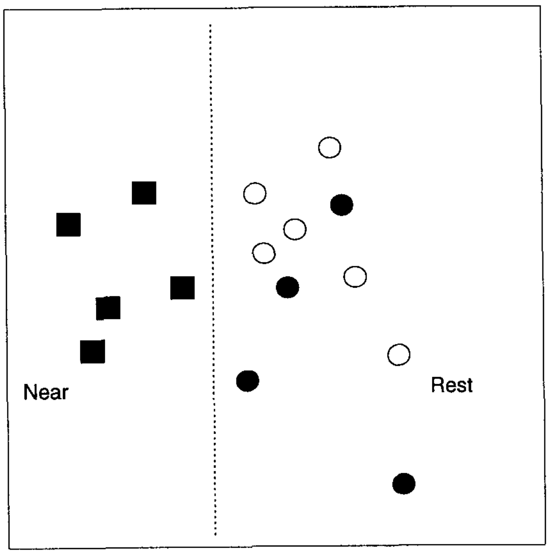


Fig. 3.7.9. MDS-plots of the April- (a) and August- (b) samples 1994. ● = samples from "inside"; ○ = samples from "outside"; Line A separates samples from inside the enclosed area from those taken outside; Line B separates samples with fine sediments from those with coarser sediments.



stress: 0.14 overall similarity: 70%

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.

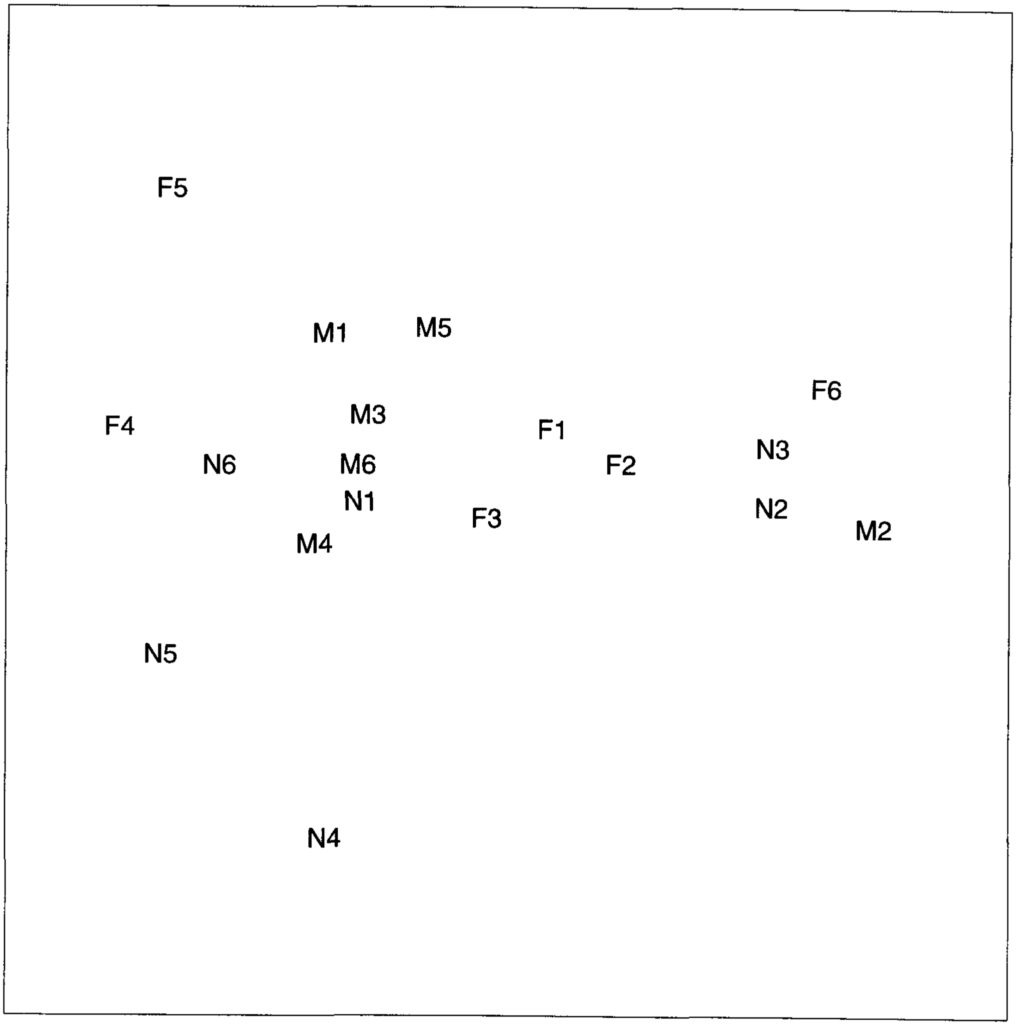


Fig. 3.7.11a. Shallow wreck site - MDS, Comparison of Iron Man wreck fauna (N=Near, M=Middle, F=Far) with near by fishing grounds: a. along the wreck transect.

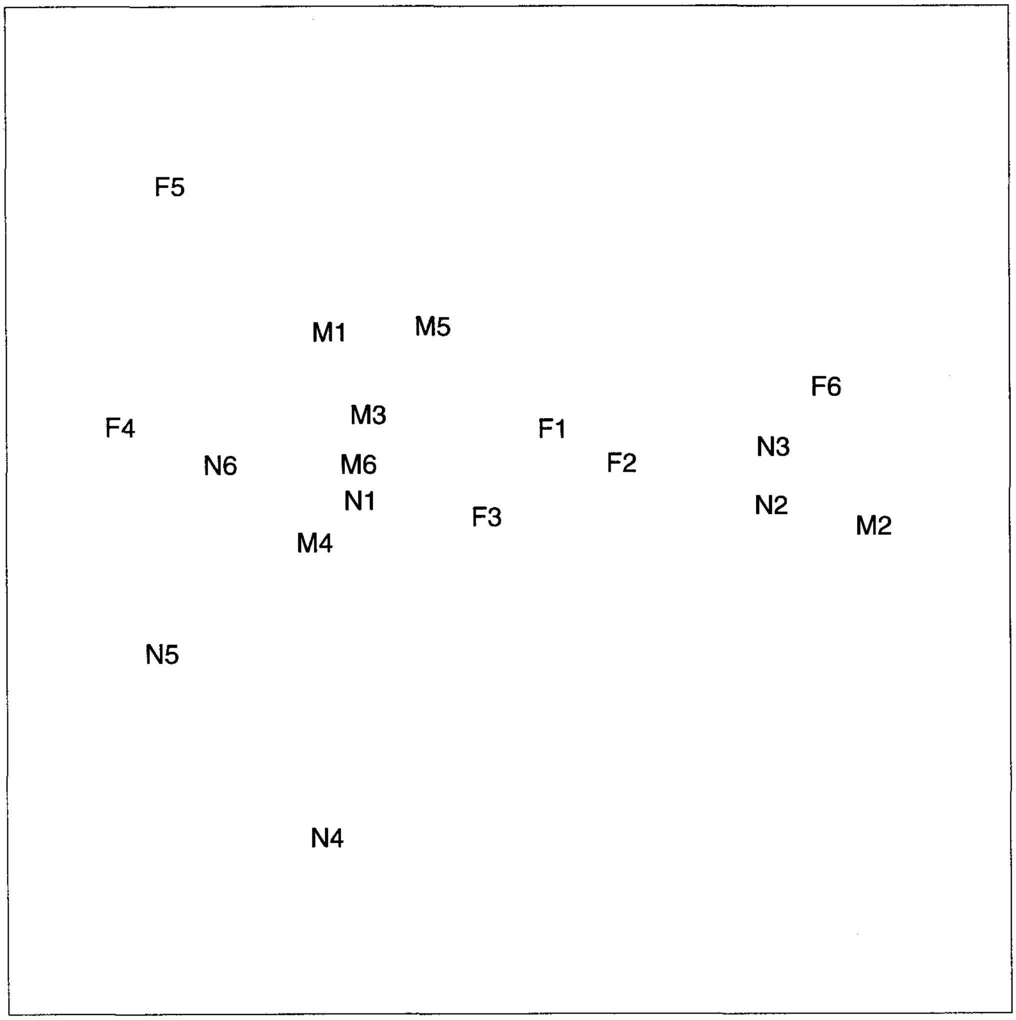


Fig. 3.7.11b. *Shallow wreck site* - MDS, Comparison of Iron Man wreck fauna (N=Near, M=Middle, F=Far) with near by fishing grounds: b. before experimental fishing (C=fishing ground).

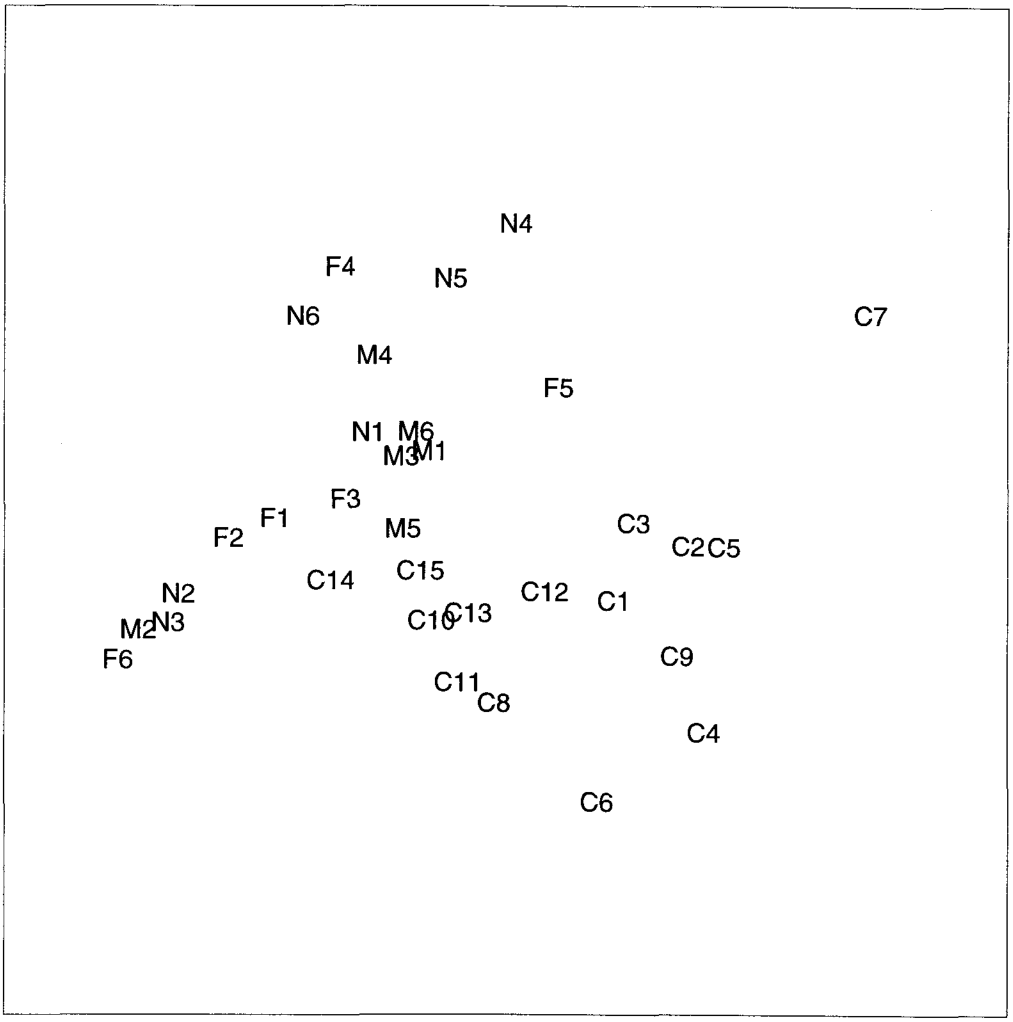


Fig. 3.7.11c. Shallow wreck site - MDS, Comparison of Iron Man wreck fauna (N=Near, M=Middle, F=Far) with near by fishing grounds: c. 24 hours after experimental fishing (I=fishing ground).

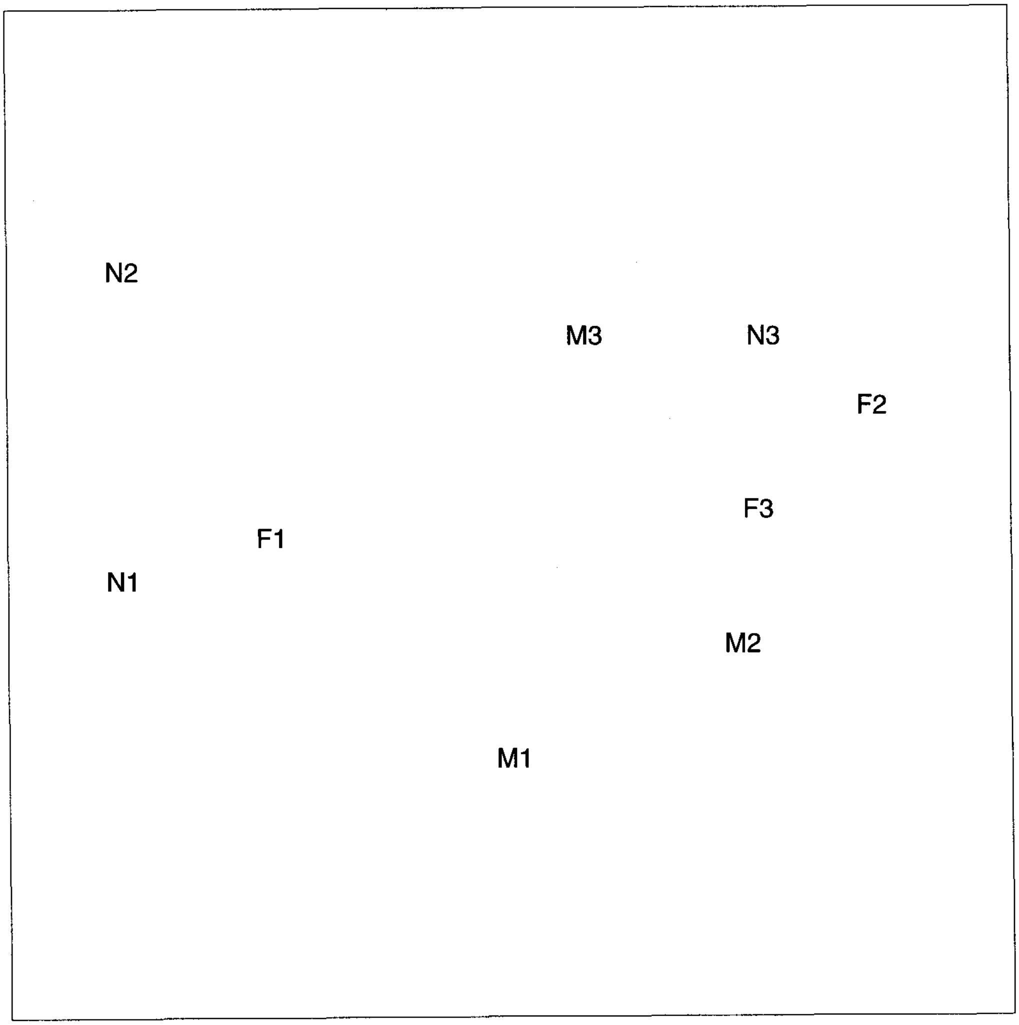


Figure 3.7.12a. Deep wreck site - MDS, Comparison of 41 Fathom Fast wreck fauna (N=Near, M=Middle, F=Far) with near by fishing grounds. a. along the wreck transect.

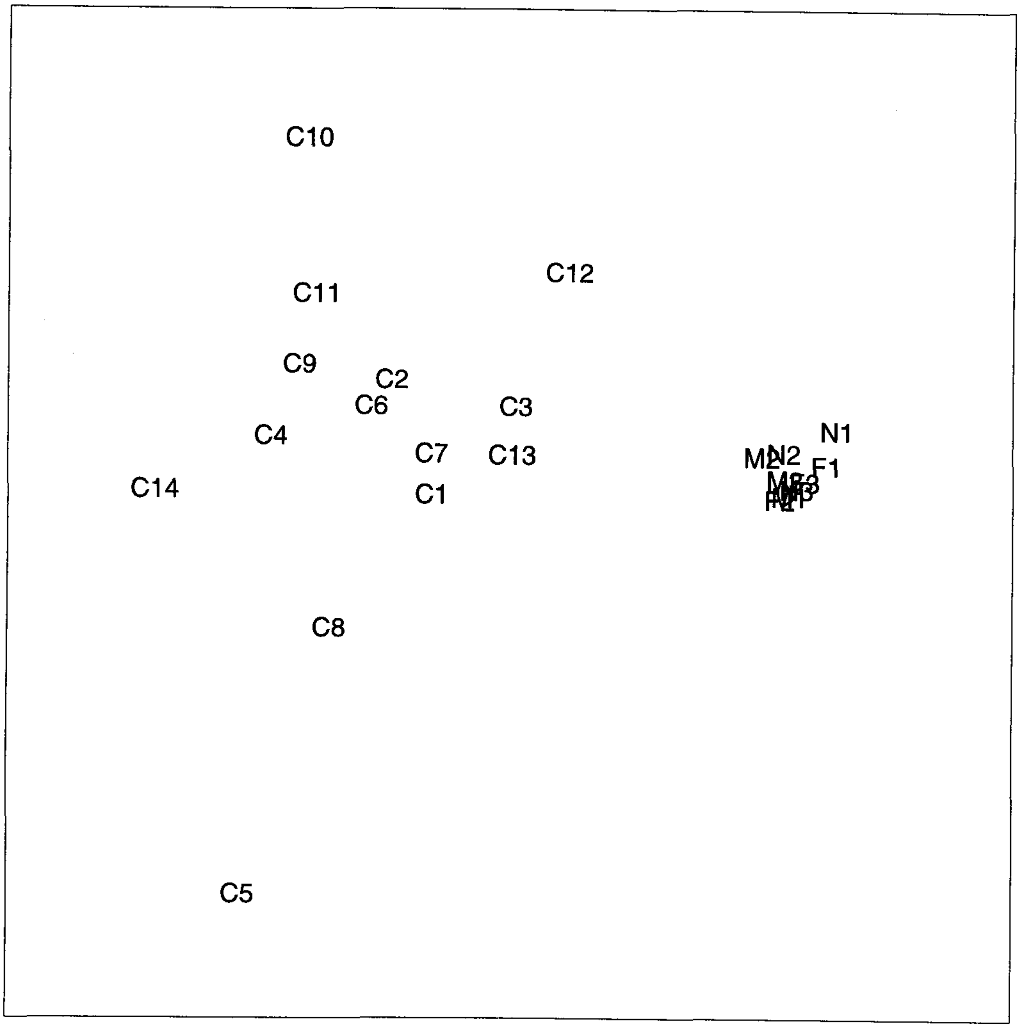


Figure 3.7.12b. Deep wreck site - MDS, Comparison of 41 Fathom Fast wreck fauna (N=Near, M=Middle, F=Far) with near by fishing grounds. b. before experimental fishing (C=fishing ground).

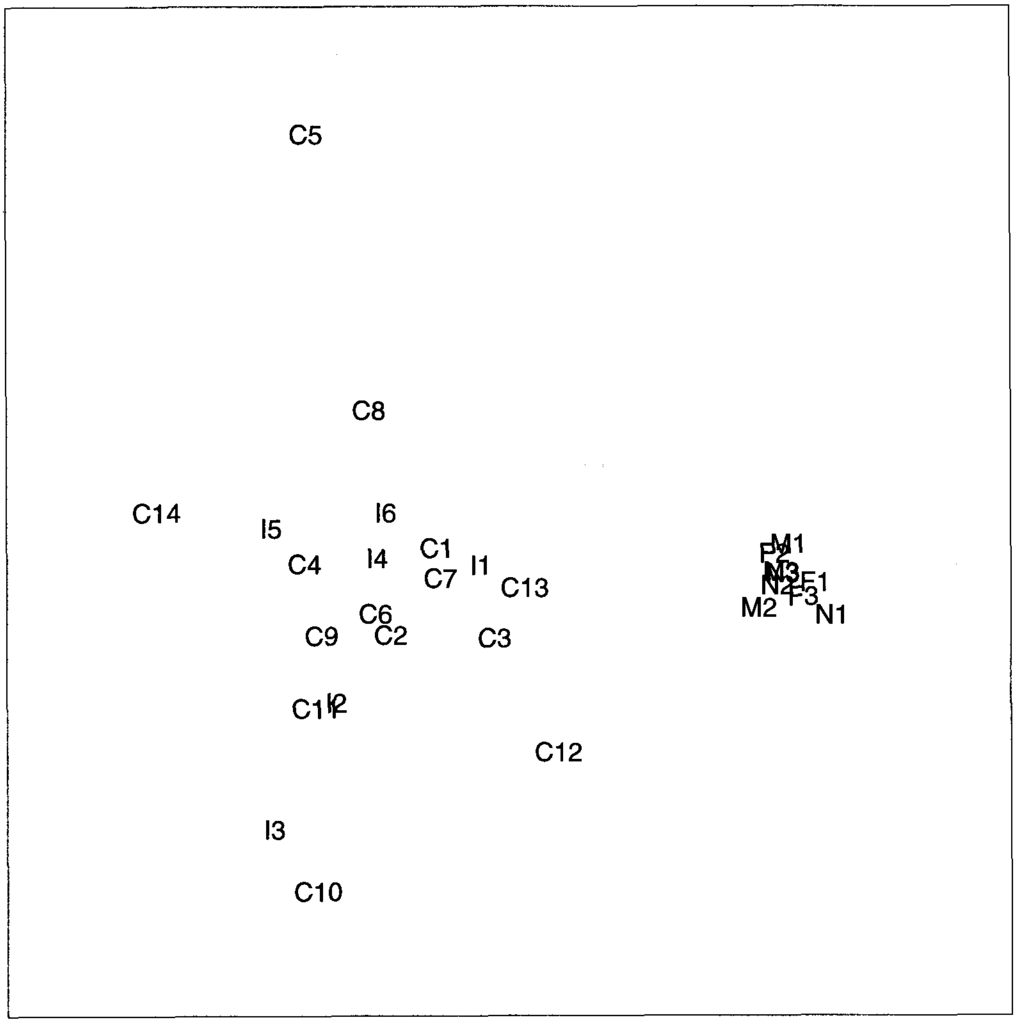


Figure 3.7.12c. Deep wreck site - MDS, Comparison of 41 Fathom Fast wreck fauna (N=Near, M=Middle, F=Far) with near by fishing grounds. c. 24 hours after experimental fishing (I=fishing ground).

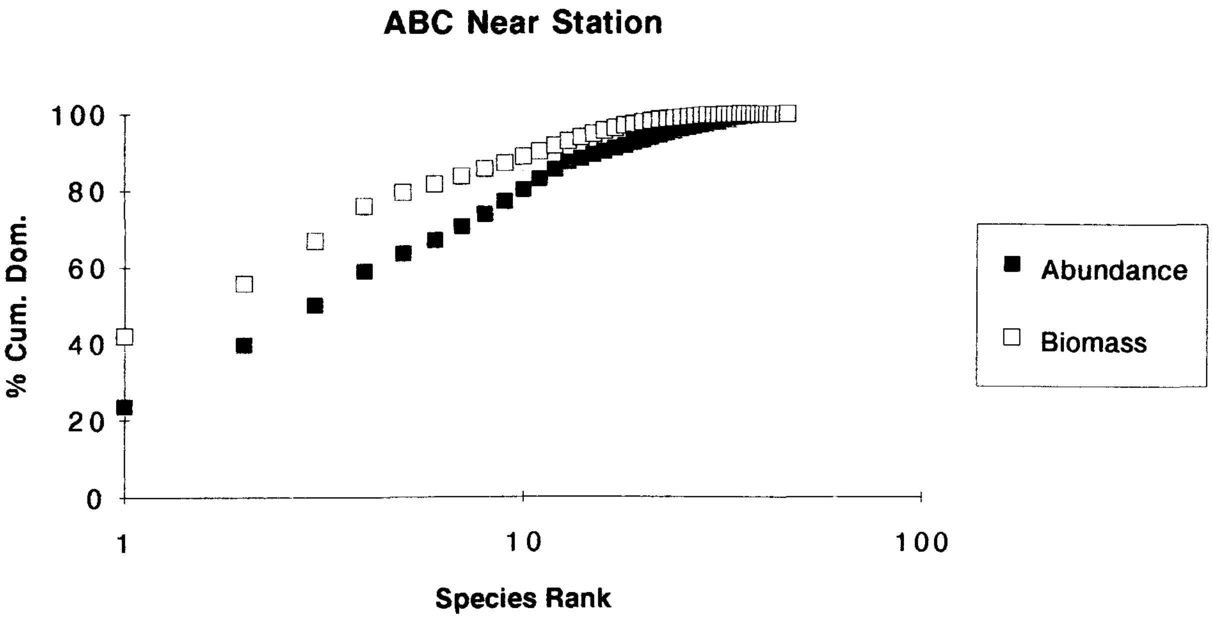


Fig. 3.7.13a. ABC curves from the 41 Fathom Fast wreck site: Near - 50 m from wreck.

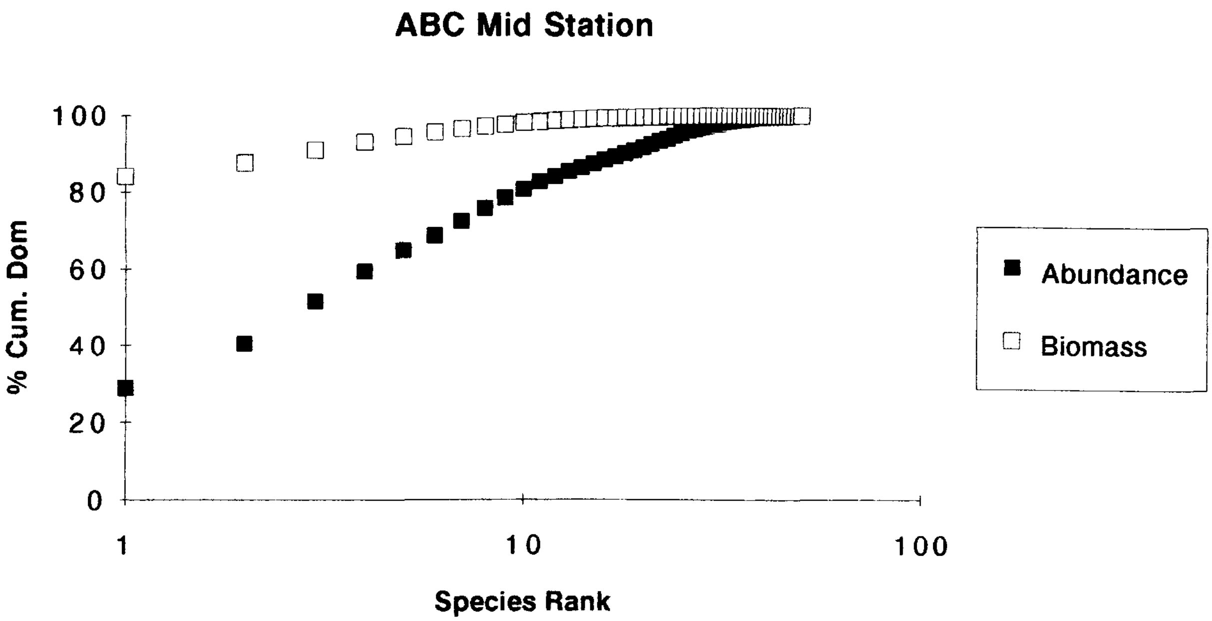


Fig. 3.7.13b. ABC curves from the 41 Fathom Fast wreck site: Middle - 250 m from wreck.

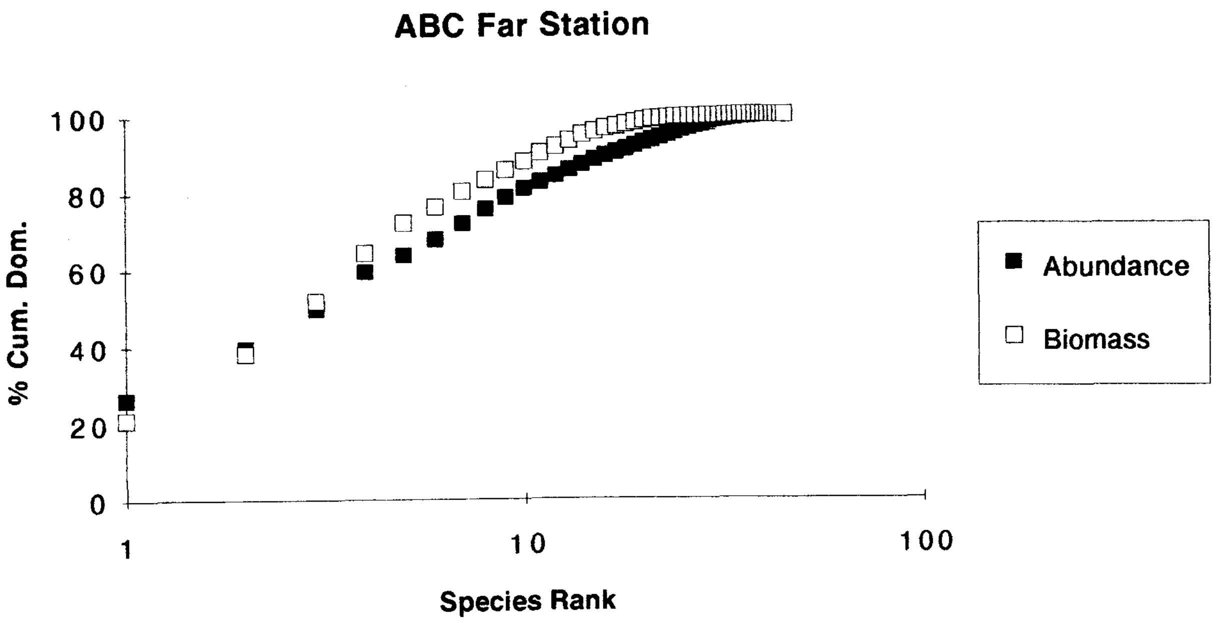


Fig. 3.7.13c. ABC curves from the 41 Fathom Fast wreck site: Far - 500 m from wreck.

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.

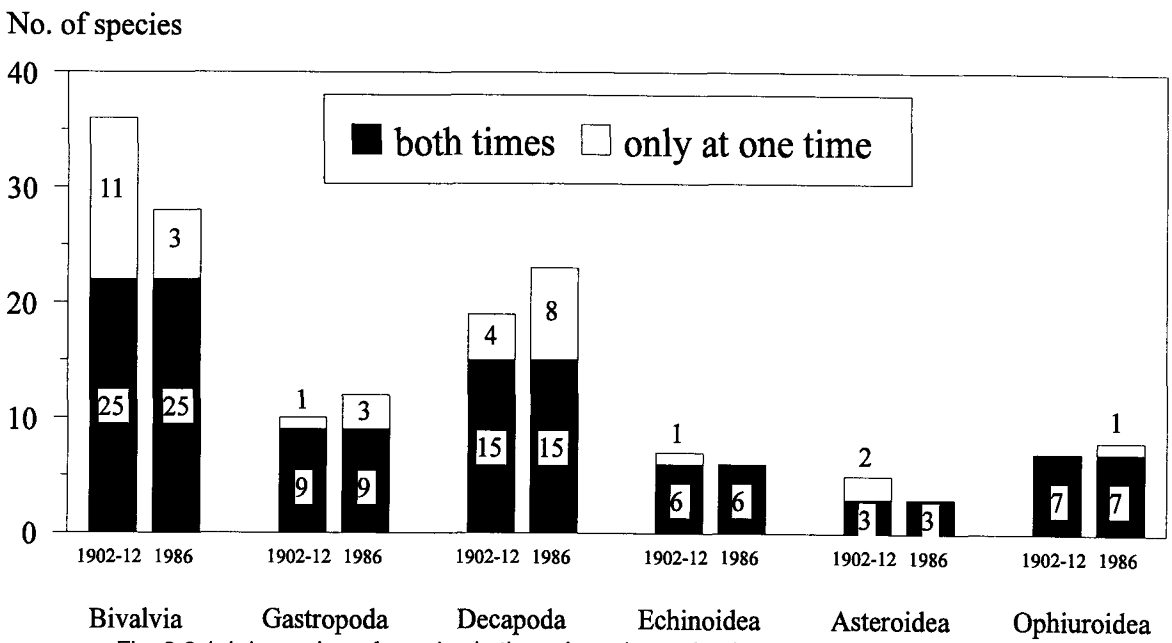


Fig. 3.8.1.1.1. number of species in the selected area for the six chosen taxonomic level.

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%).

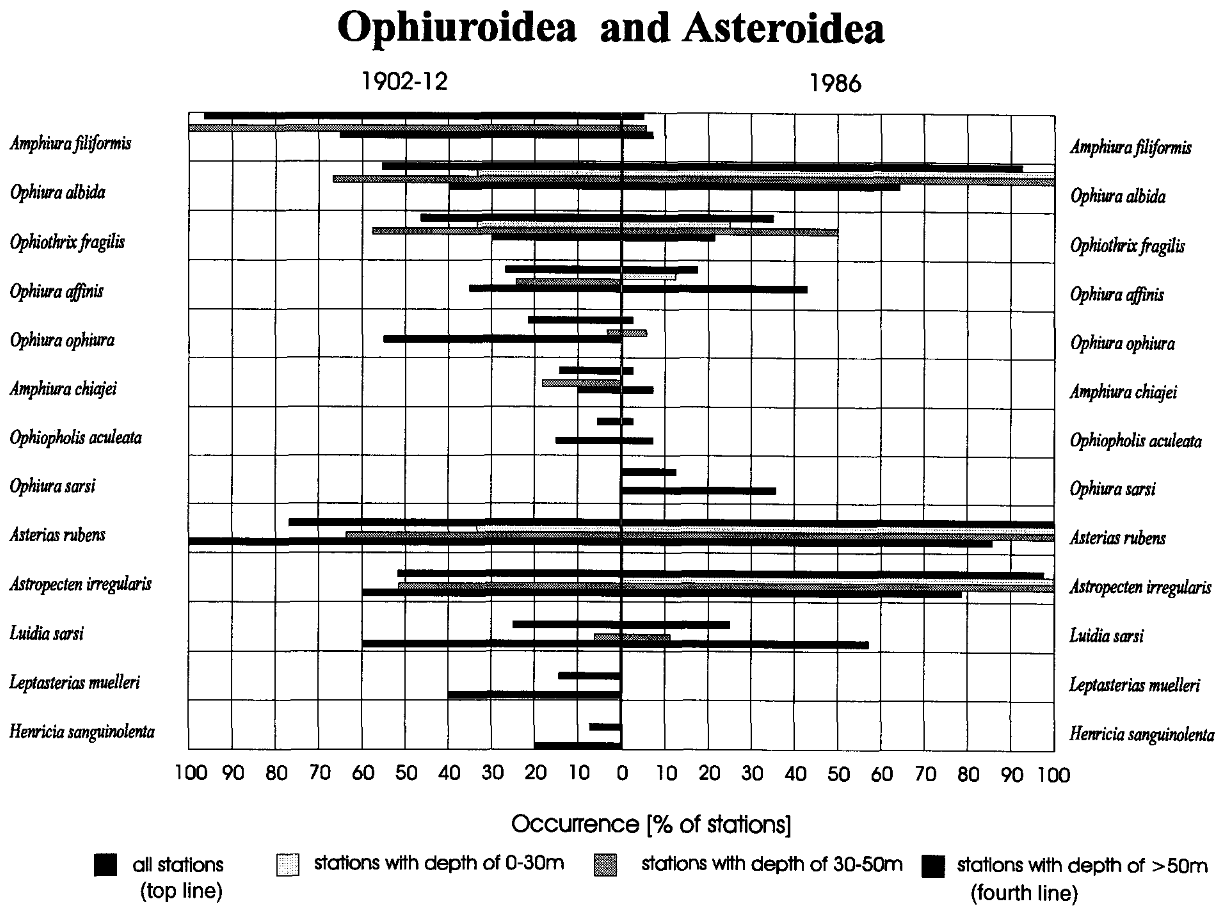


Fig 3.8.1.2.1. Occurrence [% of stations] of Asteroidea and Ophiuroidea.

Echinoidea

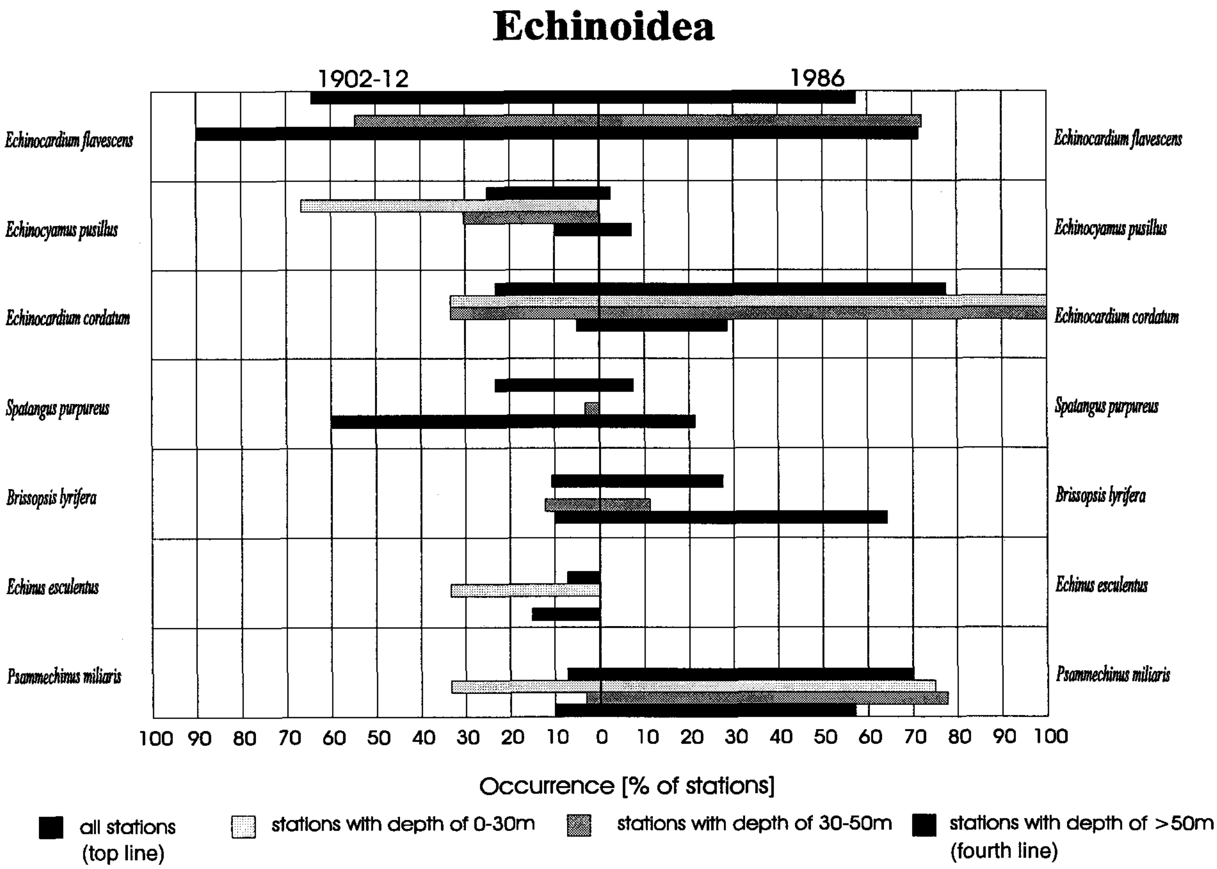


Fig 3.8.1.2.2. Occurrence [% of stations] of Echinoidea.

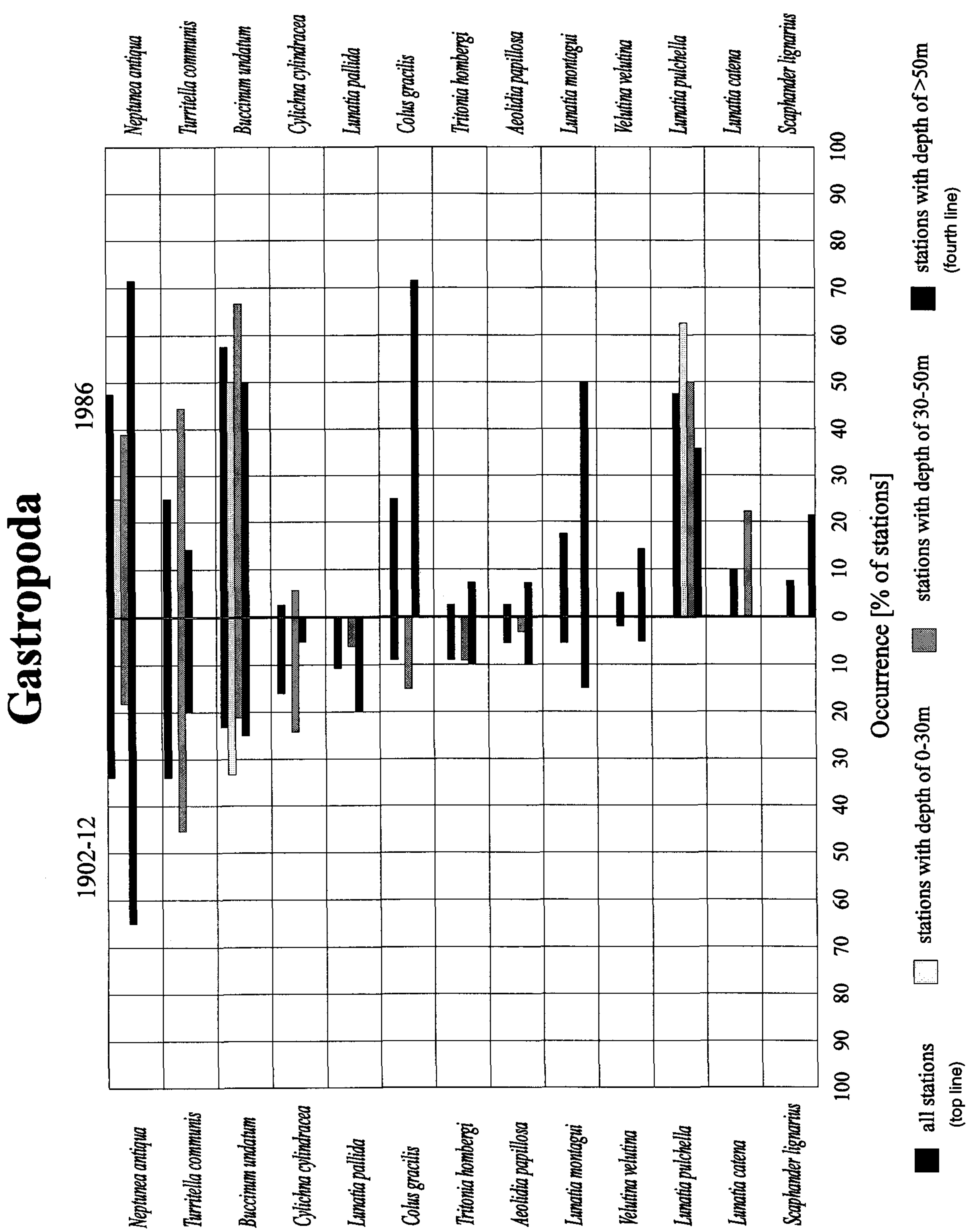


Fig. 3.8.1.2.3. Occurrence [% of stations] of Gastropoda.

Bivalvia

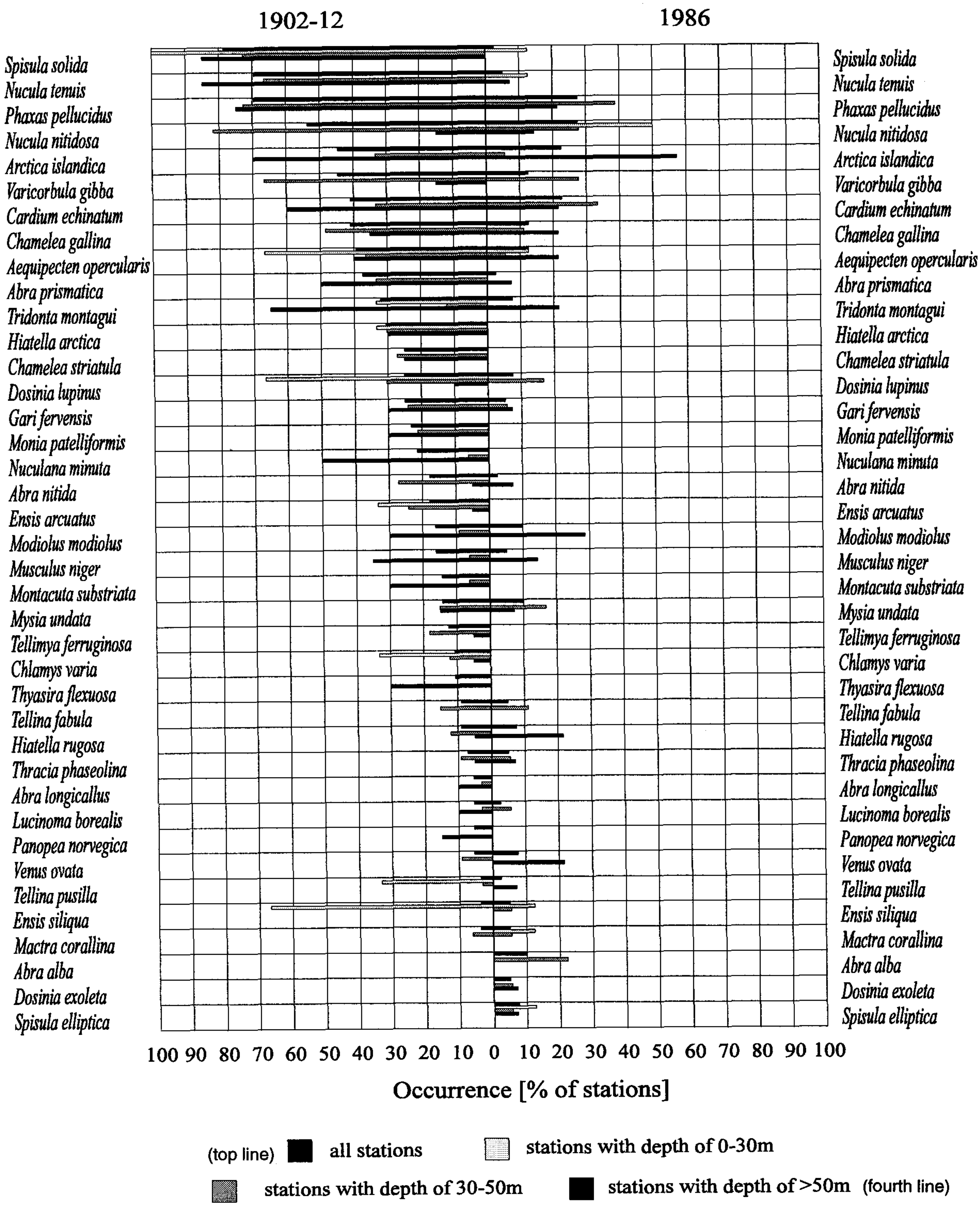


Fig 3.8.1.2.4. Occurrence [% of stations] of Bivalvia.

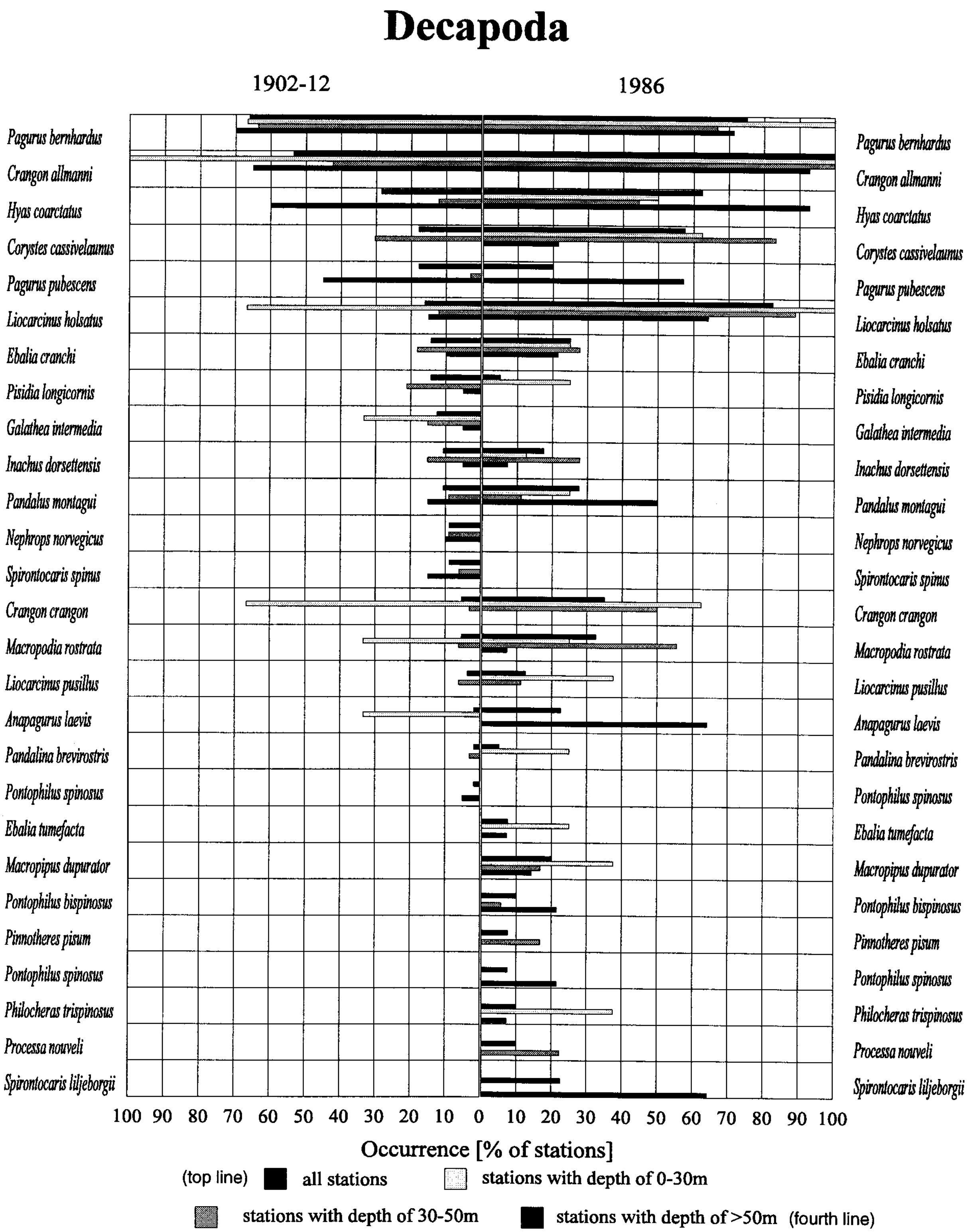


Fig 3.8.1.2.5. Occurence [% of stations] of Decapoda.

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.

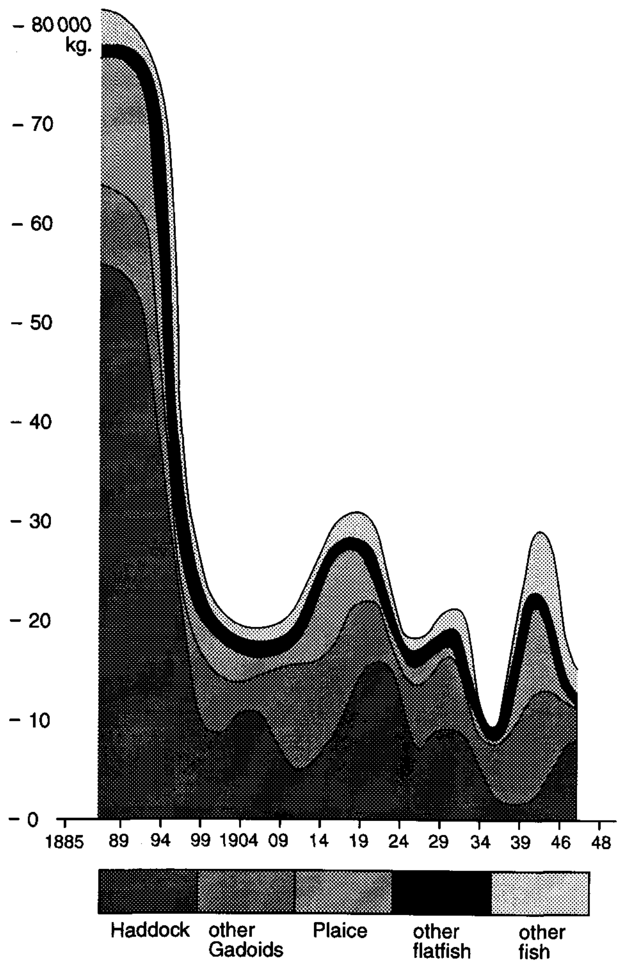


Fig. 3.8.1.2.6. Corrected yields (catch/10 d trip) of a unit trawler as a relative measure for the population density of commercial fish in the North Sea under the impact of fishing (after Hempel 1978).

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.

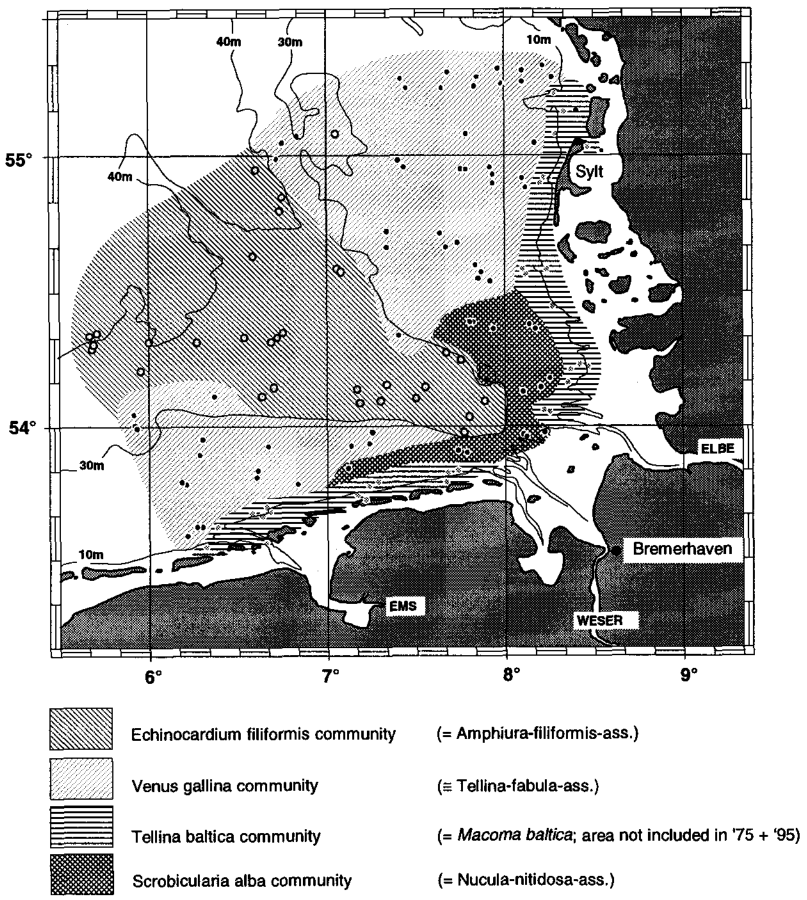


Fig. 3.8.2.1. Distribution of the communities according to Hagmeier (1925). Association names in brackets are the new names for the associations after Salzwedel *et al.* (1985).

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).

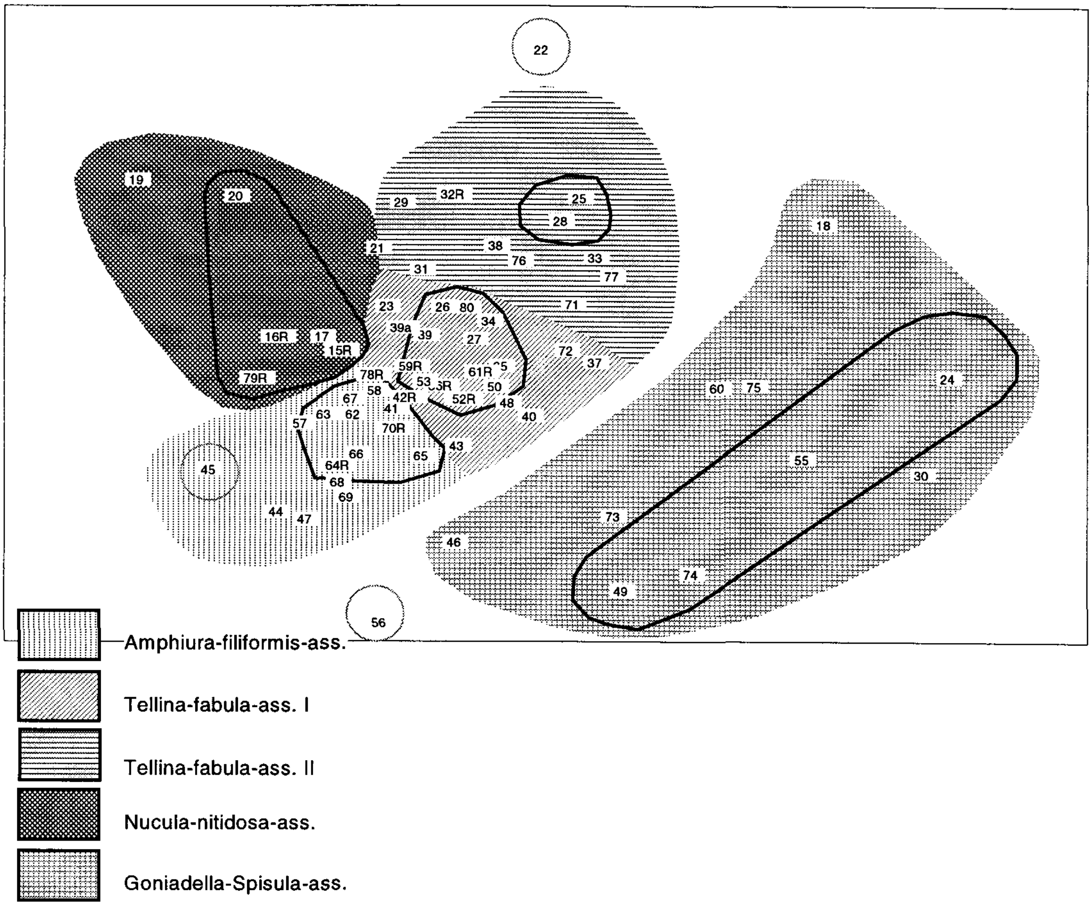


Fig. 3.8.2.2. MDS plot for all data from 1975 (Salzwedel *et al.* 1985) (stress = 0.14) (using Bray-Curtis index, 4th root transformation). Associations as joint by clusteranalysis (Complete linkage) are marked. Lines encircle the stations that were also sampled in 1995 and thus were used for the comparison 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.

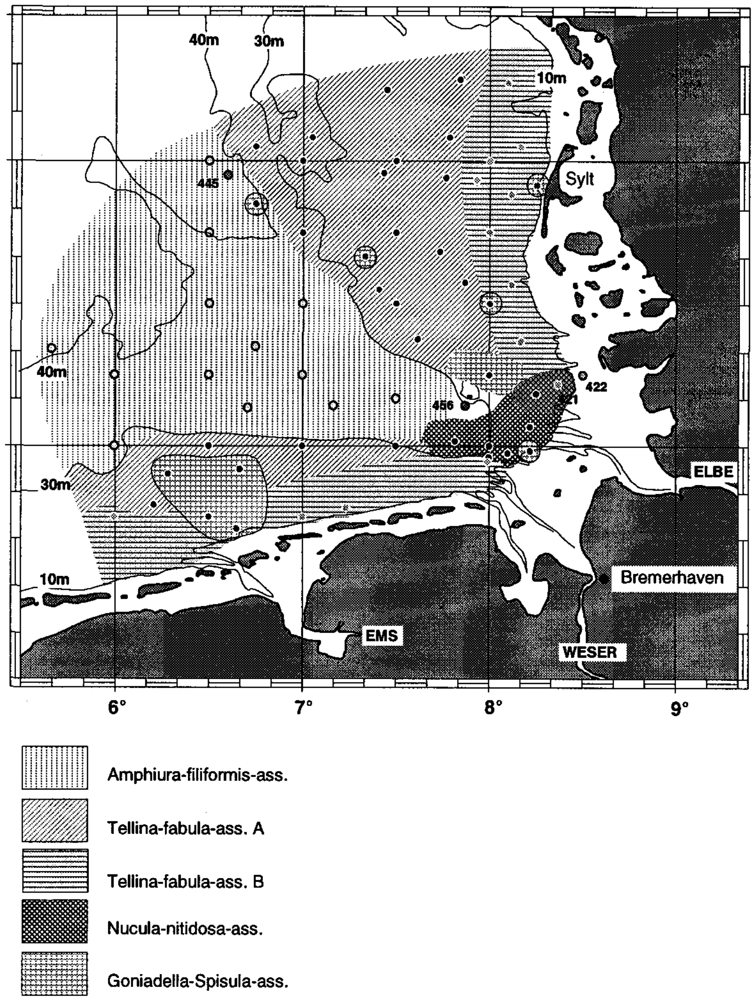


Fig. 3.8.2.3. Spatial distribution of benthic macrofauna association in the German Bight 1975 (Data from Salzwedel *et al.* (1985) reanalysed).

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).

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.

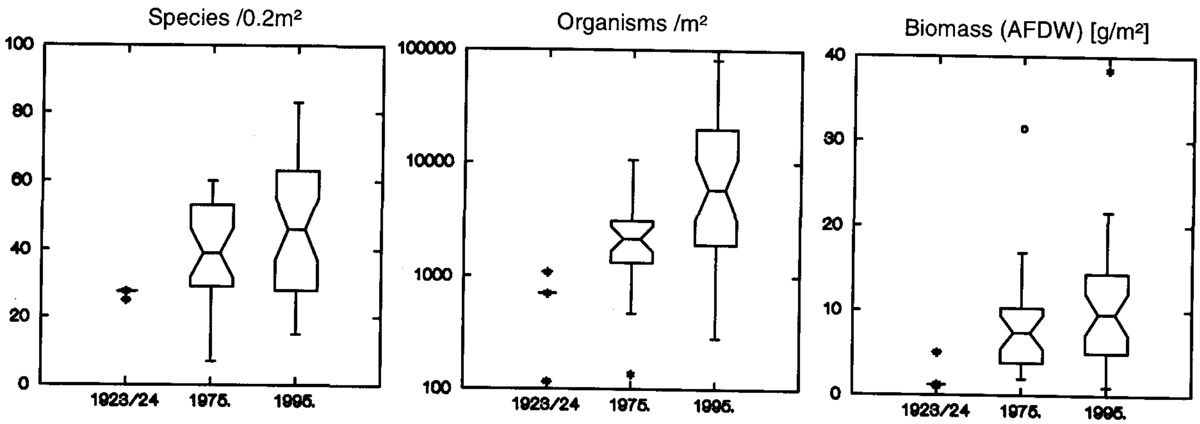


Fig. 3.8.2.6. Main characteristics of the macro benthic fauna 1923-1995. Values from 1923/24 are average values for the communities and are marked by a line with an asterisk. The number of species is expressed for the actually sampled area because extrapolation to m² is not possible.

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).

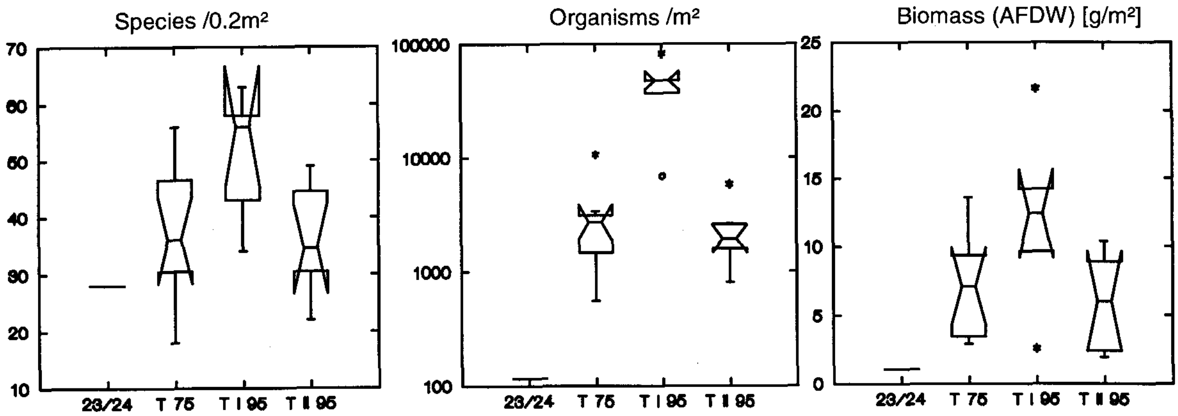


Fig. 3.8.2.7. Development of main characteristics of the *Tellina-fabula*-association 1923-1995. In 1995 this association was divides into two parts: T I and T II.

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).

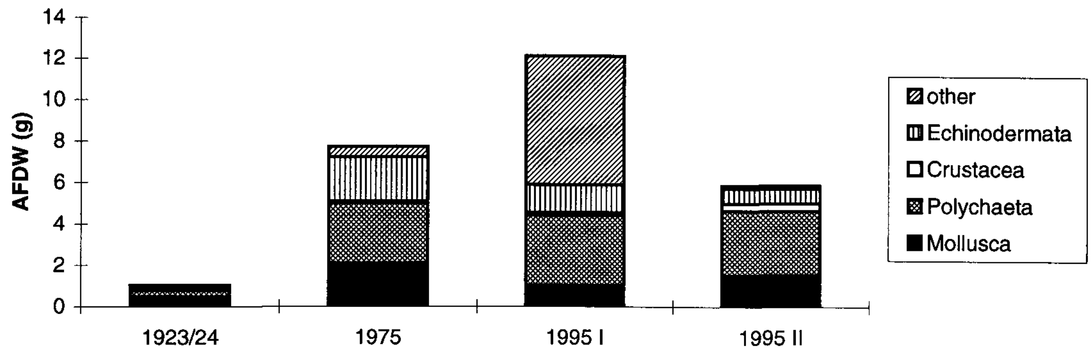


Fig. 3.8.2.8. Development of average biomass of the *Tellina-fabula*-association

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.

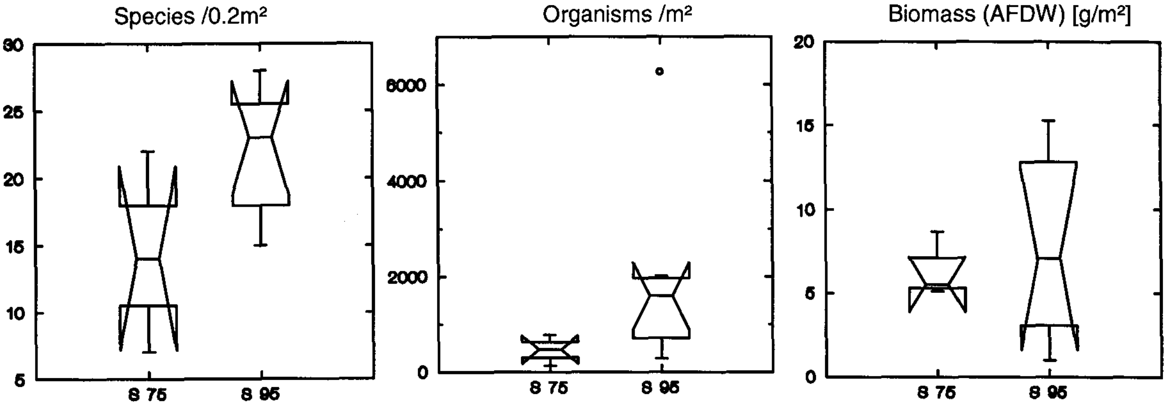


Fig. 3.8.2.9. Development of main characteristics of the *Goniadella-Spisula*-association 1975-1995.

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).

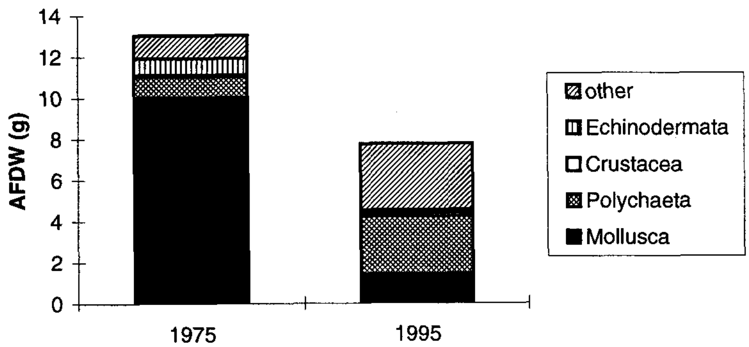


Fig. 3.8.2.10. Development of average biomass of the *Goniadella-Spisula*-associaiton.

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*	*Pisione remota*
	Spisula spp.	*Protodorvillea kefersteinii*
	Polygordius sp.	*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).

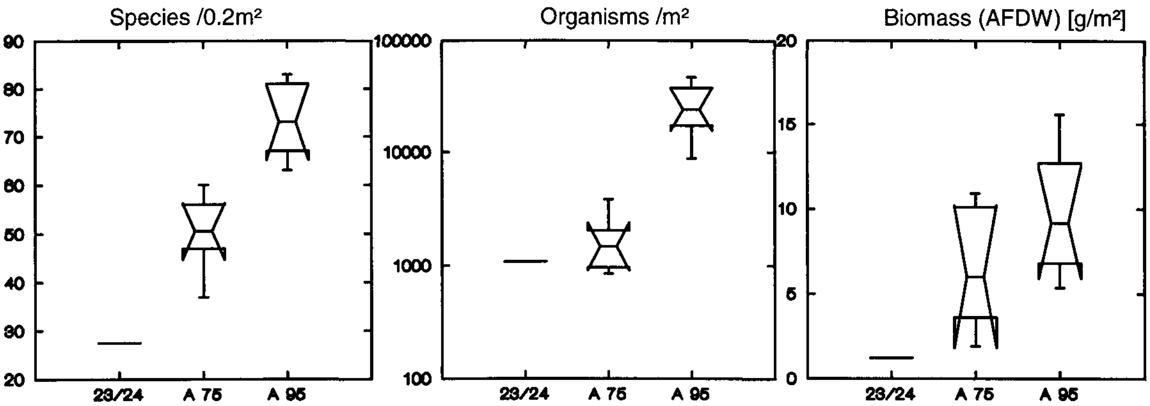


Fig. 3.8.2.11. Development of main characteristics of the *Amphiura-filiformis*-association 1923-1995.

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).

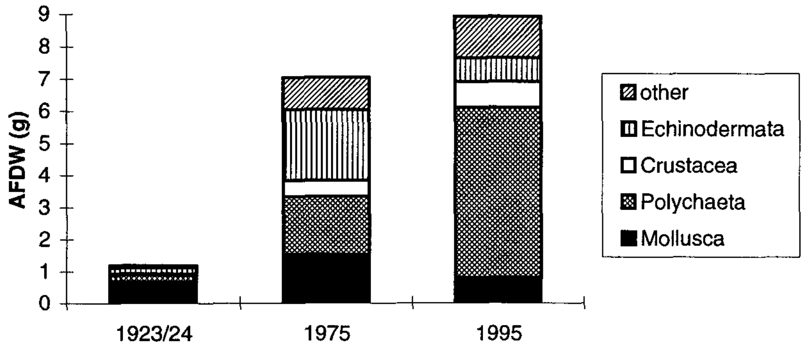


Fig. 3.8.2.12: Development of average biomass of the *Amphiura-filiformis*-association.

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*).

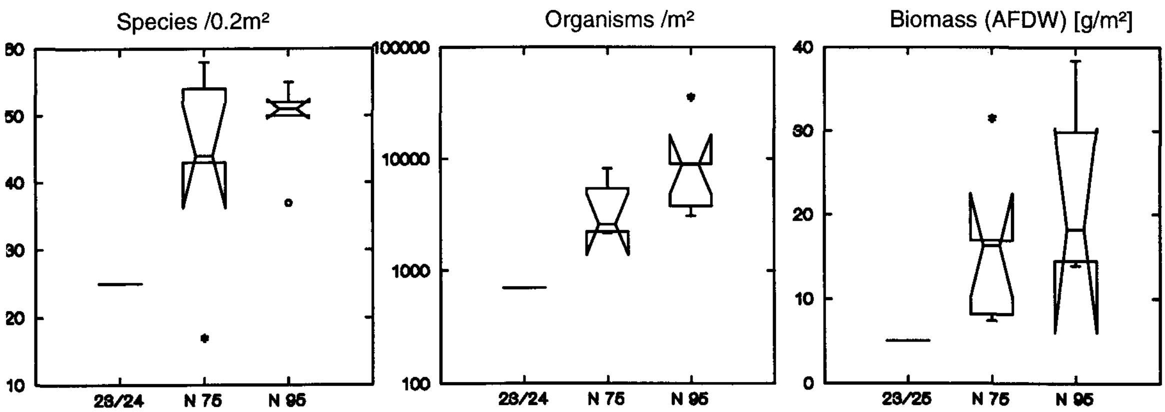


Fig. 3.8.2.13. Development of main characteristics of the *Nucula-nitidosa*-association 1923-1995.

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.

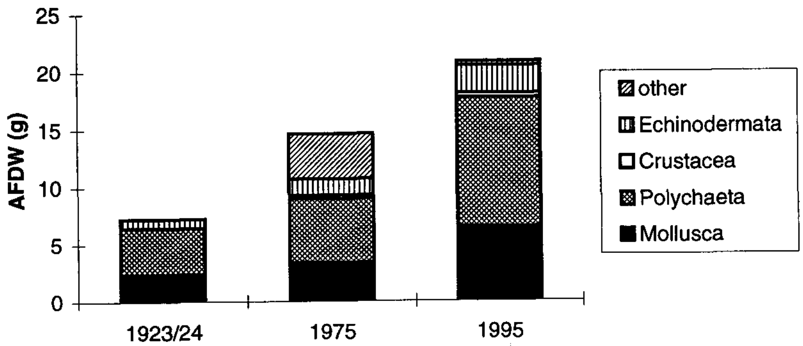


Fig. 3.8.2.14. Development of average biomass of the *Nucula-nitidosa*-association

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 ljungmani	-	-	-	-	-	-	-	-	-	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.

Species	q_1 ($n \cdot n^{*-1} \cdot e^{-1} \cdot y^{-1}$)	q_2 ($n \cdot n^{*-1} \cdot e^{-1} \cdot y^{-1}$)	N_0*	correlation coefficients $q_2\ q_1$	$q_2\ N_0$*	$q_1\ N_0$*
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).

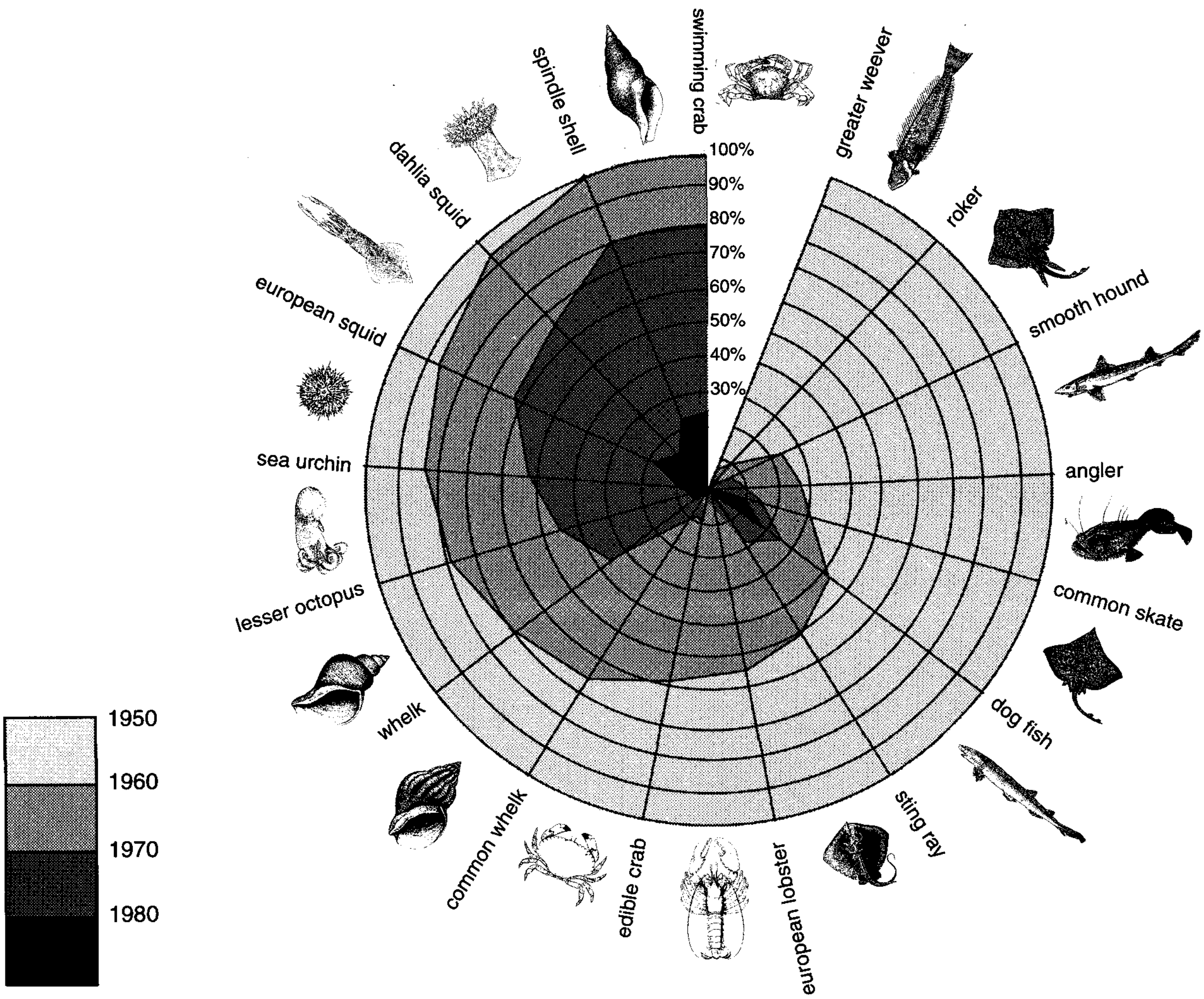


Fig. 3.8.3.1. Results from the model of long-term trends in relative abundance of demersal fish and benthic invertebrates in the south-eastern North Sea between 1947 and 1981. The relative abundance in 1960, 1970 and 1980, respectively, is expressed as a percentage of the original relative abundance 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.

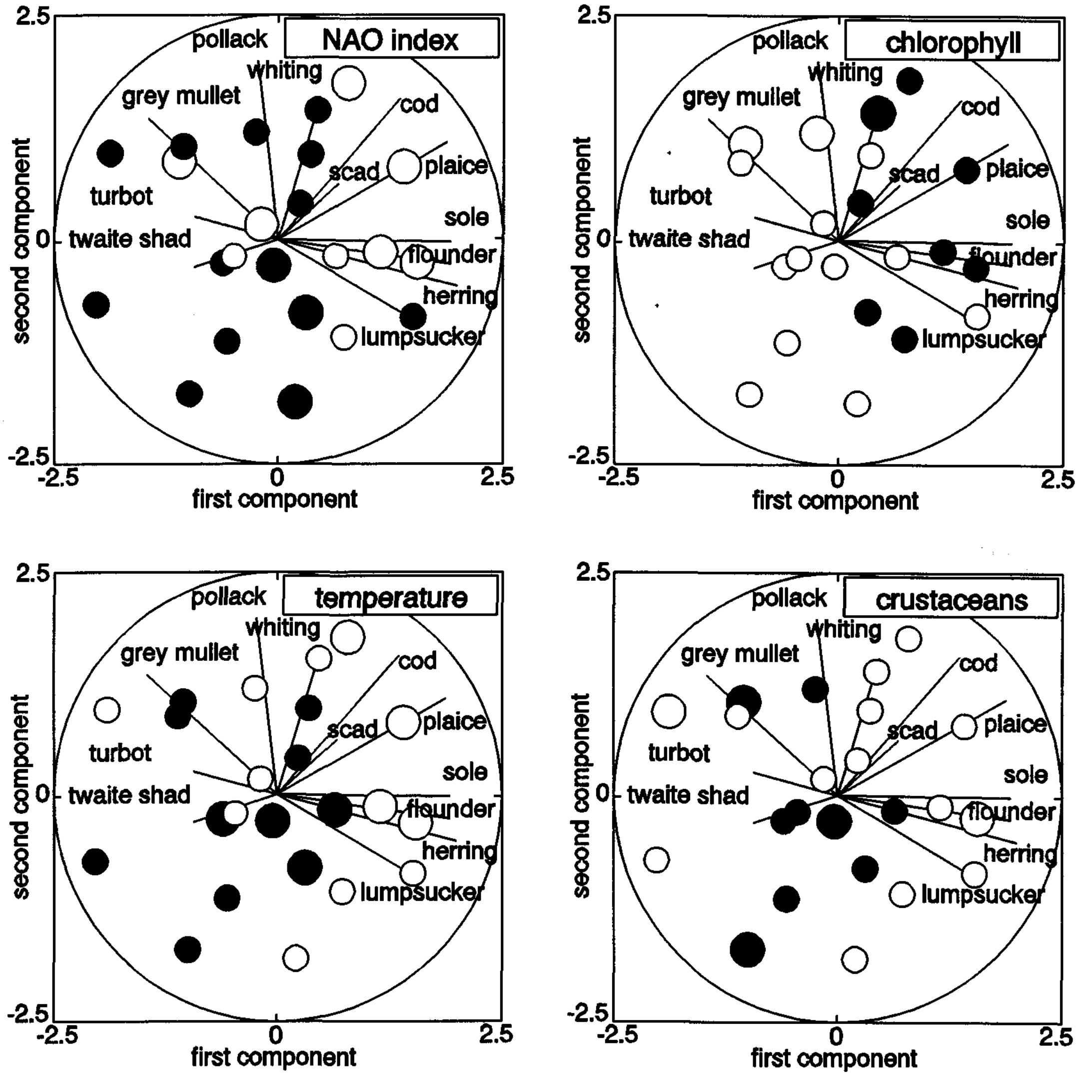


Fig. 3.8.5.1 Covariance biplots based on principal component analysis (1st and 2nd axis) of fish recruit abundance, including indications of the NAO index (Dec-Feb), the water temperature in winter (Dec-Feb), the annual chlorophyll concentration (Jan-Dec), and the predation pressure by crustaceans in 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).

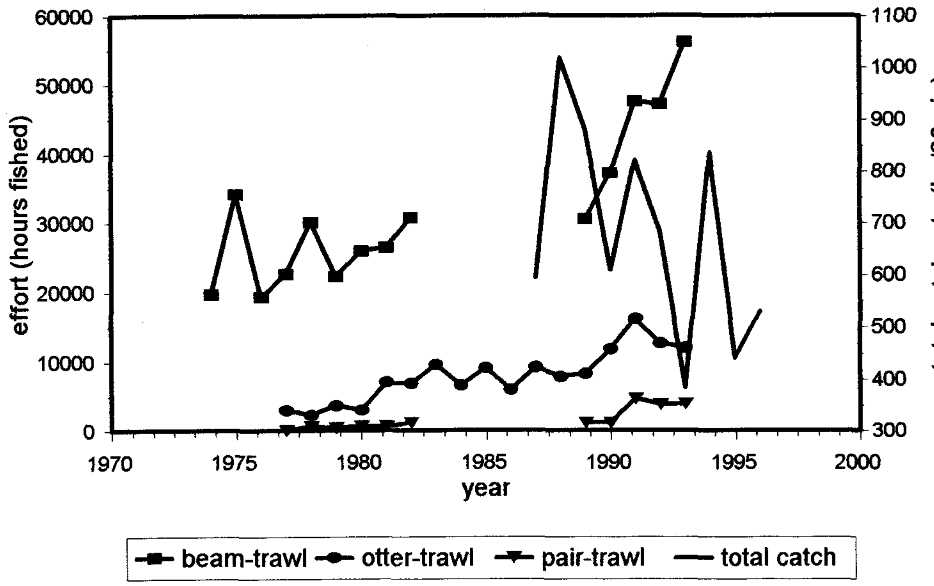


Fig. 3.8.6.1a. Trawlable biomass and fishing effort in ICES retangle 37F7 (German Bight).

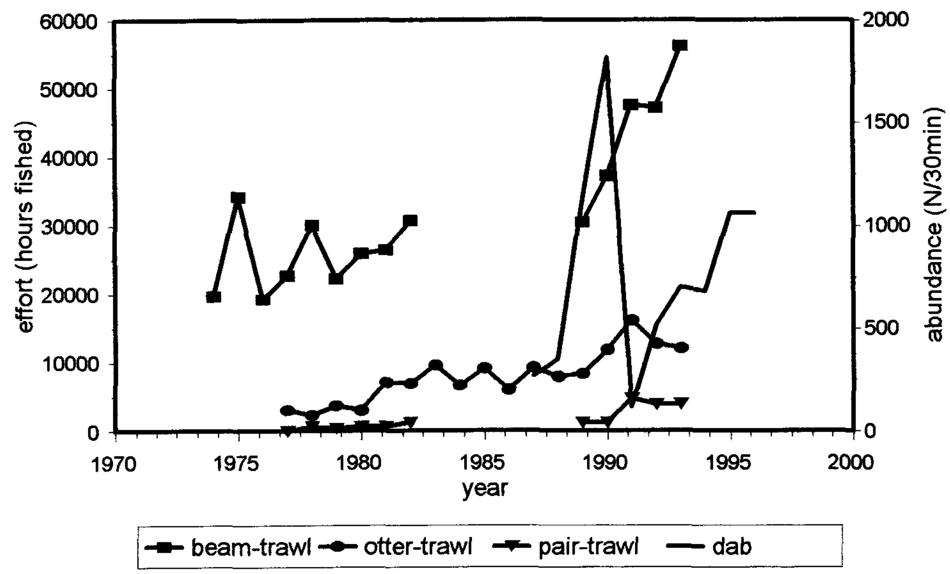


Fig. 3.8.6.1b. Dab. Abundance and fishing effort in ICES retangle 37F7 (German Bight).

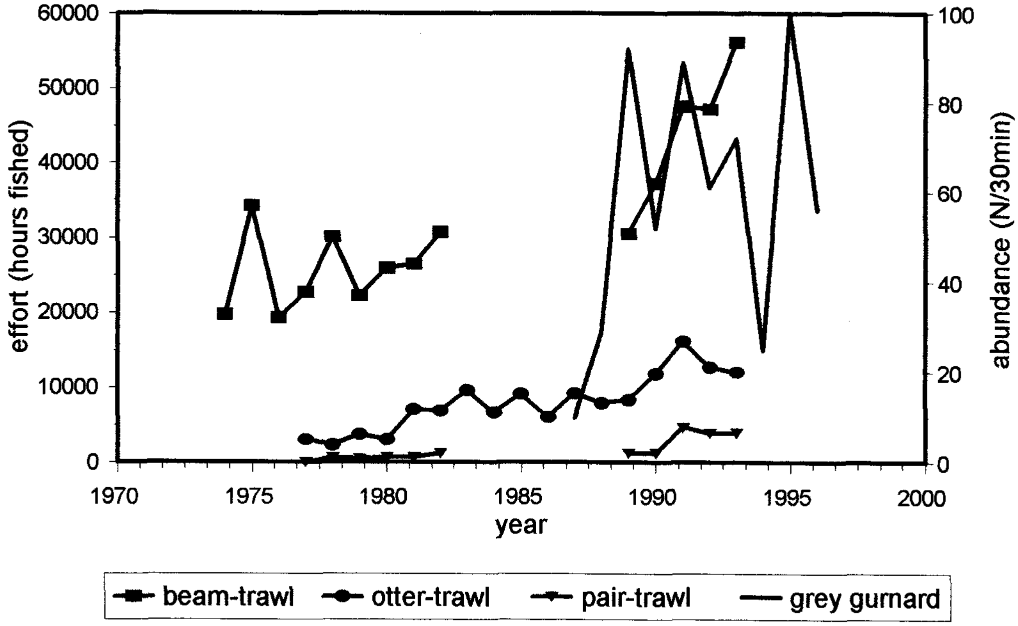


Fig. 3.8.6.1c. Grey gunard. Abundance and fishing effort in ICES retangle 37F7 (German Bight).

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.

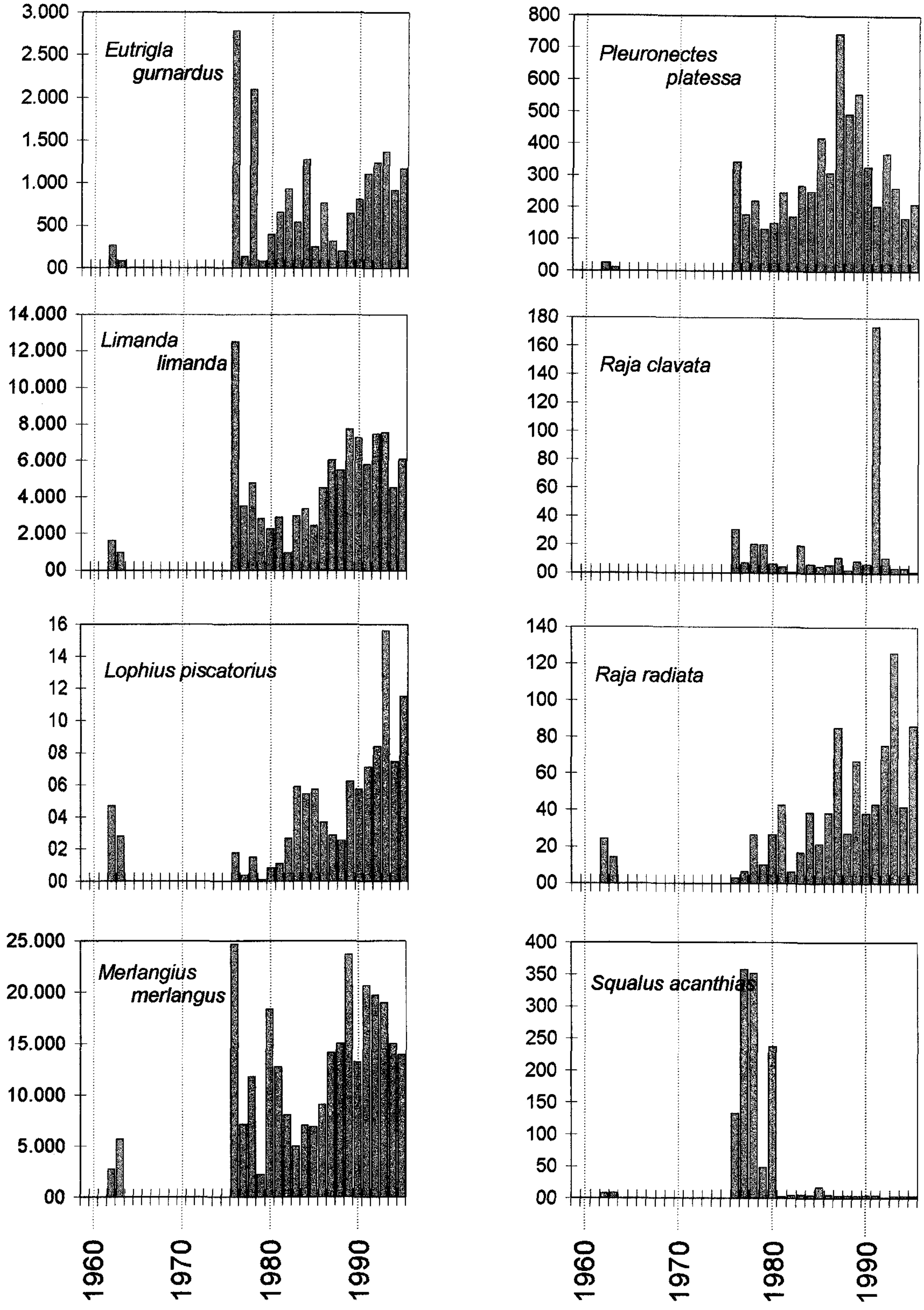


Fig. 3.8.7.1a. Mean abundance (N/10h) of species in the North Sea during Winter (quarter 1) (1962-1963, 1976-1995).

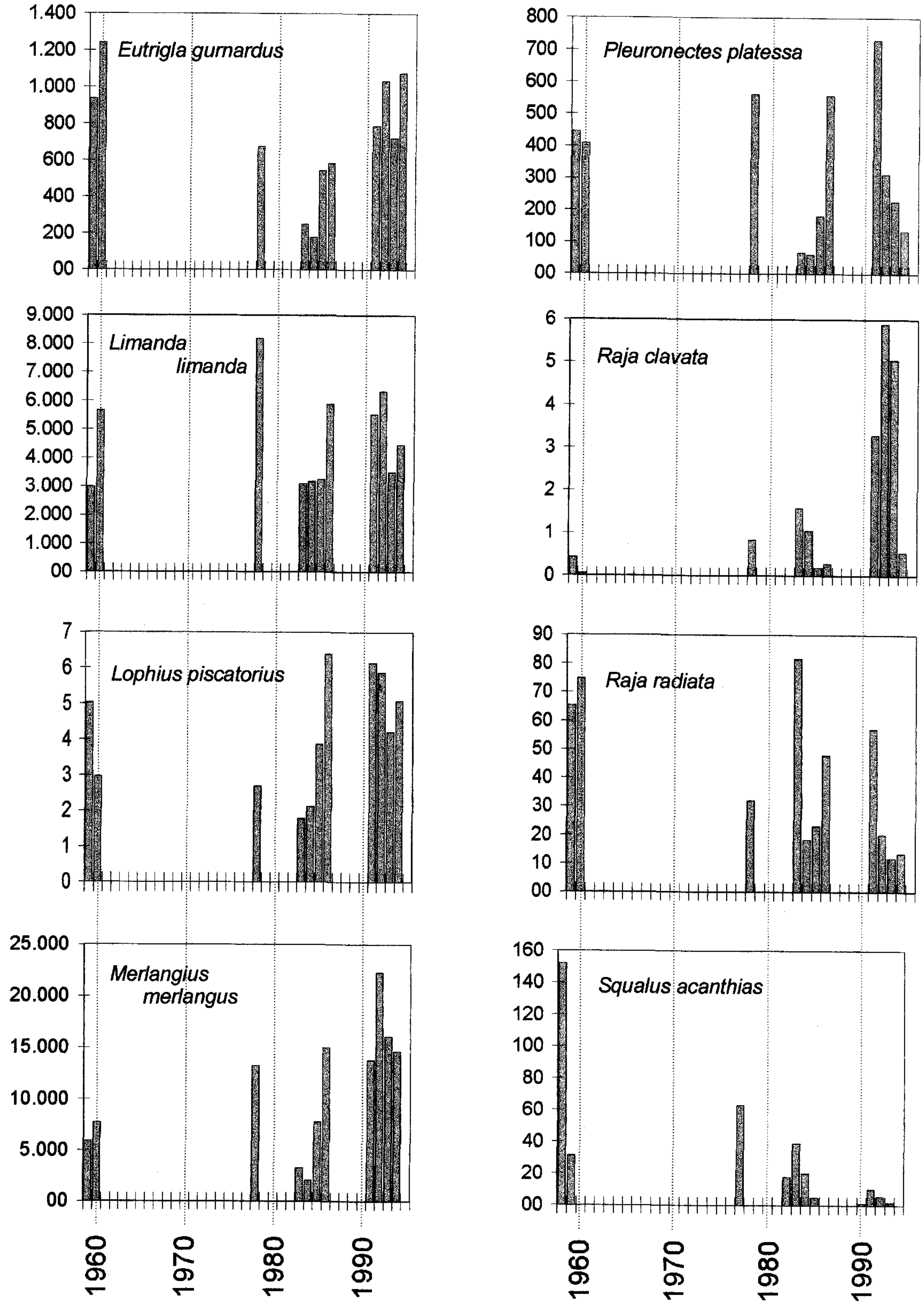


Fig. 3.8.7.1b. Mean abundance (N/10 h) of species in the North Sea during Summer (quarter 3) 1959-1960, 1978, 1983-1986 and 1991-1994.

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

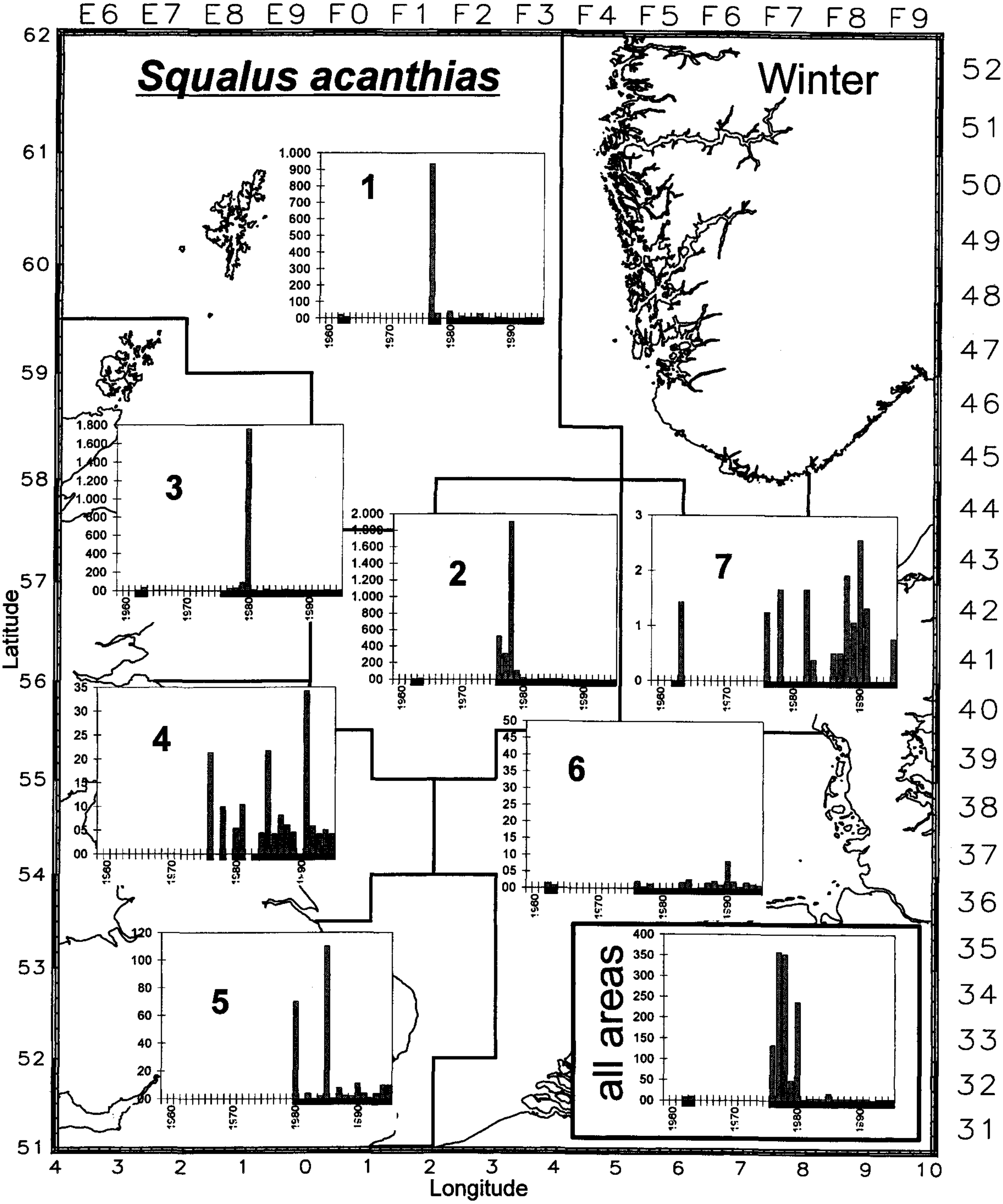


Fig. 3.8.7.2a. Spurdog: Mean catch rate (quarter 1; N/10 h) per roundfish area and in the total North Sea during the periods 1962-1963 and 1976-1995.

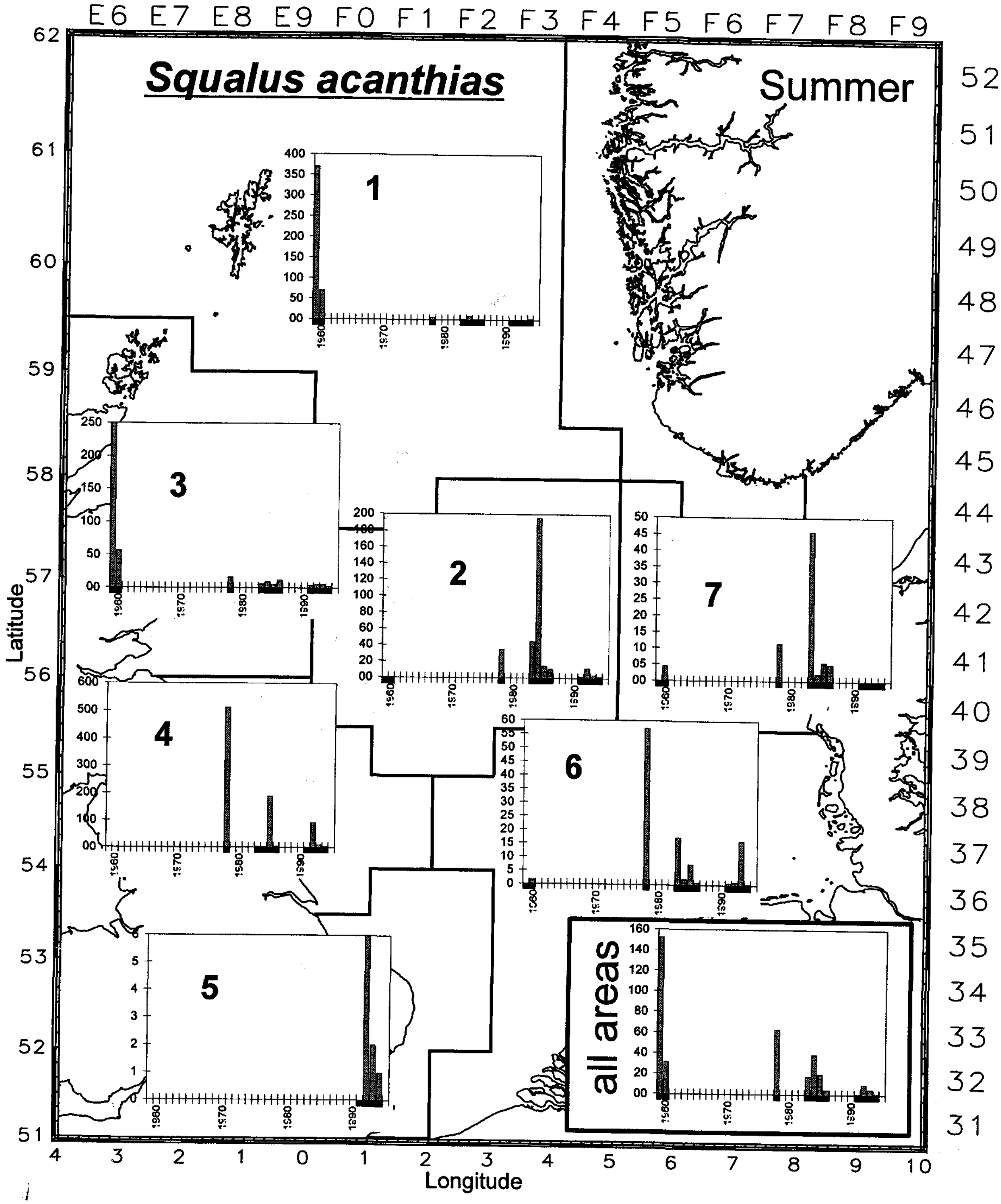


Fig. 3.8.7.2b. Spurdog: Mean catch rate (quarter 3; N/10 h) per roundfish area and in the total North Sea during the periods 1959-1960, 1978, 1983-1986 and 1991-1994.

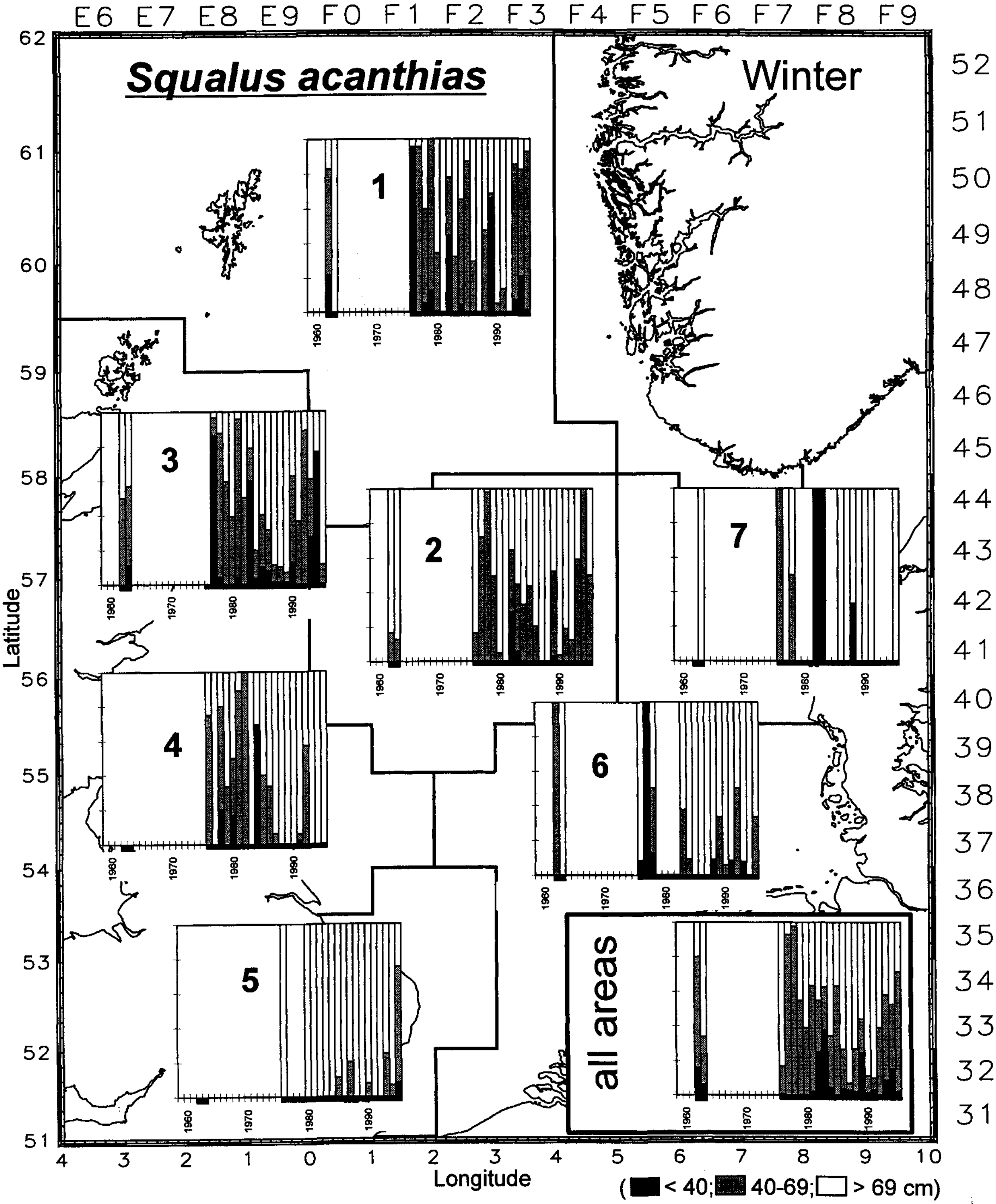


Fig. 3.8.7.2c. Spurdog: Percentage of the size classes in the mean catch rate (quarter 1).

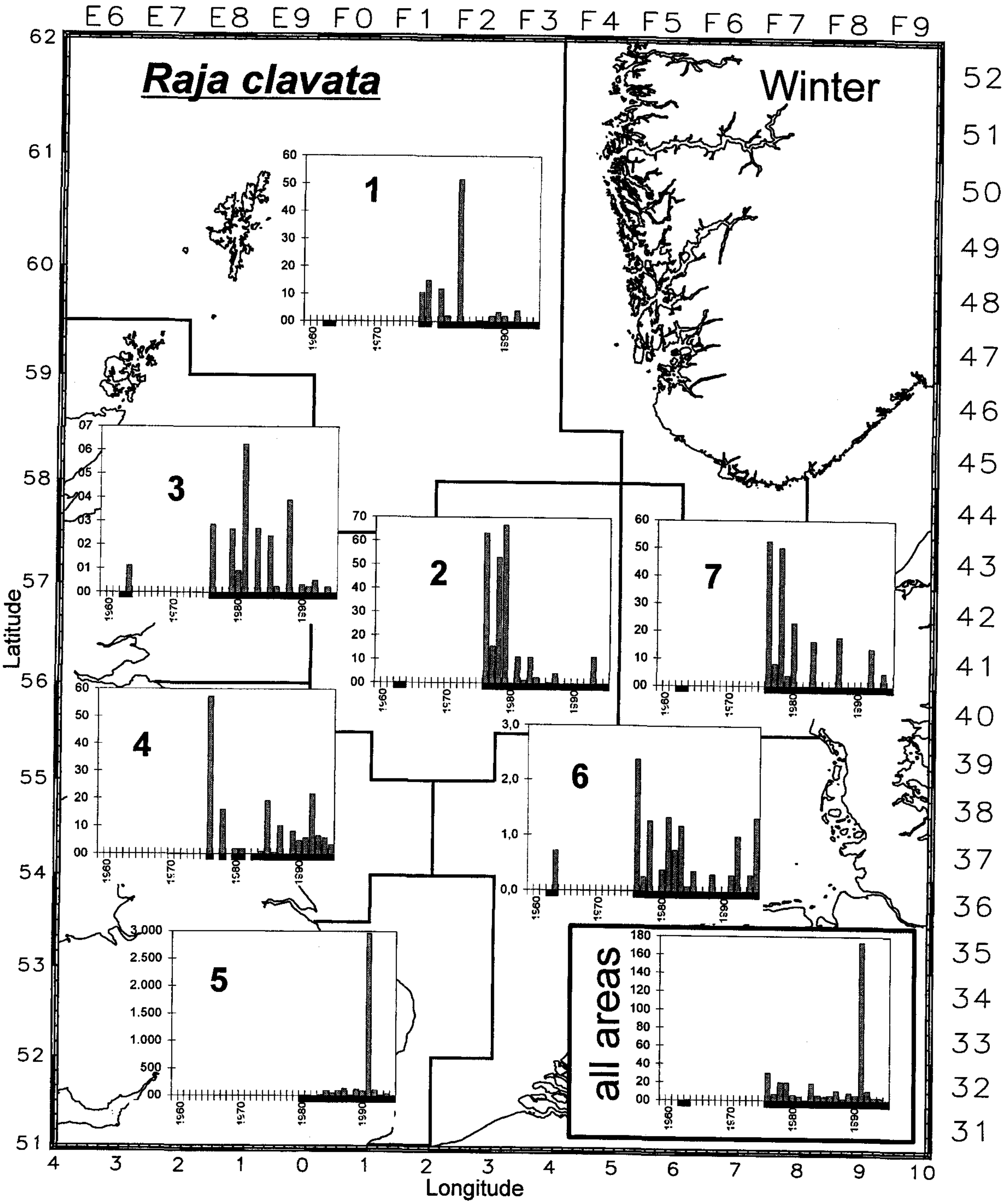


Fig. 3.8.7.3a. Thornback ray: Mean catch rate (quarter 1; N/10 h) per roundfish area and in the total North Sea during the periods 1962-1963 and 1976-1995.

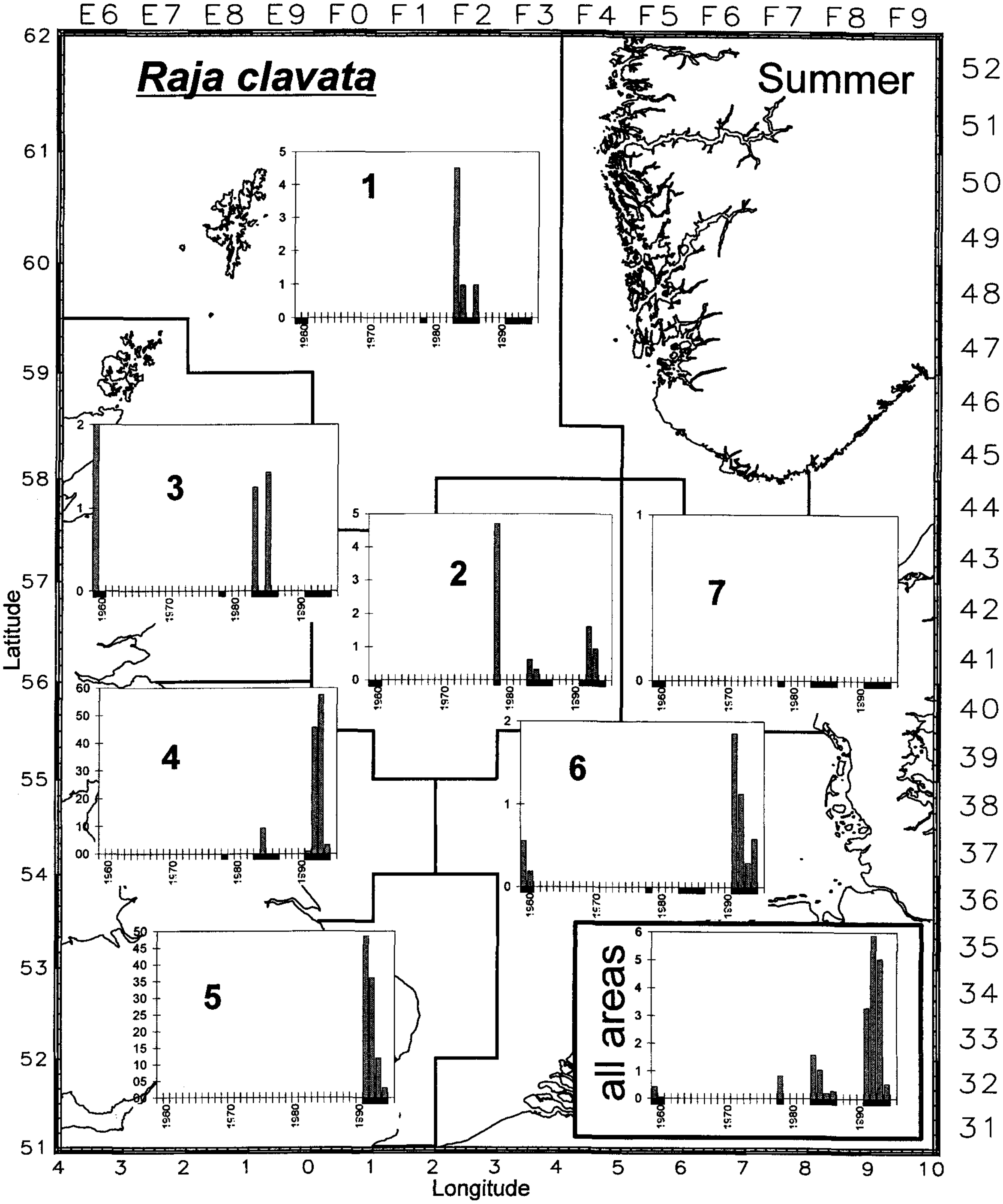


Fig. 3.8.7.3b. Thornback ray: Mean catch rate (quarter 3; N/10 h) per roundfish area and in the total North Sea during the periods 1959-1960, 1978, 1983-1986 and 1991-1994.

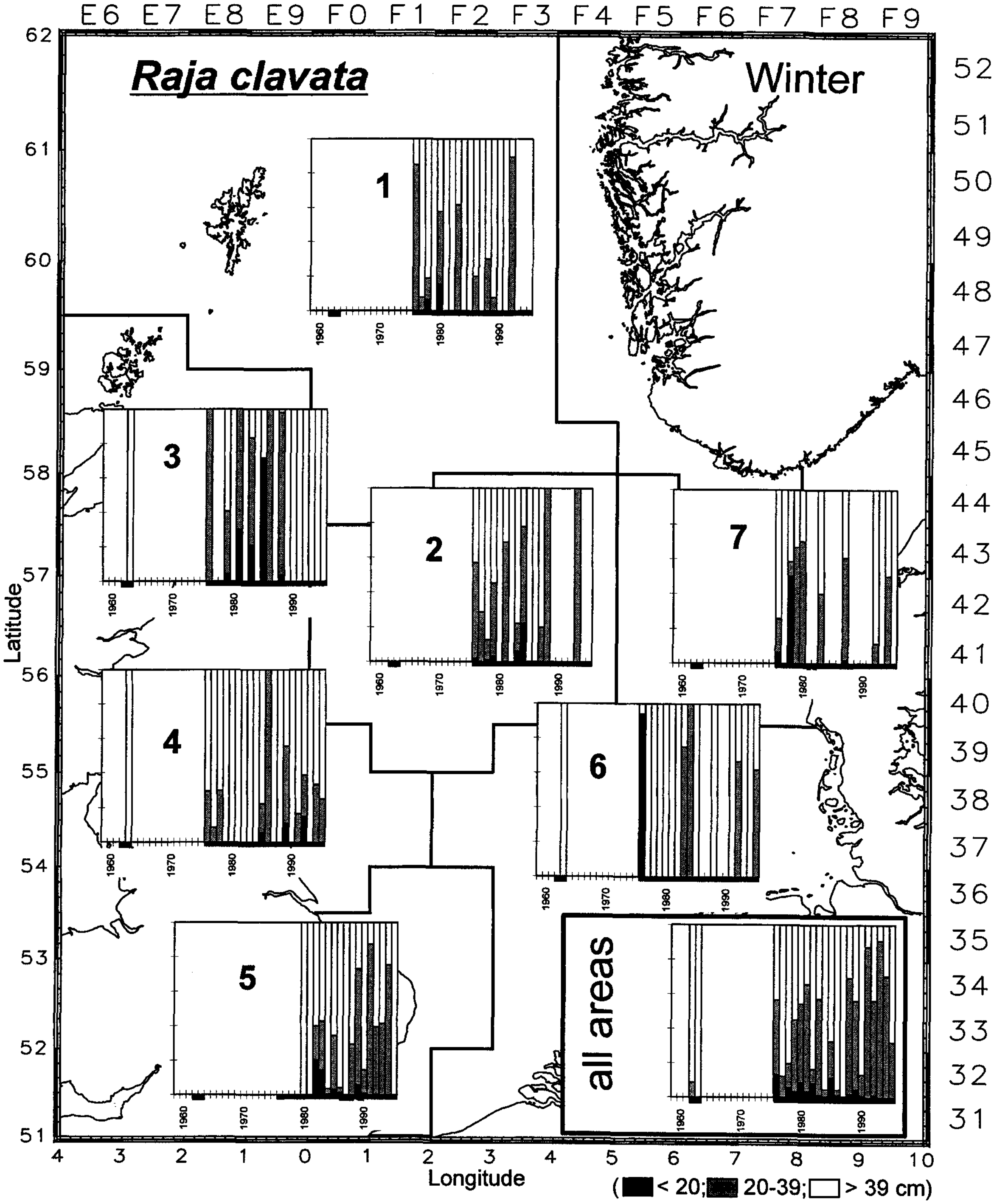


Fig. 3.8.7.3c. Thornback ray: Percentage of the size classes in the mean catch rate (quarter 1).

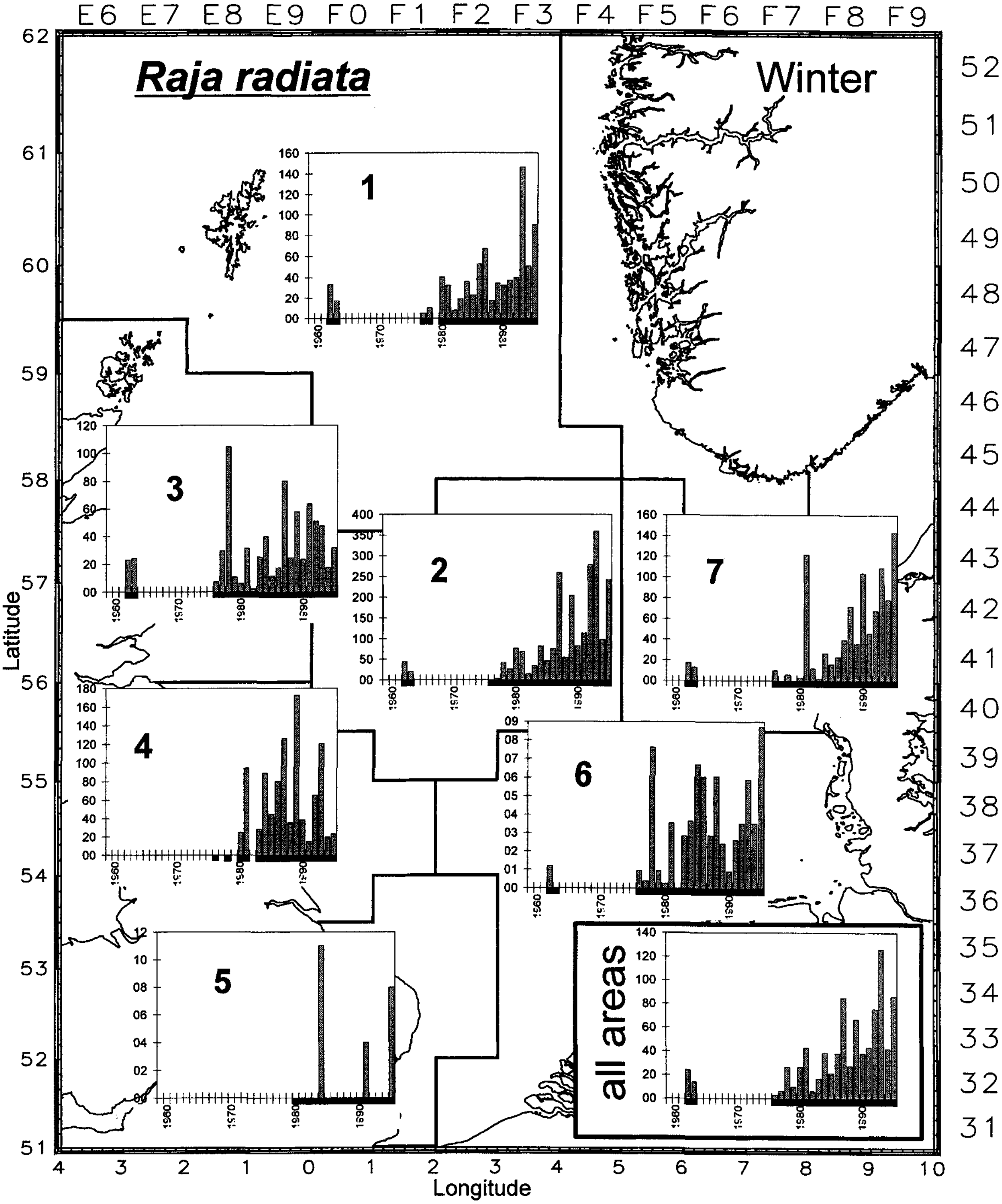


Fig. 3.8.7.4a. Starry ray: Mean catch rate (quarter 1; N/10 h) per roundfish area and in the total North Sea during the periods 1962-1963 and 1976-1995.

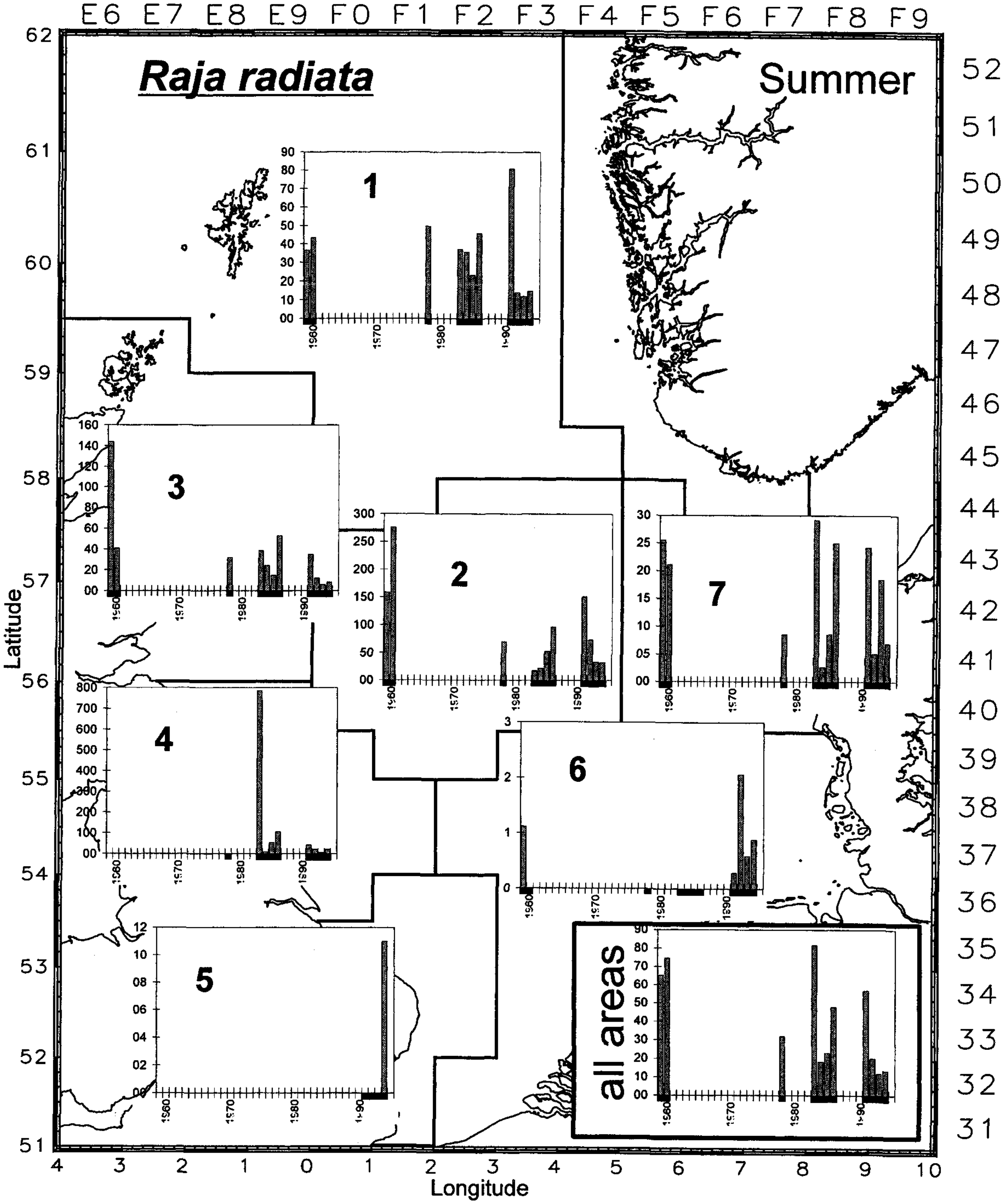


Fig. 3.8.7.4b. Starry ray: Mean catch rate (quarter 3; N/10 h) per roundfish area and in the total North Sea during the periods 1959-1960, 1978, 1983-1986 and 1991-1994.

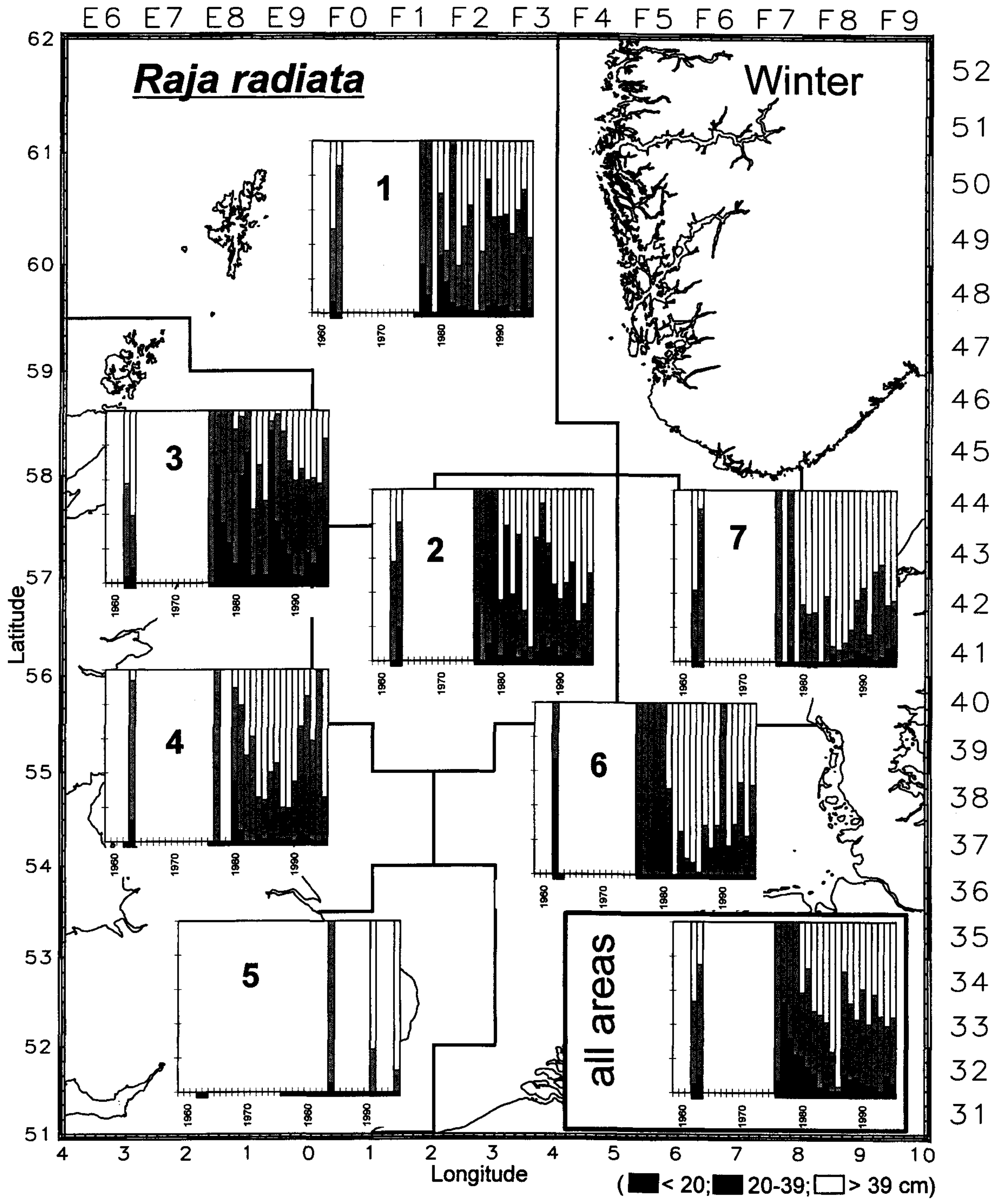


Fig. 3.8.7.4c. Starry ray: Percentage of the size classes in the mean catch rate (quarter 1).

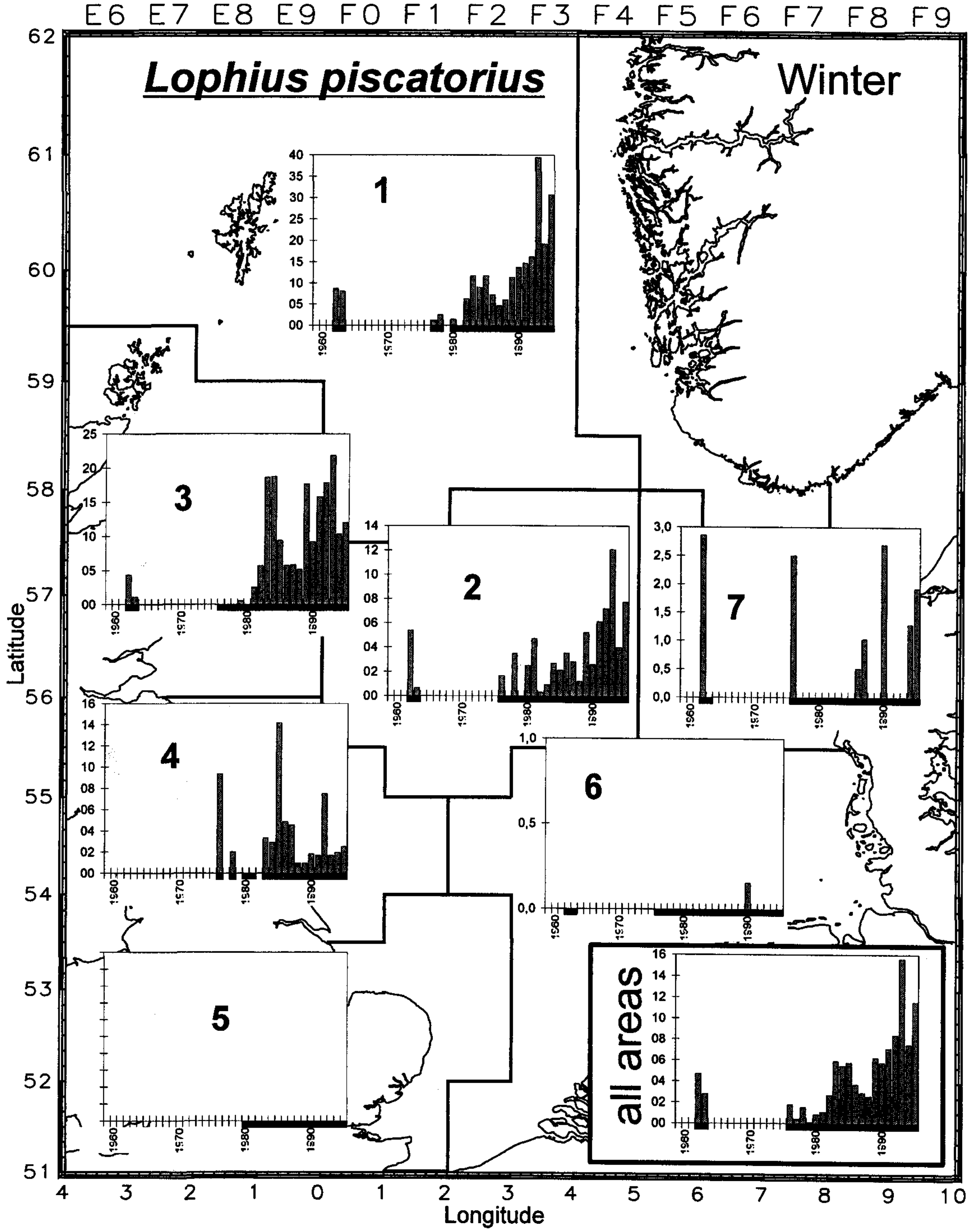


Fig. 3.8.7.5a. Angler: Mean catch rate (quarter 1; N/10 h) per roundfish area and in the total North Sea during the periods 1962-1963 and 1976-1995.

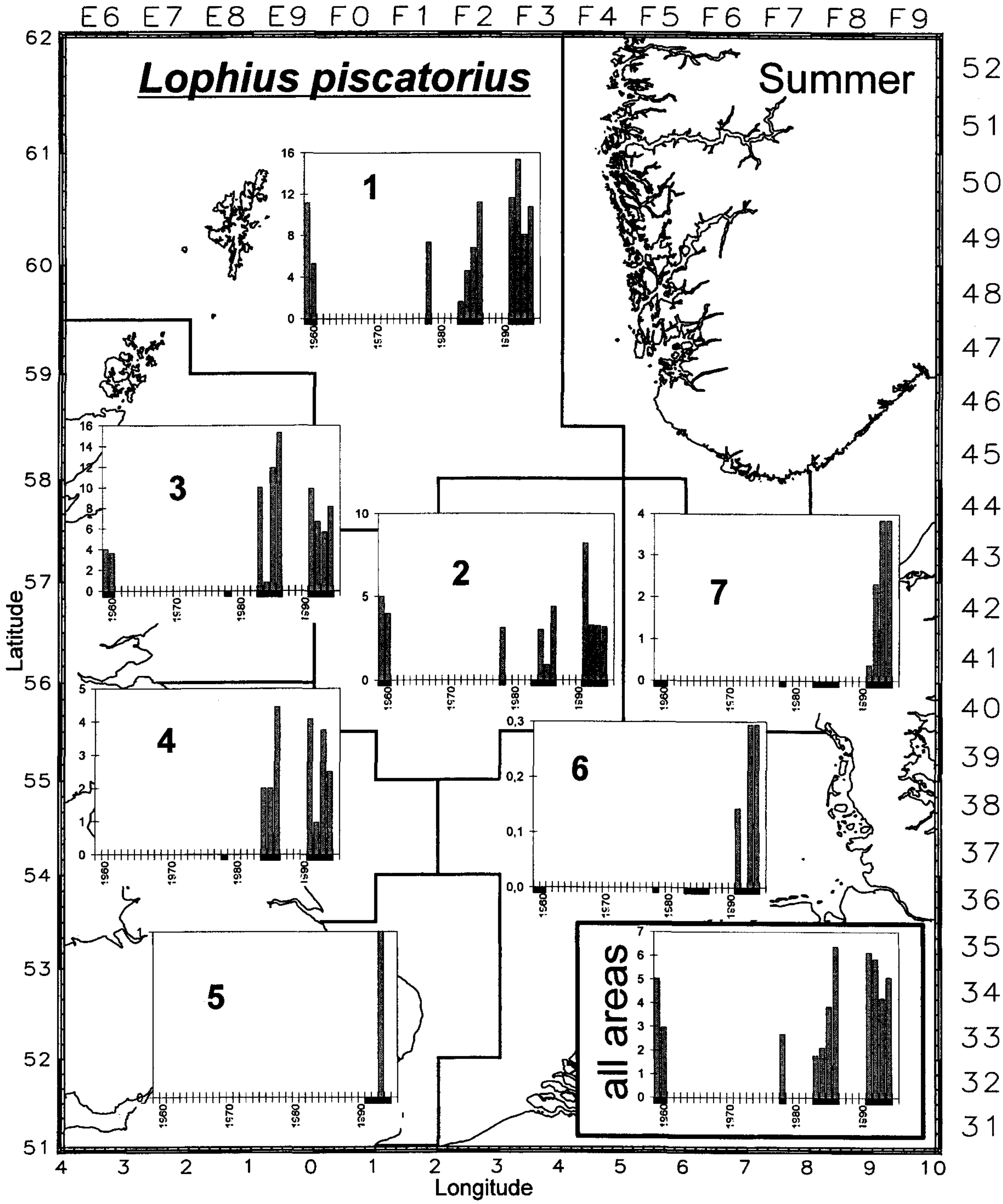


Fig. 3.8.7.5b. Angler: Mean catch rate (quarter 3; N/10 h) per roundfish area and in the total North Sea during the periods 1959-1960, 1978, 1983-1986 and 1991-1994.

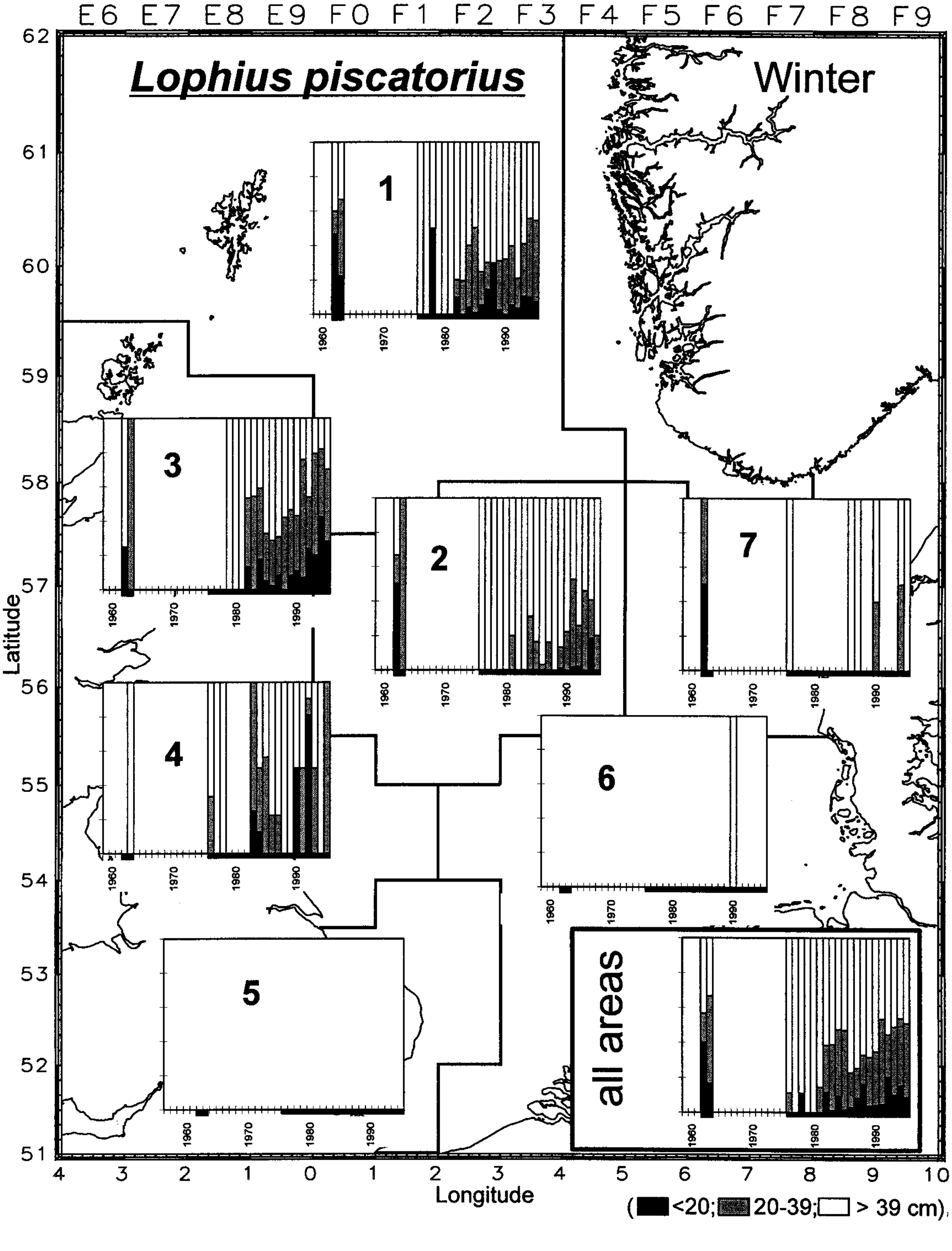


Fig 3.8.7.5c. Angler: Percentage of the size classes in the mean catch rate (quarter 1).

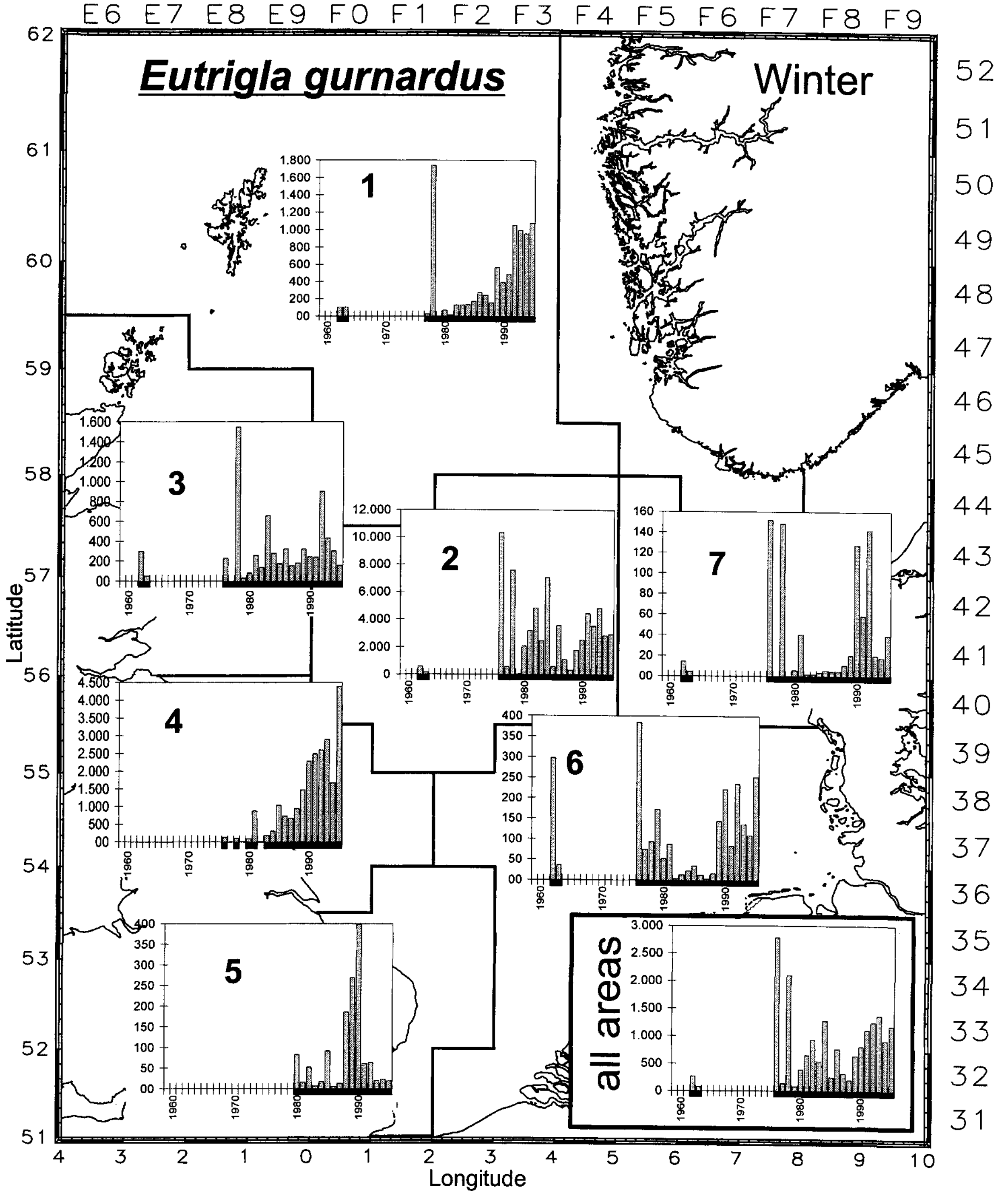


Fig. 3.8.7.6a. Grey gunard: Mean catch rate (quarter 1; N/10 h) per roundfish area and in the total North Sea during the periods 1962-1963 and 1976-1995.

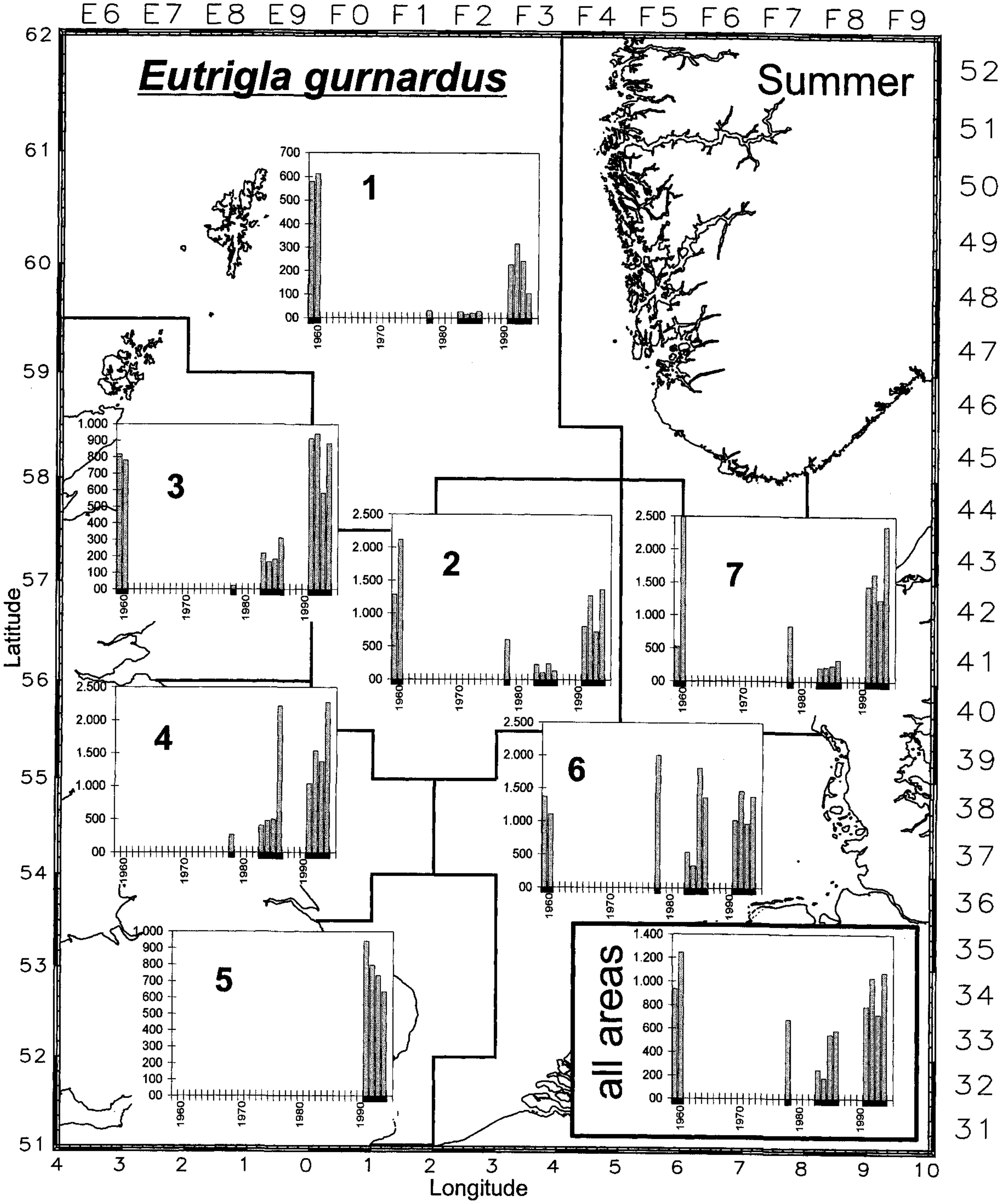


Fig. 3.8.7.6b. Grey gunard: Mean catch rate (quarter 3; N/10 h) per roundfish area and in the total North Sea during the periods 1959-1960, 1978, 1983-1986 and 1991-1994.

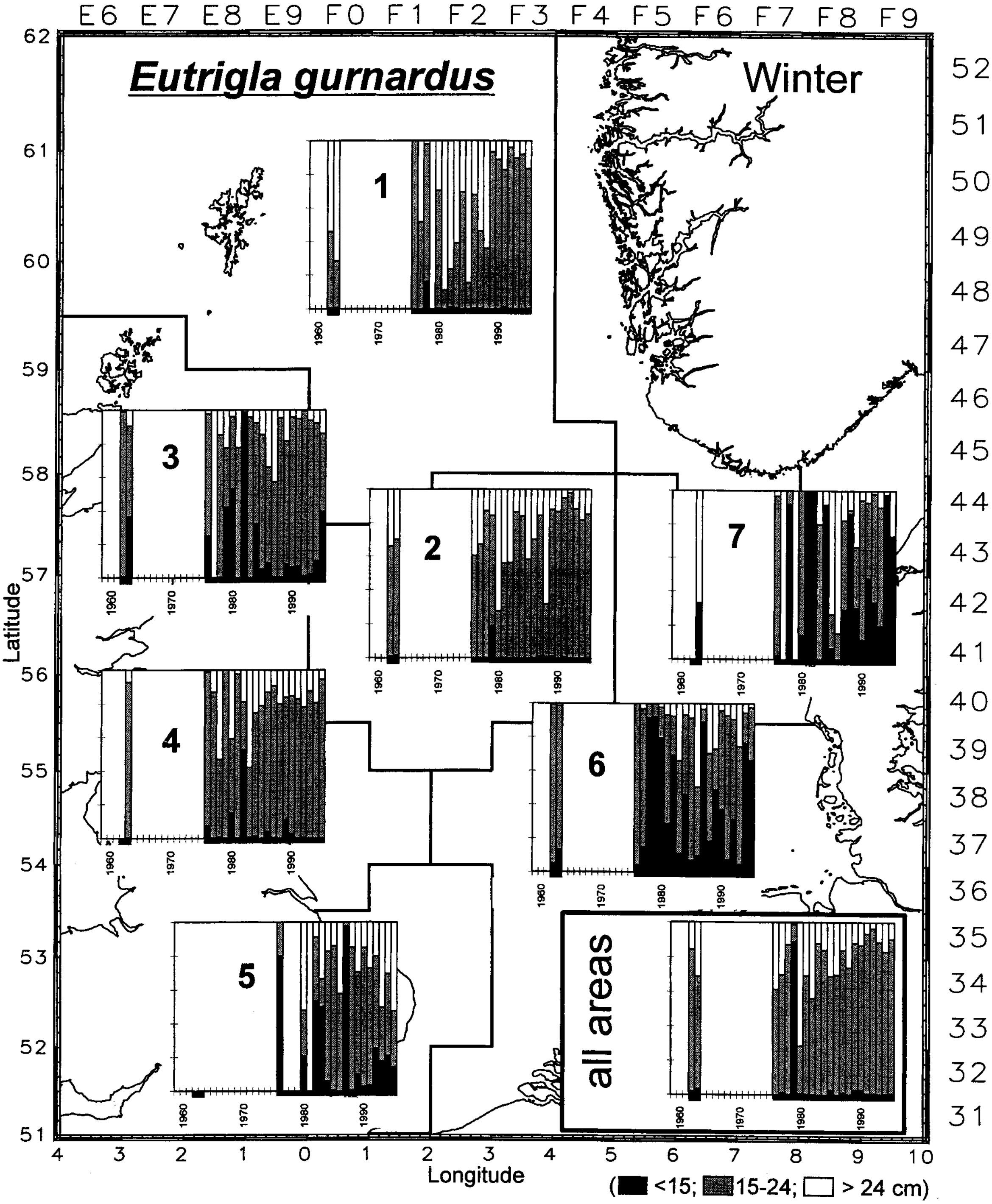


Fig. 3.8.7.6c. Grey gunard: Percentage of the size classes in the mean catch rate (quarter 1).

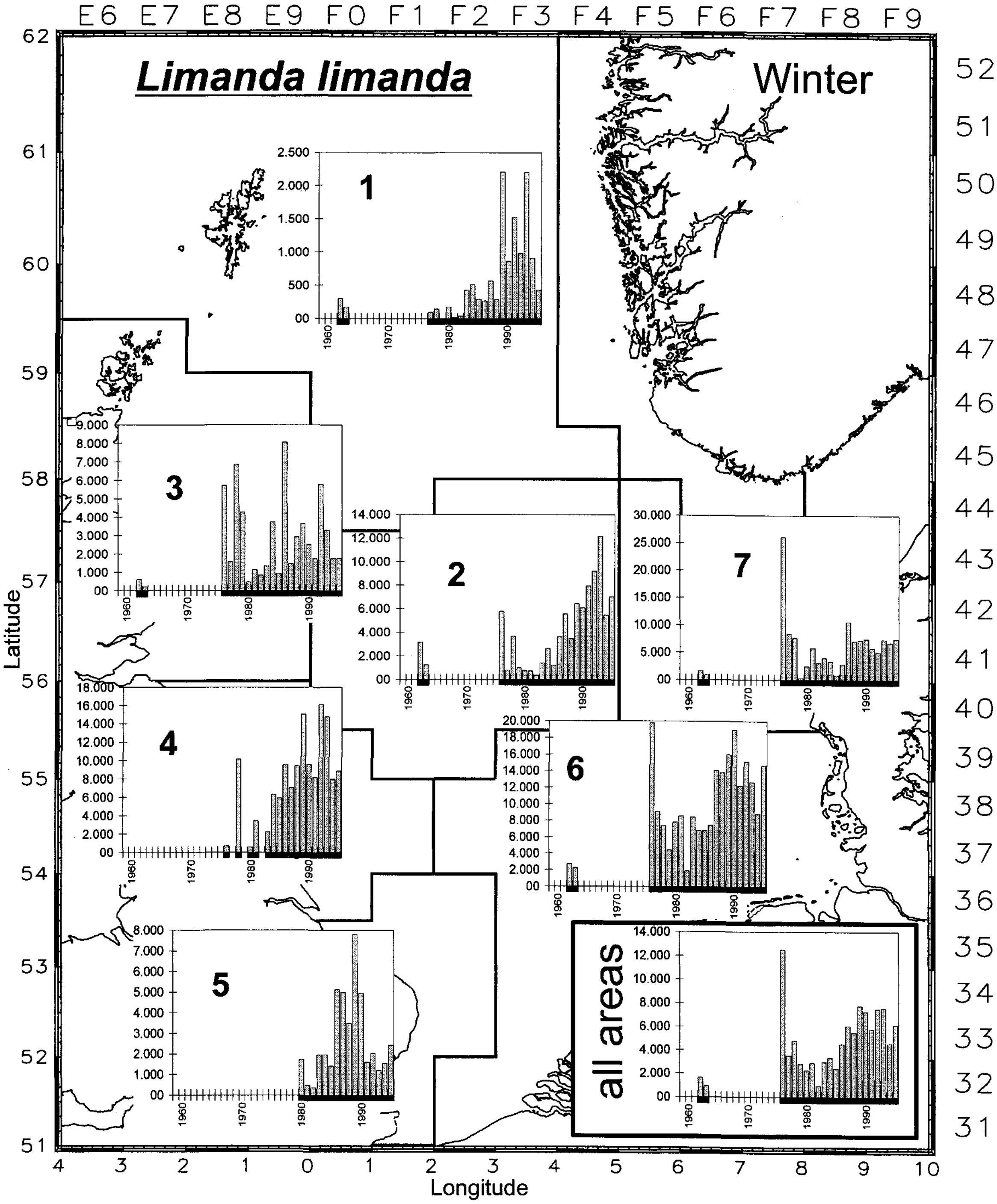


Fig. 3.8.7.7a. Dab: Mean catch rate (quarter 1; N/10 h) per roundfish area and in the total North Sea during the periods 1962-1963 and 1976-1995.

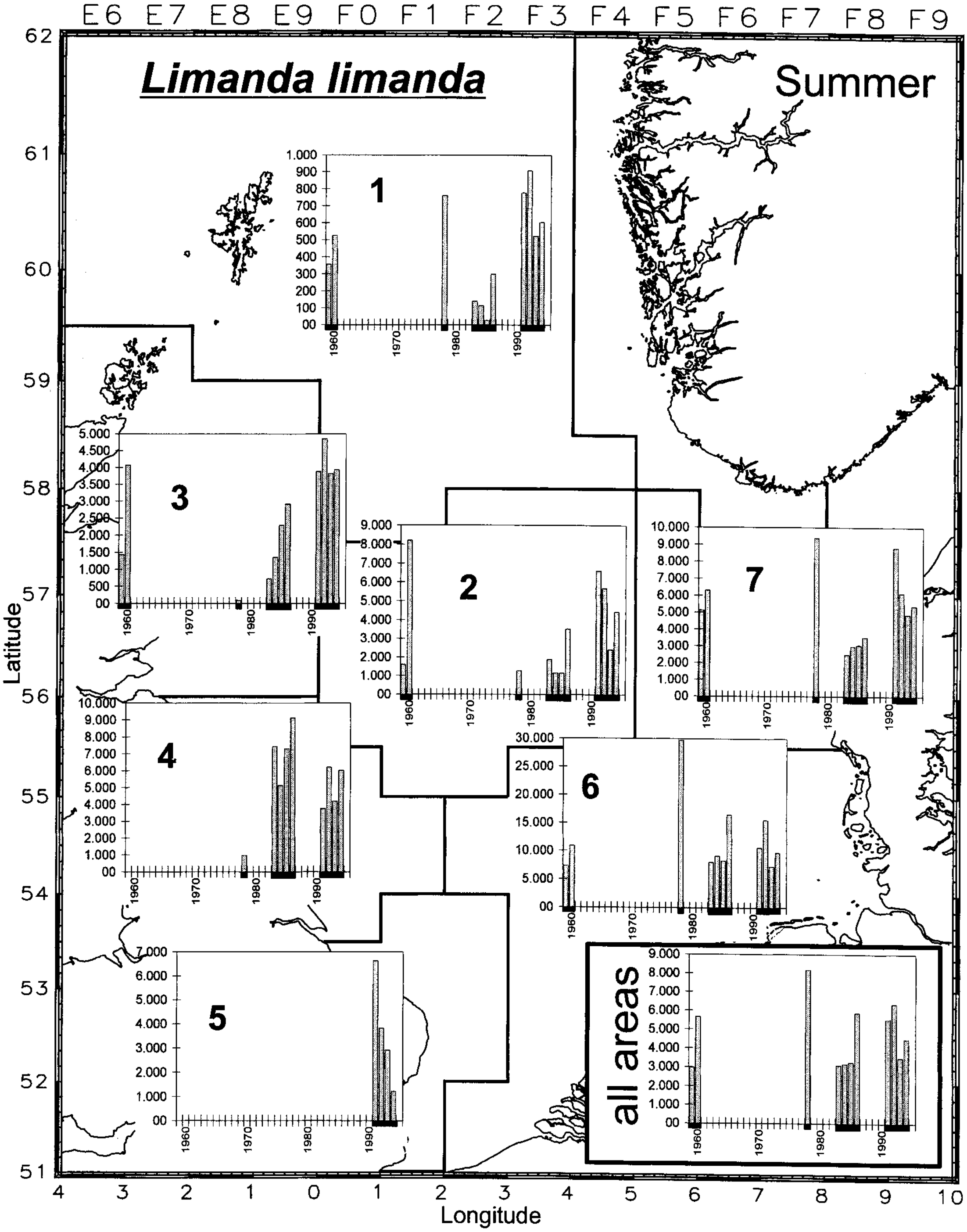


Fig. 3.8.7.7b. Dab: Mean catch rate (quarter 3; N/10 h) per roundfish area and in the total North Sea during the periods 1959-1960, 1978, 1983-1986 and 1991-1994.

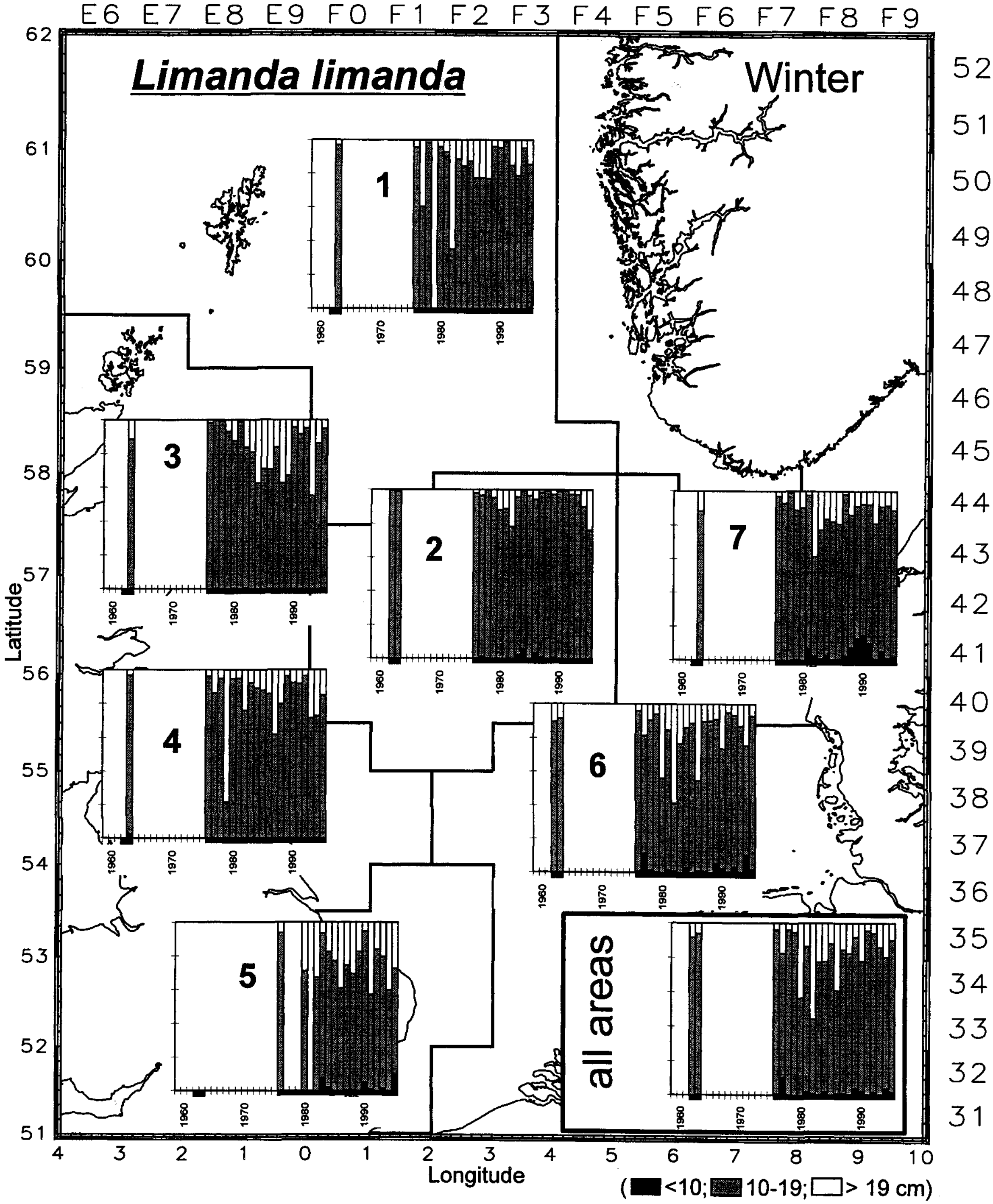


Fig. 3.8.7.7c. Dab: Percentage of the size classes in the mean catch rate (quarter 1).

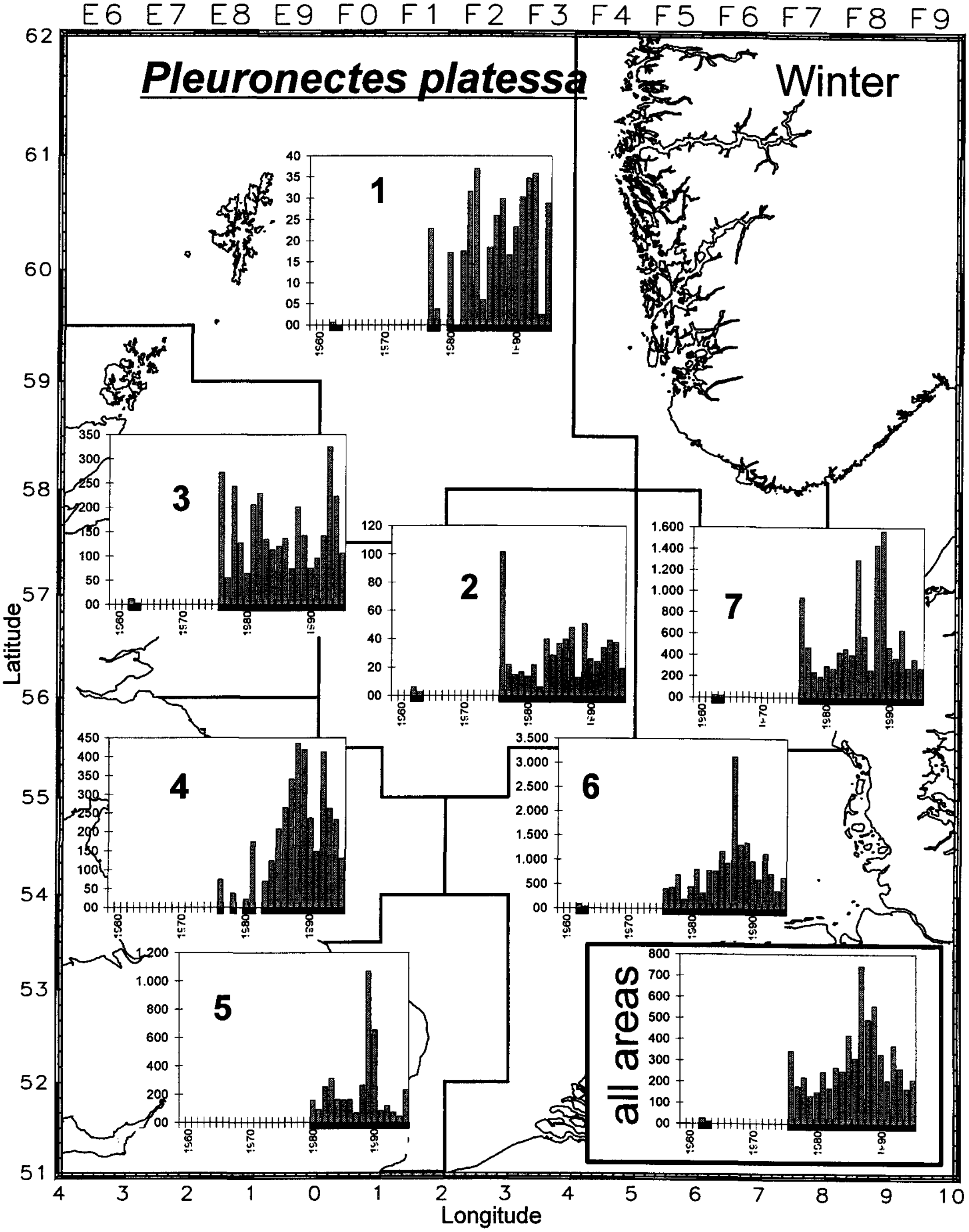


Fig. 3.8.7.8a. Plaice: Mean catch rate (quarter 1; N/10 h) per roundfish area and in the total North Sea during the periods 1962-1963 and 1976-1995.

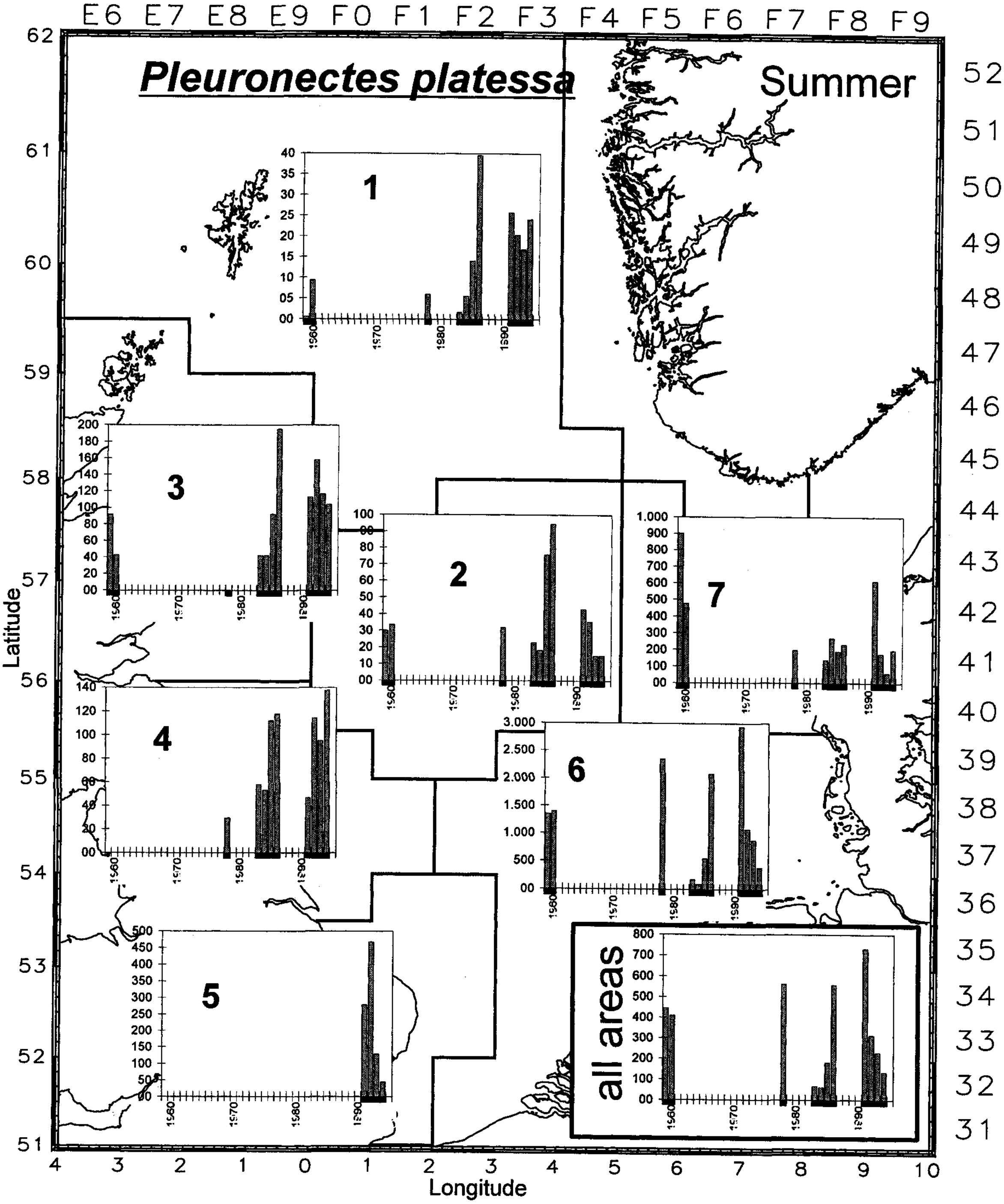


Fig. 3.8.7.8b. Plaice: Mean catch rate (quarter 3; N/10 h) per roundfish area and in the total North Sea during the periods 1959-1960, 1978, 1983-1986 and 1991-1994.

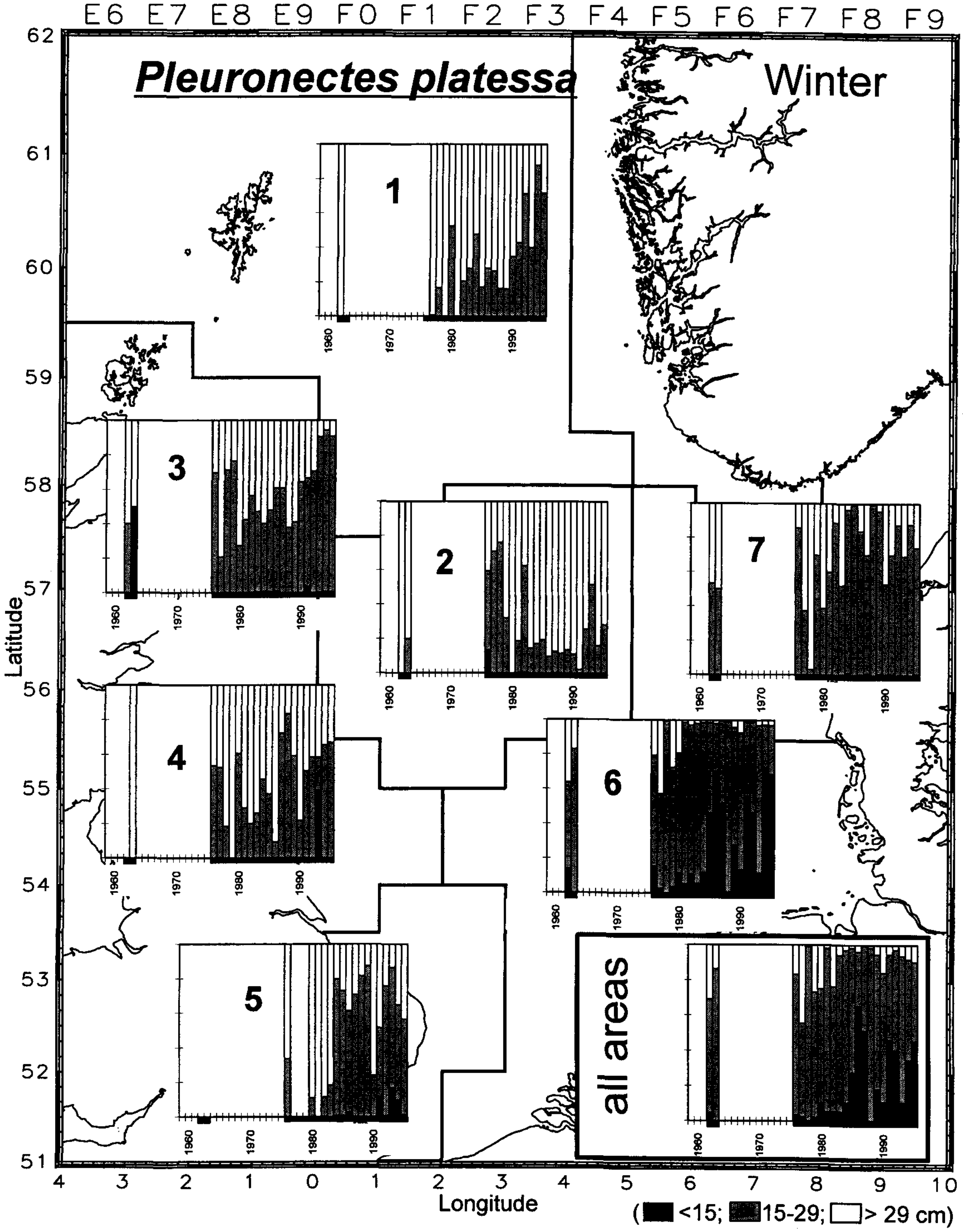


Fig. 3.8.7.8c. Plaice: Percentage of the size classes in the mean catch rate (quarter 1).

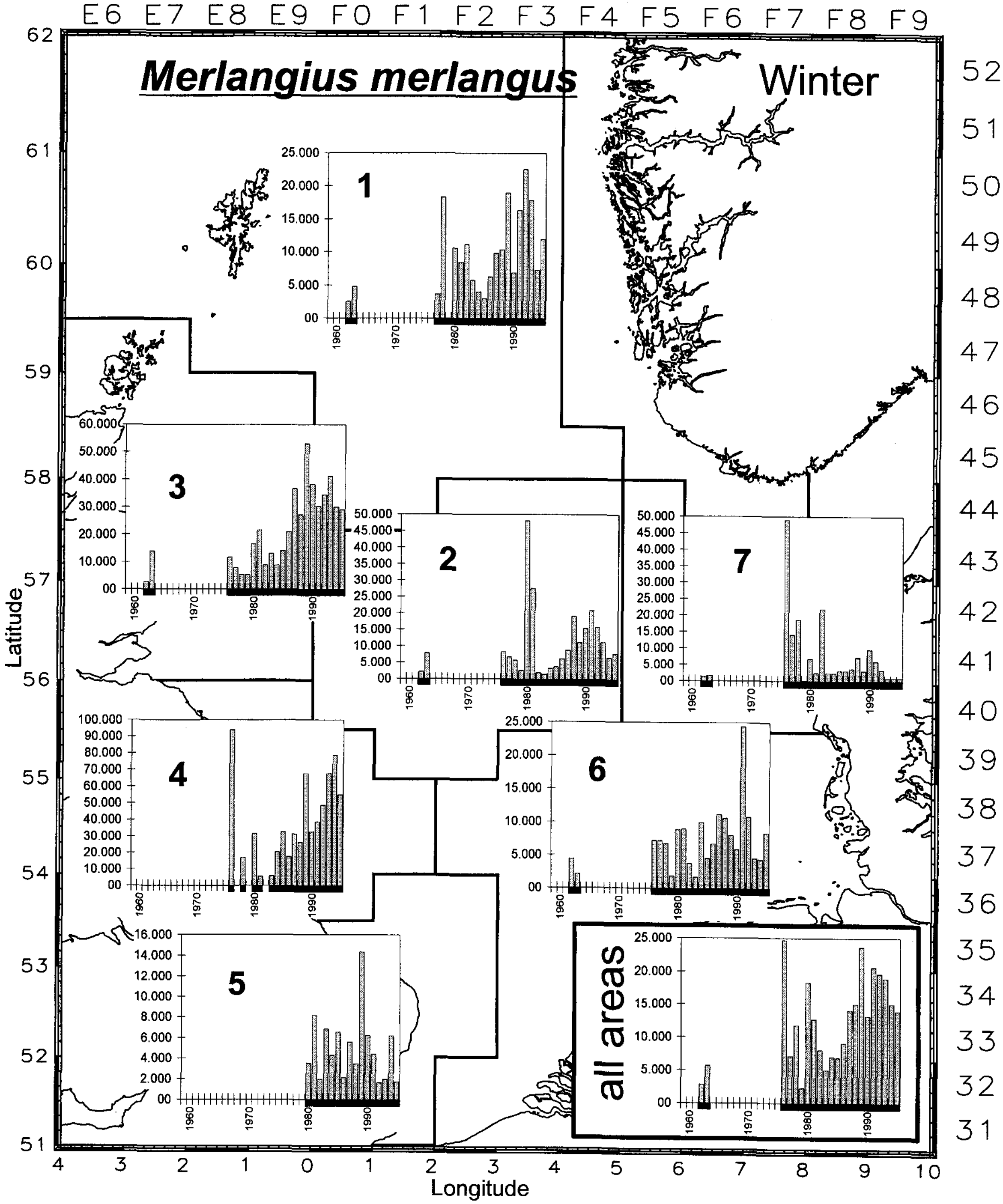


Fig. 3.8.7.9a. Whiting: Mean catch rate (quarter 1; N/10 h) per roundfish area and in the total North Sea during the periods 1962-1963 and 1976-1995.

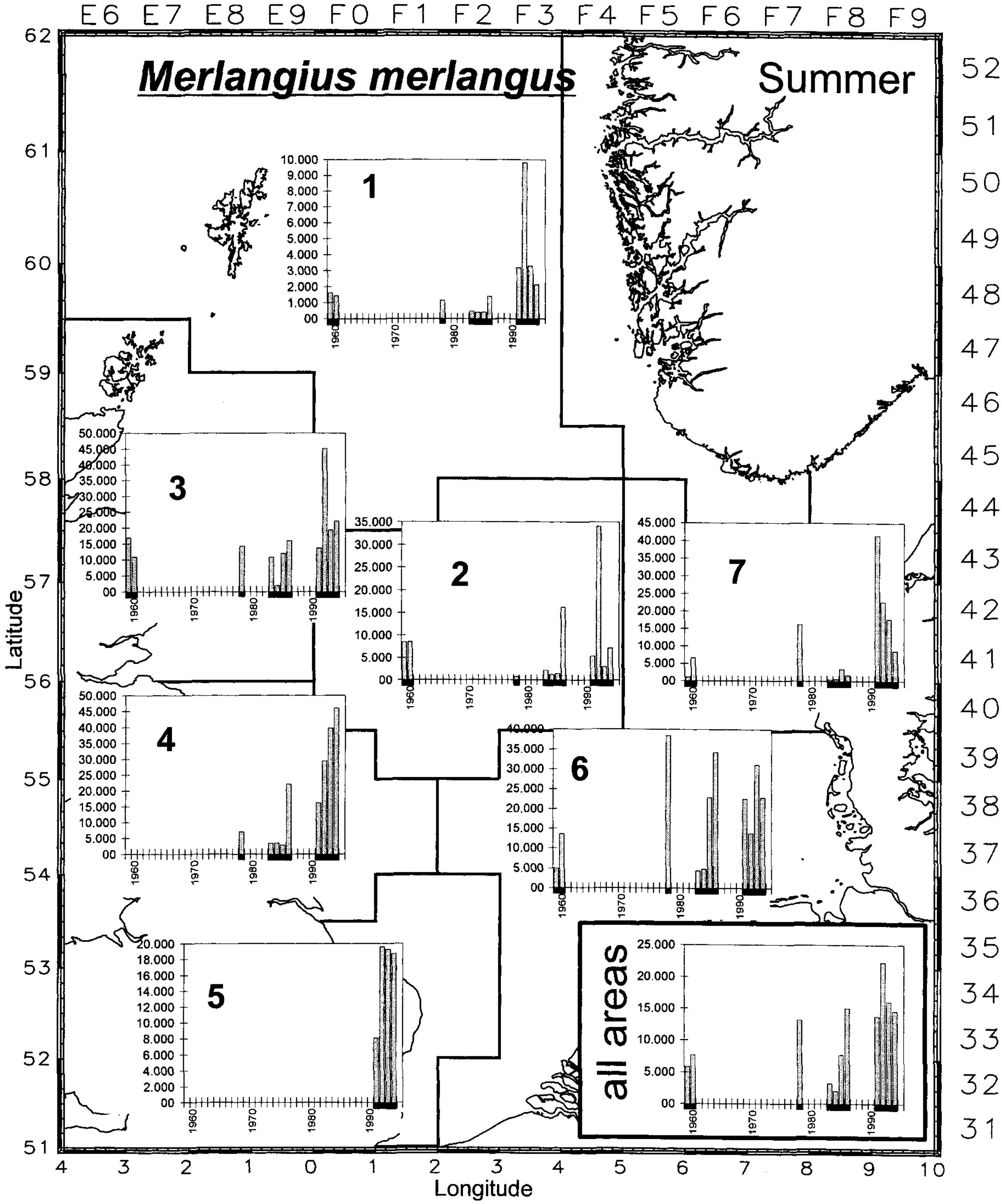


Fig. 3.8.7.9b. Whiting: Mean catch rate (quarter 3; N/10 h) per roundfish area and in the total North Sea during the periods 1959-1960, 1978, 1983-1986 and 1991-1994.

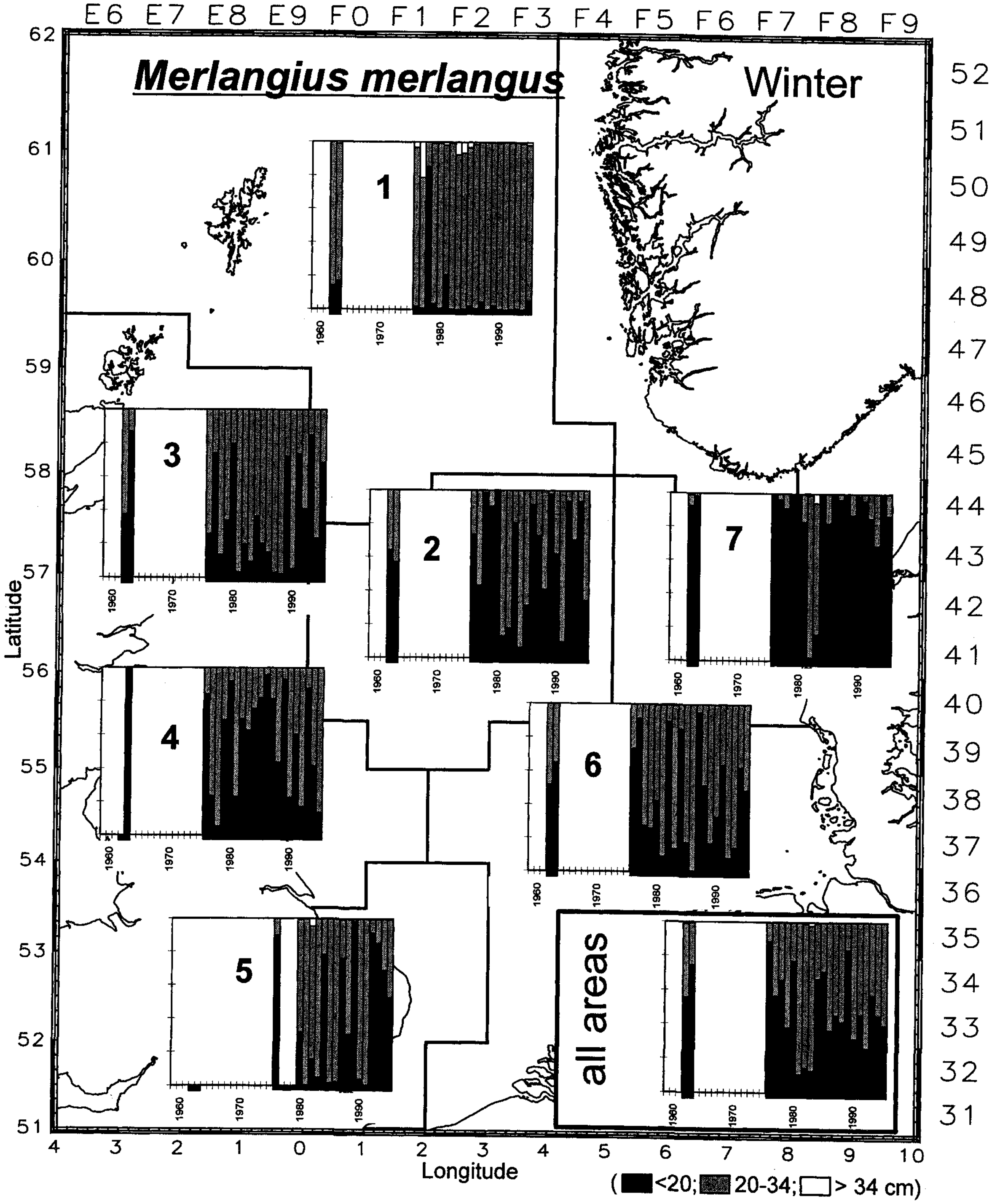


Fig. 3.8.7.9c. Whiting: Percentage of the size classes in the mean catch rate (quarter 1).

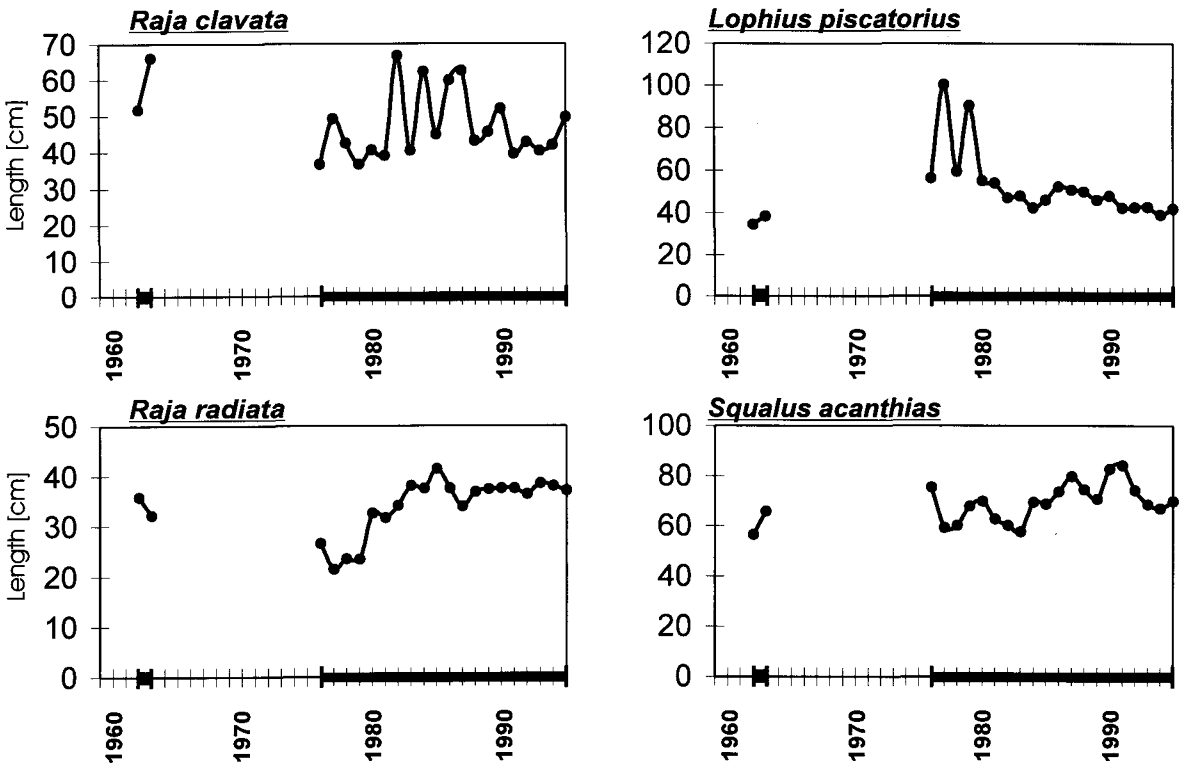


Fig. 3.8.7.10a. Changes in mean length per species during the periods 1962-1963 and 1976-1995.

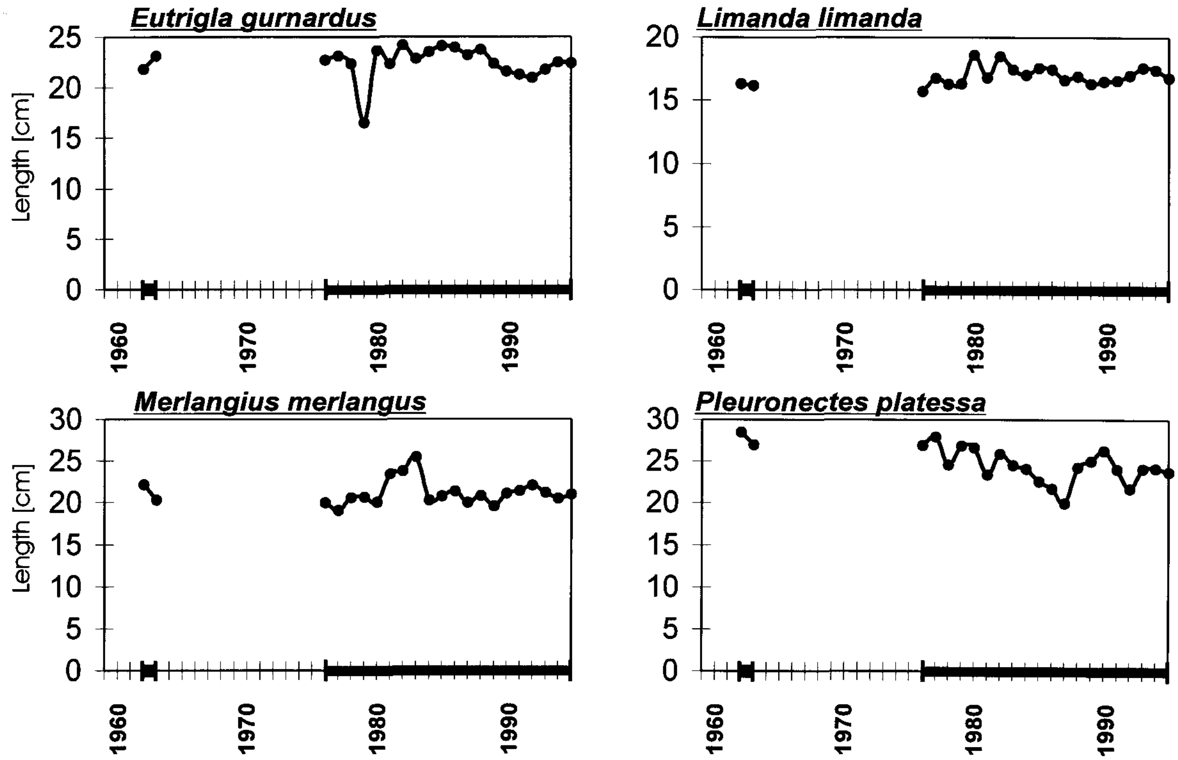


Fig. 3.8.7.10b. Changes in mean length per species during the periods 1962-1963 and 1976-1995.

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:

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

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:

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

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:

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

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.

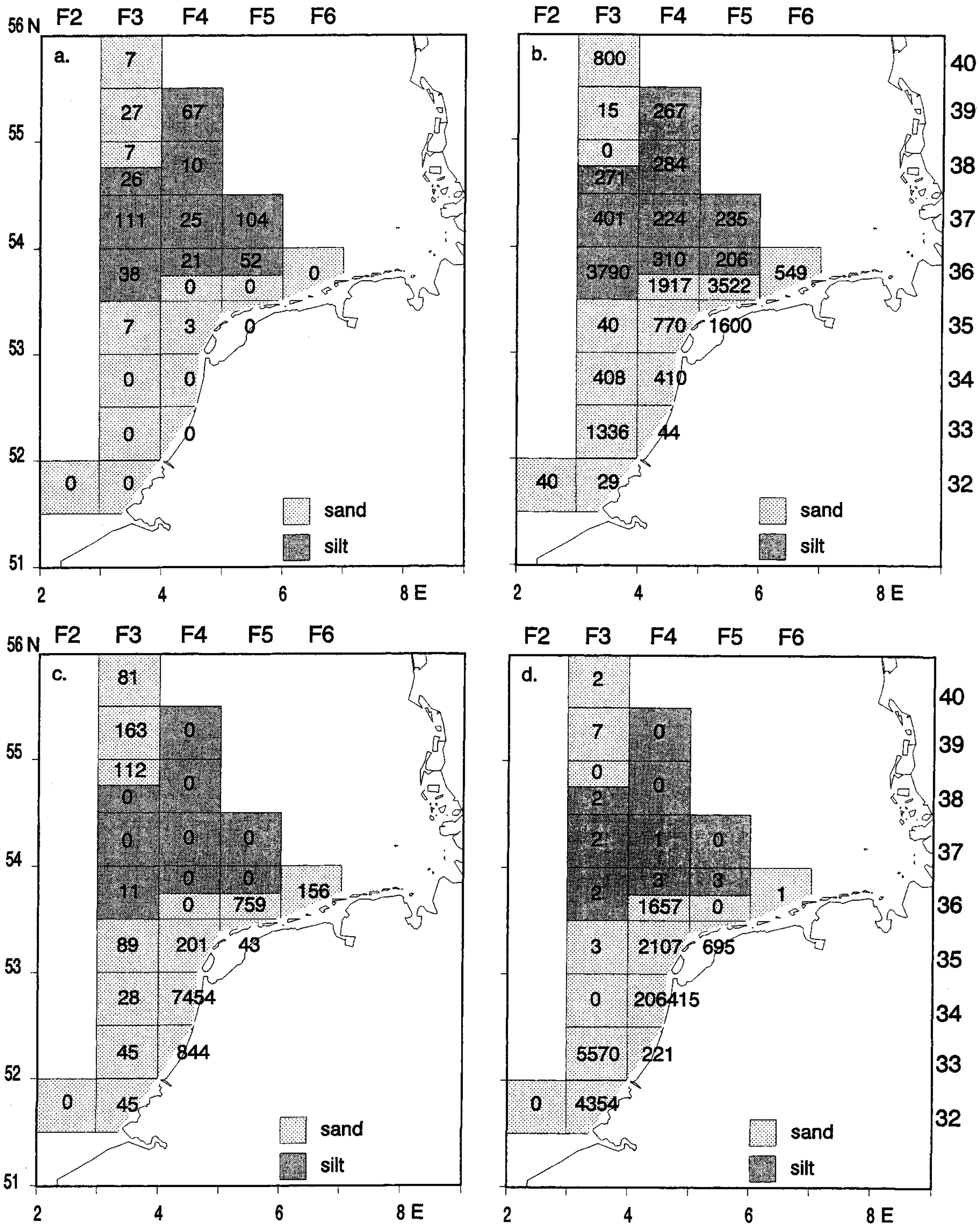


Fig. 4.1.1. Distribution of some invertebrate species over the Dutch sector. Densities were calculated per ICES rectangle in numbers per 100 m^2. Results were based on a sampling programme carried out with the Triple-D, in 1996 (Bergman & van Santbrink 1997). a. *Dosinia lupinus*, a species with a main 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.

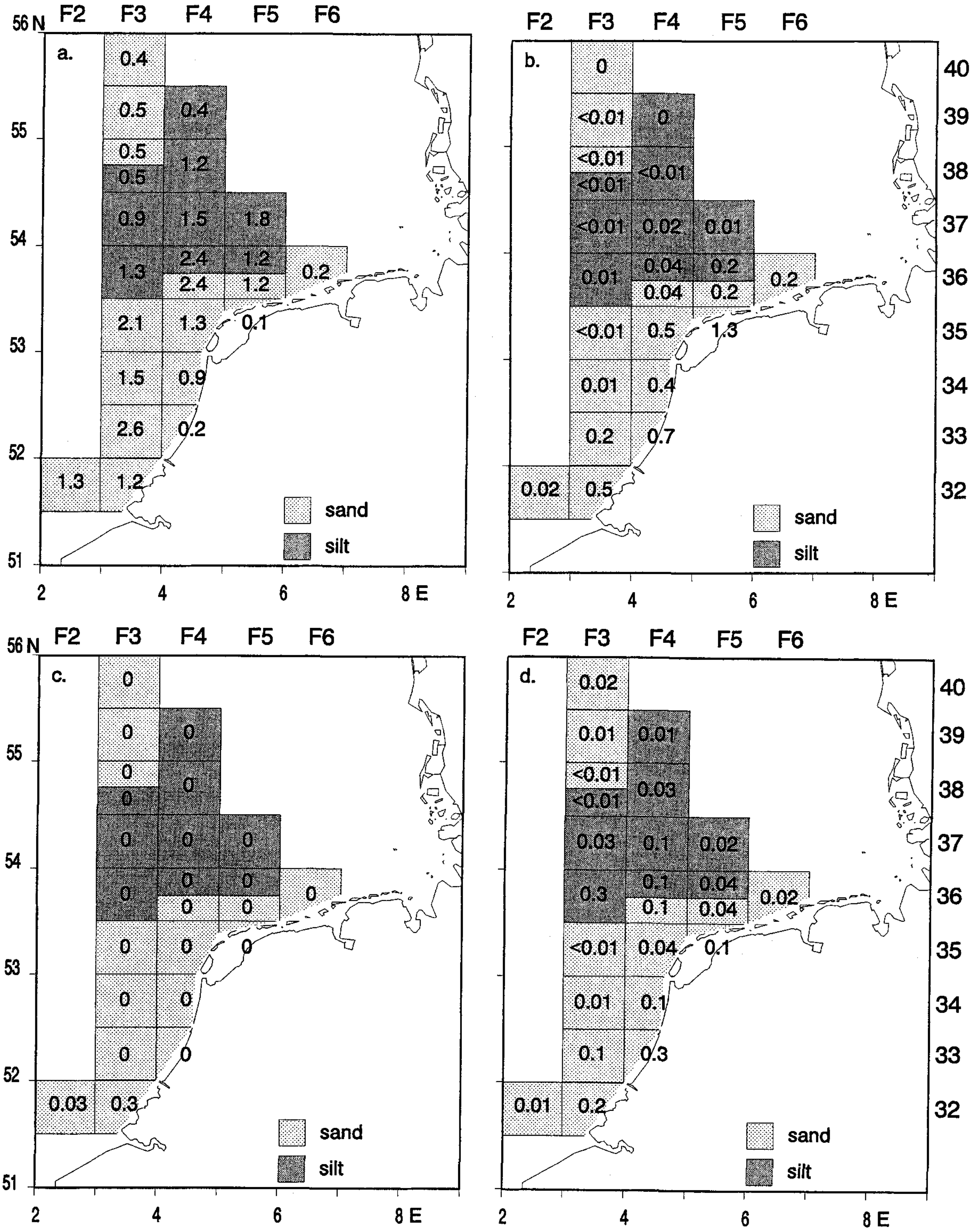


Fig. 4.1.2. Distribution of the trawling effort in 1994, for four types of trawl fisheries, over the Dutch sector. The mean yearly trawling frequency was calculated per ICES rectangle from the results in chapter 3.2.
a. 12m beam trawl fisheries using tickler chains;b. 4m beam trawl fisheries using tickler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

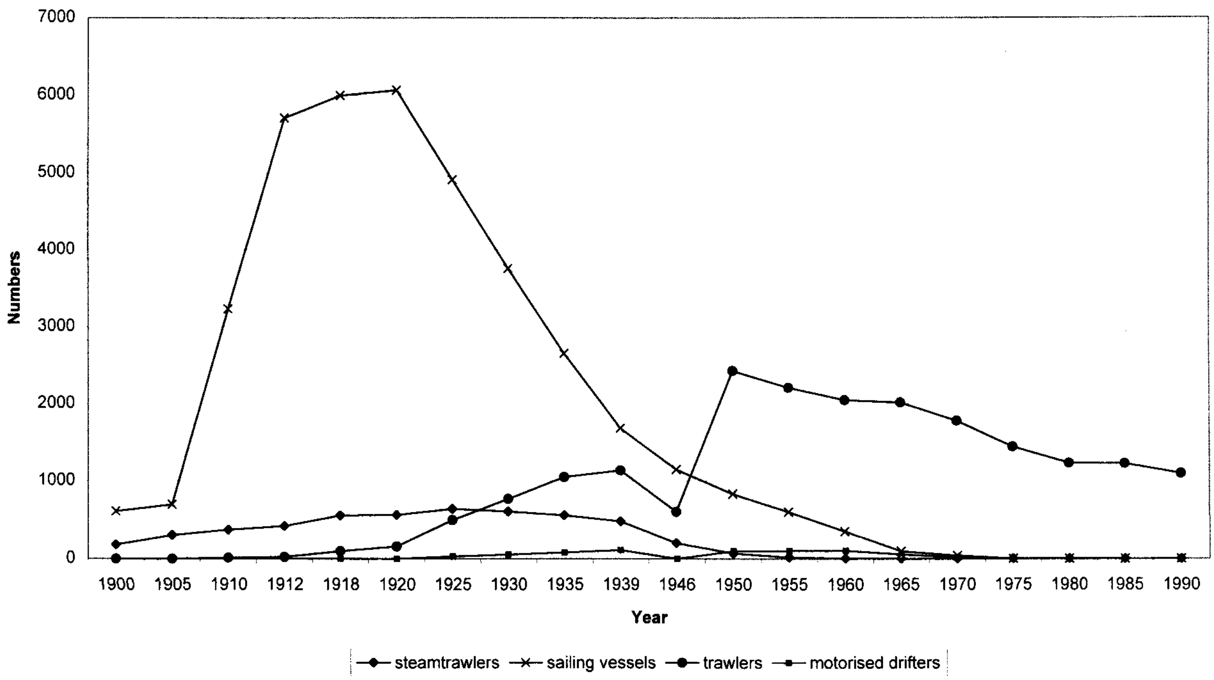


Fig. 4.2.1. Numbers of fishing vessels in the Belgian, Dutch and German fishing fleets since 1900.

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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02 Netherlands Institute for Sea Research (NIOZ), P.O. Box 59, 1790 AB Den Burg, Texel, The Netherlands
03 Institut für Meereskunde (IfM), Düsternbrooker Weg 20, D-24105 Kiel, Germany
04 Alfred-Wegener Institut für Polar- und Meeresforschung (AWI), P.O. Box 120161, D-27515 Bremerhaven, Germany
05 Rijksstation voor Zeevisserij (RSZV), Ankerstraat 1, B-8400 Oostende, Belgium
06 Rijkswaterstaat - North Sea Directorate (RWS-DNZ), P.O. Box 5807, 2280 HV Rijswijk, The Netherlands
07 Netherlands Institute of Ecology - Centre for Estuarine and Coastal Ecology (NIOO-CEMO), P.O. Box 140, 4400 AC Yerseke, The Netherlands
08 Fisheries Research Services, Marine Laboratory Aberdeen (an executive of the Scottish Office) formerly known as Marine Laboratory (MLA-SOAEFD), P.O. Box 101, Victoria Road, Aberdeen AB11 9DB, Scotland (UK)
09 Ministry of Agriculture, Fisheries and Food (MAFF), CEFAS Conwy Laboratory, Bernarth Road, Conwy, North Wales LL32 8UB (UK)
09[a] University of Wales (UWB), Bangor, Wales (UK)
10 Bundesforschungsanstalt für Fischerei - Institut für Seefischerei (BFA-ISH), Palmaille 9, D-22767 Hamburg, Germany
11 Martin Ryan Marine Science Institute (MRI), University College Galway, IR-Galway, Ireland
11[a] Fisheries Research Centre (FRC), Abbotstown, Dublin 15, Ireland

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).

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[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.

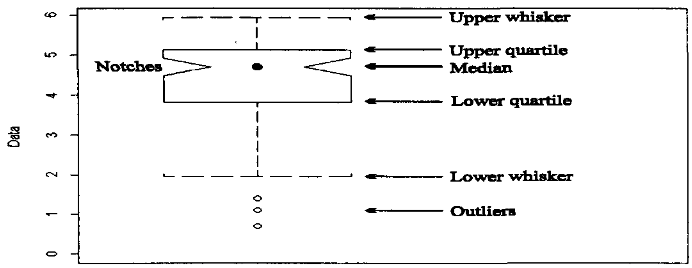
Bobbin(s); roller — A number cylinders which are threaded on wire of specified length to form part of a groundrope (Fig. 3.2.2).

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.

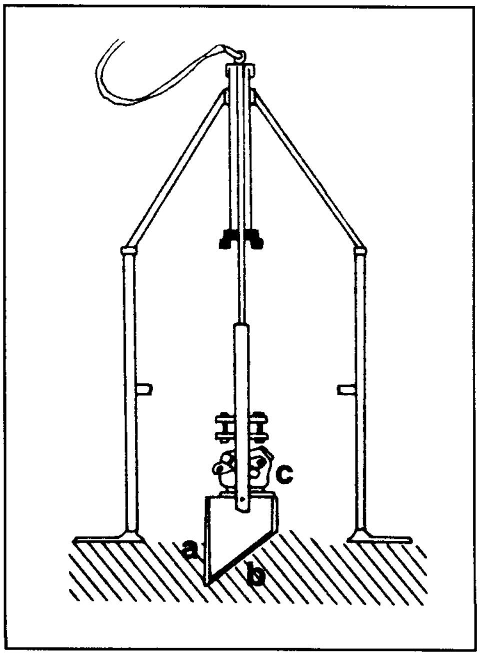
PRIMER Plymouth Routines In Multivariate Ecological Research.

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.

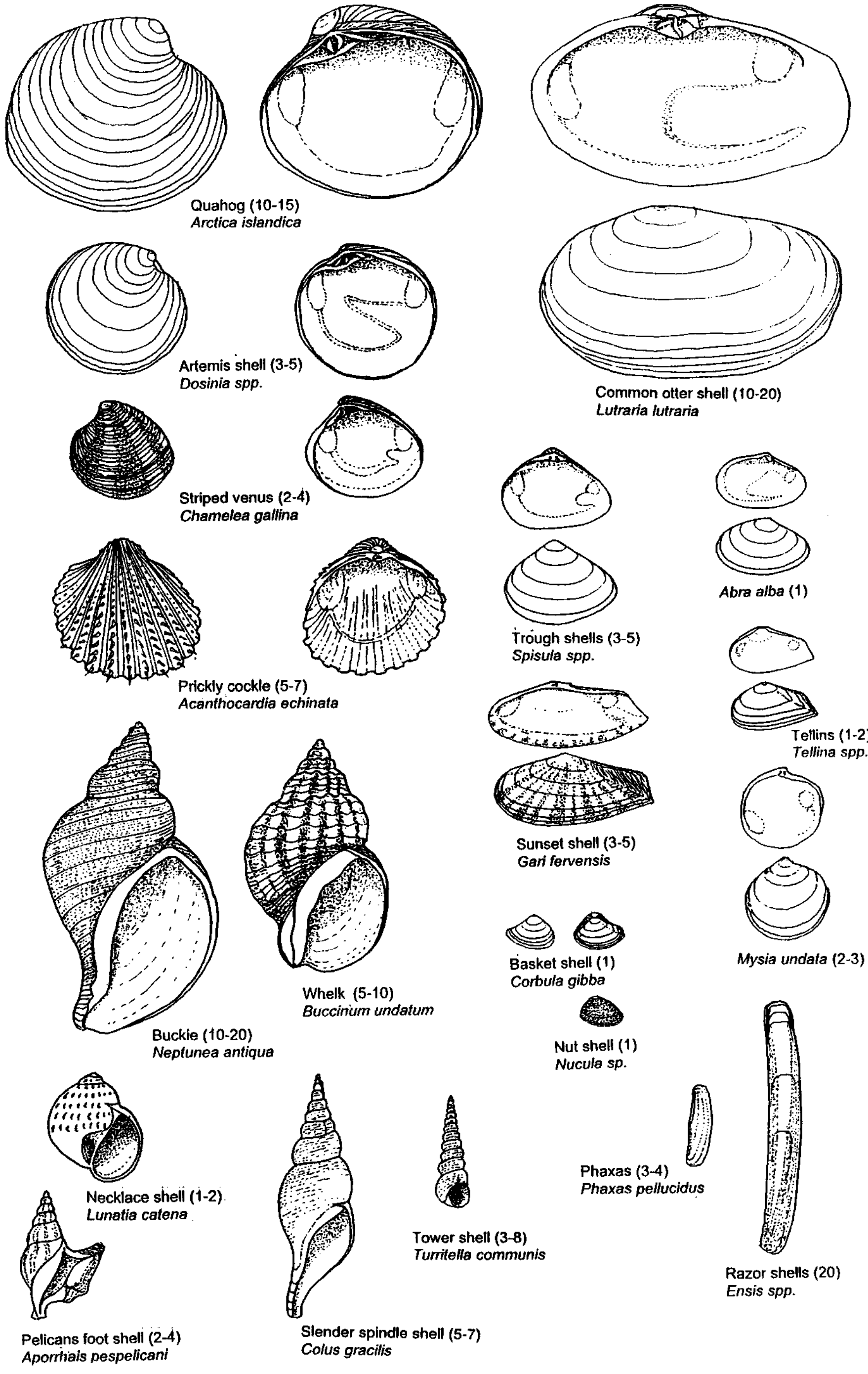
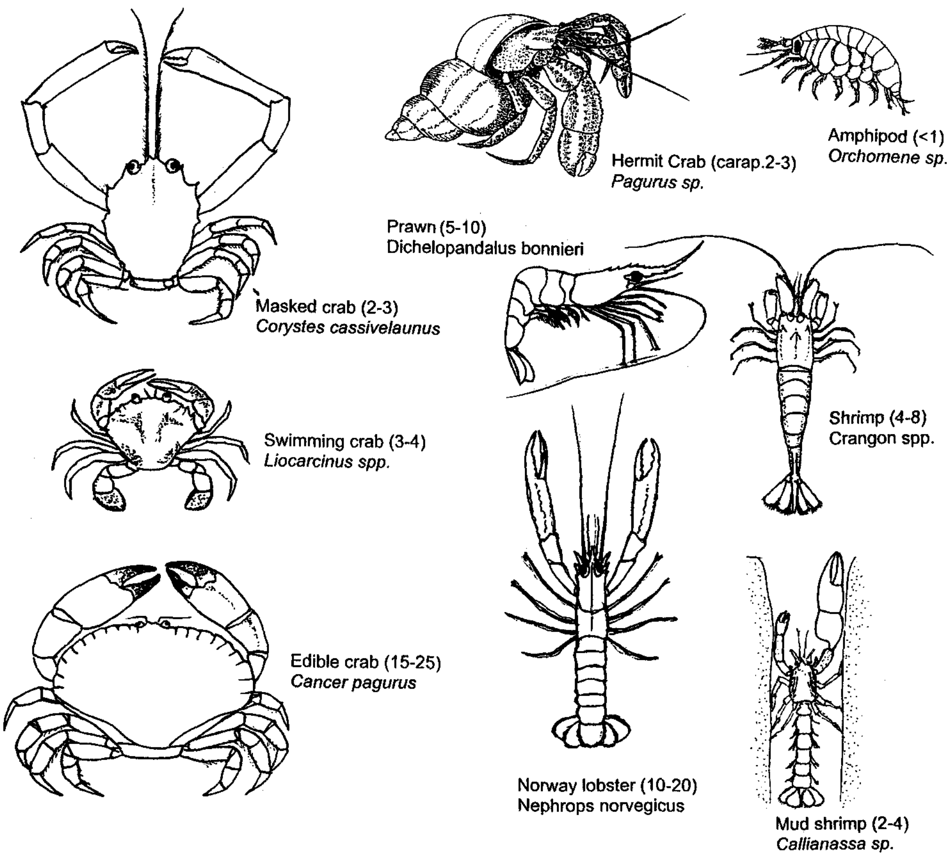


Fig. 6.1. Some of the mollusc species mentioned in the report.
In brackets: adult and maximum size in cm (bivalves: length; gastropods: height).

a



b

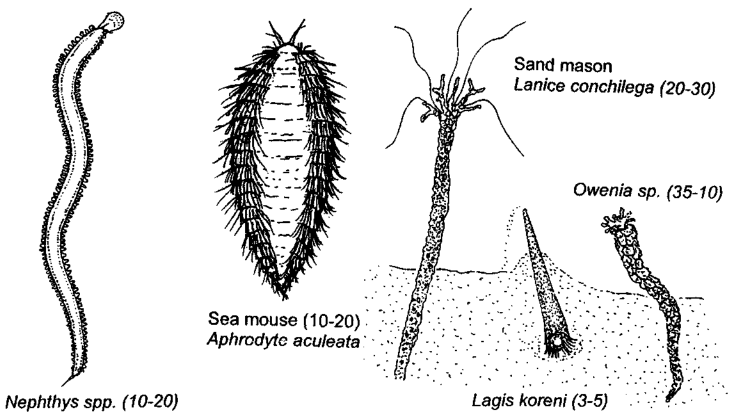


Fig. 6.2. **a**: Some of the crustacean species mentioned in the report. In brackets: adult and maximum size in cm (carapax width). **b**: Some of the polychaete species mentioned in the report. In brackets: adult and maximum length in cm.

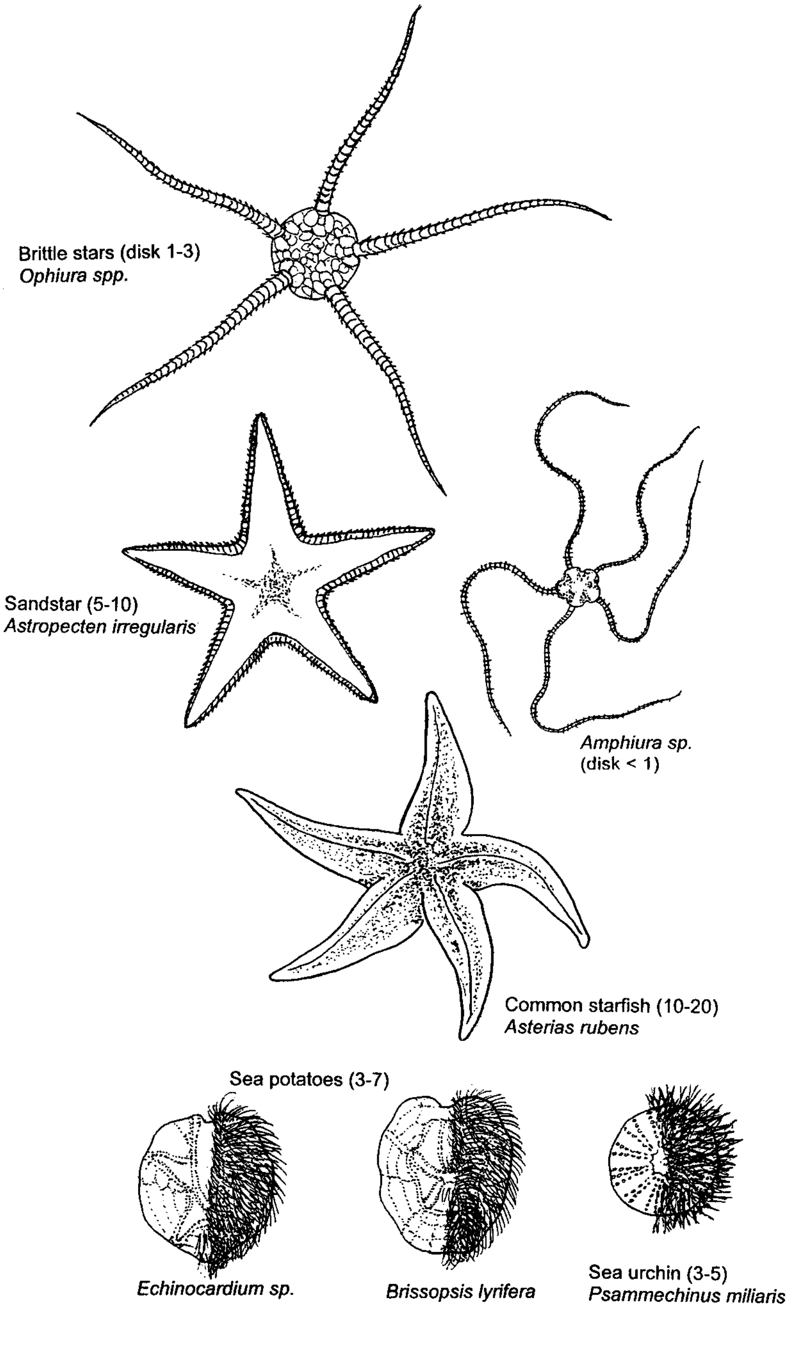


Fig. 6.3. Some of the echinoderm species mentioned in the report.
In brackets: adult and maximum size in cm (diameter or disc diameter (*Ophiura* and *Amphiura*)).

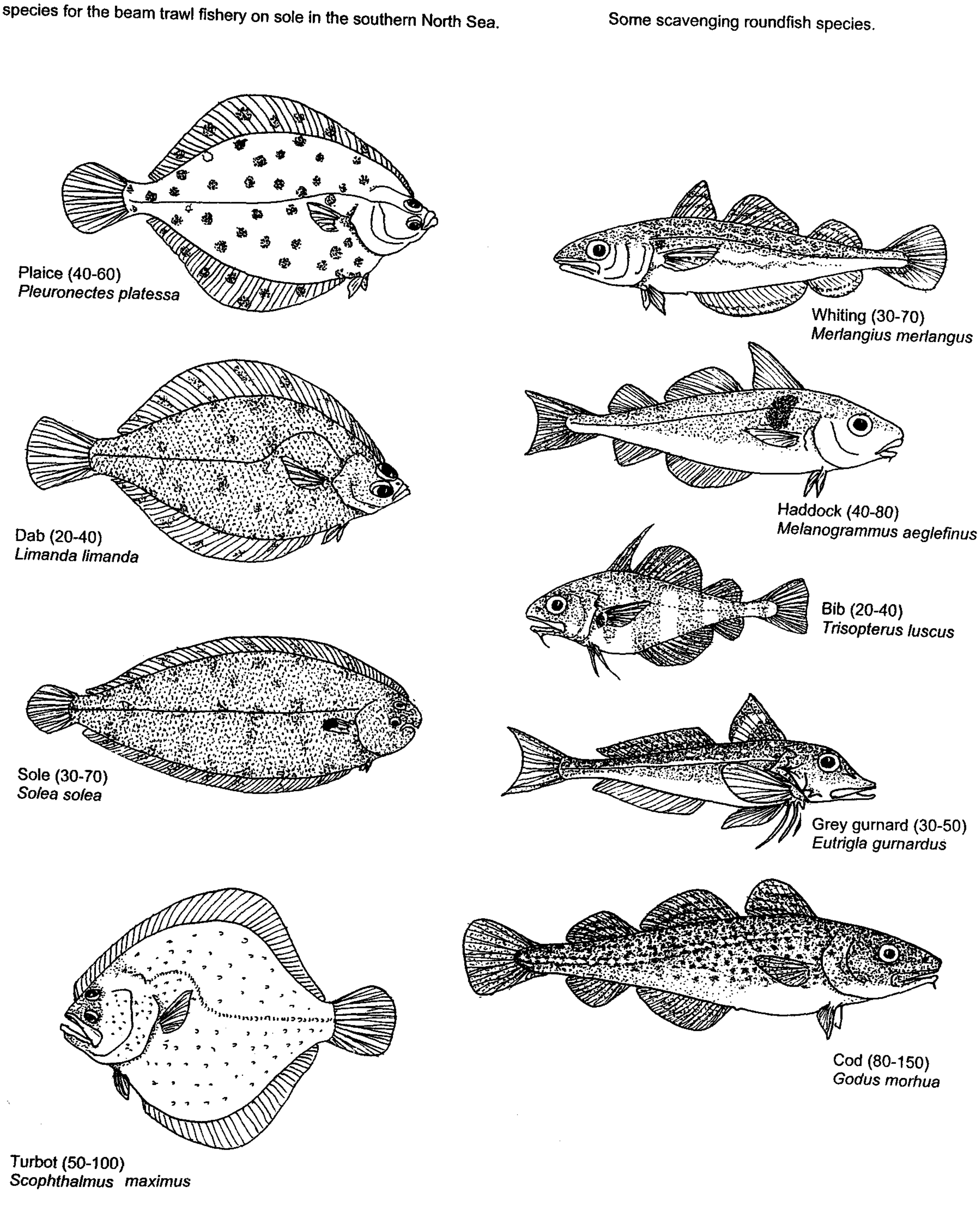


Fig. 6.4. Some of the fish species mentioned in the report.
In brackets: adult and maximum length in cm.

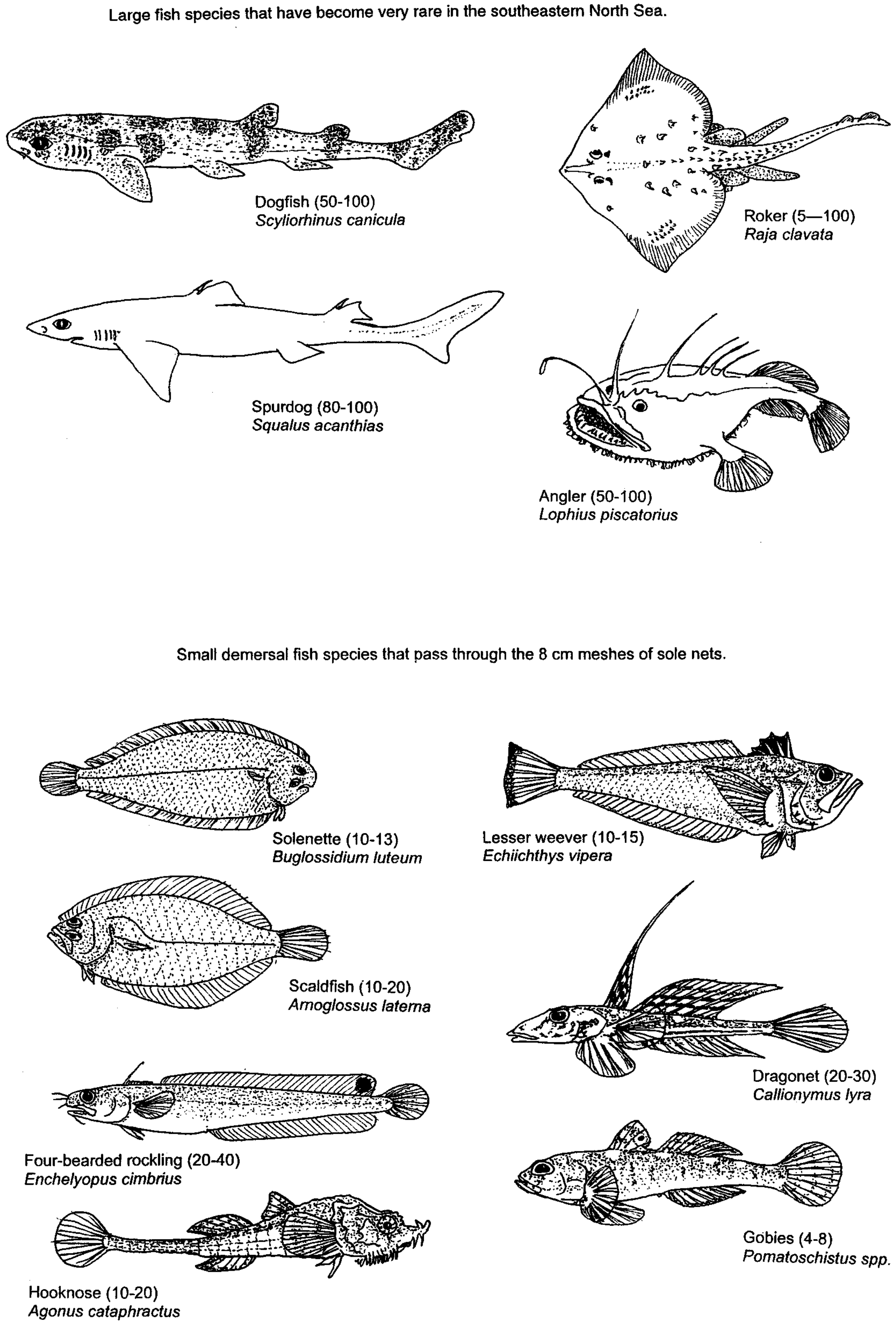


Fig. 6.4. continued.

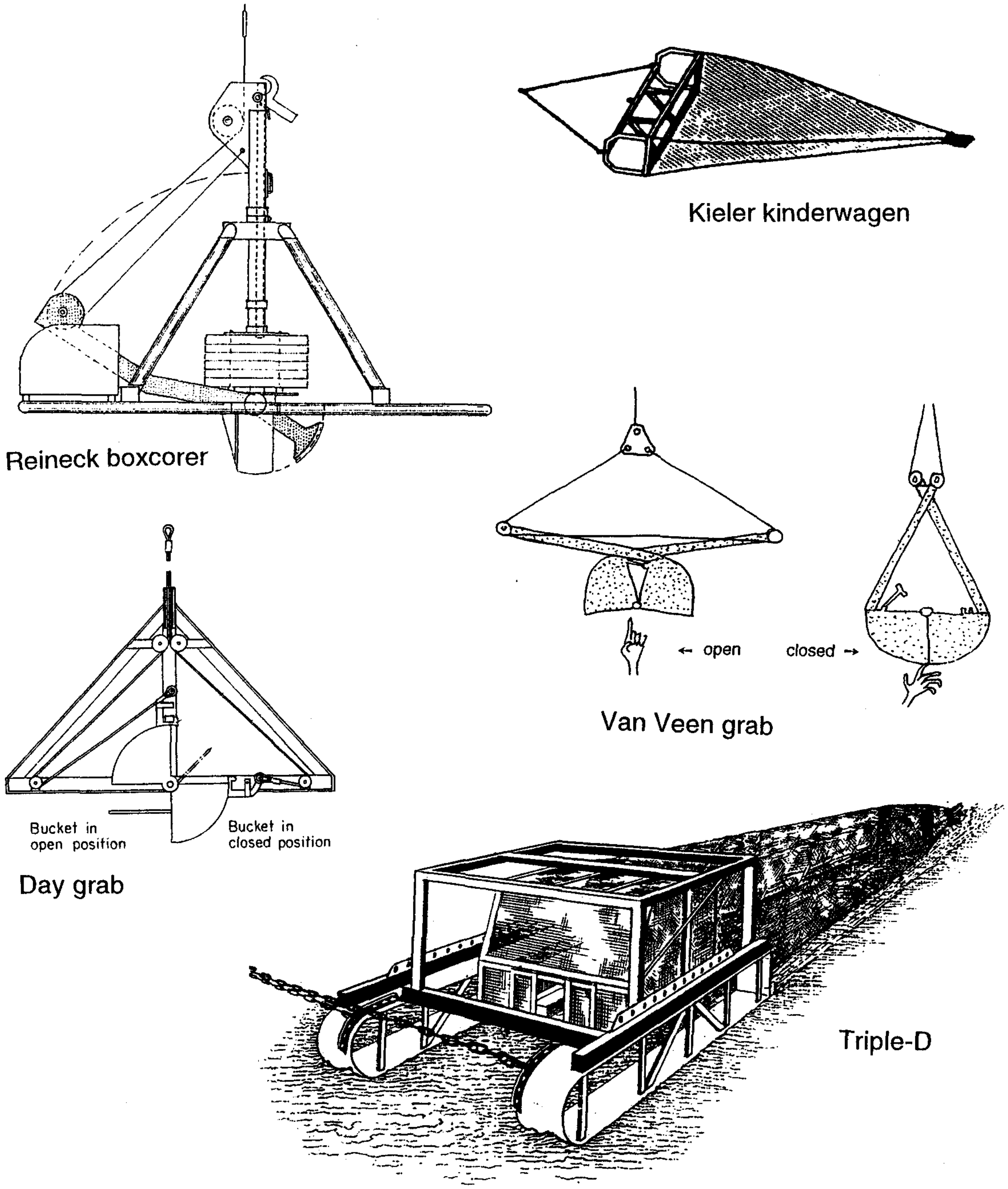


Fig. 6.5. Some of the sampling gears mentioned in the report.

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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CONTENTS

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)		Scheve-ningen	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