

# Paper I



# Species composition and distribution patterns of fishes captured by longlines on the mid-Atlantic Ridge

Inge Fossen<sup>1,4\*</sup>, Charles F. Cotton<sup>2</sup>, Odd Aksel Bergstad<sup>3</sup>, and Jan Erik Dyb<sup>4</sup>

<sup>1</sup> University of Bergen, N-5020, Bergen, Norway

<sup>2</sup> Virginia Institute of Marine Science, College of William and Mary, P.O. Box 1324, Gloucester Point, VA 23062 USA

<sup>3</sup> Institute of Marine Research, Flødevigen Marine Research Station, N-4817 His, Norway

<sup>4</sup> Moere Research, Section of Fisheries P.O. Box 5075, Larsgaard, N-6021 Aalesund, Norway

\*Corresponding author, Moere Research, Section of Fisheries, P.O. Box 5075, Larsgaard, N-6021, Aalesund, Norway. Telephone: +4770111600 Fax: + 47 70111601

E-mail address: [Inge@mfaa.no](mailto:Inge@mfaa.no), [chip@vims.edu](mailto:chip@vims.edu), [oddaksel@imr.no](mailto:oddaksel@imr.no), [janerik@mfaa.no](mailto:janerik@mfaa.no)

## Abstract

During the 2004 MAR-ECO expedition to the Mid-Atlantic Ridge the M/S *Loran* deployed longlines and caught a total of 8518 fish, representing 40 species and 17 families. The 59 longline sets were distributed across the ridge axis at depths ranging from 400 to 4300 m within two sub-areas i.e. just north of the Azores archipelago and in the Charlie-Gibbs Fracture Zone (CGFZ).

Overall, chondrichthyans dominated the catches and contributed nearly 60 % in terms of both weight and numbers. This was mainly due to the dominance of *Etmopterus princeps* in both sub-areas. Multidimensional scaling using species-by-station data indicated an assemblage distribution related primarily to factors varying by depth and latitude. Grouping patterns of stations were not very pronounced, suggesting a gradual spatial change rather than abrupt changes in species composition by depth or latitude.

Catch rates peaked at the shallower stations in the CGFZ sub-area, and generally decreased with depth. Relatively large individuals dominated, and the overall mean weight was 2.4 kg. Average fish weight was lower in the CGFZ sub-area than in the southern sub-area. No depth-related pattern was found.

Keywords: demersal fishes, distribution, assemblages, deep-sea, longline, North Atlantic, Mid-Atlantic Ridge.

## **1. Introduction**

Mid-ocean ridges are major features of the world's oceans (e.g. Garrison, 1993) and offer vast living spaces to demersal fishes, comparable in size and extent to continental slopes. Some of the ridge-associated demersal fishes are target species of commercial fisheries, hence international fisheries management require scientific information on which to base conservation actions for such areas and resources. Scientific information on ridge biota is generally scarce, and the motivation of this study is to provide comprehensive new information on species composition and distribution patterns in order to enhance basic scientific understanding and provide input to advisory processes.

Mid-ocean ridge habitats range from coastal waters around oceanic islands and rugged hills and seamounts to deep slopes and fractures with depths exceeding 4000 m. Although generally hilly and rocky, the ridges also have sediment-covered plains and valleys. Whereas continental slopes have comparatively high standing stocks and production due to the proximity to the productive coastal zones and/or boundary

currents (e.g. Longhurst, 1995), little is known about the processes sustaining macrofauna on mid-ocean ridges where terrigenous influence is very limited. However, it has been suggested that the biological productivity is enhanced on and at ridges compared with the adjacent oligotrophic ocean basins, perhaps because of the regeneration of nutrients by local upwelling as currents are influenced by topographic features.

Many deep-sea fish species and communities are believed to be particularly susceptible to overexploitation due to many species having generally slow growth and extensive longevities and also a tendency of many target species to aggregate into easily captured concentrations (e.g. Merrett and Haedrich, 1997; Koslow *et al.*, 2000). Historical data from shelf and coastal waters have shown that increased fishing activity may alter fish community structure (e.g. Rogers & Ellis, 2000), hence information on community structure and distribution patterns is valuable for present and future management of deep-water fisheries, including those conducted on oceanic ridges. Our study area, the Mid-Atlantic Ridge of the North Atlantic, has been sporadically fished by various gears since the early 1970s (Trojanovsky and Lisovsky, 1995), and there is a need for fishery-independent information in order to provide advice on management options.

Previous studies have shown that mid-ocean ridges have a diverse demersal fish fauna (e.g. Parin, 1980; Trojanovsky and Lisovsky, 1995; Vinnichenko, 1998; Thomsen, 1998; Hareide and Garnes, 2001; Magnusson and Magnusson, 1995), but scientific investigations using advanced technology have been few. Most mid-ocean ridges are rocky and rugged, and sampling near or at the seabed is difficult due to the risk of gear damage or loss. Obstacles to sampling have thus limited fisheries research on mid-ocean ridges, and therefore the understanding of species composition, abundance, distribution patterns and factors influencing habitat use by ridge-associated fish remains limited.

During the June-July 2004 MAR-ECO expedition several methodologies were adopted to achieve a comprehensive understanding of the occurrence, distribution patterns, and assemblage structure of ridge-associated macro- and megafauna, including the demersal fishes. Two ships, R/V *G.O. Sars* and M/S *Loran* were used to collect specimens and gather a suite of oceanographic data during the expedition. The study of demersal fishes comprised collection and compilation of data from quasi-synoptic fishing operations using active and passive gears, video observations from ROVs, and photographs from baited benthic landers.

Studies of deepwater community structure have mostly been conducted with trawl nets that typically undersample the larger predators and scavengers (Jørgensen, 1995; Gordon *et al.*, 2003; Clarke *et al.*, 2005). In a few cases longlines have been used, particularly on seamounts and island slopes (e.g. Uiblein *et al.*, 1998, 1999; Hareide and Garnes, 2001; Bergstad *et al.*, 2007). The sampling onboard the commercial longliner M/S *Loran* during the MAR-ECO expedition provided a rare chance to target these larger animals and to sample in rugged terrain on hard substrate with longlines at the same time as other methods and technologies were used in the same area. This paper, based solely on longline catches, aims to analyse assemblage structure and distribution patterns of demersal fishes in relation to topography, depth, and latitude as revealed by this gear type. Comprehensive comparisons between our results and those from other gears were beyond the scope of this initial account. Data based on other gear and technologies operated from RV *G.O.Sars* (trawls, ROVs, and baited photographic landers) were or will be published elsewhere (Bergstad *et al.*, 2007; King *et al.*, 2006). The longline results presented here will contribute among many other elements to MAR-ECOs comprehensive synthesis towards the end of the project period in 2010.

## **2. Materials & Methods:**

### *2.1. Areas sampled:*

The MAR-ECO project (Bergstad and Godø, 2003; Bergstad and Falkenhaus, 2005) targets the segment of the mid-Atlantic Ridge between Iceland and the Azores (Fig. 1). The longline sampling was constrained by the 3-week charter of the vessel and it was not feasible to sample the entire ridge segment by e.g. a stringent random distribution of sites. Ridge areas northwards towards Iceland, i.e. the Reykjanes Ridge, had been sampled comparatively well in previous studies with similar gears (Hareide and Garnes 2001). Our sampling was therefore concentrated in sub-areas known as the Southern and Northern MAR-ECO boxes (as given in Bergstad and Falkenhaus 2005) where also the RV *G.O. Sars* operated during the same period. The “Southern Box” encompassed an area north of the Azores and the “Middle Box” comprises the areas adjacent to and including the Charlie Gibbs Fracture Zone (CGFZ).

Within each of these two sub-areas longline sets were made along longitudinal corridors denoted in Fig. 1 as "transects". And a "station" in this account refers to an individual set of the longline, whether it is a vertical or bottom longline. Fishing stations were distributed by depth and location so as to allow comparisons along the transects by direct ordination and between transects, sub-areas and depth strata. Within the “Middle Box”, two transects were fished, one on each side of the main east-west fracture of the CGFZ (Fig. 1).

The distribution of the depth-stratified sampling effort along the three cross-ridge transects was determined in advance, but the final selection of exact fishing locations was made by the fishing skipper and principal investigators based on the best information on local topography. Since we had no advance knowledge of depth-distribution patterns, the depth zones <1500 m, 1500-2500 m, and >2500 m were used as operational intervals in order to distribute the sampling effort. The plan was that an equal number of longline sets should be deployed in each zone on either side of the ridge axis.

Between 5 and 10 July 2004 a total of 18 longline stations (42 950 hooks) were fished within the Southern Box. Within the Middle Box, a total of 23 longline stations were fished in Transect II between 12 and 19 July (26 127 hooks) and a total of 18 stations were fished in Transect III between 16 and 18 July (20 214 hooks in total).

Information about each station is summarised in Table 1.

## 2.2. Vessel and gear:

The M/S *Loran* is a technologically advanced Norwegian demersal longlining vessel (51 m length, 11 m beam) that typically fishes gadiform fishes and Greenland halibut (*Reinhardtius hippoglossoides*) along the coast of Norway, in the Barents Sea, and west of the British Isles. She is equipped with a Mustad Autoliner automated longlining system. This system baits the hooks, sets and retrieves the line, and has the capacity to set multiple hook types at a rate of up to 250 hooks per minute. The longline is polyester rope (11.5 mm), with hooks attached to 0.5 m twine leaders tied into swivels attached to the main line. The hooks used on this survey were either circle (14/0) or EZ J-hooks (Mustad 13 and 13W). These two hook types were used in equal portions on all longlines and each longline was baited with equal portions of both squid (*Illex* sp.) and Atlantic mackerel (*Scomber scombrus*).

Sampling was conducted by bottom and vertical longlines. Hooks were spaced 1.2 m apart on the bottom longlines and 0.6 m on the vertical longlines. Vertical longlines were only used on the shallower stations (Table 1). In the analyses, data from the two gear types were pooled, although some differences in catchability of certain species might be expected, due to differences in foraging behaviour.

Average depth of each bottom longline station was calculated as a simple arithmetic mean of the depth at the start and end positions of the longline (Table 1). For vertical longlines, fishing depth is reported as the depth at which the gear was deployed, although the effective fishing depth ranged from approximately 15 to maximum 351 m above bottom. The maximum number of hooks on any vertical longline was 560 hooks, which corresponds to a maximum of 336 m of line with hooks. However, the



vertical longlines are never truly vertical due to current drag on the line, and therefore the maximum distance from the bottom was less than 351 m.

### 2.3. *Data recorded at sea*

At each station, all fishes were identified to species or lowest possible taxonomical level, weighed, and measured. In addition, sex and maturity stage were determined. Total length from snout to end of the caudal fin was recorded for all species except macrourids and chimaerids. For these taxa, pre-anal fin length and length from snout to posterior end of the second dorsal fin was measured, respectively. Sexual maturity stage of chondrichthyans was assessed according to the description and scale proposed by Stehmann (2002). Sexual maturity stage of teleosts was recorded according to Mjanger *et al.* (2003, p. 109). Additional samples from some species were also collected for age and growth studies, genetic analyses, reproductive studies and diet analyses and these results will be published separately. More details on the M/S *Loran* sampling was provided in the survey report by Dyb and Bergstad (2004).

Hydrographical data were not collected by the longliner due to lack of instrumentation, but the hydrography of the area was investigated by the RV *G.O. Sars* during the same period (Søiland *et al.*, 2007).

### 2.4. *Analysis*

For each station, total catch per unit of effort (CPUE), and CPUE for each species was calculated following Equation 1. Similarly, catch rate values given as number of specimens per species was calculated by replacing weight (kg) with numbers caught in Equation 1. Shannon- Wiener index of diversity ( $H'$ ), species richness (S), and Hurlbert's evenness ( $J'$ ) were calculated using Equations 2 – 4, respectively (Beisel *et al.*, 2003).

$$(1) \text{ CPUE} = \text{Catch in kg} / 1000 \text{ hooks on the longline}$$

(2)  $H' = \sum p_i \ln p_i$ ,  $p_i$  is the fraction of species  $i$  in the sample

(3)  $S = (s-1)/\ln(N)$ ,  $s$  = number of species,  $n$  = number of specimens.

(4)  $J' = (H' - H'_{\min}) / (H'_{\max} - H'_{\min})$ ,  $H'_{\min} = \ln(n) - [(n-s+1)\ln(n-s+1)/s]$ ,

$H'_{\max} = \ln(s)$ ,

$s$  = number of species,  $n$  = number of specimens.

Prior to the analyses of CPUE values, data was  $\log(\text{CPUE}+1)$  transformed to allow for zero records and to reduce the effect of large and frequently occurring species. Average fish weight for individual species at each station was based on actual observations or in some cases estimated from length-weight relationships obtained during the survey. In order to analyze differences in mean weight between depth strata (500 m) for individual species, we used the mean weight per station. We only included stations where more than 4 specimens of a species were caught. Variation in mean weights among stations was analysed with a parametric ANOVA (*Systat 10.2*). In these analyses,  $\log(\text{mean weight})$  was used as input.

To explore patterns of variation among stations a Multidimensional Scaling (MDS) ordination was performed using Kruskal's Stress formula 1 scaling method (*Systat 10.2*). A between-station matrix of Pearson's correlation coefficients was used as input. These correlations were based on the square root transformation of CPUE (kg/1000 hooks) data of individual species by longline station. To reduce noise, only species occurring on 3 or more stations, and represented by more than 4 specimens in total were included. The MDS analysis was performed using 57 stations and 29 taxa (Table 2). For comparison a trial run was also made using square root transformation of numerical abundances.

### 3. Results

#### 3.1. Abundance and biomass

Overall, catch rates of all demersal species pooled declined with depth (Fig. 2). Highest CPUE values were recorded on the vertical longlines in the Middle Box. However, no significant differences in CPUE were observed between vertical and bottom longlines ( $F_{1,57} = 0.844$ ,  $p = 0.363$ ).

Furthermore no significant differences in catch rates were observed between the Middle and the Southern Box ( $F_{1,57} = 0.060$ ,  $p=0.807$ ) when the effect of mean station depth was removed by using it as a covariant ( $F_{1,57} = 17.842$ ,  $p<0.001$ ). Similarly no differences were observed between Transect II and III ( $F_{1,40} = 0.944$ ,  $p = 0.337$ ) using mean station depth as covariant ( $F_{1,40} = 13.996$ ,  $p<0.001$ ).

#### 3.2 Taxa recorded:

At least 40 species from 17 families were collected and the number of specimens captured and recorded was 8518 (Table 2). Of these species, 13 were only observed in the Southern Box, 13 only in the Middle Box, and 14 in both boxes (Table 2). In the Middle Box a number of species occurred that are considered boreal or sub-arctic, e.g. *Anarhichas denticulatus*, *Sebastes marinus*, *Brosme brosme*, *Phycis blennoides* and *Macrourus berglax*. In the Southern Box species associated with a more southerly distribution occurred, e.g. *Lepidion guentheri* and *Deania hystricosa*.

When considering only those species captured at 3 or more stations in the Middle Box (Table2), we found only two species, *A. denticulatus* and *P. blennoides*, exclusively on the north side of the CGFZ and only two species, *Spectrunculus sp. A*, and *Lepidion schmidti* exclusively on the south side of the CGFZ.

### 3.3 Taxonomic uncertainty

After the voucher specimens were examined more thoroughly, it was apparent that there was uncertainty with regards to the identification of some macrourids captured in this study. The identification of *Coryphaenoides armatus*, *C. rupestris* and *M. berglax* was accurate, however, it was later determined that many unidentified macrourids labelled “*Coryphaenoides* sp.” during the cruise actually consisted of a mixture of *C. guentheri*, *C. leptolepis* and *C. mediterraneus*. In the data analyses, these macrourids were left as *Coryphaenoides* sp. Similarly, the alepocephalid voucher specimens later turned out to include several species (*Alepocephalus agassizii*, *A. australis*, and *Narctes erimelas*), and therefore all alepocephalids were pooled under the family “Alepocephalidae” in the data analyses. There was also an unresolved issue with cusk eels. For the data analyses, these have been labelled “*Spectrunculus* sp. A” and “*Spectrunculus* sp. B.”, referring respectively to a large pale form and a smaller dark brown form. Table 2 contains a complete list of species captured during the cruise, including the taxa and morphospecies given provisional names.

### 3.4. Variation in species composition

Multidimensional Scaling ordination was used to explore underlying patterns of similarity among stations (Fig. 3, stress=0.169). A general linear model (GLM) was used to analyse relationships between scores on Dimension 1 and 2 with factors such as depth and latitude.

Two analyses were performed with each of the MDS dimensions as the dependent factor (Model: Dimension 1 (or 2) = Average station depth + Latitude). Both models yielded significant results ( $F_{2,56} = 51.49$ ,  $p < 0.001$ ,  $r^2 = 0.660$ , and  $F_{2,56} = 17.50$ ,  $p < 0.0001$ ,  $r^2 = 0.398$ , for Dimension 1 and 2, respectively). For Dimension 1, only average depth explained the observed variance ( $t = -9.73$ ,  $p < 0.0001$ ). This suggests that the major source of variation in the station similarity matrix, essentially species composition, was related to depth or depth-related structuring factors. For Dimension 2, only latitude was found to significantly explain variation ( $t = 4.98$ ,  $p < 0.001$ ).

These results were reflected in the graphical output (Fig. 3) where stations are generally distributed by depth and latitude along Dimensions 1 and 2, respectively.

However, a further indication of clustering is also revealed in the plot, and there are possibly three clusters. The deep stations from the Southern and Middle box appear to form a coherent group, yet with an internal latitudinal pattern, and this cluster of deep stations is separated from two shallow clusters to the right in the plot. The two shallow stations groups appear separated on Dimension 2, i.e. by latitude. The indication from this result is that latitudinal patterns in species composition are more pronounced for shallow than for deep stations. However, no clustering was found between the stations placed north or south of the Charlie-Gibbs Fracture Zone in the Middle Box. Also the MDS with numerical abundance instead of biomass as input resulted in similar plot and identical conclusions to those described above.

### *3.5 Description of species composition*

Stations in the Southern Box were generally dominated by chondrichthyans. Of the total catch of 7827 kg in the Southern Box, chondrichthyans constituted 4993 kg. This was mainly caused by the dominance of *Etmopterus princeps* at several of the stations (Table 2). Among the other dominant species was *Spectrunculus* sp. A and *Coryphaenoides armatus* in terms of numbers and *Spectrunculus* sp. A and *Centrophorus squamosus* by weight (Table 2). Stations in the Middle Box were also dominated by chondrichthyans, which constituted 6 942 kg of the total of 12 814 kg recorded for that sub-area. However, when the weight of a 700 kg Greenland shark, *Somniosus microcephalus*, was excluded, chondrichthyans and teleosts contributed more evenly to the total catch in weight, 6 242 kg and 5 872 kg respectively. Overall, the fish catches were dominated by *E. princeps* and *Antimora rostrata*, with *Hydrolagus affinis* also contributing substantially in terms of weight (Table 2).

In the shallower stations of the Middle Box (cluster 2 in Fig. 3, 440 – 949 m), *E. princeps* dominated together with *Brosme brosme* both north and south of the Charlie-

Gibbs Fracture Zone (Fig. 4). This was quite different than in the Southern Box (cluster 3 in Fig. 3, 842 – 1651 m,) where the catch was dominated both in weight and numbers by *E. princeps*, *C. squamosus*, *Centroselachus crepidater*, and *Centroscymnus coelolepis*. (Fig. 4, Table 2). The cluster consisting of the deepest stations (cluster 1 in Fig. 3, 959 – 4250 m) was dominated by *A. rostrata*, *E. princeps*, *C. armatus*, and *Spectrunculus sp. A* (Table 2, Fig. 4, Fig. 5). Although a tendency of between sub-areas differences also can be seen among the deeper stations, these deeper stations had a more similar species composition than the shallower (Fig. 3, Fig. 4).

A closer examination of species occurrence at depth reveals the depth range for each species (Fig. 5). No abrupt changes in distribution can be seen. Rather changes seem to occur gradually with increasing depth.

### 3.6. Diversity

Diversity indices calculated for the different stations showed large variation between stations (Fig. 6). Both the indices for diversity and richness peaked at depths between 1000 and 2000 m. Evenness varied markedly between stations, especially between the shallowest, but no general trend was otherwise observed.

### 3.7. Variation in mean fish weight by depth and sub-area

The overall mean weight of individual fish recorded for the entire collection was 2423 g but variation was substantial between sets and transects (Fig. 7). The mean individual weight of fishes in the Southern Box was significantly higher than that for the Middle Box ( $F_{1,57} = 9.972$ ,  $p = 0.003$ ), when the effect of station depth was removed by using it as a covariant ( $F_{1,57} = 0.987$ ,  $p = 0.325$ ) (Fig. 7).

To study intra-specific variation, the records were split into 500 m depth intervals. Only 11 species had an adequate number of records to carry out the analysis, and of

these only 4 showed a significant change in mean individual weight with increasing depth (Table 2). Mean weight of *A. rostrata* decreased below 2000 m ( $F_{4, 27} = 7.489$ ,  $p = 0.001$ ) and mean weight of *C. armatus* increased with increasing depth ( $F_{2, 15} = 5.185$ ,  $p = 0.026$ ) (Fig. 8). Mean weight of *H. affinis* varied greatly between stations but showed a decreasing trend with increasing depth ( $F_{2, 9} = 14.441$ ,  $p = 0.008$ ). Mean weight for *Macrourus berglax* was higher in the 1000-1500 m depth stratum than in shallower or deeper strata ( $F_{2, 11} = 11.658$ ,  $p = 0.004$ ) (Fig. 8).

### 3.8 New records

Several species collected during the longlining operation were notable either due to their rarity or because they had not previously been reported from these sub-areas of mid-Atlantic Ridge. We collected three specimens of the pale skate *Bathyraja pallida*, a species previously represented by only six other specimens since the original description of the species in 1967, all from the eastern North Atlantic (Orlov *et al.* 2007). Also, *B. richardsoni* had not previously been reported from the mid-Atlantic Ridge, and the 142 specimens we collected represent the largest recorded number of this species from a single expedition. Orlov *et al.* (2007) also present distribution and morphometric data of *B. richardsoni* collected during this cruise. *Hydrolagus pallidus* was only recently described by Hardy & Stehmann (1990). Our data shows a wider range both latitudinally (42°23'N – 53°02'N) and with respect to depth (883 – 2619 m) than what was previously known for this species.

Among the teleosts, two of the *Lepidion* species had not previously been reported from this part of the mid-Atlantic Ridge. Most records of *L. guentheri* are from the Mediterranean Sea, with a few records from the eastern Atlantic near Madeira Island (Cohen, 1979, Stefanescu *et al.*, 1991). In our data, a total of 19 specimens of *L. guentheri* were collected in the Southern Box (Table 2). Similarly, only two previous studies mention *L. schmidtii* from the Northeast Atlantic (Templeman, 1970; Hareide & Garnes, 2001). Anecdotal records suggest that in recent years this species has been caught with longlines on several occasions in the Hatton Bank area west of Rockall, and claims of catches of up to 2000 kg have been reported from a single longline

vessel (Ståle Dyb, MS “Loran”, pers. com.). We collected *L. schmidti* in both the Southern and Middle Boxes (Table 2). The pudgy cusk eel *Spectrunculus grandis* has previously been observed in our study area but not as frequently as in this study. A new species of cusk eel was reported in the preliminary report of the M/S Loran longline data (Dyb and Bergstad, 2004), and this caused taxonomic uncertainty. Taxonomists have confirmed that we collected a different species of *Spectrunculus* and efforts continue to clarify the status of our records. This new species has been tentatively named *Spectrunculus* sp. B, and what was formerly known as *Spectrunculus grandis* is now *Spectrunculus* sp. A (Franz Uiblein, pers. com.)

## **4. Discussion**

### *4.1. Aims, scope, and sampling*

Due to the rugged terrain and dominance of rocky substrate, sampling the near-bottom zone on a mid-ocean ridge is challenging. And as all gears are selective and have restricted operational capabilities, using several sampling and observation strategies and technologies in the same areas was considered necessary and sensible. This was reflected in the strategy of MAR-ECO (Bergstad and Falkenhaus, 2005; Wenneck *et al.*, 2007). The objective of the longline sampling was to complement sampling and observation by bottom trawl, which was essentially restricted to level soft-bottom patches. Longlining would provide information on demersal fish from rocky areas, and integration of information from longlines and trawls, ROVs, and baited benthic landers would together provide new comprehensive insight on species occurrence, distribution, and habitat utilization. This is the first account of the results of the longline studies, and a synthesis of results from all sampling technologies is a task for the future once all the gear-specific results have been evaluated.

Longlines function by attracting fish to bait, hence there is a strong selection for predatory and scavenging species (Løkkeborg and Bjordal, 1992). Furthermore,



longlines are size-selective, dependent on factors such as bait and hook sizes, bait quality etc. Hence we do not claim to present a full description of the demersal fish fauna of the study areas, essentially only the segment of the fauna attracted to and caught by baited hooks.

The selective nature of the sampling is reflected in the results in several ways. We recorded a high overall mean individual weight of 2.4 Kg, which differed markedly from the mean individual weight of 160 g recorded in the catches from the bottom trawl onboard RV G. O. Sars. Our catches of essentially only large fish were strongly dominated by scavenging sharks, e.g. *Etmopterus princeps*, and some teleosts known to be frequent visitors at baited photographic landers, e.g. *Coryphaenoides armatus*, *Spectrunculus* sp., and *Antimora rostrata* (King *et al.*, 2006). Despite the substantial effort put into longlining, we recorded considerably less species than the number recorded from bottom trawl catches, 40 on the longline compared with 70 in the bottom trawls (Bergstad *et al.*, 2007). Nevertheless longlines caught about twice the number of taxa than that recorded by the baited landers used in the same areas (King *et al.*, 2006). The between-gear differences with respect to size, number of specimens and taxa recorded illustrate the marked difference in selective properties among the gears.

Being constrained by ship-time and our limited capability for longlining from research vessels, the decision to charter an experienced and well-equipped commercial vessel was a good option. We chose to apply commercial gear that could be deployed and retrieved efficiently and reliably at all relevant depths, and we relied on the skipper's extensive experience from deepwater longlining to choose appropriate gears and fishing locations. The skipper had however to adhere to the sampling strategy where a pre-determined fishing effort was to be distributed by depth-zones and within the cross-ridge corridors or transects. This strategy led to a sampling of the full depth range on either side of the ridge axis in the two sub-areas, the "Southern" and "Middle Box". The only area not sampled quite according to plan, due to time constraints, was the western end of Transect III north of Charlie-Gibbs Fracture Zone. Our sampling

was similar to that reported by Hareide and Garnes (2001) from the same segment of the mid-Atlantic Ridge, but our depth range was substantially wider, reaching from the summit of the shallowest hills to 4200 m in the CGFZ.

Satisfactory standardization of longlining operations is difficult to achieve, but at least we managed to deploy an equal set of lines of the same type in most locations. Fishing horizontal lines in steep rugged locations near the summit of the hills is inefficient, difficult, and risky, and we therefore resorted to deploying vertical lines. These were fishing benthic and benthopelagic species in the near-bottom zone (seabed to maximum about 350 m off the bottom), and in the locations where we fished both horizontal and vertical lines, we found no difference in species composition or catch level. Hence we decided to include all sets in the analyses. The material available did not allow a thorough between gear analyses to be made and some caution should therefore be taken regarding interpretation of data.

Two other potential problems with longlining are saturation and post-capture loss. The former would presumably be most pronounced at high fish densities where the most mobile or attentive fish would outcompete others for a limited number of hooks. Post-capture loss might result from scavenging by big predators or invertebrates, or simply loss of poorly hooked specimens during hauling of the line. Although we could not make a quantitative assessment of these effects, we had no indications of substantial influence of saturation or post-capture loss on our results.

#### *4.2. Taxonomy and faunistics*

We decided to conduct our analyses of assemblage structure and distribution patterns despite the fact that some taxonomical issue remained unresolved. The most influential uncertainty concerned the relatively abundant *Spectrunculus* species that may constitute one or two species. It is likely, yet not confirmed, that the separation into species A and B is robust, and we therefore chose to keep this separation rather than

pool all specimens in a genus. The pooling of alepocephalid specimens into a family and *Apristurus* specimens into a genus was also unfortunate, but the number of specimens was low and would be unlikely to affect the result. Despite these taxonomical uncertainties, the quality of the species by station matrix was considered satisfactory to conduct meaningful exploratory analyses.

The expansion of ranges and the rather surprising observations of substantial frequencies of species previously considered rare, show that exploration of the mid-ocean habitats and fauna remains incomplete. The records of rare and unusual species were confirmed by relevant taxonomists, and the conclusions were mostly unequivocal in spite of the fact that voucher specimens were missing or too few for some species.

We recorded about 40 fish species, and while this is a small subset of the 338 demersal fishes of the North Atlantic listed by Haedrich and Merrett (1988), it is a number comparable with that reported by Hareide and Garnes (2001) from their longlining operations on the mid-Atlantic Ridge in a more limited depth range (summit to about max. 2000 m). Of all the species encountered, approximately equal proportions were found either exclusively in the Southern Box, exclusively in the Middle Box, or in both sub-areas. In the Southern Box several squaliform species (*E. princeps* primarily) dominated the shallower stations. Similarly in the Middle Box, *E. princeps* and *H. affinis* dominated along with several teleost species, such as *B. brosme*, *A. rostrata* and *M. berglax*. As Hareide and Garnes (2001), we found differences in biogeographical affinities of fishes exclusive to the two boxes, and as they suggested there appears to be a faunal change probably associated with the Sub-polar Front located just south of the Charlie-Gibbs Fracture Zone at between 48 and 52 N (Søiland *et al.* 2007).

Differences between sub-areas were not as pronounced at greater depths where bony fishes dominated the catches in both sub-areas together with *E. princeps*. The overall dominance of chondrichthyans differs from studies using trawls on the mid-Atlantic Ridge (Hareide and Garnes, 2001; Bergstad *et al.*, 2007) and on adjacent continental slopes (e.g. Haedrich & Krefft, 1978; Gordon & Bergstad, 1992; Moranta *et al.*, 1998; Musick *et al.*, 1996). This apparent gear bias is not surprising as most adult sharks are

likely to be capable of avoiding capture by an approaching trawl net. Also, sharks have an extremely acute sense of smell and hearing and can be attracted from great distances to the smell of the bait and/or the sound of struggling teleosts ensnared on the longline.

#### *4.3. Distribution patterns and diversity:*

With our relatively limited sampling effort we only expected to detect the major patterns of distribution and diversity. Catch rates of all species pooled decreased with increasing depth, probably reflecting the reduction in food biomass and quality with increased distance from the productive surface layer (e.g. Angel, 1997; Gordon *et al.*, 1995; Merrett & Haedrich, 1997; Gordon, 2005). This pattern has also been reported in other studies covering similar depths on adjacent continental slopes using trawls (Gordon & Bergstad, 1992; Haedrich & Merrett, 1992; Musick *et al.*, 1996; Haedrich, 1997). The average total catch rates for each transect and depth interval varied from 130 to 646 kg/1000 hooks, and these are numbers similar to those observed in continental slope waters using similar gears, e.g. around Hatton Bank (Møre Research, unpublished data). No difference in catch rate was found between the different sub-areas, although catch rates were especially high in the Middle Box vertical longline sets.

The exploratory multivariate analyses revealed patterns rather similar to those observed by bottom trawl (Bergstad *et al.*, 2007) and landers (King *et al.*, 2006) during the same expedition. The main faunal change occurs by depth, and latitudinal differences are less pronounced. We did not find any indications of marked East-West differences in any of the sub-areas or transects, but the sampling was too limited to draw firm conclusions. More or less the same result was reported by Bergstad *et al.* (2007) based on bottom trawl data. The changes with depth appeared gradual, reflecting species-specific distribution patterns, and we have no evidence to suggest abrupt faunal changes or distinct zonation.

The latitudinal pattern appears to be substantially stronger at summit and upper slope depths, than deeper on the slopes. This was reflected in two rather clear and separated clusters of longline sets from summit and slope depths of the two sub-areas. This difference between deep and shallow areas may indicate that the environment is more uniform at depth and thus that structuring of the assemblages is weaker.

Some stations, especially some of the shallower vertical longline stations, were dominated by only a few species. As depth increased, however, more species were recorded and the diversity and richness indices increased with depth. At greater depths, especially below 3000 m, the number of species caught at different stations decreased and the stations were again increasingly dominated by only a few species. It is interesting to note that both the indices for species diversity and richness peaked at depths around 2000 m. It has been shown for many taxa that richness seems to peak around 1500-2000 m and thereafter declines with depth (e.g. Haedrich & Merrett, 1992; Musick *et al.*, 1996; Haedrich, 1997), so patterns on the ridge appear similar to those observed elsewhere.

#### *4.4. Individual fish size/weight variation:*

A significant difference in mean individual fish weight was found between sub-areas. Specimens caught in the Southern Box were on average larger than in the Middle Box. This was mainly due to the dominance of the relatively large chondrichthyans caught in the shallower stations, together with the large cusk eel, *Spectrunculus* sp. A, that dominated the deepest stations. This pattern might indicate a more fundamental sub-area difference in production and biomass (Merrett, 1987; Haedrich & Merrett, 1992), although the data available in this study do not allow a more detailed investigation.

The general pattern of no change in individual fish weight with increasing depth was also apparent for individual species. Only four of the eleven investigated species showed a significant change or trend in mean individual fish weight with increasing depth. Of these, only *C. armatus* showed an increase. King *et al.* (2006) found a

similar pattern from lander observations in the same area. Conversely, *A. rostrata* and *H. affinis* showed a decrease in mean individual weight with increasing depth. For *A. rostrata* the more general pattern is a “smaller-shallower” pattern, which is thought to reflect the absence of juvenile specimens in this study. Around Greenland small juveniles only occur substantially shallower than the summit depths of the mid-Atlantic Ridge (Fossen and Bergstad, 2006). A third pattern was found for *M. berglax* where mean weight was higher in depths between 1000-1500 m, compared to both the shallower and deeper strata. A similar pattern has previously been described for *M. berglax* near Greenland (Fossen *et al.*, 2003). Our results do not support the general “bigger-deeper” trend often reported in the literature. It has been suggested that this trend may be a sampling artefact specific to trawl gear (Merrett *et al.*, 1991; Gordon and Bergstad, 1992).

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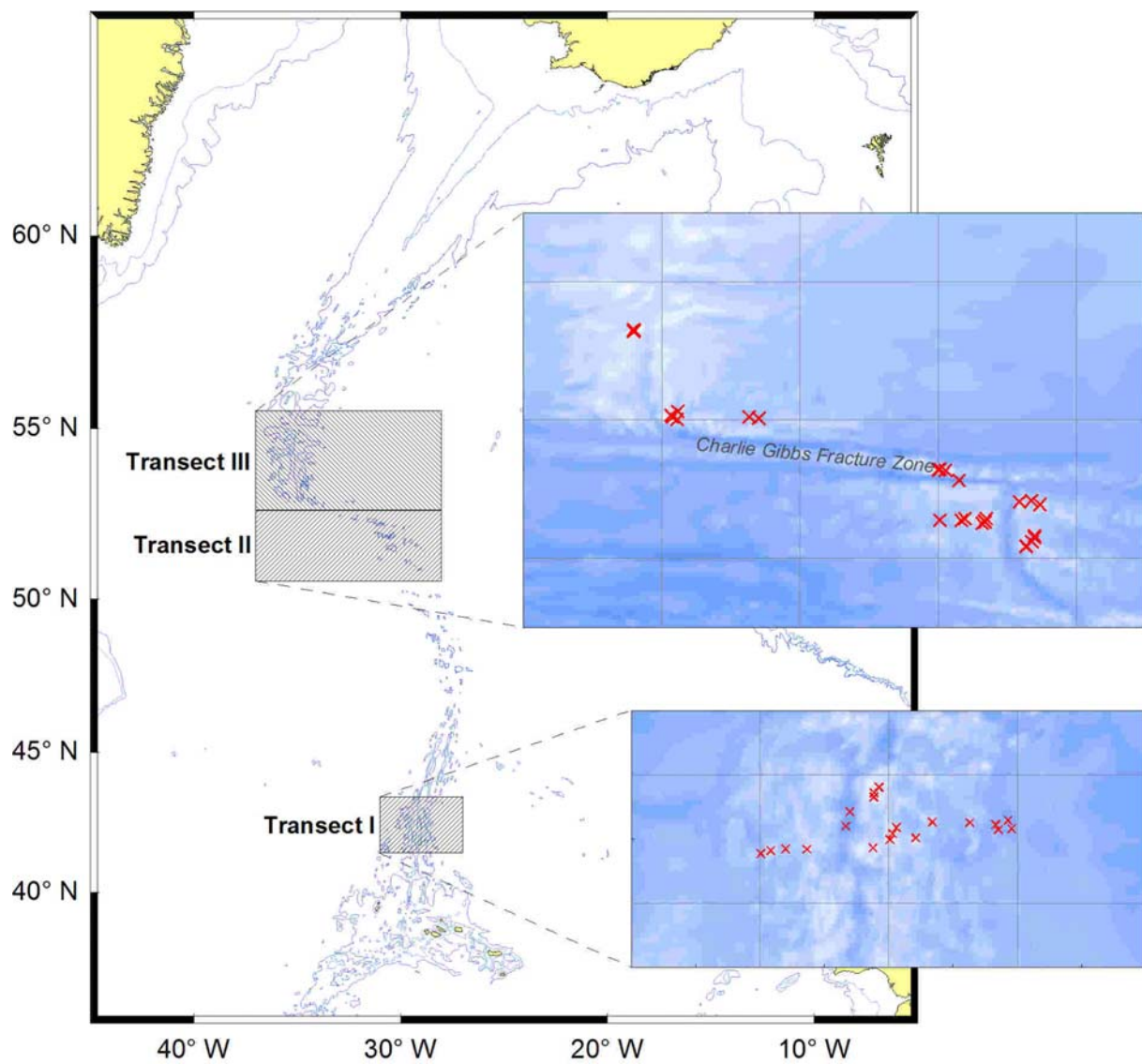
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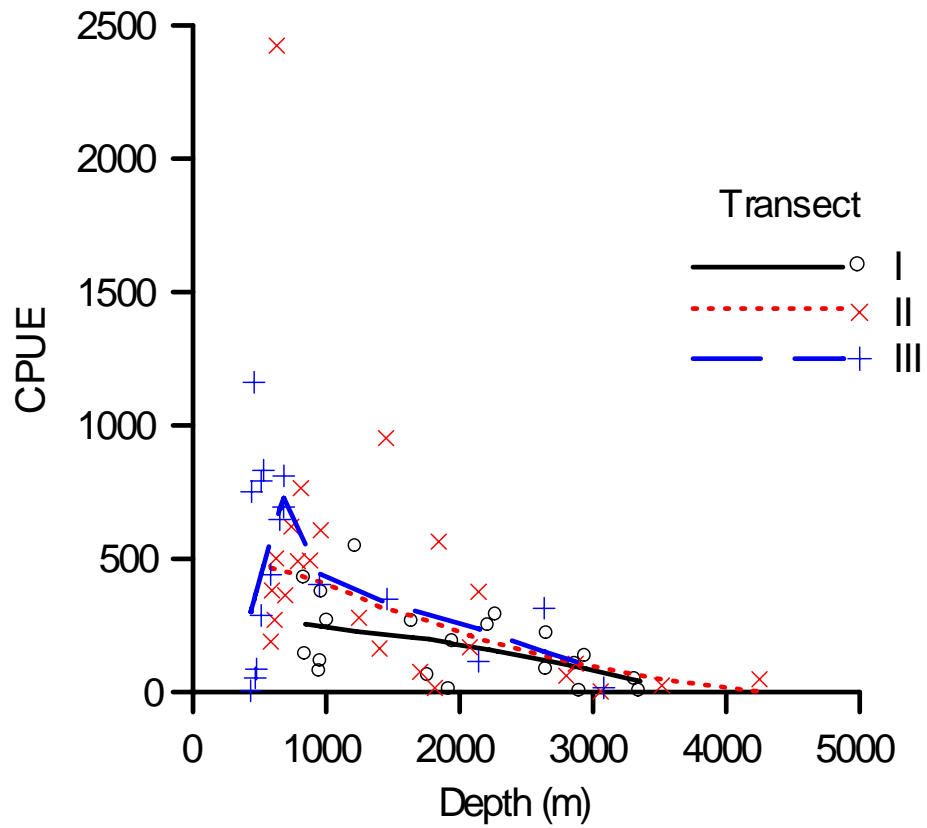


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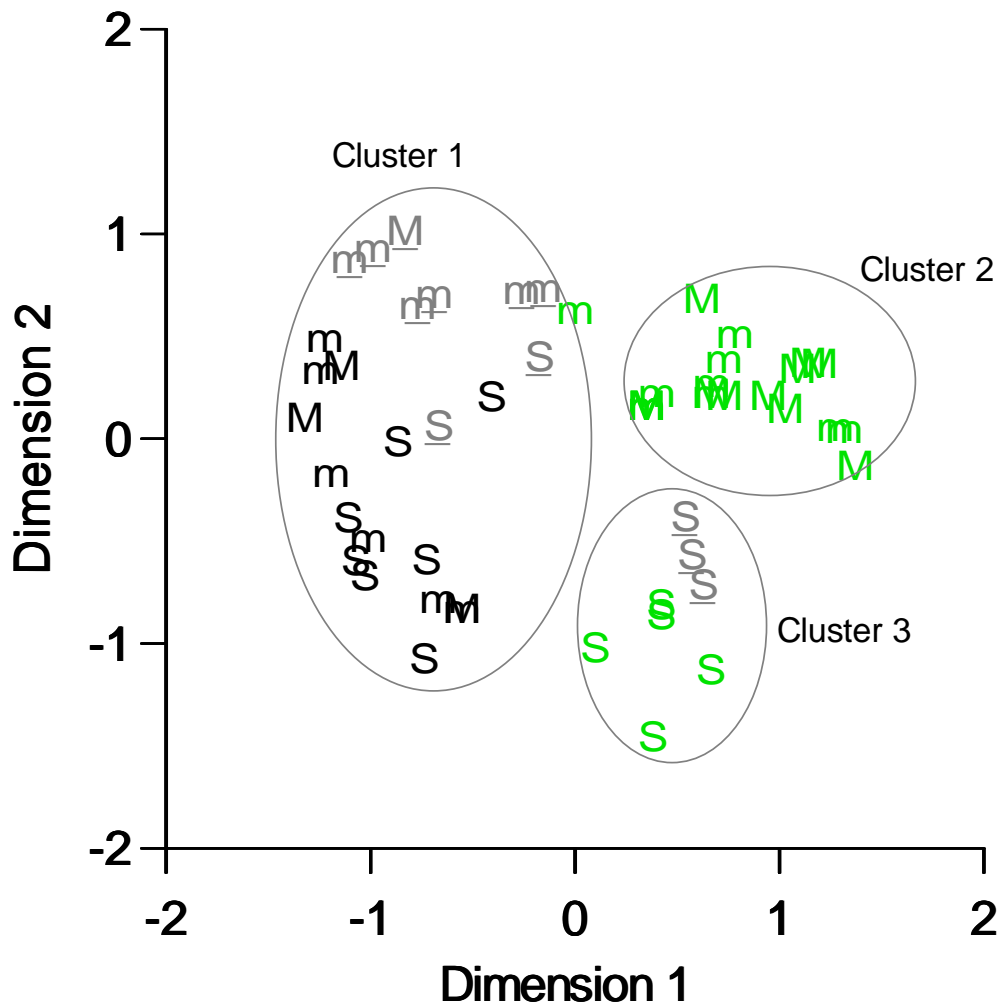
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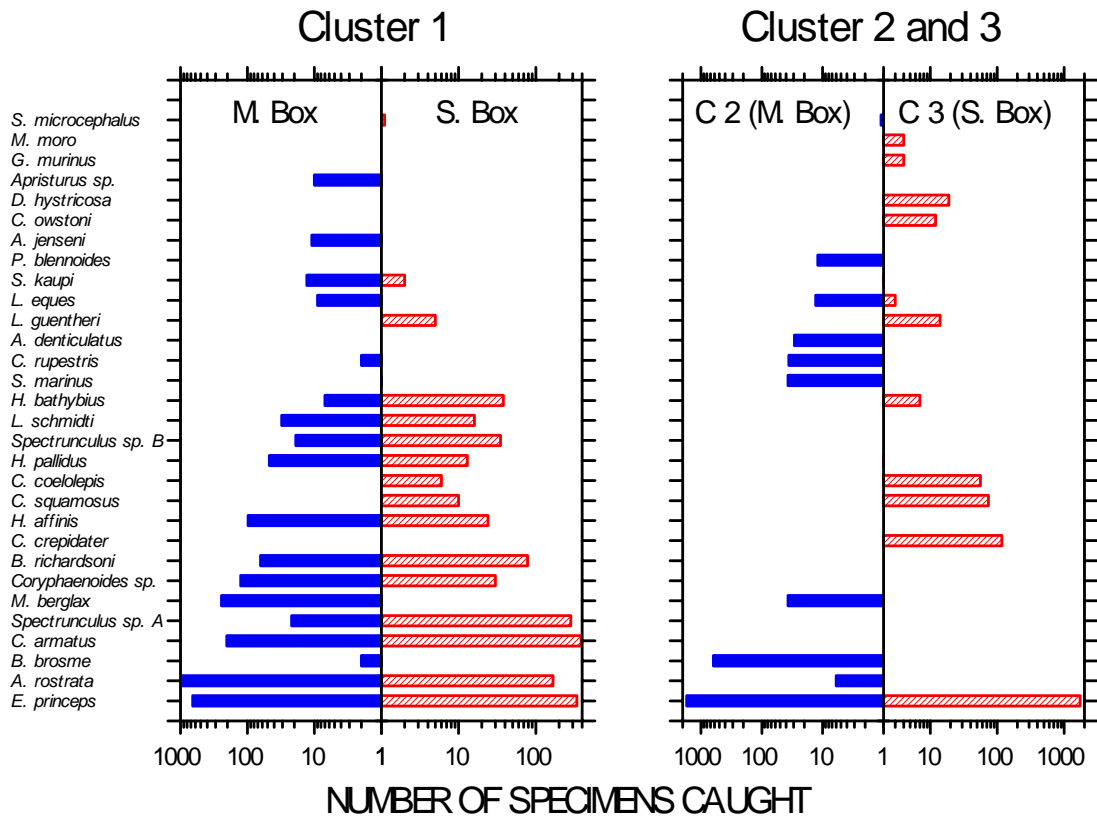
**Fig. 1** Locations of longline stations within the two investigated sub-areas along the mid-Atlantic Ridge (Southern Box and Middle Box).



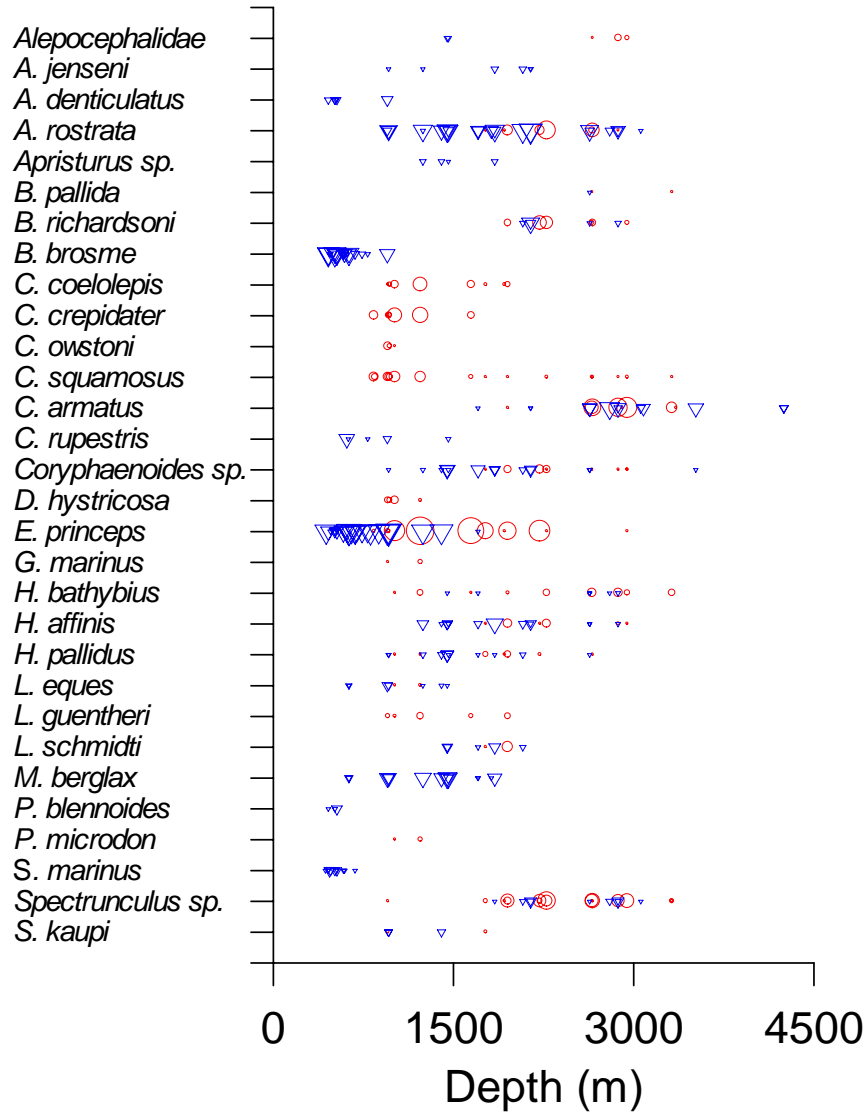
**Fig. 2** CPUE (Kg/1000 hooks) by average fishing depth for different longline stations and transects (I=Southern Box, II and III=Transects in the Middle Box). The highest value was due to a Greenland shark (750 kg) caught on a vertical longline. Smoothing = Lowess (Cleveland, 1979).



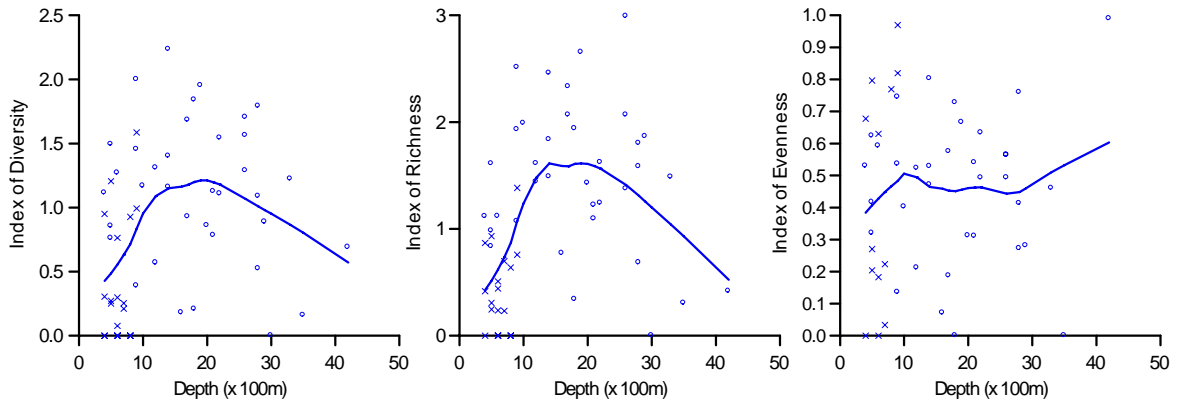
**Fig. 3** MDS ordination, showing the grouping of stations with similar fish assemblages (Stress = 0.169). Symbol indicates origin of stations (S=Transect I, m=Transect II M=Transect III). Colour and underscore are used to indicate depth of station (grey <1000 m, grey with underscore = 1000 to 2000 m, and black > 2000 m). Ellipses surround the proposed station clusters.



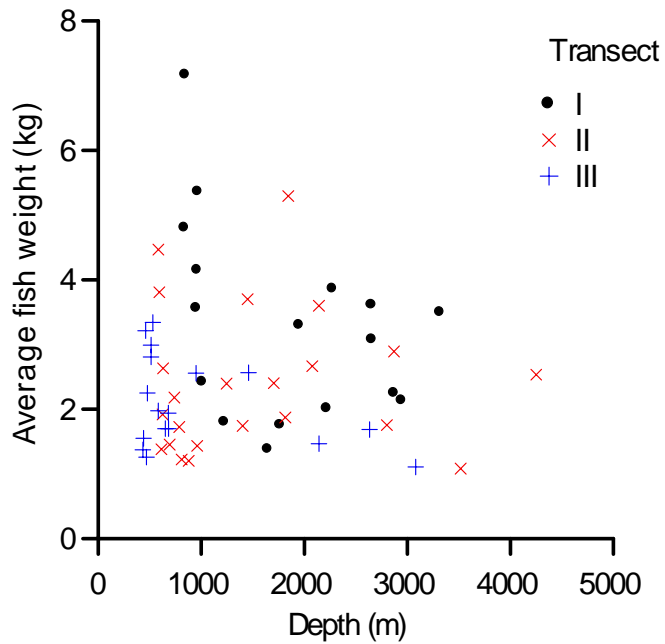
**Fig. 4** Species compositions within the 3 clusters suggested by the MDS analysis. Left: Cluster 1 showing catch composition of stations in the Middle and Southern Box. Right: Cluster 2 and 3, representing shallower stations from the Middle and Southern Box respectively. Only taxa being among the 10 most frequently caught within any of these four assemblages were included, and the x-axis was log transformed to better display less abundant species.



**Fig. 5** Average depths of stations where specimens of different taxa were caught. Symbols indicate area (○=Southern Box, triangles=Middle Box). The size of the symbols is relative to the number of specimens caught at each station ( $\text{Log}(\text{number caught} + 1)$ ). Only taxa where total catch exceeded 3 specimens are included in the figure.

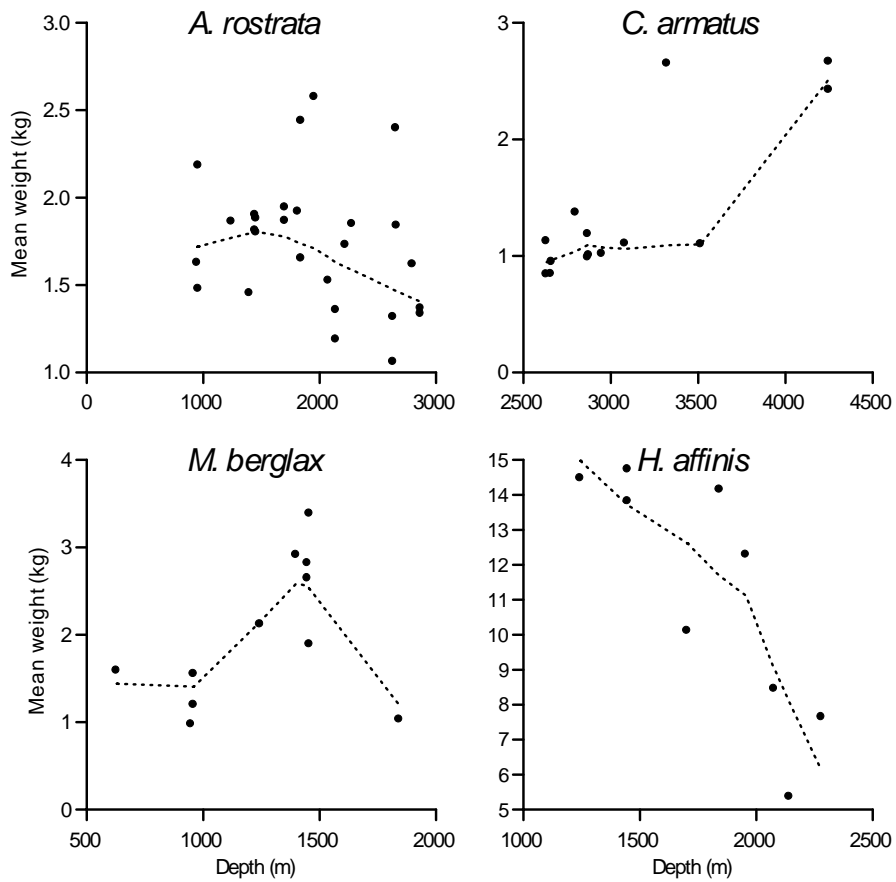


**Fig. 6** From left: Shannon-Wiener Diversity index, Species Richness, Hurlbert's Evenness for different longline stations (x=vertical, o=bottom longline). Smoothing = Lowess (Cleveland, 1979).



**Fig. 7** Average fish weight by fishing depth for different stations within Transects (I=Southern Box, II and III =Middle Box).





**Fig. 8** Average fish weight by depth for four different species. The graphs only include stations where more than 4 specimens of the species were caught. Smoothing = Lowess (Cleveland, 1979).

**Table 1** Station data: date, position, depth(s), number of hooks fished and notation of problems (stuck or loss). Transect I = Southern Box, Transect II and III = south and north of Charlie Gibbs Fracture Zone respectively in the Middle Box.

Transect	Date	Start		Depth	End Depth	# of hooks		Stuck	Loss of gear
		Latitude	Longitude			Bottom line	Vertical line		
I	05.jul	N42°34,91	W28°02,64	2925	2827	3470	-	-	-
I	06.jul	N42°38,82	W28°04,29	2992	2909	3470	-	-	-
I	06.jul	N42°34,43	W28°08,86	2734	2582	3470	-	-	-
I	06.jul	N42°37,77	W28°22,18	2125	2436	3470	-	x	-
I	07.jul	N42°37,96	W28°39,64	1572	2340	3470	-	-	-
I	07.jul	N42°32,58	W28°58,22	1411	1892	3470	-	-	-
I	07.jul	N42°35,44	W28°56,46	1478	2411	3470	-	-	All
I	08.jul	N42°29,84	W28°59,45	1100	1358	3470	-	x	-
I	08.jul	N42°25,90	W29°07,32	883	1149	2315	-	x	-
I	08.jul	N42°25,33	W29°38,20	1580	1964	2315	-	-	-
I	08.jul	N42°25,49	W29°48,14	2429	2018	2315	-	-	-
I	09.jul	N42°23,26	W29°59,71	2650	2675	2315	-	-	-
I	09.jul	N42°36,14	W29°20,05	3366	3280	2315	-	-	-
I	09.jul	N42°51,66	W29°06,81	850	-	-	260	-	-
I	09.jul	N42°54,47	W29°04,60	973	-	-	260	-	-
I	09.jul	N42°49,79	W29°06,82	842	-	-	260	-	-
I	10.jul	N42°49,61	W29°06,97	972	944	2315	-	x	-
I	10.jul	N42°54,16	W29°04,52	966	-	-	520	-	-
II	12.jul	N51°09,70	W29°43,56	612	-	-	260	-	-
II	12.jul	N51°09,87	W29°43,56	624	-	-	260	-	-
II	12.jul	N51°10,07	W29°43,63	738	-	-	260	-	-
II	12.jul	N51°10,24	W29°43,74	786	-	-	260	-	-
II	12.jul	N51°09,65	W29°43,75	692	-	-	260	-	-
II	12.jul	N51°14,12	W29°38,85	3055	2685	2315	-	-	-
II	13.jul	N51°17,49	W29°36,44	3090	2510	2315	-	-	-
II	13.jul	N51°46,15	W29°31,82	1906	1724	2315	-	-	90 %
II	13.jul	N51°49,53	W29°39,28	2280	2004	2315	-	-	-
II	13.jul	N51°48,54	W29°49,60	1327	1570	2315	-	-	-
II	14.jul	N51°33,82	W30°18,27	1208	1592	2315	-	x	-
II	14.jul	N51°31,94	W30°19,83	888	1031	2315	-	x	-
II	14.jul	N51°31,59	W30°19,82	878	-	-	260	-	-
II	14.jul	N51°31,01	W30°19,55	810	-	-	260	-	-
II	14.jul	N51°29,88	W30°21,96	1542	948	2315	-	x	-
II	15.jul	N51°33,87	W30°36,95	1880	1528	2315	-	x	-
II	15.jul	N51°32,44	W30°40,15	2404	1750	2315	-	-	-
II	15.jul	N51°32,64	W30°58,65	3533	3502	1157	-	-	-
III	16.jul	N53°01,05	W33°35,78	3094	3069	1157	-	-	-
III	16.jul	N53°02,30	W33°44,09	2619	2647	1157	-	-	-
III	16.jul	N53°02,20	W34°50,72	1050	848	1735	-	-	40 %
III	16.jul	N53°00,20	W34°46,69	2061	1305	1735	-	-	70 %
III	16.jul	N53°03,72	W34°52,04	1649	1265	1735	-	-	-
III	17.jul	N53°07,17	W34°46,09	2277	2006	1735	-	-	-
III	17.jul	N54°17,27	W35°24,31	433	-	-	260	-	-
III	17.jul	N54°17,26	W35°24,11	476	-	-	260	-	-
III	17.jul	N54°17,09	W35°24,13	468	-	-	260	-	-
III	17.jul	N54°18,20	W35°24,62	506	519	1157	-	-	-
III	18.jul	N54°16,83	W35°24,25	440	-	-	260	-	-
III	18.jul	N54°16,69	W35°24,36	512	-	-	260	-	-
III	18.jul	N54°16,53	W35°24,44	583	-	-	260	-	-
III	18.jul	N54°17,44	W35°23,78	680	-	-	260	-	-
III	18.jul	N54°17,31	W35°23,90	681	-	-	260	-	-
III	18.jul	N54°17,09	W35°23,94	651	-	-	260	-	-
III	18.jul	N54°18,18	W35°24,54	540	518	1157	-	-	-
III	18.jul	N54°17,32	W35°24,31	450	466	1157	-	-	-
II	19.jul	N52°16,91	W30°58,72	549	709	1157	-	-	-
II	19.jul	N52°16,37	W30°59,70	584	-	-	260	-	-
II	19.jul	N52°16,35	W30°59,99	592	-	-	260	-	-
II	19.jul	N52°15,66	W30°53,73	2106	1580	2315	-	-	-
II	19.jul	N52°07,17	W30°42,00	4200	4300	1157	-	-	-
Sum						83311	5980		

**Table 2** Orders, families and species of fishes captured along the mid-Atlantic Ridge. For each species, the number of stations where the species was encountered and the total number caught in each Transect is given. Taxa included in the MDS analysis are marked with an 'X' in the MDS-Depth column. 'X d' indicates species also included in analysis of mean weight vs depth. Average CPUE (kg per 1000 hooks) of the different species is included in the table (only stations where the species were caught are included in the CPUE calculation).

Order	Family	Species	Transect:	N-stations caught			N-specimens caught			MDS - Depth	Average CPUE on stations caught		
				S-Box	M-Box	III	S-Box	M-Box	III		S-Box	M-Box	III
Chimaeriformes	Chimaeridae	<i>Hydrolagus affinis</i>		6	8	3	24	91	7	X d	12.3	74.8	24.7
		<i>Hydrolagus pallidus</i>		6	7	2	15	45	2	X	5.8	35.0	16.1
Squaliformes	Centrophoridae	<i>Centrophorus squamosus</i>		16			84			X d	52.6		
		<i>Deania hystriosa</i>		4			19			X	19.1		
	Etmopteridae	<i>Etmopterus princeps</i>		11	12	11	2070	1636	733	X d	67.9	375.3	294.5
	Somniosidae	<i>Centroscymnus coelolepis</i>		7			62			X	34.9		
		<i>Centroscymnus owstoni</i>		3			12			X	16.4		
		<i>Centroselachus crepidater</i>		7			117			X d	29.4		
		<i>Somniosus microcephalus</i>		2		1	2		1	-	3.6		2692.3
Rajiformes	Rajidae	<i>Amblyraja jenseni</i>			5	1		12	1	X		10.0	1.9
		<i>Bathyraja pallida</i>		2		1	2		1	X	0.5		20.7
		<i>Bathyraja richardsoni</i>		6	3	2	78	54	10	X d	23.9	88.7	15.9
		<i>Dipturus batis</i>								1	-		
Carcharhiniformes	Scyliorhinidae	<i>Apristurus manis</i>			1			2		-			
		<i>Apristurus sp.*</i>			3	1		7	1	X			
		<i>Galeus murinus</i>		2			4			-	0.3		
	Pseudotriakidae	<i>Pseudotriakis microdon</i>		2			4			-	32.4		
Anguilliformes	Synaphobranchidae	<i>Histiobranchus bathybius</i>		9	4	1	45	5	2	X	1.4	0.5	2.1
		<i>Synaphobranchus kaupi</i>		2	2		4	13		X	0.5	1.4	
		<i>Synaphobranchus sp.</i>		1			1			-	0.3		
Osmeriformes	Alepocephalidae	<i>Alepocephalus agassizii</i>			1			1		-			
		<i>Alepocephalus australis</i>			1			1		-			
		<i>Alepocephalus sp.</i>		3	1	1	7	1	3	X	5.3	9.1	10.0
		<i>Narcetes erimelas</i>		1			3			-	4.8		
Ophidiiformes	Ophidiidae	<i>Spectrunculus sp. A (Pale)*</i>		8	3		284	22		X d	67.7	15.2	
		<i>Spectrunculus sp. B (Brown)*</i>		7	2	2	35	13	6	X d	1.5	4.0	2.1
Gadiformes	Macrouridae	<i>Coryphaenoides armatus</i>		6	6	3	387	143	61	X d	16.9	14.8	22.2
		<i>Coryphaenoides guentheri</i>		1			1			-	0.1		
		<i>Coryphaenoides leptolepis</i>		2			2			-	0.2		
		<i>Coryphaenoides mediterraneus</i>		3			3			-	0.3		
		<i>Coryphaenoides rupestris</i>			3	2		31	7	X		39.4	2.9
		<i>Coryphaenoides sp.</i>		2	9	3	24	113	13	X	1.8	8.1	2.7
		<i>Macrourus berglax</i>			8	2		200	81	X d		25.4	56.9
	Moridae	<i>Antimora rostrata</i>		7	10	4	167	701	239	X d	13.2	40.0	54.5
		<i>Lepidion eques</i>		2	5	1	3	13	9	X	0.2	0.8	2.2
		<i>Lepidion guentheri</i>		5			19			X	2.4		
		<i>Lepidion schmidti</i>		2	4		16	31		X	11.2	37.2	
		<i>Mora moro</i>		1			4		-	5.5			
	Phycidae	<i>Phycis blennoides</i>			3			12	X			22.1	
	Lotidae	<i>Brosme brosme</i>		6	9		140	487	X d		210.1	245.7	
Scorpaeniformes	Sebastidae	<i>Sebastes marinus</i>		2	7		3	35	X		12.1	14.1	
Perciformes	Anarhichadidae	<i>Anarhichas denticulatus</i>			4			29	X			43.4	
	Trichiuridae	<i>Aphanopus carbo</i>			1			1	-		-		

\* Taxonomic work still under progress

Species within the family *Alepocephalidae* and the genus *Apristurus* were pooled together under their respective taxa when used in the MDS analysis. Similarly the *Coryphaenoides sp.* group was comprised of *C. guentheri*, *C. leptolepis*, and *C. mediterraneus*. These species were pooled into the genus group when used in the MDS analysis.

*Spectrunculus sp. A* and *B* were treated as separate species in the MDS analysis. However, pooling them into only one *Spectrunculus* species did not affect the outcome of the analysis.

