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Zonation and Associations of Dominant Fish Fauna on Flemish Cap

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Abstract

Data were obtained from 682 demersal trawls made between 126 and 738 m depths on Flemish Cap in summer during the European Union research surveys in the years 1989–94. Despite the fact that the depth range for all species was not completely covered, analysis of different deep distributions of the 25 most representative species showed that the fauna are zoned with depth. Three faunal assemblages with characteristic catch rates, diversity and dominant species were found on the shelf (126–300 m), upper continental slope (300–600 m) and middle continental slope (>600 m). Catch rates were greatest on the shelf and upper continental slope, while diversity was greatest on the middle continental slope. Dominance of the commercial species Atlantic cod (*Gadus morhua*), golden redfish (*Sebastes marinus*) and American plaice (*Hippoglossoides platessoides*) on the shelf, beaked redfish (*Sebastes mentella*) and Labrador redfish (*Sebastes fasciatus*) on upper continental slope, and Greenland halibut (*Reinhardtius hippoglossoides*) on the middle continental slope. This showed an important aspect of the community structure. Diversity patterns may be understood in terms of the relationships with predation, competition, environmental heterogeneity and trophic level. Also the influence of the fisheries in the area can modify this structure. On the size-depth correlations, only longnose eel (*Synaphobranchus kaupy*), longfin hake (*Urophycis chestery*), Atlantic cod (*Gadus morhua*), beaked redfish (*Sebastes mentella*), golden redfish (*Sebastes marinus*) and Greenland halibut (*Reinhardtius hippoglossoides*) showed a significant 'bigger-deeper' relationship (i.e. larger fish in deeper strata), while spotted wolffish (*Anarhichas minor*) and witch flounder (*Glyptocephalus cynoglossus*) showed a negative 'smaller-deeper' relationship.

Key words: Depth distribution, diversity, fish assemblages, Flemish Cap, surveys

Introduction

Flemish Cap is a bank located in international waters where fishing is regulated by the NAFO. This bank was the target of an international research program developed by NAFO in the early-1980s, but that study was discontinued. A Canadian survey series covered the 1977–85 period, and USSR/Russia has supported an annual survey since 1977. The European Union developed demersal surveys on Flemish Cap from 1988 to 1994. The initial purpose of the surveys was to assess the distribution and abundance of the main commercial species Atlantic cod (*Gadus morhua*), American plaice (*Hippoglossoides platessoides*) and redfish (*Sebastes* spp.) but the sampling data provided an opportunity to describe more generally the abundance, species composition and spatial distribution of other demersal and mesopelagic fish in the region.

To date, because of the scarce information on the species which are not fished commercially in Flemish Cap, the community structure of fish fauna was not well known. Fisheries ecosystems are complex and growing international concern has called for alternative multispecies management based on a better understanding of marine communities as a whole (Gomes *et al.*, 1992). The development of new fisheries in the Flemish Cap area in recent years has been of concern. From 1990 there has been a large fishery for Greenland halibut (Junquera, MS 1994), from 1993 a major fishery for shrimp has developed (Sainza, MS 1994), and there have been increases in the redfish fishery. It is well known that such fisheries can affect the community structure.

The fish fauna community structure of the deepwater demersal species in the Northwest Atlantic has been studied by other authors (Haedrich *et al.*, 1980; Perry and Smith, 1994), but we are not aware of such studies on Flemish Cap. This work presents an initial approach to the study of the homogeneity or heterogeneity of the dominant fish fauna distribution, establishing the possible 'fish assemblage areas' on Flemish Cap. Such a study has implications on the general understanding of the bioenergetics, biogeography and community structure of fish fauna in this area.

Materials and Methods

The data presented here were gathered from standard groundfish research trawl surveys conducted by the European Union made in summer between 1989 and 1994 in NAFO Div. 3M. Table 1 shows the cruises carried out in the period studied, number of hauls and species number included in this study.

The surveys used a stratified random design, with strata based on depth boundaries of 145, 183, 255, 364, 546 and 728 m (80, 100, 140, 200, 300 and 400 fathoms) (Fig. 1). The survey sample unit was defined as the bottom area fished by a Lofoten trawl towed at a constant speed (3.5 kn.) for 30 min.

In each survey the sets, or bottom trawls, were allocated to strata according to area, with all strata containing at least two sets. Bottom trawls with unsatisfactory gear conditions were eliminated. The effect of this elimination was small since only a small percentage (<7%) of the sets in each survey fell into this category. More details of survey methodology are described by Vázquez (MS 1990).

The problems associated with net samples are well known. Trawling consistently underestimates absolute abundance (Snelgrove and Haedrich, 1985). In addition, in this study no adjustments in catch data were made for differences in catchability among species.

All species caught were identified, counted, weighed and expressed as catch per standard sample unit. Set depth was taken as the mean from initial and final depth of the trawl tow.

Twenty two demersal and three mesopelagic species were included in the analysis (Table 2). They consisted of commercial and non-commercial species but were potentially dominant species in a given region, or potential forage for other species. These 25 species constituted more than 95% of the biomass estimated in the area. All species were present in at least 4% of the total observed tows. All strata were sampled with sufficient intensity to assess their composition.

Koslow (1993) from the mid-slope depths off south-eastern Australia, found that approximately 35 samples were required before the number of new species per sample began to level off and so the point at which half the final number of species were obtained. In this work only the stratum with depths lower than 145 m represents less than 35 sets. However, this stratum we think is sufficiently sampled because demersal fish fauna is characterised by common species.

In each sample, whenever the total weight of one determined species was less than 15 g or the specimen number was one, this species was not considered in a sample. With respect to the mesopelagics, because of the small size and low frequency of the species studied here (*Serrivomer beani*, *Chauliodius sloani*, *Stomias boa*), these criteria were not applied considering the low catchability of the net used over these species.

The species of genus *Sebastes* was not identified every year. *S. marinus* was identified from 1990 and *S. mentella* and *S. fasciatus* only were identified from 1992. For this reason, the analyses where the specific composition of all species was required was only computed for the years 1992, 1993 and 1994.

As a preliminary analysis to establish whether zonation was present, a variation of the chi-square test was employed. This method (Gardnier and Haedrich, 1978) rests on the presence or absence of the species. For this analysis, the bottom trawl collections made on Flemish Cap was arranged in order of increasing depth. The area studied was

TABLE 1. Information on the bottom-trawl surveys on Flemish Cap 1989–94.

Ship	Cruise	Dates	Sets	No. Species
Cryos	Flemish Cap 89	12/7 – 1/8	118	21
Ignat Pavlyuchenkov	Flemish Cap 90	18/7 – 6/8	113	22
Cornide Saavedra	Flemish Cap 91	24/6 – 11/7	117	22
Cornide Saavedra	Flemish Cap 92	29/6 – 18/7	117	25
Cornide Saavedra	Flemish Cap 93	22/6 – 8/7	101	25
Cornide Saavedra	Flemish Cap 94	29/6 – 29/7	116	25

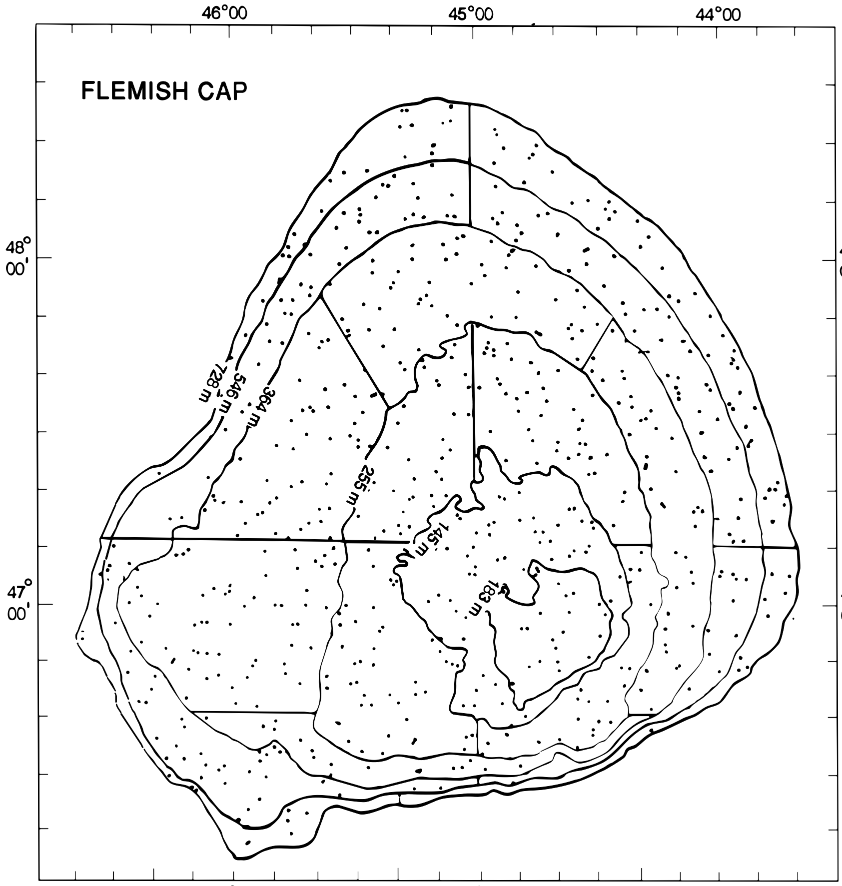

Fig. 1. Chart showing the positions of bottom trawl stations on Flemish Cap area between the years 1989 and 1994 with the approximate isobaths.

divided arbitrarily into six depth regions of 100 m depth ranges (<150 m, 151–250 m, 251–350 m, 351–450 m, 451–550 m, 551–650 m, >651 m) and the species numbers that appeared for the first time in each region (upslope boundaries) were recorded. This method tests the distribution across the area of upslope boundaries using the formula:

$$X^2 = (Q / K) \times (V - [K^2 / Q])$$

Where Q = number of regions into which the area is arbitrarily divided;

K = total number of species;

V = the sum of squares over all regions of the number of upslope boundaries.

Values of the index were compared with those in a chi-square table for Q-1 degrees of freedom. If the calculated value exceeded the value obtained from the table, the upslope boundaries were considered to be distributed non-randomly, i.e. they are zoned. For details, Gardnier and Haedrich, (1978) should be consulted.

One approach to identifying associations between catches of the 25 representative species and the depth data from the surveys was made. Firstly, we characterise the general frequency distribution of the habitat variable (depth) by constructing its empirical cumulative distribution function for observed depths in the sets. Secondly, we associated the catch of the fish (in numbers) of a particular species in each set, with the depth at the particular set as a weighting factor, and constructed the empirical cumulative distribution of depths as weighted by the number of the specimens caught by species. In our case, the allocation of the sets or bottom trawls was strictly proportional to stratum size, so that the different size of the strata can be ignored (Perry and Smith, 1994).

If there was no particular association between fish distributions and depth within the area surveyed, e.g. if the fish were randomly distributed with respect to depth, then the cumulative distribution function by each species would be almost identical to the function for observed depths. Conversely, when the fish were associated with a small depth

TABLE 2. Vertical depth ranges and catch data for fish species taken in bottom trawls on the Flemish Cap 1989–94.

Main Fish Species	Depth Range	Weight (kg)	Specimens No.	Station No.
Gadus morhua	126 – 631	48 500	119 979	459
Anarhichas lupus	130 – 497	4 950	100 063	498
*Sebastes marinus**	130 – 441	6 810	16 220	253
Glyptocephalus cynoglossus	130 – 738	540	1 242	249
*Sebastes fasciatus***	151 – 660	2 340	12 675	214
Anarhichas minor	129 – 605	2 590	1 752	302
Raja radiata	126 – 717	1 950	1 071	385
*Sebastes mentella***	249 – 738	17 100	65 618	186
Hippoglossoides platessoides	126 – 519	6 910	12 412	456
Urophycis chesteri	280 – 638	112	1 295	168
Lycodes reticulatus	155 – 683	975	5 607	281
Raja spinicauda	149 – 717	853	192	118
Anarhichas denticulatus	130 – 738	1 130	295	167
Reinhardtius hippoglossoides	221 – 753	5 550	6 821	383
Lycodes smarky	242 – 738	143	458	73
Nezumia bairdi	249 – 753	460	8 991	290
Macrourus berglax	249 – 753	1 440	2 656	179
Serrivomer beani	249 – 738	13	151	44
Stomias boa	313 – 738	4	151	30
Chaulodius sloani	263 – 753	19	67	60
Notacanthus chemnitzii	424 – 753	311	363	65
Synaphobranchus kaupi	466 – 753	445	351	72
Antimora rostrata	524 – 753	389	3 366	69
Gaidropsarus ensis	575 – 738	24	99	29
Lycodes vhali	533 – 738	89	372	38

* The data corresponds to the years 1990–94.
** The data corresponds to the years 1992–94.

range, then these functions would be very different.

These cumulative distribution functions were plotted (Fig. 2) and the potential boundaries were examined by calculating the percentage similarity (PS) between the regions involved. PS is a commonly-used measure of faunal overlap and was calculated according to the formula of Whittaker & Fairbanks (1958).

$$PS = 100 \times \left(1.0 - 0.5 \sum | P_{ia} - P_{ib} |\right)$$

Where P_{ia} = the proportion assumed by species i in sample a;

P_{ib} = the proportion assumed by species i in sample b.

PS is a theoretically insensitive index to sample size, but it is in fact highly sensitive to the relative number of species among the regions involved (e.g. if the sample size varies excessively among strata and the species number is closely related to sample size set, it will lead to a downwardly biased perception of affinities among strata) (Koslow, 1993). In the current work the narrow depth range analyzed presented small differences in the species number recorded and low relation with the sample size.

Cluster analysis method was also employed to assess faunal change with depth and to contrast with the results based on analysis of the PS indices. We used the commonest type of cluster analysis, normal or q-type analysis, in which samples are arranged into groups where each had a similar biotic composition.

To reduce the large number of sets (334 bottom trawls) for the 1992–94 period, the sets were grouped into class depth of 50 m for each year. These class depths or strata were labelled with the maximum depth value of the class. Therefore, for each year there were 13 strata named, i.e. 150, 200, 250, ...750.

The classification and ordination analyses were based upon a matrix of similarity coefficients among strata. In calculating the similarity coefficients, we used the specimen numbers per strata for each species. These values resulted in calculating the mean value from the specimen numbers by species from the sets included in the strata.

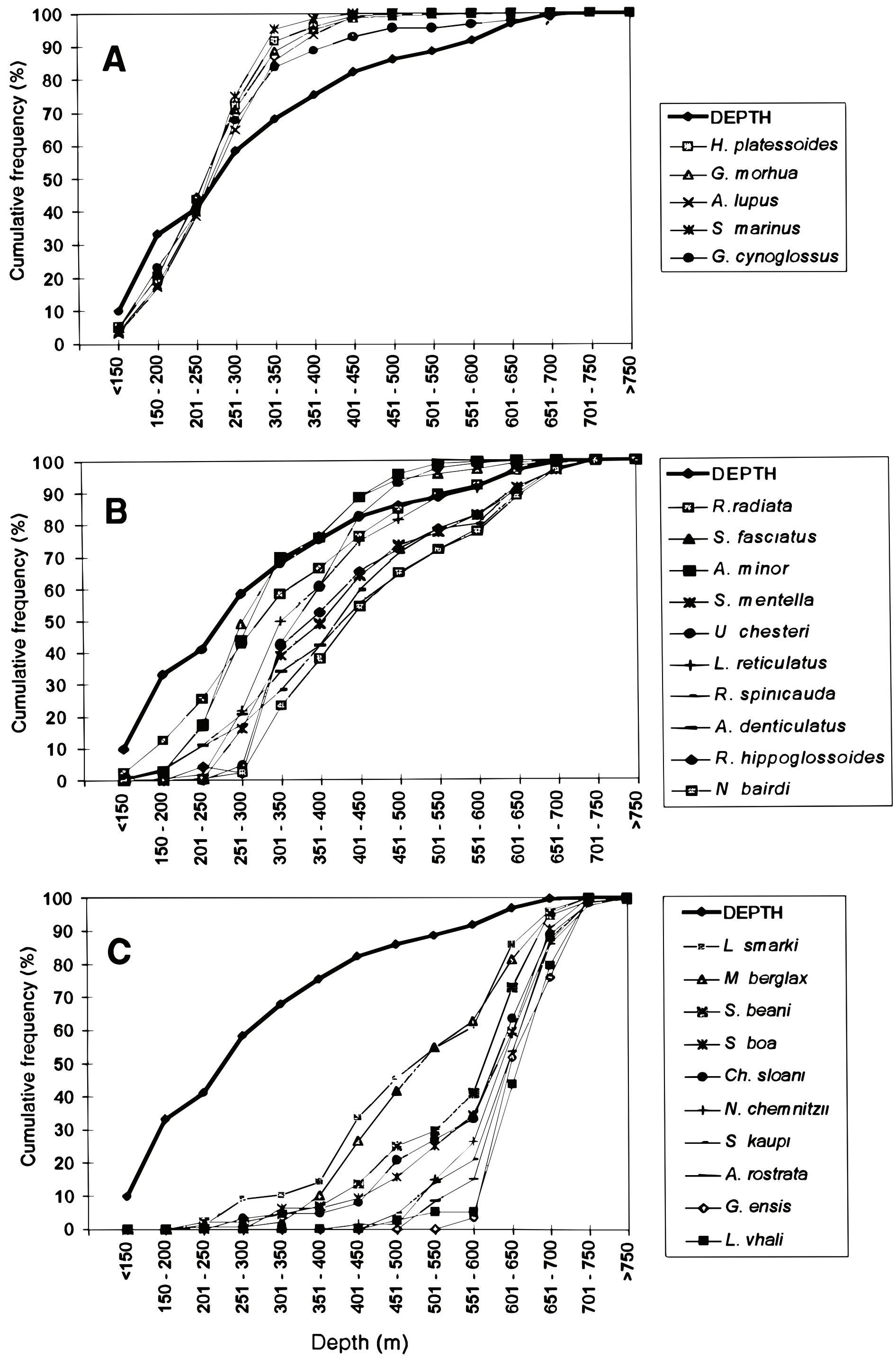

Fig. 2. Cumulative frequency distributions of depth variable and depths as weighted by the number of the specimens caught for each species on Flemish Cap in Summer 1989–94.

The data (number of specimens for each species) were root-root transformed. This transformation has the effect of scaling down the scores of abundant species to avoid swamping the other data (Field *et al.*, 1982; Clifford and Stephenson, 1975). Also the root-root transformation has the advantage that, when similarity is assessed by the Bray-Curtis measure, the similarity coefficient is invariant to a scale change (Stephenson and Burges, 1980).

We have adopted the Bray and Curtis measure of similarity because it is not affected by joint absences (Field and McFarlane, 1968) and is, therefore, sufficiently robust for marine survey data where many of the species are absent from a majority of the samples, while giving more weight to abundant species (in comparing samples) than to rare ones.

The Curtis measure has the form:

$$\delta_{jk} = \frac{\sum_{i=1}^{s} | Y_{ij} - Y_{ik} |}{\sum_{i=1}^{s} (Y_{ij} + Y_{ik})}$$

where Y_{ij} = score for the ith species in the jth sample;

Y_{ik} = score for the ith species in the kth sample;

δ_{jk} = dissimilarity between the jth and kth samples summed over all species.

The clustering strategy is the hierarchical group-average sorting, which joins 2 groups of samples together at the average level of similarity between all members of one group and all members of the other. Analyses were carried out with the standard statistical program 2M (BMDP) (Dixon *et. al*., 1990).

Diversity, H, for the resultant depth zones were calculated using the information function (Shannon and Weaver, 1963):

$$H = -\sum p_i \ln p_i$$

where p_i = the fraction of the total comprised by species i in a region.

Regressions were performed on individual species to establish whether a correlation between size and depth existed. The size was estimated by calculating the mean weight for each species and set from the total weight of the species and the specimen numbers in the set.

The BMDP package (Dixon *et. al*., 1990) was particularly useful for statistical procedures.

Results

A complete list of the species considered for the period studied 1989–94 is given in Table 2. This table shows the depth range, weight and number of specimens in the total sets by species. Each species showed a unique vertical depth range.

Establishment of zones

The chi-square test was run on all sets for the years from 1992 to 1994, grouped into regions of 100 m depth increases. Value of chi-square $X^2_{upslope} = 18.4$, exceeded the 0.01 significance level for 5 DF (= 16.81).

This indicated that, in the period considered, the distribution was zoned between 125–753 m. However the fact that the survey sampling did not completely cover the depth range of all species (the maximum depth sampled was 753 m) made it difficult to set up the zonation with certainty.

Figure 2 shows cumulative distribution functions for observed depths, and depths as weighted by the number of specimens caught by each species. We constructed three graphs where the species were grouped for similarity behaviour with respect to depth. Basically, we found three groups of species: Group A (Fig. 2A) comprised the species with cumulative occurrence percentages higher than 60% in depths less than 300 m; Group B (Fig 2B), the species presented no particular association between fish distributions and the depth within the area surveyed with a random distribution with respect to depth; Group C (Fig. 2C) composed of species with a cumulative occurrence percentage higher than 60% in depths greater than 600 m.

From Fig. 2, the potential boundaries appear to point at 300 and 600 m. These potential boundaries were examined by calculating PS between the regions involved. PS measured across the 300 m level was 21.5% and across the 600 m level was 24.4%. These data thus suggests that the distribution is zoned, but weakly between 126 and 738 m.

To contrast this result, a cluster analysis was also performed. This analysis on all species studied showed groupings with similar biotic composition and comparable depths (Fig. 3).

Figure 3 is a dendrogram showing sample affinities based on the mean root-root transformed abundance (mean number of specimens in each stratum) of the 25 species studied, using the Bray-Curtis measure of similarity and group-average sorting. Three main zones or clusters were distinguished at an arbitrary similarity level of 17%. Cluster I comprised the strata with depths lesser than 300 m, Cluster II with transition depth strata between 300 and 600 m and Cluster III with depth strata greater than 600 m.

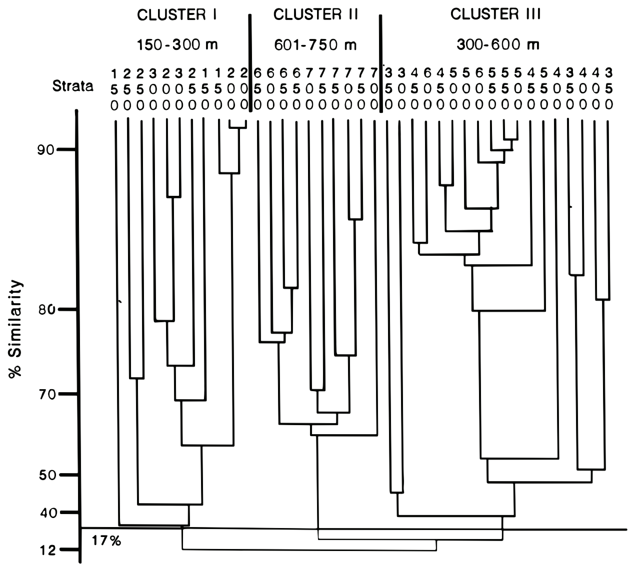

Fig. 3. Dendrogram showing classification of 334 sets grouped in 13 depth class of 50 m by each year (1992, 1993 and 1994) based on mean abundances of fish fauna species composition by depth class. Abundances were root-root transformed before comparing stations using the Bray-Curtis measure, and the dendrogram formed by group-average sorting. Three main cluster are distinguished at an arbitrarily similarity level of 17%.

These three zones (<300 m, 300–600 m, >600 m) established from the Cluster analysis agrees with the zones defined from the calculation of PS index. The agreement of the results from two independent methods is an important requirement for assemblage validity. Also, this result is in accordance with Haedrich *et al*. (1980) for the depth range studied here compared to the deep sea south of New England. These authors found distinct faunal assemblages on the shelf (40–264 m) upper continental slope (283–650 m) and middle continental slope (653–1290 m).

In order to quantify the differences between these three zones: Shelf group (comprising the sets shallower than 300 m), Upper continental slope group (comprising the sets between 300–600 m) and Middle continental slope (comprising the sets deeper than 600 m), the Table 3 and 4 shows respectively the overall community parameters and the most abundant demersal species (as percentage of total number and total biomass) at the three depth zones considered.

No one species was dominant over the whole depth sampling range (Table 4). *Sebastes mentella* was the only species present in all depth strata, standing out into the upper continental slope.

TABLE 3. Community parameters and catch rates for fish assemblages by depth zones on Flemish Cap in the years 1992–94.

Strata	126–300 m	301–600 m	601–753 m
Number of species	19	25	20
Diversity, 'H'	1.4	1.2	2.1
Number of specimens	83 611	79 053	10 761
Number of stations	177	123	34
Specimens 0.5 h–1	472	643	316
Total Biomass (Catch Kg)	31 400	2 300	4 170
Biomass (Kg 0.5 h–1)	177	187	123

Abundance and biomass both declined on the middle continental slope. In this region however, the diversity was greater than the other zones (Table 3). This fact has an important implication for fish community structure and finally, therefore, on the fisheries (Gordon *et al*., 1994). The commercially important species tend to be presents in low diversity communities where they make up a significant proportion of the total biomass (Haedrich, 1994). In agreement with this assertion, the shelf and upper continental slope presented the smallest diversity and were the regions where the commercial species exploited in the area, such as *Gadus morhua*, *Sebastes* sp. and *Hippoglossoides platessoides* were the most important species in terms of both number and biomass. In the shelf and upper continental slope, *Gadus morhua* and *Sebastes mentella* represented in each stratum more than 60% and 70% of the specimen numbers respectively (Table 4).

The representative species of the middle continental slope were more homogeneously represented. *Reinhardtius hippoglossoides*, *Sebastes mentella* and *Macrourus berglax* comprises the 74% of caught biomass and make up the objectives fish species of the most recent fisheries in the area.

The regression of mean weight-per-individual for each species *versus* depth was calculated (Table 5). Some like *Synaphobranchus kaupi*, *Urophycis chesteri*, *Gadus morhua*, *Reinhardtius hippoglossoides*, *Sebastes marinus* and *Sebastes mentella* showed a well marked 'bigger-deeper' distribution.

Other authors also observed this ‘bigger-deeper' relation in other areas for several of the species studied here. Polloni *et al*. (1979), Snelgrove *et al*. (1985) reported the 'bigger-deeper' phenomenon, on the south and north of Newfoundland's continental slope, for *Antimora rostrata*, *Synaphobranchus kaupi* and *Nezumia bairdi*. Gordon and Bergstad (1992) founded this phenom-

TABLE 4. The most abundant demersal fish species at the three depth zones considered. Values are percentages of total number and of total biomass in the years 1992–94.

Species	Number (%)	Biomass (%)
Dominant species in depths <300 m		
Gadus morhua	60.5	55.7
Sebastes marinus	14.5	17.2
Sebastes mentella	8.0	4.8
Sebastes fasciatus	6.1	3.1
Anarhichas lupus	4.5	5.9
Hippoglossoides platessoides	3.9	6.8
Dominant species in depths (301–600 m)		
Sebastes mentella	72.0	63.6
Sebastes fasciatus	9.5	5.9
Nezumia bairdi	3.1	0.5
Reinhardtius hippoglossoides	2.8	6.3
Lycodes reticulatus	2.6	1.7
Anarhichas lupus	2.4	3.3
Dominant species in depths >601 m		
Nezumia bairdi	25.6	4.4
Sebastes mentella	18.4	24.0
Antimora rostrata	15.5	5.6
Reinhardtius hippoglossoides	13.8	33.6
Macrourus berglax	10.9	16.2
Chaulodius sloani	3.0	0.3

TABLE 5. Regression parameters of mean weight per individual by species *versus* depth where the regression was significant.

Species	No. of Cases	Coeff. Regression	Significance	Parameters of Equation y = ax + b
Anarhichas minor	302	-0.601	< 0.001	a = 9.4154 b = -0.00701
Synaphobranchus kaupi	72	0.534	< 0.001	a = 3.3544 b = 0.00231
Urophycis chesteri	168	0.64	< 0.001	a = 1.7649 b = 0.00679
Gadus morhua	459	0.56	< 0.001	a = 4.5305 b = 0.007
Sebastes mentella	186	0.56	< 0.001	a = 4.8928 b = 0.00201
Sebastes marinus	253	0.52	< 0.001	a = 4.3948 b = 0.00463
Glyptocephalus cynoglossus	249	-0.673	<0.001	a = 7.1369 b = -0.00429
Reinhardtius hippoglossoides	383	0.53	< 0.001	a = 4.8408 b = 0.00359

enon for *S. kaupi* in the Rockall Trough too. For some of these species, such as *Antimora rostrata*, and *Nezumia bairdi*, this study does not report a significant bigger-deeper relation. The insufficient depth range sampled (to 753 m) and the wide depth range where this species is distributed, between

499 and 2325 m for *A. rostrata* and between 405–1475 for *N. bairdi* (Snelgrove *et al.*, 1985), may be the reason for the absence of a bigger-deeper relation.

Two species, *Glyptocephalus cynoglossus* and *Anarhichas minor* showed a significant negative correlation. Burnett *et al.* (1992) found significant differences in distribution by depth for juveniles and adults of *G. cynoglossus* in the Gulf of Maine–Georges Bank Region and, while the adults maintained a mean depth constant during all year, the juveniles were found at shallower depths than adults in winter and spring, and at greater depths in summer and autumn. If these situations were reproduced on the Flemish Cap, this could be the reason for the negative size-depth correlation present during the summer research surveys.

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