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Persistence and Variation on the Groundfish Assemblages on the Southern Grand Banks (NAFO Divisions 3NO):  
2002-2011

by

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#### Abstract

Data from EU-Spain (Instituto Español de Oceanografía) bottom trawl surveys in the NAFO Regulatory Area (2002-2011) were analyzed to examine evolution patterns in the Southern of Grand Banks (NAFO Div. 3NO) groundfish assemblage structure in relation to depth. The 1160 hauls from the slope surveys spanned between 38 and 1460 m in depth. We focused on the 28 most abundant species, which made up 92.6 % of the catch in terms of biomass. The fish biodiversity results (221 fish species) are higher than in other ecosystems, and the highest value is reached in the deeper assemblage, with diversity  $H=2.23$ .

Assemblage structure was strongly correlated with depth. For the most part, changes in assemblages seem to be fairly continuous although there were more-abrupt changes at 300 m. Three main groups and five assemblages were identified. Cluster I (Shallow) comprised the strata with depths lesser than 300 m; cluster II (Intermediate) contained the depth strata between 301 and 1000 m and cluster III (Deep) the depth strata greater than 1001 m. Cluster I could be further subdivided into two sub-clusters. Cluster Ia comprised the strata with depth less than 150 m and cluster Ib the strata with depths between 151 and 300 m. Two sub-cluster were identified in cluster II: IIa contained depths between 301 m and 600 m and IIb depths between 601 and 1000 m. Despite dramatic changes in biomass and abundance of the species in the area, the boundaries and composition assemblages seem to be similar to the previous period. Although some changes were evident, the main ones were replacement of the dominant species in several assemblages and bathymetric range extension of distribution of some species.

Yellowtail flounder (*Limanda ferruginea*) appears to be as the dominant species in shallow assemblages instead of Atlantic cod (*Gadus morhua*) and American plaice (*Hippoglossoides platessoides*) that were dominant in the period before the collapse in the area; in the intermediate assemblages redfish (*Sebastes spp*) is the dominant species.

The evolution pattern in the fish assemblages in the Southern Grand Banks is similar to other Northwest Atlantic areas; it indicates that changes in the fish populations in Northwest Atlantic have been produced on a large scale and are not limited to specific areas.

#### Introduction

Changes in ocean climate combined with direct and indirect effects of harvesting can dramatically and rapidly alter the composition of marine fish communities (Hutchings and Reynolds, 2004). The global crisis in overexploitation of fisheries has resulted in calls for multispecies and (or) “ecosystem-based” assessment and management of fish stocks and assemblages (Jennings and Kaiser, 1998). Assemblages are groups of species that can co-occur due to biological interactions, such as predation, or because of similar responses to the environment (Jaureguizar *et al.*,

2003). Marine fisheries management is slowly shifting from single-species towards ecosystem management. A first step towards ecosystem management is to identify species assemblages and the biological and environmental conditions associated with assemblages. Implementation of multispecies approaches requires improved understanding of the community ecology of fish assemblages that has rarely been explicitly incorporated into management practices.

In this paper the studied area is the Southern of Grand Banks of Newfoundland (NAFO Div. 3NO) which is included in the Large Marine Ecosystem Labrador-Newfoundland.

A combination of circumstances which included the inability to control foreign and domestic fisheries, inadequate science, inappropriate policies, ineffective management and the inability to react to local environmental and fisheries conditions and knowledge, has led to a major decline in the status of most fish stocks in the Newfoundland and Labrador marine ecosystems, and most recently to a regime shift to a crustacean-dominated biological community (Rose, 2003). Increased abundance in these species during the 1990s comprises a marine ecosystem regime shift likely caused by a change in oceanographic climates compounded by a reduction in predators, in particular cod (Rose, 2003).

The reasons for the above mentioned changes in community structure are still under debate, but overexploitation of groundfish, climate change (e.g. cooler water temperatures) and trophodynamics (e.g. predation release) are some of the hypotheses used to explain them. However, the most likely scenario involves some combination of all these driving forces.

Spanish fishery is developed along the continental slope of the east of the Grand Banks of Newfoundland. This area fits in with what has been normally used by the Greenland halibut fishery (González-Costas and González-Troncoso, 2009). Since 2001, the distribution of the Greenland halibut fishery has been quite constant (see more details on the evolution of the fishing effort distribution in González-Troncoso *et al.*, 2007). Both the shallower area and around 400–500 m depth of the Grand Banks are moderately trawled; these areas fit in with the thorny skate and the shrimp fishery, respectively (González-Costas and González-Troncoso, 2009). The remaining areas seem to be untrawled or slightly trawled.

An ecosystem approach to fisheries management in marine waters has long been advocated to gain a better understanding of the structure and functioning of ecosystems and to eventually restore and sustain them (Tolimieri and Levin, 2006). A first step in the complex process of ecosystem management is to reduce the complexity of the ecosystem and search for patterns by describing species abundance and distribution, and identifying assemblages (Mahon and Smith, 1989; Gomes *et al.*, 1992; Tolimieri and Levin, 2006). Although single-species management is still commonly practiced, several studies have examined the structure of fish assemblages in the North Atlantic. In the last decades numerous papers have described demersal fish assemblages: in tropical areas (Bianchi, 1991); in the Scotian Shelf and Gulf of St Lawrence (Bundy, 2005); Norwegian Sea (Lekve *et al.*, 1999); Mediterranean Sea (Moranta *et al.*, 1998); in the NW Iberian Peninsula (Fariña *et al.*, 1997); East coast of North America (Mahon *et al.*, 1998); the Azores Archipelago -mid-Atlantic (Menezes *et al.*, 2006). Mahon and Smith (1989) have identified ten offshore assemblages of relatively similar species composition on the Scotian Shelf and Bay of Fundy from 1970 to 1981; in the Flemish Cap (NAFO Div. 3M) three main assemblages were identified (Paz and Casas, 1996; González-Troncoso *et al.*, 2006); Gomes *et al.* (1992) have found six assemblages over 16 years (1971-82, 1984-87) on the Grand Bank of Newfoundland.

There are three main approaches for field studies on the impacts of fishing gears on benthic communities: designed experiments, comparisons among areas with different fishing histories at one point in time and comparisons of single areas across time. Each approach has its own strengths and weaknesses (Rice, 2005).

Fish assemblage areas are appropriate geographic compartments for modelling and/or management purposes. Attention can be focused on investigating biological variability and organizational structure within each area, as well as interactions between areas. Standardized bottom-trawl surveys are one of the few comprehensive sources of data to assess temporal changes in diversity of marine communities and assemblages. Their strengths include relatively long duration, standardized sampling and species identification over many decades. These surveys were designed to capture commercially important fish species, so there is a direct link between the biological diversity and the

ecosystem service provided by the fisheries. This strength is also a weakness given that the trawls capture only a slice of the ecosystem, or even of the fish community.

Studies on fish assemblages have been carried out thanks to the increasing number of large data sets available from long term research vessel surveys (Gomes *et al.*, 2001). These surveys typically occur at the same time of the year and cover the same area. They are most often conducted by government scientists to determine the annual change in abundance, size structure and age structure of commercially important fish. In the Northwest Atlantic, these surveys are typically conducted by research trawlers operating far from shore on the continental shelf and deeper slope waters (Paz and Durán, 1999).

In recent decades, with the extension of deep-sea fisheries, it was increased attention to the ecology of deep-sea species (Priede *et al.*, 2010) and the bottom trawl survey often reach 1400 m depth (González-Troncoso *et al.*, 2011). These time series data surveys allow studies such as this one, covering a wide bathymetric range, including deep-sea species.

Even if the bathymetric range was limited (Gomes *et al.*, 1992), previous studies have defined and described the fish assemblages in the Grand Banks, although few studies reach the deep fauna. Rather they are not current (Gomes *et al.*, 1992), or are spatially very limited (Snelgrove and Haedrich, 1985), or when they reach deeper fauna they were using the longline (Murua and Cárdenas, 2005) which implies the limitation of biodiversity in the catch.

Bottom trawl survey on Southern Grand Banks (NAFO Regulatory Area Div. 3NO) (Figure 4) has been performed by the Spanish Administration since 1995<sup>1</sup> (Paz *et al.*, 2002).

From the bottom trawl survey data the objective of this paper is to describe the homogeneity and heterogeneity of dominant fish fauna in the Southern Grand Bank during the period 2002-2011 and to explore the possible changes that have taken place in the communities. This study was intended to identify, describe and map broad groundfish assemblage areas on that area at wide depth range (38-1460 m). The specific questions addressed are: (i) to extend the bathymetric range for the identification and description of fish assemblages; (ii) do the species assemblages of demersal fish follow similar depth patterns in temporal scale in the area?; (iii) were there any changes in the dominant species in each assemblage?

This study will contribute to the process of moving towards a more holistic approach to fisheries management by reducing the complexity of the Gran Banks ecosystem into fish assemblages that could be used as a possible tool in the management resources.

## Material and Methods

### Material

The data used in the present paper come from the Spanish Spring Survey that has been carried out every year since 1995 in late spring (May-June) in the Div. 3NO of the NAFO Regulatory Area by the Instituto Español de Oceanografía (IEO) to evaluate the status of demersal resources. The time series since 2002 to 2011, performed by the B/O Vizconde de Eza with a net type Campelen, was used in the analysis. Table 1 shows the dates, the number of sets, the depth covered and the number of species caught of each year.

Hauls are made following the stratification charts described in Bishop (1994). Sets were allocated in accordance with the area of the strata with a minimum of two planned hauls per stratum and the trawl positions were chosen at randomly. Abundance and biomass for all species were estimated by swept area method (Cochram, 1997).

The sampling unit consisted in 30-minutes hauls at a speed of 3.0 knots using a *Campelen* 1800 otter trawl gear. The mesh size was 44 mm for the net and 12 mm for the cod end. The mean horizontal opening was 26 m and the vertical opening was 4.1 m. The otter trawl was monitored using a Scanmar net control system. For temporal series details see Paz *et al.* (2002).

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Around 120 valid hauls are made each year. In each haul all the individuals caught are systematically sorted by species and the length distribution is obtained. To know more about the methodology of the surveys, see González-Troncoso *et al.*, 2004. The mean of the initial and final depth has been used to define the depth of each haul. The mean depth varies from 38 to 1460 m.

A total of 1160 hauls were made in the survey between 2002 and 2011. The position of these hauls is represented in Figure 1.

In this analysis twenty-six demersal species, one pelagic species (capelin, *Mallotus villosus*) and one mesopelagic genus (redfish, *Sebastes spp*)<sup>2</sup> were included. They consisted on commercial and non-commercial species, but they were potentially dominant species in a given region or potential forage for other species. These twenty-eight species amounted 92.64% of the total catch. All species were present at least in 6.29% of the total observed tows. All strata were sampled with sufficient intensity to assess their composition.

A complete list of species considered in this study for the period 2002-2011 is given in Table 2. The data are for all valid hauls (1160). Species were ordered by weight. This table shows the depth range weight, the total sets by species and percentage of occurrence.

### Methods

As a preliminary analysis to set up whether zonation was present, an application of the chi-square test (Gardiner and Haedrich, 1978) was used. This method is applied to the presence or absence of the species. To apply it, the bottom trawl hauls available were arranged in order of increasing depth. Hence, the area studied was arbitrarily divided into 10 depth regions of 150 m depth ranges ( $\leq 150$  m, 151-300 m, 301-450 m, 451-600 m, 601-750 m, 751-900 m, 901-1050 m, 1051-1200 m, 1200-1350 m,  $\geq 1351$  m) and the number of species that appeared for the first time in each region (upslope boundaries; they were not present in these regions anytime) were recorded. This method tests the distribution across the area of upslope boundaries using the formula:

$$\chi^2 = \frac{Q}{K} \left( V - \frac{K^2}{Q} \right) \quad \text{with } Q-1 \text{ degrees of freedom}$$

where:  $Q$  = numbers of regions into which the area was randomly divided

$K$  = total number of species

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

The null hypothesis of this test is that the locations of upslope boundaries are uniformly distributed along with the gradient and that there is no tendency towards clustering. In order to reject this hypothesis with a significant level of  $\alpha$ , a two-tailed test is performed with chi-square distribution of  $Q-1$  degrees of freedom. So, 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, that is, they are zoned.

An analysis with Box-Plot graphs was performed in order to know how the catches are distributed with regards to the depth. In Box-Plot graphs catches are represented as a function of depth. So that, the more times one species was captured at a given depth, the more times this depth will be represented in the graph. We had to obtain catches as frequency by depths. First, depths and catches were arranged according to increasing depths. Then the per million ( $0/_{000000}$ ) was calculated for the catches of all species in each depth. Finally, we pondered in order to obtain

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<sup>2</sup> There are three redfish species in the study area, *S. fasciatus* (Acadian redfish), *S. mentella* (deepwater redfish), and *S. marinus* (golden redfish). Due to the difficulty of visual identification of different species, the catches are usually reported by genus as *Sebastes spp*. In NAFO, the *S. fasciatus* and *S. mentella* are managed as an only species and *S. marinus* is not yet regulated.

1,000,000 datum of frequencies of depths for each species. This was calculated in Matlab and data were represented by Box-Plots.

To identify associations between the catches of the 28 selected species a series of analysis taking into account the data of the catches were performed. As a preliminary exploration, cumulative distributions of biomass of the specimens caught by species were compared with the empirical cumulative distribution of the depths of the hauls. The number of hauls in each stratum was strictly proportional to the stratum area, so that the different size of the strata can be ignored (Perry and Smith, 1994). If there is no clear association between fish distribution and depth within the area surveyed, then the cumulative distribution function for each species would be almost identical to the function for depth. On the other hand, when the fish were associated with a small depth range these functions would be very different.

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 following the formula of Whittaker and Fairbanks (1958):

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

where  $P_{ia}$  = the proportion assumed by species  $i$  in sample  $a$

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

It is known that PS is no sensitive to sample size, but highly sensitive to the relative number of species among the regions involved. So, for example, if the sample size varies excessively among strata and the species number is closely related to sample size, it will lead to a downwardly biased perception of affinities among strata (Koslow, 1993).

Another analysis carried out to know more about the existing associations was a cluster analysis. This analysis is a perfect complement to the PS analysis to confirm the boundaries found in it. One of the more common types of cluster analysis, joining analysis, was employed. Samples were arranged into groups where each had a similar biotic composition. As the number of hauls (1160) does not permit to make a clear representation of the cluster regions, they were grouped into classes of 150 m depth for every two years. These class depths or strata were labelled with the maximum depth value of the class. Therefore, for every two years (2002-2003, 2004-2005, 2006-2007, 2008-2009, 2010-2011) there were 10 strata named: 150, 300, 450, ..., 1350, 1500, resulting in a total of 50 strata.

The classification and ordination analysis were based on a matrix of similarity coefficients among strata. To calculate the similarity coefficients we used the mean numbers of specimens per strata for each species was used. These data were root-root transformed ( $X^{1/4}$ ). This transformation has the effect of scaling down the scores of abundant species to avoid swamping the other data (Field *et al.*, 1982).

The measure of similarity adopted has been the Bray and Curtis measure. It has the advantage that is not affected by join absences (Field and McFarlane, 1968) so is sufficiently robust for marine survey data where many of the species are absent from the majority of the samples, while it gives more importance to abundant species (in comparing samples) than to rare ones. Moreover, with the root-root transformation and the Bray-Curtis measure the similarity coefficient is invariant to a scale change (Stephenson and Burges, 1980).

The Bray-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:  $Y_{it}$  = score for the  $i^{\text{th}}$  species in the  $t^{\text{th}}$  sample

$\delta_{jk}$  = dissimilarity between the  $j^{\text{th}}$  and the  $k^{\text{th}}$  samples summed over all species

The dissimilarity matrix of the data was calculated in R. The clustering strategy is the hierarchical weighted group-average sorting, which joins two 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 Statistica program.

In order to complement and try to confirm the results of the cluster analysis, two more multivariate techniques were used: correspondence analysis and principal components. The data and the transformations utilized in these analyses were the same used in the cluster analysis.

Correspondence Analysis (CA) is an ordination method in which each site is located at the centre of gravity of the species that occur there. This method is unaffected by double-zero, i.e., tows in which both species which are being compared are absent (Kendrick and Francis, 2002).

Principal Component Analysis (PCA) was also used to test the results obtained in the cluster and Correspondence Analysis. Species loadings of principal components were used to identify groups of species that tend to co-occur (i.e., assemblages). The eigenvalue associated with a Principal Component indicates the relative importance of that component. Principal Components with eigenvalues  $> 1$  are considered to represent statistically significant assemblages (Jolliffe, 1986). VARIMAX rotation was used for the data and was performed by Statistica program (Mahon *et al.*, 1998).

The index of diversity H was calculated using the function by Shannon and Weaver (1963):

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

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

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

#### Sampling Errors and limitations

The surveyed area outside the ZEE does not completely covers the species distribution in the area, especially on the continental shelf. Therefore, although the sampling in the shallow zone can be considered significant with regards to the specific catch composition or weight of the species present in it, their relative composition could vary if deemed the total area of the continental shelf.

Bottom trawls are both species and size selective, and it was impossible to adjust this type of selectivity without knowing the behaviour of most species or the real age/size structure of populations.

### **Results**

A total of 938201.77 kg were caught during the 10-years time series (2002-2011), of which 877874.44 kg were fishes, corresponding to the 93.56 % of the total capture, and representing 240 taxons (221 fish species) belonging to 86 families. Species were caught in depths between 38 to 1460 m.

A complete list of species considered in this study for the period 2002-2011 is given in Table 2. The highest catch corresponded to redfish. The most present species (% occurrence) was American plaice.

The biomass and abundance of the main commercial species was plotted in Figure 2. Within the last years of the studied period, the estimated indices for Yellowtail flounder and redfish increased. In 2011, Atlantic cod and American plaice continued to be under historically levels.

The chi-square test was run on all sets for the period 2002-2011, grouped into regions of 150 m depth intervals. The value of chi-square  $\chi_{upslope}^2 = 127$  exceeded the 0.01 significance level for 9 d.f. ( $\chi^2 = 21.67$ ). The null hypothesis that fishes were randomly distributed across the depth was rejected, indicating that assemblage patterns existed. The result showed that, in the period considered, the fish distribution was zoned between 38 and 1460 m.

Figure 3 shows the descriptive analysis made with Box-Plots. The graphs represent how catches were concentrated according to the depth and depth range distribution of the species. Median and quartiles were represented. Species graphs were ordered by increasing median depth catches value so we observed an increasing gradient of depth for each one. Out of a total of 28 species analysed, 17 appeared distributed between the depth ranges surveyed. Three different types of species were observed in relation with pattern of depth distribution. Some species presented a limited shallow distribution (e.g., yellowtail flounder, sea raven (*Hemitripterus americanus*), northern sand lance (*Ammodytes dubius*), capelin, moustache sculpin (*Triglops murrayi*), Atlantic wolffish (*Anarhichas lupus*)). Other species presented wider bathymetric distribution (e.g., witch flounder, Northern wolffish). The rest of the species were restricted to a deep range distribution (e.g., black dogfish (*Centroscyllium fabricii*), Arctic skate (*Amblyraja hyperborea*), rat fish (*Harriotta raleighana*)).

Some features revealed differences with regards to some well-known characteristics distribution patterns of the species. There are some typical shallow species that show a very wide range bathymetric distribution, for instance American plaice and thorny skate, whereas there are some usually deeper species that appear at very shallow depths too (less than 150 m) as marlin spike (*Nezumia bairdii*), roughhead grenadier (*Macrourus berglax*) and Northern cutthroat eel (*Syphobranchus kaupii*).

Median values of all species considered on the analysis had also wide range distribution. 14 species presented a median less than 300 m. Median was bigger than 1001 m for six species. The rest of species had a median between 301 and 1000 m.

Second analysis was made via empirical cumulative distribution functions for observed depth and depth weighted by the biomass of specimens caught of each species. It was observed that species presented different behaviour with respect to depth. Some species presented a distribution above the function for depth; those species presented cumulative occurrence percentages higher than 80% in depths less than 300 m. Cumulative distribution of those species was plotted in Figure 4, group A (Shallow). Other species showed no particular association between fish distribution and depth within the area surveyed. This group comprised species with very different behaviour and variability in a wide range of depth (Figure 4, group B (Intermediate)). One species, witch flounder, had a random distribution in respect of the depth. Other species presented a distribution below the function for depth, with cumulative occurrence percentage higher than 80% in depths greater than 1001 m (Figure 4, group C (Deep)).

The potential boundaries suggested by the patterns in the cumulative curves were examined by calculating PS between the regions involved. In order to quantify the zonation, PS was calculated between each region of 150 m intervals until 1050 m and the regions between 1051 m and 1460 m with the boundary in 1200 m. PS percentages for each depth boundary was given in the Table 3. All PS boundaries values were higher than 50 % except 150 m and 600 m.

A cluster analysis was performed to contrast these results. The examination of the dendrogram identified five zones within three main groups at the 47% level of dissimilarity: Cluster I, Cluster II and Cluster III (Figure 5).

Cluster I (Shallow or “Continental Shelf”) comprised the strata with depth lesser than 300 m; cluster II (Intermediate or “Upper Continental Slope”) contained the depth strata between 301 and 1000 m and cluster III (Deep or “Slope”) the depth strata greater than 1001 m. Cluster I could be further subdivided into two sub-clusters at a dissimilarity level of 37%. Cluster Ia comprised the strata with depth less than 150 m and cluster Ib the strata with depths between 151 and 300 m. At the level of 27% of dissimilarity, we found two other sub-clusters in cluster II: IIa

contained depths between 301 m and 600 m and IIb depths between 601 and 1000 m. The results showed groups of species with similar biotic character and comparable depth preferences.

Besides this, we conducted two more multivariate analyses in order to confirm the results. Correspondence Analysis (Figure 6) made three different groups in agreement with the three main clusters of the dendrogram and with the three groups plotted by the cumulative distribution functions except for thorny skate and American angler (*Lophius americanus*) which appear in group I and group II superimpose. In the third group two subgroups, IIIa and IIIb, were distinguished.

A Principal Components Analysis (Figure 7) was also made. We found three components eigenvalues (Table 4) greater than 1, which explained more than the 84% of the total variance. The first two components explained more than 79%, so we graphed those components. We found three main groups of species, which are the same as in the analysis below except for American angler and thorny skate which appear only in the group I. Also, in the Group I we could distinguish two subgroups for group I: Ia and Ib. Those two subgroups agreed with the two sub-clusters found in the shallow zone. In this analysis we observed the three main assemblages better defined than in the Correspondence Analysis.

The subgroups found in the second zone (clusters IIa and IIb) of the dendrogram analysis were confirmed neither in the Correspondence Analysis nor in the Principal Components Analysis. The species were overlapped here, which confirmed different depth pattern distribution of intermediate species (Figure 4, group B), agree with the small percentage level of dissimilarity (PS) at the boundary of 600 m, which indicate weak zonation.

Two subgroups appeared in the Deep Assemblage (IIIa and IIIb) both in the Principal Component Analysis and in the Correspondence Analysis, although these two subgroups were not represented in the dendrogram. One deep subgroup was compound by four species included in the assemblage IIIa: marlin spike, spinytail skate (*Bathyraja spinicauda*), Greenland halibut and roughhead grenadier. Box-Plots graphs and cumulative distribution graphs also defined those subgroups: those species that had the same medians and their curves were separated from the others, showing a very similar distribution. They followed a wide distribution, mainly deep.

From those analysis five assemblages appeared: Shallow assemblages comprised first Shelf group Ia (comprising sets shallower than 150 m) and second Shelf group Ib (comprising sets between 151 and 300 m); Intermediate assemblage Upper Continental Slope group IIa, comprising sets between 301 and 600 m, and Slope Group IIb between 601 and 1000 m, and Deep assemblage III Continental Slope, comprising sets deeper than 1001 m.

Tables 5 and 6 show, respectively, the most abundant demersal species (like percentage of total biomass) and percentage of occurrence in the five depth zones considered and the overall community parameters.

In the assemblage Ia yellowtail flounder and American plaice were dominant with an occurrence higher than 85%; redfish was the dominant species in the Ib assemblages with a very high proportion of biomass in comparison with proportion of others species in the same group. In the Ib, Atlantic cod and American plaice had a very high occurrence, more than the 89%, although the percentage of biomass is very low (less than 10 times redfish biomass). In the IIa group, redfish was also the dominant species in terms of biomass but Greenland halibut and marlin spike had an occurrence higher than 91%. In the IIb Greenland halibut and roughhead grenadier were the dominant species. In the group III blue hake was the dominant species, although Northern cutthroat eel and roughhead grenadier reached similar biomass and occurrence values.

In general, most important and present taxon was redfish. Although the species number was similar in the five groups, redfish biomass was very high in the Ib and IIa assemblages, whereas the proportion of species was most homogeneous in deeper assemblages (IIb and III). For those reasons biodiversity index was higher in deeper groups (Table 7).

To test “bigger-deeper” species distribution, regression analysis of mean weight per individual for some species versus depth was performed (Table 8). Some species like marlin-spike and Greenland halibut showed a well marked “bigger-deeper” distribution. Blue hake showed less marked length dependent distribution.

One species, *Glyptocephalus cynoglossus* showed a significant negative correlation.

## Discussion

The Southern Grand Banks show high diversity in relation with other ecosystems. The 240 taxons caught from 86 families represented a bigger fish fauna diversity than the 39 fish species caught in bottom trawls on the Newfoundland continental slope at depths from 204 to 2345 meters near Carson Submarine Canyon (Snelgrove and Haedrich, 1985), the 82 fish species collected in a continuous transect between depths of 200 and 1800 m of the Balearic Islands during the QUIMERA-I cruise carried out on board the RV *García del Cid* in October 1996 (Moranta *et al.*, 1998) as well as the 230 fish species in the Gulf of Tehuantepec (Mexico) and the Gulf of Papagayo (Costa Rica) (Bianchi, 1991). However, it represents only the 71% of the 310 fish species obtained in 1991 in depths between 200 and 1400 m in the continental slope off western Australia during a demersal trawling survey by a research vessel (FRV *Southern Surveyor*), and between 1989 and 1991 during commercial fishing operations (Williams *et al.*, 2001).

According to Spanish-EU surveys in the NAFO Divisions 3NO, the biomass and abundance of the main commercial species reflected the collapse period (1985-1993) when the surveys started in 1995 (Figure 2). About twenty years after the moratorium, even some important commercial species (e.g. Atlantic cod and American plaice) present some signs of recovery but did not reached their historical levels. Other species increased their historical average, e.g. yellowtail flounder and redfish. Some similar signs during the last few years appeared in Flemish Cap, which is close to the studied area. For instance, the Atlantic cod increased, redfish reached very high biomass levels and only the American plaice maintained the depressed situation (Casas and González-Troncoso, 2011).

Most of the studies on demersal fish assemblages have indicated that the main faunal changes occur along the depth gradient, so depth is the factor which most influenced the distribution of the species (Murua and De Cardenas, 2005; Bianchi, 1991; Moranta *et al.* 1998; Labrapoulou and Papaconstantinou, 2004). Physical characteristics of water masses, as well as bottom type, light intensity, pressure, etc., are mostly depth-dependent, and depth obviously reflects the combined effects of these factors (Bianchi, 1991). Most of the species present a wide range distribution, but they tend to be dominant in a given depth. Despite the collapse of species, some among them maintained a wide bathymetric range and we even observed that in the case of main commercial species this range increased.

Snelgrove and Headrich (1985) found that Atlantic cod occupied depth ranging from 204 to 307 m in the Carson Submarine Canyon, and Gonzalez-Troncoso *et al.* (2006) found depth range from 126 to 343 m for the same species in Flemish Cap. In our analysis we found that this species occupied very wide depths, from 40 m to 1455 m. For Greenland halibut, typical deep species, it was found a wide depth distribution, from 43 m to 1449 m (maximum depth surveyed). Similar findings were observed by Murua and De Cardenas (2005) with a depth range from 200 to 2000 m combining results from different surveys carried out in the NAFO Area, and Casas and González-Troncoso (2011) found this species in all the depth ranges surveyed (120 to 1400 m) in Flemish Cap.

Even in the species that presented a wide range distribution, catch was concentrated around a strictly depth range, shallow or deep in most of the cases (Figure 3).

González-Troncoso *et al.* (2006) and Paz and Casas (1996) found a strictly shallow distribution for American plaice, Atlantic cod and wolffish in Flemish Cap. This is consistent with our results. Other species such as black dogfish and longnose chimera showed a strictly deep distribution also found as reported by Murua and De Cardenas (2005).

Along with this we also observed that some species, as American plaice, considered strictly shallow, showed a large range of occurrence. This same case was observed by Iglesias *et al.* (1996) with information of catches in 1991 and during the second half of 1990 as well as in years 1992 and 1993 collected by observers on board the Spanish trawl fleet in Divs. 3LNM from the Regulatory Area of NAFO. American plaice presented a record occurrence in depths greater than the limits observed in the literature (deepest occurrence at over 1400 m).

Analysis of 10-years from the Spanish trawl surveys data collected in the South of the Grand Banks of Newfoundland (NAFO Regulatory Area) identified five main assemblages.

The boundaries established in 300 m and 1000 m by the cluster analysis coincide with zones with higher Percentage of Similarity index (86.9% in 300 m and 85.89 % in 1050 m). The main determining feature associated with the structure of the demersal fish assemblages is depth, as it reflects the changes from continental shelf to continental

slope (Labropoulou & Papaconstantinou, 2004). PS in the boundaries at 150 and 600 m was low and suggested little zonation; this was confirmed by the low level of dissimilarity in the cluster analysis. For the general zonation pattern three main assemblages (Shallow, Intermediate and Deep) were identified and their boundaries and species composition were similar to those found in the previous studies in this area (Gomes and Headrich, 1992) and in Flemish Cap (González-Troncoso *et al.*, 2006).

In the area of the Grand Banks of Newfoundland, different fish assemblages at depths from 40 to 500 m have been described by Gomes and Headrich (1992). Similar fish assemblages were also defined by Paz and Casas (1996) and González-Troncoso *et al.* (2006) in Flemish Cap. Although bathymetric ranges in those studies were different and dramatic changes in abundance and biomass of species caused changes in dominant species of assemblages, we observed persistence of assemblages over the time.

We observed changes in dominant species composition in each assemblage, especially for American plaice, Atlantic cod and thorny skate when comparing our results with assemblages found by Gomes *et al.* (1992). In that paper, the authors analysed data from stratified-random groundfish Spring surveys in most of the whole Grand Banks, in NAFO Div. 3LNO, in a previous period (1971-82, 1984-87) to the second collapse of the Atlantic cod stocks (Rose, 2005). In our first assemblage (depth less than 150 m) yellowtail flounder was the most dominant species, while Gomes *et al.* (1992) found American plaice as the dominant species both in depths less than 70 m and in depths less than 200 m. Boundaries for our second and third assemblages were in 300 m and 600 m, and a similar approach could be found in Flemish Cap by Paz and Casas (1996) and González-Troncoso *et al.* (2006). González-Troncoso *et al.* (2006) found boundaries between 300 and 500 m, and Paz and Casas (1996) between 300 and 600 m.

In our analysis the most important boundary appears at about 300 m. Weakest zonation around 600 m confirmed the wide range distribution of some species, for instance witch flounder, Northern wolffish and redfish. Those intermediate species presented no particular association with any depth range. Species from the third and fourth assemblages were overlapped. Those results were confirmed in the Correspondence Analysis and the Principal Components Analysis where all intermediate species were mixed in the second main groups of the two analyses.

Our assemblage results did not agree with Snelgorve and Headrich (1992) on the fact that suggested that zonation of fish assemblages is not present in a restricted area, the Carson Submarine Canyon (Newfoundland) at range from 204 to 2325 m.

Dramatic decreasing on biomass of traditional target species for commercial fishing in the area, such as Atlantic cod and American plaice, can be a cause of changes in the composition of assemblages (Hutchings, 2000; González-Troncoso *et al.*, 2006). In our assemblages, a huge increase of biomass catch for redfish, probably due to the constant decrease of its main predator species, like cod, can be observed. A similar situation occurred in Flemish Cap. Paz and Casas (1996) and González-Troncoso *et al.* (2006) found in Flemish Cap (1992-94 and 1995-2002) that redfish was the dominant species in depths lesser than 300 m and in depths between 301 and 500 m. The reduction of Atlantic cod abundance and distribution on the eastern Scotian Shelf, where it had historically been the dominant piscivore, may have permitted one or more of its preys or competitor species to increase in abundance and thereafter impacting the recovery of Atlantic cod (Fisher and Frank, 2004). Thus, we appreciated that Atlantic cod was the second dominant species for Gomes *et al.* (1992) in their Shallow, Intermediate and Deep Assemblages. In our first and second assemblage Atlantic cod represented only around 8% of the catch.

Regarding the second intermediate assemblage (600-1001 m) three species appeared as dominant in similar magnitude: Greenland halibut, redfish and roughhead grenadier. In more restricted range, in Flemish Cap, González-Troncoso *et al.* (2006) found that marlin spike was the dominant species. In depths bigger than 1001 m blue hake, Northern cutthroat eel and roughhead grenadier had a similar importance with biomass catch resulting in 19.5%, 16.9% and 16.5% respectively, and each one had a 95% of occurrence.

In order to compare with the assemblages found by Gomes *et al.* (1992) in the Grand Banks, we carried out a cluster analysis considering the depth range truncated in 500 m. Figure 8 shows the cluster results where we took into account only samples between 38 and 500 m. No changes in assemblage boundaries were found. In the resulting dendrogram three similar main zones found by Gomes *et al.* were distinguished: Shallow assemblage at depths of less than 70 m, Intermediate assemblage at depths between 71 and 200 m and Deep assemblage at depths bigger than 201 m. Yellowtail flounder is the most abundant species at depths of less than 70 m for us, for Gomes *et al.* (1992) was the American plaice.

Snelgrove and Headrich (1985) observed a bigger-deeper relation for blue hake and roundnose grenadier. We also found also this phenomenon in our analysis of blue hake and Greenland halibut. Wenner and Musick (1977) suggested that blue hake matures in shallow waters, but Snelgrove and Headrich (1985) sampled larger individuals at all depths and immatures could be seen only in shallow samples creating the appearance of a bigger-deeper relation where it did not exist.

Witch flounder showed a significant negative correlation. Paz and Casas (1996) found the same correlation for this species in Flemish Cap. Burnett *et al.* (1992) found significant differences in distribution according to depth for juveniles and adults of this species in the Gulf of Maine-Georges Bank Region and, while adults maintained a mean depth constant during all year, juveniles were found at shallower depths than adults in winter and spring, and at greater depths in summer and fall. This is attributed to differences in prey distribution associated with differences in the diet (Bunnet *et al.*, 1992).

Biomass declined on the middle continental slope; in this region the diversity was greater than in other zones. This coincides with the results found by González-Troncoso *et al.* (2006) and Paz and Casas (1996) in Flemish Cap. This fact has an important effect on fish community structure and eventually on the traditional fisheries (Gordon *et al.*, 1994). Commercially important species tend to be present in low diversity communities where they reach a significant proportion in the total biomass (Headrich, 1994). In agreement with this assertion, the Shelf and Upper Continental Slope presented the smallest diversity and they were the regions where the traditional commercial species exploited in the area, such as Atlantic cod, redfish, yellowtail flounder and American plaice, are present.

González-Troncoso *et al.* (2006) and Paz and Casas (1996) found that representative species from the middle continental slope of Flemish Cap were more homogeneously represented. We also found that biomass catch of different deeper species (forth and fifth assemblage) were more homogeneously represented *versus* shallower species. However, Menezes *et al.* (2006) found strongly domination of one or two species in the deepest strata and similar abundance of many species in the shallow depths stratum in Azores. It must be noted that the selectivity of the longline used in their study can reduce the biodiversity of the catch.

Our results confirm the temporal persistence of boundaries and composition fish assemblages in the area. That is in consonance with Overholtz and Tyler (1985), where assemblages persisted over the long-term and changed spatial configuration only slightly on a seasonal basis.

On the other hand, changes in dominant species in the different assemblages, redfish replacing Atlantic cod and American plaice, were observed. Similar pattern presented between Southern Grand Banks and Flemish Cap in the evolution of these fish assemblages indicates that changes in fish populations in the Northwest Atlantic have been produced on a large scale, affecting Large Marine Ecosystem, and not limited to specific areas.

In the slope the assemblage species composition were similar to the results of the recent by-catch studio in the Greenland Halibut fishery (Patrocinio and Paz, 2011). Although the methodology is not comparable, their results can be considered indicatives. A total of 51 species/taxa were identified in the discarded catch, 38 of which accounted for less than 0.5%. Discarded biomass represented 4.3% of the total catch. Discards composition was dominated, in biomass, by the macrourids roughhead grenadier, marlin spike and roundnose grenadier, which together accounted for 61.2% of the total discarded biomass. The fourth species was blue hake. At depth ranges between 601 and 1460 m we found that Greenland halibut, redfish, roughhead grenadier, blue hake and Northern cutthroat eel were the main species. The presence of redfish and Northern cutthroat eel could be explained by the large difference in gear selectivity. Trawl surveys used the *Campelen* gear, with vertical opening greater and mesh size much smaller than the gear used in fishing activities.

Knowledge of the assemblages of fish can be used to improve the management of multispecies resources exploited, although the definition of assemblages in an area just explains the functioning of the ecosystem. For this reason, it would be necessary other studies to understand the interrelationships between species, such as feeding relationships and trophic guilds.

### Conclusions

- The Southern Grand Banks show high diversity in relation with other ecosystems.
- There are some typical shallow species that show a very wide bathymetric range distribution, for instance American plaice and thorny skate, whereas there are some others (usually deeper species) that appear at very shallow depths too (less than 150 m), such as marlin spike, roughhead grenadier and Northern cutthroat eel.
- Despite the decline in abundance and biomass of the main commercial and non-commercial fishes, we observed persistence in the species composition of assemblages.
- From the 1980's, yellowtail flounder replaced American plaice and Atlantic cod and were dominant species in shallow assemblages.
- Higher diversity was observed in deeper depths than in shallower assemblages.
- Assemblage composition persistence and changes in principal dominant species were similar to the evolution in near ecosystems such as Flemish Cap.
- The evolution pattern in the fish assemblages in the southern Grand Banks, similar to other Northwest areas, indicates that the changes in fish populations in the Northwest Atlantic have appeared on a large scale and have not been limited to specific areas.

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### References

- Bishop, C. A., 1994. Revisions and additions to stratification schemes used during research vessel surveys in NAFO subareas 2 and 3. NAFO SCR Doc., No 43, Serial No N2413, 23 pp.
- Bianchi, G., 1991. Demersal assemblages of the continental shelf and slope edge between the gulf of Tethuantepec (Mexico) and the Gulf of Papagayo (Cosa Rica). *Mar Ecol Prog Ser* 73: 121-140.
- Burnett, J., M. R. Ross and S. H. Clark., 1992. Several biological aspects of the witch flounder (*Glyptocephalus cynoglossus* (L.)) in the Gulf of Maine-Georges Bank Region. *J. Northw. Atl. Fish. Sci.*, 12: 49-62.
- Cochran, W. G., 1997. Sampling techniques. J. Wiley and Sons, N.Y., 428 pp.
- Casas, M. and D. González-Troncoso, 2011. Results from the bottom trawl survey on Flemish Cap of June-July 2010. NAFO SCR Doc 11/21. Serial Number N5904.
- Fariña AC, Freire J and E. González-Gurriarán, 1997. Demersal fish assemblages in the Galician continental shelf and upper slope (NW Spain): spatial structure and long-term changes. *Estuarine, Coastal and Shelf Sci.* 44 (1997b), pp. 435-454.
- Field, J. G. and G. McFarlane, 1968. Numerical methods in marine ecology. I. A quantitative similarity analysis of rocky shore samples in False Bay, South Africa. *Zool. Afr.* 3: 119-138
- Field, J. G., K. R. Clarke and R. M. Warwick, 1982. A practical strategy for analysing multispecies distribution patterns. *Mar. Ecol. Prog. Ser.*, Vol. 8: 37-52
- Fisher, J. and Headrich R.L., 2000. The realized Annual Niche Space of Common Fish Species off Newfoundland. *NAFO Sci. Coun Studies*, 33: 11-28.
- Fisher, J. A.D. and K. T. Frank, 2004. Abundance-distribution relationships and conservation of exploited marine fishes. *Mar. Ecol. Prog. Ser.* Vol. 279: 201-213.
- Gardiner, F. P. and R. L. Haedrich, 1978. Zonation in the deep benthic megafauna. Application of a general test. *Oecologia (Berl.)* 31, 311-317
- Gomes, M. C, R. L. Haedrich and J. C. Rice, 1992. Biogeography of groundfish assemblages on the Grand Bank. *J. Northw. Atl. Fish. Sci.* 14: 13-27.

- Gomes, M. C., E. Serrão and M. F. Borges, 2001. Spatial patterns of groundfish assemblages on the continental shelf of Portugal. *ICES J. Mar. Sci.* 58: 633-647.
- González-Costas, F. and D. González-Troncoso, 2009. Spanish 2006-2008 Fisheries Footprint, scientific Observers and surveys coverage and update of the Standardized CPUE Indices for Greenland Halibut. NAFO SCR Doc.09/022, Serial No. N5657.
- González Troncoso, D., C. González and X. Paz, 2004. American plaice biomass and abundance from the surveys conducted by Spain in the NAFO Regulatory Area of Divisions 3NO, 1995-2003. NAFO SCR Doc. 04/09, Serial Number N4954, 22 pp.
- González-Troncoso, D., X. Paz and X. Cardoso, 2006. Persistence and Variation in the Distribution of Bottom-trawl Fish Assemblages over the Flemish Cap. *J. Northw. Atl. Fish. Sci.*, Vol. 37: 103–117.
- González-Troncoso, D., M. Sacau and F. González-Costas, 2007. A study of Spanish Greenland Halibut commercial effort and CPUE in 3LMNO using GIS with comparisons to the Spanish Division 3NO survey and EU Flemish Cap survey catches. NAFO SCR Document No. 54, Serial No. N5406. 12 pp.
- González-Troncoso, D, C González and X Paz, 2011. Yellowtail flounder, redfish (*Sebastes* spp) and Witch flounder indices from the Spanish Survey conducted in Divisions 3NO of the NAFO Regulatory Area. NAFO SCR Doc. 11-006. Serial No. N5886. 42 pp.
- Gordon, J.D.H., N.R. Merret and R. Headrich, 1994. Environmental and biological aspects of slopedwelling fishes of the North Atlantic. In: *Deep Water Fisheries of the North Atlantic Oceanic slope*, A.G. Hopper (ed). Proceedings of the NATO Advanced Research Workshop, March 1994, Kluwer, Dordrecht, The Netherlands.
- Headrich, R.L., 1994. Structure over time of an exploited deep water fish assemblage. In: *Deep Water Fisheries of the North Atlantic Oceanic slope*, A.G. Hopper (ed.). Proceedings of the NATO Advanced Research Workshop, March 1994, Kluwer, Dordrecht, The Netherlands.
- Hutchings JA., 2000. Collapse and recovery of marine fishes. *Nature*, Vol 406, 24 August 2000. [www.nature.com](http://www.nature.com)
- Hutchings, J. A. and Reynolds, J. D. 2004. Marine fish population collapses: consequences for recovery and extinction risk. *BioScience* 54: 297-309.
- Iglesias, S., X. Paz and E. De Cardenas, 1996. Occurrence of American plaice (*Hippoglossoides platessoides*) at non-habitual depths in the northwest Atlantic, 1990-93. *NAFO. Sci. Coun. Studies*, 24: 91-95.
- Jaureguizar, A. J., R. Menni, C. Bremec, H. Mianzan and C. Lasta, 2003. Fish assemblage and environmental patterns in the Río de la Plata estuary. *Est. Coast. Shelf Sci.* 56: 921-933.
- Jennings, S. and MJ. Kaiser, 1998. The effects of fishing on marine ecosystems. *Adv. Mar. Biol.* 34: 203–352.
- Jolliffe, I. T., 1986. *Principal components analysis*. Springer-Verlag. New York.
- Kendrick, T. H. and M. P. Francis, 2002. Fish assemblages in the Hauraki Gulf, New Zealand. *N.Z. J. Mar. Freshwat. Res.*, Vol. 36: 699-717.
- Koslow, J. A., 1993. Community structure in North Atlantic Deep-Sea Fishes. *Prog. Oceanog.*, 31: 321-338
- Labrapoulou M. and C. Papaconstantinou, 2004. Community structure and diversity of demersal fish assemblages: the role of fishery. *Sci. Mar.* 68 (Suppl.1):215-226
- Lear, W. H., 1998. History of fisheries in the Northwest Atlantic: the 500 year perspective. *Journal of Northwest Atlantic Fisheries Science*, 23, 41–73.
- Lekve, K., N. C. Stenseth, J. Gjøsæter, J. M. Fromentin and J. S. Gray, 1999. Spatio-temporal patterns in diversity of a fish assemblage along the Norwegian Skagerrak coast. *Mar. Ecol. Prog. Ser.* 178: 17-27.
- Mahon, R. and R. W. Smith, 1989. Demersal fish assemblages on the Scotian Shelf, Northwest Atlantic: spatial distribution and persistence. *Can. J. Fish. Aquat. Sci.* 46 (Suppl. 1): 134-152.
- Mahon, R., S. K. Brown, K. C. T. Zwanenburg, D. B. Atkinson, K. R. Buja, L. Claflin, G. D. Howell, M. E. Monaco, R. O'Boyle and M. Sinclair, 1998. Assemblages and biogeography of demersal fishes of the east coast of North America. *Can. J. Fish. Aquat. Sci.* 55: 1704-1738. 42
- MATLAB 6.1, 2000. The MathWorks Inc., Natick, MA. <http://www.mathworks.com>
- Menezes, GM, HM Sigler, MR Silva, MF Pinho, 2006. Structure and zonation of demersal fish assemblages off the Azores Archipelago (mid-Atlantic). *Mar Ecol Prog Ser.* Vol. 324: 241–260, 2006.
- Moranta J., C. Stefanescu, E. Massutí, B. Morales-Nin and D. Lloris, 1998. Fish community structure and depth-related and depth-related trends on the continental slope of the Balearic Islands (Algerian basin, western Mediterranean). *Mar. Ecol. Prog. Ser.* Vol. 172: 247-259,
- Murua H. and E. de Cardenas, 2005. Depth-distribution of Deepwater Species in Flemish Pass. *J. North. Atl. Fish. Sci.* Vol. 37: 1-12.
- Overholtz, W. J. and A. V. Tyler, 1985. Long-term responses of the demersal fish assemblages of Georges Bank. *Fish. Bull.* 83: 507-520.

- Patrocínio T. and X. Paz, 2011. Discards and by-catch in Spanish fleet targeting Greenland halibut (*Reinhardtius hippoglossoides*) in NAFO. Divisions 3LMNO: 2008 and 2009. NAFO SCR Doc. 11/8. Serial No. N5888.
- Paz, X. and J.M. Casas, 1996. Zonation and Associations of Dominant Fish Fauna on Flemish Cap. NAFO Sci. Coun. Studies, 25: 67–75
- Paz, X. and P. Durán, 1999. Results from the 99 Spanish Bottom Trawl Survey in the Regulatory Area for Divisions 3NO Serial No. N4116 NAFO SCR Doc. 99/57.
- Perry, R. I. and S. J. Smith, 1994. Identifying habitat associations of marine fishes using survey data: an application to the Northwest Atlantic. *Can. J. Fish. Aquat. Sci.*, Vol. 51: 589-602
- Priede IG, JA Godbold, NJ King, MA Collins, DM Bailey and JDM Gordon, 2010. Deep-sea demersal fish species richness in the Porcupine Seabight, NE Atlantic Ocean: global and regional patterns. *Marine Ecology* 31 (2010) 247–260.
- Rice, J., 2005. Recent developments in the inclusion of biodiversity concerns in the management of fisheries. *Biodiversity: Science and Governance*, Paris, 24-28 January 2005.
- Rose, G. A., 2005. On distributional responses of North Atlantic fish to climate change. *ICES J. Mar. Sci.* 62: 1360-1374.
- Shannon, C. E. and W. Weaver, 1963. *The mathematical theory of communication*. Univ. of Illinois Press, Urbana.
- Statsoft, Inc, 1998. *Statistica for Windows*. Tulsa, OK. <http://www.statsoft.com>.
- Stephenson, W. T. and D. Burges, 1980. Skewness of data in the analysis of species-in-sites-in-times. *Proc. R. Soc. Queensland*, 91: 37-52
- Snelgrove PVR and RL Haedrich, 1985. Structure of the deep demersal fish fauna off Newfoundland. *Mar. Ecol. Prog. Ser.* 27: 99-107.
- The R Project for Statistical Computing. <http://www.r-project.org/>
- Tolimieri, N. and P. S. Levin, 2006. Assemblage structure of Eastern Pacific groundfishes on the U.S. continental slope in relation to physical and environmental variables. *Trans. Am. Fish. Soc.* 135: 317-332.
- Wenner, C.A. and J.A. Musick, 1977. Biology of the morid fish *Antimora rostrata* in the western North Atlantic. *J. Fish. Res. Bd Can.* 34: 2362-2368.
- Williams A, JA Koslow and PR Last, 2001. Diversity, density and community structure of the demersal fish fauna of the continental slope off western Australia (20 to 35° S). *Mar Ecol Prog Ser* 212:247–263.
- Whittaker, R. H. and C. W. Fairbanks, 1958. A study of plankton copepod communities in the Columbia Basin, Southeastern Washington. *Ecology*, 39: 46-59.

**Table 1.-** Number of hauls, depth covered, dates and number of species by year. R/V *Vizconde de Eza* has been used all years.

Year	Valid hauls	Depth range (m)	Dates
2002	125	39-1460	April 29-May 19
2003	118	38-1460	May 11-June 02
2004	120	43,5-1449	June 06-June 24
2005	119	49-1402	June 10-June 29
2006	120	45,5-1457	June 7-June 27
2007	110	46,5-1373	May 29-June 19
2008	122	40-1435	May 27-June 16
2009	109	44,5-1386	May 31-June 18
2010	95	40-1390	May 30-June 18
2011	122	44,5-1430	June 5-June 24
<b>2002-11</b>	<b>1160</b>	<b>38-1460</b>	

**Table 2.-** Vertical ranges and catch data for fish species taken by bottom trawls in the Spanish 3NO surveys 2002-2011 including all valid hauls.

Main Fish Species	Common name	FAO Code	Depth range	Weight (kg)	No. Of Stations	Occurrence (%)
<i>Sebastes sp</i>	Redfish	RED	46-1460	378039.5	489	42.5
<i>Limanda ferruginea</i>	Yellowtail flounder	YEL	38-190	149196.5	435	37.5
<i>Hippoglossoides platessoides</i>	American plaice	PLA	38-1460	132409.9	771	66.5
<i>Gadus morhua</i>	Atlantic cod	COD	40-1355	51787.53	549	47.3
<i>Mallotus villosus</i>	Capelin	CAP	38-454	33938.7	487	44.3
<i>Amblyraja radiata</i>	Thorny skate	RJR	38-1449	31892.9	753	64.9
<i>Ammodytes dubius</i>	Northern sand lance	SAN	38-229	25143.1	404	34.8
<i>Macrourus berglax</i>	Roughhead grenadier	RHG	119.5-1449	12629.9	528	45.5
<i>Reinhardtius hippoglossoides</i>	Greenland halibut	GHL	43-1449	9777.0	732	63.1
<i>Antimora rostrata</i>	Blue antimora	ANT	215.5-1460	8694.3	403	34.7
<i>Sypnabobranchus kaupii</i>	Northern cutthroat eel	SSK	62-1460	6707.6	445	38.4
<i>Nezumia bairdii</i>	Marlin-spike	NZB	58.5-1460	4133.1	537	46.3
<i>Anarhichas lupus</i>	Wolfish (Catfish)	CAA	44.5-635	4037.3	287	24.9
<i>Glyptocephalus cynoglossus</i>	Witch flounder	WIT	43.5-1460	3930.7	576	49.7
<i>Centroscyllum fabricii</i>	Black dogfish	CFB	232-1457	3867.6	232	20.0
<i>Coryphaenoides rupestris</i>	Roundnose grenadier	RNG	225-1460	2071.5	362	31.2
<i>Urophycis tenuis</i>	White hake	HKW	58.5-980	1994.2	136	11.7
<i>Anarichas denticulatus</i>	Northern wolfish	CAB	56-1434.5	1446.4	283	24.4
<i>Lycodes reticulatus</i>	Arctic eelpout	LCT	48.5-1299	1233.8	370	31.9
<i>Lophius americanus</i>	American angler	ANG	47.5-1230.5	821.2	88	7.6
<i>Phycis chesteri</i>	Longfin hake	GPE	168-1355.5	812.7	257	22.2
<i>Harriota raleighana</i>	Longnose chimera	HCR	440-1448.5	779.7	108	9.3
<i>Bathyraja spinicauda</i>	Spinytail skate	RJQ	233.5-1401	760.7	73	6.3
<i>Tryglops murrayi</i>	Moustache sculpin	TGM	38-566	743.1	502	43.3
<i>Amblyraja hyperborea</i>	Arctic skate	RJG	312-1448.5	640.9	121	10.4
<i>Hemitripterus americanus</i>	Web (whip) sculpin	SP1	44-334.5	614.3	105	9.1
<i>Anarichas minor</i>	Spotted wolfish	CAS	110.5-823.5	576.2	98	8.5
<i>Notacanthus nasus</i>	Snubnosed spiny eel	NNN	409-1460	543.1	273	23.6

**Table 3.-** Percentage of similarity among regions of 150 m.

Regions intervals (m)	Boundaries (m)	PS (%)
38-150/151-300	150	16.2
151-300/301-450	300	86.9
301-450/451-600	450	93.1
451-600/601-750	600	40.0
601-750/751-900	750	53.5
751-800/901-1050	900	78.1
901-1050/1051-1200	1050	85.9
1051-1200/1201-1460	1200	80.7

**Table 4.-** Eigenvalues from the Principal Component Analysis performed on root-root transformed data.

Value	Eigenvalue	% Total Variance	Cumulative Eigenvalue	Cumulative %
1	16.843814	60.15648	16.84381448	60.15648028
2	5.3201131	19.000404	22.1639276	79.1568843
3	1.5673906	5.5978237	23.73131823	84.75470798

**Table 5.-** Most abundant demersal fish species at the three depth zones considered. Values are percentages of total biomass and occurrence.

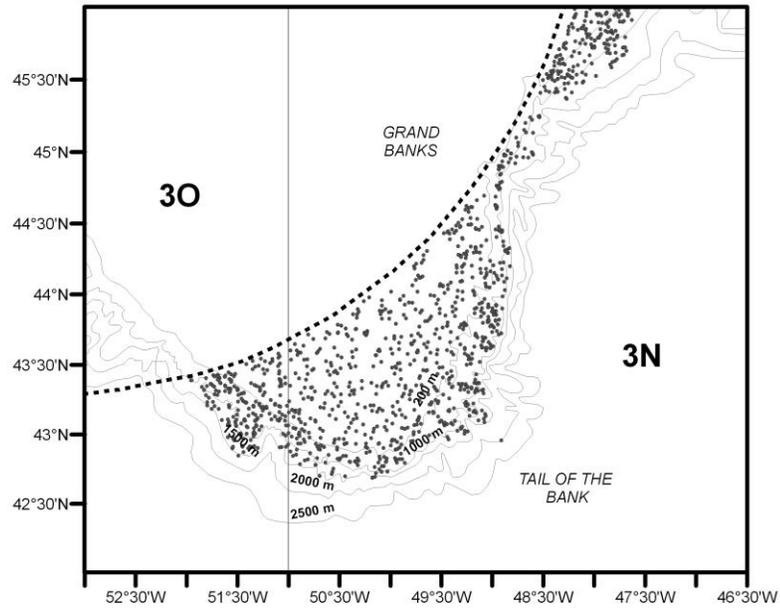
Species	Bio (%)	Occur (%)	Species	Bio (%)	Occur (%)
<b>Dominant species in depths &lt;150 m (Ia)</b>			<b>Dominant species in depths between 151 - 300 m (Ib)</b>		
<i>Limanda ferruginea</i>	39.09	85.57	<i>Sebastes sp</i>	82.47	89.44
<i>Hippoglossoides platessoides</i>	32.12	99.80	<i>Gadus morhua</i>	7.19	89.44
<i>Mallotus villosus</i>	8.08	78.56	<i>Hippoglossoides platessoides</i>	2.85	96.48
<i>Gadus morhua</i>	8.01	64.73	<i>Ammodytes dubius</i>	2.07	23.24
<i>Amblyraja radiata</i>	5.91	86.37	<i>Amblyraja radiata</i>	1.33	85.21
<i>Ammodytes dubius</i>	5.28	74.35	<i>Mallotus villosus</i>	1.30	40.14
Total	98.49		Total	97.20	
<b>Dominant species in depths between 301 - 600 m (IIa)</b>			<b>Dominant species in depths between 601 - 1000 m (IIb)</b>		
<i>Sebastes sp</i>	91.24	100.00	<i>Reinhardtius hippoglossoides</i>	14.79	96.00
<i>Amblyraja radiata</i>	1.86	76.51	<i>Sebastes sp</i>	14.65	70.29
<i>Macrourus berglax</i>	1.65	85.91	<i>Macrourus berglax</i>	14.63	96.57
<i>Hippoglossoides platessoides</i>	1.39	59.73	<i>Antimora rostrata</i>	10.80	96.57
<i>Reinhardtius hippoglossoides</i>	0.77	97.32	<i>Gadus morhua</i>	8.34	3.43
<i>Gadus morhua</i>	0.63	60.40	<i>Nezumia sp</i>	6.55	96.57
<i>Nezumia sp</i>	0.47	91.95	<i>Synaphobranchus kaupii</i>	6.35	94.86
<i>Lycodes reticulatus</i>	0.32	85.91	<i>Amblyraja radiata</i>	4.73	34.86
Total	98.33		Total	80.85	
<b>Dominant species in depths &gt;1001 m (III)</b>					
<i>Antimora rostrata</i>	19.51	95.38			
<i>Synaphobranchus kaupii</i>	16.91	95.38			
<i>Macrourus berglax</i>	16.54	93.85			
<i>Reinhardtius hippoglossoides</i>	13.14	87.69			
<i>Centroscyllium fabricii</i>	10.79	80.51			
<i>Coryphaenoides rupestris</i>	5.26	94.36			
<i>Amblyraja radiata</i>	4.90	13.33			
<i>Nezumia sp</i>	4.52	88.21			
Total	91.57				

**Table 6.-** Community parameters and catch rates for fish assemblages by depth strata on the Southern Grand Banks in the years 2002-2011.

	Depth strata (m)				
	38-150	151-300	301-600	601-1000	1001-1459.5
Number of species	20	25	26	24	21
Diversity, H	1.54	0.8	0.5	2.53	2.23
Number of stations	499	142	149	175	195
Total biomass (Catch kg)	379133.34	248075.73	185110.29	29009.30	27914.16
Biomass (kg 0.5 / h)	760	1747	1242	166	143

**Table 7.-** Regression parameters of mean per individual by species versus depth where the regression was significant.

Species	No. Of Cases	Correlation		Parameters of Equation $y=ax+b$	
		coefficient	Significance	<i>a</i>	<i>b</i>
<i>Limanda ferruginea</i>	434	0.107	<0.05	0.0004	0.2968
<i>Urophycis tenuis</i>	113	0.173	<0.05	0.0012	1.1127
<i>Coryphaenoides rupestris</i>	343	0.237	<0.05	0.0009	0.0171
<i>Ammodytes dubius</i>	193	0.346	<0.05	0.00005	0.0092
<i>Glyptocephalus cynoglossus</i>	574	0.0.414	<0.05	-0.0003	0.5232
<i>Sebastes sp</i>	477	0.545	<0.05	0.003	0.4469
<i>Antimora rostrata</i>	369	0.647	<0.05	0.003	0.0645
<i>Nezumia bairdii</i>	442	0.792	<0.05	0.0004	0.0151
<i>Reinhardtius hippoglossoides</i>	731	0.825	<0.05	0.0009	0.0558



**Figure 1.-** Hauls position in the Spanish Spring Survey in Div. 3NO in the whole period (2002-2011).

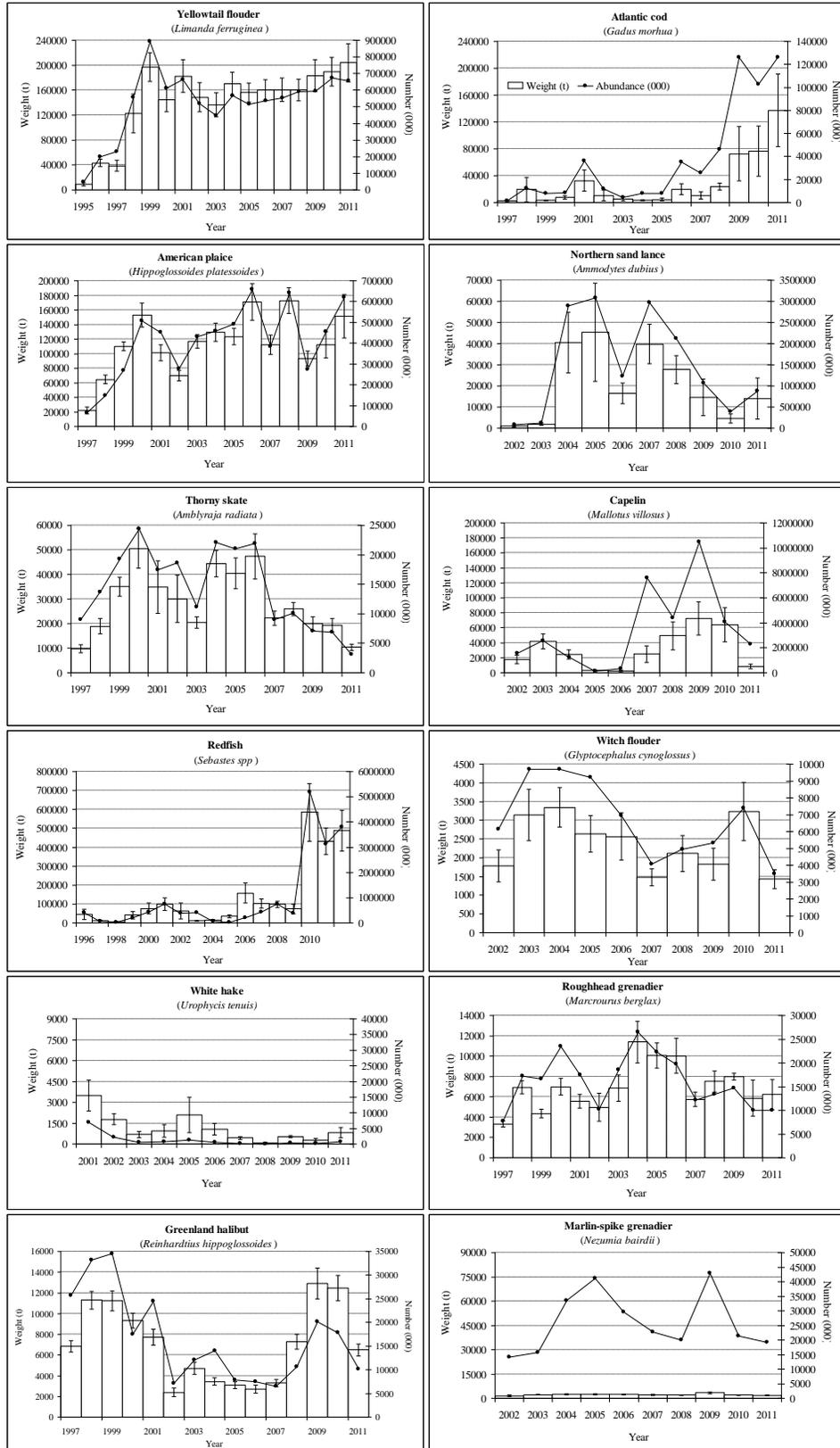
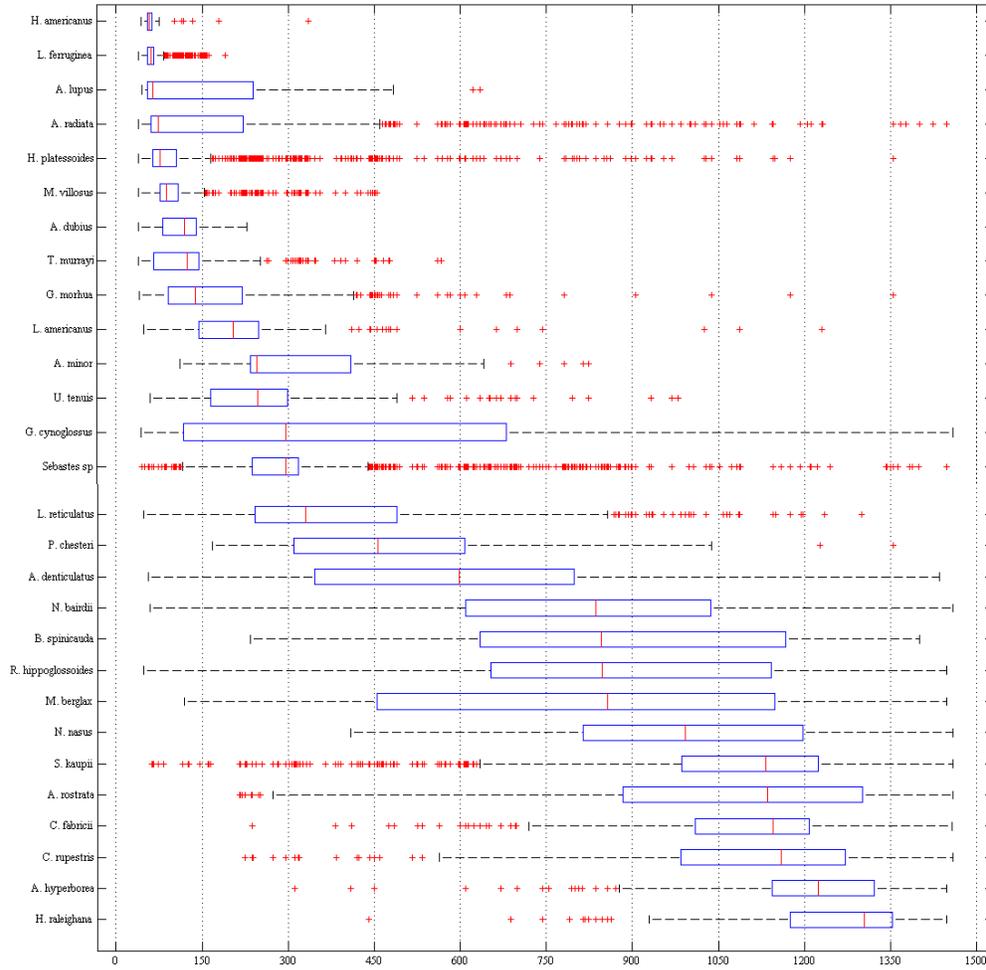
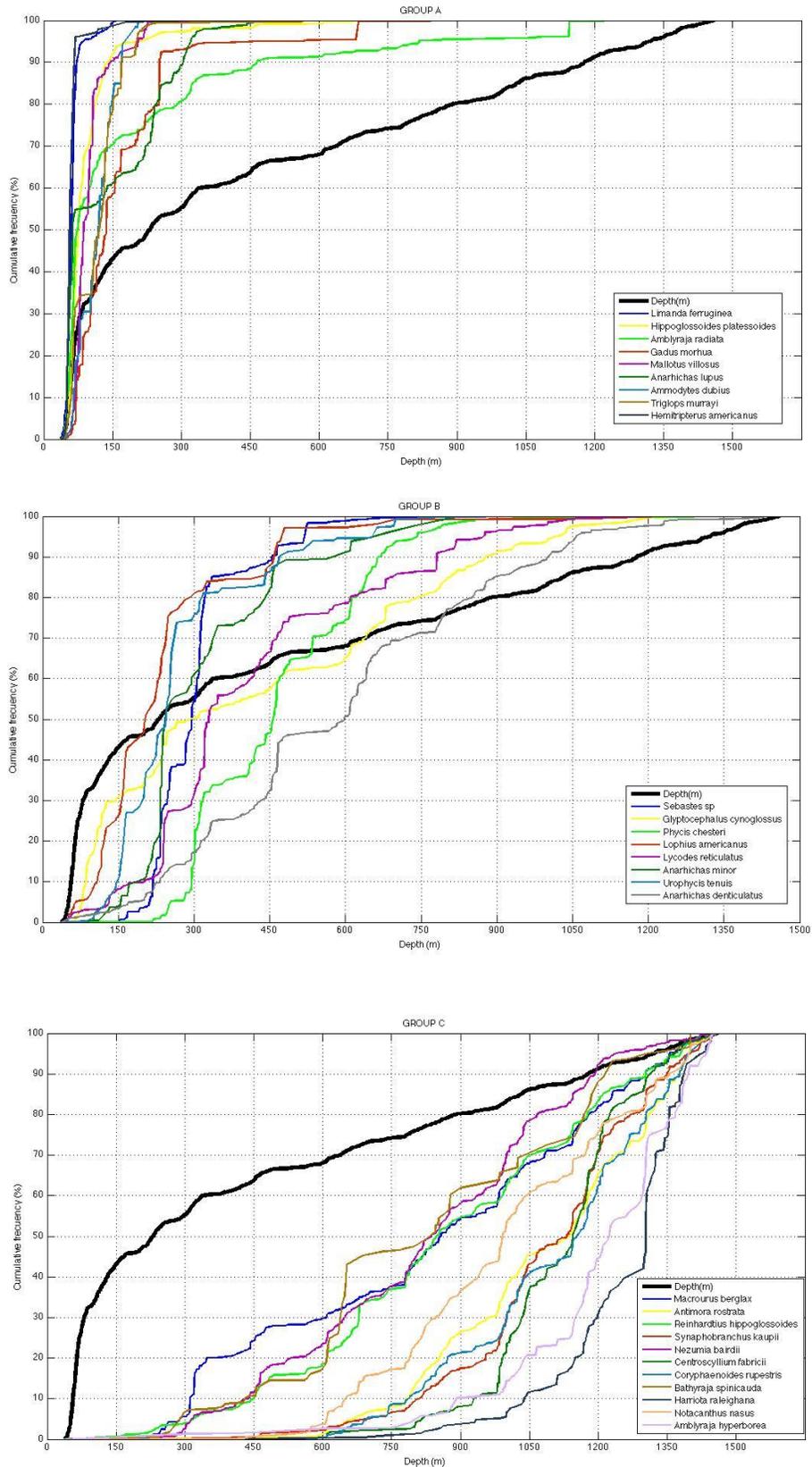


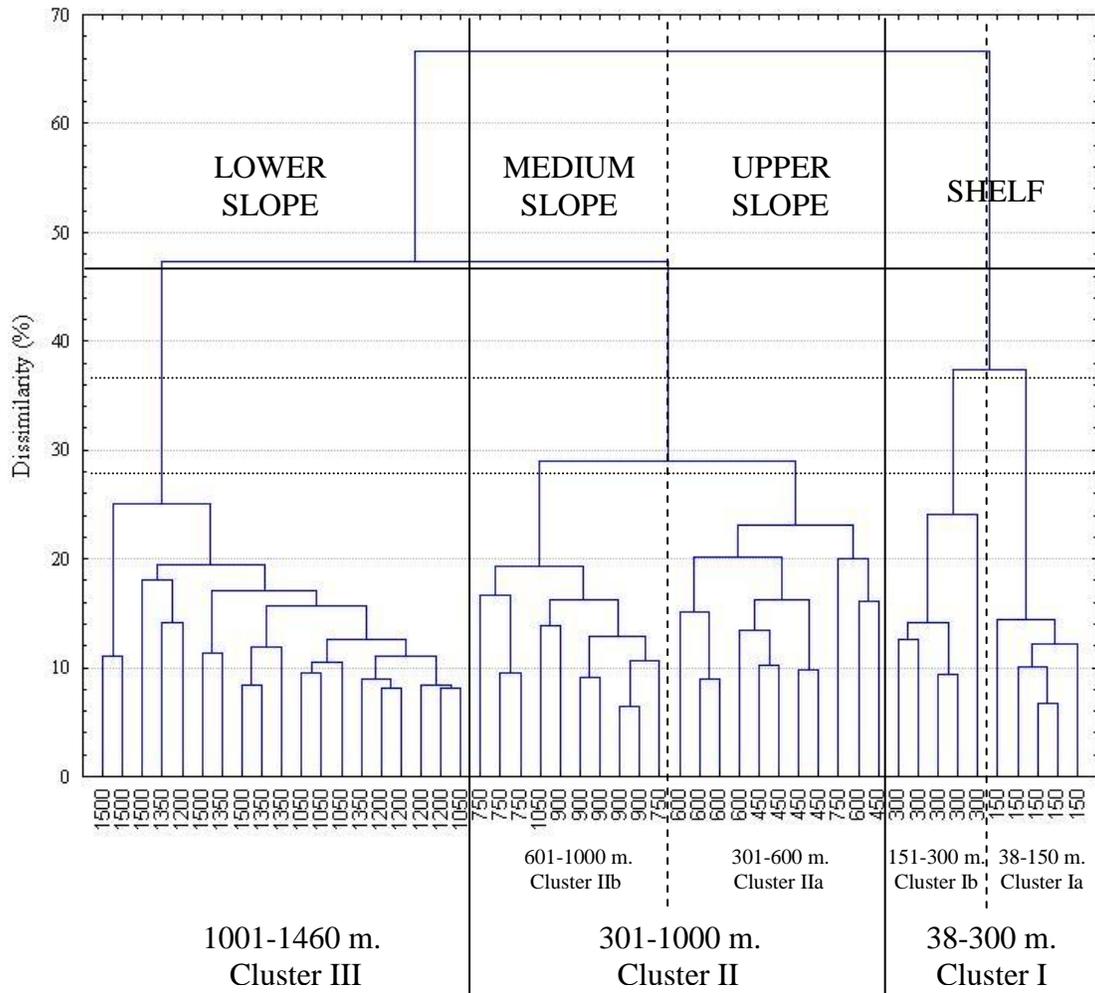
Figure 2.- Abundance and Biomass estimates for the main species from Spanish bottom trawl survey 3NO, 2002-2011.



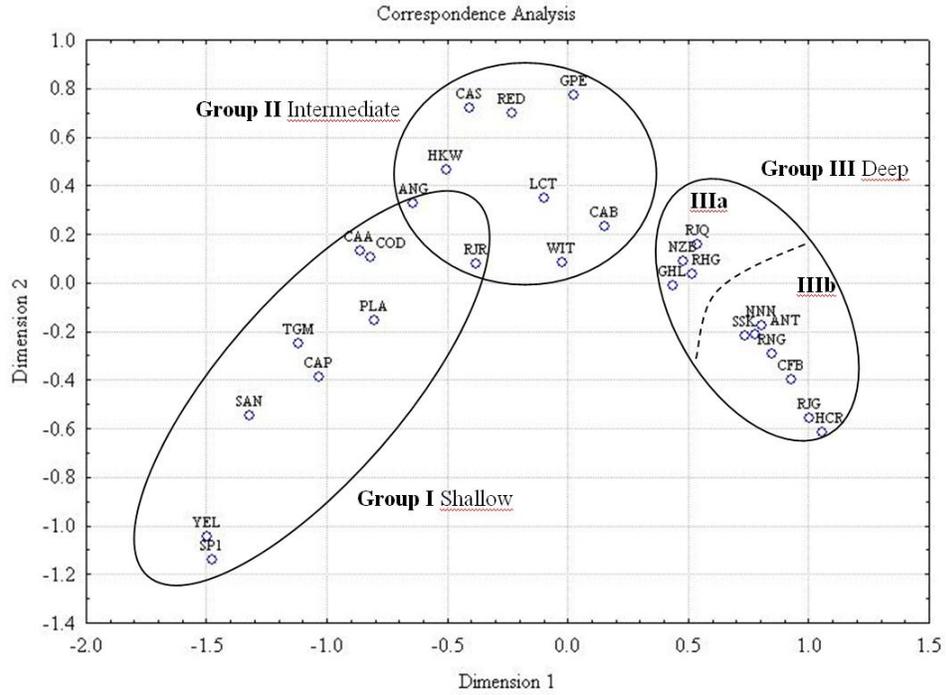
**Figure 3.-** Box-Plots of depth distribution of the most abundant species caught in the deep water trawl survey in NAFO Div. 3NO, 2002-2011.



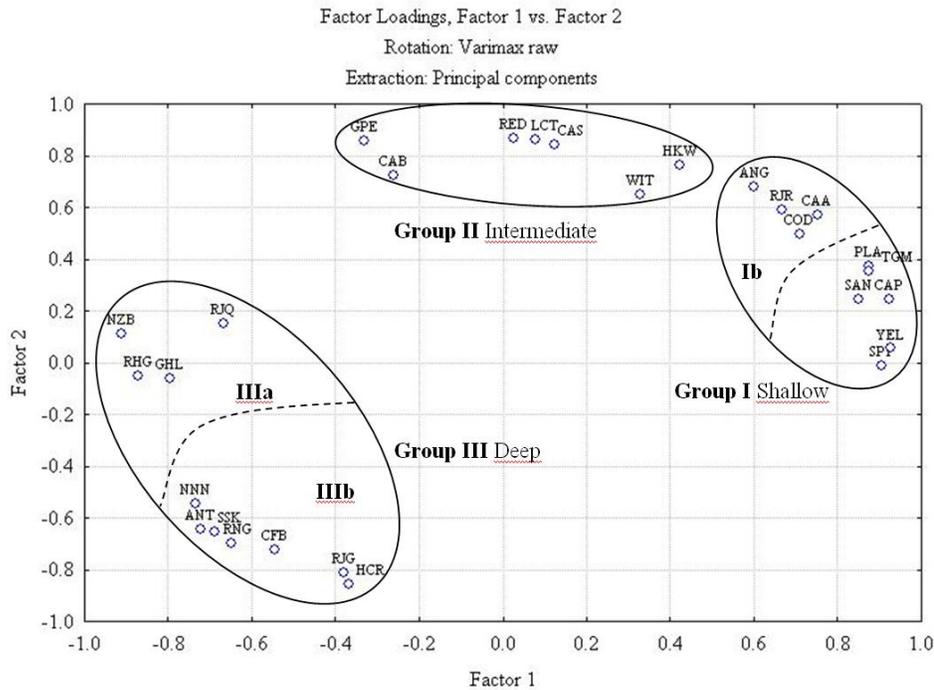
**Figure 4.-** Cumulative frequency distributions of depth variable and depths as weighted by biomass of the specimens caught for each species on the Southern Grand Banks in 2002-2011.



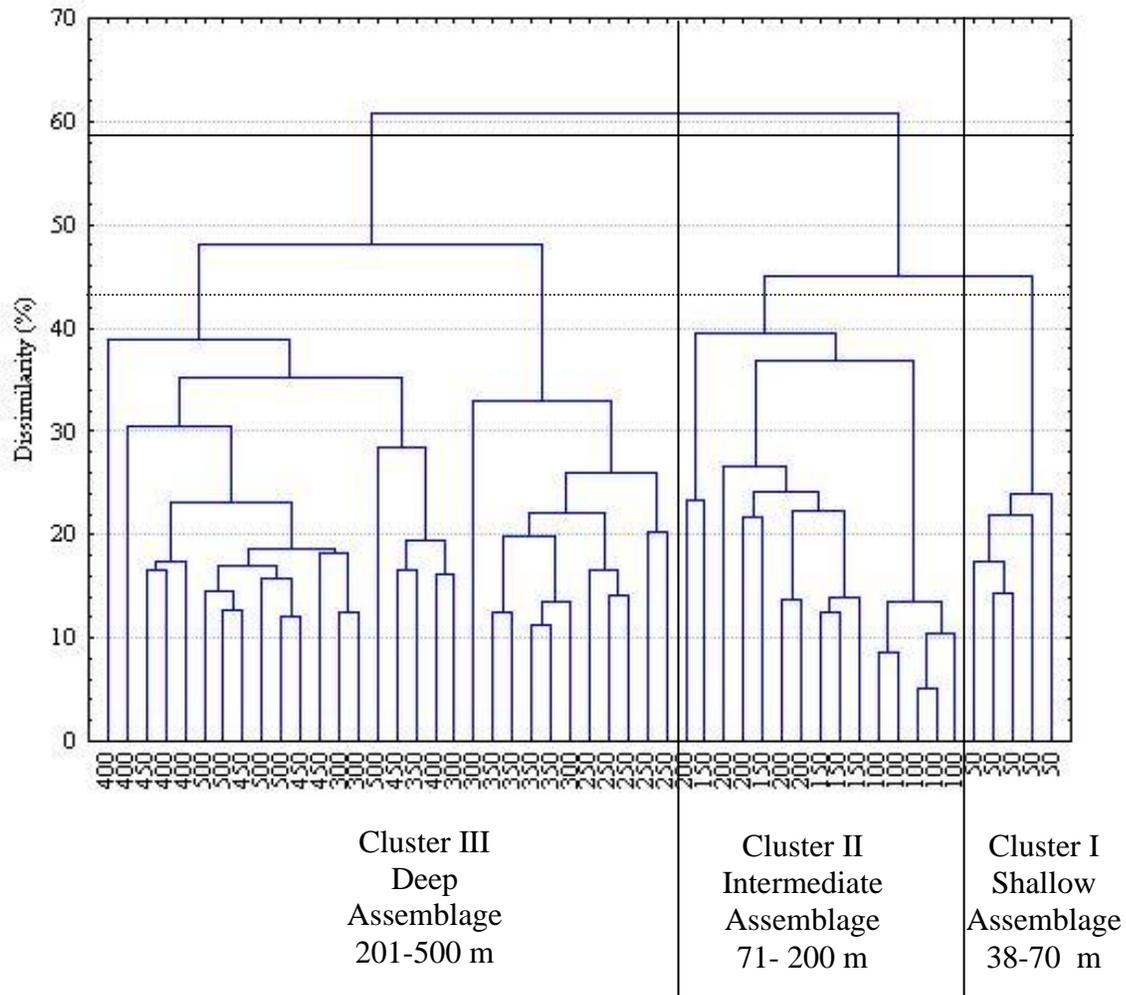
**Figure 5.-** Dendrogram showing the classification of 1160 sets grouped in 10 depth class of 150 m by two years (2002-03, 2004-05, 2006-07, 2008-09, 2010-11) based on mean abundance of fish fauna species composition by depth class. Catch was root-root transformed before comparing stations using the Bray-Curtis measure, and the dendrogram formed by group-average sorting. Three main clusters are distinguished at an arbitrary dissimilarity level of 47%. Two secondary sub-groups are observed at a dissimilarity of 37% and 28%.



**Figure 6.-** Data on species assemblages and distribution from southern Grand Banks in 2002-2011, all years combined. Correspondence Analysis ordination plot of axes I and II relating abundance variations to the depth range: 38-1460m. Hauls number: 1160.



**Figure 7.-** Data on species assemblages and distribution from southern Grand Banks in 2002-2011, all years combined. Principal Components Analysis ordination plot of axes I and II relating abundance variations to the depth range: 38-1460m. Hauls number: 1160.



**Figure 8.-** Dendrogram showing classification of 773 sets grouped in 10 depth class of 50 m by two years (2002-03, 2004-05, 2006-07, 2008-09, 2010-11) based on mean abundance of fish fauna species composition by depth class. Catch was root-root transformed before comparing stations using the Bray-Curtis measure, and the dendrogram formed by group-average sorting. Three main clusters are distinguished at an arbitrary dissimilarity level of 44%.