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# Ecological trend on demersal community in the Southern Grand Banks (NAFO Div. 3NO) from the Spanish Surveys: 2002- 2011

by
Adriana Nogueira, Xabier Paz and Diana González-Troncoso

Instituto Español de Oceanografía
P.O. Box 1552. Vigo, Spain
e-mail: diana.gonzalez@vi.ieo.es

## Abstract

Some ecological indices were calculated from the data obtained in the research surveys conducted by Spain in NAFO divisions 3NO between the years 2002 and 2011. These indices were calculated for individual populations (intrinsic population rate of growth and mean length) and for all the community (ABC curves, indices about faunal diversity, proportion of non-commercial species, mean length in community and size spectra). We use the data of twenty five species caught in the survey along the years, included Northern shrimp (*Pandalus borealis*). The data of Northern shrimp, capelin (*Mallotus villosus*) and Northern sand lance (*Ammodytes dubius*) have a great influence in the value of the indices, as their abundance is very high in relation to their contribution to the biomass. The indices present a general stable pattern with a slight improvement in recent years. After two decades of moratorium, yellowtail flounder (*Limanda ferruginea*) seems to be recovered and other important commercial species as Atlantic cod (*Gadus morhua*) and American plaice (*Hippoglossoides platessoides*) begin to recover in the South of the Grand Banks.

## Introduction

It has been long recognized that single-species-based fisheries management approaches should be informed by multispecies and/or ecosystem-based approaches that place the species being managed in the broader context of the ecosystem (environmental, ecological and socio-economic). This line of thinking has become evident in several international conventions and agreements. During the past decade, there has been a strong movement towards the ecosystem approach to fisheries (EAF) worldwide.

One approach to integrate ecosystem-level information is the use of carefully selected and appropriate indicators to translate ecosystem impacts and changes into management measures that can be assessed for their effectiveness. To take forward the work that was completed in 2004 by the SCOR/IOC Working Group on Quantitative Ecosystem Indicators (Cury and Christensen, 2005) the IndiSeas Working Group was established, under the auspices of the Eur-Oceans European Network of Excellence (NoE), to look at "EAF Indicators: a comparative approach across ecosystems"(Shin and Shannon, 2010).

In spite of the grateful necessity of the EAF for improving the exploited resources (ICES, 2000; FAO, 2001), few attempts have been undertaken status of ecosystem by metrics indicators in the Northwest Atlantic (Zwanenburg, 2000; González-Troncoso and Paz, 2007; Pérez-Rodríguez *et al.*, 2012, Pérez-Rodriguez, 2012)

Many indicators targeting various components of Ecosystem have been developed, and used based on experience of more or less explicit assumptions, stemming from diverse ecological theories. Several studies have carried out critical revisions (Rochet and Trenkel, 2003) of the indicators of the impact of the fishing in the ecosystems (Rochet and Trenkel, 2003; Fulton *et al.*, 2004; Shin *et al.* 2010). Others provide the usefulness and relevance of size based indicators (SBIs) to EAF (Yunne-Jai Shin *et al.*, 2005) and some papers present the performance in indicators derived from abundance estimates for detecting the impact of fishing on a fish community (Trenkel and Rochet, 2003; Houle *et al.*, 2012 ).

Newfoundland Shelf had supported one of the world´s greatest fisheries. Many stocks were decimated. Annual landings of all groundfish species declined sharply in the early 1990s. Many ground fisheries, including Atlantic cod, were closed in 1992. Changes in abundance, mean size and biomass are not restricted to commercial species; non commercial species have also shown declines (Haedrich and Barnes, 1997; Kulka, 1996; Kulka, 2004). Over-fishing, predation, changes in prey availability and environmental factors have all been pinpointed as possible causes for the observed declines in size and abundance of demersal species.

The best known example of decline is the Northern Atlantic cod, but this is only one of many species that is likely at all time historic low levels of abundance, including potentially valuable commercial species such as redfish (*Sebastes spp.)*, haddock (*Melanogrammus aeglefinus*), and American plaice, pelagic fishes, especially capelin, and also species of lesser or no commercial importance. In the early years of the 21st century, the fishery has become dependent on snow crab (*Chionocetes opilio*) and Northern shrimp. 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).

Numbers and biomass decreased and for both target and non-target species mean size in the 90's has dropped dramatically from what it was in the early 80's. The decline in size results from the removal of the larger (and presumably older) individuals with the result that the population structure has been fundamentally changed. The trend of decreasing mean size over time is not an isolated occurrence on the Northeast Newfoundland and Labrador shelf, but is also observed in the groundfish community off west Greenland during a similar time period (Haedrich and Barnes, 1997; Hutchings, 2005).

Up to the present mainly studies related to Southern Gran Banks have been published at the species level, so much of their biology. Status commercial stocks has been analyzed as: Atlantic cod (Power *et al.*, 2010), American plaice (Dwyer *et al.*, 2009), Greenland halibut (*Reinhardtius hippoglossoides*) (Healey, 2009), yellowtail flounder (Parson *et al.*, 2008), thorny skate (*Amblyraja radiata*) (Simpson *et al.*, 2012); snow crab (Boudreau *et al.*, 2011) and non commercial species as wolffishes (*Anarhichidae*) (Kulka *et al.*, 2004). Also some biological traits of commercial species were studied (Morgan *et al.*, 2011; Morgan *et al.*, 2012) or species interactions (Lilly *et al.*, 2000) and some ecological approach were published, e. g.: fish pattern distribution and assemblages (Baker *et al.*, 2001); or fishing impact (Bailey *et al.*, 2009; Baker *et al.*, 2009). But they have not been developed attempts in order to perform indicators at population and or community level to measure the impact of the fishing in the ecosystem status as whole. The persistence and variation in the demersal assemblages in NAFO divisions 3NO were studied by Nogueira *et al.* (2012).

The Spanish Administration has performed a multi-species bottom trawl survey on Southern Grand Banks in May-June since 1995 (NAFO Regulatory Area Div. 3NO) (Figure 1) (Paz *et al.*, 2002). Here, we use data from this survey for the period 2002-2011 to estimate for first time several ecological indexes in the NAFO Divisions 3NO. During 1988-2002, survey biomass indices indicated a shift in the predominant groundfish species from American plaice and Atlantic cod to yellowtail flounder and redfish. Our objective is to contribute to the diagnosis of the general tendency of the ecosystem status in this area.

## Material and methods

### Material

We used data from the Spanish Survey conducted by the Instituto Español de Oceanografía (IEO) to estimate abundance and biomass of demersal resources in the Div. 3NO of the NAFO Regulatory Area. This survey has been carried out every year since 1995 in late spring (May-June). From 1995 to 2001, it was conducted on board the C/V

*Playa de Menduiña* using bottom net type *Pedreira* and, since 2002, the R/V *Vizconde de Eza* has replaced the former vessel in conducting surveys using a *Campelen* type bottom trawl. In 2001 a comparative survey between the two vessels was made in order to transform the historic time series into the new vessel index, making 92 paired hauls. The survey indices of the most important species were transformed to use the whole time series in the assessments of these species. For details of the indices transformation, see Paz *et al.*, 2002. As in this work species that are not usually assessed have been used, the transformation of their indices is not available. For this reason we used data from 2002 to 2011. Hauls were 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. Trawl positions were chosen randomly. The sampling unit consisted in 30-minute 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). 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 (González-Troncoso *et al.*, 2004). The mean of the initial and final depth has been used to define the bottom 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 (Table 1 and Figure 1).

Twenty five species were selected in order to estimate several indices (Table 2). It was considered their importance in occurrence, biomass and abundance as the available data of each of them. The goal of the survey data is that they consisted of commercial and non-commercial species, but they were potentially dominant species in a given region, or potential forage for other species. We considered 22 demersal species, one pelagic species (capelin), one mesopelagic genus (redfish)[1] and a shrimp (Northern shrimp). The species *Sebastes marinus*, *Sebastes mentella* and *Sebastes fasciatus* were recorded together as redfish. These 25 species amounted more than the 91% of the total catch in the period studied. All strata were sampled with sufficient intensity to assess their composition.

## Methods

The data used for each species are biomass, abundance and numbers by length. These indices were calculated by the swept area method (Cochran, 1997) assuming catchability factor of 1 from the catches and the numbers, respectively, for each species.

Different ecological indexes have been proposed in the literature (ICES, 2005) although not all are sustained in a theoretical base (Rochet and Trenkel, 2003).

We use indicators for species and for the community, based in the data of the 25 selected species, in order to try to measure the impact of fishing in the whole community. In Tables 3 and 4 we present a resume with all the models used and their characteristics.

Preliminary analyses indicate that Northern shrimp, capelin and Northern sand lance have a different habitat and/or very little size/individual in relation to the other species, so different catchability. Those species have a great influence in the total abundance with regard to biomass. Some indices more sensitive to numbers could suffer great changes with the inclusion or not of these species in their calculation. For these indices, we made two analyses, one with all the species and another one without one or three of these species.

### Population indicators

#### *Abundance and biomass indices*

Abundance and biomass for all species were estimated by the swept area method (Cochram, 1997).

[1] There are three redfish species in the study area, Acadian redfish (*S. Fasciatus* ), deepwater redfish (*S. Mentella*) and golden redfish ( *S.* Marinus). Due to the difficulty of visual identification of different species, the catches are usually reported by genus as redfish (*Sebastes spp*). In NAFO, the Acadian redfish and deepwater redfish are managed as an only species and golden redfish is not yet regulated.

***Intrinsic population rate of increase***

The intrinsic population rate $\left(r_i\right)$ is estimated using annual abundance estimates. The population dynamics model underlying this indicator is the following one:

$$N_i(t) = N_i(t-1)e^{r_i}$$

where $N_i(t)$ is the abundance of the species $i$ in the year $t$

This model can be linearised by taking logarithms of both sides (Table 3, eq. 1):

$$\log(N_i(t)) = \delta_i + r_i t + \varepsilon_{i,t}$$

As the log-transformation is also applied to abundance estimates, the transformation stabilizes variances and justifies the use of standard regression techniques for estimating r as the slope. For our study we use as estimation model a simple linear regression. Taking r=0 as the reference point assumes that without any noticeable impact of fishing the population would be stable although randomly varying between years.

***Mean length in population***

With the aim of knowing the health of each species, we analyse the progress of the mean length in population, $L_{mean}$ . A linear regression was adjusted to the data to know if a variation in the length distribution has occurred (Table 3, eq. 2). If the cero is among the 95% confidence interval, it is assumed that without any noticeable impact of fishing the population would be stable although randomly varying between years.

**Community indicators**

***ABC curves***

Abundance biomass comparison (ABC) curves is a very used indicator in the marine ecology literature (Warwick, 1986).

ABC curves are the combined k-dominance curves for species biomass and numbers. They have a theoretical background in classical evolutionary theory of r- and k-selection. In undisturbed states, the community is supposed to be dominated by k-selected species (slow-growing, large, late maturity) and the biomass curve lies above the abundance curve. With increasing disturbance, slow-growing species can not survive, the system is increasingly dominated by r-selected species (fast-growing, small, opportunistic), and the biomass curve will be below the abundance curve (Blanchard *et al.*, 2004, Yemane *et al.*, 2005). The difference between the two curves is given by the W-statistics, which represents the area between them and takes the following form:

$$W = \frac{\sum_{i=1}^{S}\left(\sum_{j=1}^{i} b_j - \sum_{j=1}^{i} a_j\right)}{50(S-1)}$$

where

$b_j$ is the biomass of the species $j$ , so $\sum_{j=1}^{i} b_j$ is the cumulative biomass

$a_j$ is the abundance of the species $j$, so $\sum_{j=1}^{i} a_j$ is the cumulative abundance

$S$ is the total number of species

In order to make the calculation, the species were ranked in decreasing order of abundance.

***Faunal diversity***

Species diversity is classically assessed with the species richness $S$, the Shannon-Wiener diversity index $H$ and the Pielou evenness index $J$, calculated as follow (Blanchard *et al*., 2004):

$S$ is the number of species

$H = -\sum_{i=1}^{S} p_i \log p_i$, where $p_i$ is the abundance or biomass ratio of the species $i$

$$J = \frac{H}{\log S}$$

The diversity indices $N$ of Hill (1973) and $D$ of Simpson were also assessed. The first is less sensitive to dominant species and the second to the sampling effort that the previous indices:

$$N = \exp(H)$$

$$D = \frac{1}{\sum_{i=1}^{S} p_i^2}$$

Those indices were calculated with abundance and with biomass data.

Another reasonable index of ecological stress, derived in this case of the idea of the ABC curves of comparing abundance and biomass, is the Shannon-Wiener evenness proportion $(SEP)$ index, calculated as McManus and Pauly (1990):

$$SEP = \frac{J_{biomass}}{J_{abundance}} = \frac{H_{biomass}}{H_{abundance}}$$

Warwick (1986) stays that under severe stress, community biomass will be more evenly distributed among species that numbers of individual are. So, in the case of non-stressed communities, the SEP index will have no trend along the time.

***Proportion of non-commercial species***

The relative importance of non-commercial species in the community is expressed in terms of either abundance or biomass (Table 4, eq. 1):

$$\frac{\hat{B}_n(t)}{\hat{B}(t)}, \frac{\hat{N}_n(t)}{\hat{N}(t)}$$

where

$\hat{B}_n(t)$ is the estimated biomass of all non-commercial species

$\hat{B}(t)$ is the estimated biomass of all commercial species

$\hat{N}_n(t)$ is the estimated abundance of all non-commercial species

$\hat{N}(t)$ is the estimated abundance of all non-commercial species

Under the impact of fishing, this proportion is expected to increase. The relationship of the proportion of non-commercial species with time is modelled by logistic regression (general linear model (GLM) with binomial distribution and logit-link function), where time is the explanatory variable. A positive slope is taken to suggest a significant impact of fishing (Trenkel and Rochet, 2003)

***Mean length in community***

We calculate the mean length in the community by confounding the lengths of all the species except Northern shrimp (Table 4, eq. 2). Fishing is expected to shift the distribution to smaller lengths. As in the community there are species with different growth, and in order to avoid the influence of recruitment and outlier lengths, we use only the lengths between the $5^{th}$ and the $95^{th}$ percentile for each species to calculate the mean (Shin *et al.* 2010).

***Size spectra***

To calculate the size spectra, we used abundance estimates at length in 5-cm length classes, with all the species confounded except Northern shrimp. The smallest length class observed and used for the annual size spectra was 0-5 cm. The largest length class was 156-161 cm. These classes were used as a compromise between the desired precision of abundance estimates and the number of length classes available to fit the relationship (Trenkel and Rochet, 2003; Munyandorero, 2006). The size spectra is usually represented as a relationship between natural log of abundance numbers versus natural log of the mid-length of each length class. The inspection of the scatter points suggested that the quadratic model was appropriate to represent the annual size spectra across the whole observed length ranges (Table 4, eq. 3).

Let i (i = 1,…,k) be the length class and $L_i$ and $N_i$ the corresponding mid-length and total number for all fish species recorded, respectively. The inspection of the scatter points suggested that the quadratic functions were appropriate to represent the annual size spectra across the whole observed length ranges:

$$n_i = \alpha + \beta l_i + \gamma l_i^2 + \varepsilon_i$$

where $n_i$ = Ln ($N_i$), $l_i$ = Ln ($L_i$), α, β and γ are parameters (α: intercept; β: linear term; γ: curvature term) and $\varepsilon_i$ the residual error terms assumed to be normally distributed with 0 mean and variance $\sigma_\varepsilon^2$. Such a representation (i.e., $n_i$ versus $l_i$) was chosen because it was applied to many fish communities and, hence, facilitates comparisons.

## Results

Population indicators

***Abundance and biomass indices***

Considering all species together (Figure 2), the indices of abundance and biomass increase due to the improvement of the status of three commercial stocks: yellowtail flounder, Atlantic cod and redfish. Thorny skate (*Amblyraja radiata*) and Northern shrimp decrease. Greenland halibut shows variability with increment last three years (Figure 3).

***Intrinsic population rate of increase***

Increase rate estimates for nineteen species indicated that there was no evidence to reject the null hypothesis of a zero increase rate, so the population would be stable. Whereas three populations were significantly increasing (yellowtail flounder, Atlantic cod, redfish), three species were significantly decreasing (thorny skate, Northern shrimp, Moustache sculpin (*Triglops murrayi*)). Note that only Moustache sculpin is not a commercial species (Table 5).

***Mean length in population***

The mean of the length remains significantly stable along the years for eighteen species of the twenty five species (Table 6). For one species, black dogfish (*Centroscyllium fabricii*), the mean decreases, and increases only for five species, witch flounder (*Glyptocephalus cynoglossus*), yellowtail flounder, Roughhead grenadier (*Macrourus berglax*), Greenland halibut and Roundnose grenadier (*Coryphaenoides rupestris*). It is interesting to note that yellowtail flounder has also an increasing intrinsic population rate.

**Community indicators**

***ABC curves***

We present the results for all species and for all species except Northern shrimp, capelin and Northern sand lance. In all years for all species, the abundance curve lies above the biomass curve, so the W statistic is negative, showing a slow increasing. Without Northern shrimp, capelin and Northern sand lance, curves of biomass and abundance are closely coincident. In 2003 and 2008 they intersect. W- statistics has very small negative trend along the years with higher values than those found in the previous analysis with all species (Figures 4a, 4b and 5).

***Faunal diversity***

Table 7 (A and B) shows the results of the diversity indices calculated. In this case we calculated the indices with all the species and the indices without Northern shrimp, capelin and Northern sand lance, in order to know the impact that these three species have in the community. In general, the impact of this three species is not too high, less in biomass than in abundance. Generally, the diversity is higher for biomass and lower for abundance when we use all the species, but the trend is the same in all the cases, with a slight decrease in the indices along the years. Diversity of biomass is less with all species and higher for abundance except the last three years.

The results of the index SEP can be seen in Figure 6. As we can see, when Northern shrimp, capelin and Northern sand lance are eliminated, SEP values do not present trend along years until 2009.

***Proportion of non-commercial species***

A list of the species considered commercial or no commercial is in Table 2. We made the analysis for all the species and without Northern shrimp, capelin and Northern sand lance. Ratio values became smoothed when the three species were eliminated. In all cases the ratio decreases (Figure 7).

***Mean length in community***

The mean population length without Northern shrimp and without Northern shrimp, capelin and Northern sand lance has decreased in the period studied (Figure 8).

***Size spectra***

All size spectra showed regular decreasing patterns generally indicative of high fish numbers in smaller sizes and viceversa in large sizes (Shin, 2000; Munyandorero, 2006) (Figure 9). They were rather curvilinear and well fitted by quadratic functions, with $R^2$ varying between 0.95 and 0.98.

Analysis of size spectra without Northern shrimp, capelin and Northern sand lance only remove small size individuals peaks (Figure 10). On the other hand, large fish observed in 2002 are removed and appears again in 2006, 2007 and 2008. Since 2009 large fish are again removed.

It must be noted in the graph that, if we consider only the larger sizes, the scatter points seem to fit a linear line. The size spectra is usually described by a decreasing linear function, but irregularities may occur, particularly among the smaller sizes, causing a curvature in the spectrum (Munyandorero, 2006).

## Discussion

There are many studies that try to explicate the effect of fishing in individual populations or, more and more, in communities, trying to contribute to the development of an ecosystem approach in the evaluation of fisheries. But it must be noted that the majority of the ecosystem indicators are sensitive but not specific to fishing impacts (Shin *et al.*, 2005). It has been shown that the relationships between diversity, stability and stress are far very complex and difficult to explain.

From the above analysis we can conclude that the performed indices seem to be more or less in accordance. In the case of population indices, the mean length and the intrinsic population rate, the vision in general is that the community, except for some species, remain rather stable or improve in the analyzed decade. The community indices are in general in accordance with the fact that the community is stable or a bit improving last years for three commercial species since the moratoria of 1992. This is the case for Atlantic cod, the main species collapsed, although it has not reached historical levels (Nogueira *et al.*, 2012). Yellowtail flounder and redfish show an increasing intrinsic population rate and are the most abundant species in the period studied. This may be because since the collapse yellowtail flounder has replaced Atlantic cod in shallower depths, and redfish has been increasing since the mid. 2000's in intermediate depths and was the most dominant species in that period (Nogueira *et al.*, 2012). Two commercial species, thorny skate and Northern shrimp, decreased. The first one can be attributed to impact of fishing, currently there is a fishery in this area, and the second one almost disappears last years (Figure 3), probably affected by the recent increasing in the sea temperature. Mean length of population increases for five commercial "Bigger slope species" is for Greenland halibut, which notably increases its biomass and abundance last years (Figure 2).

Results for ABC curves and W-statistics with all species showed a disturbed state of the community. When Northern shrimp, capelin and Northern sand lance were eliminated from the analysis a moderate disturbance can be observed, that was higher last three years due to increment of redfish biomass (Figure 3). Those results are similar with those found in Flemish Cap by González-Troncoso and Paz (2007). Although with all the species the trend is positive, that could mean a general community improving, without the three species that more contribute to the abundance the general trend is negative, although with a smaller value, which means that the community is not in a good health (because the abundance is above the biomass) and that it seems not to be recovered (because of the negative trend).

Lower diversity in 2009 and 2011 for abundance without Northern shrimp, capelin and Northern sand lance may be due to a very high abundance of redfish.

Both ratio of abundance and biomass for non commercial and commercial species suggested improvement of commercial species, but probably due specially to the increase of redfish last years. Similar results were found in Flemish Cap by González-Troncoso and Paz (2007).

Results of the mean length of community indicate that fishing shifts the distribution to smaller lengths or an increase of individuals of small size due to recruitment. Mean length of community with all species is lower in 2007 and 2009 because those years the abundance of capelin is very high due to the recruitment. Trend was negative when Northern shrimp, capelin and Northern sand lance were eliminated because proportion of these species is much higher last years.

Changes in the curvature term in size spectrum (Figure 9) respond to fishing. They usually decrease with increasing fishing pressure and removals of large fish (Shin, 2000; Munyandorero, 2006). But the linear trends have not yet been given any fishery or biological interpretation. In the other hand, changes in the intercept followed variations in total abundance and biomass (Trenkel and Rochet, 2003). During the studied period we can observe the cyclic effect of fishing affecting the presence or not of large fishes.

The presence of species that have a high abundance in regards to their biomass, as Northern shrimp, capelin and Northern sand lance, has strong influence in some of the indices performed.

In general, it seems that the community of the South of the Grand Banks was improve in the last years but is not yet recovered. The observed trends in community metrics can be attributable to the effects of fishing and the regulation in the area.

It is clear that not only fishing affects a marine community. They may be more factors such as environment, predation, migration... In addition, in this work we study only one part of the ecosystem of the Grand Banks. And we do not study all the community of the Grand Banks, only twenty five species, of which twenty four are fishes. Surely, there are more interactions between another species, fishes and not fishes, that we are not being studied in the present paper.

As in Flemish Cap (González-Troncoso and Paz, 2007) no trends can be observed in the South of the Grand Banks. The stability of more of the indices in the period of years suggest a new state of equilibrium in the South of the Grand Banks due to the collapse of Atlantic cod and the present dominance of the species of genus *Sebastes* and yellowtail flounder (Nogueira *et al.*, 2012). The shift in the abundance and biomass of these species can be due to the collapse of the Atlantic cod, which is the more direct competitor as predator in the community for redfish.

By considering the species as a whole, specific trends in our results are smoothed. The fishing effort is not evenly distributed throughout the bathymetric range, so the effects of fishing must be different in each assembly identified in the area (Nogueira *et al.* 2012). To observe the differential effects of fishing is necessary to estimate ecological indices within each assemblage. In addition, it would be interesting to open new ways of investigation in the area of indicators, taking into account another parameters not using here, as can be oceanographic or feeding parameters. The present global warming in the area could restore the conditions presented before the cooling trend when was the collapse, contributing to the recovery of the ecosystem.

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**Table 1.-** Number of trips and hauls made during EU bottom trawl surveys on NAFO Division 3NO on board the R/V *Vizconde de Eza* (2002-2011).

| Year | Valid hauls | Depth range (m) | Dates |
|---|---|---|---|
| 2002 | 125 | 39-1460 | April29-May19 |
| 2003 | 118 | 38-1460 | May 11-June 02 |
| 2004 | 120 | 43-1449 | June 06-June 24 |
| 2005 | 119 | 49-1402 | June 10-June 29 |
| 2006 | 120 | 45-1457 | June 07-June 27 |
| 2007 | 110 | 46-1373 | May 29-June 19 |
| 2008 | 122 | 40-1435 | May 27- June 16 |
| 2009 | 109 | 44-1386 | May 31-June 18 |
| 2010 | 95 | 40-1390 | May 30-June 18 |
| 2011 | 122 | 44-1430 | May 30-June 18 |
| 2002-2011 | 1160 | 38-1460 | |

**Table 2.-** Species included in the analysis

| Main Fish Species | Common name | FAO Code | Status | Depth range |
|---|---|---|---|---|
| *Sebastes sp* | Redfish | RED | Commercial | 45.5-1460 |
| *Limanda ferruginea* | Yellowtail flounder | YEL | Commercial | 38-190 |
| *Hippoglossoides platessoides* | American plaice | PLA | Commercial | 38-1460 |
| *Gadus morhua* | Atlantic cod | COD | Commercial | 40-1355 |
| *Mallotus villosus* | Capelin | CAP | Commercial | 38-454 |
| *Amblyraja radiata* | Thorny skate | RJR | Commercial | 38-1448.5 |
| *Ammodytes dubius* | Northern sand lance | SAN | No commercial | 38-228.5 |
| *Macrourus berglax* | Roughhead grenadier | RHG | Commercial | 119.5-1448.5 |
| *Reinhardtius hippoglossoides* | Greenland halibut | GHL | Commercial | 43-1448.5 |
| *Antimora rostrata* | Blue antimora | ANT | No commercial | 215.5-1460 |
| *Syphobranchus kaupii* | Northern cutthroat eel | SSK | No commercial | 62-1460 |
| *Nezumia bairdi* | Marlin-spike | NZB | No commercial | 58.5-1460 |
| *Anarichas lupus* | Wolfish (Catfish) | CAA | No commercial | 44.5-635 |
| *Glyptocephalus cynoglossus* | Witch flounder | WIT | Commercial | 43.5-1460 |
| *Centroscyllium fabricii* | Black dogfish | CFB | No commercial | 232-1456.5 |
| *Coryphaenoides rupestris* | Roundnose grenadier | RNG | No commercial | 225-1460 |
| *Urophycis tenuis* | White hake | HKW | Commercial | 58.5-980 |
| *Anarichas denticulatus* | Northern wolfish | CAB | No commercial | 56-1434.5 |
| *Lycodes reticulatus* | Arctic eelpout | LCT | No commercial | 48.5-1299 |
| *Phycis chesteri* | Longfin hake | GPE | No commercial | 168-1355.5 |
| *Bathyraja spinicauda* | Spinytail skate | RJQ | No commercial | 233.5-1401 |
| *Tryglops murrayi* | Moustache sculpin | TGM | No commercial | 38-566 |
| *Amblyraja hyperborea* | Arctic skate | RJG | No commercial | 312-1448.5 |
| *Anarichas minor* | Spotted wolfish | CAS | No commercial | 110.5-823.5 |
| *Pandalus borealis* | Northern shrimp | PRA | Commercial | 44.5-1401 |

**Table 3.-** Indicators for measuring the impact of fishing on population i

| Indicator | Description | Required information | Model | Estimation method | Null hypothesis $H_0$ | Hypothesis test method |
|---|---|---|---|---|---|---|
| $r_i$ (1) | Intrinsic population rate of increase | $N_i(t)$ | $N_i(t) = N_i(t-1)e^{r_i}$ | $\log(N_i(t)) = \delta_i + r_i t + \varepsilon_{i,t}$ | $r_i = 0$ | 0 within 95% CI of $\hat{r}_i$ |
| $L_{mean_i}$ (2) | Mean length | $C_{l,i}$ | $L_{mean_i} = \frac{1}{C_i}\sum_{l=1}^{L} C_{l,i} l_l$ | $\hat{L}_{mean_i} = \frac{1}{\hat{C}_i}\sum_{l=1}^{L} \hat{C}_{l,i} l_l$<br>$\hat{L}_{mean_i} = a_i + b_i t + \varepsilon_{i,t}$ | $b_{ii} = 0$ | 0 within 95% CI of $\hat{b}_i$ |

**Table 4.-** Indicators and their data requirements for measuring the impact of fishing on a community consisting of S species (i=1,…,S).

| Indicator | Name of indicator | Estimator | Method to obtain indicator distribution | Null hypothesis | Alternative hypothesis | Hypothesis test method |
|---|---|---|---|---|---|---|
| $\frac{B_n(t)}{B(t)}, \frac{N_n(t)}{N(t)}$ (1) | Proportion of non-commercial species | $\frac{\hat{B}_n(t)}{\hat{B}(t)}, \frac{\hat{N}_n(t)}{\hat{N}(t)}$ | Linear regression | $\frac{\hat{N}_n(t)}{\hat{N}(t)} = a + ct,\ c = 0$ no trend | Increase in proportion of non-commercial species, $c > 0$ | 0 within 95% CI of $\hat{c}$ |
| $\overline{L} = \frac{1}{C}\sum_{l=1}^{L} C_l l_l$ (2) | Mean length in community | $\overline{L} = \frac{1}{C}\sum_{l=1}^{L} C_l l_l$ | | No change | SLOPE=0 | 0 within 95% CI of $\hat{c}$ |
| $slope_{l_s}$, $int_{l_s}$ (3) | Curvature term and intercept of length spectra | Quadratic regression: $\ln(N_{i,t}) = \alpha_t + \beta_t \ln(l_i) + \gamma_t \ln(l_i)^2 + \varepsilon_i$ | Unknown | $\alpha_t = 0$<br>$\gamma_t = 0$ | $\alpha_t \neq 0$<br>$\gamma_t \neq 0$ | Visual (trend of the points) |

**Table 5.-** Intrinsic population rate of increase for all the species

| Main fish species | r | Std | Confidence interval (95%) | Test |
|---|---|---|---|---|
| *Amblyraja hyperborea* | -0.0816776 | 0.1014183 | -0.3155- 0.15219 | r=0 |
| *Ammodytes dubius* | 0.1322161 | 0.1395980 | -0.1896- 0.4541 | r=0 |
| *Anarhichas denticulatus* | 0.0928833 | 0.0616966 | -0.0493- 0.2351 | r=0 |
| *Anarhichas minor* | 0.0100355 | 0.0974346 | -0.2146- 0.2347 | r=0 |
| *Anarhichas lupus* | -0.0625594 | 0.0467249 | -0.1703- 0.0451 | r=0 |
| *Antimora rostrata* | 0.0313654 | 0.0250945 | -0.026- 0.089 | r=0 |
| *Bathyraja spinicauda* | -0.0770163 | 0.0467147 | -0.1847- 0.0307 | r=0 |
| *Centroscyllium fabricii* | 0.0566189 | 0.0366091 | -0.0278- 0.141 | r=0 |
| *Coryphaenoides rupestris* | -0.0178207 | 0.0544434 | -0.1433- 0.1077 | r=0 |
| *Gadus morhua* | 0.3781126 | 0.0578315 | 0.2447- 0.5114 | Up |
| *Glyptocephalus cynoglossus* | -0.0742480 | 0.0329023 | -0.1501- 0.0016 | r=0 |
| *Hippoglossoides platessoides* | 0.0322768 | 0.0348685 | -0.0481- 0.1126 | r=0 |
| *Limanda ferruginea* | 0.0344602 | 0.0072099 | 0.0178- 0.051 | Up |
| *Lycodes reticulatus* | -0.1182203 | 0.0656681 | -0.2696- 0.0332 | r=0 |
| *Macrourus berglax* | -0.0570993 | 0.0360892 | -0.1403- 0.0261 | r=0 |
| *Mallotus villosus* | 0.1713394 | 0.1429847 | -0.1583- 0.501 | r=0 |
| *Nezumia bairdii* | -0.0038796 | 0.0325600 | -0.0789- 0.0712 | r=0 |
| *Phycis chesteri* | 0.0438445 | 0.0738317 | -0.1264- 0.2141 | r=0 |
| *Raya radiata* | -0.1564018 | 0.0474555 | -0.2658- -0.0469 | Down |
| *Reinhardtius hippoglossoides* | 0.0513884 | 0.0423699 | -0.0463- 0.149 | r=0 |
| *Sebastes sp* | 0.4524206 | 0.0755942 | 0.278- 0.6267 | Up |
| *Synaphobranchus kaupii* | -0.0082275 | 0.0480960 | -0.1191- 0.1026 | r=0 |
| *Triglops murrayi* | -0.2225120 | 0.0758047 | -0.3973- -0.0477 | Down |
| *Urophycis tenuis* | -0.2133745 | 0.1195504 | -0.489- 0.0623 | r=0 |
| *Pandalus borealis* | -0.4632840 | 0.0525763 | -0.5845- -0.342 | Down |

**Table 6.-** Mean length of each species

| Main fish species | **Slope** | **Confidence interval (95%)** | Tendency |
|---|---|---|---|
| *Amblyraja hyperborea* | 1.0693938 | -0.4051 - 2.5439 | Stable |
| *Ammodytes dubius* | 0.0522413 | -0.1621 - 0.2666 | Stable |
| *Anarhichas denticulatus* | -0.3109354 | -1.1198 - 0.498 | Stable |
| *Anarichas minor* | 0.7686557 | -0.2067 - 1.7443 | Stable |
| *Anarhichas lupus* | 0.8511354 | -1.4723 - 3.1746 | Stable |
| *Antimora rostrata* | -0.0148213 | -0.4656 - 0.436 | Stable |
| *Bathyraja spinicauda* | 3.1861227 | -0.8804 - 7.2527 | Stable |
| *Centroscyllium fabricii* | -0.5753861 | -0.9491 - -0.2016 | Down |
| *Coryphaenoides rupestris* | 0.1026182 | 0.0681 - 0.137 | Up |
| *Gadus morhua* | 0.3394175 | -1.8737 - 2.5526 | Stable |
| *Glyptocephalus cynoglossus* | 0.4265506 | 0.0381 - 0.815 | Up |
| *Hippoglossoides platessoides* | 0.1909602 | -0.1308 - 0.5127 | Stable |
| *Limanda ferruginea* | 0.1855108 | 0.096 - 0.275 | Up |
| *Lycodes reticulatus* | -0.5406064 | -1.264 - 0.1648 | Stable |
| *Macrourus berglax* | 0.2976243 | 0.1495 - 0.4457 | Up |
| *Mallotus villosus* | -0.3853858 | -0.8659 - 0.1252 | Stable |
| *Nezumia bairdii* | 0.0998061 | 0.0114 - 0.1881 | Stable |
| *Phycis chesteri* | 0.3038519 | -0.1019 - 0.7096 | Stable |
| *Raya radiata* | 1.1218434 | -0.0786 - 2.3224 | Stable |
| *Reinhardtius hippoglossoides* | 1.5355846 | 0.6815 - 2.3896 | Up |
| *Sebastes sp* | -0.1673774 | -0.3941 - 0.0594 | Stable |
| *Synaphobranchus kaupii* | -0.102664 | -0.3456 - 0.1403 | Stable |
| *Triglops murrayi* | 0.0150006 | -0.069 - 0.099 | Stable |
| *Urophycis tenuis* | 0.2808176 | -2.7104 - 3.2721 | Stable |
| *Pandalus borealis* | -0.0599233 | -0.2489 - 0.1291 | Stable |

**Table 7.-** Diversity index for the years 2002-2011. A) With all the species; B) Without *Pandalus borealis*, *Mallotus villosus* and *Ammodytes dubius*. 1) Abundance and 2) Biomass.

**1) Abundance**

| | H | | J | | N | | D | |
|---|---|---|---|---|---|---|---|---|
| **Year** | **A** | **B** | **A** | **B** | **A** | **B** | **A** | **B** |
| **2002** | 1.594 | 1.604 | 0.495 | 0.519 | 4.925 | 4.973 | 3.134 | 3.166 |
| **2003** | 1.452 | 1.723 | 0.451 | 0.558 | 4.273 | 5.599 | 2.492 | 3.810 |
| **2004** | 1.698 | 1.844 | 0.528 | 0.597 | 5.464 | 6.323 | 3.739 | 4.521 |
| **2005** | 1.556 | 1.613 | 0.483 | 0.522 | 4.738 | 5.019 | 2.956 | 3.641 |
| **2006** | 2.002 | 1.689 | 0.622 | 0.547 | 7.402 | 5.415 | 5.684 | 4.142 |
| **2007** | 1.166 | 1.607 | 0.362 | 0.520 | 3.211 | 4.990 | 2.258 | 3.795 |
| **2008** | 1.433 | 1.620 | 0.445 | 0.524 | 4.191 | 5.054 | 2.960 | 3.894 |
| **2009** | 1.154 | 0.682 | 0.359 | 0.221 | 3.171 | 1.979 | 2.456 | 1.375 |
| **2010** | 1.392 | 1.072 | 0.432 | 0.347 | 4.022 | 2.920 | 2.988 | 1.972 |
| **2011** | 1.504 | 0.985 | 0.467 | 0.319 | 4.500 | 2.677 | 3.402 | 1.863 |

**2) Biomass**

| | H | | J | | N | | D | |
|---|---|---|---|---|---|---|---|---|
| **Year** | **A** | **B** | **A** | **B** | **A** | **B** | **A** | **B** |
| **2002** | 1.755 | 1.584 | 0.545 | 0.512 | 5.782 | 4.873 | 3.514 | 3.104 |
| **2003** | 1.868 | 1.662 | 0.580 | 0.538 | 6.477 | 5.271 | 4.162 | 3.402 |
| **2004** | 2.000 | 1.730 | 0.621 | 0.560 | 7.391 | 5.641 | 4.868 | 3.810 |
| **2005** | 1.902 | 1.727 | 0.591 | 0.559 | 6.699 | 5.625 | 4.885 | 4.209 |
| **2006** | 1.872 | 1.758 | 0.582 | 0.569 | 6.502 | 5.801 | 4.626 | 4.315 |
| **2007** | 1.932 | 1.672 | 0.600 | 0.541 | 6.901 | 5.324 | 4.937 | 3.910 |
| **2008** | 1.977 | 1.726 | 0.614 | 0.558 | 7.223 | 5.616 | 5.083 | 4.010 |
| **2009** | 1.605 | 1.401 | 0.499 | 0.453 | 4.976 | 4.061 | 3.044 | 2.615 |
| **2010** | 1.657 | 1.484 | 0.515 | 0.480 | 5.242 | 4.411 | 3.585 | 3.130 |
| **2011** | 1.553 | 1.466 | 0.482 | 0.474 | 4.726 | 4.332 | 3.416 | 3.273 |

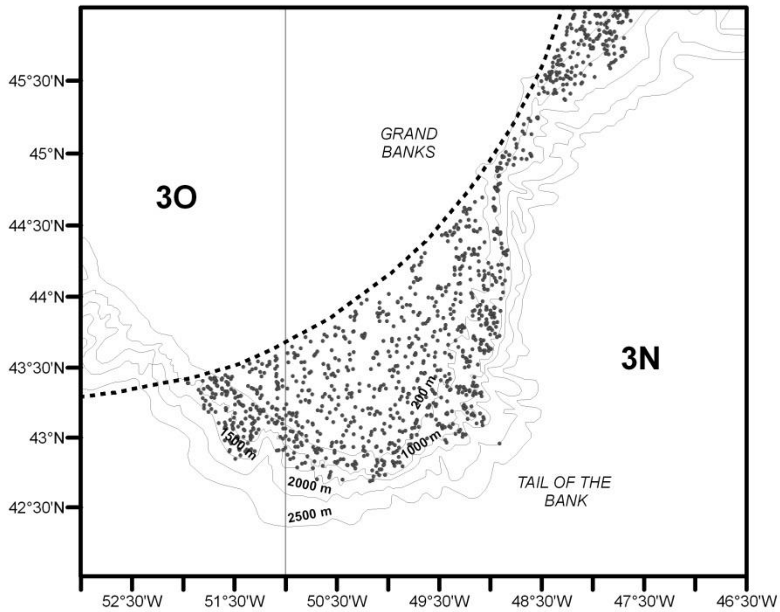



**Figure 1**.- Chart showing the hauls position in the Spanish Spring Survey in Div. 3NO in the whole period (2002-2011).

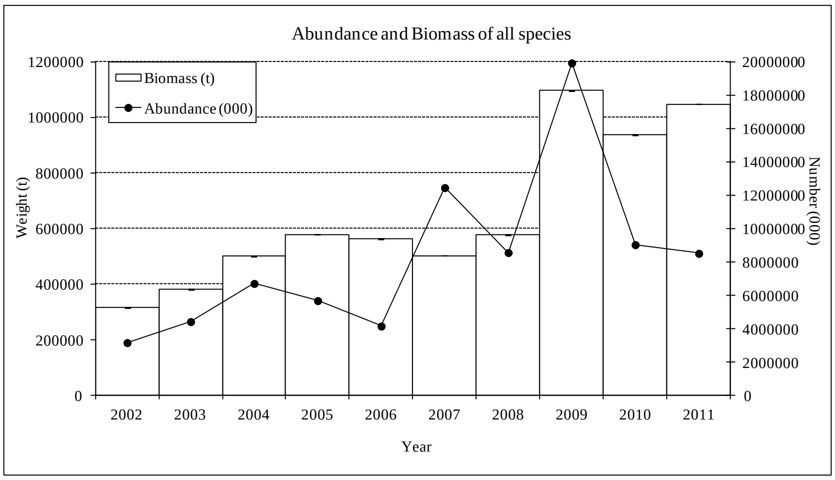



**Figure 2.-** Abundance and Biomass estimates for all species from Spanish bottom trawl survey 3NO. 2002-2011.

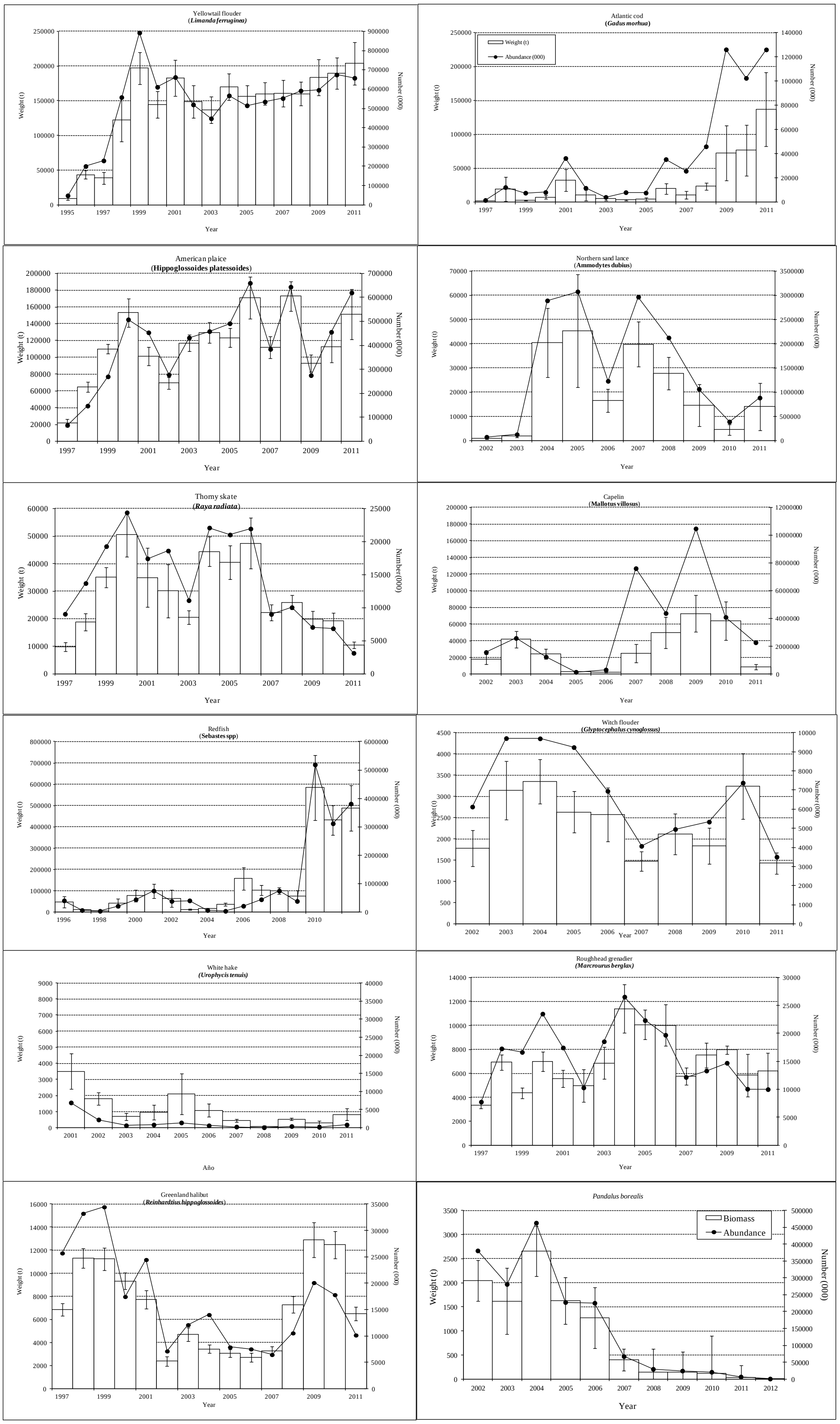



**Figure 3**.- Abundance and Biomass estimates for the main species from Spanish bottom trawl survey 3NO. 2002-2011.

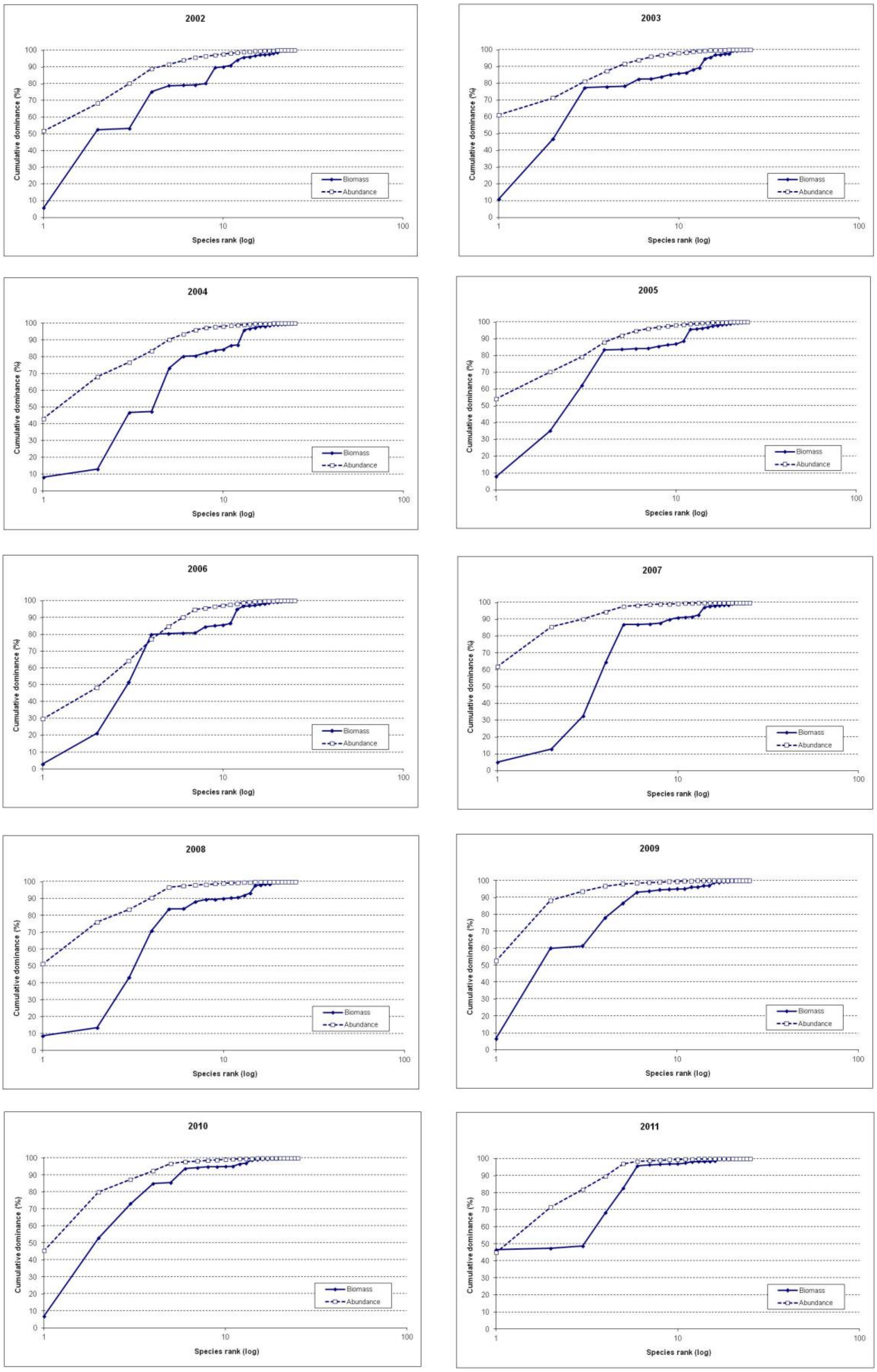



**Figure 4a**.- ABC curves for all the species.

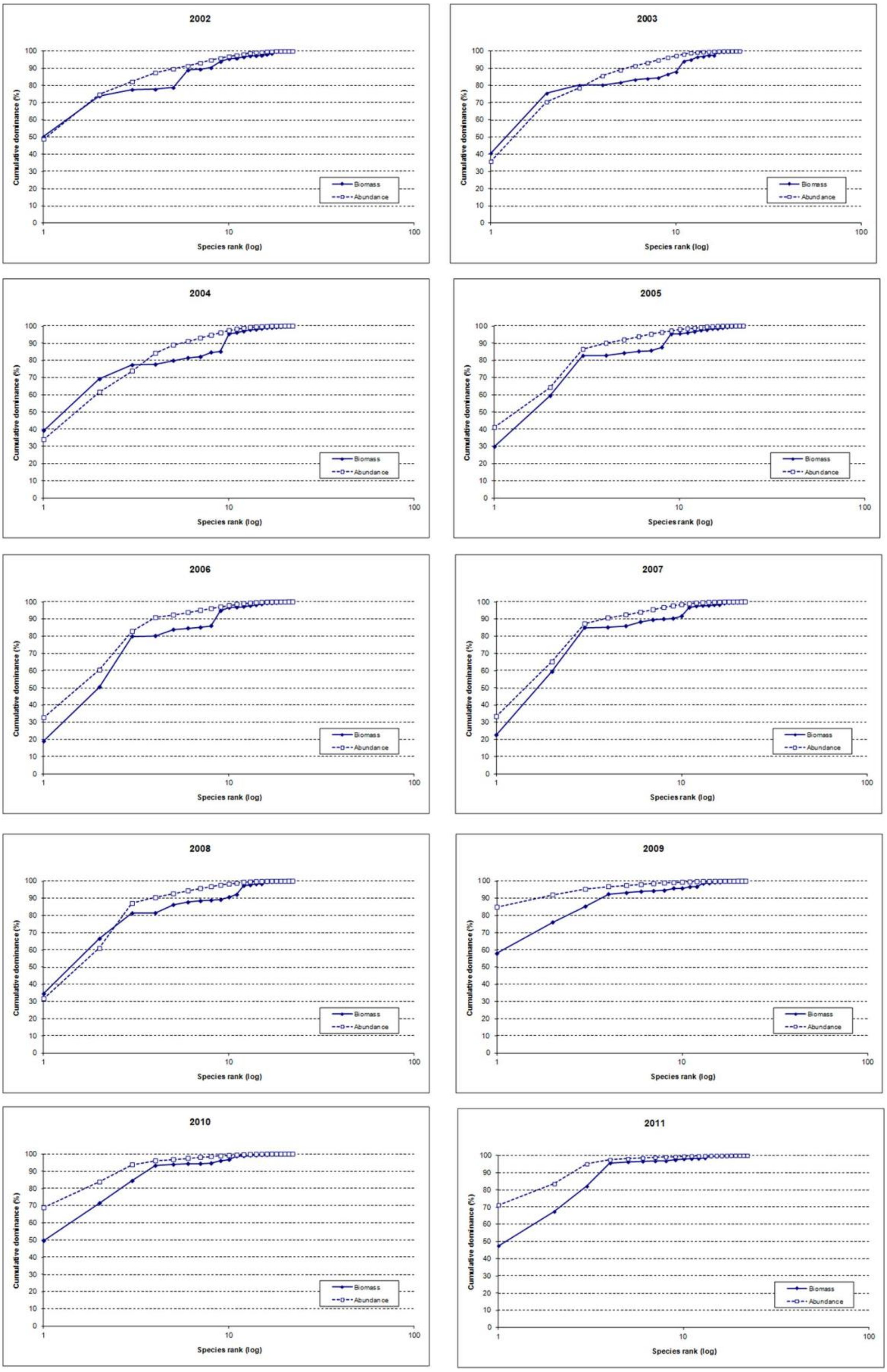



**Figure 4b**.- ABC curves for all the species except *Pandalus borealis*, *Mallotus villosus* and *Ammodytes dubius*.

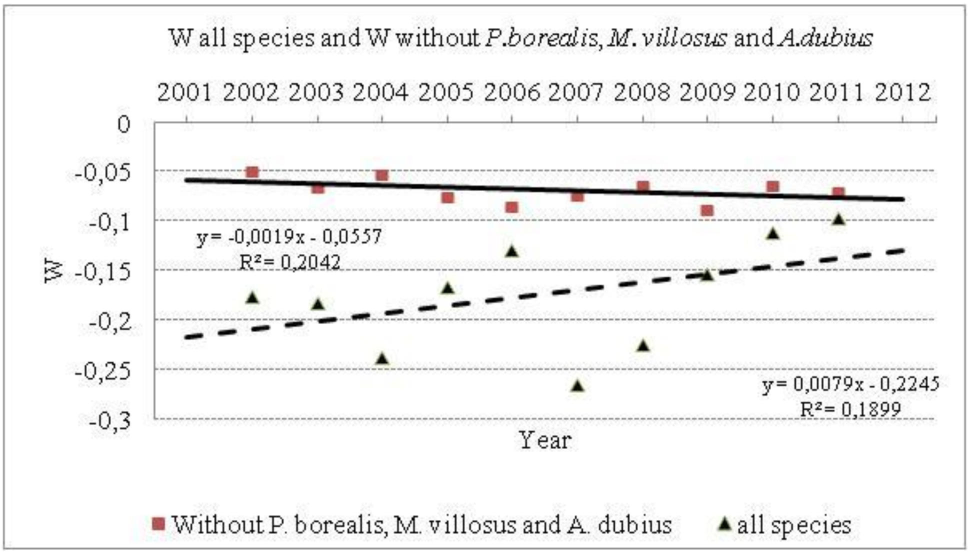



**Figure 5**.- Trend of the W-statistic for all the species and all species except *Pandalus borealis, Mallotus villosus* and *Ammodytes dubius*.

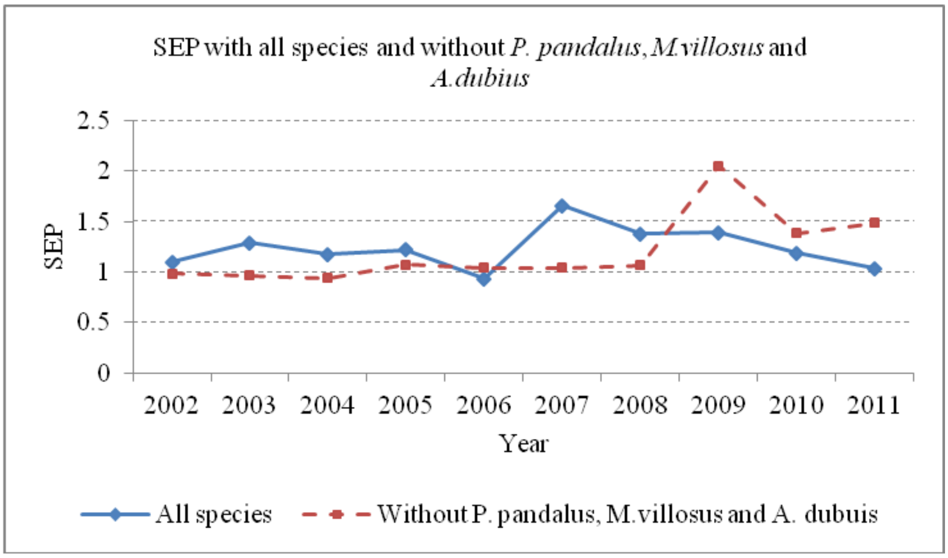
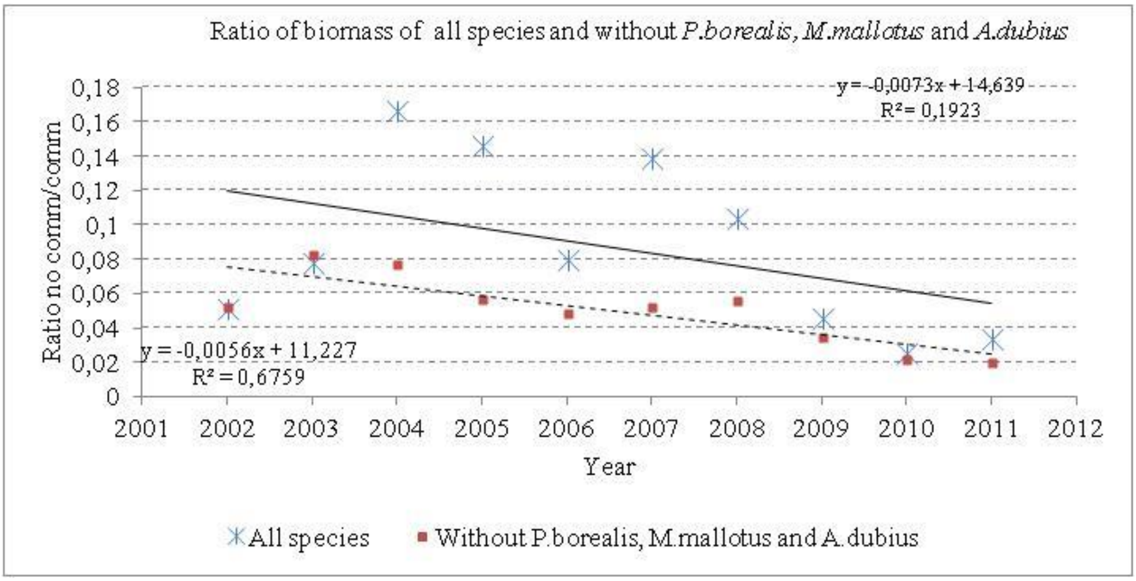



**Figure 6**.- Trend of the SEP-statistic for all species and all species except *Pandalus borealis, Mallotus villosus* and *Ammodytes dubius.*

A)




B)

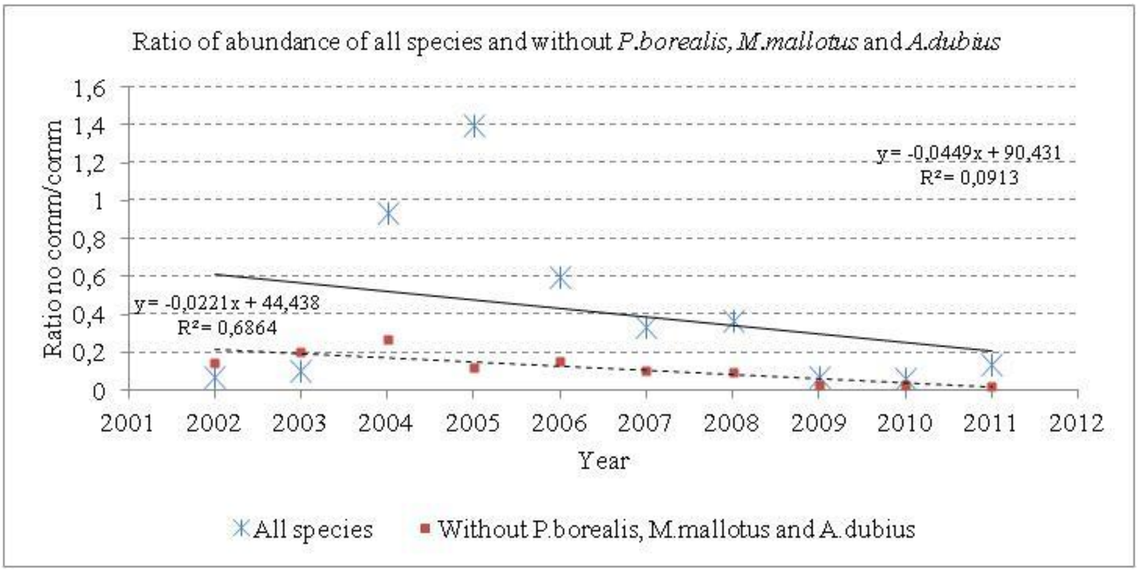



**Figure 7**.- Ratio of abundance and biomass of no commercial/commercial species. A) Abundance and B) Biomass

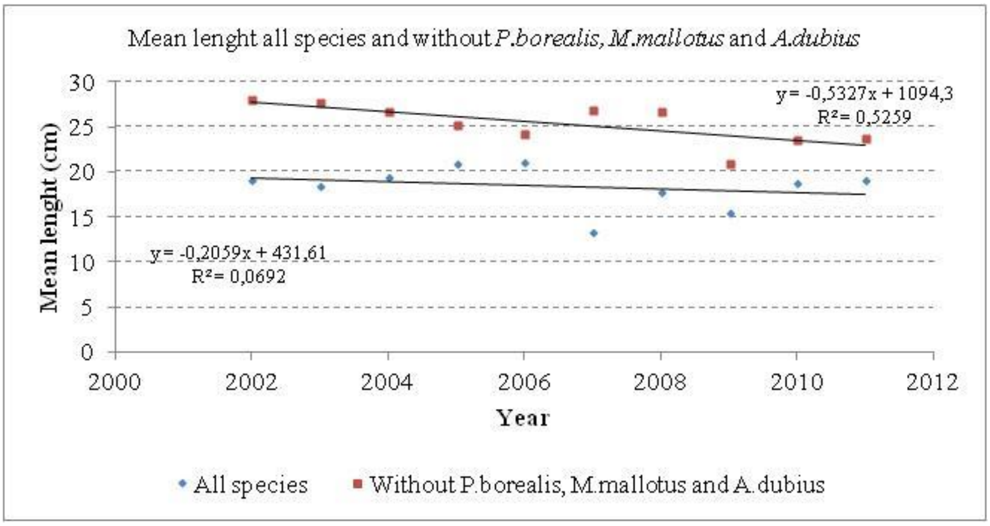



**Figure 8**.- Mean length in community comparison all species and without *P. borealis, M. villosus* and *A. dubius*.

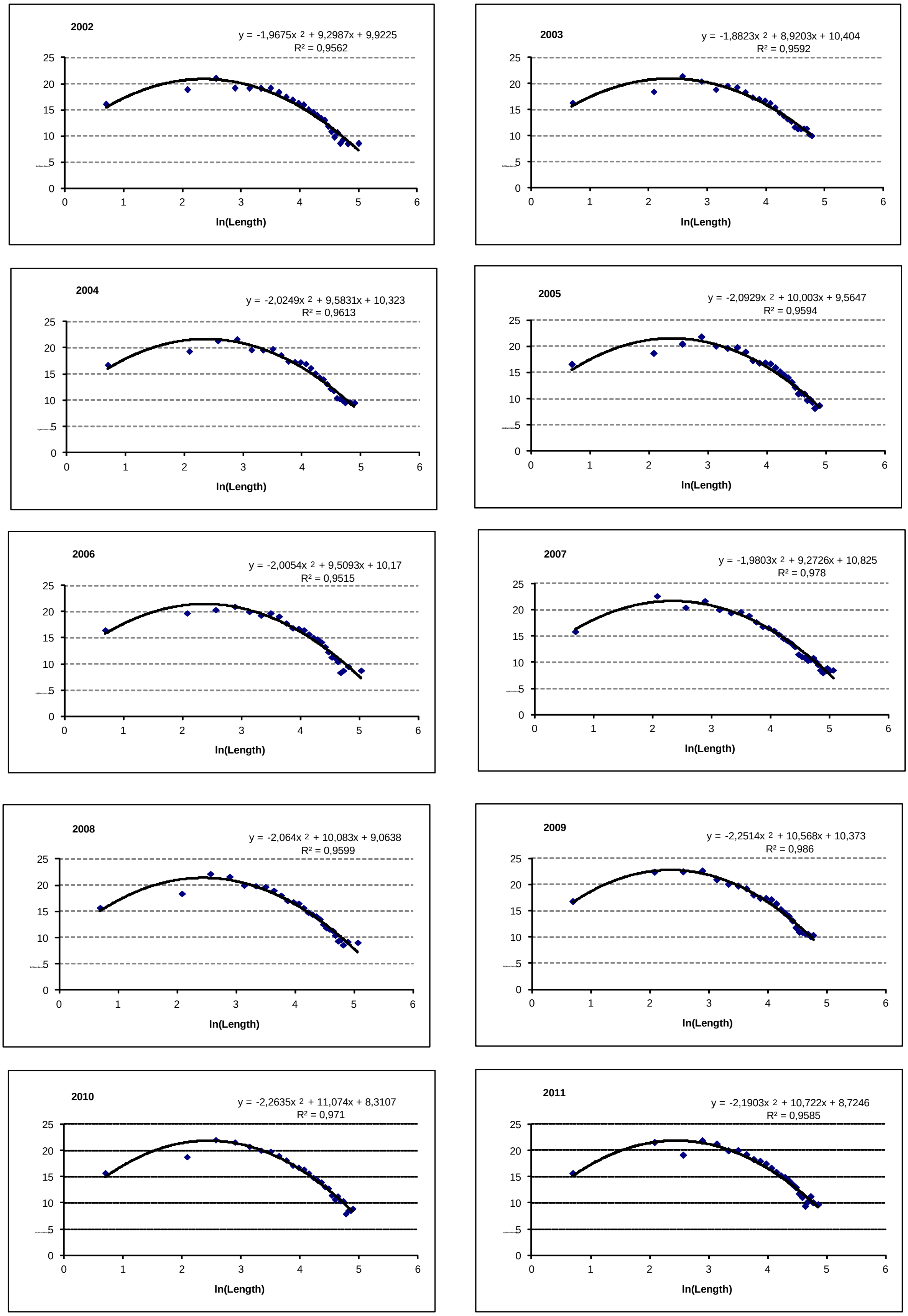



**Figure 9a**.- Scatter plots for the size spectra by year without *Pandalus borealis.*

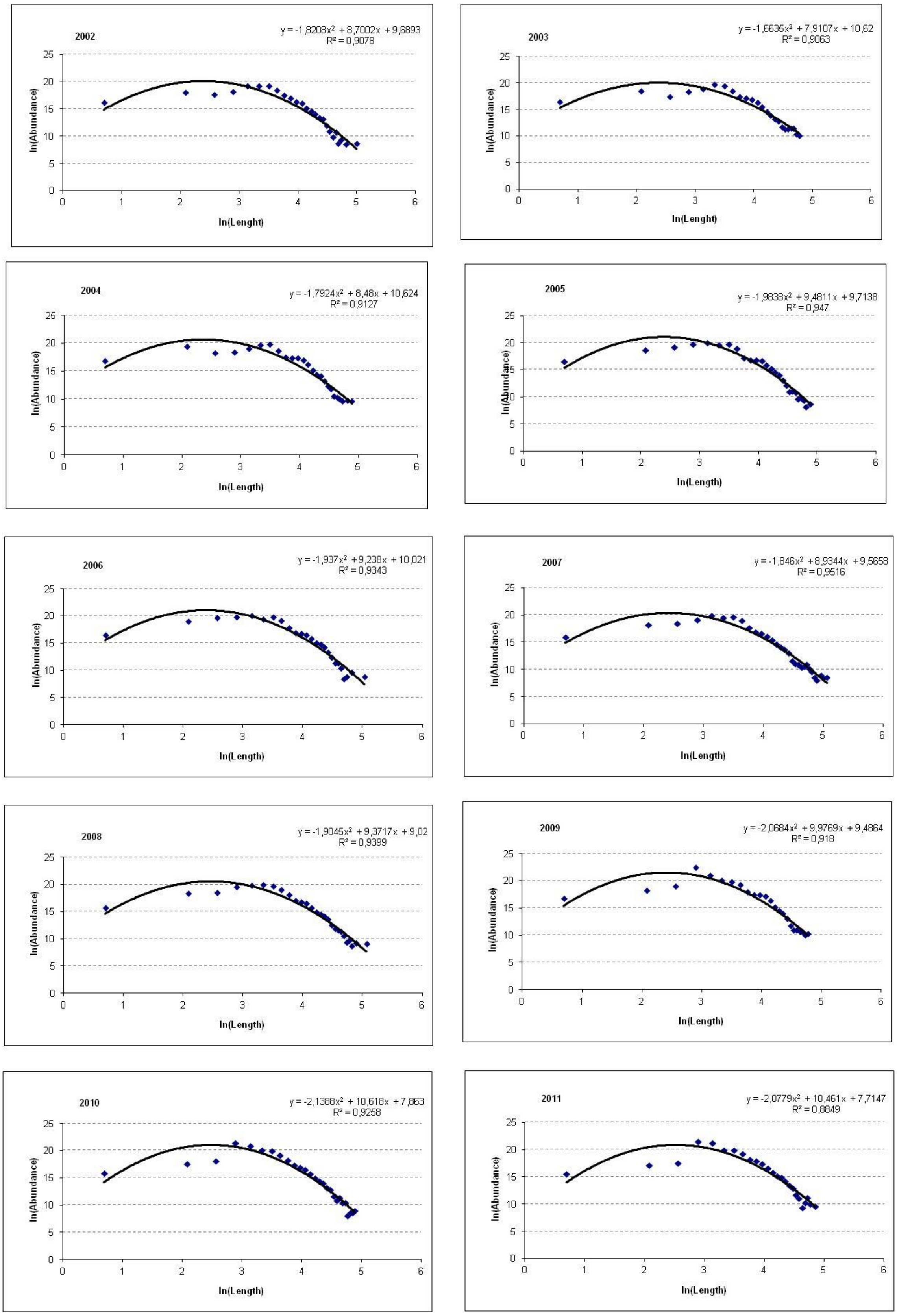
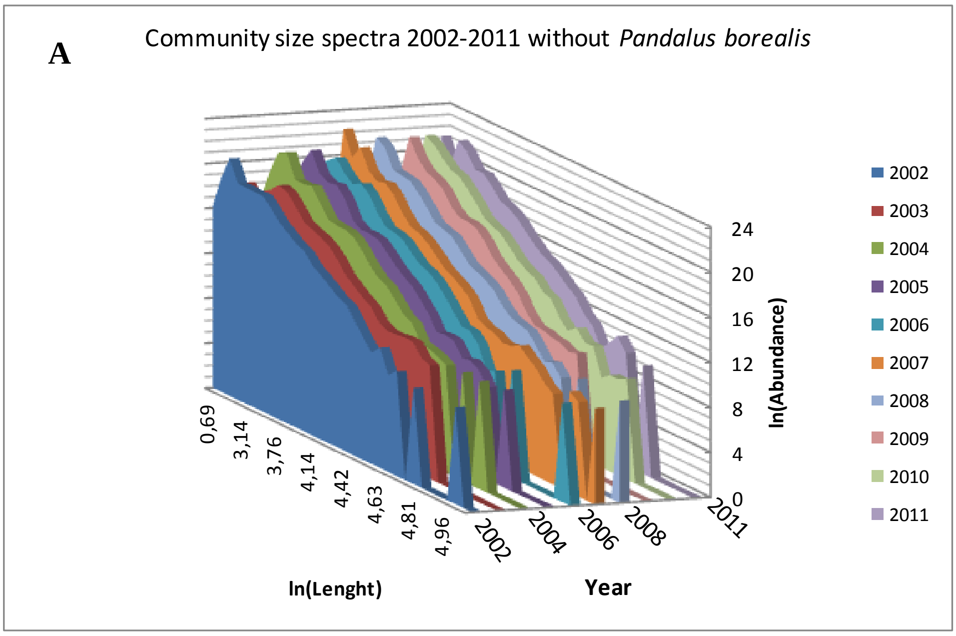



**Figure 9b**.- Scatter plots for the size spectra by year without *Pandalus borealis*, *Mallotus villosus* and *Ammodytes dubius.*



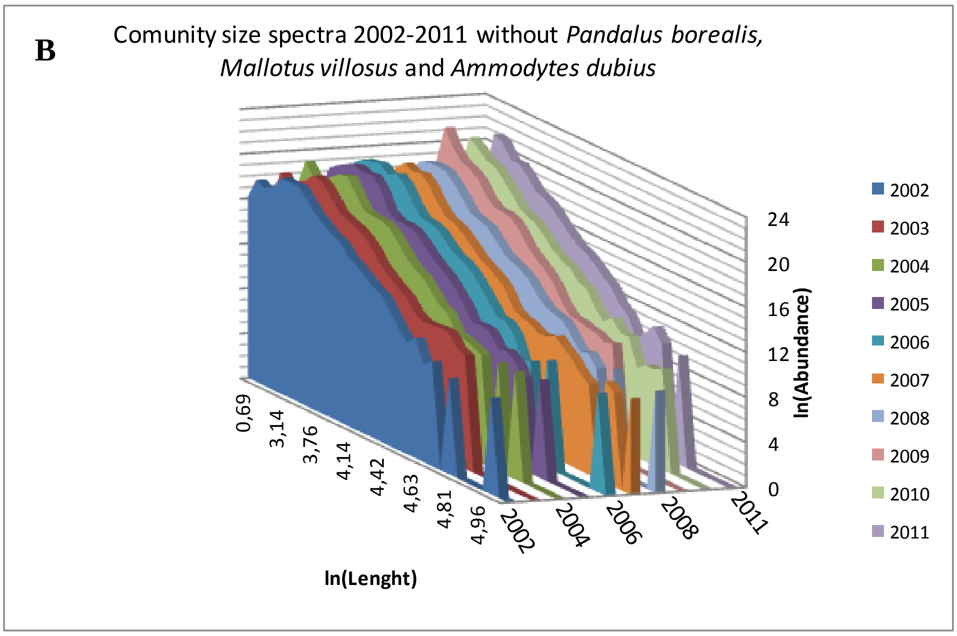




**Figure 10**.- Scatter plots for the size spectra for all years **A**) without *Pandalus borealis* and **B**) without *Pandalus borealis. Mallotus villosus* and *Ammodytes dubius.*