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# The impact of climate change on the fish community structure of the eastern continental shelf of the Bay of Biscay

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**Abstract:** Many fish species are at the southern or northern limit of their distribution range in the Bay of Biscay, where large-scale hydroclimatic changes have occurred in recent decades. We attempt here to identify the impact of these changes on the fish community of the eastern continental shelf of the Bay of Biscay. Data collected during 14 autumn groundfish surveys in 1973 and from 1987 to 2002 are used. The study area is between latitudes 48°30′N and 43°30′N while the depth ranges from 15 to 200 m. Annual abundance indices (number of individuals per km2) of 56 fish taxa present on average in at least 5% of the tows are computed. Multivariate analysis is used to detect temporal trends in these species' abundance indices. Assuming that increased water temperature may favour subtropical species and hinder temperate ones, knowledge about the latitudinal distribution range is used to interpret time trends. Results show an increasing abundance trend with time for fish species having a wide distribution range in latitude (mainly subtropical ones), whereas the abundance of temperate and the least widely distributed species decreased steadily.

**Keywords:** Bay of Biscay; climate change; fish community; groundfish surveys

## 1 Introduction

Large-scale changes in the biogeography of calanoid copepods have been reported for the eastern North Atlantic and European shelf seas (Beaugrand *et al.*, 2002). Strong biogeographical shifts in all copepod assemblages have occurred with a northward extension of warm-water species associated with a decrease in the number of colder-water species. These biogeographical shifts were related to increasing trends in both Northern Hemisphere temperature and the North Atlantic Oscillation.

Northward extensions in the distribution of tropical fish species in East-Atlantic waters have been recorded (Quero, 1998). Further evidence was provided that warming of the North Atlantic is responsible for the northward extensions of the ranges of warm water fish species, causing increasing numbers of southern immigrant species to appear off the Cornish coast of the UK (Stebbing *et al.*, 2002).

The existence of a long-term increasing trend in sea surface temperature (a mean rise of 1.4 °C for the period 1972-1993) was confirmed for the south-eastern part of the Bay of Biscay (Koutsikopoulos *et al.*, 1998). Reviewing the multi-decadal variations of three key regional climate and hydrological factors (sea surface temperature, wind speed and river run-off), Planque *et al.* (2003) have shown that the 1990s were characterized by warmer temperature (up to 0.6°C increase per decade from 1971 to 1998 in the southern part of the Bay) and windier conditions than the previous century. Désaunay *et al.* (2005) have demonstrated that although the increase of sea temperature is lower in the northern part of the Bay of Biscay, a significant warming of winter temperatures occurred there.

The eastern continental shelf of the Bay of Biscay is part of the subtropical/boreal transition subprovince of the biogeographic Lusitanian province (OSPAR-Commission, 2000). The fauna in this area are mixed with groups of boreal and subtropical origin and many fish species reach the southern or northern limit of their distribution in the Bay of Biscay.

Community studies in regions of overlapping “polar” and “temperate” species base the conclusion of climate change impacts on the differential response of these two categories (Parmesan and Yohe, 2003). Polar species tend to be stable or decline in abundance whereas temperate species at the same site increase in abundance and /or expand their distributions.

In this study, we use this approach to identify the impact on the fish community of the warming occurring in the Bay of Biscay. For this, data provided on 56 fish taxa by groundfish surveys carried out in 1973 and during the period 1987-2002 were analysed. Previous work (Poulard *et al.*, 2003) has shown the relative stability through time of the spatial demersal fish community organisation. Thus, we have chosen to focus the present study on temporal variations.

## 2 Materials

Data were first collected during a groundfish survey carried out in November and December 1973 on the eastern continental shelf of the Bay of Biscay (Quéro *et al.*, 1989). Data were also provided by 13 groundfish surveys carried out by IFREMER since 1987 (EVHOE series with gaps in 1991, 1993 and 1996) in the same area from October to December (ICES, 1997; Poulard *et al.*, 2003; Souissi *et al.*, 2001). The sampling design is stratified according to latitude and depth. A 36/47 GOV trawl is used with a 20 mm mesh codend liner. Haul duration is 30 minutes at a towing speed of 4 knots. Fishing is mainly restricted to daylight hours. Catch weights and catch numbers are recorded for all species, all finfish are measured since 1992 while length compositions of a selection of them were recorded prior to 1992.

The study area was restricted in latitude (between 48º30'N and 43º30'N) and depth range (from 15 to 200 m) to the area sampled in 1973 (Figure 1). The number of hauls per survey varied from 56 to 154. Overall 1279 hauls were analysed. A total of 168 fish species were caught but only 56 fish taxa, present on average in at least 5% of the tows, were included in the analysis.

## 3. Methods

Mean catch per tow was computed per species and per year accounting for the stratified sampling design. Annual abundance indices were then normalised to maximum species-specific numerical abundance. The chosen normalisation allows to assign the same weight to each species in the following multivariate analysis, this objective being not achieved by using a log-transformation of the data. Standardised annual abundance indices were used as input in a Correspondence Analysis (Lebart *et al.*, 1984) to detect time trends in the fish abundance indices. The variables (columns) were the years and the profiles (rows) were the species.

Latitudinal distribution ranges of species were used to interpret the temporal trends. The latitudinal range and its midpoint have been defined for each species considering the most northern and southern latitudes reported in the literature (Froese and Pauly, 2004; Whitehead *et al.*, 1986). Latitude ranges and mean latitudes of species distributions were transformed into nominal variables by creating four equiprobable categories. This additional information is used as supplementary (or illustrative) variables that are projected into the space of the data but are not used to compute the factors of the Correspondence Analysis.

Overall mean length weighted by species abundance was computed per year from the species mean length in the survey of the year. Prior to 1992, when data on length was missing, the species mean length computed over the available years was used.

The species trophic levels used were those provided by Pinnegar *et al.*(2002) for the Celtic sea complemented by fishbase (Froese and Pauly, 2004). The overall mean trophic level weighted by species abundance was computed per year.

A locally weighted regression smoother (Cleveland, 1979) was fitted to the survey species biomass for visualising trends, the associated 95% confidence limits were also computed. LOESS (local regression) is a method for smoothing a scatterplot ($(x_i, y_i)$ with i=1, …, n). To fit a value at $x_k$, a window is placed about $x_k$; data points that lie inside the window are weighted so that nearby points get the most weight and a robust weighted regression is used to predict the value $x_k$ (Venables and Ripley, 1994).

To test for significant long-term trends in survey data, non-parametric Mann-Kendall tests were performed (Gilbert, 1987), differences were judged significant when $P<0.05$.

## 4 Results

The first two axes of the Correspondence Analysis account for 35 % of the total variance. The first axis divides the study period into two parts (Figure 2): the years from 1973 to 1995 have positive coordinates on this axis while the years 1997 to 2002 have negative ones. This contrast between years indicates that two main opposite trends can be identified in the species abundance indices. Species located on the right side of the first axis show a declining trend over the study period (Figure 3a) while species having negative coordinates on the first axis exhibit an increasing trend (Figure 3b).

The second axis takes into account the changes in the species abundance indices occurring mainly between 1997 and 2002. The second axis is particularly explained by species like *Engraulis encrasicolus* and *Scomber japonicus* which had high abundance indices in 1997 and low ones in 2001 and 2002.

The two extreme categories of the illustrative variable “species range” (i.e. wide range and narrow range, Figure 2) and those of the illustrative variable “mean latitude” (i.e. low mean latitude and high mean latitude, Figure 2) have significant coordinates on the first axis.
Then, two species groups can be identified from the species abundance trends observed over the study period. First, the abundance indices declined or fluctuated for 20 species (group A), more than one third of these species has a narrow range in latitude distribution and a high mean latitude distribution (Table 1). Secondly, the abundances increased for 36 species (group B), one third of these species has a wide range in latitude distribution and a low latitude distribution mean.
Changes in biomass over years for the two groups of species are illustrated in Figure 4. The biomass of group A is very variable from one year to another and does not exhibit any trends over the study period. On the contrary, the biomass of group B shows an increasing trend from 1987 to 2002 (Mann-Kendall S=52, P<0.0001) even when the less precise values of the years 1999 and 2002 are not considered (Mann-Kendall S=39, P=0.002).
The biomass were computed per species range category given in Table 1. For the species of group A, the biomass of the narrowest range and the most northern species (species range category 1) declined significantly from 1987 to 2002 (Mann-Kendall S= - 42, P=0.01; Figure 5a). There was no significant trend for the other species range categories. The main species contributing to about 90 % of the biomass of the group in 1973 and during the period 1987-2002 are listed Table 2. Blue whiting (*Micromesistius poutassou*) replaced poor cod (*Trisopterus minutus*) as dominant species throughout the period 1987-2002 and hake (*Merluccius merluccius*) and whiting (*Merlangius merlangus*) lost their second and fourth rank respectively.
In species group B, both species range categories 2 and 3 increased significantly from 1987 to 2002 (Mann-Kendall S=52, P<0.0001 and S=40, P=0.01 respectively; Figure 5b). Although horse mackerel (*Trachurus* spp) remained at the first rank, there were several changes at the lower levels (Table 2). The three benthic species, red gurnard (*Chelidonichthys cuculus*), anglerfish (*Lophius piscatorius*) and cuckoo ray (*Leucoraja naevus*), present at one of the first five ranks in 1973 were replaced by a small demersal species, boarfish (*Capros aper*), and two pelagic species, mackerel (*Scomber scombrus*) and sardine (*Sardina pilchardus*), during the period 1987-2002.
The mean length of species group A (Figure 6) declined steadily from 1987 to 1990 and exhibited an increasing trend later (Mann-Kendall S=20, P=0.044). The mean length of species group B decreased sharply from 1990 to 1994 and, although variable, remained at a low level during the following years.
The mean trophic level of species group A (Figure 7) declined significantly from 1973 to 2002 (Mann-Kendall S=-45, P=0.01). The main change occurred between 1973 and the period 1987-2002 which was caused by the relative biomass increase of the blue whiting feeding at a low trophic level. The mean trophic level of species group B (Figure 7) was rather stable until 1992 and became very variable afterwards. Its decline in some years was largely due to increased catches of boarfish (*Capros aper*) which feeds at a lower trophic level than the other species occupying the first five ranks of the species group B (Table 2).

## 5 Discussion

In the group of species showing a declining trend of their abundance indices, seven of them (i.e. about 1/3 of the group) have a northerly distribution and a narrow latitude distribution range. The biomass of these boreal species declined during the study period whereas the total biomass of other species (mainly transition species) varied from one year to another without trend.

Twelve species (i.e. 1/3 of the species) of the group exhibiting an increasing trend of their abundance indices are characterised by a southern distribution and wide species range. The biomass of these subtropical species increased from 1987 to 2002 like the biomass of transition species.

The decrease of the mean length of the “boreal” species group (A) between 1987 and 1990 was related to the decline of the biomass of the transition species (range category 2; Figure 5A). Recruitment of several species (silvery pout *Gadiculus argenteus*, poor cod, bib *Trisopterus luscus*, hake and blue whiting) increased sometimes at the same moment during the period 1990-1995 what have also contributed to lower the mean length of group A. Its following increase was mainly due to continuous weaker recruitment. The sharp decrease of the mean length of “subtropical” species group (B) was due to the increase in abundance of small fish species (e.g. boarfish, Mann-Kendall S=59, P<0.0001; imperial scaldfish *Arnoglossus imperialis*, Mann-Kendall S=59, P<0.0001) combined with the increase of the recruitment of some other species (e.g. wedge sole *Dicologlossa cuneata*, Mann-Kendall S=45, P=0.01).

In the absence of time-series isotope data from the study area, we got our trophic level values from the literature. For most of the fish species the diet may vary according to length. So, the values used were probably not the most suitable given potential differences in length compositions between the Celtic Sea and our study area, for instance the horse mackerel trophic level was calculated for fish having a mean length of 347 mm (Pinnegar *et al.*, 2002) while the mean length of horse mackerel in our surveys was 172 mm. We assume also that species trophic levels are stable from year to year. Nevertheless, there are some indications that trophic levels of both species groups have gone down in recent years (the lowest values of both groups were recorded in 2000). Warm-water species seem to be responsible for the decrease of individual size and trophic level in the fish community.

Our study results point out a causal link between the observed changes in the fish community of the eastern shelf of the Bay of Biscay and ocean warming.

In the same way, although records of rare tropical fish on the eastern continental shelf of the Bay of Biscay are not recent, their number increased since 1980 and this mainly in the southern part of the area (Quero *et al.*, 1998). Likewise, the climate-induced changes in the abundance of four common flatfish species were demonstrated for the Vilaine estuary and the Bay of Biscay (Désaunay *et al.*, 2005).

However, changes occurring in the fish community are not important enough to have had an effect on the spatial organisation level of the demersal fish community (Poulard *et al.*, 2003). Even if there is positive correlation between the species abundance indices and the species occurrences in the catches of the same survey (correlation equal or greater than 0.5 for 9 surveys out of 14, results not shown). This means, that usually the spatial distribution of a species increases when its abundance increases and conversely.

Causal attribution of recent biological trends to climate change is complicated because non-climatic influences dominate local short-term biological changes (Parmesan and Yohe, 2003). Changes which have occurred in species composition and trophic level of the "boreal" species group (A) after 1973 could be attributed to fishing (Pauly *et al.*, 2001). Indeed hake, bib and whiting contribute significantly to the French landings of demersal fish species coming from the eastern continental shelf of the Bay of Biscay (Poulard and Léauté, 2002). Part of their diet consists mainly of fish, also a release from predation may occur and account for increase in dominance of smaller/lower trophic level species. The predation release will interact with climate warming which will favour subtropical species and is thought to have a major impact on low trophic level pelagic fish abundances (Pinnegar *et al.*, 2002).

There were changes in the sampling procedure of the groundfish surveys and above all, trawling operations were carried out with a new research vessel from 1997 onwards (Poulard *et al.*, 2003). Unfortunately, there was no intercalibration experiment between the two research survey vessels in the Bay of Biscay. Conversion coefficients were available for some species from experiments carried out in North Sea and Celtic Sea (Pelletier, 1998). Generally, using these coefficients did not modify the observed species trends and sometimes reinforced them. In fact, most of the changes in the species abundance indices had happened around 1994-1995 when the old research vessel was still used. The position of the year 1995 on the first axis of the AFC (Figure 2) supports this interpretation.
This study does not establish a strong relationship between climate warming and changes in the fish community of the eastern continental shelf of the Bay of Biscay. However, we bring together a body of proof indicating that some climate-induced changes may have occurred which could have been amplified by fishing.

## 6 Acknowledgements

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Table 1. Composition of the two species groups identified from the Correspondence Analysis (CA) results according to the two nominal variables: mean latitude and species range. Number of species per species group, per category of latitude range and of mean latitude. The categories are those used in the CA, except that the two middle ones for each variable were pooled together.

| Species group | Mean latitude (in ° of latitude) | | Species range (in ° of latitude) | | | Total |
|---|---|---|---|---|---|---|
| | Category | | 1 | 2 | 3 | |
| | | Limits | [20-40[ | [40-67[ | [67-127] | |
| A | 1 | [2.5-28[ | 0 | 0 | 2 | 2 |
| | 2 | [28-47.5[ | 2 | 5 | 0 | 7 |
| | 3 | [47.5-60] | 7 | 4 | 0 | 11 |
| | | Total | 9 | 9 | 2 | 20 |
| B | 1 | [2.5-28[ | 0 | 1 | 12 | 13 |
| | 2 | [28-47.5[ | 5 | 15 | 0 | 20 |
| | 3 | [47.5-60] | 2 | 1 | 0 | 3 |
| | | Total | 7 | 17 | 12 | 36 |

Table 2. Dominant species per group during the groundfish surveys carried out in 1973 and over the period 1987-2002 on the eastern continental shelf of the Bay of Biscay. Two species of horse mackerel have been caught (*Tachurus trachurus,* the bulk of the catch, and *T. mediterraneus*) but due to mistakes in the determination of these species in the recent surveys they were pooled.

| Group | Groundfish surveys | | | |
|---|---|---|---|---|
| | 1973 | | 1987-2002 | |
| | Species | % Biomass | Species | % Biomass |
| A | *Trisopterus minutus* | 50 | *Micromesistius poutassou* | 60 |
| | *Merluccius merluccius* | 17 | *Trisopterus minutus* | 17 |
| | *Trisopterus luscus* | 12 | *Trisopterus luscus* | 7 |
| | *Merlangius merlangus* | 9 | *Merluccius merluccius* | 6 |
| B | *Trachurus spp* | 84 | *Trachurus spp* | 75 |
| | *Chelidonichthys cuculus* | 2 | *Capros aper* | 8 |
| | *Lophius piscatorius* | 2 | *Scomber scombrus* | 5 |
| | *Scyliorhinus canicula* | 2 | *Sardina pilchardus* | 4 |
| | *Leucoraja naevus* | 2 | *Scyliorhinus canicula* | 1 |

Figure legends

Figure 1. Area of the eastern continental shelf of the Bay of Biscay studied during the 14 groundfish surveys carried out by IFREMER from October to December, in 1973, from 1987 to 1990, in 1992, 1994, 1995 and from 1997 to 2002.

Figure 2. Correspondence analysis, projection of the 14 active variables (◆ years), two illustrative variables (● mean latitude category of species latitude distribution, ■ range category of species latitude distribution) and the 56 individuals (△ species) in the principal plane (first and second axis plane). Symbol size is proportional to the contribution of years or species to the building of axes.

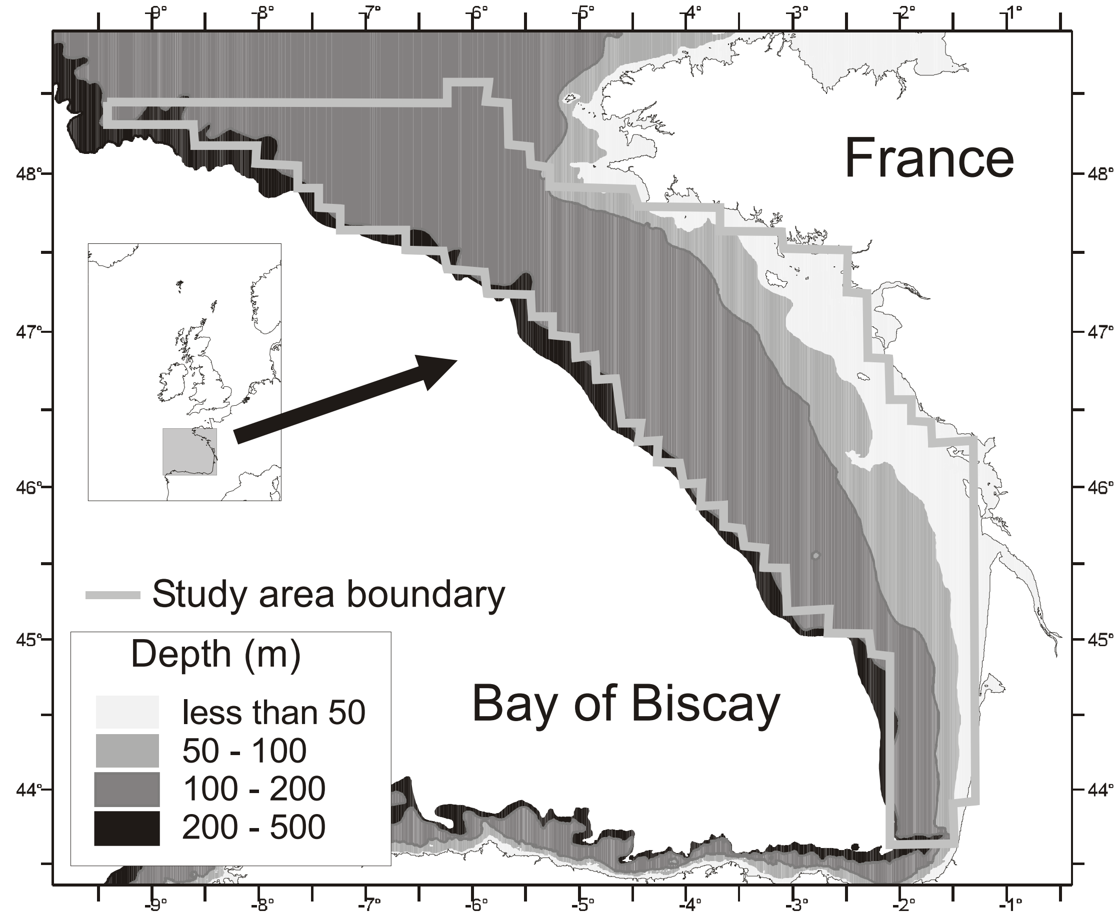
Figure 3. Examples of distribution of standardised abundance indices for species having negative (*Echiichthys vipera*) or positive (*Molva molva*) coordinates on the first axis of the correspondence analysis (see Figure 2).

Figure 4. Evolution of the biomass of the two species groups identified from their coordinates on axis 1 of the correspondence analysis. Species group A includes a significant proportion of species with a narrow distribution range in latitude and a high mean latitude distribution. Species group B includes a significant proportion of species with a wide distribution range in latitude and a low mean latitude distribution.

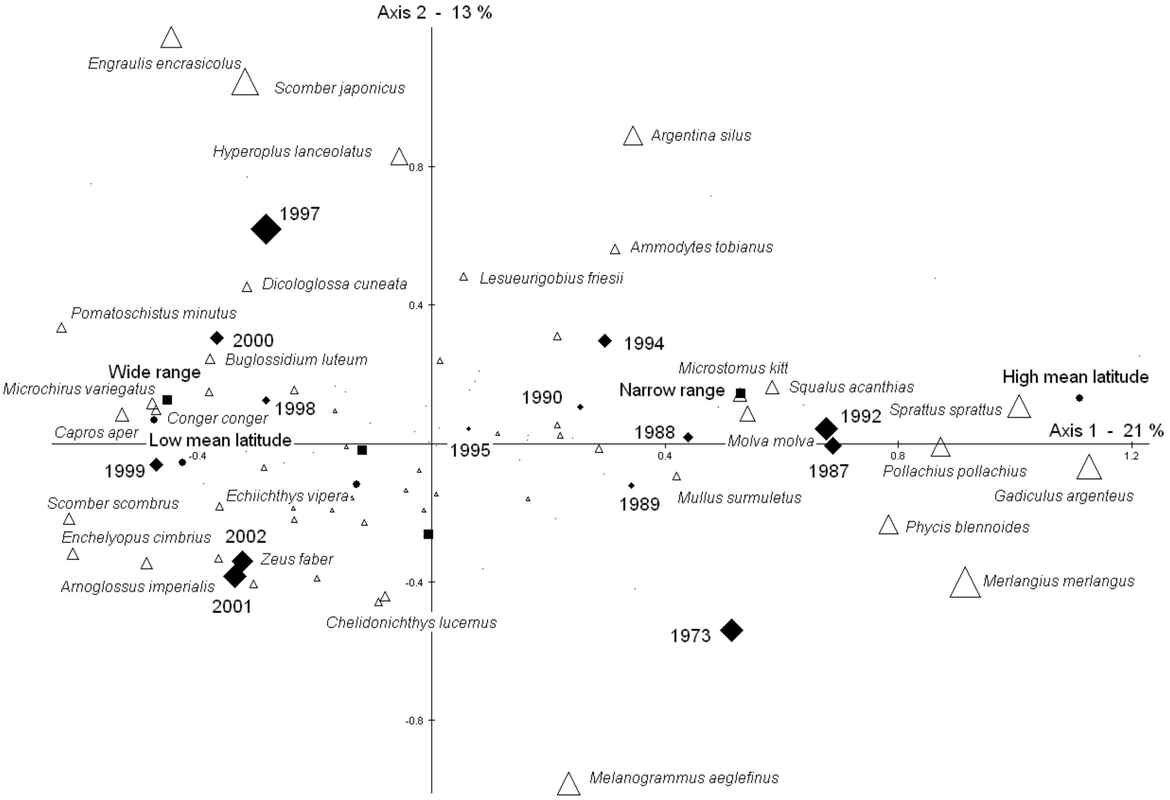
Figure 5. Biomass of the two species groups identified from their coordinates on axis 1 of the correspondence analysis (see figure 4) broken down per species range category.

Figure 6. Mean lengths of the two species groups identified from their abundance trends in groundfish surveys over the period 1973-2002.

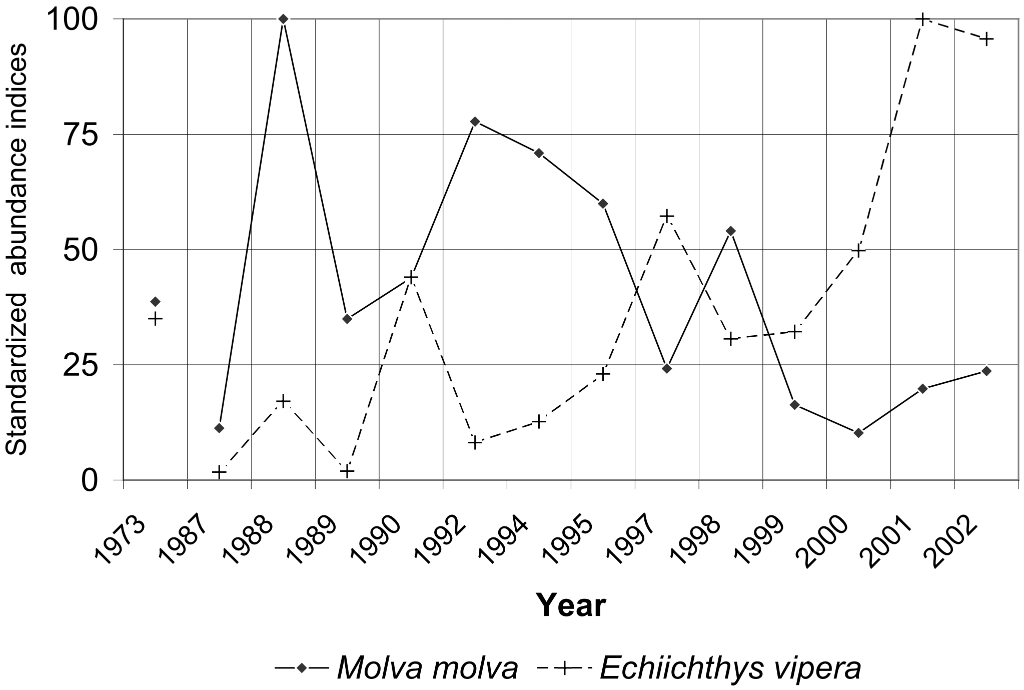
Figure 7. Patterns of changing in mean trophic level for the two species groups identified from their abundance trends in groundfish surveys over the period 1973 to 2002.



Poulard & Blanchard Figure 1

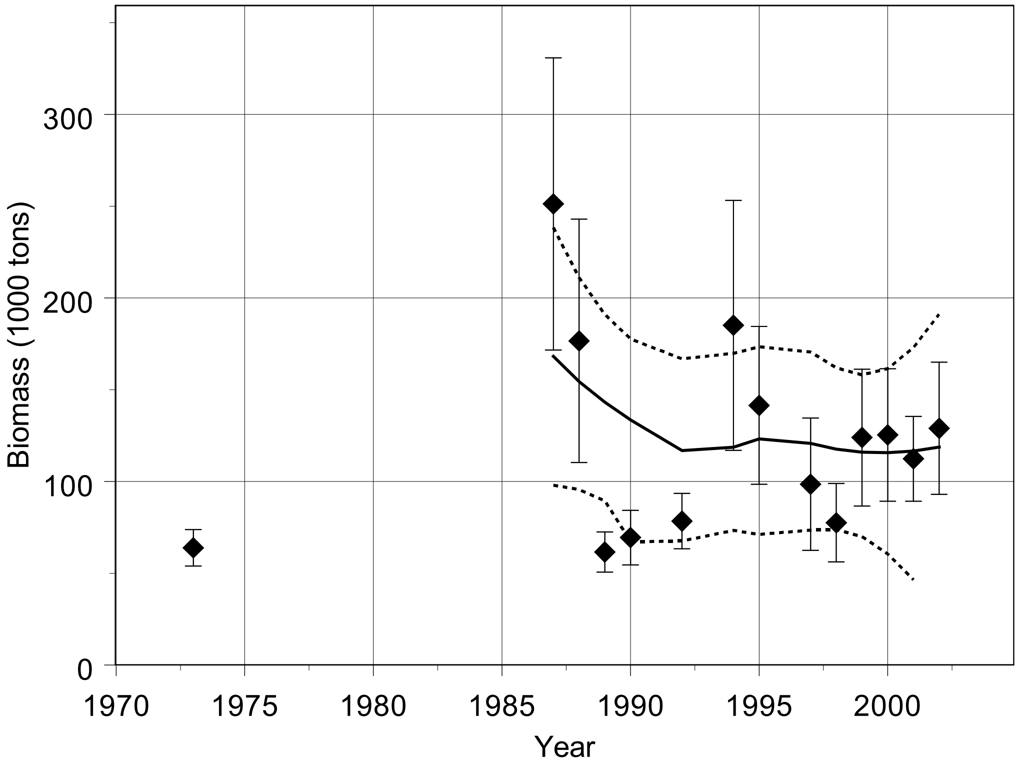


Poulard & Blanchard Figure 2

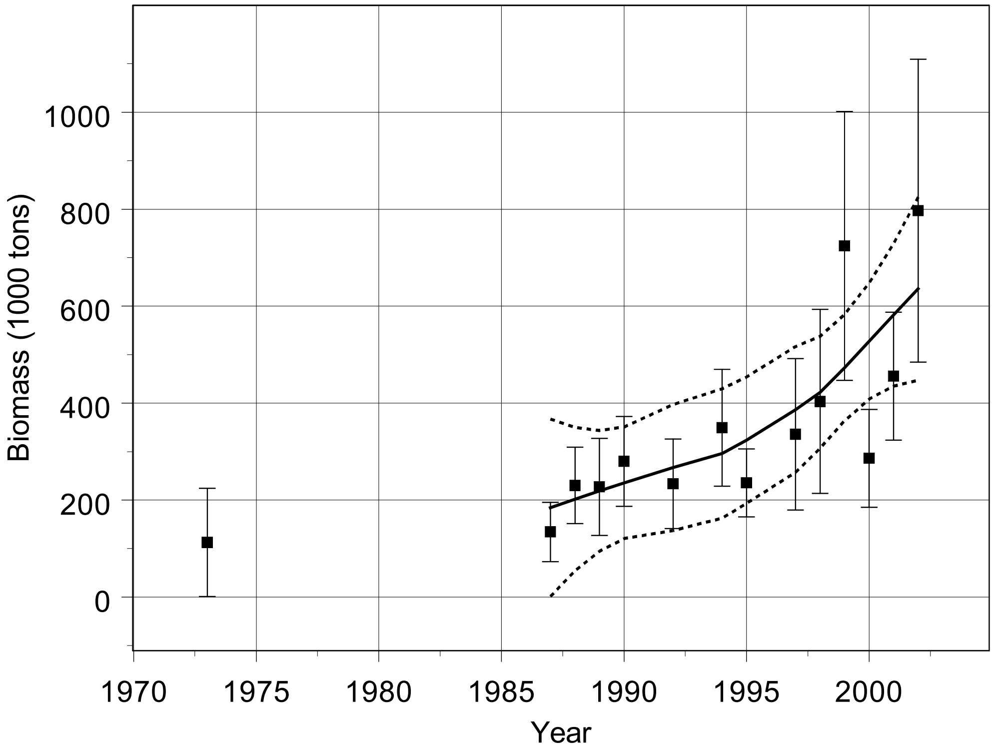


Poulard & Blanchard Figure 3

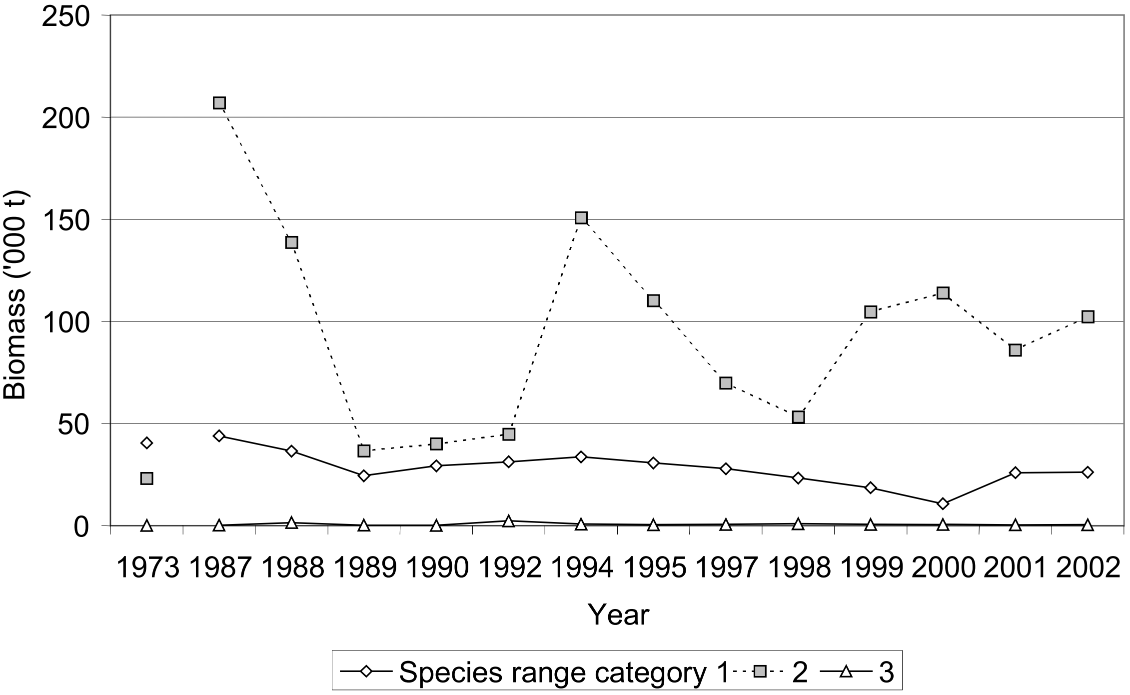
Species group A biomass



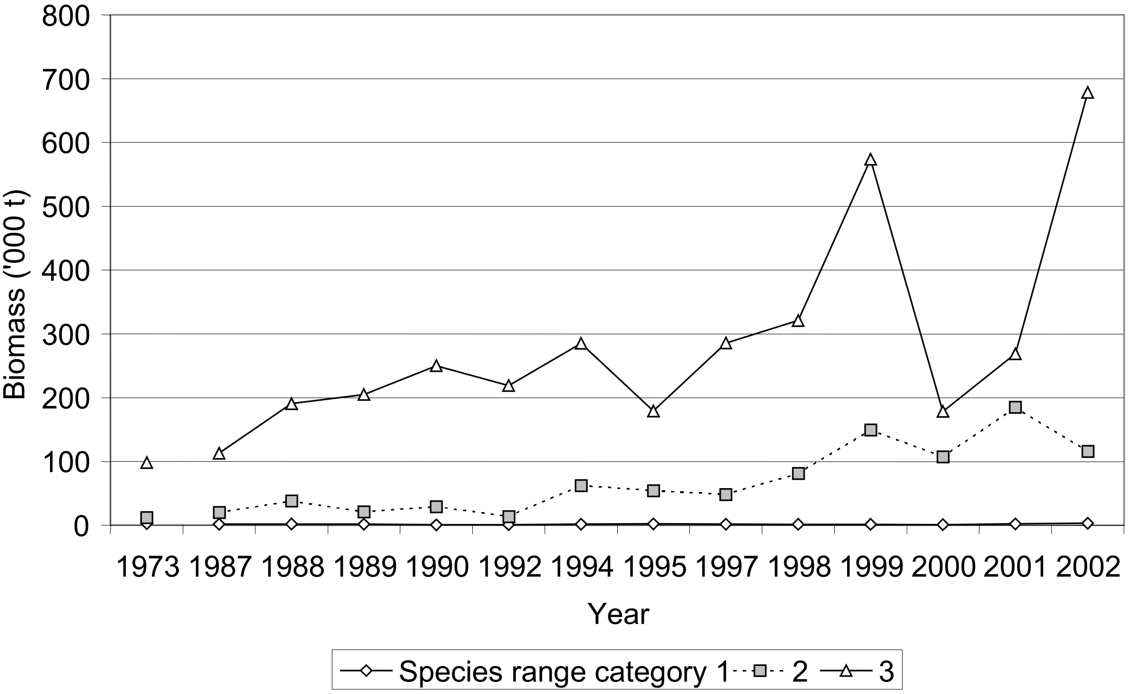
Species group B biomass



Poulard & Blanchard Figure 4

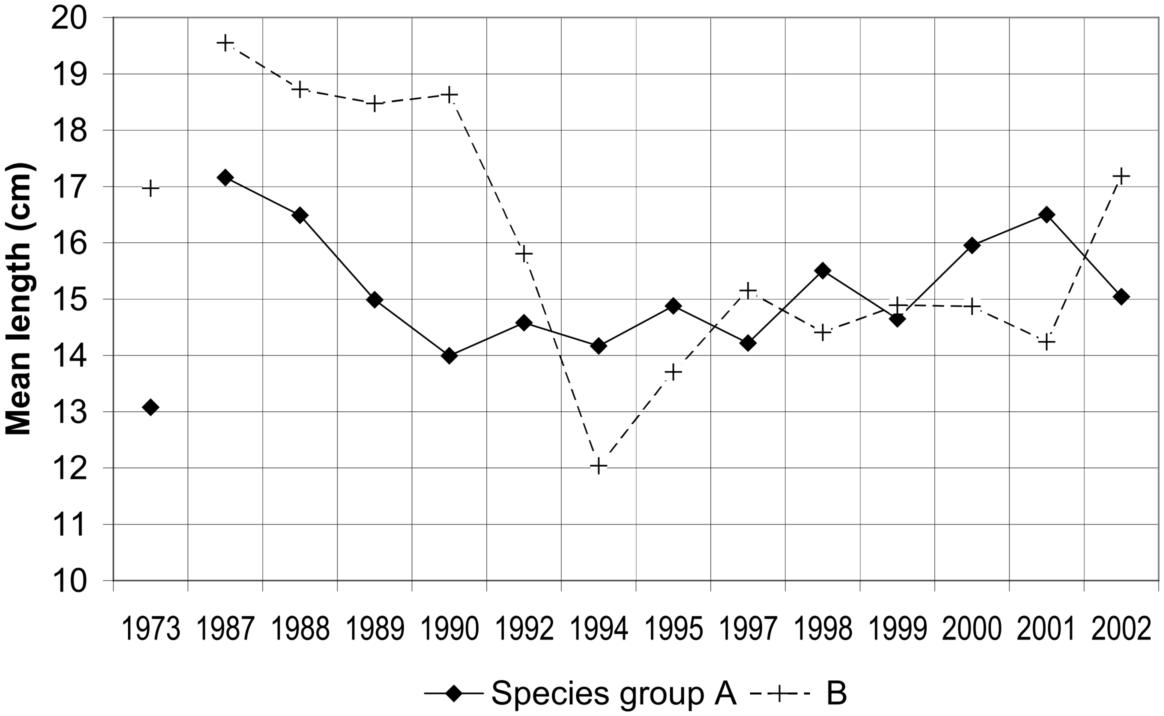


A

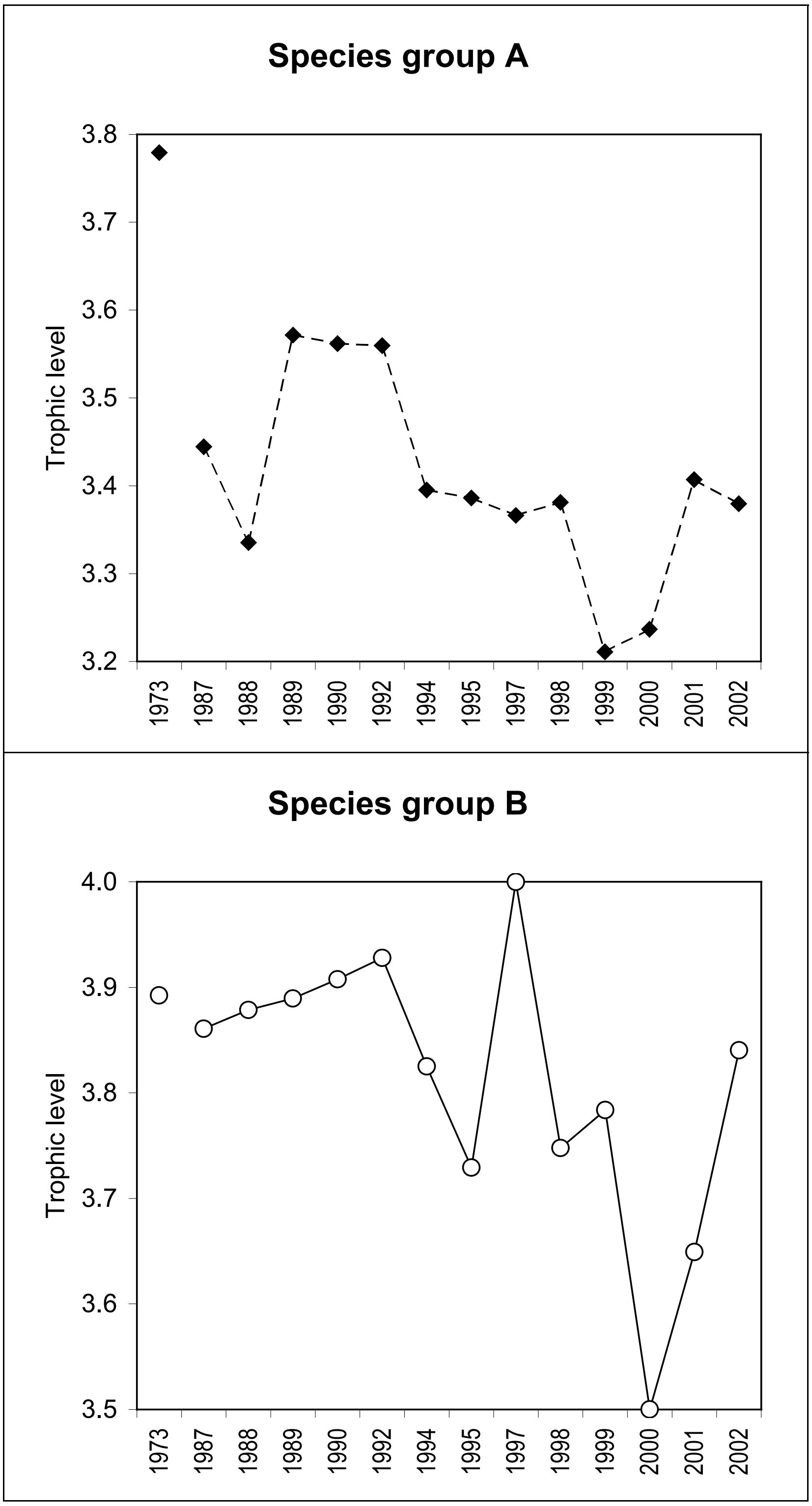


B

Poulard & Blanchard Figure 5



Poulard & Blanchard Figure 6



Poulard & Blanchard Figure 7