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The Role of Elasmobranchs in the Cantabrian Sea Shelf Ecosystem and Impact of the Fisheries on Them

(Elasmobranch Fisheries - Oral)

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Abstract

Elasmobranchs apparently play an ecological role of relevance in the demersal community of the Cantabrian Sea. Using biomass indices obtained from bottom trawl surveys the most significant elasmobranch species in the continental shelf ecosystem are described. By combining their spatial distribution with multivariate analysis, including other fish species, it is possible to place them within the communities that structure the ecosystem. Considering all the fish species inhabiting the continental shelf and applying a trophodynamic model which incorporates biomass, production, biological parameters, feeding diets and catches and discards of the fisheries, the trophic level of the main elasmobranch groups and their relationship with others species inhabiting the same area are obtained. Also an estimation of the impact of the different fisheries (gears) that operate in the study area is made. Finally, some time-spatial simulations of the consequences of some management measurements affecting elasmobranch populations such fishery closed areas, have been performed. The results of these simulations are validated *in situ* by carrying out experiments in a closed area located in the central Cantabrian Sea shelf.

Introduction

The Cantabrian Sea area is the subtropical/boreal transition zone of the Eastern Atlantic. As a result, typical temperate-water species from the south occur together with those of northern origin and, consequently, high biodiversity indices exist in comparison with adjacent areas (Olaso, 1990; Sánchez, 1993; OSPAR, 2000). In addition, the topographical complexity and wide range of substrates on its continental shelf result in many different types of habitats. The inner shelf (with a depth of less than 100 m) bottoms are mainly rocky or sandy, whereas the outer shelf has predominantly muddy bottoms. The production of the area is greatly influenced by a seasonal coastal upwelling (spring and summer) and hydrographic mesoscale activity along the north-western shelf-break. This is a consequence of winter fluxes from the warm poleward current (also known as the "Navidad Current"), which results in a convergent front at the boundary between coastal and oceanic waters (OSPAR, 2000; Sánchez and Gil, 2000). These produce a regular pattern of hydrographic conditions throughout the year characterised by winter mixing and summer stratification, with phytoplankton blooms occurring during the transition periods. This seasonal pattern has a significant effect on the dynamics of the ecosystem.

This diversity is reflected in the biological richness of the region that includes many species of commercial interest. The fisheries, which have been operating for centuries, have an enormous effect on the structure and dynamics of the Cantabrian Sea ecosystem (Sánchez and Olaso, 2002); they have become more industrialised over the last 50 years, with the catch reaching about 200 000 tonnes per year. Trawlers fish on the muddy bottoms of the shelf, whereas longliners operate mainly on the shelf-break bottoms and gillnets are used on rocky grounds near the coast and shelfbreak.

Elasmobranchs are well represented on the continental shelf of the Cantabrian Sea, particularly with respect to demersal species (Sánchez, 1993; Sánchez *et al*., 1995, 2002). The bottom trawl surveys carried out in this area and the main fisheries themselves suggest that elasmobranchs play an important role in the ecosystem. In this study, an attempt is made to describe the relationships among the main elasmobranchs groups that inhabit the shelf in relation with the rest of the species that live together. For this purpose, all the information available to date such as biomass index, spatial and bathymetrical distribution, biological parameters, food habits, catches, discards, etc., has been used and joined with other components of the system, in a mass-balance model of trophic interactions.

Material and Methods

The Cantabrian Sea is considered as the southern region of the Bay of Biscay. However, for practical reasons, this study considers the zone in its wider meaning (ICES Division VIIIc), which includes the Galician shelf to the north of Cape Finisterre (at latitude 43ºN) and is the upper limit of the subtropical Lusitanic area (Fig. 1). Division VIIIc has some relatively homogeneous biogeographical characteristics in relation to adjacent areas and fishing statistics and information are available from the evaluation of stocks carried out by the ICES stock assessment working groups, which were indispensable for developing the model. In this study, we refer to the neritic area of the Cantabrian Sea, with a total continental shelf surface of about 16 000 km², and the neighbouring oceanic area.

The Model

The Ecopath (version 4.0) model was applied in order to produce a balanced steady-state description of the Cantabrian Sea shelf ecosystem. The Ecopath model combines estimates of biomass and food consumption of the various components (species or groups of species) in an aquatic ecosystem with an analysis of flows between the ecosystem elements (Polovina, 1984 and further developed by Christensen and Pauly, 1992, 1993). The energy balance of each trophic group is given by the basic equation:

$$\text{Consumption} = \text{Production} + \text{Respiration} + \text{Unassimilated food}$$

The production of each trophic group is balanced by its predation by other trophic groups in the system, its exports from the system and mortality. The ecosystem is modelled using a set of simultaneous linear equations (one for each group *i* in the system), i.e.:

> Production by (*i*) - all predation on (*i*) - non predation losses of (*i*) - export of (*i*) - biomass accumulation of (*i*) = 0, for all (*i*).

This can also be expressed as:

$$B_i \cdot P_i/B_i - \Sigma\, B_j \cdot Q_j/B_j \cdot DC_{ji} - P_i/B_i\,(1- EE_i\,) - EX_i\ = 0$$

where B_i is the biomass of (*i*); P_i/B_i is the production/biomass ratio (equal to the instantaneous rate of total mortality Z in steady-state systems) of (*i*); B_j is the biomass of predator *j*; Q_j/B_j is the consumption/biomass ratio of predator *j*; DC_{ji} is the fraction of prey (*i*) by weight in the average diet of predator *j*; EE_i is the ecotrophic efficiency of (*i*): expressing the fraction of total production consumed by predators or caught by a fishery; and EX_i is export of (*i*): sum of fisheries catches plus emigration to adjacent ecosystems.

A classification of species according to their prey was carried out as a first step. On this basis, and to construct the mass-balance model, 28 trophic groups were defined, 15 of which were fish, 6 invertebrates, 5 groups of plankton, detritus and fishery discards. In each group, we considered species of similar size, habitat, diets, consumption rates, mortality and production rates. All the available data of biomass, landings and discards were converted into the same unit ($\text{tonnes} \cdot \text{km}^{-2}$) expressed as wet weight. Estimations of biomass, mortality, consumption and ecotrophic efficiency by different methods for each trophic group were used in the model (Sánchez and Olaso, 2001 and 2002). Discards data were first available in 1994; for that reason and in order to harmonise the information, all the input data used in the study correspond to 1994.

Biomass and production estimates

Different and complementary sources of biomass have been used in the analysis. On the one hand biomass estimates of all the species are based on the bottom trawl surveys carried out in this area, applying the swept area method

(Sánchez *et al*., 1995; 2002) on the other hand, estimations of the main commercial species are based on the reports of their respective stock assessments (ICES, 2002b, 2002c).

To simplify and because not full data is available for all elasmobranchs species two trophic groups of elasmobranchs were considered in the model, Dogfish and Rays. Lesser spotted dogfish (*Scyliorhinus canicula*) comprises a total of 80% of the Dogfish group biomass. Other species in this group were small demersal sharks, like black mouth dogfish (*Galeus melastomus*), *Deania calceus* and *Etmopterus spinax*. At least eight species of rays exist in the area (Sánchez *et al*., 1995; 2002) of which the most abundant is the thornback ray, *Raja clavata* (50% of the biomass in the model), followed by *R. montagui* and *Leucoraja naevus*.

Total biomass of Dogfish and Rays species obtained from bottom trawl surveys applying the swept area method (Sánchez *et al*., 1995; 2002) was underestimated because only an unknown percentage of the population is accessible to the gear. However a comparison made between the biomass estimated by stock assessments and survey index of similar behaviour demersal species, like hake and megrim, makes it possible to predict that the survey only estimates the 10-15 % of the total biomass. Assuming the same proportion for Dogfish and Rays results in a total biomass of 8 250 t and 5 250 t, respectively, in the ICES Division VIIIc. Recently a preliminary assessment of lesser spotted dogfish (ICES Division VIIIc), *R. clavata* (IVb and IVc Divisions) and *L. naevus* (VIIIghj and VIIIab) has been undertaken by DELASS project (ICES, 2002a). Despite the difficulties associated with the data requirements and the methods used, the total biomass of lesser spotted dogfish estimates from VPA outputs in 1994 for the ICES Division VIIIc was 5 933 t. These estimates (adding a 20% corresponding to the other species of small sharks to complete the Dogfish trophic group) are very close to those estimated from the surveys index.

Total mortality (Z) of dogfish and rays in this area is unknown, based on the knowledge of these species and compare to data from other areas a value of Z= 0.25 has been used in the model as PB (production/biomass ratio) for Dogfish and Z=0.30 for Rays. Mortality estimates of Rays in the North Sea gave Z values of 0.58 for *R. clavata*, 0.54 for *R. montagui* and 0.58 for *L. naevus*. However these species are heavily exploited in this area and support a high fishing mortality (Walker, 1998).

Feeding

The links between groups were their feeding habits; the information needed to create the diet matrix was taken from different sources (Sánchez and Olaso, 2002). A quantitative analysis was undertaken for 10 200 stomach contents from 36 species of fish in the study area. The species selected constituted a significant percentage (90%) of the demersal fish biomass. In order to obtain an appropriate representation of the annual diet of the fish, the seasonal diet change that takes place in many species was also considered. Concerning to the elasmobranchs diet matrix, a total de 4 348 lesser spotted dogfish, 794 black mouth dogfish and 1 734 rays stomachs were analysed over the study period (Olaso *et al*., 2002b; Velasco *et al*., 2002). The diet of Dogfish is mainly based in decapod crustaceans, blue whiting and discards. The food habits of Rays includes principally crustacea Brachiura and Natantia being more specialist than the Dogfish.

Fisheries

The statistical data for fisheries landings were provided by the ICES stock assessment working groups and by the IEO Fishery Database team. The data were subsequently summarised and combined by trophic group (Sánchez and Olaso, 2002). Regrettably, landings data for all elasmobranch species are not available since most of this species have a low commercial value and are taken as a by-catch, which implies that traditionally these species were landed together in the same category. Considerable effort has been recently made in collecting and improving data from elasmobranch fisheries, particularly from 1996 to 2001 (one of the main objectives of DELASS project). The data of landings by fishing gear used in this paper have been improved from the original model; however no information is available for 1994 so estimations have been made. Landings of *S. canicula* remain more or less stable around 200 t showing and increasing trend in the last years; in 1994 a total of 250 t was estimated, of which 215 t belonged to trawl catches. In the case of Rays an increasing trend is also observed in the last years, showing more fluctuations among years; an estimated of 450 t landed in 1994, (405 from trawl) have been assigned.

The highest dogfish landings are those of bottom trawl (75%) followed by longline (21%) and gillnet (3%); some landings of purse seine or traps have also been occasionally recorded. In the case of rays data from the fishery indicate that the most abundant species are *R. montagui*, *R. clavata* and *L. naevus* and the highest landings come from trawl (81%) followed by gillnet (11%) and longline (8%); some landings with purse seine or traps have also been occasionally recorded (Fernández *et al*., 2002) .

Discards

Mainly sea birds, fish and benthic scavenger species consume discards (20% of the total catches in the Cantabrian Sea). In this study, information was based on the results of the discard sampling programme which covered the activities of some of the most important Spanish fleets during 1994 in ICES Division VIIIc, such as trawlers, gillnets, longliners, and purse seiners (Pérez *et al*., 1996). Blue whiting and horse mackerel were the main species discarded. It has been estimated that 6 149 and 5 040 t of these two species, respectively, were discarded during 1994. Other heavily discarded trophic groups were lesser spotted dogfish, some of which survive the process (Rodriguez-Cabello *et al*., 2001), benthic invertebrate carnivores, small demersal fish and other invertebrates. In order to determine the species that benefit from the discards, some studies have been carried out in the area (Olaso *et al*., 1998; Olaso *et al*., 2002a), including the results in the present model.

Mixed Trophic Impacts

The mixed trophic impact (MTI) of different trophic groups and fisheries on other groups is obtained using the Leontief economic matrix routine implemented in Ecopath, following the subsequent development described by Ulanowicz and Puccia (1990). This analysis quantifies the direct and indirect interactions in a balanced system. The MTI for living groups is calculated by constructing a matrix, where the i,j^{th} element representing the interaction between the impacting group i and the impacted group j is

$$MTI_{ij} = DC_{ij} - FC_{j,i} ,$$

where DJ_{ij} is the diet composition term expressing how much j contributes to the diet of i, and $FC_{j,i}$ is a host composition term giving the proportion of the predation on j that is due to i as a predator. When calculating the host compositions the fishing fleets are included as "predators". The mixed trophic impact routine gives an idea of how important the different fisheries are for the trophic dynamics of the system.

Model Simulations

We use the recent expansions of the Ecopath approach (Ecosim and Ecospace) to simulate changes in fishing pattern and intensity through time in an ecosystem framework. Ecosim is a time-dynamic simulation tool for studying fisheries policy options (Walters *et al*., 1997). Ecosim includes biomass and size structure dynamics: mixed differential and difference equations and use of mass-balance assumptions for parameter estimation. Time patterns of biomass and equilibrium system responses under different exploitation regimes are predicted by these differential equations. Ecospace is a mesoscale spatial simulation tool for predicting spatial patterns and runs the Ecopath model through Ecosim to check the behaviour of ecosystem. Numerical approximation by linearisation, and matrix exponential solution method generate projection predictions towards spatial equilibrium. Walters *et al*. (1998) describe all the functions used in Ecospace simulations. To explore the simulation capacity of Ecospace we defined a base-map of central area of the Cantabrian Sea with five habitats: oceanic, break shelf, outer shelf, inner shelf and coastal waters. We also define the habitat preferences of trophic groups, based in Sánchez (1993) and Sánchez and Serrano (2002), and gears and the movement rates and vulnerability in bad habitats of the 26 living trophic groups.

To calibrate if the simulations of the management measures using the trophodynamic model are realistic we studied the recovery rates after trawl disturbance in an existing restricted area. Fishery policy establishes that bottom trawl gears are forbidden to work on fishing grounds less than 100 m deep in the Cantabrian Sea. To exclude illegal trawling operations, concrete blocks (artificial reefs) were placed by local fisheries authorities, on some of < 100 m soft grounds. To estimate the effect of this management measure a study was carried out in the Llanes area (Asturias, central Cantabrian Sea), where in 1993 artificial reefs were placed. A historical series of bottom trawl surveys data were analysed, from 1983 to the present, trying to determine if the differences among the previous period to the exclusion and the later one are significant. After 1993, we used bottom trawl surveys in a zone free of blocks not used by trawlers, included in the Llanes area to obtain information of the impact of the management measure. We assume for this study that the surface occupied by concrete blocks (< 0.02%) is irrelevant to modify the soft grounds community structure.

Results and Discussion

The main elasmobranch species that inhabit the continental shelf of the Cantabrian Sea, based on the bottom trawl survey index (from years 1997-1999) are shown in Table 1. Lesser spotted dogfish (*S. canicula*) is particularly abundant in the study area during the last years, being the fifth species in biomass after blue whiting, horse mackerel, hake and sea bream (Sánchez *et al*., 2002). The two most abundant dogfish species, *S. canicula* and *G. melastomus,* show similar trends in their abundance pattern along the historical series (Fig. 2) which suggests that both species have similar environmental requirements. The first one inhabits shallower waters and it is representative of the inner shelf community; *G. melastomus* is found at deeper waters in the outer shelf community (Sánchez, 1993; Sánchez y Serrano, 2002b). Considering that their food habits are not very different (Olaso *et al*., 2002) both species have been included in the same trophic group for the model analysis. The rays *R. clavata*, *R. montagui* y *L. naevus* contribute in a great proportion to the total biomass of the Rays group (Table 1). All of them show an increasing trend in their abundance index in the last five years (Fig. 2).

Elasmobranchs are well represented in the main fish communities described in the continental shelf of the Cantabrian Sea (Sánchez, 1993) and moreover some of them contribute to define the structure of these communities (Sánchez and Serrano, 2002). The rays *R. clavata* y *R. montagui* belong to the group of species that define the structure of the coastal community and *S. canicula* is one of the main species in the inner shelf community. The fish assemblage that comprises the outer shelf is structured, among other species, by *G. melastomus* and the shelf break by deep water sharks like *E. spinax* y *D. calceus*. Data from these fish communities studies have been used to assign the preference habitats (Table 1) in the spatial-temporal simulations carried out with Ecospace.

Trophodynamic Model

A summary of the input parameters for the balanced trophodynamic model is given in Table 2 together with some parameters estimated using Ecopath. The total biomass sustained by the ecosystem was estimated at 226 $t\cdot km^{-2}$, which corresponded to 49.5%, 27.3% and 23.2% of the pelagic, demersal and benthic domains, respectively. This evidences the great importance of the bottom communities and benthic producers in the area. Tuna (4.71), large hake (4.77) and anglerfish (4.80) showed the highest trophic level in their respective domains. Due to their scavenger and opportunistic habits the two groups of elasmobranchs considered have a lower trophic levels than the apex predators, being in an intermediate level between the Large Demersal Fish and Benthic Fish. The ecotrophic efficiency (EE) of elasmobranchs is low compared to the rest of demersal fishes, which means that only a 40-60 % of their production is used within the system. This means that they are not subject to a strong pressure neither by predation or fishing. Nearly 1.3 $t\cdot km^{-2}\cdot year^{-1}$ is consumed by the two groups of elasmobranchs considered. In the case of Dogfish this biomass is comprised by Blue Whiting (probably discarded), Benthic Invertebrates Carnivores (mainly crustacea) and discards. The opportunistic behaviour of this group of elasmobranchs in taking advantage of the discards of the fleet (2.3 $t\cdot km^{-2}\cdot year^{-1}$ estimated), as it has been already confirmed in previous studies (Olaso *et al*., 2002a), and its high capacity of survived after being discarded (Rodríguez-Cabello *et al*., 2001), certainly confers them many adaptive advantages. In the case of Rays most of the biomass consumed is made up of Benthic Invertebrates Carnivores (mainly crustacea brachiura) and Shrimps (crustacea natantia).

To compare the relative role of the pelagic, demersal and benthic sub-systems, Fig. 3 shows the major biomass flows for the Cantabrian Sea ecosystem in 1994. The groups represented by small plankton, invertebrate filter feeders and detritivores were in trophic level II. Part of their production is transferred to the large plankton, benthic and suprabenthic invertebrates, and clupeiform fish (level III). The planktophagous fish of medium size, together with the rays and benthic fish were, at level IV. The highest level, close to level V, corresponded to apex pelagic fish (tuna), squids, and large demersal and benthic fish.

In the benthic and demersal domain, most of the biomass and production was associated with detritus. Due the particular primary production blooms pattern of the Cantabrian Sea, feeding pressure on phytoplankton was low in the system (EE=0.2), which meant that a large percentage of this biomass passed to detritus (3064 $t\cdot km^{-2}\cdot year^{-1}$). This is corroborated by studies in the area that indicate that a high percentage of the primary production is exported to the bottom as particulate organic matter (Bode *et al*., 1996; Barquero *et al*., 1998; OSPAR, 2000). The detritus in the model accounted for 19.3% of total consumption and constituted one of the main energy flow inputs. Consequently, detritivorous species were an important component of the Cantabrian Sea ecosystem and suspension feeders (i.e. suprabenthic zooplankton, shrimps) and deposit feeders (polychaetes and other invertebrates) constituted a high percentage of the biomass between trophic levels 2 and 3 (Table 2; Fig. 3) to the detriment of pelagic plankton. This has considerable significance for Dogfish and Rays since it provides a high quantity of available food making possible a high level of biomass by surface for these groups in this area. Considering the abundance and distribution of elasmobranch species along the north of the continental shelf of the Iberian Peninsula (Sánchez *et al*., 1995 and 2002) their presence is remarkable higher in the Cantabrian Sea. Performing a trophodynamic model in the high productivity Northern Benguela upwelling system, Shannon and Jarre-Teichmann (1999) estimated a chondrichtyans biomass by surface area half than in our study area.

The model shows that the fisheries utilised 36.6% of the total primary production. This high PPR (primary production required) value corroborates the conclusion that the fisheries of the Cantabrian Sea use a large proportion of the productive capacity of the shelf ecosystem (Sánchez and Olaso, 2002). The results indicate a level of fisheries impact in the Cantabrian Sea comparable to the most intensively exploited temperate shelf ecosystems of the world. Similar systems exhibit values of PPR from 24.2 to 35.3% (Pauly and Christensen, 1995) and 29% of the primary production is required to sustain the catches in the North Sea ecosystem (Christensen, 1995). The Dogfish and Rays mortality estimates obtained from the model indicate very low values for both the F and M (Table 2). A preliminary assessment of this species carried out under DELASS project using VPA (ICES, 2002a) gave even lower values of F (0.04). However in the VPA analysis only landings were taking into account not the true catch (including discards) which really accounts for the fishing mortality. On the other hand Ecopath uses the catch but does not take into account the high percentage of lesser spotted dogfish discarded that survive (78% estimated by Rodriguez-Cabello *et al*., 2001) which might overestimate the fishing mortality. A study carried out by Pérez *et al*. (1994) in 1994 estimated that the percentage of discards made by the trawl fleet in this area for dogfish and rays were around 80-90 % and 20-30% respectively. Because the estimations of total biomass and landings of elasmobranchs species are not so precise as they should be, the model outcomes must be considered as preliminary.

Mixed Trophic Impacts

Figure 4 shows the mixed trophic impacts of different groups and fisheries using the Leontief matrix. This analysis allows estimate of the relative impact of a change in the biomass of one group on other components of the ecosystem, under the assumption that the diet composition remains constant (Ulanowicz and Puccia, 1990). The impacts produced by Dogfish and Rays have rather low values compared to the impacts that other trophic groups have on them. At the same time, the lack of elasmobranchs predators make that the highest negative impacts on them are caused mainly by the fisheries.

Regarding Dogfish (Fig. 4A) the only notable negative impact is produced to Small hake, to Megrim, its own intraspecific competition (considering its high abundance) and the one produced to the discards (by consumption). The most important negative impact on dogfish are those produced by the commercial trawl fishery and in less quantity by the longline fishery, which are the main causes of its total mortality. From living groups, Large Demersal Fish, Benthic Fish and Benthic Cephalopods have a high percentage of prey overlap (80%, 70% and 60% respectively, Table 3) and have a negative impacts on Dogfish. It is likely that the groups Small Demersal Fish and Horse Mackerel have also a negative impact since they consume large quantities of Zooplankton Suprabenthic, one of the main preys of Dogfish juveniles. Finally, it is significant the positive impacts on Dogfish population caused by Benthic Invertebrates Carnivores, the Discards (extremely important in its diet) and the Detritus (the food of many of their preys).

The Rays group (Fig. 4B) is subject to more impacts than the small sharks. The positive impacts are caused by their common preys (mainly detritivorous organisms) and the Discards and Detritus, similar to those of Dogfish. The trawl fishery has a very negative effect, at a higher level than for small sharks, as is the case of gillnet fishery. Many other trophic groups compete against Rays, like their main food competitors (Benthic Cephalopods, 90% prey overlap) and all the components of the main trophic flow pelagic-demersal (Phytoplankton->Mesozooplankton->Zooplankton suprabenthic->Small Demersal Fish->Blue Whiting). These outcomes seem to indicate that the ecosystems whose production is based on the Phytoplankton and the pelagic trophic net do not benefit Rays; on the contrary, the ecosystems with high level of detritus flow (which is the case of the Cantabrian Sea) are more appropriate.

A reduction in the fishing effort has been going on in the last years (ICES, 2002b and Fig. 2). Considering that the impact caused by the trawl fishery is the major limiting factor over the population according to MTI analysis, the effort reduction might have been the responsible for the biomass index increase reflected in the different elasmobranchs groups in the study area (Fig. 2). Also, the natural diet of Dogfish and Rays is modified and it benefits from food provided by discards (Kaiser and Spencer, 1994; Olaso *et al*., 1998 and 2002a), and on the other hand, lesser spotted dogfish is discarded and returned to its natural state with a survival rate of over 78% (Rodríguez-Cabello *et al*. 2001).

Temporal and Spatial Simulations

Simulation and projections with Ecosim with different trawl fishing regimes starting from the present model of 1994 inputs, using mixed trophic control between the "top-down" and "bottom-up" strategic trophic alternatives hypotheses, are implemented. For wider ranges of F the basic Ecosim output is a graphical display of the relationship between equilibrium biomasses, catch and fishing rates. Rays and Dogfish (large-bodied species which have low rates of turn-over), Anglerfish, Megrim (only trawl catch), Hake (strong trawl effect on juveniles), Benthic Cephalopods and Large Demersal Fish are the main trophic groups which increase their biomass when the trawl fishing regime decrease. Mackerel, Small Demersal Fish, Sardine and Anchovy (populations with high rates of turnover and planktophagous habits) are not affected by the different values of trawl regimes. In addition, the scavenging species, as Benthic Invertebrate Carnivores, are not affected by different trawl regime. Ecospace predictions of steady-state biomass densities in the base-map of the central Cantabrian Sea scenario during five years simulation (including the effect of a closed area to trawling) show that in the closed area the biomass levels of Rays, Dogfish, Large Demersal Fish, Benthic Fish, Small Demersal Fish and Benthic Cephalopods are higher than in adjacent areas (Figure 5). Also, the trawl exclusion in this area reduces the biomass of small pelagic fish (Anchovy, Sardine) Blue Whiting (more pressure of predators), Megrim and show low values of Discards.

Figure 6 show the time series of bottom trawl surveys abundance indices (kg/30 min. haul) by trophic group of the Llanes closed area. The main fish species groups that get benefit from the trawl exclusion are elasmobranchs (Dogfish and Rays), Small Demersal Fish (*Pagellus*, *Boops*, etc.), Benthic fish (mullet, gurnards and great weever). Also, Benthic Cephalopods (octopus and white octopus) and Other Invertebrates (sea urchins) groups show major level of biomass in the Llanes closed area after closure of trawl operations. In general terms, the validation of the trophodynamic model, using abundance indices of surveys, suggests that the simulations provided by Ecospace are very realistic.

The demersal elasmobranchs groups considered in this study do not make long migrations (Rodríguez-Cabello *et al*., 1998) and have a tendency to remain in the same area if the conditions are suitable for them. Studies carried out in the North Sea reveal that rays (*R. clavata*) do not make extensive migrations, most of them within 50-60 km (Walker, Howlett and Millner, 1997). Elasmobranchs are considered typical *k* strategists which have low growth, late sexual maturity and produce relatively few offspring with low natural mortality after their long reproductive cycles and furthermore have a long life. These characteristics make Dogfish and Rays very prone to changes in the areas influenced by fishing, and we know that the catch of elasmobranchs in many fisheries has increased or fallen due to the mortality caused by fishing activities (ICES, 1995; Pratt and Gruber, 1990; Sánchez, Olaso and Goñi, 1998). For this reason, the consequences of the marine protected areas on elasmobranchs are obvious.

Regrettably the lack of information available concerning biomass, food habits, production, fisheries, etc. of the small deep water sharks that inhabit the break shelf (*Deania calceus*, *Etmopterus spinax*, *Scymnodom ringens*, *Centroscymnus* sp., *Dalatias licha*, etc.) have hinder us to create another trophic group separated of Dogfish. The existence in the study area of a longline fishery targeting these species and the particularities of this important group of elasmobranchs, which are very sensitive to the fishing pressure, requires that a research effort must be done in order to estimate its actual status and establish the possible management measures. On the other hand further studies should be promoted in order to improve the estimates of biomass and mortality of Rays and Dogfish groups to improve the estimations of the model.

Conclusions

The Cantabrian Sea ecosystem, because of its particular characteristics (grounds types, primary production mechanisms, trophic net, artisanal fisheries, etc.), with a notable importance of the demersal and benthic domains, is very prone to the presence of demersal and benthic elasmobranchs.

The capacity of Dogfish to survive long periods of emersion and consequently to be alive after being discarded, together with the advantage of feeding on discards as well as in an very exploited area provides this species with a lot of adaptive benefits.

The new control made by policy measures on trawlers working illegally on grounds at less than 100 m, and the settlement from 1993 in certain areas anti-trawling devices (artificial reefs) has caused a notable recovery of population of Dogfish and Rays.

The explanation of the main causes of the elasmobranchs increase in the last years can be a decrease in the fishing mortality originated by the reduction of the trawl effort.

In an ecosystem heavily exploited by multispecific fisheries, as is the case of the Cantabrian Sea, the present management system based on TACs and quotas regimes, with a very low number of species under assessments, is not suitable to sustain the elasmobranchs species. A management measure based on the control and reduction of the fishing effort and the establishment of certain areas closed to some fisheries would be a better approach for a global management in the ecosystem context.

The Ecopath model (and the recent expansions Ecosim and Ecospace) can be a valuable tool for understanding the ecosystem functioning and for the design of ecosystem-scale adaptive management experiments. Further research is required in order to improve input data and to sustain or diminish the results presented in this preliminary model. Specially, the limited availability of parameter estimates of some fish groups (i.e. deep water sharks) and the main invertebrate groups of the Cantabrian Sea on an annual basis reflects a need for such studies.

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References

Barquero, S., Cabal, J. A., Anadón, R., Fernández, E., Varela, M., Bode, A., 1998. Ingestion rates of phytoplankton by copepod size fractions on a bloom associated with an off-shelf front off NW Spain. *J. Plankton Res.* 20 (5), 957–972.

Bode, A., Casas, B., Fernández, E., Marañón, E., Serret, P., Varela, M., 1996. Phytoplankton biomass and production in shelf waters off NW Spain: spatial and seasonal variability in relation to upwelling. *Hydrobiologia* 341, 225–234.

Christensen, V., 1995. A model of trophic interactions in the North Sea in 1981, the Year of the Stomach. *Dana*, 11 (1), 1–28.

Christensen, V., Pauly, D., 1992. ECOPATH II – a software for balancing steady-state models and calculating network characteristics. *Ecol. Model.* 61, 169–185.

Christensen, V., Pauly, D., 1993. On Steady-State Modelling of Ecosystems. In: Christensen, V., Pauly, D. (Eds.), *Trophic Models of Aquatic Ecosystems*. ICLARM Conf. Proc. 26, pp. 14–19.

Fernández, A.,C. Rodríguez-Cabello, R. Gancedo, A. Punzón, I. Olaso, F. Sánchez and O. Cendrero, 2002. Overview of continental shelf elasmobranch fisheries in the Cantabrian Sea. *NAFO SCR Doc.* 02/115 (this Symposium).

ICES, 1995. Report of the Study Group of elasmobranch fishes. *ICES CM*: 1995/G:3, 88 pp.

ICES 2002a. Report of the study group on elasmobranch fishes. Copenhagen, 6-10. May 2002. *ICES C.M.* 2002/G:08 ref. ACFM.

ICES, 2002b. Working Group on the Assessment of Southern Shelf Demersal Stocks. *ICES CM* 2002/ACFM:05.

ICES, 2002c. Report of the Working Group on the Assessment of Mackerel, Horse Mackerel, Sardine and Anchovy. *ICES CM* 2002/ACFM: 06.

Kaiser, M.J. and Spencer, B.E. 1994. Fish scavenging behaviour in recently trawled areas. *Marine Ecology Progress Series*, 112: 41-49.

Olaso, I., 1990. Distribución y abundancia del megabentos invertebrado en fondos de la plataforma Cantábrica. *Publ. Espec. Inst. Esp. Oceanogr.* 5, 128 pp.

Olaso, I., F. Sánchez, C. Rodríguez-Cabello and F. Velasco, 2002. The feeding behaviour of some demersal fish species in response to artificial discard. *Sci. Mar.*, 66 (in press).

Olaso, I., Velasco, F., Pérez, N., 1998. Importance of blue whiting (*Micromesistius poutassou*) discarded in the diet of lesser-spotted dogfish (*Scyliorhinus canicula*) in the Cantabrian Sea. *ICES J. Mar. Sci.* 55, 331–341.

Olaso, I., F. Velasco, F. Sánchez, A. Serrano, C. Rodríguez-Cabello and O. Cendrero, 2002. Trophic relations of lesser spotted dogfish (*Scyliorhinus canicula*) and black mouth dogfish (*Galeus melastomus*) in the benthic and demersal communities of the Cantabrian sea. *NAFO SCR Doc*. 02/123 (this Symposium).

OSPAR., 2000. Quality Status Report 2000. Region IV – Bay of Biscay and Iberian coast. OSPAR Commission, London, 134 + xiii pp.

Pauly, D., Christensen, V., 1995. Primary production required to sustain global fisheries. *Nature* 374, 255–257.

Pérez, N., Pereda, P., Uriarte, A., Trujillo, V., Olaso, I., Lens, S., 1996. Descartes de la flota española en el área del ICES. *Datos y Resúmenes. Instituto Español de Oceanografía*, Núm. 2, 142 pp.

Polovina, J. J., 1984. Model of a coral reef ecosystem I. The ECOPATH model and its application to French Frigate Shoals. *Coral Reefs* 3, 1–11.

Pratt, H., and J. G. Casey. Shark Reproductive Strategies as a Limiting Factor in Directed Fisheries, with a Review of Holden's Method of Estimating Growth-Parameters. In: *Elasmobranchs as Living Resources: Advances in the Biology, Ecology, Sistematics, and the Status of the Fisheries* (Toro Tanuchi editors). NOOA Tech. Report., 90, 97-109.

Rodríguez-Cabello, C., F. De la Gándara and F. Sánchez, 1998. Preliminary results on growth and movements of dogfish (*Scyliorhinus canicula*, Linnaeus, 1758) in the Cantabrian Sea. *Oceanologica Acta* 21,2, 363-370.

Rodríguez-Cabello, C., A. Fernández, I. Olaso and F. Sánchez, 2001. Survival of lesser-spotted dogfish (*Scyliorhinus canicula*, L.) discarded by trawlers. *ICES CM* 2001/N:06, 10 pp.

Sánchez, F., 1993. Las comunidades de peces de la plataforma del Cantábrico. *Publ. Espec. Inst. Esp. Oceanogr.* 13, 137 pp.

Sánchez, F., M. Blanco and, R. Gancedo, 2002. *Atlas de los peces demersales y de los invertebrados de interés comercial de Galicia y el Cantábrico. Otoño 1997-1999*. Ed. CYAN (Inst. Esp.Oceanogr.), 158 pp.

Sánchez, F., de la Gándara, F., Gancedo, R., 1995. Atlas de los peces demersales de Galicia y el Cantábrico, Otoño 1991–1993. *Publ. Esp. Inst. Esp.Oceanogr.* 20, 99 pp.

Sánchez, F., Gil, J., 2000. Hydrographic mesoscale structures and Poleward Current as a determinant of hake (*Merluccius merluccius*) recruitment in southern Bay of Biscay. *ICES J. Mar. Sci.* 57, 152–170.

Sánchez, F. and I. Olaso, 2001. Cantabrian Sea ecosystem model and fishery resources management. *Oceanographie du Golfe de Gascogne*, Ed. Ifremer, Actes Colloq., 31, 187-194.

Sánchez, F. and I. Olaso, 2002. Effects of fisheries on the Cantabrian Sea shelf ecosystem. In: "Placing Fisheries in their Ecosystem Context". *Ecological Modelling* (in press).

Sánchez, F., I. Olaso and R. Goñi, 1998. Changes in bottom trawl survey catch rates in dogfish (*Scyliorhinus canicula*) and Thornback ray (*Raja clavata*) in the Cantabrian sea between 1983 and 1997. In: Report of the Working Group of Ecosystem Effects of Fishing, *ICES CM* 1998/ACFM/ACME:1, Ref.:E:1, 263 pp.

Sánchez, F. and A. Serrano, 2002. Variability of groundfish communities of the Cantabrian Sea during the decade of the 1990s. *ICES Journal of Marine Science*, ICES Decadal Symposium, Edinburg-2001 (in press)

Shannon, L.J. and A. Jarre-Teichmann, 1999. A model of trophic flows in the Northern Benguela upwelling system during the 1980s. *South African Journal of Marine Science*, 21, 349-366.

Ulanowicz, R.E. and C. J. Puccia, 1990. Mixed trophic impacts in ecosystems. *Coenoses* 5 (1), 7–16.

Velasco, F., I. Olaso and A. Serrano, 2002. Alimentación de tres especies de la familia Rajidae en el sur del Golfo de Vizcaya. *Actas del 8º International Symposium on Oceanography of the Bay of Biscay*, Gijón, April 2002.

Walker, P., 1998. *Fleeting images: Dynamics of Ray populations in the North Sea*. Doctoral Thesis. 143 pp.

Walker, P., G. Howlett and R. Millner, 1997. Distribution, movement and stock structure of three ray species in the North sea and eastern English Channel. *ICES, J. of Marine Science*, 54: 797-808.

Walters, C., V. Christensen and D. Pauly, 1997. Structuring dynamic models of exploited ecosystems from trophic mass-balance assessments. *Reviews in Fish Biology and Fisheries*, 7, 139-172.

Walters, C., D. Pauly and V. Christensen, 1998. Ecospace: prediction of mesoscale spatial patterns in trophic relationships of exploited ecosystems, with emphasis on the impacts of marine protected areas. *ICES, C.M.* 1998. Theme Session (S), 22 pp.

Table 1. Main species of Elasmobranchs caught during the groundfish surveys ordered by biomass indices (kg/30 min. haul from 1997-1999 period) and percentage of participation in each trophic group in the trophodynamic model. The habitat preferences was used in the Ecospace spatial-temporal simulations.

		Abundance indices		Trophic group		
Family	Specie	Kg/haul	No./haul	Dogfish	Rays	Habitat preferences
SCYLIORHINIDAE	*Scyliorhinus canicula*	3.093	10.396	80%		Inner and middle shelf
RAJIDAE	*Raja clavata*	0.999	0.926		50%	Coastal and inner shelf
SCYLIORHINIDAE	*Galeus melastomus*	0.600	4.942	15%		Outer shelf
RAJIDAE	*Raja montagui*	0.565	0.664		30%	Coastal and inner shelf
SQUALIDAE	*Squalus acanthias*	0.369	0.085	X		Middle and outer shelf
RAJIDAE	*Leucoraja naevus*	0.183	0.298		15%	Inner and middle shelf
SQUALIDAE	*Deania calceus*	0.173	0.432	X		Shelf break
SQUALIDAE	*Etmopterus spinax*	0.099	1.758	X		Shelf break
RAJIDAE	*Raja undulata*	0.057	0.024		X	Coastal and inner shelf
SQUALIDAE	*Scymnodom ringens*	0.045	0.129	X		Shelf break
MYLIOBATIDAE	*Myliobatis aquila*	0.028	0.022		X	Coastal and inner shelf
SCYLIORHINIDAE	*Scyliorhinus stellaris*	0.022	0.123	X		Inner and middle shelf
HEXANCHIDAE	*Hexanchus griseus*	0.016	0.010	X		Middle and outer shelf
TORPEDINIDAE	*Torpedo marmorata*	0.013	0.009		X	Coastal and inner shelf
TRIAKIDAE	*Galeorhinus galeus*	0.001	0.004	X		Inner and middle shelf
TRIAKIDAE	*Mustelus mustelus*	0.001	0.004	X		Inner and middle shelf
RAJIDAE	*Raja brachyura*	0.000	0.004		X	Coastal and inner shelf
RAJIDAE	*Leucoraja circularis*	0.000	0.002		X	Inner and middle shelf

Table 2. Input values (in italics) and estimates of some parameters in the balanced trophodynamic model of 1994 for each trophic group. TL = Trophic level, PB = Production/Biomass ratio, QB = Consumption/Biomass ratio and EE = Ecotrophic efficiency. Biomass, PB, Food intake, Flow to detritus and Catches (landings+discards) are expressed in t·km^{-2}.

	Group name	TL	Biomass	PB / year	QB / year	EE	Food Intake	Flow to detritus	Catches	Fishing mortality	Natural mortality
1	Tuna	4.7	*0.384*	*0.82*	*9.50*	0.85	3.65	0.76	*0.27*	0.70	0.12
2	Large hake	4.7	*0.876*	*0.53*	*3.90*	0.79	3.42	0.78	*0.37*	0.42	0.11
3	Small hake	4.4	*0.185*	*0.80*	*6.50*	0.91	1.20	0.25	*0.08*	0.45	0.35
4	Anglerfish	4.8	*0.746*	*0.38*	*1.90*	0.56	1.42	0.41	*0.16*	0.21	0.17
5	Megrim	4.2	*0.237*	*0.66*	*3.00*	0.78	0.71	0.18	*0.09*	0.38	0.28
6	Large demersal fish	4.3	*2.115*	*0.60*	*2.70*	0.87	5.71	1.24	*1.08*	0.51	0.09
7	**Dogfish**	**4.0**	***0.330***	***0.25***	***2.50***	**0.42**	**0.83**	**0.22**	***0.04***	**0.11**	**0.15**
8	**Rays**	**3.8**	***0.210***	***0.30***	***2.20***	**0.61**	**0.46**	**0.13**	***0.04***	**0.18**	**0.12**
9	Benthic fish	3.6	*2.940*	*1.20*	*2.80*	0.87	8.23	2.09	*0.23*	0.08	1.12
10	Blue whiting	3.8	*16.415*	*0.48*	*5.30*	0.93	87.00	17.90	*1.50*	0.09	0.39
11	Small demersal fish	3.6	*15.040*	*1.20*	*6.40*	0.84	96.26	22.15	*0.20*	0.01	1.19
12	Horse mackerel	3.8	*14.771*	*0.32*	*4.30*	0.83	63.52	13.52	*1.95*	0.13	0.19
13	Mackerel	3.8	*11.486*	*0.43*	*4.60*	0.28	52.83	14.12	*1.57*	0.14	0.29
14	Anchovy	2.9	*2.832*	*1.98*	*9.13*	0.82	25.86	6.16	*1.24*	0.44	1.54
15	Sardine	2.8	*6.978*	*0.58*	*8.80*	0.60	61.41	13.92	*1.58*	0.23	0.35
16	Squids	4.4	0.929	*3.20*	*7.50*	*0.95*	7.23	1.55	*0.16*	0.17	3.03
17	Benthic cephalopods	3.8	1.072	*3.00*	*6.00*	*0.95*	6.70	1.44	*0.38*	0.35	2.65
18	Benthic invertebrates	2.9	6.564	*2.60*	*5.60*	*0.95*	38.72	8.25	*0.13*	0.02	2.58
19	Shrimps	2.8	8.263	*4.20*	*9.67*	*0.95*	81.63	17.76	*0.02*	0.00	4.20
20	Polychaetes	2.2	11.575	*4.80*	*12.00*	*0.95*	143.33	30.65	*0.08*	0.01	4.79
21	Other invertebrates	2.1	7.642	*2.50*	*6.50*	*0.95*	50.99	10.93	*0.25*	0.03	2.47
22	Zoopl suprabenthic	2.7	12.192	*16.00*	*32.00*	*0.95*	392.36	87.84	*0.00*	0.00	16.00
23	Macrozooplankton	3.1	3.483	*18.00*	*38.00*	*0.95*	133.25	29.62	*0.00*	0.01	17.99
24	Mesozooplankton	2.2	*8.889*	*39.08*	*80.00*	0.99	711.12	144.25	*0.00*	0.00	39.08
25	Microzooplankton	2.1	3.973	*45.28*	*120.00*	*0.95*	477.71	104.36	*0.05*	0.00	45.28
26	Phytoplankton	1.0	*32.760*	*148.11*	-	0.21	0.00	3064.46	*0.00*	0.00	148.11
27	Discards	1.0	*2.400*	-	-	0.98	0.00	0.03	*0.00*	0.00	0.00
28	Detritus	1.0	*50.000*	-	-	0.13	0.00	0.00	*0.00*	0.00	0.00

Table 3. Estimates of prey overlap between megafaunal trophic groups in the Cantabrian Sea 1994 scenario.

GROUP NAME	Tuna 1	Large hake 2	Small hake 3	Anglerfish 4	Megrim 5	Large demersal fish 6	**Dogfish 7**	**Rays 8**	Benthic fish 9	Blue whiting 10	Small demersal fish 11	Horse mackerel 12	Mackerel 13	Anchovy 14	Sardine 15	Squids 16	Benthic cephalopods 17	Benthic invert. carniv. 18
1 Tuna	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2 Large hake	0.33	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3 Small hake	0.54	0.31	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4 Anglerfish	0.57	0.82	0.64	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5 Megrim	0.16	0.06	0.72	0.32	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-
6 Large demersal fish	0.19	0.45	0.57	0.57	0.68	1.00	-	-	-	-	-	-	-	-	-	-	-	-
7 Dogfish	**0.25**	**0.42**	**0.49**	**0.49**	**0.64**	**0.80**	**1.00**	**-**	-	-	-	-	-	-	-	-	-	-
8 Rays	**0.02**	**0.01**	**0.31**	**0.03**	**0.73**	**0.50**	**0.68**	**1.00**	-	-	-	-	-	-	-	-	-	-
9 Benthic fish	0.00	0.01	0.31	0.05	0.66	0.56	**0.69**	**0.81**	1.00	-	-	-	-	-	-	-	-	-
10 Blue whiting	0.05	0.07	0.41	0.10	0.29	0.12	**0.24**	**0.17**	0.31	1.00	-	-	-	-	-	-	-	-
11 Small demersal fish	0.01	0.01	0.36	0.01	0.31	0.14	**0.31**	**0.32**	0.47	0.96	1.00	-	-	-	-	-	-	-
12 Horse mackerel	0.11	0.15	0.51	0.22	0.34	0.25	**0.29**	**0.13**	0.28	0.90	0.87	1.00	-	-	-	-	-	-
13 Mackerel	0.22	0.27	0.31	0.24	0.08	0.16	**0.24**	**0.04**	0.17	0.80	0.77	0.86	1.00	-	-	-	-	-
14 Anchovy	0.00	0.00	0.03	0.00	0.01	0.00	**0.01**	**0.01**	0.02	0.29	0.29	0.46	0.48	1.00	-	-	-	-
15 Sardine	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	**0.00**	0.00	0.20	0.21	0.37	0.41	0.98	1.00	-	-	-
16 Squids	0.58	0.23	0.78	0.44	0.58	0.54	**0.48**	**0.22**	0.29	0.36	0.31	0.52	0.32	0.05	0.03	1.00	-	-
17 Benthic cephalopods	0.01	0.01	0.43	0.03	0.73	0.39	**0.60**	**0.90**	0.81	0.51	0.61	0.41	0.26	0.04	0.00	0.33	1.00	-
18 Benthic inv. carniv.	0.00	0.00	0.07	0.00	0.13	0.12	**0.13**	**0.24**	0.54	0.11	0.24	0.11	0.07	0.01	0.00	0.05	0.27	1.00

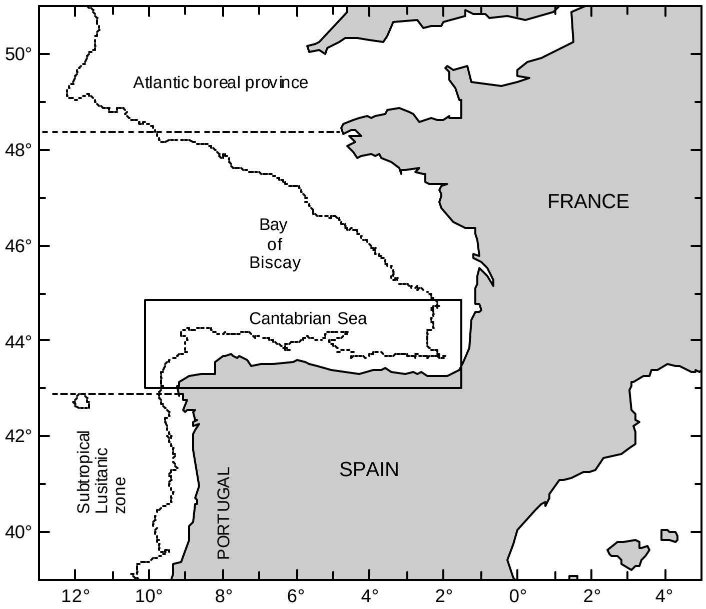

Fig. 1. The Cantabrian Sea area as defined in the ecosystem model.

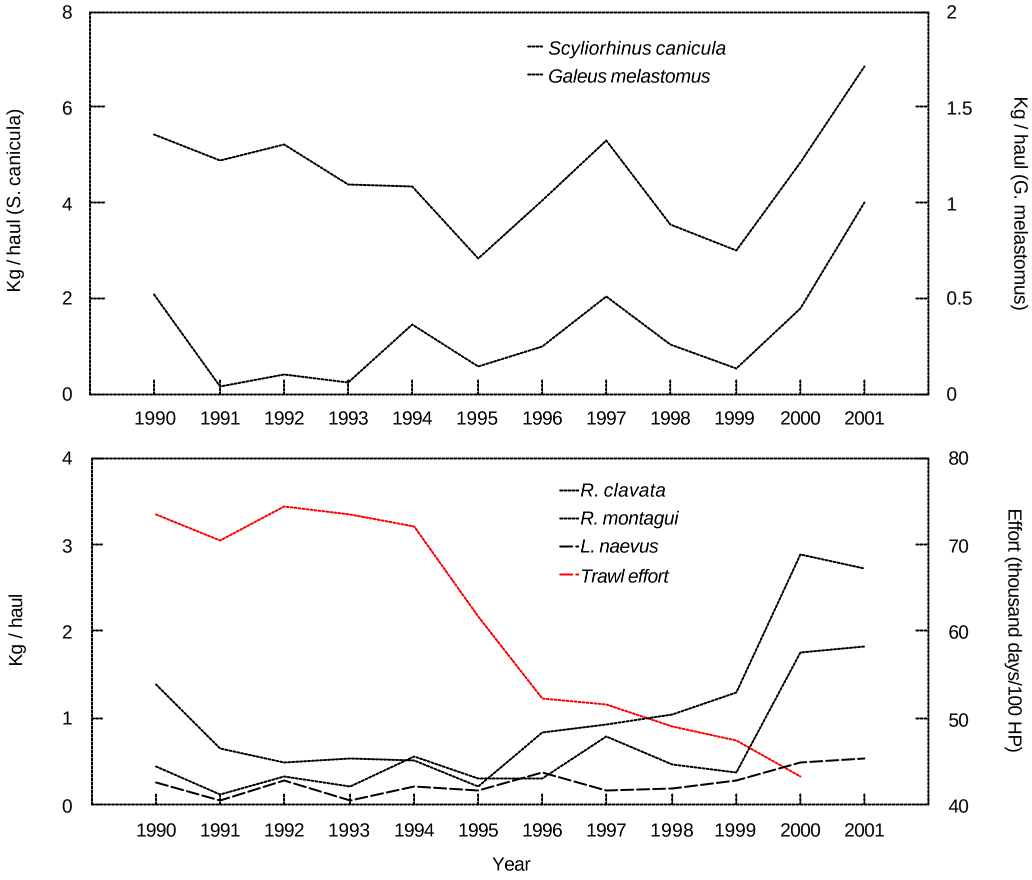

Fig. 2. Bottom trawl surveys biomass indices (kg/30 min. haul) of the main species of elasmobranchs and trawl fishery effort (thousand days by 100 HP) in the Cantabrian Sea.

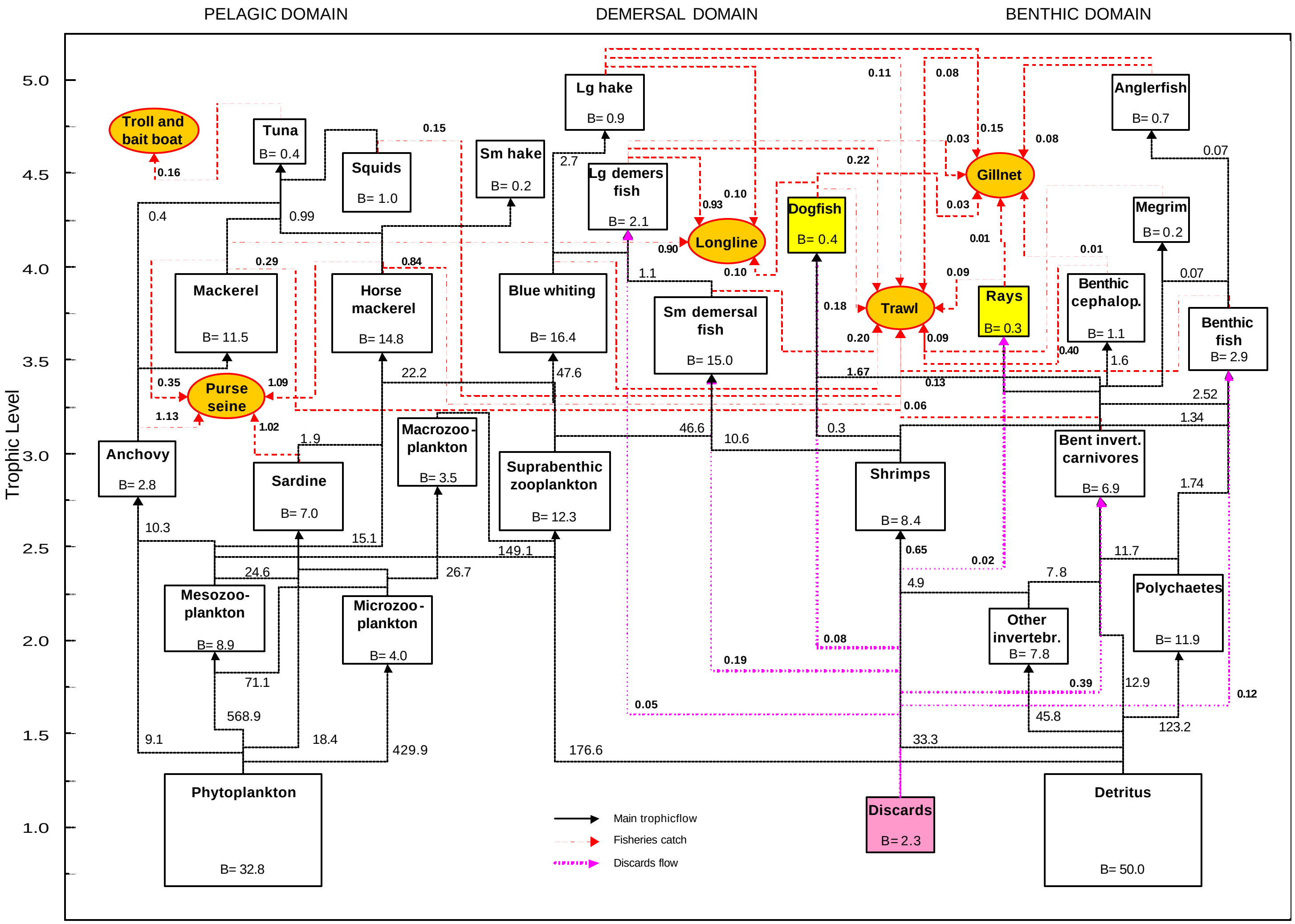

Fig. 3. Main trophic interactions in the Cantabrian Sea, 1994. The boxes are arranged on the y-axis after trophic levels, and to some degree on a pelagic to benthic scale on the x-axis. Only the main flows (trophics, catches and discards flows) are shown expressed in t·km^{-2}·year^{-1}, and the biomass of each trophic group (B) in t·km^{-2}. Minor flows, respiration and all backflows to the detritus are omitted. Each fishery is represented as ellipse (no biomass) in their trophic level. Elasmobranchs trophic groups are highlighted.

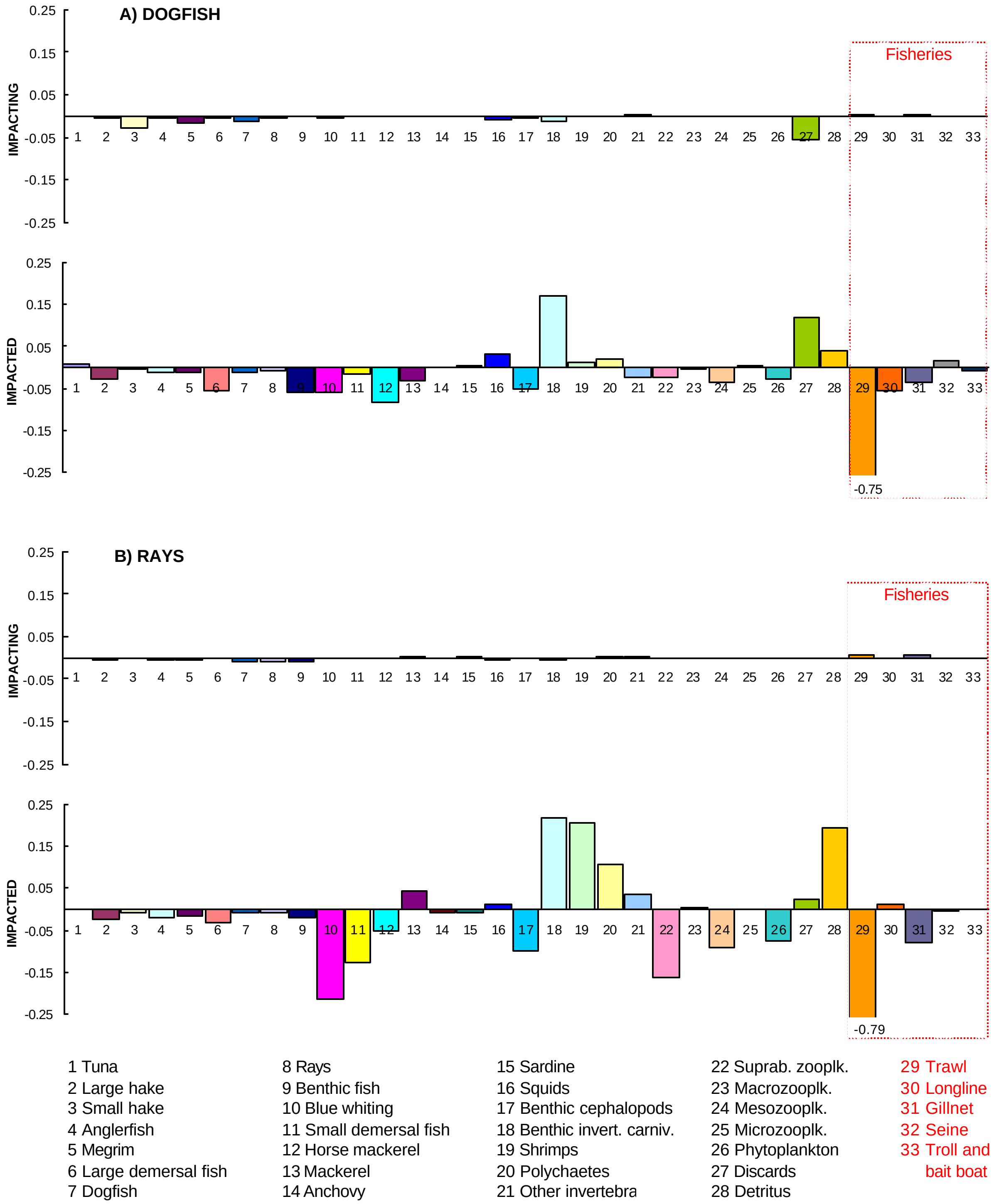

Fig. 4. Mixed trophic impacts using the Leontief matrix. The computed impacts are relative on a scale from –1 to 1, where 0 indicates no impact, but comparable between groups. The bars quantify the direct and indirect trophic impacts that the groups Dogfish (A) and Rays (B) have on the groups listed at the bottom and viceversa.

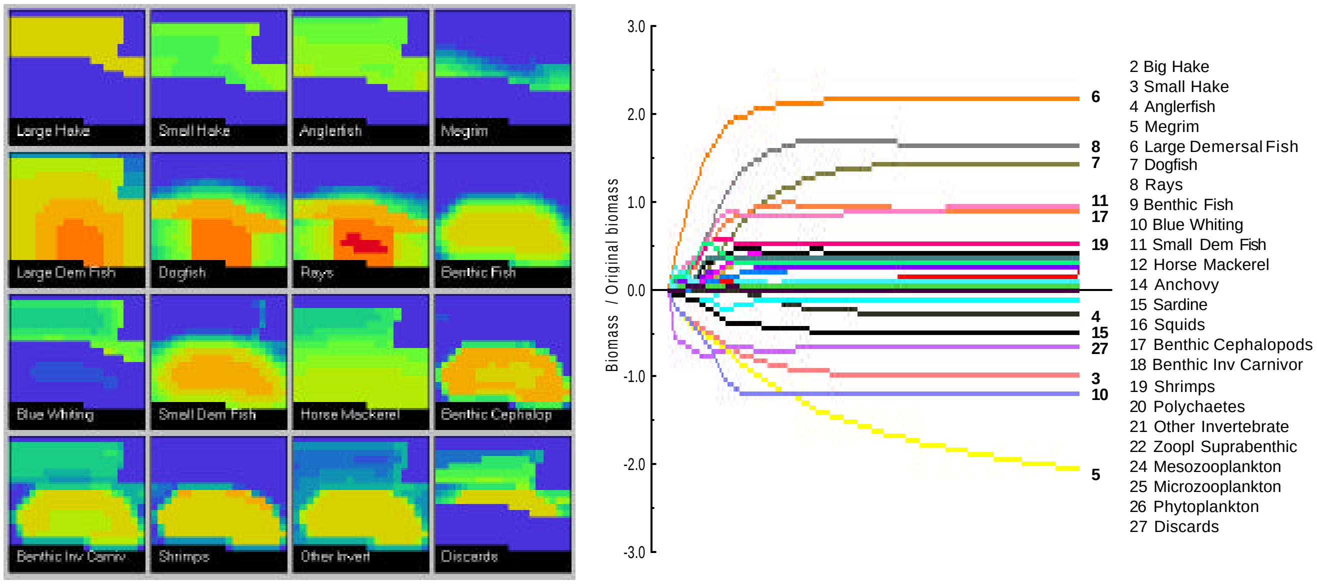

Fig. 5. Five years Ecospace simulation using the effect of trawl closed area in the central Cantabrian Sea scenario. Biomass of different trophic groups are relative to the start situation.

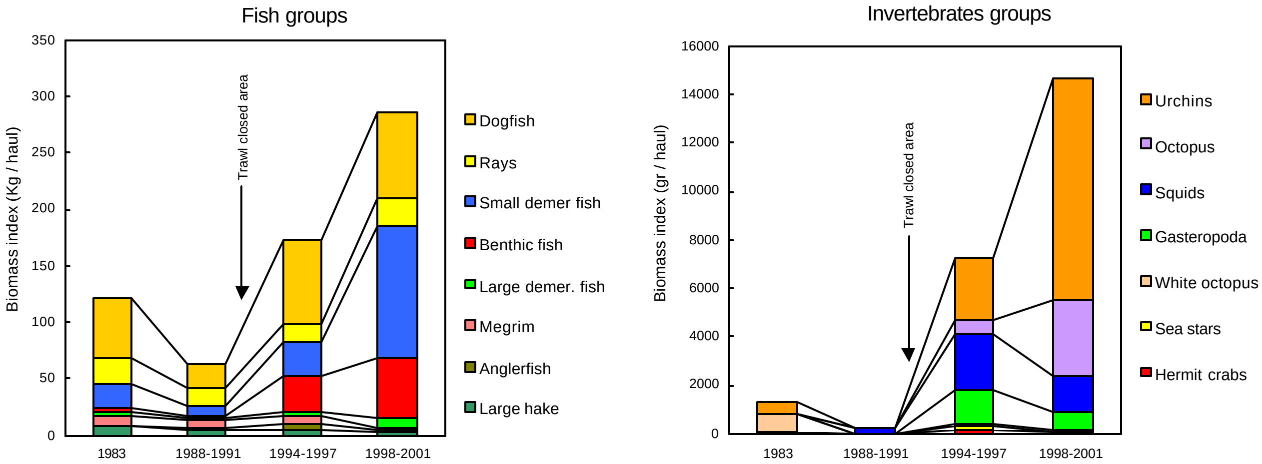

Fig. 6. Bottom trawl survey indices of main fish (Kg/haul) and invertebrates (gr/haul) groups in the Llanes trawl closed area. The period 1983-1991 was before closure and the period 1994-2001 was after closure of trawlers operations.