ICES Journal of
Marine Science

ICES Journal of Marine Science (2019), doi:10.1093/icesjms/fsz231



# History of the Spanish demersal fishery in the Atlantic and Mediterranean Seas

Antonio Punzón [1]*, Lucia Rueda[2], Augusto Rodríguez-Basalo[1], Manuel Hidalgo [3], Pere Oliver[3], José Castro[4], Juan Gil[2], Antonio Esteban[5], Luis Gil de Sola[6], and Enric Massutí[2]

[1]Instituto Español de Oceanografía, P.O. Box 240, Santander 39080, Spain
[2]Instituto Español de Oceanografía, P.O. Box 2609, Cádiz 11006, Spain
[3]Instituto Español de Oceanografía, P.O. Box291, Palma de Mallorca 07015, Spain
[4]Instituto Español de Oceanografía, P.O. Box 1552, Vigo 36200, Spain
[5]Instituto Español de Oceanografía, P.O. Box 22, San Pedro del Pinatar (Murcia) 30740, Spain
[6]Instituto Español de Oceanografía, P.O. Box 285, Fuengirola (Málaga) 29640, Spain

*Corresponding author: tel: +34 942 29 17 16; e-mail: antonio.punzon@ieo.es

Punzón, A., Rueda, L., Rodríguez-Basalo, A., Hidalgo, M., Oliver, P., Castro, J., Gil, J., Esteban, A., Gil de Sola, L., and Massutí, E. History of the Spanish demersal fishery in the Atlantic and Mediterranean Seas. – ICES Journal of Marine Science, doi:10.1093/icesjms/fsz231.

Received 7 October 2018; revised 4 November 2019; accepted 8 November 2019.

Long fisheries time series allow the review of baselines and inform our knowledge of past events that have conditioned the recent history of the stocks. In this study, we investigated trends in fisheries landings data for the most representative Atlantic and Mediterranean demersal fisheries off the Spanish Iberian Peninsula and the Balearic Islands (1933–1986). The aim was to analyse the evolution of demersal species exploitation and detect changes in landings and fishing tactics. Ten species were selected, which included teleosts, crustaceans, and cephalopods. Results indicated a decrease in Landings Per Unit of Capacity (LPUC) in six of the species examined. While in the Atlantic the process of substitution or incorporation of new species to the fisheries occurs progressively, in the Mediterranean this incorporation occurs simultaneously for many of the species. Four main fishing tactics (landing pattern obtained from the classification analysis of landings per species) were identified. Geographically nearby and connected regions developed similar fishing tactics to each other, and also changed over time. While the fleets from isolated regions were more specialized, and only carrying out one fishing tactic during the study period. Improvements in LPUC with the implementation of new technology and legislative and management measures were not observed.

**Keywords:** exploitation pattern, historical ecology, Iberian Peninsula, landing per unit of capacity, time series

## Introduction

Fish stocks fluctuate naturally over temporal scales (Cushing, 1982; Brander, 2010). Such fluctuations are induced by a broad range of biological, ecological, and physical processes (Stenseth *et al.*, 2002; Rouyer *et al.*, 2008), climate forcing being one of the main drivers of variation (Perry *et al.*, 2005; Stige *et al.*, 2010). In addition, fishing exploitation of marine living resources is known to strongly alter the structure of marine populations (Jackson *et al.*, 2001; Pauly *et al.*, 2002; Christensen *et al.*, 2003), influencing their temporal and spatial dynamics and, indirectly, altering their sensitivity to climate change (Planque *et al.*, 2010). This triggers important consequences not only for the economy of fishing activities (Sumaila *et al.*, 2011), but also because fishing is one of the main sources of animal proteins for a significant proportion of the human population (FAO, 2016a).

Short-term data sets provide more reliable and complete information to assess stock status compared to many longer time series collected primarily for government monitoring or statistical purposes. Nevertheless, such short data sets provide baseline information from populations that may be already under intense fishing exploitation levels, leading to inappropriate reference points for biological assessment (Pauly, 1995). In addition, the period of time covered by most ecological studies fails to contain the life span of long-living species and/or shifts in oceanographic regimes (Jackson *et al.*, 2001). Long-term data sets are often the only source of information on fisheries from pre-exploitation or low exploitation levels. Therefore, to achieve an accurate evaluation of the present state of marine resources, more recent observations need to be compared with historical records (Barrett *et al.*, 2004; Engelhard *et al.*, 2016; Thurstan *et al.*, 2016). Within this context, the scientific discipline of marine historical ecology has emerged, aiming to analyse the interactions between human activities and marine communities through time (Engelhard *et al.*, 2016).

Although many studies have focused on the analysis of fisheries time series (e.g. Fiorentini *et al.*, 1997; Jennings *et al.*, 1999; Caddy and Surette, 2005; Erzini, 2005; Rouyer *et al.*, 2008, Fortibuoni *et al.*, 2017), few have been conducted in Spanish waters (Lloret *et al.*, 2001; Quetglas *et al.*, 2013; Coll *et al.*, 2014), one of the most important fishery grounds in European waters (https://www.eurofish.dk/spain). Here, we analysed historical data (1933–1986) from landings of the most important commercial demersal species in weight and economic value, and number of boats of Spanish fisheries in Atlantic and Mediterranean waters along the Iberian Peninsula and the Balearic Islands.

Our main goal is to understand the historical evolution of these Spanish Atlantic and Mediterranean fisheries by means of the analysis of the landings per unit of capacity (LPUC), which provide a measure of the landings accounting for the number of boats. In addition, the influence of legislative measures and technological improvements related to the fishing industry on the LPUC is also investigated. We applied a multi-method approach to (i) analyse the effect of historical events on LPUC; (ii) investigate the evolution of species exploitation and detect the long-term trend of species LPUC; (iii) identify potential synchronies between regions, and finally; (iv) determine the evolution of fishing tactics (landing pattern obtained from the classification analysis of landings per species).

## Material and methods

### Data source

Data were obtained from the Spanish annual demersal landings statistics between 1933 and 1986, which provided the same source of information for the full-time period. This information was compiled and published in the two book collections "Estadística de Pesca" [Fishing Statistics] (1933–1972) and "Anuario de Pesca Marítima" [Yearbook of Maritime Fishing] (1973–1986), the modification of the names was due to changes in the Ministries during these years. The data were not collected by the ministries for scientific purposes; the aim of such compilation of landings and effort was to obtain national statistics on fishing activities. After this period, due to the entry of Spain into the European Union, compilation of fisheries information changed and with it the standardization of the data; therefore, data were only used until 1986.

From the total demersal species present in the annual landings data, ten species or groups of species were selected. The selection criteria was (i) that at present they are target species of the demersal fisheries, (ii) that they were recorded as landed throughout the time series studied, and (iii) nowadays working groups exist, which include these demersal species as targets for data collection due to their commercial interest. These commercial categories corresponded to hake (*Merlucciusmerluccius*), blue whiting (*Micromesistius poutassou*), red mullets (*Mullus* spp.), horse mackerels (*Trachurus* spp.), blackspot seabream (*Pagellus* spp.), megrims (*Lepidorhombus* spp.), monkfish (*Lophius* spp.), shrimps (mainly *Parapenaeus longirostris* in the Atlantic and *Aristeus antennatus* in the Mediterranean), Norway lobster (*Nephrops norvegicus*), and octopus (mainly *Octopus vulgaris*). Information on the annual number of fishing vessels was also compiled to account for a measure of fishing capacity throughout the study period. In the annual landing statistics, the data are split into coastal and long-distance fleets. For this article, the data from the coastal demersal fleet were used, which includes landings from fishing grounds on the national continental shelf and catches that occur mainly near the landing harbour. Data on both landings and vessels were disaggregated from the official statistics into the following seven geographical regions along the Spanish coasts: *Cantabrica*, and *Noroeste* on the northern Atlantic coast; *Suratlantica* on the southern Atlantic coast; and *Surmediterranea*, *Levantina*, *Tramontana*, and *Balear* along the Mediterranean coast (Figure 1).

Landings were compiled per species, year, and region. Although the landings data do not take into account discards, in our article, most of the results are based on trends and, as we can see for the Mediterranean and Atlantic sea in Pauly and Zeller (2016), the trends of the time series with or without discards estimations do not change substantially. The number of demersal fishing vessels was available per harbour within the region and year. There was no information on the number of fishing boats from 1964 to 1972; hence, the number of fishing vessels per region for those years was estimated as the average between the number of fishing boats in the years before and after this period. Annual LPUC for each species and region was calculated as follows:

$$LPUC_{ijt} = {}^{L_{ijt}}/_{n_{jt}},$$

where $L_{itj}$ is the total landings in tonnes for species $i$ in region $j$ during year $t$; and $n_{jt}$ is the total number of fishing boats in region $j$ during year $t$.

### Data analysis

#### *Effect of historical events on LPUC*

With the aim of analysing the effect of socio-economic and technological events on LPUCs, Classification and Regression Trees (CARTs) were performed (Breiman *et al.*, 1984). CARTs produce decision trees to display class memberships by recursively partitioning heterogeneous data into subsets (also called classes, groups, or nodes) by means of a series of binary splits (Pesch *et al.*, 2008). This statistical technique is adapted to account for non-additive behaviour; therefore, variable interactions are automatically included (Breiman *et al.*, 1984; Pesch *et al.*, 2008). In our study, the target variable was LPUC and the predictors were, respectively, year, socio-economic, and technological aspects treated as presence/absence data (Supplementary Table S1). The year was used to represent the behaviour of LPUC data series itself. In the case of technological aspects, we used those whose implementation was relatively easy in the sense that no important modifications on the boats were needed, so they could reach the fleet in a moderately short time. Thus, the year of introduction considered was the moment it reached the highest rate of implementation or covered nearly half of the fleet, and the period of greater influence considered was 15 years from the year that the innovation was adopted by half of the fleet. While we recognize that technological innovations continue to influence catches after a 15-year period, after the

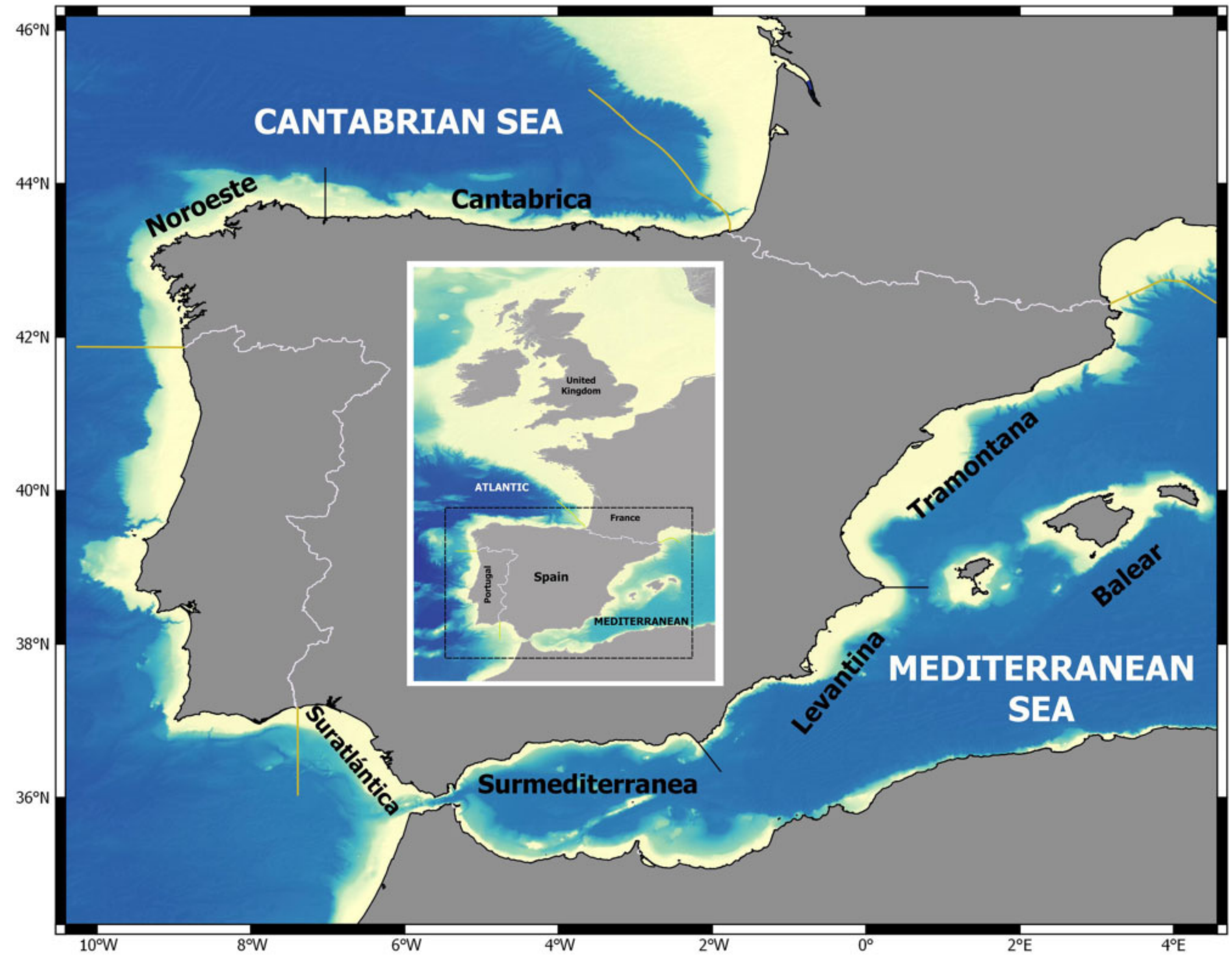


**Figure 1.** Study area showing the seven geographical regions considered in Spanish annual landings statistics.

fleet has incorporated the technological advance (>80% of the fleet; López-Losa, 2000; Sinde *et al.*, 2005) its influence is no longer readily detected. To identify possible trends within these 15 years, we considered separately each 5-year period.

### *Evolution of species exploitation*

With the aim of displaying the evolution of the exploitation of demersal species by region, a Traffic Light approach was used (Caddy and Surette, 2005). The range of landings, between 0 and the maximum landing of species $i$ in a region $j$, was split into four quartiles. Each quartile is represented by a different colour, which is assigned to each year of the time series according to the annual landings. If the landings of a specific year are within the first quartile the corresponding colour is red, the second quartile is represented with yellow, the third with green and, finally, the fourth quartile with the highest landings of the time series for a specific region is symbolized with blue. From the 10 chosen species, we only included the species that accounted in each region for over 1% of landings. Furthermore, years when 50% of cumulative landings were reached for each species in each region were identified.

To visualize the general long-term trend in the LPUC data series, locally weighted regressions (LOESS) were fitted by species and region (Cleveland *et al.*, 1992; Zuur *et al.*, 2007) and the mean value of the smoothing curves was calculated. LOESS smoothers fit a polynomial surface, determined by one or more numerical predictors, using local fitting by applying weighted regressions. That is, the fit of each point is made using points in a weighted neighbourhood distance ($\alpha$), which was set at 1 to capture the general trend in our series (Zuur *et al.*, 2007).

### *Synchrony between regions*

In order to determine which regions showed similar LPUC patterns through time, we applied principal component analysis (PCA) correlation bi-plots (Legendre and Legendre, 1998; Zuur *et al.*, 2007) on the time series of the LPUC for each species. The variables used for the analysis were the annual LPUCs in each region and a PCA was conducted for each species. The plots represent the best linear combinations between the regions for the LPUCs taking into account the temporal component (year of the landings). This allows for clear visualizations of the relationships between regions overtime for each species.

### *Evolution of demersal fishing tactics*

There are many definitions in fisheries science of "fishing tactics" (Pelletier and Ferraris, 2000), all of them are associated with the landing composition by area and gear. In our case, we lack information on the type of demersal gear used, hence "fishing tactic" was defined as each landing pattern obtained from the classification and ordination analysis of landings per species, region, and year (Struyf *et al.*, 1996; Punzón *et al.*, 2010). To standardize the information, the specific composition of landings per region and year was expressed as a percentage with respect to the weight of total landings for that year (Punzón *et al.*, 2010). For classification of landing composition by region and year in fishing tactics, the non-hierarchical cluster technique Partition Around Medioids (Kaufman and Rousseauw, 1986) was applied. Silhouette Width was used to select the number of groups, which according to Kaufman and Rousseauw (1986) can be identified from the following four levels of the Overall Silhouette Coefficient (OSC): consistent pattern (0.71–1.00), reasonable pattern (0.51–0.70), weak pattern (0.26–0.50), and no pattern (<0.26). The Partial Silhouette Coefficient (PSC) was also calculated to estimate homogeneity within each group and heterogeneity with respect to the other groups. Species typifying each cluster group were determined using a SIMPER analysis (similarity percentages) obtained from a Bray–Curtis similarity matrix (Clarke and Warwick, 1994). A correspondence analysis (CA) was used to evaluate the different associations between variables (species), characterizing the combinations between year and region and their affinities (Gordon, 1999). These results also contribute to the interpretation of the final results obtained using the classification technique.

## Results

Total landings showed different patterns in the two investigated regions (Figure 2). A continuous upward trend reaching maximum values during the decade of the 1970s and decreasing afterwards was observed in the Atlantic series. On the other hand, landings in the Mediterranean did not show a clear pattern, with a maximum in 1958 and two other periods with high landings at the beginning and end of the time series. The lowest values occurred during the 1950s and in the mid-1970s, both coinciding after increases in the Atlantic series. The two extreme observations in the Mediterranean, the maximum at the end of the 1950s and the minimum of the 1970s, can be explained by an increase in landings of horse mackerel and a decrease in landings of blue whiting and hake, respectively (Supplementary Figures S1 and S2). Such variations in the Mediterranean time series could also be due to data collection issues of which we are not aware. In both seas, the increase in number of boats was constant throughout the time series (Figure 2).

### Effect of political, technological, and administrative events on LPUC

While the Second World War was taking place in Europe during the mid-1940s, Spain had just finished a Civil War that sank the country into a dictatorship. This period could be divided into two different phases with distinct effects on the fishing industry (Figure 2). The first is the establishment of the autarchy, between 1939 and 1959, when borders were closed and national industry was promoted. The second is the opening up phase, which started with the stabilization plan in 1959 and the law of protection and renewal of the fleet in 1961. This second phase started with extensive boat building endorsed by credits and external assistance promoted by this law in 1961, and ended with the end of the dictatorship in 1975. Disregarding this post war increase in landings, the rise in captures was significant over the 1950s, partly due to the financing and protection of the fleet, but also due to the development of the echo sounder that was quickly implemented during this decade (Sinde *et al.*, 2005). Coinciding with the beginning of the decline in total landings, the EEZ (Economic Exclusive Zone) came into force in 1977. This event exclusively affected the north Atlantic coast fishing fleet.

With LPUCs (Atlantic and Mediterranean) as the response variable and year as first explanatory variable, a four-leaf tree was shaped with three splits in years 1951, 1960, and 1972 (Figure 3a); with the first significant split representing >77% of the variance explained; the second, 10%; and the third, 3%. Taking legislative and socio-economic aspects into account as explanatory variables, a three-leaf tree was obtained (Figure 3b), with the implementation of the EEZ and total allowable catches (TACs), and the Law of 1961 as the most important factors. The variance explained by the first split was 32%, whereas the second one was 1%. Finally, when including technical aspects as explanatory variables, a four-leaf tree with three splits was obtained (Figure 3c), with the first two splits, Radar/Sonar and Nylon net, representing 36% and 18% of the explained variance, respectively, and just 1% for the Echo sounder split.

### Evolution of species exploitation and long-term trend

The temporal evolution of species exploitation revealed two differentiated patterns in general terms (Figure 4). In the Atlantic regions (*Cantabrica*, *Noroeste*, and *Suratlantica*), there were species with constant levels of landings throughout the series (e.g. hake, blackspot seabream, and horse mackerel), whereas others entered the fishery consecutively (Figure 4). The years when 50% of accumulated landings were reached were temporarily related to the beginning of their exploitation. In contrast, in the Mediterranean regions (*Surmediterranea*, *Tramontana*, *Levantina*, and *Balear*) there were some species with permanently low levels of exploitation throughout the series (e.g. horse mackerel in *Surmediterranea* and *Levantina* regions); species with constant levels of landings (e.g. red mullet); and species that entered the fishery later, reaching their maximum landings in the last decade of the time series. The most similar patterns were found between adjacent regions: *Cantabrica* and *Noroeste* in the Atlantic and *Tramontana* and *Levantina* in the Mediterranean.

From the species point of view, three main patterns were identified. First, species exploited since the beginning of the time series and common to most regions, such as horse mackerel, hake, blackspot seabream, and Norway lobster (except in *Cantabrica* and *Noroeste* regions). These species generally reached 50% of their accumulated catches at the beginning of the series. A second pattern corresponded to species that had relatively little importance at the beginning of the series and entered the fisheries gradually later on, reaching 50% of landings at the end (e.g. blue whiting and monkfish). And third, species whose landings were more abundant in particular regions, reaching their cumulative 50% of landings at the beginning of the series. This is the case of red mullet in the *Balear* region; shrimp and Norway lobster in the Mediterranean and *Suratlantica* regions; and megrims in the northern Atlantic coast regions.

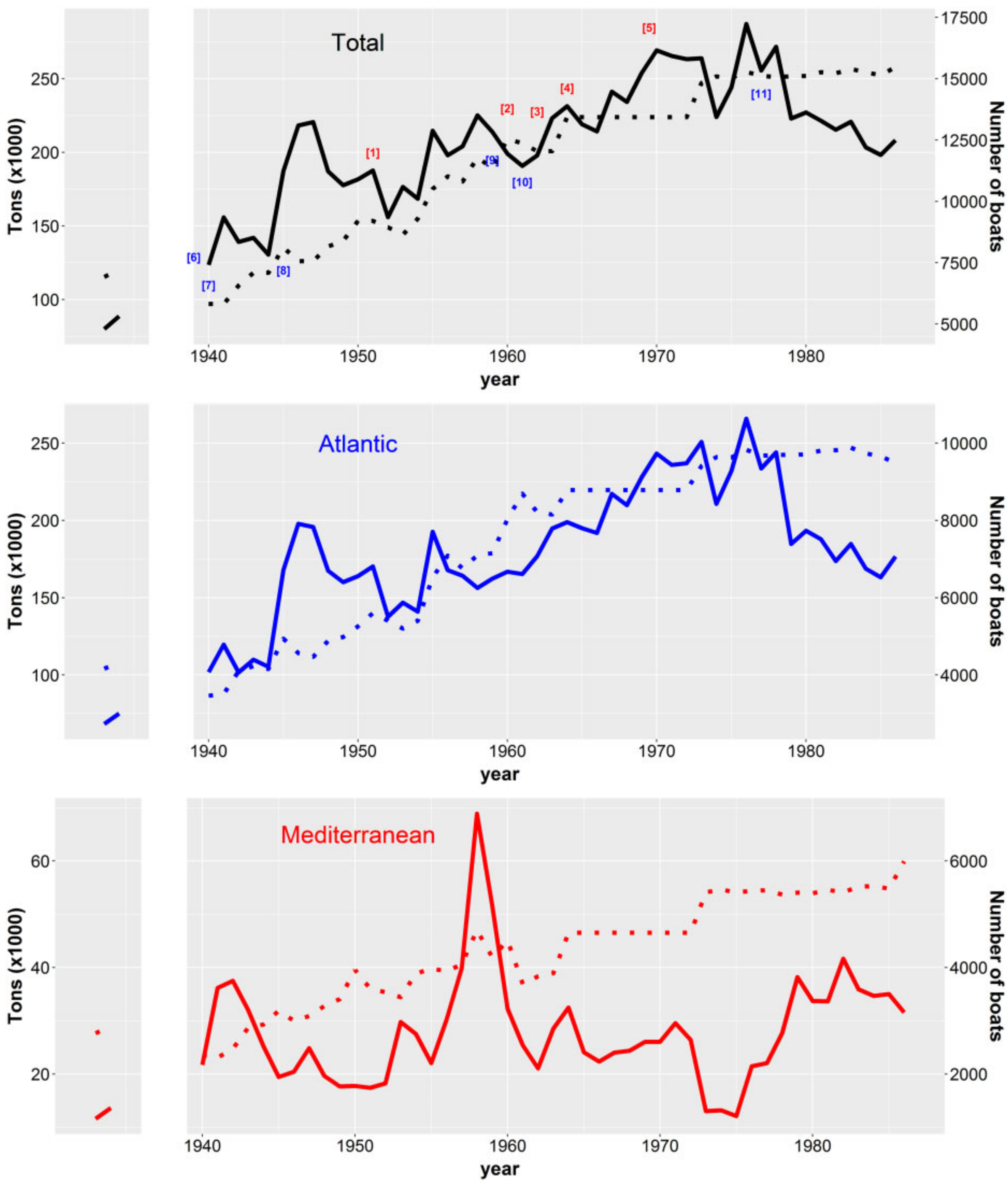


**Figure 2.** Landings (tonnes; solid line) of the ten most important fishing demersal species or group of species in Atlantic and Mediterranean waters along the Iberian Peninsula and the Balearic Islands, and number of boats (dotted line) per year, obtained from the Spanish annual landings statistics between 1933 and 1986. Numbers in top graph represent external factors that may influence landings. Technical innovations are represented in red: [1] Echosounder; [2] Nylon net; [3] Diesel engine; [4] Hauler; and [5] Radar/Sonar. Socio-economic and legislative factors in blue are: [6] Post war, autarchy, and beginning of Second World War (WW II); [7] end of WW II; [8] Ship financing, industrial protection, and Spanish fleet reconstruction laws of 1939 and 1941; [9] Stabilization Plan and End of autarchy; [10] Law of Protection and renewal of the fleet (Law of 1961); and [11] 200 miles EEZ (Economic Exclusive Zone), TACs, and Quotas (González-Laxe, 1987; Eiroa del Rio, 1997; López-Losa, 2000; Sinde *et al.*, 2005).

Results from the mean LOESS calculated per species showed different long-term trends in LPUC with some species decreasing, whereas others displayed a slight increase throughout the series (Figure 5). Four of the seven species of fishes (hake, red mullet, horse mackerel, and blackspot seabream) and the two crustaceans (shrimp and Norway lobster) revealed a general decreasing

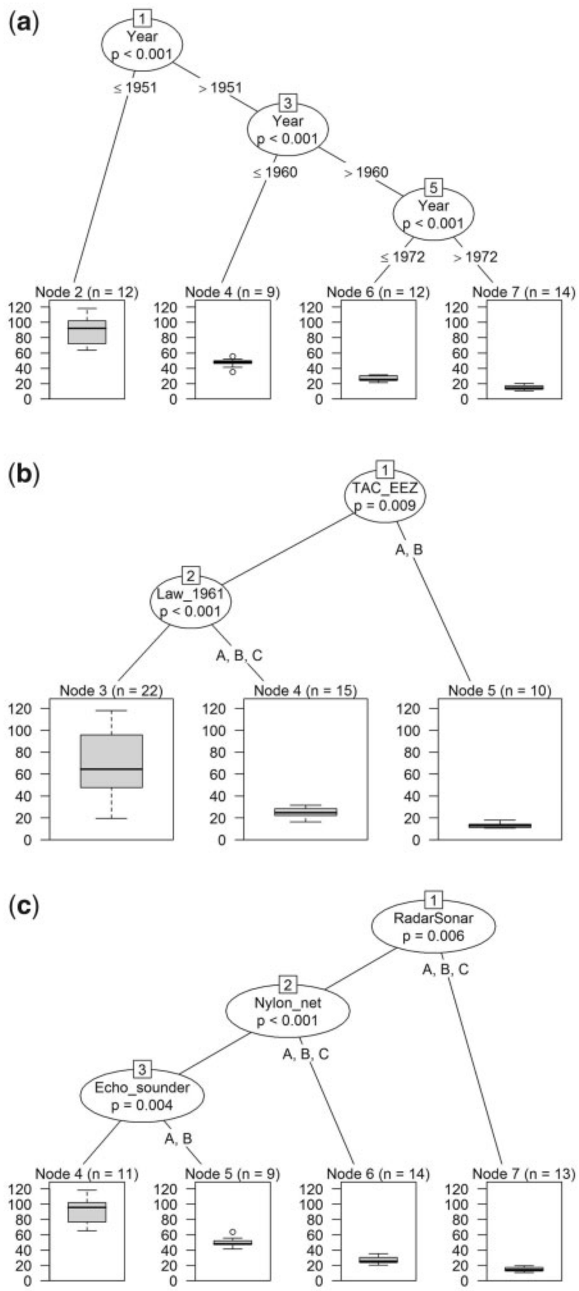


**Figure 3.** Regression tree analyses on total LPUCs investigating the effect of year (a), socio-economic and legislative factors (b), and technical innovations (c). Box plots of the distribution of the LPUCs are shown for each of the leaves (terminal nodes). *P*-value and inclusion order are labelled in each node.

long-term trend for all regions. Meanwhile, LPUCs of megrim, monkfish, and octopus showed an overall slight increase, whereas LPUC of blue whiting remained fairly constant over regions. Though these patterns in the general long-term trend were similar between Atlantic and Mediterranean regions two differences emerged (Supplementary Figure S3). Blue whiting and octopus displayed contrasting trends being the LPUC lower at the beginning of the series in the Atlantic regions compared to the Mediterranean ones, higher in the mid-years of the study and decreasing in the final years while increasing again in the Mediterranean.

## Synchrony between regions

The PCA showed similar variations throughout the LPUC time series for some species and regions (Figure 6). The percentage of variation explained by the PCA for each species ranged from 58% to 76%.

For hake and red mullet, LPUCs were highest in most regions around the 1940s, especially in the Atlantic regions and the *Surmediteranea* region. The eastern Mediterranean regions *Tramontana* and *Levantina* were also alike, whereas in the *Balear* region LPUCs for hake were abundant later on, during the 1970s and 1980s.

LPUCs of blue whiting, monkfish, and octopus were abundant in most regions during the 1970s and 1980s, with some exceptions. They were higher in *Cantabrica* and *Noroeste* during the 1950s and 1960s for blue whiting; in *Surmediterranea* and *Suratlantica* during the 1960s for monkfish; and in Noroeste during the 1960s for octopus. Some of the Mediterranean regions (*Tramontana* and *Levantina*) showed similarities for the three species; as well as the southerly regions (*Surmediterranea* and *Suratlantica*) for blue whiting; northerly regions (*Noroeste* and *Cantabrica*) for monkfish; and *Cantabrica*, *Suratlantica*, and *Levantina* regions for octopus.

Horse mackerel, blackspot seabream, and Norway lobster did not show clear relationships in the temporal evolution of LPUCs among most of the regions. Abundant values for horse mackerel were obtained in the *Suratlantica* region around the 1950s and in the *Cantabrica* region during the 1970s. For blackspot seabream, LPUCs were higher from the 1940s to the 1960s in the *Balear* region and during the 1960s and 1970s in the *Suratlantica* and *Surmediterranea* regions. LPUCs values of Norway lobster were abundant during the 1980s in the *Cantabrica*, *Noroeste*, and *Balear* regions, while in *Surmediterranea*, *Levantina*, and *Tramontana*, the highest values were obtained during the 1930s and 1940s.

For megrim, LPUCs were abundant in the eastern regions (*Tramontana, Levantina*, and *Balear*) during the 1950s and 1960s, whereas in the *Cantabrica*, *Noroeste*, and *Surmediterranea*, the most abundant LPUCs were found between the 1960s and the 1980s. Finally, LPUCs of shrimp were abundant in all regions during the 1950s and 1960s.

## Evolution of demersal fishing tactics

Four main fishing tactics were identified (Table 1), with an OSC value of 0.35. From the PSC, cluster 1 (PSC = 0.14) showed the most heterogeneous internal structure and the main overlapping with other clusters. Regarding percentage of LPUC, cluster 1 was mainly characterized by red mullet, while the species that contributed most to the dissimilarity with the rest of the clusters were horse mackerel, blue whiting, and hake (Supplementary Table S2). The next species accounting for the dissimilarity was shrimp. Cluster 2 (PSC = 0.33) was represented by horse mackerel. Clusters 3 and 4 were more internally homogeneous, with less overlapping (PSC = 0.4 and 0.53, respectively), with the former characterized by blue whiting and the latter by hake. Both were species that contributed most to the dissimilarity with the rest of species.

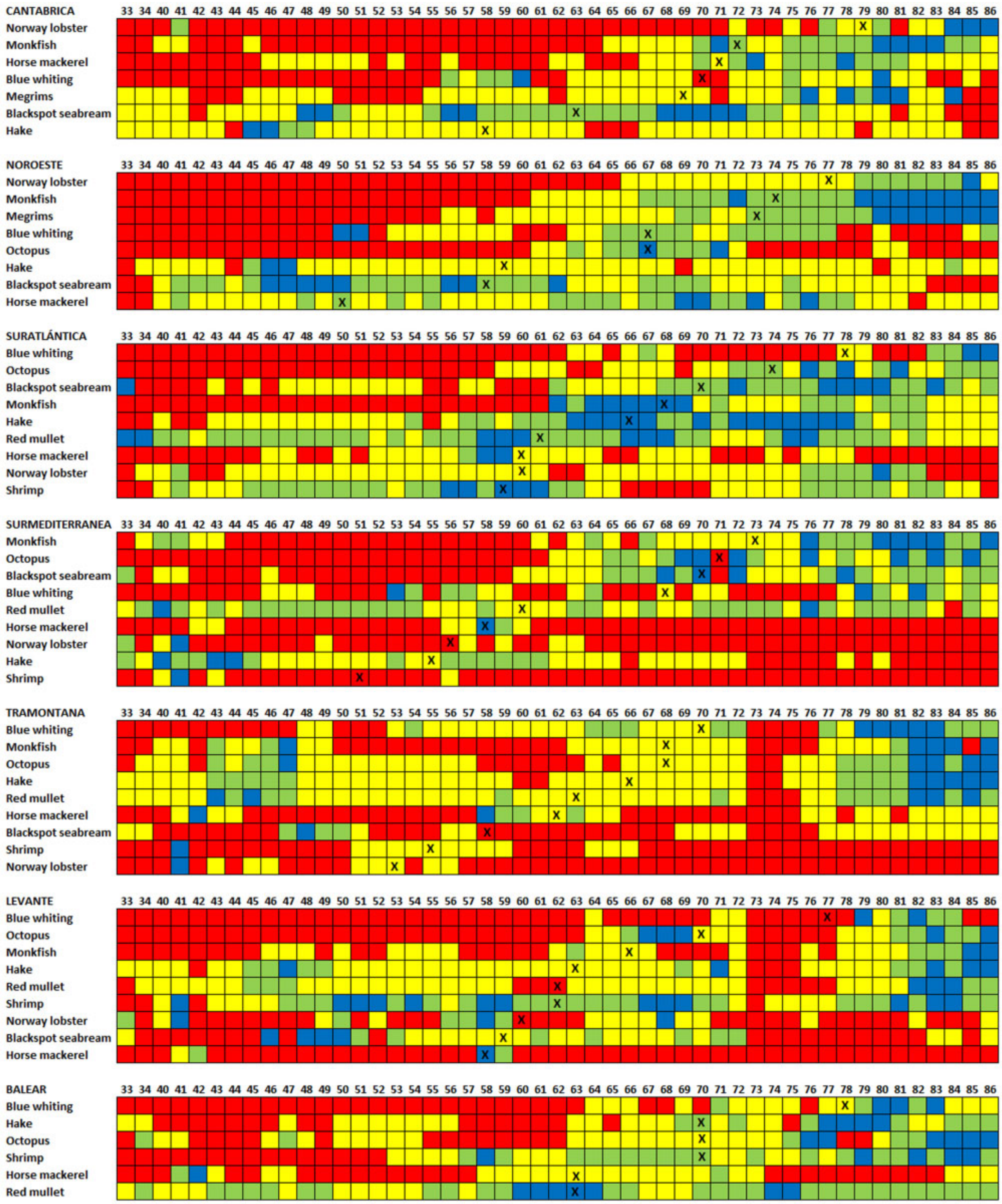


**Figure 4.** Evolution of species exploitation by region, standardized from 0 to the maximum landing of species *i* in a region *j*, and split into four quartiles identified by colours with increasing landings: red for the years with lowest landings, then yellow, green, and finally blue for the years with highest landings. "X" shows the year when 50% of accumulated landings were reached.

The first two axes of the CA, which was conducted to identify the landings proportion of species by region and year corresponding to the four above-mentioned clusters (Supplementary Figure 4a), explained 55% of variance. The bi-plot distribution of the species in each quadrant is shown in Supplementary Figure 4b. Cluster 4 was in quadrant I, characterized by hake; while cluster 2

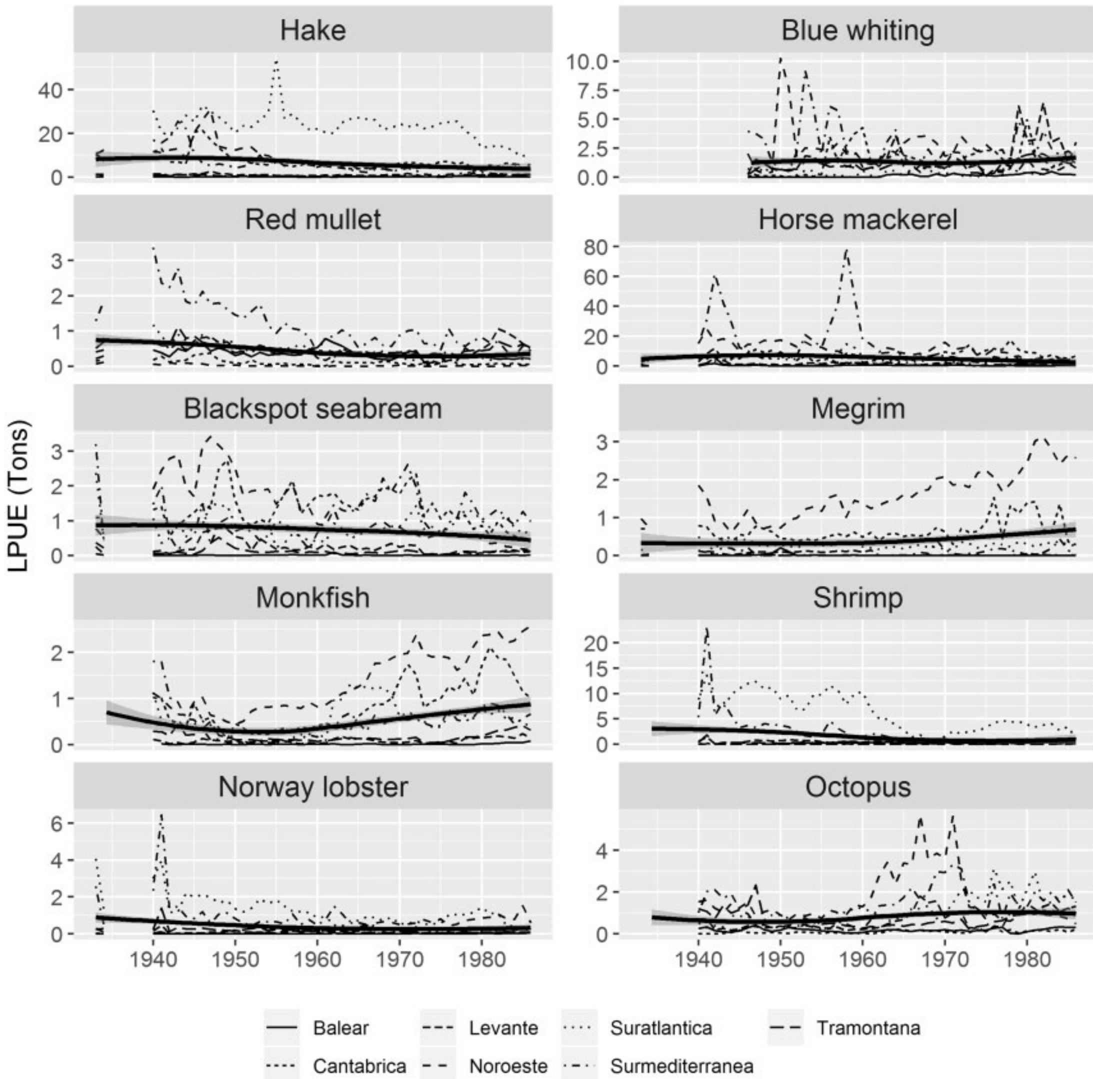


**Figure 5.** Mean LOESS smoothers and 95% confidence intervals of LPUC by species and region from 1933 to 1986. Gaps in the time series indicate years with no data.

was in quadrant II, characterized by horse mackerel and, to a lesser extent, by blackspot seabream, megrim, and monkfish. Quadrant III included the samples belonging to cluster 3, characterized by blue whiting; while quadrant IV included cluster 1 with red mullet and shrimp. The catch profiles of these clusters consisted of cluster 1 targeting red mullet and shrimp (MUX), cluster 2 with many target species (MIX), cluster 3 targeting blue whiting (WHB), and cluster 4 targeting hake (HKE). The proportions of these catch profiles by region, as a proxy of fishing tactics, are shown in Figure 7. In the Atlantic, MIX was the most important catch profile in the *Cantabrica* and *Noroeste* regions, followed by HKE, whereas this last catch profile accounted for the whole proportion in the *Suratlantica* region. In the Mediterranean, the importance of the MIX catch profile decreased from the southern (*Surmediterranea*) to the northern (*Tramontana*) regions, whereas the proportion of the WHB catch profile increased. In the *Balear* region, the main catch profile was MUX.

The CA applied to analyse the temporal evolution of these fishing tactics by region and to identify the samples (landings by region and year) and fishing tactics to which they belong showed two different patterns in the Atlantic regions (Figure 8). In the northern *Cantabrica* and *Noroeste* regions, there was an evolution from a catch profile targeting hake (cluster 4) to a catch profile targeting horse mackerel, megrim, and monkfish. In contrast, no temporal pattern was detected in the *Suratlantica* region, which showed a catch profile targeting mainly hake throughout the whole time series. In the Mediterranean, three main patterns were found: in the *Balear* region, no temporal pattern was detected, with a catch profile targeting mainly red mullet and shrimp (cluster 1). In the *Tramontana*, there was a shift from a catch profile targeting shrimp and red mullet at the beginning of the time series, to a catch profile targeting blue whiting (cluster 3). In the *Levatina* and *Surmediterranea* regions, there was no clear temporal pattern, with most of the samples in the origin of the coordinates axis.

## Discussion

By using a multi-method analysis approach, the present study provides a view of the historical evolution of two of the most

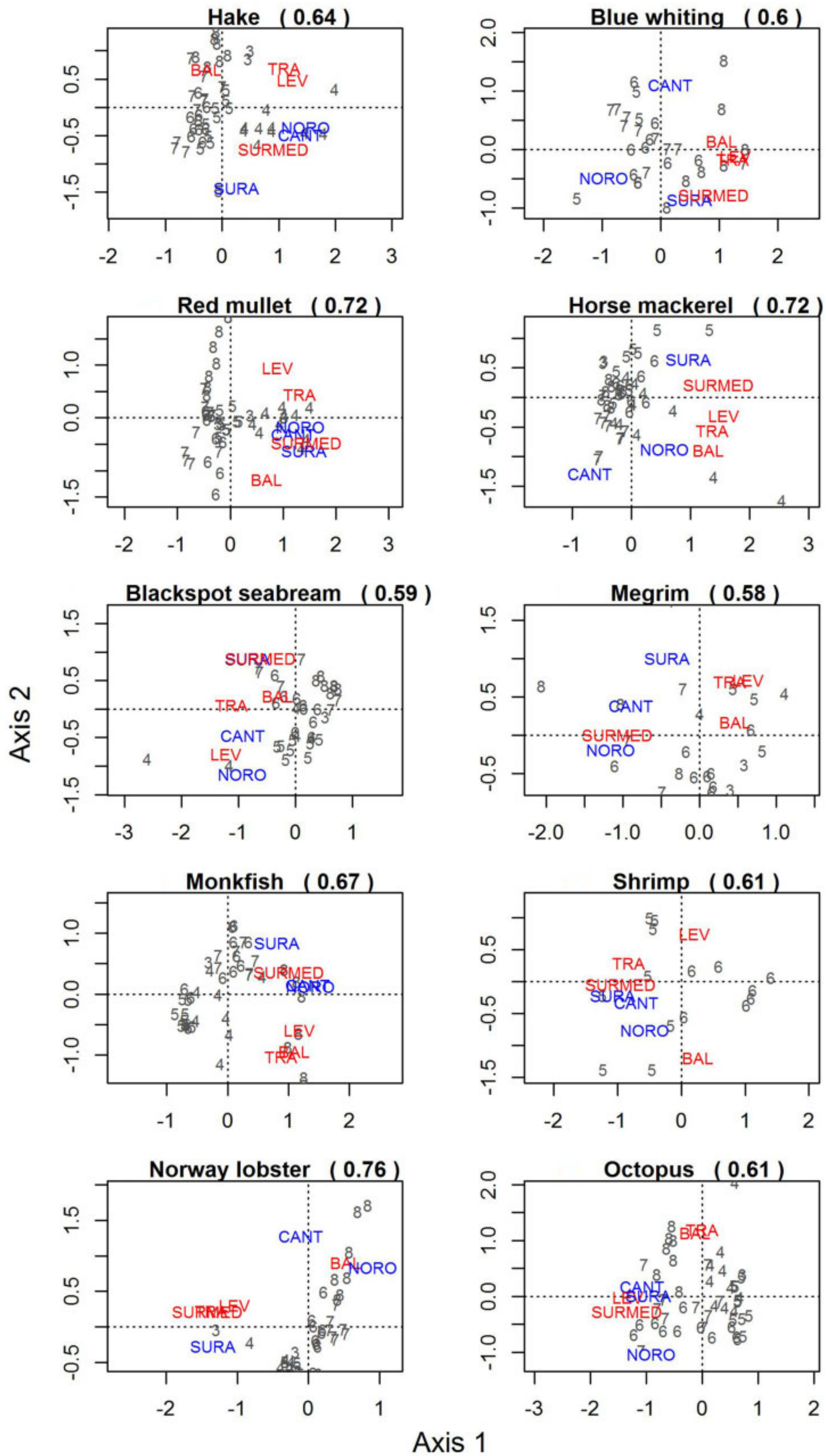


**Figure 6.** PCA correlation bi-plots for LPUCs time series of the ten species. Numbers in the plots represent decades from 1930s to 1980s. The number within parenthesis in the title of each plot shows the percentage variance explained by each model. In blue colour the Atlantic regions and red colour the Mediterranean regions. CANT, *Cantabrica*; NORO, *Noroeste*; SURA, *Suratlantica*; SURMED, *Surmediterranea*; LEV, *Levantina*; TRA, *Tramontana*; BAL, *Balear*.

important fisheries in southern European waters. This article shows the temporal dynamism of fishing exploitation in both seas (Atlantic and Mediterranean), with changes witnessed over time in most regions in their target fishery species as well as in their fishing tactics. Meanwhile, there is certain spatio-temporal synchrony in the LPUC, with geographically proximate areas sharing common strategies and evolution in time.

All the changes in patterns of catches and yields are linked to three main aspects that are crucial in the development of a fishery: legislative measures, technological development, and scientific advice. Without regarding any aspect in particular, neither legislative or technological, the most significant change occurred in 1951 (Figure 3a), probably due to the wars that took place in Spain and Europe at the end of the 1930s and in the first half of the decade of 1940, respectively, and the subsequent technological improvements that the fleet started to implement. From the legislative point of view, the implementation of measures to improve the competitiveness of national fleets or the control of catches or fishing effort only caused a temporary increase of landings associated with a decrease of LPUC. TACs and EEZ were implemented at the same time. The application of the EEZ had negative consequences on the Spanish fleet, with loss of traditional fishing grounds and boats in international waters because of EEZ requirements (López-Losa, 2008). In addition, the increase in the EEZ did not imply an increase in fishing possibilities for Spain, as opposed to other countries, due to the narrowness of the Spanish shelf. Hence, fleets that had traditionally fished in offshore grounds had to come back to fishing grounds in national waters. Regarding technological aspects, the results were similar. There was an increase in landings of fleets with a significant technological improvement, but no improvement in yields was observed after their implementation. All these factors had led to an over-exploitation status of many of the stocks in both areas by the end of the 20th century (Colloca *et al.*, 2013; Quetglas *et al.*, 2013; Modica *et al.*, 2014). Taking into account the governance structure and environmental characteristics of the Mediterranean Sea, the state of over-exploitation in this sea persists, while in general terms it has been reversed in the Atlantic (Fernandes and Cook, 2013; Fernandes *et al.*, 2017).

**Table 1.** Mean percentage of species in landings by the four clusters identified.

| Species | 1 (0.14) | 2 (0.33) | 3 (0.4) | 4 (0.53) |
|---|---|---|---|---|
| Blackspot seabream | 2.7 | 4.8 | 3.4 | 3.8 |
| Blue whiting | 4.7 | 8.6 | 27.9 | 2 |
| Hake | 20.1 | 25.1 | 14.9 | 60.4 |
| Horse mackerel | 21.2 | 41 | 17.6 | 14.7 |
| Megrims | 0.3 | 6.1 | 0.2 | 1.4 |
| Monkfish | 2.5 | 6 | 3.6 | 1.9 |
| Norway lobster | 4.8 | 1.6 | 2.4 | 2.1 |
| Octopus | 13.4 | 5.6 | 15.7 | 2.9 |
| Red mullet | 14.9 | 0.6 | 9.2 | 1 |
| Shrimp | 15.5 | 0.6 | 5.1 | 9.7 |

Numbers in parentheses show the PSC.

The quantitative amount and temporal behaviour of the total catches in the Atlantic and Mediterranean regions are very different throughout the series. In this study, we worked with landings, without considering the discards. Although they have an effect on the total catch, Pauly and Zeller (2016) showed that such an effect was not shown on the overall catch trends for these two seas, although it could be important for some particular species. The general trend observed in the landings of the demersal Spanish fleet from the Atlantic is very similar to the one documented by Pauly and Zeller (2016) for the total landings in Northeast Atlantic. There is a general upward trend in catches, except for a decrease after the Second World War in the 1940s, until the mid-1970s when catches start descending. A similar trend has been observed in the Northeast Atlantic (Pauly *et al.*, 2002; Christensen *et al.*, 2003; Caddy and Surette, 2005). This global increasing



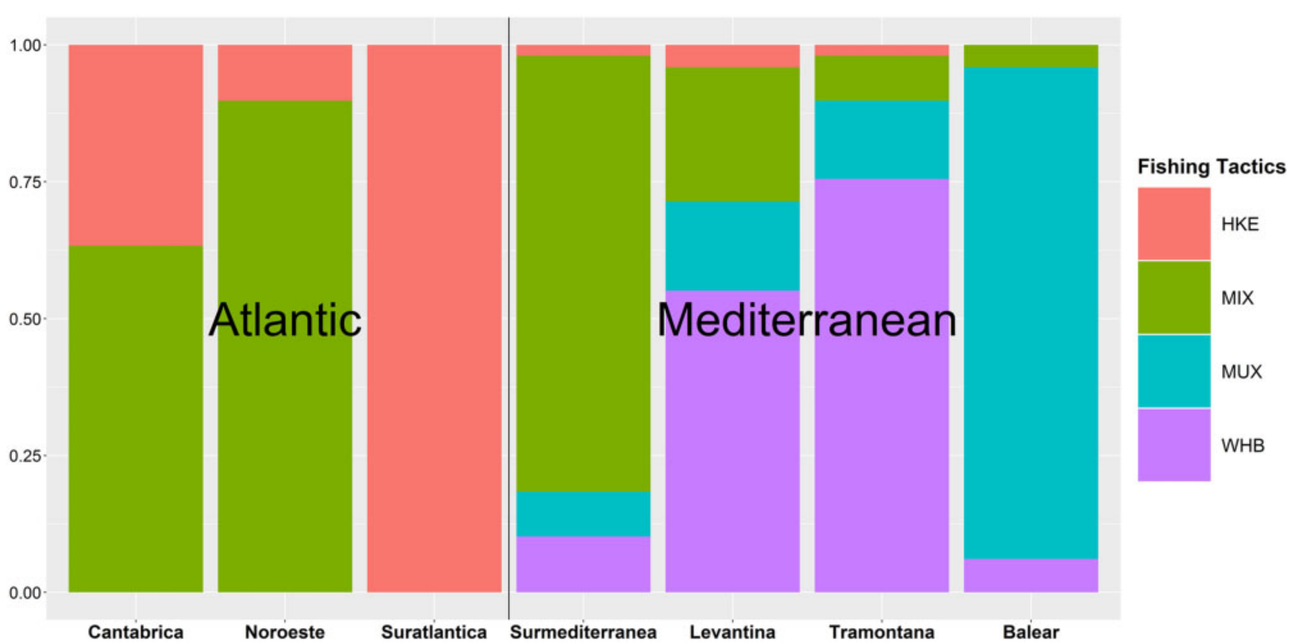


**Figure 7.** Proportion of catch profiles of the four fishing tactics is identified by region. MUX, targeted red mullet and shrimp; MIX, many target species; WHB, targeted blue whiting; HKE, targeted hake.

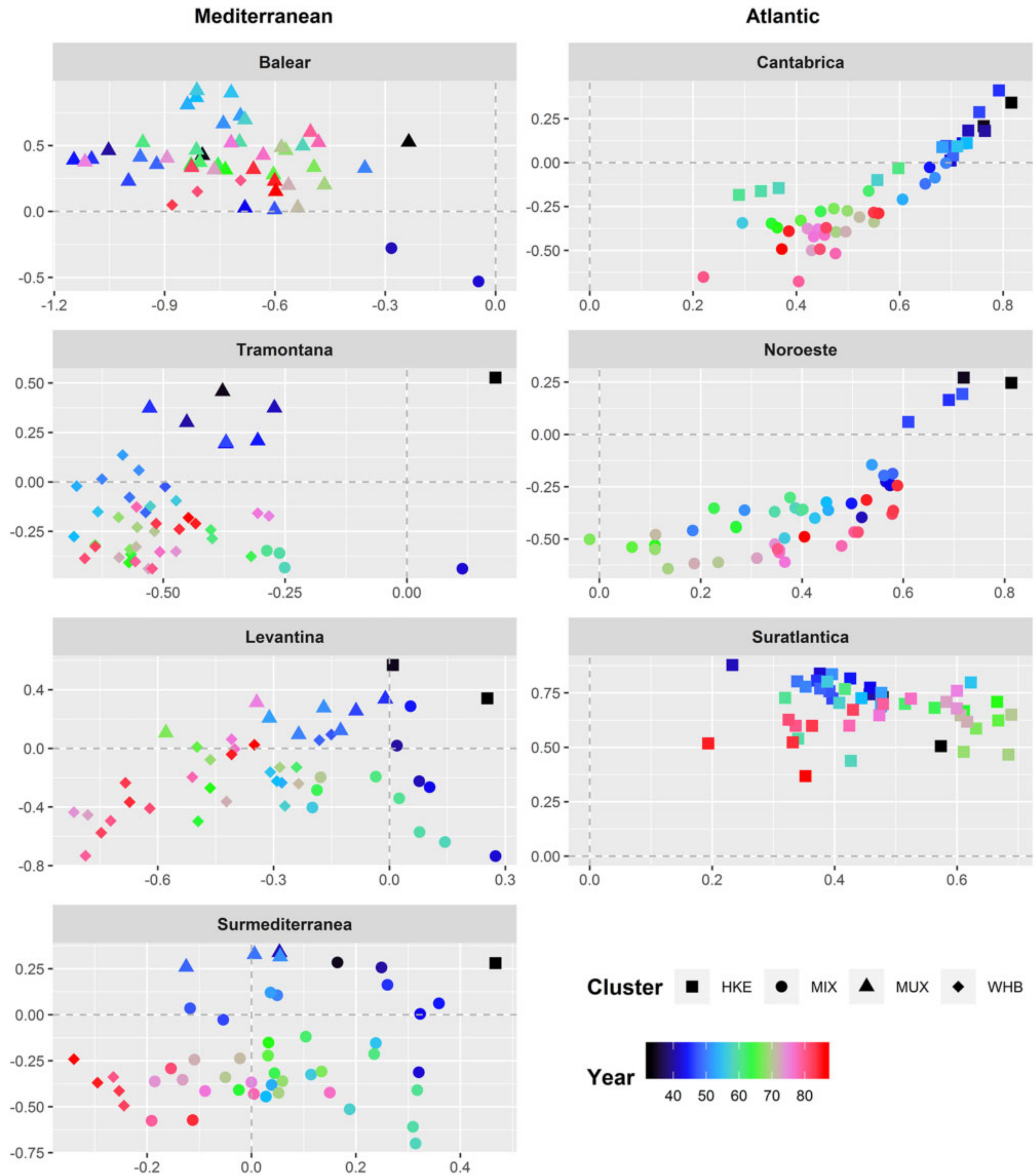


**Figure 8.** Distribution in CA coordinates of samples (landings per region and year) by fishing tactic (shapes) and year (colours). MUX, targeted red mullet and shrimp; MIX, many target species; WHB, targeted blue whiting; HKE, targeted hake.

trend in the Atlantic series could be a consequence of the absence of fishing effort during war periods for the beginning of the time series, and an increase in the effort and capacity related with technological innovations, and the promotion of boat building (Bailey and Jentoft, 1990; Pauly *et al.*, 2002, Bell *et al.*, 2017). In addition, in the Atlantic regions, new species were gradually incorporated into the demersal fishery. Therefore, the high catches maintained over time of the species that are traditionally exploited (hake, horse mackerel, and blackspot seabream) provide this image of continuous growth in landings. The development of fisheries and the increase in effort and capacity resulted in a situation of stock depletion, with decreases in catches and yields of species that had been traditionally exploited, similar to the observed in other fishing grounds (Worm *et al.*, 2009). In fact, at the end of the series, we can see a decline of the total landings, coinciding with the moment when the fishery assessment began to be progressively implemented in the Atlantic Iberian waters within the framework of ICES.

Meanwhile, in the Mediterranean series, there is a significant increase in catches after the civil war but only for a short period of time. A subsequent decrease in catches for some of the species is observed, which coincides with the one reported by Caddy and Oliver (1996). These events are typical of less productive seas such as the Mediterranean, with a lower carrying capacity of ecosystems, where it is easy to overfish stocks (Piroddi *et al.*, 2017). New species were exploited more heavily at the end of the series, though the majority of them were already being moderately exploited before. Therefore, the change in fishing tactic (from MUX fishing tactic to MIX and WHB) may have been caused by a response to the decrease in catches, similar to what happened in the North Atlantic when the fleet started targeting blue whiting after the collapse of herring (*Cuplea harengus*; Martin *et al.*, 2016). It is, however, worth noticing that the strong impact on catches as a consequence of the long-term scenario of high exploitation in the Mediterranean here reported occurred right after the period investigated (i.e. from early 1980s), as has been reported in the western Mediterranean (Hidalgo *et al.*, 2009, Quetglas *et al.*, 2013) and the whole basin (FAO, 2016b).

Two important events occurred in the Mediterranean series, which were also observed by Coll *et al.* (2014), with an unusual increase in catches in 1958 and a sharp decrease in the mid-1970s. The former was produced by a rise in the catches of horse mackerel (*Trachurus trachurus* and *Trachurus mediterraneus*; Fiorentini *et al.*, 1997). This might have been due to a very good recruitment of the species with gradual full recruitment to the fishery, followed by a decrease in catches as a consequence of the depletion of the year class. Similar events have been observed in the Atlantic for these species (Abaunza *et al.*, 2003; De Oliveira *et al.*, 2010). The decrease in the mid-1970s is mainly due to a simultaneous reduction in catches of blue whiting and hake. This could have been associated with adverse oceanographic conditions, bad recruitment events in previous years, and/or recruitment failure associated to a severe change in climate and more particularly to the strength of convection events in winter in the north-western Mediterranean or due to over-exploitation (Bas and Calderón-Aguilera, 1989; Martin *et al.*, 2016). In the case of hake, a similar trend has been observed during the same period in the Balearic Islands (Massutí *et al.*, 2008; Hidalgo *et al.*, 2009, 2011).

The observed general long-term decrease in LPUCs for most species coincides with the depletion of many fish stocks worldwide (Jackson *et al.*, 2001; Pauly *et al.*, 2002; Christensen *et al.*, 2003; Myers and Worm, 2003; Mullon *et al.*, 2005; Mora *et al.*, 2009; Froese *et al.*, 2012). The collapse or reduction of fishing yields of traditionally exploited stocks brings along an increase in catches of previously non-target species to compensate for such over-exploitation (Myers and Worm, 2003). When fleets start capturing a new species, the trade-off between its economic value and the yields that it provides will result in the continuation of its exploitation. There are two types of species incorporating to the fishery. On the one hand, the replacement described by Worm *et al.* (2009) with pelagic species, which have low-economic value but account for a high volume of catches, entering the fisheries. In this study, these species are represented by blue whiting and horse mackerel. On the other hand, there are new species with greater economic value, such as monkfish, blackspot seabream, and Norway lobster. The incorporation of monkfish could be due to a shift from it being considered as discard to becoming a target species around the 1960s (Fariña *et al.*, 2008). Blackspot seabream and Norway lobster, however, have been exploited since the beginning of the series in some regions; hence, their incorporation into other regions might be explained by changes in their distribution and abundance (Lorance, 2011; for Norway lobster http://www.ices.dk/community/advisory-process/Pages/Latest-Advice.aspx) or changes in the spatial distribution of the fishing effort (Gil, 2006; Burgos *et al.*, 2013).

The spatial pattern of fishing tactics indicates that regions that are geographically closer and connected have a similar pattern of catches. This can be explained by socio-economic factors such as fishing traditions, shared fishing grounds and same market criteria, similar oceanographic conditions that favour the development of analogous fishing communities, and the contiguous large biogeographic distribution of species. Those areas that are relatively more geographically isolated, like the *Suratlantica* and *Balear* regions, developed characteristic dominant patterns in fishing tactics that differentiate them from the rest of the regions. Regarding the temporal pattern, the fishing activity developed in geographically connected regions has a more dynamic behaviour over time than isolated ones that are more stationary. That is, in connected regions fishing tactics change over time, with a clear temporal trend in the case of North Atlantic regions. On the other hand, in isolated regions the fishing tactic remains constant with time. There may be additional reasons as to why in isolated regions fisheries are more static and specialized, such as the reduced influence of fishing traditions from neighbouring regions, the absence of common fishing grounds, or confluence of fleets. Besides, the activity is probably driven by food supply and demand from local markets, which leads to maintaining the same resources. In addition, this situation may benefit the maintenance of the exploitation levels of the resources to a certain degree, thereby keeping the pattern of catches constant with time. Being able to provide an economic yield in isolated situations could favour self-management of resources because only local sectors are involved and they usually share common interests (Berkes, 2009). This could be translated into a more effective and quick application of specific measures and a more efficient flow of information between stakeholders and managers (Johannes *et al.*, 2000; Berkes, 2009).

In conclusion, the observed long-term trend of historical dynamism in these fisheries suggests that the calculation of the baseline status of stocks might require longer data series, not only in order to overcome the reduction in biomasses (Pauly, 1995) but also to account for the inherent changing nature of stocks. In general, these inherent changes together with the effect of the political decisions and technological advances produce more dynamic fleets, both in terms of their spatial cover capabilities as well as their capacity to find new fishing grounds and/or target species. However, we have observed that the fleets in isolated regions were able to maintain their exploitation pattern over time. It is likely that this is due to the geographic location of these areas having more constant fleets in terms of exploitation patterns and effort. Finally, this study might provide useful information for scientists and managers on the quantitative dimension of historical catches of some of the most important demersal species for the Spanish fishery; the contrasting behaviour of such fisheries in different geographic areas; and ultimately the effect of technological advances and management decisions on the exploitation of the stocks.

## Supplementary data

Supplementary material is available at the *ICESJMS* online version of the manuscript.

## Acknowledgements

This study was funded by ECLIPSAME (Plan Nacional I + D+i CTM2012-37701, Ministry of Economy and Competitiveness) and CLIFISH projects (CTM2015-66400-C3-1-R MINECO-FEDER). We are grateful to Celia Trápaga and Regina Herrera for the fishery information recovery and database work.

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*Handling editor: Ruth Thurstan*