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Identification of métiers of the Northern Spanish coastal bottom pair trawl fleet by using the partitioning method CLARA

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ABSTRACT

Cluster analyses of catch profiles by fishing day and trip (1986–2007) are used to identify métiers in the Northern Spanish coastal bottom pair trawl fleet (PTB) operating in ICES Divisions VIIIc and IXa North. The method CLARA (Clustering Large Applications) was chosen to analyze these databases because it is a partitioning technique specifically designed to manage very large data sets. The results obtained allow us to identify two métiers, which are in concordance with knowledge of the fishery, one targeting blue whiting and hake (PTB1), and another targeting mackerel (PTB2). PTB2 shows a seasonal pattern related to the reproductive cycle of mackerel off the Cantabrian coast in the Bay of Biscay. The CLARA method is shown to be useful tool for analyzing this type of large data set, although the coverage level of its sampling algorithm must be taken into account.

1. Introduction

Spanish national waters are divided into four fishing grounds for management purposes: Cantabrian-Northwestern waters, Gulf of Cádiz, Mediterranean waters, and Canary Islands waters. The first one of these, covering ICES Divisions VIIIc (Cantabrian Sea and Northern Galician waters) and IXa North (Southern Galician waters), is exploited by a variety of fleets, among which the trawl fleet stands out because of its mixed-species nature. Administrative control is achieved through a common fishing license for the whole trawl fleet, the size of which has decreased from 279 vessels in the early 1990s (STECF, 1994) to 122 vessels registered in 2008. During the last two decades, the Northern Spanish coastal trawl fleet has been made up of boats using two main gear types, the bottom otter trawl (OTB) and the bottom pair trawl (PTB). Pair trawlers have been traditionally defined as a highly mono-specific fleet, targeting blue whiting (*Micromesistius poutassou*, Risso 1827) by using a characteristic gear which permits a vertical opening up to 25 m. However, it is known that they have been recently developing new fishing strategies to adapt to changes in species abundance and market demand. Regarding management regulations, from 1983 trawlers targeting pelagic species were allowed to use meshes of 40 mm size whenever their catches of hake were less than 15% of the total catch (BOE no. 192, Order 30 July 1983), but this minimum mesh size was increased to 55 mm in 2002 (BOE no. 4, Order APA/16/2002).

Ignoring the dynamics of the fleets, which represent the main predators of the fished species, can result in an inaccurate perception of the fishery dynamics and hence inappropriate management advice (Hilborn and Walters, 1992). Lack of knowledge on fleet dynamics is particularly problematic in multi-species multi-fleet fisheries, known as mixed fisheries, in which a variety of species are caught together under a complex scheme of technical interactions among the fleets. One way of parameterizing these technical interactions in mixed fisheries is to disaggregate the fleet(s) into homogeneous fishing categories of fishing activity, defined according to target species, fishing area and fishing season. Identification of groups of vessels with the same exploitation pattern over time, usually referred as "métiers" (Laurec et al., 1991) (although various other names have been proposed, e.g. "fishing strategies", He et al., 1997), can greatly contribute to the design of more efficient sampling schemes, thereby contributing to more effective fisheries management (Pelletier and Ferraris, 2000).

The Northern Spanish coastal bottom pair trawl fleet is important in terms of both the weight and value of landings, contributing around 90% of the total Spanish landings (by weight) of blue whiting and 30–50% of the total Spanish landings of the southern stock of hake. Consequently there have been several previous attempts to identify métiers within this fleet. All previous segmentation stud-

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ies have found two groups, a main cluster targeting blue whiting, and a secondary and smaller cluster the main target species of which has variously been identified as mackerel (*Scomber scombrus*, Linnaeus 1758) or hake (*Merluccius merluccius*, Linnaeus 1758) (Punzón et al., 2008). However, these previous attempts of segmentation were based on relatively small databases from different time periods.

In relation to fishery management, the Spanish coastal bottom pair trawl fleet, particularly vessels based in the port of A Coruña port, is of particular interest because of its use as a tuning fleet in the assessment of the southern stock of hake. Nevertheless, strong concerns about trends founds in catchability made it advisable to split this time series into two periods (ICES, 2002), being finally removed from the assessment (ICES, 2004).

Therefore, the main objective of the current work is to clarify the identification of métiers in the Northern Spanish coastal bottom pair trawl fleet, based on the longest time series of landings data available. Due to the computational complexities of analyzing such a large data sets, a secondary objective was to test the applicability of the CLARA method (Kaufman and Rousseeuw, 1990), a variant of the PAM (Partitioning Around Medoids) method especially adapted to deal with very large data sets but rarely used previously in fleet segmentation studies (Duarte et al., 2009).

2. Material and methods

2.1. Databases

Two different datasets were compiled. The first one is based on the sampling, carried out by "Instituto Español de Oceanografía" (IEO) for the period 1986–2002, of fishing trips in ICES Division VIIIc by pair trawlers mainly based at the port of A Coruña. In 2000 and 2001 data were also collected from some other ports. This dataset contains information on date of landing, landing port, and landed weight of species by trip (1.5 days) and includes records of 31,612 trips.

The second dataset was compiled from the official logbooks for the period 2003–2007, which has been facilitated by "Ministerio de Medio Ambiente y Medio Rural y Marino" (MARM). This dataset contains information on fishing area, date of landing, landing port (all Spanish ports are included), base port, and landed weight of species by fishing day and ICES rectangle. Data of a total of 44,653 fishing days from the 2003–2007 period were analyzed.

Both datasets were reorganized into two different time periods due to marked changes in sampling coverage. Data for the period from 1986 to 1999 were analyzed separately, because they derive exclusively from only one port (A Coruña). The following part of the sampling time series, from 2000 to 2002, was joined to the logbook time series (2003–2007) since this contains information from a variety of other Spanish ports (Table 1). For the whole time series, information on the technical features of vessels was also compiled, consisting of length, gross tonnage (GT), horsepower (HP), and construction year.

In addition, after having identified the seven fishing associations related with the Spanish pair trawl fleet, three interviews with skippers randomly selected (covering around 12.5% of the fleet) were carried out to obtain technical information on gear design, haul duration and fishing strategies. The information obtained was also compared with data collected by on-board observers as part of the "IEO's discarding sampling program".

2.2. Multivariate analysis

Increasing computer capacity has facilitated the development of several modern techniques for both main types of cluster analysis: partitioning and hierarchical methods. Among the former, which are less susceptible to atypical elements than hierarchical algorithms (Hair et al., 1999), the "Partitioning Around Medoids" method (PAM) (Kaufman and Rousseeuw, 1990) is of particular interest. This method replaces the traditional centroids, the parameter used to characterize each cluster, by medoids, the object within a cluster for which the average dissimilarity to the remaining objects is minimal, which is more robust to irregular values in the matrix because of the minimization algorithm involved (Struyf et al., 1996). Another advantage of PAM is that it provides a novel graphical display, the silhouette plot, and a corresponding quality index allowing selection of the most appropriate number of the clusters (Rousseeuw, 1987). Both plot and index are calculated using the dissimilarities of each object i from all other objects in the same cluster and in all other clusters. The silhouette values of each object are averaged by cluster, $s(i)$, and an "average silhouette width" (ASW) is given as a quality index of the whole clustering procedure. The method facilitates exploration of different number of clusters (k), and to compare the resulting silhouette plots. Finally, the value of k selected so as to maximize the value of ASW. An interpretation proposed by Kaufman and Rousseeuw (1990) identifies a reasonable structure when ASW is higher than 0.5.

Due to time and memory requirements, the algorithm PAM is not practical for clustering large data sets. For this reason Kaufman and Rousseeuw (1990) developed a method especially adapted to large data sets: CLARA ("Clustering LARge Applications"). This algorithm works by applying a PAM clustering on data subsets of fixed size, so that the overall time and storage requirements become a linear rather than a quadratic function of the total number of objects, economizing on computational time. A standard partitioning method means that its main computational effort is directed at searching among a large number of subsets of k objects (C_n^k possible subsets), for a subset yielding a satisfactory, locally optimal, clustering. With increasing values of n the number of subsets increases dramatically: for fixed k the rate of increase is of order of the kth power of n. Another factor with the same effect is the storage requirement, making the number of memory locations less dependent on the number of objects, of which it is a

Table 1
Number of records by landing port for the two time series compiled of the Northern Spanish coastal pair trawl fleet: trips from the IEO sampling (1986–2002), and fishing days in logbooks (2003–2007).

Year	A Coruña	Avilés	Celeiro	Gijón	OTH
1986	1489				
1987	1707				
1988	792				
1989	962				
1990	1167				
1991	1868				
1992	1574				
1993	1343				
1994	4059				
1995	3865				
1996	2254				
1997	2183				
1998	328				
1999	122				
2000		211	1720	385	
2001		249	2408	734	
2002	770	265	2535	497	30
2003	1459	1269	1400	676	3503
2004	1848	1349	1580	672	4466
2005	1956	1011	1686	302	4074
2006	1958	869	1578	463	3976
2007	2048	626	1756	434	3694

OTH: remaining landing ports.

quadratic function in the PAM algorithm (Kaufman and Rousseeuw, 1990).

2.3. Data analysis

The métier definition used here follows the hierarchical structure proposed by ICES (2003), first defining fleet units (groups of vessels with similar technical features) and then defining units with similar kinds of fishing operation (groups of trips or fishing days with homogenous species composition). The analysis of the technical features of vessels, standardised by using the mean and standard deviation of each parameter, was carried out using the PAM method, due to the manageable size of this data set, while analysis of trip characteristics was carried out using CLARA.

The algorithm of the CLARA method permits choosing different combinations of subset size and number of subsets. In the approach proposed here, combinations of different subset size and number of subsets are tested regarding the consistency of the structure of the groups of landing profiles obtained. Then, for each combination of number of subsets and subset size, sets of k clusters are made, with k varying from 2 to 10. Finally, the clusters obtained are analyzed against different parameters (year, month, landing port, and ICES rectangle) in order to understand the fleet behaviour and characterize the fishing operation.

All multivariate analyses were made with the R language for statistical computing (R Development Core Team, 2008; URL: http://www.R-project.org).

3. Results

3.1. Interviews with skippers

From interviews with skippers of boats deploying PTB, it is apparent that traditional pair trawl gear is used to catch blue whiting and hake with similar fishing characteristics: 20–50 m vertical opening, a cruising speed not higher than 2 knots, and a typical haul duration of 10 h. However, from this apparently homogeneous fleet another fishery has emerged, specifically targeting mackerel by using a new gear specifically designed to fish faster swimming pelagic species. This gear has a shorter vertical opening (around 20 m) in order to increase the cruising speed up to 4 knots. As a consequence, hauls become shorter, with an average duration of 3 h.

3.2. Analysis of time series 1986–1999

The technical features of the vessels with trips in this time series had the following mean values: 28.6 m total length, 159.4 GT, 484.4 HP, and mean year of construction around 1973 (range between 1946 and 1999). A PAM analysis of the technical features of vessels failed to find a significant structure, yielding non-significant ASW coefficients.

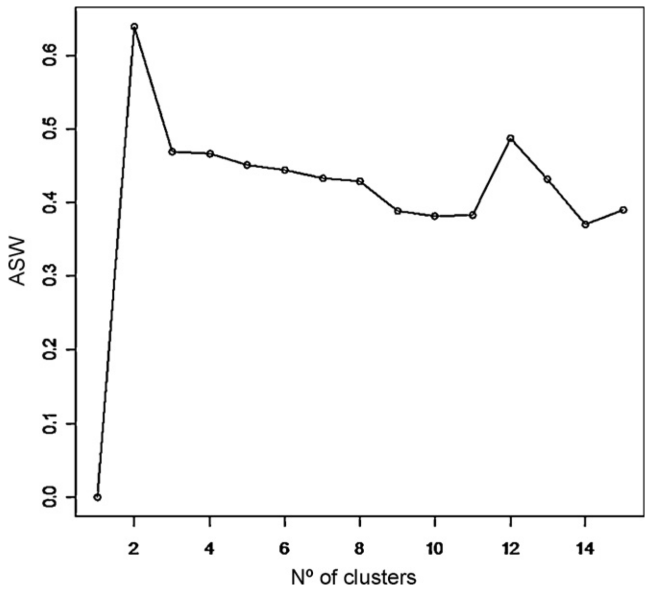

Fig. 1. Silhouette coefficients (ASW) obtained for different number of clusters of the 1986–1999 time series of the Northern Spanish coastal bottom pair trawl (PTB) fleet.

A number of CLARA analyses were made using a range of subset sizes and numbers of subsets, covering different percentages of the total matrix of 22,018 trips. All the highest ASW values were obtained when two clusters were selected (Table 2). For higher numbers of clusters, the ASW values were lower and non-significant (Fig. 1). The silhouette indices indicate the presence of one big cluster (75% of trips) with a very significant silhouette index ($s(i) = 0.81$), and the second one with a much weaker structure ($s(i) = 0.12$). Regarding the catch profile, the first cluster is mainly mono-specific, targeting blue whiting, while the second one shows a variety of target species, including blue whiting, hake, mackerel, and horse mackerel (Fig. 2).

3.3. Analysis of time series 2000–2007

Regarding the technical features of that group of vessels, no internal structure was found with a PAM multivariate analysis. Therefore, that was considered as one homogeneous group of vessels with an average of 26.8 m of total length, 130 GT, and 443.9 HP. A total of 57 of those vessels have reported effort higher than 50 days in their logbooks in the period 2003–2007.

A number of CLARA analyses were made using a range of subset sizes and numbers of subsets, covering different percentages of the total matrix of 54,247 fishing days. All but one combination yielded three clusters. When 50 subsets of 100 elements were selected, two clusters were obtained (Table 2). In all the cases, ASW coefficients obtained from four or more clusters were lower and mostly non-significant (Fig. 3). Two of the three clusters identified were well-

Table 2
Results by sampling scheme of CLARA clustering for both the time series used in the analysis (k: number of clusters; ASW: average silhouette width).

Sample size	Number of samples	Time series 1986–1999		Time series 2000–2007	
		k	ASW	k	ASW
100	50	2	0.64	2	0.69
300	50	2	0.62	3	0.70
500	50	2	0.61	3	0.71
100	100	2	0.64	3	0.75
300	100	2	0.54	3	0.72
500	100	2	0.61	3	0.72

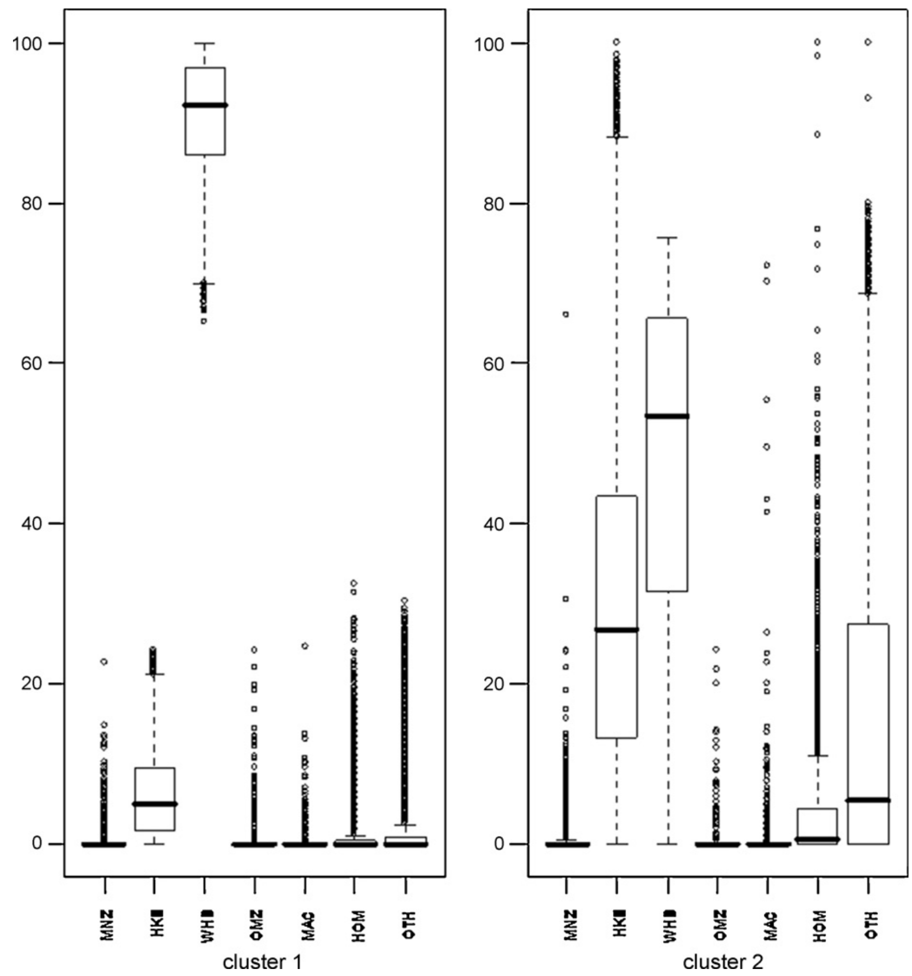

Fig. 2. Box and whisker plots of specific composition by cluster in percentage by trip obtained from the 1986–1999 time series of the Northern Spanish coastal bottom pair trawl (PTB) fleet clustering. FAO species codes: MNZ (anglerfish), HKE (hake), WHB (blue whiting), OMZ (Ommastrephidae), MAC (mackerel), HOM (horse mackerel), and OTH (other species).

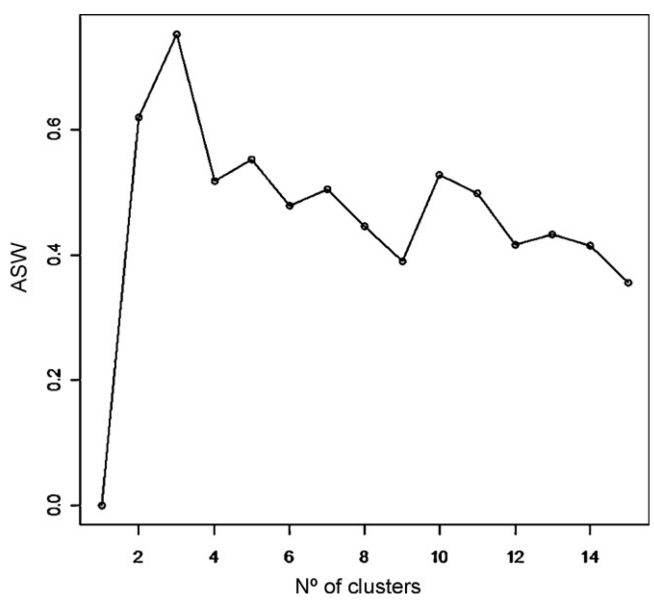

Fig. 3. Silhouette coefficients (ASW) obtained for different number of clusters of the CLARA analyses made on the 2000–2007 time series of the Northern Spanish coastal bottom pair trawl (PTB) fleet.

defined, with silhouette coefficients higher than 0.6, while the third cluster had a very weak internal structure ($s(i) = 0.12$). Regarding the two significant clusters, one is identical to that obtained in the previous analysis and targets blue whiting, and the second one is a new cluster which has mackerel as the target species. The weakly defined cluster corresponds to trips mainly landing hake (Fig. 4). There was a clear seasonal pattern in the cluster targeting mackerel, effort being concentrated in the first four months of the year, from January to April (Fig. 5).

3.4. Métier characterization

Since no fleet units with different technical features were found, the métier characterization depends only on the identification of specific types of fishing activity. Regarding the interpretation of results of the multivariate analysis of catch profiles, the low silhouette index of the mixed cluster obtained in both analyses suggests that it is a mis-defined part of another cluster. Therefore, the Northern Spanish coastal pair bottom trawl fleet can be characterized as composed of two métiers (Table 3):

1. PTB1: pair trawlers targeting blue whiting and hake, which represents the main component of the fleet with around 85% of the total effort.
2. PTB2: pair trawlers targeting mackerel in a seasonal fishery which covers the remaining 15% of total effort.

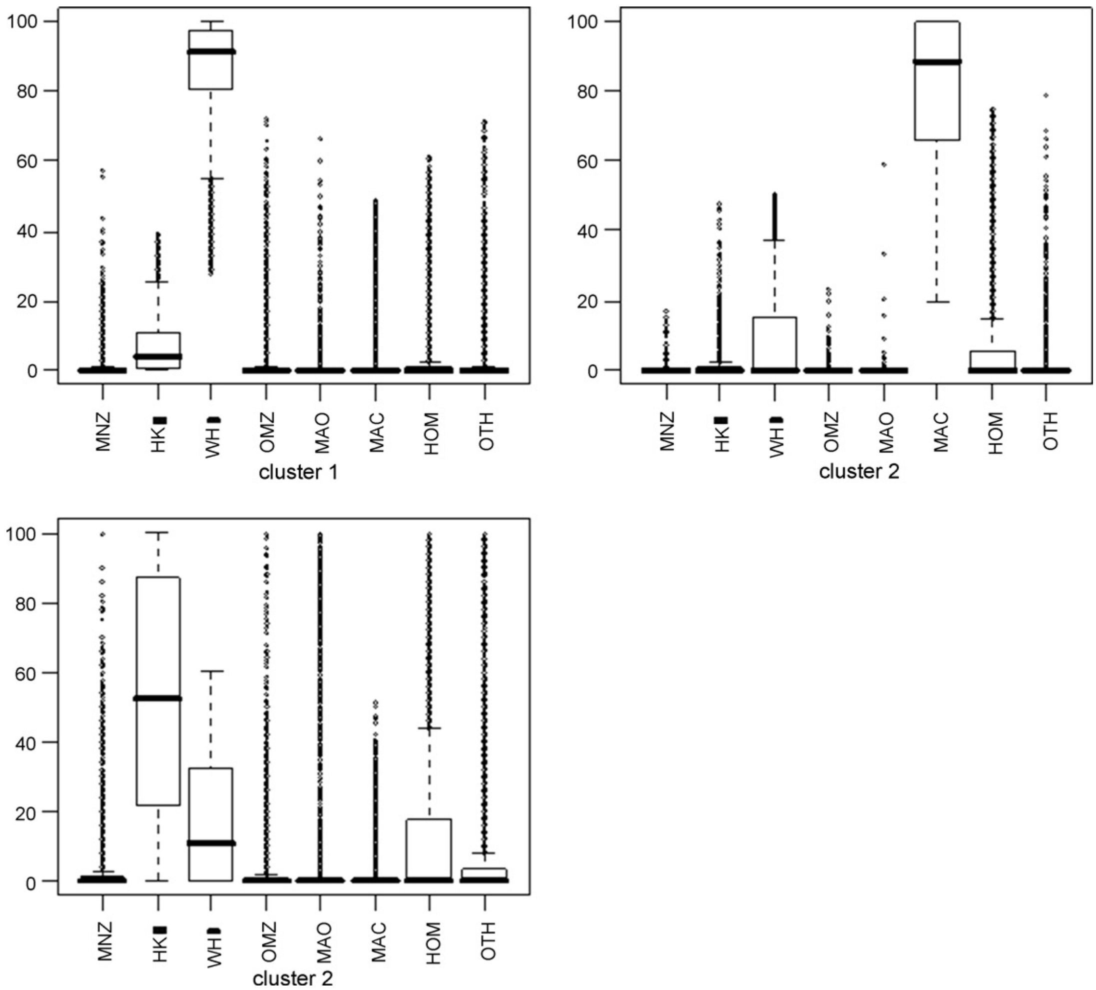

Fig. 4. Box and whisker plots of specific composition by cluster obtained in the 2000–2007 time series of the Northern Spanish coastal bottom pair trawl (PTB) fleet clustering. FAO species codes: MNZ (anglerfish), HKE (hake), WHB (blue whiting), OMZ (Ommastrephidae), MAS (chub mackerel), MAC (mackerel), HOM (horse mackerel), and OTH (other species).

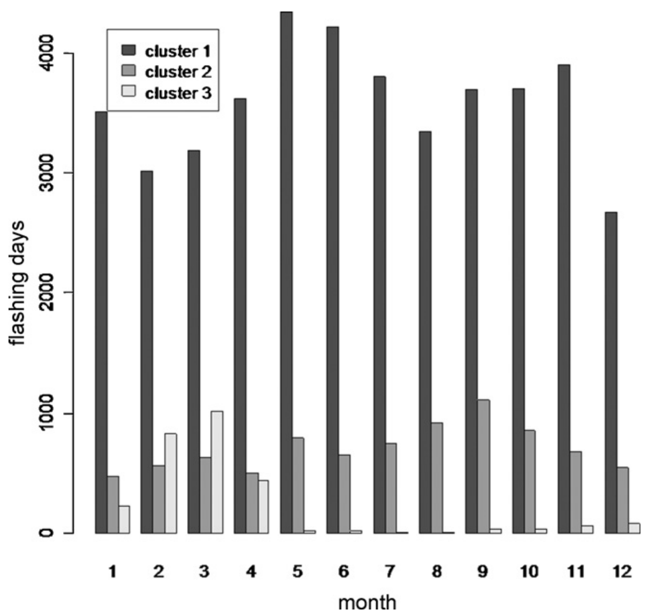

Fig. 5. Monthly analysis of the three clusters obtained for the Northern Spanish coastal bottom pair trawl (PTB) fleet from 2000–2007 time series.

A compilation of the historical catch profile by métier shows a relatively stable pattern in métier PTB1 since 1986, except for the importance of hake which has been increasing during the last three years (Fig. 6). Regarding métier PTB2, during the short period available (2000–2007) there were no important changes in the proportion of mackerel in the catches (Fig. 7).

A monthly analysis of PTB2 in the more spatially representative time series, logbooks 2003–2007, indicates than the peak of catches occurs in March in all years except 2007, when the highest catches were taken in February. Geographically, strong differences between métiers can be observed regarding landing port. Thus, some ports have similar landings from both métiers (e.g. Avilés) while others have no PTB2 activity (e.g. A Coruña) (Fig. 8). The activity of PTB2 is concentrated in Cantabrian waters (Fig. 9).

Table 3
Mean landing profile by the two métiers obtained for both the time series used in the analysis: PTB1: pair trawlers targeting blue whiting and hake; and PTB2, pair trawlers targeting mackerel in winter–spring in Cantabrian waters.

Species	PTB1	PTB2
Merluccius merluccius	11.0	0.8
Micromesistius poutassou	78.5	7.0
Scomber scombrus	0.8	86.4
Trachurus trachurus	4.0	4.7
Others	3.4	0.9

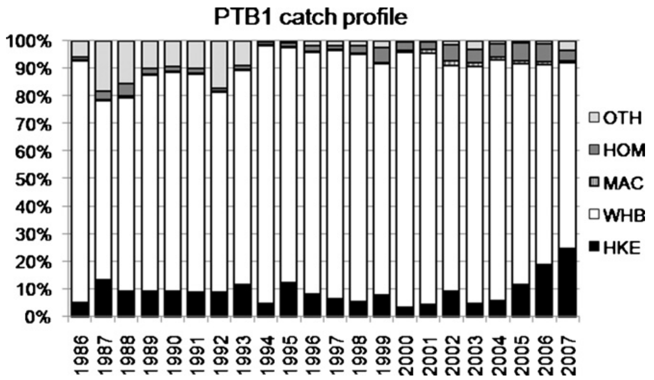

Fig. 6. Catch profile of historical time series (1986–2007) of métier PTB1, corresponding with the Northern Spanish coastal bottom pair trawl fleet targeting blue whiting and hake.

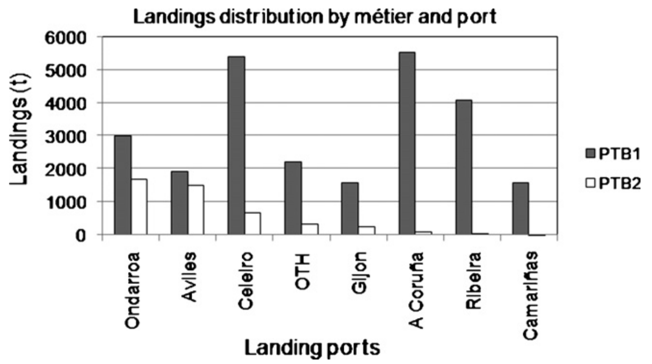

Fig. 8. Distribution of total landings of the Northern Spanish coastal bottom pair trawl fleet by métier and landing port for the logbooks time series (average 2003–2007). OTH: remained ports.

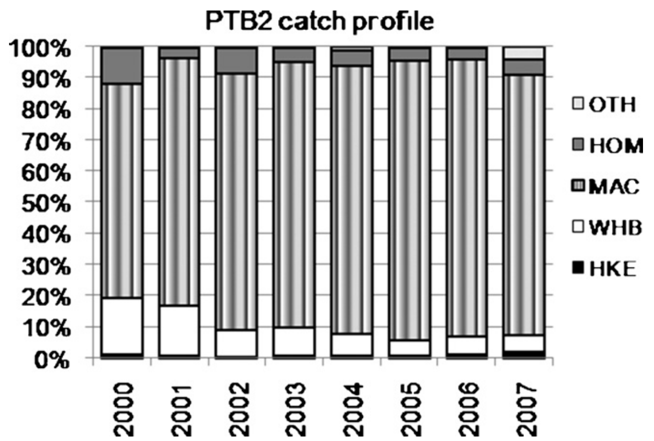

Fig. 7. Catch profile of time series available (2000–2007) of métier PTB2, corresponding with the Northern Spanish coastal bottom pair trawlers targeting mackerel.

4. Discussion and conclusions

From the results obtained, two métiers have been identified in the Northern Spanish coastal pair bottom trawl fleet: métier PTB1 targeting blue whiting and hake; and métier PTB2 targeting mackerel in a seasonal fishery, mainly from January to April.

Regarding the interpretation of results, once the ASW has been found significant, the internal silhouette coefficient $s(i)$ of each cluster must be taken also into consideration. The cluster given low silhouette coefficients in both the time series analyzed shows a very weak internal structure. In fact, this kind of cluster works as a group of the "rare" cases belonging to one of the "clean" clusters. However, these results need to be compared with other sources of information, as done here by using interviews with the PTB skippers, which suggested that the mixed cluster corresponds with hauls in which the standard proportion between blue whiting and hake is shifted in favour of hake. Therefore, it can be said that, from a traditionally homogeneous fleet (PTB1), has emerged another fishery targeting mackerel (PTB2) adapted to the biology of this species.

These results explain the inconsistencies detected in previous analyses of segmentation of the fishing activity of this fleet in which, apart from a main cluster targeting blue whiting, the second cluster obtained showed a different catch profile in each analysis. Abad et al. (2007) found a second cluster targeting mackerel when analyzing a logbook dataset from 2003 to 2005 using the CLARA algorithm. It is possible that this cluster was miss-identified as the proportion of hake in the catch ranges from 0.8% in 2003 to 13.8% in 2005; however no exploration of the sampling possibilities offered by the CLARA algorithm was carried out. On the other hand, the secondary cluster found by Punzón et al. (2008) presents a mixed catch profile in which hake stands out over a variety of species such as blue whiting, mackerel, and horse mackerel. In this analysis, a partitioning "*k-mean*" method was used on data from trips by the A Coruña fleet sampled in 2002–2004, and it has been shown in the present study that PTB2 is absent from A Coruña.

The activity of métier PTB2 identification in the present study is concentrated between January and April, coinciding with the spawning season of the southern component of the mackerel stock (in Division VIIIc) (ICES, 2007). Spawning takes place over and off the continental shelf from February to June with a peak in April (Solá et al., 1990), and finishes with the mackerel migration towards feeding areas along the coast of Norway at the end of spring (Uriarte

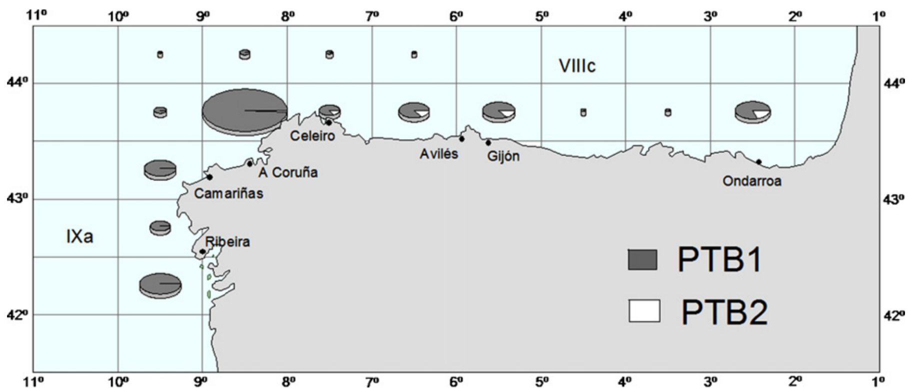

Fig. 9. Mean geographical distribution of effort (fishing days) for the two *métiers* of Northern Spanish coastal bottom pair trawl fleet from logbooks 2003–2007, where geographical position at ICES rectangle level is available. PTB1: pair trawlers targeting blue whiting and hake; and PTB2: pair trawlers targeting mackerel.

and Lucio, 2001). The timing of PTB2 is slightly ahead of the most important mackerel fishery in the area carried out by the handline fleet, the peak of which is traditionally in April (Punzón et al., 2004). However, recent analyses of this fishery indicate a shift forward in recent years (Punzón and Villamor, 2009), corresponding to a similar progressive change found in the timing of the pre-spawning migration of the western component of mackerel (Reid et al., 2003).

Assessment of the status of the southern hake stock has proved problematic due to variation over time in catchability (ICES, 2002, 2004). Unfortunately, the results presented here do not solve the problems detected in the southern hake assessment; because the newly identified métier PTB2 does not occur in the port of A Coruña, and so no improvement of the tuning fleet indices can be achieved by applying métier identification. Nevertheless, even though métier PTB2 is targeting mackerel and only represents 15% of the total pair trawl effort, its identification could contribute important information for the evaluation of the success of the recovery plan recently implemented for the southern stock of hake (EC Reg. 2166/2005), mainly based on effort control. Now that the métier structure of the Spanish Northern coastal pair bottom trawl fleet has been characterized, tracking of its future evolution will be facilitated, and other relevant information not available for the present study could also be taken into account, notably economic and discarding data.

Regarding the second objective of the present study, the CLARA approach provides a straightforward way of clustering large data sets, which would be less practical or even unfeasible with approaches followed by other authors, e.g. using principal component analysis (PCA) followed by an agglomerative hierarchical clustering analysis (HCA) (Campos et al., 2007). The characteristics of CLARA make it especially useful for working in data mining of fishery information from logbooks or "vessel monitoring system" (VMS).

However, the sampling scheme of the CLARA algorithm must be cautiously used by taking into account the coverage level of the analysis. A set of exploratory analyses, as used here, are recommended in order to test the consistency of results, with the objective of having a reasonable probability of finding objects from all the "existing" clusters in at least one of the generated subsets. In the case study illustrated here, the cluster targeting mackerel (PTB2), the elements of which represent 15% of a matrix of 54,247 records, is not detected when 50 subsets of 100 objects are sampled.

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