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Factors affecting catch rates of NW Mediterranean trawl fleets and derivation of standardised abundance indices

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Objectives of the study

Based on the now available catch and effort time series, this study aims to analyse factors that affect catch rates of hake *Merluccius merluccius*, one of the main groundfish species in north-western Mediterranean trawl fisheries, and to estimate standardised indices of abundance. These factors include: months, years, characteristics of the fleets related with their vessel fishing power (length of the vessel, GRT, HP and GT), fishing regulations i.e. closures and areas (harbors). Data to be used in the study are mainly from 1991 to 1999 from 5 harbours situated in the north-western Mediterranean along the Italian, French and Spanish coast.

This study does not intend to develop statistical techniques. Statistical models have already been successfully applied to produce standardised abundance indices derived from commercial data. First, the study will prepare and explore available catch and effort data, some of which were computerised and integrated into a database. Basic statistical evaluation of individual data sets will be fulfilled before analysis are performed.

Next, statistical modelling will be used to investigate the factors affecting catch rates by fishing ports and to derive annual abundance indices. The analysis of catch rates will be through generalized linear and additive models. Validity of the assumptions involved in the analysis will be checked. The derived indices will be compared with survey-based indices from the International Bottom Trawl Surveys in the Mediterranean (MEDITS project).
Scientific summary

In the Mediterranean groundfish trawl fisheries have traditionally played an important socio-economic role. These fisheries are multispecific, with up to 104 fish species recorded in commercial tows in some areas. Due to their multispecific nature and the large number of landing harbours involved, it has been traditionally difficult to gather long and reliable series of catch and effort data of trawl fisheries for stock assessment purposes.

Based on now available catch and effort data series from a number of western Mediterranean bottom trawl fleets, this study aimed to analyse factors that affect catch rates of hake *Merluccius merluccius*, one of the main target species of these fisheries, and to estimate standardised indices of abundance. Factors affecting catch rates studied were: time (months and years), vessel characteristics as they relate to fishing power (vessel size, GRT, HP and GT), fishing regulations, e.g., closures and geographic area (harbour). Data records contained monthly landings of main commercial species by vessel and number of days fished. The data come from three groundfish fisheries along the Spanish Mediterranean coast (harbours of Santa Pola, Castellón and Barcelona), one from south-eastern France (harbour of Sète) and one from northwest Italy (harbour of Santo Stefano). Data from the following periods were used: Santa Pola 1992-1998, Castellón 1991-1998, Barcelona 1992-1998, Sète 1994-1999 and Santo Stefano 1991-1999. Hake catch rates were analysed by generalised linear and additive models applying routines contained in the S-Plus programming environment.

Hake catches consist mainly of recruits, although older age groups are also present and their relative importance varies spatially and temporally. Since hake landings from the fisheries of Castellón and Barcelona lump together recruits and older ages, in order to model hake recruitment indices it was necessary to identify the components of the fishing activity (vessel-months) targeting the 0-age group. Multivariate analyses (Principal Components, Cluster, and Multiple Correspondence) were used to identify métiers/fishing tactics targeting hake recruits. Models were run with catch rates of the métiers selected to generate standardised recruitment indices.

Results of modelling showed that vessel identity was the main factor affecting hake catch rates. Among the vessel characteristics, size was the best descriptor of fishing power in the selected trawl fleets. Abundance indices exhibited significant inter-annual and seasonal variations and significant but smaller geographic differences. Main effect models were run to compare abundance indices between: a) the 20 métiers identified within the study fleets, and b) the 5 study areas. Models of recruit catch rates were run to compare recruitment indices between a) the 7 métiers identified as representing recruitment within the study fleets, and b) the 4 study areas were recruitment indices could be estimated. Interactions among factors were also analysed. Trends of standardised recruitment indices obtained in this study were consistent with those derived from surveys (MEDITS serie). This result strongly supports the applicability of catch and effort data to assess hake abundance trends.

*Keywords:* cpue, hake, métiers, recruitment, north western Mediterranean
Résumé scientifique

En Méditerranée la pêche au chalut des espèces de fond joue traditionnellement un rôle socio-économique important. Ces pêcheries ont un caractère multispécifique prononcé, avec, à titre indicatif, une valeur maximale observée de 104 espèces pêchées dans un trait de pêche commercial. Ce caractère multispécifique de ces pêcheries associé à l'éparpillement de la flottille dans de nombreux ports font qu'il est habituellement difficile de rassembler des données de capture et d'effort pour estimer les stocks exploités par ces flottilles.


Les captures de merlu sont composées principalement de recrues, bien que des individus plus âgés soient présents dans les captures, à un taux variable selon l'espace et le temps considéré. En ce qui concerne le cas particulier des pêcheries de Castellon et Barcelone dont les captures sont composées à la fois de recrues et d'individus plus âgés, il est nécessaire de sélectionner au préalable les composantes de l'activité de pêche (mois et bateaux) qui visent le groupe d'âge 0. D'une manière générale, les analyses multivariées sont utilisées préalablement à la modélisation pour identifier les métiers/tactiques de pêche qui ciblent les recrues de merlu. Ensuite seules les données de rendements de pêche qui appartiennent à ces métiers sont utilisées pour extraire à partir des modèles linéaires généralisés les indices d'abondance standardisés de recrutement de merlu.

Les résultats de la modélisation montre que le navire est le facteur principal qui affecte les rendements de pêche de merlu. Parmi les caractéristiques physiques des navires, la longueur reste le meilleur indicateur des puissances de pêche des chalutiers. Les facteurs mois et années montrent également des effets significatifs sur les rendements de pêche. Quant au facteur géographique, il est aussi significatif mais à un degré moindre. Un modèle linéaire à plusieurs facteurs sans interaction est mis en œuvre pour comparer les indices d'abondance entre a) les 20 métiers identifiés dans les flottilles étudiées, et b) les cinq zones étudiées. Le même modèle est utilisé pour déterminer les indices annuels de recrutement et pour comparer ces indices de recrutement entre a) les sept métiers identifiés comme étant spécialisés dans la pêche des recrues et b) les quatre zones d'étude où un indice de recrutement est disponible. Les interactions entre facteurs sont aussi analysées. Les tendances des indices de recrutement standardisés obtenues dans cette étude sont cohérentes avec celles obtenues par pêche expérimentale (campagne MEDITS). Ce résultat conforte l'applicabilité des données de capture et d'effort à la mesure de l'évolution de la biomasse de merlu.
Non-specialist summary

Trawl fisheries constitute a traditional and important reality in the western Mediterranean, not just for their social and economic implications (linked, for example, to the number of people employed), but also for its importance in terms of food production and economic value. About 2600 trawlers operated in the area in the early 1990s. Although trawling may take place in the 30-800 m bathymetric range, most fishing effort concentrates between 70-300 m depth. An important characteristic of these fisheries is that they are highly multispecific, with up to 104 different fish species recorded in commercial tows in some areas. However, a small number of species accounts for a large proportion of the catch and of its economic value. In the northwestern Mediterranean 11 species account for most of the production. These species, in declining order of importance in the landings, are: hake (*Merluccius merluccius*), red mullet (*Mullus* spp.), poor cod (*Trisopterus capelanus*), sole (*Solea solea*), anglerfish (*Lophius* spp.), pandora (*Pagellus erythrinus*), octopus (*Octopus vulgaris*), squid (*Loligo vulgaris*), cuttlefish (*Sepia officinalis*), red shrimp (*Aristeus antennatus*), and Norway lobster (*Nephrops norvegicus*).

The catch of a bottom trawler is determined by three main factors: 1) the time that the vessel spends fishing, 2) the abundance of species in the area fished, and 3) the fishing power of the vessel (which in turn depends on some vessel characteristics such as size or engine power, on the gear used, and on other factors that include the crew’s skills). The abundance of the species is thus proportional to the catch obtained per unit of fishing effort, the later representing the combined effect of fishing power and fishing time. Fisheries scientists and the national and international fisheries management bodies use catch and effort data to derive abundance trends of the exploited species. However, the fishing power of a fleet rarely stays constant. Fishermen engage in a continual search for more efficient fishing methods and technologies, and this normally involves developments in vessel types, size or power, in fishing gears, as well as knowledge acquisition. There is a large body of literature relating vessel characteristics such as size, tonnage, or power to catch rates (e.g. catch per unit time). In some cases correlations are good while in other cases they are poor. Nonetheless, as a rule, in fisheries where there are large differences in vessel sizes and in the volumes swept by the gear, as is the case in a trawl fishery, we should expect to find a good correlation between catch rates and vessel characteristics. Thus, in order to estimate abundance indices from catch and effort data one may try to quantify the different components of fishing effort and their variations along the period studied. Alternatively, one can perform analyses aimed at understanding what determines the catching power of individual vessels and then correct for changes in fleet composition over time.

Due to the multispecific nature of Mediterranean trawl fisheries and to the large number of landing harbors involved, it has been traditionally difficult to gather long and reliable series of catch and effort data for stock assessment purposes. Based on the now available catch and effort time series this study aimed to analyse factors that affect catch rates of hake *Merluccius merluccius*, one of the main groundfish species in trawl fisheries in the area, and to estimate standardised indices of abundance. These factors included: months, years, characteristics of the fleets related with their vessel fishing power (length of the vessel, GRT, HP), geographic area. The study was conducted with data of 1991 to 1999 from five fisheries, represented by the harbours of Porto Santo Stefano in Italy, Sète in France and Santa Pola, Castellón and Barcelona in Spain. Data records consist of monthly catches by species of each vessel and the number of days fished per month.

Data sets were analysed using generalised linear and additive models first to investigate the best determinant of fishing power and then to assess the dependency of the catch rates of both hake and recruits on fishing power, year, month and fishery regulations by
area. Although it is well known that in the western Mediterranean hake trawl catches are mainly composed of recruits (fish in the first year of life), the length distribution of the catch was not available for all harbours involved in the study. Thus, in order to be able to derive recruitment indices from total catch and effort data, métiers were identified within each fleet which are representative of the recruitment. A métier is a coherent functional entity in terms of vessel type and size, gear, target species (or group, or size), and spatio-temporal fishing pattern. An integrated analysis was thus conducted to generate standardised recruitment indices. The overall analysis yielded annual indices of both total and recruit abundance by geographic area.

The final step was to compare recruit abundance indices with the abundance indices from an independent data series such as that obtained for EU-MEDITS surveys (from 1994 to present). Both series showed good agreement in the five study areas. Thus, results of this study suggest that hake catch rates data collected from surveys and from commercial fisheries convey similar information and that fishery data can provide a cost-effective way to obtain year-round figures with a good spatial coverage in the western Mediterranean.
1. Introduction

In the Mediterranean groundfish trawl fisheries are widely spread and have traditionally played an important socio-economic role in the region. The trawl fleets operating in the western Mediterranean consist of about 2600 units with an average gross registered tonnage (GRT) of 40 and an average horsepower (HP) of 300 (Oliver and Massuti, 1995; STCF, 1991).

Mediterranean groundfish trawl fisheries are multispecific, with up to 104 fish species recorded in commercial tows in some areas (Massuti et al., 1996). However, a small number of species accounts for a large proportion of the catch and of its economic value. In the northwestern Mediterranean 11 species account for most of the production (Alvarez, 1992). These species, in declining order of importance in the landings are: hake (*Merluccius merluccius*), red mullet (*Mullus* spp.), poor cod (*Trisopterus capelanus*), sole (*Solea solea*), anglerfish (*Lophius* spp.), pandora (*Pagellus erythrinus*), octopus (*Octopus vulgaris*), squid (*Loligo vulgaris*), cuttlefish (*Sepia officinalis*), red shrimp (*Aristeus antennatus*) and Norway lobster (*Nephrops norvegicus*).

Due to the multispecific nature of Mediterranean trawl fisheries and to the large number of landing harbors involved, it has been traditionally difficult to gather long and reliable series of catch data for stock assessment purposes. Hake yield per recruit (Y/R), virtual population (VPA) and length cohort (LCA) analyses have been performed for limited periods and specific fisheries in the northwestern Mediterranean (e.g., Martin, 1989; Oliver, 1991, 1993; Recasens, 1992; Aldebert et al., 1993; Aldebert and Recasens, 1996). Results indicate that hake suffer high exploitation rates at the recruit stage and that stocks are overexploited. However, these type of analyses are data-intensive and are not widely applied. Alternatively, catch and effort data from commercial fisheries provide one of the most readily available sources of information to assess the condition of exploited stocks (Gulland, 1956; Gavaris, 1980). Nevertheless, in northwestern Mediterranean fisheries these data have not been regularly collected because, as in other fisheries (e.g., Fox and Starr, 1996), it has been assumed that they do not provide accurate indices of fish abundance. This perception rests on the assumption that commercial fishing patterns and catch rates are strongly influenced by market conditions, management regulations, weather and other factors. Conversely, surveys, not affected by these factors, are considered to provide reliable data on actual fish distribution and abundance (Fox and Starr, 1996). Thus, series of Mediterranean-wide annual bottom trawl surveys (MEDITS) were initiated in 1994 with the objective of obtaining direct annual estimates of relative abundance of groundfish commercial species (Bertrand et al., 1997). Despite these arguments, in the past decade several institutions of Mediterranean coastal countries established sampling and information networks to collect catch and effort data from the main fisheries.

In terms of management of Mediterranean fisheries, measures to regulate fishing effort exist together with technical measures (i.e. minimum mesh and landing size, minimum distance from the shore and/or minimum depth, temporal closures). Some states have also developed licensing schemes in order to control and monitor their fleets. Due to the diversity of both the typology of fleets and the species composition of catches, the FAO-General Council for Fisheries Management in the Mediterranean (GCFM) has placed emphasis on direct control of fishing capacity and effort rather than of the catches. In this context, a priority of the GCFM Scientific Advisory Committee is to encourage the collection of basic information and the development of methodologies for designing and implementing fishing effort regulations. However, a factor that prevents the implementation of effort regulations is that their effect on each fleet component participating in the fisheries is different. In order to define these fleet components, the métier concept has been used (EEC, 1987). A métier is a coherent functional entity in
terms of vessel type and size, gear, target species (or group), and spatio-temporal fishing pattern, which can be summarized by a consistent array of catchabilities by species and ages. Consequently, any attempt to estimate effective fishing effort as relevant to the fishing mortality in a multi-species fishery, should start with identification of métiers according to this definition (Alvarez et al., 1999).

Catch and effort data have been used to derive indices of relative abundance for many world fisheries (Gulland, 1956; Robson, 1966; Kimura, 1981; Large, 1992; Mejuto and García, 1996; Hoey et al., 1996; Kimura and Zenger, 1997). However, the use of commercial fishery statistics in constructing indices of abundance requires accounting for changes in fleet composition and characteristics (Hilborn and Walters, 1992). For example, standardization is required to correct for changes in the ability of vessels to catch fish (Kimura and Zenger, 1997). Multiplicative models have been used to obtain standardized catch rates in a number of fisheries (Robson, 1966; Kimura, 1981; Large, 1992; Hilborn and Walters, 1992; Hoey et al., 1996; Punt et al., 2000). The model coefficients can be estimated by Generalized Linear Modeling (GLM) techniques (McCullah and Nelder, 1989; Chambers and Hastie, 1992; Hilborn and Walters, 1992). This approach has been applied recently to the hake trawl fishery of the Spanish harbor of Castellón and, to our knowledge, constitutes the first attempt to use the method in Mediterranean fisheries (Goñi et al., 1999).

This study aims to analyze and derive standardized hake indices of cpue for total catch and for recruitment in five trawl fisheries from the western Mediterranean (Figure 1.1). Although length distributions of the catch are not ordinarily collected in all harbors, it is well known that commercial (Oliver and Massuti, 1995; Martín et al., 1998) and survey (MEDITS, Gil de Sola and Ferrandis, 2000) hake catches consist mainly of recruits. As recruits may be spatially segregated and different components of the fleets operate preferentially in certain shelf areas (inner, medium, outer, slope) our analysis includes the identification of métiers as components of trawl fleets operating on hake recruits. This analysis is intended to: a) improve our knowledge of factors affecting hake trawl catch rates, b) investigate methods to improve the applicability of catch and effort data to assess abundance trends, and c) obtain trends of recruitment indices in different areas and to compare them with abundance of recruits from surveys. This is judged highly relevant given the paucity of population data in the area and the high cost of direct assessment surveys.
Figure 1.1 Ports and fishing areas considered in the study: Santa Pola (SP), Castellón (C), Barcelona (B), Sète (S) and Porto Stefano (SPP).
2. Material and methods

2.1. Data

The information used in this study come from three groundfish fisheries along the Spanish Mediterranean coast (harbours of Santa Pola, Castellón and Barcelona), one from South-eastern France (harbour of Sète) and one from northwest Italy (harbour of Porto Santo Stefano). Data from the following periods have been used: Santa Pola 1992-1998, Castellón 1991-1998, Barcelona 1992-1998, Sète 1994-1999 and Porto Santo Stefano 1991-1999. Data records contain species monthly landings by vessel, days fished, and vessel characteristics. Hake landings from Santa Pola and Porto Santo Stefano were available by commercial size categories. Vessel information consists of gross registered tonnage (GRT), horsepower (HP), vessel length (L), and in some cases gross tonnage (GT). Data are collected from commercial catches every month, except in Porto Santo Stefano where information is collected at auction during 3-5 days per month. A two-month fishing closure in spring-summer affects to Castellón fleet. Monthly catch rates by species and vessel were calculated as the ratio of the recorded landings to the number of days fished by each vessel. Hake landing data are considered reliable estimates of catches because in these fisheries discards of hake are negligible (Carbonell et al., 1997).

2.2. Analysis by port

2.2.1. Basic model of cpue

The efficiency of the fishing fleets rarely stays constant. Fishermen engage in a constant search for more efficient fishing methods and technologies, and this normally involves changes in fishing gear as well as knowledge. Fishing vessels are different and some vessels are more efficient than others. Thinking of fishing vessels as discrete classes, we can think of the catch rate obtained as the product of the abundance in a particular year times the efficiency of the vessel class

\[ m_{ti} = A_t q_i \]

where \( m \) is the catch rate, \( A \) is the abundance of fish, and \( q \) is the efficiency. The subscript \( t \) refers to time and \( i \) refers to vessel class. The statistical model then is:

\[ m_{ti} = \mu_{11} \cdot a_t \cdot b_i \cdot e_{ti} \]

where \( \mu_{11} \) is the catch rate obtained by the first vessel class in the first time period, \( a_t \) is a factor that is the abundance in year \( t \) relative to year 1, \( b_i \) is the efficiency of vessel class \( i \) relative to year 1, and \( e_{ti} \) is a factor that accounts for the deviation between the observed \( m_{ti} \) and the expected value for \( t \) and \( i \).

Taking logarithms of both sides, the following linear statistical model is obtained:

\[ \log(m_{ti}) = \log(\mu_{11}) + \log(a_t) + \log(b_i) + e_{ti} \]

The values of \( \log(\mu_{11}) \), \( \alpha \) and \( \beta \) can be estimated using the Generalized Linear modelling (GLM) techniques. GLM is a powerful and useful procedure because it provides a framework to analyse 1) catching power information, 2) other factors in addition to vessel class and time, 3) discrete and continuous variables, 4) interactions between factors and 5) standardised catch rates. From the analysis it may be obtained a “time effect”, which
corresponds to an annual standardised abundance index (if time = years) and thus an abundance trend for the studied species.

The overall modelling procedure of total hake catch rates and catch rates of recruits is summarised in the flowchart of Figure 1.2. The analysis was performed for each fishing area. The first step was to apply a GLM to hake catch rates with vessel, year, month and closure (where applicable) as descriptors. The model used is as follows:

\[ \ln \mu_{cmyp} = \alpha + \delta_c + \phi_m + \lambda_y + \gamma_p + \varepsilon_{cmyp} \]

where, \( \mu_{cmyp} \) is the expected catch for vessel class, month \( m \), in year \( y \), and following or not a closure period, and \( \alpha \) is the catch rate obtained by vessel 1 in January of the first year considered in the analysis, \( \delta_c \) the efficiency of vessel class \( c \) relative to class 1, \( \phi_m \) the abundance in month \( m \) relative to January, \( \lambda_y \) the abundance in year \( y \) relative to the first year, \( \gamma_p \) the change in catch rate if the month is preceded by a closure period, and \( \varepsilon_{cmyp} \) the deviation between the observed catch rates and the expected value for \( cmyp \).

Analysis of deviance to evaluate the significance of the factors in the model and also of the interactions was performed by forward selection comparing models excluding one term at the time. Routines contained in the S-Plus programming environment were used (Becker et al., 1988).

The appropriate probabilistic distribution was investigated since the frequency distributions of hake catch rates were skewed (Figures 2.4, 4.4 and 6.6) and the variances not independent from the means. The results indicated that a gamma distribution was adequate because the variance was proportional to nearly the square of the mean (Figures 2.5 and 4.5). This procedure is similar to that used by Stéfansson (1996) for modelling cpue of groundfish from Icelandic waters. The gamma density function is expressed within GLM's in terms of the mean \( \mu \) and the parameter \( \nu \) that determines the shape of the distribution. The parameter \( \nu \), assumed constant for all observations, is \( \sigma^{-2} \), where \( \sigma \) is the coefficient of variation. The gamma variance \( V(\mu) = \mu^2/\nu \), and a logarithmic-link \( \log(\mu) \) functions were used to relate the expected catch rates to the predictors.

2.2.2. Identification of the best descriptor of fishing capacity

In order to compare hake catch rates between fishing areas, it was necessary to identify a vessel characteristic that could be used as best common descriptor of the fishing power/capacity. The basic model of cpue was used and results of models using different vessel characteristics (TRB, GRT, GT, HP, L) in addition to the other factors (year, month, closure where applicable) were compared. Overall, vessel length was the characteristic that explained more variance in hake catch rates.

2.2.3. Identification of métiers

Hake catches consist mainly of recruits, although older age groups are also present and their relative importance varies spatially and temporally (Oliver and Massutti, 1995). The spatial and/or temporal segregation of hake recruits allows the various components of the each fleet (or métiers) to behave differently with respect to them. Since hake landings from the fisheries of Castellón and Barcelona lump together recruits and older ages, to model hake recruitment indices it was necessary to determine which components of the fishing activity (vessel-months) in these fisheries were targeting the 0-age group. We did this by examining the species composition of the catches, their seasonal variations, and ancillary information of the fisheries.
Figure 1.2. Flowchart of the methodology used to obtain abundance indices from commercial trawl catches in western Mediterranean.
Different multivariate analyses have been applied to the study of commercial catch and effort data in order to identify métiers/fishing tactics in multispecies fisheries (Murawski et al., 1983; Rocha et al., 1991; Sobrino et al., 1995, 1996; He et al., 1997; Alvarez et al., 1999; Pelletier and Ferraris, 2000). Here we have followed an approach similar to that used by Pelletier and Ferraris (2000) to define fishing tactics from commercial catch and effort data. First, Principal Component Analysis (PCA) was performed using a matrix of species proportions by vessel-month observations, excluding species mixtures and groups. The number of species selected for the PCA analysis was determined according to their importance in the landings of each fleet. The S-Plus routine for PCA with scaling – covariance was used. Using PCA as an exploratory tool provides insight into the number of fishing tactics or métiers as revealed by the species composition of in each harbour. It also provides a geometric representation of data and variables, which is easier to interpret than the initial data matrix. Additionally, examination of the principal components (PC) shows which species play a larger role in explaining the observed catches by contrast to species that do not contribute. Data reduction can be achieved by calculating scores for each underlying component and substituting them for the original variables which can be used in further analysis. In addition, information on the variance explained by the single components is available and a decision on this level could be taken. As input variables for further analyses we used the scores of the PCs that explained around 80% of the variance.

Once PCA was performed an Agglomerative Hierarchical Clustering (HAC) was applied using PC scores selected to classify the observations (month-vessel) in each fishery in groupings reflecting fishing patterns, i.e. species mixes linked to a fishing tactic or métier. Use selected PC scores instead of the original variables (matrix of species proportions) allows using only the variables (species) with highest power of discrimination and this excluding from the analysis highly correlated variables (species) or redundant information.

In this technique the clusters are built by successive pairwise agglomerations of elements based on the minimum variance criterion of Ward (1963). Euclidean distance was applied as measure of similarity. The technique provides nested partitions under the form of a dendrogram that were visually interpreted. The distance at combinations in the dendrograms was used to select the number of clusters to be considered. There is no standard objective procedure to select the number of clusters. To explore the different fishing tactics that the cluster analysis may reveal, observations were assigned to either of 3, 4 or 6 cluster classifications.

For each selection of clusters, the species composition within each cluster was calculated. Where relevant, the size category of some species was also included in the species composition. Using these figures and complementary information about the empirical knowledge of the fleets behaviour and fishing grounds plus the differential bathymetric distribution by length/age of hake populations (Oliver and Massuti, 1995) and of other species in the catch, we determined the optimal number of clusters or fishing tactics (métiers) in fleets studied. Single observations were assigned to members of each selected cluster.

As a last step a Multiple Correspondence Analysis (MCA) was carried out to provide a multivariate representation of the interdependence of seasonal patterns, fishing tactics (clusters) and vessels size (length category).

The multivariate analysis were performed with routines contained in the S-Plus programming environment (Becker et al., 1988).
2.2.4. Models by métier

To assess annual and seasonal patterns of activity and cpue trends by métier, individual models were run for hake cpue of each cluster identified with year, month, closure (only in métiers of the Castellón fishery) and vessel as descriptors.

Examination of the results of these models (seasonal pattern of effort, in particular), together with those of the MCAs and the species composition of the catches of each métier, were used to determine which clusters represented fishing tactics directed to hake recruits. Empirical knowledge of the *modus operandi* of each fishery and of the spatial distribution of fishing effort by vessel size was also employed in the process of identification of clusters associated with recruitment.

Finally, models of hake cpue for the clusters (métiers) identified in each area as targeting recruits were also run to obtain recruitment indices by year and month for each fishery. These annual indices were taken as the best estimates of recruitment trends obtained from commercial catches for the study areas and were later compared with the MEDITS abundance indices in the 100-200 m depth stratum where recruits are most abundant.

2.2.5. Global analyses (five ports together)

To compare hake abundance indices and recruitment indices among the five study areas we run models with total hake catch rates and recruit catch rates (in this case only with data from the métiers identified as targeting hake recruits in each fishery), incorporating year, month, and harbour as factors and vessel length as a continuous variable. The indices obtained are the output of this project and the best approach to estimate both indices of hake abundance and of recruitment from commercial catches.

2.2.6. Comparison with survey indices

As an initiative of the European Commission, the Mediterranean International Trawl Surveys (MEDITS Project, co-financed by EU-DG XIV) programme has been designed with the aims of: a) to contribute to the characterisation of groundfish resources in the Mediterranean in terms of population distribution (relative abundance indices) as well as demographic structures (length distributions), and b) to provide data for modelling the dynamics of the populations of 30 targeted species (Bertrand *et al*., 1997). Each year since 1994, standardised surveys are carried out during the spring and the beginning of summer along the coasts of Spain, France, Italy and Greece. In MEDITS a stratified sampling design is used with randomly located stations inside each depth stratum. The bathymetric range covered is 10-800 m., and in the area analysed in this study the average sampling coverage is one station per 60 nm².

Recruitment trends obtained from models of hake cpue for the métiers targeting recruitment in each fishery were compared with the series of MEDITS abundance indices obtained in the same geographic areas since 1994.
3. Results

3.1. Analysis by port

3.1.2. Port of Castellon

3.1.2.1. Data used in the analysis

Data used for the analysis of the Castellón trawl fleet are from 1991 to 1998. The catch records contain monthly landings from 44 vessels, the number of fishing days and the vessel characteristics (length, GRT and HP). The composition of the fishing fleet is as shown in Figure 2.1. The information and sampling network of the Instituto Español de Oceanografía provided the data. Monthly catch rates by vessel were calculated as the ratio of the recorded landings to the number of days fished (all vessels operate 12 hours per day). Due to the sporadic participation in the fishery during the studied period, 9 vessels were excluded in the analysis. As a result, a total of 2667 records were used.

The fleet operated on a 40 mile long stretch of the continental shelf at depths between 20 and 350 m (Figure 2.2). The smaller units operate inshore between 20 and 50 m and the medium and large vessels further offshore, about 50-100 and 100-350 m of depth respectively. This pattern changes when unfavourable weather conditions force small units to stay in port and large units to operate close to shore. As a management regulation, a two-month closure in spring-summer is established (Llorca and Tegedor, 1997). This measure is intended to protect recruitment of hake and of other species of interest (Suau, 1967; Oliver and Massuti, 1995).

The monthly mean cpue of hake in the period 1991-1998 has ranged between 26.5 and 37.7 Kg/day/vessel in 1995 and 1996 (Figure 2.3). No seasonal pattern can be observed but there is a predominance of high cpue’s in spring and lowest values in autumn. Except for 1991, 1996 and 1998, hake cpue in months following the closures were not clearly higher than those before the closure. In general, standard errors were high due to the variation of catch rates among different vessels.

3.1.2.2. Basic models

Modelling the error distribution

Given that the frequency distribution of the hake catch rates was skewed (Figure 2.4) and the variance proportional to nearly the square of the mean (Figure 2.5) a gamma distribution was used in the analysis.

A GLM was run in order to investigate the variation of hake trawl catch rates with vessel, year, month and the fishing closure, a variable indicating if a month is followed by fishing closure. Results from the analysis of deviance (Table 2.1) indicate that all the variables are significant (P<0.00). The model reduces the null deviance from 3926 to 678 which is similar to obtaining a $R^2$ of 0.83 in a normal regression. Most of the variation is explained by vessel which accounts for 78% of the model deviance. Figure 2.6 illustrates the contribution of each of the main effects to the variation of hake catch rates. Rates vary according to the vessel size, as found in previous analysis for the period 1991-1996 (Goñi et al., 1999), and confirm the presence of a seasonal trend in hake abundance in the area. Levels are relatively stable from January to March, increase from April to August and decline to reach minimum values at the end of the year. Significantly higher cpue levels were found from 1991 to 1993, 1996 and 1997. Hake catch rates during the month
following a closure period were significantly higher than catch rates for that month not preceded by a closure.

3.1.2.3. Identification of best descriptor of fishing capacity

Results of models where vessel, as independent variable, was replaced by GRT, HP and vessel length (m) are presented in Table 2.2. Vessel characteristics were modelled as non-linear continuous variables by mean of a non-parametric smoother within a generalized additive model framework. Results indicate that vessel length explains the highest percentage of the explained model deviance (60%) and thus is the vessel characteristic which best represents fishing power. Other variables explain less than 55%.

3.1.2.4. Identification of métiers

PCA was performed with the monthly species proportions of the 35 vessels selected for the analysis. The original database contained 19 species and 3 multispecific commercial categories. For the analysis we selected the 19 species. From the results shown in the biplot in Figure 2.7 at least three groups of fishing strategies can be distinguished. One group is dominated by hake, a second by a snail (Murex brandaris), and a third by mullet (Mullus spp). These results can be related with characteristics of the fleet as follows: the first axis corresponds to large and medium–large vessels fishing mostly for hake and blue whiting (Micromesistius poutassou) and operating from the mid-shelf to the slope; the second axis results from medium-size vessels fishing a mix of species such as mullets, hake and cuttlefish (Sepia officinalis) operating in the middle and inner shelf; and the third axis results from small vessels targeting on coastal species such as snail, Scilliarides (Squilla mantis) and octopus (Octopus vulgaris). The bulk of the observations, however, falls in the centre of these three axes. The results show that over 85% of the variability is explained by the first 6 PCs (Figure 2.8). Loadings of the first 5 PCs are shown in Figure 2.9.

HAC was used to assess the existence of different fishing strategies or métiers in the Castellón fleet that could help identify groups of observations (vessel-months) with different strategies with respect to hake fishing. As input data for the cluster analysis we used the scores of the first 6 PCs of the PCA. Figure 2.10 shows the results as a dendrogram. Observations were assigned to 3 groups of clusters, with 3, 4 and 6 cluster respectively. The species composition by cluster (métier/fishing tactics) of the classification in 6 clusters is shown in Figure 2.11 and can be described as follows:

1. Cluster 1: The main catches are made up by Mullus spp. (31%), Trachurus trachurus, Sparus aurata and hake (9%). However, the presence of several species of molluscs such as Sepia officinalis, Murex brandaris and Loligo vulgaris, and the crustacean Squilla mantis. This catch composition reflects fishing activity along the coastal area.

2. Cluster 2: Main target species are Mullus spp. (15%), Trachurus trachurus and Merluccius merluccius. These two species represent a larger fraction of the catch than within cluster 1 (12%). The lower representation of the species of molluscs and crustacean present in cluster 1 indicate that fishing is performed near the coast but also offshore.

3. Cluster 3: Main target species are Murex brandaris, Squilla mantis and Sepia officinalis which account for 75 % of catches. Merluccius merluccius represents only 2.5 %. This catch composition is characteristic of fishing activity of shallow waters on the coast. The area covered by this activity is restricted to boats of small size.
4. Cluster 4: Main target are fish species such as *Merluccius merluccius*, *Mullus* spp. *Trachurus trachurus* and *Lophius piscatorius* which account for 68% of the catch. Hake is the main species (30%) followed by mullets (14%). This catch composition and presence of some more coastal species (about 2%) are indicative of a medium-shelf activity.

5. Cluster 5: Is the métier with lowest number of observations and main targets are *Micromesistius poutassou* (42%) and *Merluccius merluccius* (30%). This catch composition is related to a fishing activity located mainly on the shelf edge.

6. Cluster 6: This is the métier with the highest proportion of hake in the catch (55%). Other important species are *Lophius piscatorius* and *Mullus* spp. This catch composition is indicative of activity in areas similar to Clusters 4 and 5.

As in the case of PCA, the fishing tactics identified with the HAC reflect the spatial distribution of the activity of the fleet, which covers from the coastal area (cluster 3) to the shelf edge (cluster 5). Hake is present within the 6 métiers (clusters) reflecting its wide bathymetric distribution. In terms of vessel characteristics, the activity of small vessels (S) can be related with cluster 3; that of medium-small (MS) vessels with cluster 1; that of medium-large (ML) vessels with cluster 2; that of large vessels (L) with cluster 4; that of larger vessels (XL) with cluster 6 and that of the largest vessels (XLL) with cluster 6.

MCA was carried out to explore the seasonal patterns of the identified 6 métiers and the relationship between métier and vessel size. Results are in Figure 2.12. Vessel sizes were reassigned into 4 groups: small (S), medium (M), large (L) and extra-large (XL). As can be seen in Figure 2.12 and as indicated in Figure 2.11, métier 3 is related to the small vessels which do not exhibit a seasonal pattern. Métier 1 is related to medium size vessels and exhibit a clear pattern of activity in autumn months. This activity is directed to the mullet fishery and well referenced (Sánchez et al., 1995; Martin et al., 1998). Métier 2 is also related to medium-size vessels but takes place throughout the year. Métier 4 exhibits a similar pattern to métier 2 but is related to the largest vessels. The métiers 5 and 6 are similar to métier 4 in terms of vessel size. All of three take place during the first 3 quarters of the year.

### 3.1.2.5. Basic models for métiers

In order to compare hake cpue in the different groupings of métiers identified (3, 4 and 6), GLMs were applied including month, year, closure, vessel and métier (cluster) as variables. Figure 2.13 shows the results. A high percentage of the deviance is explained in the three models, with a small increase from 85% to 86.2% in the model including 3 clusters to the model including 6 clusters. The percentage explained by the cluster in each of the three models range from 2.5% to 3.5% respectively and the difference in cpue between clusters were significant (P<0.01). Based on these results cluster 6 was chosen as the more suitable to split the different strategies to be discussed regarding the fishing activity on hake.

### 3.1.2.6. Model for recruitment indices

Hake recruits are mainly concentrated in the range 80-200 m depth (Campillo et al., 1989; Oliver and Massuti, 1995; MEDITS surveys, Gil de Sola y Ferrandis, 2000). This bathymetric range in the fishing grounds of the trawlers from Castellón is the widest stretch of the continental shelf of the Spanish Mediterranean coast.
Because the hake length distribution in the catch is not available for Castellón it is not possible to point out which of the above-mentioned métiers best represents recruitment indices. Thus we used results of multivariate techniques (Figure 2.11 and 2.12). We also used the results of the analysis from Santa Pola which gives information about the areas where hake <20 cm are mainly caught. Further, the MEDITS hake abundance indices by depth and the knowledge on fishing behaviour were also considered.

We determined that métiers 2 and 4 from the classification of 6 métiers are those likely to represent hake recruitment abundance. These métiers are related with medium to large size vessels that operate all year round preferentially between 75-200 m of depth, and exploiting a mixture of shelf species.

3.1.2.7. Models for recruitment indices

A GLM of hake cpue of the two métiers selected was run. CPUE was modelled as a function of month, year, closure and vessel length (the best available descriptor of fishing power) as variables (Figure 2.14). Analysis of deviance shows that all variables were significant (P<0.01). Results indicate that recruitment was fairly stable in the period of study and highest recruitment occurred in 1996 and lowest in 1995. Recruitment peaks in May-June and lowest values are in March. The effect of the fishing closure is significant.
Figure 2.1. Frequency distribution of horse power (HP), Gross Registered Tonnage (GRT) and Length (m) of the Castellón groundfish trawl fleet.

Figure 2.2. Map showing the fishing grounds of the Castellón groundfish trawl fleet.
Figure 2.3. Monthly evolution of hake cpue (Kg/day, ± se) of the Castellón groundfish trawl fleet.
Figure 2.4. Frequency distribution of monthly hake catch-rate (Kg/day) of the vessels of the Castellón groundfish trawl fleet in 1991-1998.

log(varcpue) = 0.005 + log(meancpue) * 1.61

Figure 2.5. Regression of log variance/log mean of hake catch-rates (Kg/day) by vessel category (according its GRT) and month of the Castellón groundfish trawl fleet for the period 1991-1998.
Overall CPUE: 91-98

Figure 2.6. Results of main effects model. Each plot represents the contribution of the correspondent variable to the fitted linear predictor: a) vessel; b) year; c) month and d) temporal closure. The fitted values are adjusted to average zero and the broken bars indicate two standard errors. The width of the slid bars at the base of the plots is proportional to the number of observations at each level of the factors.
Figure 2.7. Biplot for the test scores principal factor solution.
Figure 2.8. Screeplot indicating the explained variance by each PC.

Figure 2.9. Leading plot providing a summary of the influence of the original variables (species) on the PCs.
Figure 2.10. Cluster analysis dendrogram illustrating the relationship between groups of vessel/species.
Figure 2.11. Species composition (proportions) of the 6 clusters considered in the Castellón trawl fishery.
Figure 2.12. Relationships between seasonal patterns, vessel size and métier as a result of MCA.

Figure 2.13. GLM predictions of hake cpue considering 3, 4 or 6 métiers.
Figure 2.14. Results of GLM (month, year, closure, vessel length as variables). The model incorporates the two métiers from Castellón trawl fleet considered as targeting on hake recruits.
Table 2.1. Analysis of deviance table for GLM fitted to hake catch rate data from the trawl fishery in Castellón for the period 1991-1998.

<table>
<thead>
<tr>
<th>Terms</th>
<th>Df</th>
<th>Dev.explained</th>
<th>Expl.</th>
<th>Pr(F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessel</td>
<td>34</td>
<td>3066.2</td>
<td>78%</td>
<td>0.000</td>
</tr>
<tr>
<td>Year</td>
<td>7</td>
<td>58.9</td>
<td>2%</td>
<td>0.000</td>
</tr>
<tr>
<td>Month</td>
<td>11</td>
<td>115.2</td>
<td>3%</td>
<td>0.000</td>
</tr>
<tr>
<td>Closure</td>
<td>1</td>
<td>6.9</td>
<td>&lt;1%</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Table 2.2. Comparisons of GLMs on hake catch rates considering different vessel characteristics of trawl fleet based on Castellón.

<table>
<thead>
<tr>
<th>TERMS</th>
<th>Res. dev.</th>
<th>Res. df</th>
<th>Explained variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year+Month+Closure+(vessel)</td>
<td>678.5</td>
<td>2613</td>
<td>78%</td>
</tr>
<tr>
<td>Year+Month+Closure+ s(length)</td>
<td>1507.6</td>
<td>2643</td>
<td>60%</td>
</tr>
<tr>
<td>Year+Month+Closure+ s(GRT)</td>
<td>1720.8</td>
<td>2643</td>
<td>54%</td>
</tr>
<tr>
<td>Year+Month+Closure+ s(GT)</td>
<td>1758</td>
<td>2643</td>
<td>54%</td>
</tr>
<tr>
<td>Year+Month+Closure+ s(HP)</td>
<td>1838</td>
<td>2643</td>
<td>52%</td>
</tr>
</tbody>
</table>
3.1.3. Port of Santa Pola

3.1.3.1. Data used in the analysis

Data used for the analysis of the Santa Pola trawl fleet are from 1992-1998. The records contain monthly landings of more than 105 species and several commercial categories. Hake landings include 4 commercial categories according to length: smallest (<12 cm); small (13-20 cm); medium (21-30 cm) and big (>30 cm). Number of days fished are also available. The vessel characteristics (length, GRT, GT and HP) are in Figure 3.1. A total of 112 vessels operate in this fishery. The information and sampling network of the Instituto Español de Oceanografía provided the data. Most of the fishing activity takes place on the shelf of mainland, except about 25 trawlers that fish in the Ibiza channel. The fleet operating in the mainland shelf undertakes daily trips (12 hours per day), while the units fishing in the Ibiza channel may be at sea up to 4 days. Monthly catch rates by vessel were calculated as the ratio of the recorded landings to the number of days fished.

The fleet operates on a 70 mile long stretch of the continental shelf at depths between 20 and 600 m (Figure 3.2). The seabed of the shelf consists mainly of sand and mud while the slope has muddy bottoms and canyons. The closure for Castellón fleet in spring-summer is not applied to the Santa Pola trawl fleet.

The monthly mean cpue of hake in the period 1992-1998 has ranged between 30 and 51.5 kg/vessel/day in 1994 and 1993 respectively, and no general pattern can be discerned in its seasonal evolution (Figure 3.3).

3.1.3.2. Basic Model for total cpue

A GLM was applied in order to investigate the variation of hake catch rates with vessel, year and month as variables. Results from the analysis of deviance indicate that all otherables are significant (Table 3.1). The model reduces the null deviance from 5145 to 1970 which is similar to obtaining a $R^2$ of 0.62 in a normal regression. Most of the variation is explained by the variable vessel which accounts for 55% of the explained model deviance. Figure 3.4 illustrates the contribution of each of the main effects to the variation of hake catch rates. Highest value is for 1993, and also 1992 and 1996 were above the mean. A decreasing trend in the first semester and an ascending trend in the second semester can be observed.

3.1.3.3. Identification of best descriptor of fishing capacity

Models with year and month were run in order to analyse the vessel characteristics. Results in Table 3.2 indicate that HP explained 40% of the model deviance while GRT, GT and vessel length explained between 54 and 60% of the total variation of hake catch rates.

3.1.3.4. Identification of métiers

PCA was performed with proportions of the selected species and the 112 vessels retained. At least three groups of fishing strategies can be distinguished in the PCA biplot (Figure 3.5). One dominated by blue whiting (Micromesistius poutassou), the second one by the red shrimp (Aristeus antennatus), and the third by octopus. These three axes may be associated with: 1) medium-large vessels acting between the mid-shelf and the
beginning of the slope (150-350 m depth) and fishing mainly on blue whiting, hake and some crustaceans as Norway lobster (*Nephrops norvegicus*), 2) medium-large vessels fishing over 350 m depth and targeting mainly on crustaceans such as red shrimp, red crab (*Gerion longipes*), and fishes such as greater forkbeard (*Phycis blennoides*), hake and blue whiting, and 3) small-medium vessels directed towards more shelf-coastal species such as octopus, horse mackerel (*Trachurus* spp.), mullets (*Mullus barbatus*) and cuttlefish (*Sepia officinalis*). The bulk of the observations, however, fall in the centre of these three axes. The results show that 86% of the variability is explained by the first 6 PCs (Figure 3.6). The loadings of the 5 main PCs are in Figure 3.7.

Next, cluster analysis was used to analyse fishing strategies or métiers in the Santa Pola trawl fleet that could help identify groups of observations (vessel-months) with different strategies with respect to hake fishing. Unlike Castellón fleet, the availability of length distribution of catches allows the recruits to be identified, and the extraction of the group of vessel-month observations that more clearly correspond the fishery for hake recruits can be done directly.

As input data for the cluster analysis we used the scores of the first 6 PCs of the PCA. Figure 3.8 shows the dendrogram. To explore the different fishing tactics that the cluster analysis may reveal, observations were assigned to 3 cluster classification. The species composition of the classification retained is shown in Figure 3.9.

As indicated by the results of PCA, the tactics derived by HAC correspond basically to a spatial gradient of fishing strategies, covering from the more coastal activity (cluster 3) to the slope zone (cluster 2). Most of the important species are known as target species. The hake is present within the 3 métiers reflecting again its wide bathymetric distribution.

The species composition of métiers are as follows:

1. **Cluster 1.** This métier contains an average of 21 vessels by year and a total of 96 vessels in the whole period. Its characteristics are: 18.8 m length, 72 GRT and 95 GT. The 72% of catches are fishes such as blue whiting, scabbardfish (*Lepidopus caudatus*), hake and horse mackerel. The proportion of hake <21 cm is 10%. However, the presence of greater forkbeard, red shrimp and deepwater red shrimp (*Parapeneus longirostris*) denotes activity on the upper slope.

2. **Cluster 2.** It’s the lesser abundant and an average of 15 vessels by year and 66 vessels in the whole period were associated to this métier. Their characteristics are slightly lower than métier 1, with averages of 18.4 m length, 68.3 GRT and 76 GT. The catches are representative from slope fishing grounds, with crustaceans and the presence of the higher proportion of old hakes (8%), typical of deeper bottoms. The proportion of hake <21 cm is 1%.

3. **Cluster 3.** It’s the more frequent with an average of 29 vessels by year and 96 vessels in the whole period. Their characteristics are: 15.8 m length, 44.6 GRT and 59 GT, representing the group of smaller vessels. The catches indicate a fishing activity on mid- and inner–shelf. The proportion of hake <21 cm is 8%.

### 3.1.3.5. Models for recruitment indices

To improve the predictive ability of the general model and to compare the hake recruits (<20 cm) cpue of the different tactics, we run a complete model using month, year, vessel length, as the vessel characteristic which allows comparison among the fleets from different ports. Figure 3.10 shows the predictions. The 54% of the deviance is explained by the model, meanwhile the percentage explained by clusters was 42% (P<0.01).
According the proportion of recruits in the catches, métiers 1 and 3 target clearly on the 
aannual hake recruitment, showing no particular trend among years, although in 1993 and 
1996 the values were over the average. The seasonal evolution shows that levels 
decrease from January to June, increase to reach a maximum in October and decrease 
towards the end of the year.

A new model with métiers 1 and 3 only was run and considered as representative of hake 
recruitment in the area where the trawl fleet from Santa Pola develops its activity. The 
outputs are shown in Figure 3.11.
Figure 3.1. Vessel characteristics of the trawl fleet from the port of Santa Pola.
Figure 3.2. Fishing grounds of the trawl fleet from the port of Santa Pola.
Figure 3.3. Monthly evolution of the hake cpue (Kgr/vessel/day) (±se) of the trawl fleet from the port of Santa Pola.
Figure 3.4. Results of main effects model. Each plot represents the contribution of the correspondent variable to the fitted linear predictor: a) year; b) month; c) vessel. The fitted values are adjusted to average zero and the broken bars indicate 2 s.e. The width of the slid bars at the base of the plots is proportional to the number of observations at each level of the factors.
Figure 3.6. Screeplot indicating the explained variance by each PC.

Figure 3.5. Biplot for the test scores principal factor solution.
Figure 3.7. Leading plot providing a summary of the influence of the original variables (species) on the PCs.

Figure 3.8. Cluster analysis dendrogram illustrating the relationship between groups of vessel/species.
Figure 3.9. Species composition (proportions) of the 3 clusters considered in the Santa Pola trawl fishery.
Figure 3.10. GLM predictions of catch rate of hake recruits (TL < 20 cm) considering 3 métiers in the Santa Pola trawl fishery.
Figure 3.11. GLM predictions of catch rate of hake recruits (TL < 20 cm) considering only métiers 1 and 3 in the Santa Polar trawl fishery.
Table 3.1. Analysis of deviance table for GLM fitted to hake catch rate data from the trawl fishery in Santa Pola for the period 1992-1998.

<table>
<thead>
<tr>
<th>Terms</th>
<th>Df</th>
<th>Dev.</th>
<th>Expl.</th>
<th>Pr(F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessel</td>
<td>122</td>
<td>2817</td>
<td>55%</td>
<td>0.000</td>
</tr>
<tr>
<td>Year</td>
<td>6</td>
<td>307</td>
<td>6%</td>
<td>0.000</td>
</tr>
<tr>
<td>Month</td>
<td>11</td>
<td>51</td>
<td>1%</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Table 3.2. Comparisons of GLMs on hake catch rates considering different vessel characteristics of trawl fleet based on Santa Pola.

<table>
<thead>
<tr>
<th>TERMS</th>
<th>Res. dev.</th>
<th>Res. df</th>
<th>Explained variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year+Month+(vessel)</td>
<td>1970</td>
<td>4971</td>
<td>62%</td>
</tr>
<tr>
<td>Year+Month+s(length)</td>
<td>2381</td>
<td>4858</td>
<td>54%</td>
</tr>
<tr>
<td>Year+Month+s(HP)</td>
<td>3082</td>
<td>4886</td>
<td>40%</td>
</tr>
<tr>
<td>Year+Month+s(GRT)</td>
<td>2083</td>
<td>4848</td>
<td>59%</td>
</tr>
<tr>
<td>Year+Month+s(GT)</td>
<td>2101</td>
<td>4853</td>
<td>59%</td>
</tr>
</tbody>
</table>
3.1.4. Port of Barcelona

3.1.4.1. Data used in the analysis

Data from the port of Barcelona used in the analysis are from 1992 and 1998. The fishing grounds covered by the trawling fleet are shown in figure 4.1. A total of 50 trawlers with a total of 32,538 boat-day of landings operated during the period covered by this study. Of these 50 boats, 15 were excluded from the analysis because they had landed fish only in a single year or in a few days per year (between 1 and 42). Those retained had fished more than one year and they have a total number of landings between 278 and 1513.

For the 35 vessels included in the analysis, data on GRT, HP and length of the vessel are available. For 33 boats the value of GT is also available. These descriptors had the following basic statistics:

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Minimum</th>
<th>Maximum</th>
<th>mean</th>
<th>sd</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessel Length</td>
<td>8.1</td>
<td>24.0</td>
<td>16.58</td>
<td>4.19</td>
<td>0.25</td>
</tr>
<tr>
<td>GRT</td>
<td>4.4</td>
<td>98.61</td>
<td>40.84</td>
<td>24.49</td>
<td>0.60</td>
</tr>
<tr>
<td>GT</td>
<td>4.72</td>
<td>133.35</td>
<td>58.76</td>
<td>38.82</td>
<td>0.66</td>
</tr>
<tr>
<td>HP</td>
<td>40</td>
<td>633</td>
<td>261.12</td>
<td>158.45</td>
<td>0.61</td>
</tr>
</tbody>
</table>

Vessel characteristics are highly correlated. The correlation between descriptor pairs was always positive and very high, between 0.89 (HP-Boat Length) and 0.96 (GRT-Boat Length).

The composition of the Barcelona fleet represented as frequency distributions of the main vessels characteristics is shown in Figure 4.2. Based on the composition two main vessel groups can be identified: small (9 units) and large boats (24 units), which can be summarised as follows:

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Small Vessels</th>
<th>Large Vessels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boat Length</td>
<td>&lt; 12.5</td>
<td>&gt; 15.6</td>
</tr>
<tr>
<td>GRT</td>
<td>&lt; 14.5</td>
<td>&gt; 35</td>
</tr>
<tr>
<td>GT</td>
<td>&lt; 22.5</td>
<td>&gt; 37</td>
</tr>
<tr>
<td>HP</td>
<td>&lt; 82</td>
<td>&gt; 160</td>
</tr>
</tbody>
</table>

Monthly variation of the mean hake cpue from 1992 to 1998 in the port of Barcelona showed few annual differences (Figure 4.3). Within this fleet there is no regulatory closure of the fishery for management purposes. The highest mean cpue in the period was observed in 1993 (15.2 kg/day/vessel), while 1995 registered the lowest levels (10.6 kg/day/vessel). Although the mean cpue were quite regular in the course of the year, a certain seasonal pattern can be observed. In general, lowest cpue were registered in the first months of the year (January to April), while highest levels occurred between May and
July, with values falling gradually until December. This pattern was especially evident in the years 1993, 1996 and 1998. In the years 1992, 1994, 1995 and 1997 a clear tendency did not exist. It is important to point out that the standard error is generally high, due to the great variation of catch among vessels.

### 3.1.4.2. Basic models

**Modelling the error distribution**

The frequency distribution of the hake catch rates was skewed with most values around 25 kg/day per vessel (Figure 4.4). Further, the variance of the catch rates was proportional to nearly the square of the mean as indicated by the slope of the regression shown in Figure 4.5. Thus, a gamma distribution was used for the analysis in modelling hake cpue.

The results of the GLM model where the overall monthly catch rates is a function of vessel incorporated as a 33 level factor, year as a 7 level factor and month a 12 level factor indicate that rates varied significantly between vessels, years and month (Figure 4.6.). The variable that explains most of the variation is the vessel. Rates in 1992 and 1993 were significantly highest and significantly lowest in 1995 and 1996. A peak in catch rates occurred from April to September.

### 3.1.4.3. Identification of best descriptor of fishing capacity

The results of models where vessel, as independent variable was replaced by GT, GRT, HP and vessel length (m) are presented in Table 4.1. The factor vessel explained 70% of the deviance meanwhile the vessel length explains 59% and the rest of the variables less than 55%. Thus, length of the vessel was selected for further analysis as the best descriptor of the fishing capacity for this fleet.

### 3.1.4.4. Identification of métiers

The original database contains up to 100 commercial denominations (*species and multispecifc commercial categories*) and 50 boats. The boats that did not land fish during the whole period were eliminated and the occasional and low-abundance species were also eliminated.

The final data set was a file containing 24 boats and 20 species. These species are those that present the highest percentage of catch and are not mixtures of several species (soup fish, “morallá” and “raballa” (mixed categories of small fish and fry fish)). Thus, PCA was performed using the relative composition of the 20 species retained by vessel.

The results from the PCA analysis are shown in figure 4.7. Three main axis can be distinguished that are suggestive of groups of fishing strategies: The first group is characterised by the red shrimp (*Aristeus antennatus*), the second one by the blue whiting (*Micromesistius poutassou*) and the third one by crabs (*Liocarcinus spp*). The bulk of the observations, however, fall in the centre of these three axes. 87% of the variability is explained by the first 6 PCs (Figure 4.8). The loadings of the first 5 PCs are shown in Figure 4.9.

With the first 6 PCs a cluster analysis was carried out based on the Euclidean distance and the Ward algorithm. Results are presented in Figure 4.10. Observations were
assigned to 3, 4 and 5 groups of clusters. Classification into 4 clusters was considered the best representation of the fishing strategy of the Barcelona fleet. The specific composition of each of these 4 clusters are presented in Figure 4.11. The tactics correspond basically to a spatial gradient of fishing strategies, covering from the more coastal activity (cluster 2) till the slope area (cluster 4). The species composition of métiers are as follows:

Group 1. Identified as the one presenting highest hake percentage (17%). The most important species in this group are blue whiting (28%), greater fork-beard (11%) and shrimp (9%). There are 739 records (vessels/month) associated to this group.

Group 2. Corresponding to the métier conducted by the small vessels. The most important species in this group are crabs (20%), octopus (18%), small octopus (8%) and hake (5%). There are 487 records associated to this group.

Group 3. Corresponds to a mixed type métier with highly variable composition. Important species are: red mullet (19%), octopus (14%), horse mackerel (12%) and sea bream (12%). Hake represents 7%. There are 401 registers associated to this group.

Group 4. Corresponds to the métier which operates on the slope. The target species are shrimp (59%), followed by greater fork-beard (12%), hake (8%) and blue whiting (8%). There are 243 registers associated to this group.

In general the vessels don't stay in a single group or métier but rather they show registers in several métiers. A table showing the pairwise correlation among the groups is the following:

<table>
<thead>
<tr>
<th></th>
<th>group 2</th>
<th>group 3</th>
<th>group 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>group 1</td>
<td>-0.67</td>
<td>-0.29</td>
<td>0.12</td>
</tr>
<tr>
<td>group 2</td>
<td>-0.25</td>
<td>-0.40</td>
<td></td>
</tr>
<tr>
<td>group 3</td>
<td></td>
<td>-0.36</td>
<td></td>
</tr>
</tbody>
</table>

Métiers 1 and 2 were mostly excluding of each other, while the only positive, although weak correlation, is given among the groups 1 and 4.

Results of MCA to investigate the pattern of activity are presented in Figure 4.12. The main objective was to know the relationship between size of vessels, métiers and months. Métier 1 was associated with large vessels, showing a clear seasonal pattern of activity, mainly in June -July. The same occurred with métier 4 that corresponded to medium size vessels and they centred their activity in spring. Métier 3 exhibited activity throughout the year. Métier 2 corresponded to the small vessels and they did not exhibit any seasonal pattern.

3.1.4.5. Basic model for métiers

GLMs were applied considering month, year, vessel and classification in 3, 4 and 5 clusters as explanatory variables. Results are in Figure 4.13. A high deviance is explained in the three models, with a small increase from 72% to 75% in 3 to 5 clusters. The percentage explained by the 3 to 5 clusters range from 3.2% to 5.6% and cpue varied
significantly with clusters in all three cases \((P < 0.00)\). Although the classification of 5 clusters explained the highest percentage of the deviance, the empirical knowledge of the behaviour of the fleet and the results of the multivariate analysis suggested that 4 clusters is the more suitable option to split the vessels in the different fishing strategies.

Results of a GLM on hake cpue considering vessel length as the best available descriptor of the fishing power, year, month and 4 clusters are represented in Figure 4.14. The model explains 64% of the deviance and all the variables were significant \((P < 0.00)\).

Fitted values of hake cpue for 1992 and 1993 are above the mean, 1995 and 1996 are the years of lowest values and 1997 and 1998 show a certain recovery although below the mean. The monthly evolution shows that the period between May and September is above the mean. These months coincide with the recruitment peak of the species to the gear (Oliver and Massutí, 1995). The cluster corresponding to Métier 1 ("hake") presents the highest cpue, while métier 3 ("mixed"), 4 ("red shrimp") and especially métier 2 ("coastal") have lower values.

To decide which of the above-mentioned métiers best represents the trend of recruitment indices in Barcelona fishing area auxiliary information was used. Information about the bathymetrical distribution of recruits from MEDITS surveys, the seasonal pattern and specific composition of métiers and depth range of fishing fleet suggest that métiers 1 and 2, which usually operate between 70 and 300 m, are the more likely indicators of recruitment indices.

### 3.1.4.6. Models for recruitment indices

A GLM where the hake cpue from métiers 1 ("hake") and 2 ("coastal") are a function of month, year, and vessel length (the best available descriptor of fishing power) as variables was applied to obtain recruitment indices by year and month in Barcelona. Analysis of deviance showed that all the variables were significant \((P < 0.00)\). Results are represented in Figure 4.15. Abundance indices are highest for 1992 and 1993 and lowest in 1995. Seasonal trend indicates that recruitment clearly starts in spring. This image is sharper than that provided by the analysis incorporating the 4 clusters in Figure 4.14, reinforcing the choice of clusters 1 and 2 as best representation of recruitment in this area.
Fig. 4.1. Fishing grounds of the Barcelona trawling fleet (redrawn from Lleonart, 1990).
Figure 4.2. Distribution of vessel descriptors for the Barcelona fleet.
Figure 4.3. Time series of monthly hake cpue (1992-1998) in the port of Barcelona.
Figure 4.4. Hake cpue frequency distribution in the Barcelona fleet (1992-1998).

Figure 4.5. Regression of log (hake cpue mean, kg/day) to log (hake cpue variance) by vessel and month.

\[ y = 1.8741x + 0.3361 \]
Figure 4.6. Results of the main effects model: vessel, year and month.
Figure 4.7. Plot of the first two components of PCA.

Figure 4.8. Variability explained by the first 10 PCs.
Figure 4.9. Specific composition of the 5 firsts PCs.

Figure 4.10. Dendrogram of the cluster analysis.
Figure 4.11. Relative specific composition of catches by métier.
Figure 4.12. Representation of the MCA plot showing the relationships between métiers, vessel size and months.
Figure 4.13. GLMs predictions of hake cpue considering 3, 4 and 5 métiers. Correspondence with vessel’s length is indicated by letters in boxes. L: large (métier “hake”); S-M: small-medium (métier “mixed”); ML: medium-large (métier “shrimp”); S: small: (métier “coastal”).
Figure 4.14. Result of complete GLM (vessel length, year, month and cluster 4). Each plot represents the contribution of the corresponding variable to the fitted linear predictor (hake cpue).

Figure 4.15. Results of GLM (month, year, vessel length as variables). The model incorporates the two métiers from Barcelona trawl fleet considered as targeting on hake recruits.
### Table 4.1. Comparisons of GLM’s on hake catch rates considering different vessel characteristics of trawl fleet based on Barcelona.

<table>
<thead>
<tr>
<th>Terms</th>
<th>Res. Dev.</th>
<th>Res. Df</th>
<th>Explained variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year+month+Vessel</td>
<td>1033.4</td>
<td>1829</td>
<td>69.5%</td>
</tr>
<tr>
<td>Year+month+length</td>
<td>1402.1</td>
<td>1848</td>
<td>58.6%</td>
</tr>
<tr>
<td>Year+month+GT</td>
<td>1551.6</td>
<td>1848</td>
<td>54.2%</td>
</tr>
<tr>
<td>Year+month+GRT</td>
<td>1769.3</td>
<td>1848</td>
<td>47.8%</td>
</tr>
<tr>
<td>Year+month+HP</td>
<td>2018.3</td>
<td>1848</td>
<td>40.5%</td>
</tr>
</tbody>
</table>
3.1.5. Port of Santo Stefano

3.1.5.1. Data used in the analysis

The area investigated was located in the Northern Tyrrhenian Sea, along the Tuscany coast (Figure 5.1). It is delimited to the North by the Elba Island and to the South by the promontory of Argentario and Island of Giannutri.

The coastline is characterised by vast sandy coastal zones alternating with rocky coastal areas, the most important of which are the Piombino and Monte Argentario Promontories. In addition, there are five islands belonging to the Tuscan Archipelago: Elba, Pianosa, Montecristo, Giglio and Giannutri. The Island of Elba, the largest among the Islands of the Archipelago (223.5 km²), is of particular importance as it constitutes an important barrier between the Ligurian basin (to the North) and the Tyrrhenian basin (to the South).

The study area stretches for almost 11000 km², with 80% of its extent exploitable by trawling. The sea bottom shaped like an amphitheatre degrading southwards between the islands of Giglio and Montecristo, where the maximum depths of over 700 m are reached. The continental shelf is vast, with depths down to 200 m occupying almost 70% of the total surface.

In the period comprised between 1990 and 1999, 58 trawlers were engaged in fishing activity in Port Santo Stefano. Their basic characteristics are in Table 5.1. Figure 5.2 shows the frequency distributions of the four vessel descriptors. A very similar distributions of GRT and GT is observed. The range of values of both descriptors was extremely wide. Vessel length was more homogeneous, with the majority of the vessels ranging between 17 and 22.9 m. There was a wide range of engine power, but a high percentage of boats showed values concentrated in the 200-299 and 400-449 HPA classes.

Over the last 10 years, the fleet has been greatly modified (Figure 5.3, above). First, a marked and constant reduction of number of boats was observed, falling from a maximum of 48 units in 1990 to a minimum of 29 in 1997 (39.6% reduction). A slight increment was noted in the last two years (32 boats). Moreover, the renewal of this fleet was accentuated by the periodic substitution of some units by boats from other ports. During the study period, annual total GRT, GT, Length and HP composition of the fleet showed a trend similar to that of boat number (Figure 5.3, left side). In contrast, no particular trends were observed in the annual mean of the four descriptors, confirming only small changes in the boat characteristics during the past decade (Figure 5.3, right side).

Data are from 1991 to 1999 monthly sampling of Porto Santo Stefano commercial trawl landing. Data were collected during two to five days per month by researchers of the Dipartimento di Scienze dell’Uomo e dell’Ambiente (DSUA). During sampling, landings by each species (or group of species) was recorded by commercial category. Landing data collected on sampling days were subsequently extrapolated to estimate total monthly production of the fleet, by means of conversion factors computed from a comparison, for each month, of days of sampling with total fishing days of the fleet.

Hake landings of Porto Santo Stefano are market in four categories, closely correlated with the size of the specimens (Table 5.2).

The reduction in number of boats observed during the period studied was also reflected in the total monthly fishing days of the fleet (Figure 5.4, above). Mean monthly fishing days per boat also showed a more noticeable decrease in the past two years (Figure 5.4, below).
Hake commercial landings were also studied according to the catch per unit of effort (cpue), with the fishing day considered as unit of effort. Cpue was expressed as mean daily landing per boat during the 3-5 days of direct sampling at auction, without extrapolation of these data to the month. Monthly cpue evolution for each year is displayed in Figure 5.5. Years show no clear monthly patterns for total hake, with values ranging from 30.4 to 119.3 kg/day per boat. Annual variability in the cpue trend was also observed for small hake. However, for this commercial category the highest values were more frequently observed in February-March and in Autumn (maximum value 82.4 kg/day per boat in September 1995).

In addition to landing data, information on the type of trawl net used by each boat during each fishing day was also recorded. Two types of trawl net were used in Porto Santo Stefano, Traditional (TT) and Wide Opening (WOT) trawl. These were considered as two distinct gears, as they presented quantitative and qualitative differences in the catches. The Traditional trawl net, locally called “tartana” and/or “volantina” was characterised by a vertical net mouth of about 1 meter, which could be utilised without distinction by small and large boats. The Wide Opening trawl net (about 4-5 m of vertical opening at the net mouth) was employed only by more powerful vessels. As a matter of fact, the latter type of net was the bigger of the two, requiring large sized steel doors (up to 300 kg) for its utilisation.

The different structure of the two nets involved a different activity at sea. TT was utilised in a broad depth range, varying from 100 to 600 m (Figure 5.6, above). The most important target species of this gear were hake, Norway lobster (Nephrops norvegicus), horned octopus (Eledone cirrhosa), deep water rose shrimp (Parapenaeus longirostris) and red shrimps (Aristaeomorpha foliacea and Aristeus antennatus). Vessels using WOT net generally worked on shallow bottoms of the continental platform, usually at less than 150 m depth (Figure 5.7, below), and mainly employed this net to catch red and striped red mullets (Mullus barbatus and Mullus surmuletus), hake (Merluccius merluccius), squid (Loligo vulgaris), Sparids and Serranids.

Use of WOT net in Porto Santo Stefano increased from 1990 until 1996, with the consequence that the 50% of the boats utilised this type of net in 1996 (Figure 5.7). From 1998 onwards, a stabilisation of the fleet around 32 units was observed and a new increased use of TT as compared to WOT. On 31 December 1999 The Porto Santo Stefano trawl fleet was composed of 32 vessels, 19 of which using TT and 13 WOT.

Trawlers using TT had a mean engine power and a mean gross tonnage of 300 kW and 40 tons respectively. However, greater variability in boat characteristics was observed in this group, because this type of net was utilised both by smaller vessels fishing on the continental platform as far down as the upper limit of the continental shelf, and also by larger vessels fishing on bathyal bottoms. Generally, TT boats departed from the port at 3.00-4.00 a.m. and returned late in the afternoon, after carrying out a minimum of two commercial hauls (4-5 hours each) during the winter and a maximum of 3-4 hauls during the summer. In favourable sea conditions, TT vessels frequently performed 2 or 3 day trips, carrying out nightly hauls each lasting 5-6 hours, mostly designed to catch rose or red shrimps.

Trawlers using WOT showed, on average, greater gross tonnage and engine power (≥50 tons and 400 kW) than TT boats. Generally departing very early from the port (0.00-1.00 a.m.), they worked exclusively on the continental platform. On each fishing day these boats carried out 45 hauls, each lasting 1.5-3 hours. These larger trawlers likewise performed 2 or 3 day trips, fishing during the night.
Although all Porto Santo Stefano trawlers exploited hake, the boats with TT were selected to identify the fishing strategy (“metier”) more representative of recruitment of this species. It was found that medium-small boats employing this type of net actively fished on the bottoms where the nursery areas of this species are localised. The Porto Santo Stefano Database contained data on 20 boats using Traditional trawl in the period comprised between 1991 and 1999. For each boat a mean monthly cpue for hake was calculated, the fishing day being considered as the effort unit. A total of 1045 observations were available in the Database. The file also contained boat characteristics and the landings of 19 species or groups of species which were used in further analysis to identify the different typologies of fishery involving the Traditional net.

3.1.5.2. Identification of métiers

In order to evaluate the presence of different fishery strategies or métiers in the Porto Santo Stefano Traditional trawl fleet, PCA was performed on the proportion of nineteen species. Results showed that the first five components accounted about 78% of the variability (Figure 5.8). The most important species for the 5 first components are displayed in Figure 5.9. The biplot of first and the second components are displayed in Figure 5.10. The bulk of the 1045 observations fell in the centre of a triangle, because the species considered for analysis were generally an important component in the landings of all the boats using this type of net. Despite this, different typologies of fishery could be identified in the biplot considering the three vertices of the triangle: observations characterised by small and medium size hake catches (M.merl1 and M.merl2), observations with large size E. cirrhosa (E.cirr2) and observations characterised by catches with deeper species (M. poutassou, P. longirostris and N. norvegicus). A relation between metier and boat characteristics were identified: the activity targeting deeper species was mainly carried out by larger boats, while the other two métiers were performed by small-medium vessels.

Scores assigned to the five components were used to create a matrix in order to classify the fishing activity by cluster analysis. Applying HAC, three main clusters were identified (Figure 5.11).

Cluster 1 was characterised by deep fishery targeting crustacean Decapods (Figure 5.13). The most important species of this metier were M. poutassou (26% of the total biomass landed), small size M. merluccius (13%), N. norvegicus (12%) and P. longirostris (10%). Catch of large boats mainly contributed to this cluster (Table 5.3).

Cluster 2 showed a landing composition (Figure 5.12) containing a large proportion of more coastal species in comparison to cluster 1, with great abundance of M. merluccius (62% of the total) and E. cirrhosa (15%). This fishing activity was carried out mainly by small-medium size boats (Table 5.3) and was designed to catch small size specimens of horned octopus (6%). Hake landing was composed of a large quantity of small size specimens (over 32% of the total landing), because of the overlapping of fishing grounds with the nursery areas of this species.

In cluster 3 the species composition of the landing was very similar to that of cluster 2 (Figure 5.13). M. merluccius (39%) and E. cirrhosa (34%) were found to be the two most important species. The major difference compared to cluster 2 was the landing of a notable quantity of large specimens of E. cirrhosa. But as in cluster 2, small hake constituted an important component, representing about 15% of total biomass.

The landing composition and boat characteristics contributing to the clusters 2 and 3 were very similar. Separation of the two clusters was mainly due to a temporal factor, as the
boats and the bottoms exploited largely coincided in these two cases. However, cluster 2 represented the fishing activity of small-medium boats from August to November, when small specimens of *E. cirrhosa* were recruited to the gear on bottoms ranging from 80 to 200 m of depth, while cluster 3 resulted from the fishing activity carried out by the same boats during the other months when this resource was not available, as clearly explained in Figure 5.13.

3.1.5.3. Model for recruitment indices

GLM was applied to the hake cpue belonging to the small size commercial category (Mmerl1). Factors taken into account for the analysis were vessel, year, month and cluster. On the basis of the results obtained through HAC, GLMs were applied to two data sets: in the first analysis clusters 2 + 3 were aggregated (fishery nearer the coast); in the second analysis clusters 2 and 3 were maintained separated. The results are shown in Tables 5.4 and 5.5 respectively. In both models incorporating all independent variables without interactions reduced the deviance by about 30 %.

Results in Figure 5.14, above, show that cpue of small hake in cluster 1 was significantly lower than in clusters 2+3. The analysis performed with the three clusters maintained separate showed that cluster 2 was higher than the other two (Figure 5.14, bellow).

The contribution of the three main effects (year, month and vessel) to the variation of cpue of small hake within cluster 1, 2, 3 and cluster 2 + 3 is illustrated in Figure 5.16. Although some differences between clusters were observed, clusters 2 and 3 were chosen, because empirical knowledge indicate that these best represented the hake recruitment. Note that these métiers were carried out by the same small-medium boats fishing on bottoms where small hake were very abundant. High similarity in annual cpue trends between clusters 2 and 3 is shown with minimum values in 1996 and 1998 and fairly stable values in the others seven years (Figure 5.15). The correspondence was low when monthly trends were compared, partly because the two métiers showed a seasonality of activity.

Over the nine years, no constant monthly cpue pattern was observed even when clusters 2 and 3 were analysed together (Figure 5.16). However, minimum values were found more frequently in May, July and August.

Therefore, the observations of clusters 2 and 3 from Porto Santo Stefano were selected to represent recruitment. These two métiers corresponded to the activity of small-medium boats using the Traditional trawl net.
Figure 5.1. Study area. Northern Tyrrhenian Sea.
Figure 5.2. Distributions of the descriptors. Porto Santo Stefano.
Figure 5.3. Evolution of the trawl fleet in the period 1990-1999. Porto Santo Stefano.
Figure 5.4. Total monthly fishing days of the Porto Santo Stefano trawl fleet (above) and mean monthly fishing days per boat (below).
Figure 5.5. Monthly evolution of hake cpue (± s.e.) in Porto Santo Stefano.
Figure 5.6. Fishing areas of the Porto Santo Stefano trawl fleet. Above: fishing grounds exploited by Traditional Trawl. Below: fishing grounds exploited by Wide Opening Trawl.

Figure 5.7. Subdivision of the trawl fleet by type of gear. Porto Santo Stefano.
Figure 5.8. Results of PCA. Variability of Traditional trawl landing composition accounted by the first ten components.

Figure 5.9. Most important species for the first five components of PCA.
Figure 5.10. Results of PCA. The nineteen species selected and the 1045 Traditional trawl observations plotted on the plane identified by the first two components.

Figure 5.11. Dendrogram from cluster analysis. Porto Santo Stefano.
Figure 5.12. Species composition of the three main clusters. Porto Santo Stefano.
Figure 5.13. Fishing activity performed during the year by the boats of the three clusters identified.
Figure 5.14. Model fitted to small hake cpue data of Porto Santo Stefano, considering two (above) or three clusters (below).
Figure 5.15. Results of the main effects model applied to each cluster.
Figure 5.16. Results of the main effects model applied to clusters 2+3. Monthly trends of small hake cpue in each year considered.
Table 5.1. Basic characteristics of the Porto Santo Stefano trawl fleet.

<table>
<thead>
<tr>
<th>Category</th>
<th>Size of the specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>Until 15 cm of total length (TL)</td>
</tr>
<tr>
<td>Medium</td>
<td>From 15 cm to 22 cm TL</td>
</tr>
<tr>
<td>Large</td>
<td>From 22 cm to 40 cm TL</td>
</tr>
<tr>
<td>Very large</td>
<td>Larger than 40 cm TL</td>
</tr>
</tbody>
</table>

Table 5.2. Hake commercial categories in Porto Santo Stefano trawl landings.

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>st. dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boat length</td>
<td>11.2</td>
<td>29.1</td>
<td>20.1</td>
<td>3.5</td>
</tr>
<tr>
<td>HPA</td>
<td>130</td>
<td>900</td>
<td>442</td>
<td>185</td>
</tr>
<tr>
<td>GRT</td>
<td>9.7</td>
<td>119.6</td>
<td>45.1</td>
<td>21.8</td>
</tr>
<tr>
<td>GT</td>
<td>11.6</td>
<td>122.0</td>
<td>50.5</td>
<td>24.0</td>
</tr>
</tbody>
</table>

Table 5.3. Characteristics of the boats contributing to the three clusters.

<table>
<thead>
<tr>
<th>CLUSTER</th>
<th>Boat Length</th>
<th>HPA</th>
<th>GRT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>st. dev.</td>
<td>st. dev.</td>
<td>st. dev.</td>
</tr>
<tr>
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</tr>
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<td>3</td>
<td>19.33</td>
<td>361.7</td>
<td>39.06</td>
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Table 5.3. Characteristics of the boats contributing to the three clusters.
<table>
<thead>
<tr>
<th></th>
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<th></th>
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</tr>
</thead>
<tbody>
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<td>NULL</td>
<td></td>
<td></td>
<td>991</td>
<td>968.1918</td>
</tr>
<tr>
<td>Vessel</td>
<td>19</td>
<td>118.4557</td>
<td>972</td>
<td>849.7360</td>
</tr>
<tr>
<td>Year</td>
<td>8</td>
<td>47.8490</td>
<td>964</td>
<td>801.8870</td>
</tr>
<tr>
<td>Month</td>
<td>11</td>
<td>67.8237</td>
<td>953</td>
<td>734.0633</td>
</tr>
<tr>
<td>Clusters2</td>
<td>1</td>
<td>34.1137</td>
<td>952</td>
<td>699.9496</td>
</tr>
</tbody>
</table>

Deviance explained: 27.7 %
Deviance explained by clusters2: 3.5 %
Deviance explained by vessel: 12.2 %

Table 5.4 Analysis of deviance table for the GLM applied by grouping clusters 2 and 3.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>NULL</td>
<td></td>
<td></td>
<td>991</td>
<td>968.1918</td>
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<tr>
<td>Vessel</td>
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<tr>
<td>Year</td>
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<td>47.8490</td>
<td>964</td>
<td>801.8870</td>
</tr>
<tr>
<td>Month</td>
<td>11</td>
<td>67.8237</td>
<td>953</td>
<td>734.0633</td>
</tr>
<tr>
<td>Clusters3</td>
<td>2</td>
<td>67.6867</td>
<td>951</td>
<td>666.3766</td>
</tr>
</tbody>
</table>

Deviance explained: 31.2 %
Deviance explained by clusters3: 7.0 %
Deviance explained by vessel: 12.2 %

Table 5.5. Analysis of deviance table for the GLM applied by maintaining the three clusters separate.
3.1.6. Port of Sète

3.1.6.1. Data used in the analysis

The fleet of Sète is composed by about 40 boats distributed in two categories: 11 bottom trawl trawlers (CF) oriented exclusively toward benthic and demersal species, and 29 trawlers that use high vertical opening trawl (GOV) and that target benthic and demersal species alternately with small pelagics as anchovy and sardine.

The principal characteristics of these trawlers are described in Table 6.1 and Figure 6.1.

The vessels using the two types of fishing gear show different characteristics: the trawlers using the CF correspond to the smallest (16 to 20 m) and oldest vessels (> 30 years on the mean) and with mean engine power of 290 kw and mean tonnage equal to 44 GT. Trawlers operating with GOV fishing gear are newer and larger (24.5 m in mean) and better equipped with catch capacity with engine of 316 kw and tonnage of 64 GT.

For the analysis of the port of Sète, trawlers with high vertical opening (GOV) were selected. In this group, we also have selected the trawlers having landed more than 500 kg / year of hake.

Figures 6.2 and 6.3 show the relationships between characteristics of the 40 vessels in the fleet. Variables are positively correlated and the tonnage and engine power increase with the length of the vessel. 36 vessels have an engine power of 316 kw nevertheless they have a wide range of fishing power. In fact, above 316 kw, boats move from one administrative group to another and are taxed more heavily. This is the reason why a bias exists between the engine power declared and the actual engine power.

Figure 6.4 shows the variation of hake mean monthly cpue by boat and day of fishing from 1994 to 1999. The mean is equal to 98 kg/day/boat with a coefficient of variation of 33%. The inter-yearly evolution of the mean is marked by a fall of the cpue in 1997 followed by an increase of the same magnitude in 1998. During these two years of large variation, the coefficient of variation reaches 43%. Seasonal variation of cpue is characterised by two seasonal peaks with a variation coefficient in the order of 16%.

Data are from the network inter auctions RIC (Réseau Inter Criée), department which is responsible for the Direction of Fishing Administration for data collection. The RIC makes a first check of the information received from auctions, detects the mistakes of data catches and of coding, and assure a standardisation of the codes used by the different auctions. The RIC is responsible for the control of the reliability of the information transmitted by the different auctions by checking them against files of reference previously established. But the major part of the production of small pelagic fishes (sardine, anchovy) by the trawlers of the Gulf of Lions is sold through the intermediary of some organisations of producers (OP). The information that comes from the organisations of producers (OP) are not built-in in the RIC data until 1997.

The data base is explained in detail in Pérodou (1999).

3.1.6.3. Identification of métiers

The goal of this section is to define métiers and to classify the trawlers in the identified métiers. The 16 species that were retained for the analysis are the following: sardine (Sardina pilchardus), anchovy (Engraulis encrasicolus), hake, poor-cod (Trisopterus capelanus), anglerfish, skate (Raja spp.), red mullet, octopus, cuttlefish, sole, red squid
(Todarodes sagittatus) common pandora (Pagellus erythrinus), axillary sea bream (Pagellus acarne), bogue (Boga boga), sea bass (Dicentrarchus labrax), and gilt-head sea bream (Sparus aurata).

PCA analysis was performed by year to investigate possible tendencies in the various métiers. In the analysis n rows and p column elements (i,j) correspond to the proportion of the jth species in weight made by the ith boat in one year. PCA provides a descriptive graph of the activity of the trawlers, and a classification of these trawlers in the various métiers. The software SPAD.N (CISIA, 1996) was used for the multivariate analysis.

Results of PCA showed no differences in the analysis of the six years of observation. Thus, the results for year 1999 presented in Figure 6.5 are representative for the period. Three main groups are distinguished in the plan of the factorial axis 1 and 2. The first three factorial axis explain 75% of the total variance.

To classify the trawlers in the three groups described, an automatic classification method (criteria of Ward, 1963) was used. This exploration of the data permits us to draw up a balance of the resemblance between boats and to determine groups that are homogeneous, in parallel to draw up a balance of the resemblance between percentages by species and to show some homogeneous groups of variables, and finally to superpose the two previous typologies in order to characterise one by the other. In the ideal situation, the two typologies are superposed, every group of species characterises a group of boats and reciprocally.

Based on the results obtained, the three métiers and the corresponding vessel characteristics are as follows:

1) Métier I ("small pélagic fishes") is a group well differentiated, and is composed of boats that fish as target species the blue fish (sardine, anchovy), and secondarily the hake.

2) Métier II ("inshore demersal species") is composed of few trawlers that target on inshore groundfish species like sole, red mullet, octopus, cuttlefish, and of other groups of species that migrate to sea-lagoon like the sea bass and the gilt-head sea bream.

3) Métier III ("offshore demersal species") is composed of trawlers that exploit as target species the hake and offshore groundfish species as the anglefish, the poor cod and the squid.

A description of the typology of these 3 métiers derived by PCA by year are summarised in table 6.2. These typologies are identical to that found by Taquet et al. (1997) in an analysis concerning catches from the fleet of Sète with data from 1989.

Further analysis are based on data from the métier III specialised in the catch of the hake. In this group, the mean vessel length is equal to 24.8 m (23 m min. and 25 m max.) and the mean tonnage is equal to 69 GRT (49 GRT min. and 84 GRT max.). The engine power, equal to 316 kw, is identical for all boats.
3.1.6.5. Basic model for métiers

Description of the data from métier III

In the case of the analysis of the Port of Sète the catch classified as belonging to métier III are catches from vessels operating within the distribution of hake and are representative of hake total abundance and not as of mainly recruitment as in the case of the analysis of the other ports in the study.

The fishing trips of boats which belong to the métier III represent 12017 trips from the initial base of 165000 trips. Records of catches lower than 10 kg of hake by fishing trip, which correspond in general to incidental catches, were removed. Also data from boats present just one or two years on the 6 years in the study were excluded. Thus, a set of 9918 trips was selected. Extreme values go from 10 kg/day to 636 kg/day. The median value is equal to 123 kg/day and the mean equal to 134 kg/day with a standard deviation of 81 kg/day.

The distribution of the cpue is skewed (Figure 6.6) and the slope of the regression of mean catch rates versus variance is around 2. Thus a gamma distribution was used to model the cpue variation in further modelling.

In Figure 6.7 an almost-parallel evolution of the yearly means of hake rates of trawlers belonging to métier III can be seen. This indicate absence of interactions between year and vessel factors. Figure 6.8 suggests that interaction between the factors year and month exits.

Results from the model including year, month and vessel are represented in Figure 6.9. Extreme lowest value was obtained for 1997 and highest corresponds to 1999. A seasonal pattern shows two peaks in spring and autumn. Results of the deviance analysis presented in Table 6.3, indicates that the model without interaction explains 21.6% of the deviance of the data, while 13.8% is explained by the boat factor, 6.9% by the year and 0.8% by the month. The effect of these three factors is significant (P<0.01). Intercept and year coefficients from the model are presented in Table 6.4.

The table of deviance in Table 6.5 indicates that model with 3 factors and year and month interaction explains 33% of the total deviance, the interaction explains 11.5% .

3.1.6.4. Identification of best descriptor of fishing capacity

In a precedent study (Pérodou, 2000) the factors which are likely to explain the differences seen in the fishing capacity between boats have been researched. Factors analysed were their technical characteristics as length, engine power and tonnage. Engine power did not appear to be a major factor in the difference in catch rates between vessels. Two other explanatory factors were significant. These factors are the port where the catch is landed and the type of trawl. These are the bottom trawl (CF) and the trawl with the large vertical opening (GOV) trawl. In this case, the length of all the vessels selected for the analysis is about 25 m (Figure 6.1), thus the effect of this factor was not investigated. The same was true for the engine power.

The comparison of the model incorporating GRT as a descriptor of fishing capacity and a model incorporating the vessels themselves is presented in Table 6.6. Vessel explains 37% of the deviance and GRT 26%. Figure 6.10 shows that no relationship exist between catch rates of hake and the GRT of the vessels selected for this analysis.
3.1.6.6. Model for recruitment indices

Data from 1997 to 1999 were used to model recruitment. For earlier years length distribution of catches was not available. Results are presented in Figure 6.11. Similar pattern to that observed for the model based on total catch (Figure 6.9) was obtained with lowest value in 1997 and highest value in 1999 but not significantly different from 1998. The seasonal pattern is also similar but values in August and September are not as low as for the total catch results.

![Fig. 6.1. Histograms of main characteristics of Sete's trawlers. (GOV : high vertical opening trawl ; CF : bottom trawl).](image-url)
Figure 6.2. Relationship between vessel length (m) and engine power (Kw) for the trawlers of Sète.

Figure 6.3. Relationship between vessel length and GT for the trawlers of Sète.
Figure 6.4. Hake mean monthly cpue for the period studied (1994-1999).
Figure 6.5. Results of PCA using proportion in weight of 16 species in the catch of Sète trawl fleet in 1999 and representative of the 6 years in the study.
Figure 6.6. Frequency hake cpue in métier III the Sète trawl fleet from 1994 to 1999.

Figure 6.7. Monthly mean catch rates of hake in métier III by vessel.

Figure 6.8. Monthly mean catch rates by year of hake in métier III.
Figure 6.9. Results from a GLM of hake catch rates in metier III modelled as a function of year, month and vessel and incorporating a gamma distribution of the errors.

Figure 6.10. Effect of GRT on catch rates of total hake from a model where cpue is modelled as a function of year and month factors and GRT as a smooth variable. Data from 11 selected trawlers using GOV.
Figure 6.11. Results of GLM where catch rates of hake commercial category 5 representing recruits are modelled as a function of vessel, year and month.

<table>
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<tr>
<th></th>
<th>Length (m)</th>
<th>Engine power (kw)</th>
<th>Tonnage (gt)</th>
<th>Year of launching</th>
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<td>C.P.</td>
<td>19.5 (3.9)</td>
<td>290 (51.8)</td>
<td>44 (24.8)</td>
<td>1967 (14)</td>
</tr>
<tr>
<td>G.O.V.</td>
<td>24.5 (1.5)</td>
<td>315 (4.1)</td>
<td>64.3 (19)</td>
<td>1978 (7)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
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<td>60</td>
<td>66</td>
<td>57</td>
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<tr>
<td><strong>Axis 2 (cumul. %)</strong></td>
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<td>60</td>
<td>54</td>
<td>75</td>
<td>78</td>
<td>79</td>
</tr>
<tr>
<td><strong>Axis 3 (cumul. %)</strong></td>
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<td>72</td>
<td>66</td>
<td>83</td>
<td>84</td>
<td>84</td>
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<tr>
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<tr>
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</tr>
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<tr>
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</tr>
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<td></td>
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</tr>
<tr>
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<tr>
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<td>Rou</td>
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<tr>
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<td>Bar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Chin</td>
</tr>
</tbody>
</table>

Table 6.2. Typology of the Sète trawlers obtained by PCA and automatic clustering using the annual species composition of catch by trawler. (Anc: anchovy; Sar: sardine; Sei: cuttlefish; Bar: sea bass; Dau: Gilt-head sea bream; P.aca: axillary sea bream; P.com: common pandora; Sol: sole; Pou: octopus; Bog: bogue; Chin: horse mackerel; Mlu: hake; Enc: squid; Bau: anglefish; Cap: poor-cod; Rai: skate; Maq: mackerel; Rou: red mullet).
Table 6.3. Analysis of Deviance Table from a model of cpue as a function of year, month and vessel. Terms added sequentially (first to last).

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Lower limit</th>
<th>Upper limit</th>
<th>Mean</th>
<th>Standard error</th>
<th>Variation coefficient (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>125.9508</td>
<td>128.7047</td>
<td>127.3278</td>
<td>0.7025</td>
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<tr>
<td>1994</td>
<td>1.0792</td>
<td>1.1273</td>
<td>1.1032</td>
<td>0.0123</td>
<td>1.11</td>
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<td>1995</td>
<td>1.0716</td>
<td>1.1210</td>
<td>1.0963</td>
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<td>1.15</td>
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<tr>
<td>1996</td>
<td>0.8864</td>
<td>0.9274</td>
<td>0.9069</td>
<td>0.0105</td>
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<td>1997</td>
<td>0.6717</td>
<td>0.7052</td>
<td>0.6884</td>
<td>0.0085</td>
<td>1.23</td>
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<td>1998</td>
<td>1.0562</td>
<td>1.1090</td>
<td>1.0826</td>
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<tr>
<td>1999</td>
<td>1.2250</td>
<td>1.2250</td>
<td>1.2250</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 6.4. Intercept and coefficients of the year factor of the GLM were hake cpue in métier III is modelled as a function of year, month and vessel.
Table 6.5. Analysis of deviance table from a model where hake cpue is modelled as a function of factors year, month and vessel and with month and year interactions. Terms added sequentially (first to last).

<table>
<thead>
<tr>
<th>TERMS</th>
<th>Residual Deviance</th>
<th>Residual df</th>
<th>Explained deviance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year+Month+Vessel</td>
<td>140</td>
<td>696</td>
<td>37%</td>
</tr>
<tr>
<td>Year+Month+s(GRT)</td>
<td>163</td>
<td>703</td>
<td>26%</td>
</tr>
</tbody>
</table>

Table 6.6. Comparison of GLM of hake catch rates as a function of vessel and GRT as a descriptor of fishing capacity.
3.2. Global analysis

3.2.1 Global analysis of total cpue

Main effect models were run to compare rates of total hake catch between 1) 20 métiers identified within the study and 2) 5 study areas. The model incorporates cpue as a function of métier or area, month and year as factors and the length of the vessel as a non-linear variable, and a gamma distribution of the errors. Vessel length was found to be a good descriptor of vessel fishing capacity/power in most of the 5 study areas. The overall vessel length in these areas ranged from 9 to 27 m. For this analysis, nevertheless, data from vessels between 15 and 25 m were selected to have a range common to all ports (Barcelona 8.9-24 m; Castellón 11-23.5 m, Pt. Santo Stefano 15.6-27.2 m; Sète 23-25 m; Santa Pola 13-24.4 m). Also, records from 1994 to 1998 were selected as these are years for which data for all areas are available. 10238 records were used in the analysis.

Analysis with métiers

Results from the model are presented in Figures 7.1 and 7.2. Métiers within the analysis are 4 from the port of Barcelona, 6 from Castellón, 6 from Porto Santo Stefano, 3 from Santa Pola, and 1 from Sète. Rates from all métiers in Barcelona are below the mean, half from the métiers in Castellón are also below the mean, while métiers from Santo Stefano are all above the mean, and from those from Santa Pola and Sète mostly all above the mean. Highest values are for 1996 and 1998. Monthly rates are fairly stable with higher values for January, February and November. Seasonal patterns vary greatly within métiers, and yearly variation varied between métiers thus these results must be interpreted with care has they are dominated by métiers with large amount of data.

Analysis with area

Results from the model are presented in Figure 7.3 and Table 7.1. Rates differed significantly by area. Analysis of deviance of the main effect model indicate that the variation between areas is larger than variation resulting from differences in the vessel length within the range considered. Annual and particularly monthly variation are unimportant compared to regional differences or to the variation due to the fishing power of the fleet.

Highest rates were from the port of Sète. Catch rates from Santo Stefano and Santa Pola were also relatively high. Lowest rates were obtained in Barcelona. Rates in Castellón were significantly higher than those in Barcelona but were still below the mean. Differences in catch rates between some areas are probably greatly influenced by the use of two trawl gears exploiting different ranges of length of the hake population (Aldebert et al., 1993). Namely, the fleet of Sète and some vessels from Santo Stefano used a wide opening trawl (GOV), while other fleets used a traditional bottom trawl. Rates obtained in 1995 were much higher than in other years and monthly variation show a peak in June-July and lowest values during November and December. These patterns must be interpreted with caution because interactions involving area are significant and most data are from Santa Pola which dominates the results.
Analysis of area-year-month interactions

Results from analysis of deviance to test interaction of the main factors are presented in Table 7.1. Interactions were significant. The most important interaction is between area and vessel length, which indicates that the increase in cpue with fishing power differs by area. This results is certainly influenced by unbalanced data matrix in the size composition of the fleet by study area. One interesting point to consider is that the deviance explained by the difference in monthly variation between areas is larger than the deviance explained by the month variable itself indicating little stability of the seasonal patterns.

Results of models to analyse monthly and yearly variation by study areas are shown in Figure 7.4. Since these models were run by study area, data used were from 1992 to 1998. The only similarity in the annual variation between areas is the decrease in levels from 1993 to 1994. Seasonal patterns in Barcelona and Castellón present higher values in spring-summer than during the rest of the year. In Santa Pola, peaks during November and during January and February can be observed. In Sète, low values are only during 3 months in the fall, and in Pto Santo Stefano levels start to decrease in the summer.

3.2.2. Global analysis of recruitment

Main effect models were run to compare hake rates in catches representing recruitment between 1) 7 métiers identified within the study and 2) 4 study areas. The model incorporates cpue as a function of métier or area, month and year as factors and the length of the vessel as a non-linear variable, and a gamma distribution of the errors. Vessel length, between 15 and 25 m, is introduced as a descriptor of vessel fishing capacity/power as in the case of the analysis of the total hake cpue. Years in the analysis are from 1992 to 1998. Data are from catches in métiers 1 from ports of Barcelona, 2 and 4 of Castellón, 1 and 3 of Santa Pola, and 1 and 3 of the traditional trawl from Santo Stefano. The analysis excludes data from the port of Sète. 6100 records were used in this analysis. This is because information on length composition of the catch is available only from 1997 to 1999. Further, this available information shows that there is great annual variation in the proportion of recruitment in weight in the catches (around 20 to 80%). Thus, total catch from the métier selected in this port is probably not always representative of juvenile abundance.

Analysis with métier

Main effect models to compare hake rates in catches representing recruitment between métiers in the study were run. Results from the modelling are presented in Figure 7.5. Highest levels are in métier 4 of Castellón while lowest levels (and not significantly different among them) were for métiers 2 of Castellón, 1 of Barcelona and 3 of Santo Stefano. Intermediate levels obtained for the two métiers selected for Santa Pola and métier 2 from Santo Stefano. Rates obtained in 1993 and 1996 were much higher than in 1994, 1995, 1997 and 1998 while rates in 1992 were intermediate. Monthly variation shows a peak from August to October and another during January and February.

Analysis with area

Main effect models to compare hake rates in catches representing recruitment between 4 areas in the study were run. Results are presented in Figure 7.6 and Table 7.2. Rates differed between areas but the variation explains less 1% of the total deviance which is
minor compared to the annual variation (about 6%) and to the variation due to the fishing power of the fleets (16%). Monthly variation also explains only around 1% of the deviance. Yearly and monthly patterns are similar to those obtained in the analysis with métier. These patterns must be interpreted with caution because interactions involving area are significant and most data are from Santa Pola which dominate the results. In terms of the comparison between areas, rates in Castellón are similar to those in Santa Pola (Figure 7.5), those from Porto Santo Stefano are intermediate and the lowest are those from Barcelona. The relative magnitude of these figures is somehow different to those obtained for the total catch where, excluding Sète, Santo Stefano had the highest rates. That analysis nevertheless included the métiers from Santo Stefano using GOV trawl. In that analysis Santa Pola showed higher rates than Castellón.

Analysis of area-month-year interactions

Results from analysis of deviance to test interaction between the main factors are presented in Table 7.2 Interactions are significant. The most important interaction is between year and month, which indicates that seasonal fluctuations differed by years. This suggest that factors affecting recruitment are local phenomena rather than major forces occurring at a large geographic scale. Results of Sète are the same as in Figure 7.4 based on total catch. Patterns differed by port.

Figure 7.7 shows the results of the analysis by port of monthly and yearly variations of catch rates representative of recruitment and indicates different temporal patterns in the study areas. Off the southern Iberian Peninsula (fishing grounds of the Castellón and Santa Pola fleets) recruitment indices oscillated around the mean of the period, with highs in 1993 and 1996 and lows in 1994-1995 and 1998. Conversely, off the northern Iberian Peninsula (Barcelona), hake recruitment declined progressively from 1992 to 1996 and remained stable thereafter. A different recruitment trend is observed in the grounds exploited by the Sète fleet. Indices fell progressively between 1994 and 1997 and rose sharply to a maximum in 1999. Finally in the grounds of the Santo Stefano fleet, recruitment was fairly stable, declining gradually from 1991 to 1994 and oscillating around the mean levels for the period thereafter. Seasonal trends are fairly similar in Castellón and Barcelona with a maximum in spring-summer and in Santo Stefano with a maximum occurring later in the year towards fall and winter.

These results suggest that in the western Mediterranean there are separate hake recruitment areas that in the region studied should include the region south of the Ebro River, the region north from the Ebro River, the Gulf of Lyons, and the northern Thyrrenian Sea. There are a number of factors that may explain the lack of correlation between recruitment trends in different areas of the western Mediterranean, among them general and local ocean circulation patterns, river outflow and nutrient fluxes. Recruitment processes of European hake are poorly understood and in the western Mediterranean the EU project “Impact of fishery and environment on hake recruitment in north-western Mediterranean” (Contract FAIR CT97/3522) constitutes the only concerted effort to study recruitment processes at small and medium spatial scales. Results of this project are not available yet, however In a recent study of hake recruitment in the southern Bay of Biscay, Sánchez and Gil (2000) showed that processes of recruitment lead to well-defined patches of juveniles in localised areas of the continental shelf. These concentrations remained generally stable from year to year although their density varied according to the strength of the year-class. The single most influential factors for determining year class strength were the strength of prevailing currents, mesoscale events close to the shelf and upwelling.
Table 7.1: Analysis of deviance table of GAMs to compare cpue between areas and where hake catch rates of all ports considered in the analysis are modelled as a function of area, month, year, and length of the vessel (with 3 df). Years are from 1994 to 1998 and vessel length from 15 to 25 m.

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Table 7.2: Analysis of deviance table of GAMs to compare hake cpue representative of recruitment between areas and where hake catch rates of ports considered in the analysis are modelled as a function of area, month, year, and length of the vessel (with 4 df). Years are from 1992 to 1998 and vessel length from 15 to 25 m. The analysis excludes data from the port of Sète.

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Interactions

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Figure 7.1. Fitted values of total hake cpue for métiers from all areas in the study from a GAM where total hake catch rates are modelled as a function of month, year, and métier as factors and length of the vessel introduced as a non-parametric smooth variable.
Figure 7.2. Fitted values of the effect of length of the vessel, year and month on total hake cpue for métiers from all areas in the study from a GAM where rates are modelled as a function of month, year, and métier as factors and length of the vessel introduced as a non-parametric smooth variable.
Figure 7.3. Fitted values of total hake cpue from a main effect GAM where rates are modelled as a function of month, year, and area as factors and length of the vessel introduced as a non-parametric smooth variable.
Figure 7.4. Results from GLMs were total hake catch rates by study area are a function of the vessel, month and year as factors.
Figure 7.5. Results from a GAM to compare recruitment between métiers where rates of catches obtained in fishing operations classified as corresponding to métiers representing recruitment were modelled as a function of métier, year and month as factors and length of the vessel as a smooth variable. Data from Sète are excluded. Lines in the plot for métier are to delimit results from left to right for ports of Barcelona, Castellón, Santa Pola and Santo Stefano.
Figure 7.6. Results from a GAM to compare recruitment between areas where rates of catches obtained in fishing operations classified as corresponding to métiers representing recruitment were modelled as a function of area, year and month as factors and vessel length as a smooth variable. Data from Sète are excluded. Areas are: BCN Barcelona, CAS Castellón, PSS Pto. Santo Stefano and SPO Santa Pola.
Figure 7.7. Results from GLMs were hake rates of catches obtained in fishing operations representing recruitment by study area are a function of the vessel, month and year as factors.
3.2.3 Comparison of recruitment trends with MEDITS indices

The comparison of recruitment trends obtained in this study with hake abundance indices from MEDITS surveys in the stratum of 100-200 m depth (mostly recruits) shows good agreement between both series of data in the five study areas (Figure 7.8). Very close agreement may be observed in particular between the series of recruitment indices from Castellón and Santa Pola and abundance indices of MEDITS from the Southern Iberian Peninsula, as well as between the indices of Porto Santo Stefano and those of MEDITS in the Thyrrenian Sea and those of Sète and the Gulf of Lions.

The results of this study suggest that hake cpue data collected from surveys and from commercial fisheries convey similar information and that fishery data can provide a cost-effective way to obtain year-round figures with a good spatial coverage in the western Mediterranean. Similar conclusions where reached by Fox and Starr (1996) when comparing commercial fishery and survey cpue data for the US West Coast groundfish trawl fishery. Thus, it is suggested that monitoring segments of the fleets exploiting a groundfish resource may suffice to obtain representative abundance indices. To corroborate this point, longer series of standardized catch rates should be compared to abundance indices derived from surveys. Also, to validate this approach similar studies should be carried out for other commercial demersal species.
Figure 7.8. Hake recruitment indices from MEDITS surveys and from modelling commercial trawl catch rates considering data from métiers targeting recruits in the five fisheries of the study area.
4. Conclusions

A database was created containing catch and effort data from commercial trawl fisheries of the following north-western Mediterranean harbors: Sète (France); Barcelona, Santa Pola and Castellón (Spain) and Santo Stefano (Italy). Data records contained monthly landings of main commercial species by vessel and number of days fished and, depending of the harbour, it covers the period 1991-1999.

The factors that affect catch rates of hake *Merluccius merluccius*, as one of the main target species of these fisheries, were analysed in order to estimate standardised indices of abundance. Factors affecting catch rates studied were: time (months and years), vessel characteristics as they relate to fishing power (vessel size, GRT, HP and GT), fishing regulations, e.g., closures and geographic area (harbour). Generalized Linear Modelling was applied to total hake catch rates in each fishing area. Among the vessel characteristics the length was identified as the best descriptor for fishing power. Annual and seasonal variations were also identified as significant factors but of relatively minor importance. Abundance indices exhibited significant inter-annual and seasonal variations and significant but smaller geographic differences.

Hake catches consist mainly of recruits, although older age groups are also present and their relative importance varies spatially and temporally. Length distributions of catches were available from Santa Pola, Santo Stefeno and from 1997-1999 in Sète. Since hake landings from the fisheries of Castellón and Barcelona lump together recruits and older ages, components of the fishing activity (vessel-months) in these fisheries that were targeting the 0-age group were identified in order to model hake recruitment indices.

Different multivariate techniques applied to percentage species composition of landings allowed the identification of 20 different métiers within the study fleets. Overall, they correspond basically to a spatial gradient of fishing strategies in each fishing area, covering from the more coastal activity to the slope zone. Examination of the species composition within each métier, their seasonal variations and ancillary information of the fisheries, helped to establish the relationship between métiers and catch of recruits. A total of 7 métiers were identified as representing recruitment within the study fleets.

The global analysis of total hake cpue considering the 20 métiers showed that monthly cpue is fairly stable with higher values for January, February and November. However, both seasonal annual abundance patterns vary greatly among métiers, although these results must be interpreted with caution as they are dominated by métiers with the largest amount of data.

Cpue differed significantly by area, but differences in cpue between Sète and the other study areas are influenced by the use of a wider opening trawl gear in Sète. Thus model cpue were highest in Sète, followed by Porto Santo Stefano and Santa Pola. The lowest cpues were obtained in Barcelona. Hake cpues in Castellón were significantly higher than those in Barcelona but were still bellow the overall mean.

The analysis of hake catch rates for the 7 métiers identified as representing recruitment and for 4 geographic areas (Sète was excluded because only 3 years of data were available), indicated that values in 1993 and 1996 were the highest of the 1991-1998 period. Monthly variation showed a peak from August to October and another during January and February. Rates differed between areas but the variation explains less 1% of the total deviance which is minor compared to the annual variation (about 6%) and to the variation due to the fishing power of the fleets (16%). Analysis of interactions indicated that the most important interaction is between year and month, which means that seasonal fluctuations differed by years. This suggests that factors affecting hake...
recruitment in the western Mediterranean are local phenomena rather than major forces occurring at large geographic scales.

Modelling the cpue of recruit métiers for each geographic area separately shows different temporal patterns of recruitment in the study areas. These results suggest again that hake recruitment is determined locally and that there are separate recruitment areas in the western Mediterranean. Within the 5 study areas, 4 patterns may be distinguished: one off the Iberian peninsula south of the Ebro River, a second one off the Iberian peninsula north from the Ebro River, the Gulf of Lions and the northern Thyrrenian Sea.

The comparison of recruitment trends obtained in this study with hake abundance indices from MEDITS surveys in the stratum of 100-200 m depth (mostly recruits) shows good agreement between both series of data in all the study areas. Very close agreement may be observed in particular between the series of recruitment indices from Castellón and Santa Pola and abundance indices of MEDITS from the Southern Iberian Peninsula, as well as between the indices of Porto Santo Stefano and those of MEDITS in the Thyrrenian Sea and those of Sète and the Gulf of Lions.

The results of this study suggest that hake cpue data collected from surveys and from commercial fisheries convey similar information and that fishery data can provide a cost-effective way to obtain year-round figures with a good spatial coverage in the western Mediterranean. Thus, it is suggested that monitoring segments of the fleets exploiting a groundfish resource may suffice to obtain representative abundance indices.

4.1 Suggestions on future applications

The availability of data of catch by vessel/day-fishing/species/gear and harbour would allow regular assessments of the Mediterranean exploited populations of the kind presented in this study. To obtain these data, however, it is necessary to set up adequate administrative and data collection structures at the national and EU levels. Among the activities to be controlled, the EU regulation 2847/93 of the Council includes the first sale of fishery products. First sale data include information on the harbour, vessel, days fishing (one in most Mediterranean trawl fisheries), species and gear of capture which must be entered in appropriate data bases in the wholesale fish markets. These data are expected to be transmitted to the EU via the member states.

The General Council of Mediterranean Fisheries (GCFM-FAO) has recently created the Scientific Advisory Committee (SAC) in charge of providing advice to the GCFM on the status of the exploited marine populations and of proposing management measures. Given that the main constraint met by the SAC to carry out its work is the lack of reliable fishery data series, it would be most useful to ensure that the above-mentioned data bases were built and made available to the SAC and its various stock assessment sub-committees. In the 2001 meeting of the sub-committee for the assessment of demersal stocks, the SAC recommended the use of GLM techniques to obtain standardised abundance indices of the various exploited populations. This is a necessary step to assess to which extent the methods successfully applied to the hake bottom trawl fisheries in this study would be applicable to other species and fisheries in the Mediterranean.
5. References


Centre International de Statistiques et d’Informatique Appliquées (CISIA), 1996.SPAD.N.version 3. CISIA, saint-Mandé, France.


