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Determination of effective fishing effort on hake *Merluccius merluccius* in a Mediterranean trawl fishery*

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SUMMARY: The direct control of fishing effort as a management tool is of special interest in the Mediterranean, where the lack of effective international management systems and the high diversity of the catches significantly increases the complexity of implementing TAC's as an indirect control of fishing effort. However, its enforcement should be based on the precise knowledge of the relationship between the fishing effort and its corresponding fishing mortality. In this sense, the general aim of this study was to develop an approach for analysing this relationship. In order to estimate the annual effective fishing effort on hake, a relational data base including daily landings by vessel and species of trawl fleet based on the port of Palma, Mallorca island (western Mediterranean) during the period 1983-1991 was built. Fishing mortalities were available from VPA. Fishing effort and fishing mortality were split by subfleets or métiers which were identified by cluster analysis. Significant linear relationships between the two parameters were obtained when fishing effort was considered as the number of days in which hake catch was higher than 10 kg multiplied by GRT of correspondent vessels. These CPUE values are mainly obtained when trawlers operate in the muddy bottoms of the shelf and on the upper slope, where hake populations are mostly distributed. On the other hand, no clear trends in catchability by métier were found during the period analysed.

Key words: *Merluccius merluccius,* métiers, effective effort, catchability, western Mediterranean.

RESUMEN: DETERMINACIÓN DEL ESFUERZO EFECTIVO DE PESCA SOBRE LA MERLUZA, *MERLUCCIUS MERLUCCIUS*, EN LA PESCA DE ARRASTRE DEL MEDITERRÁNEO. – La gestión mediante el control directo del esfuerzo de pesca adquiere especial interés en el Mediterráneo, donde la carencia de sistemas internacionales efectivos de gestión y la alta diversidad de las capturas aumenta en gran medida la complejidad del establecimiento de TAC's como control indirecto del esfuerzo de pesca. Sin embargo, su puesta en marcha debería basarse en un conocimiento preciso de la relación entre el esfuerzo pesquero y su correspondiente mortalidad por pesca. En este sentido, el objetivo del presente trabajo ha sido realizar una aproximación de manera que permitiera analizar dicha relación. Con el fin de estimar el esfuerzo efectivo de pesca sobre la merluza, se elaboró una base de datos relacional que incluía los desembarcos diarios por especie y barco de la flota de arrastreros del puerto de Palma de Mallorca referidos al período 1983-1991. Las mortalidades por pesca obtenidas por VPA estaban disponibles. El esfuerzo de pesca y la mortalidad por pesca se separaron por subflotas o métiers, los cuales se identificaron aplicando análisis cluster. Se obtuvieron relaciones lineales significativas entre ambos parámetros cuando se consideró el esfuerzo efectivo sobre merluza como el número de días de pesca con capturas superiores a 10 kg multiplicados por el TRB de los correspondientes arrastreros. Estos valores de CPUE se obtienen fundamentalmente cuando la flota opera en fondos fangosos de la plataforma y en el límite superior del talud, en los que la merluza se distribuye con mayor densidad. Por otro lado, no se encontró una tendencia definida de la capturabilidad de cada métier durante el período analizado.

Palabras clave: *Merluccius merluccius,* métiers, esfuerzo efectivo, capturabilidad, Mediterráneo occidental.

INTRODUCTION

Groundfish trawling is widely spread over the Mediterranean and has traditionally played an important socio-economic role in the region. In terms of management of these fisheries, measures to regulate fishing effort exist together with technical measures, i.e. minimum mesh size and landing size, minimum distance from the shore and/or minimum depth, and temporal closures. Some states have also

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developed licensing schemes in order to control and monitor their fleets. Due to the diversity of both the types 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 on the catches.

In this context, the relationships between fleet capacity, effort and the generated fishing mortality are important. One of the key problems in reducing fishing mortality through effort control is to ensure that the effort parameters which are selected for control are relevant to fishing mortality. A factor that prevents the success of the implementation of global effort regulations in terms of reduced fishing mortalities of some species is that their effect on each fleet component participating in the fisheries, and hence on the effective fishing effort directed to the several target species, is different. In order to define these fleet components, the métier concept is normally used and can be defined as a coherent functional entity in terms of vessel type and size, gear, target species (or group), and spatio-temporal fishing pattern (Laurec *et al*., 1991; Lewy and Vinther, 1994).

During the analysed period (1983-1991), the fleet of Palma consisted of an average number of 24 trawlers (average 47.4 GRT and 250 HP) operating simultaneously. This trawl fleet works on a 20 mile-long stretch between 50 and 800 m depth (Fig. 1) carrying out a spatial gradient of activity (Bruno *et al*., 1979; Oliver, 1993; Merella *et al*., 1998; Carbonell *et al*., 1999). Mediterranean groundfish trawl fisheries are multispecific, with up to 104 fish species recorded in commercial tows in some areas such as the Balearic Islands (Massutí *et al*., 1996). However, a small number of species accounts for a large proportion of the catch and of its economic value. Taking into account the mean value of the annual landings during the analysed period, the main target species were red shrimp (*Aristeus antennatus*), blue whiting (*Micromesistius poutassou*), picarel (*Spicara smaris*), striped red mullet (*Mullus surmuletus*), octopus (*Octopus vulgaris*) and hake (*Merluccius merluccius*). However, from the economic point of view, the main species were, in this order, red shrimp, red mullet and hake. Thus, hake can be considered as a target species.

The objective of this paper is to assess the relationships between fishing effort and fishing mortality for hake exploited off Majorca island and to explore the catchability values. We analyse the relationships between partial fishing mortality and effort levels corresponding to the different trawl subfleets or métiers. To our knowledge, this is the first attempt on this subject in the Mediterranean fisheries.

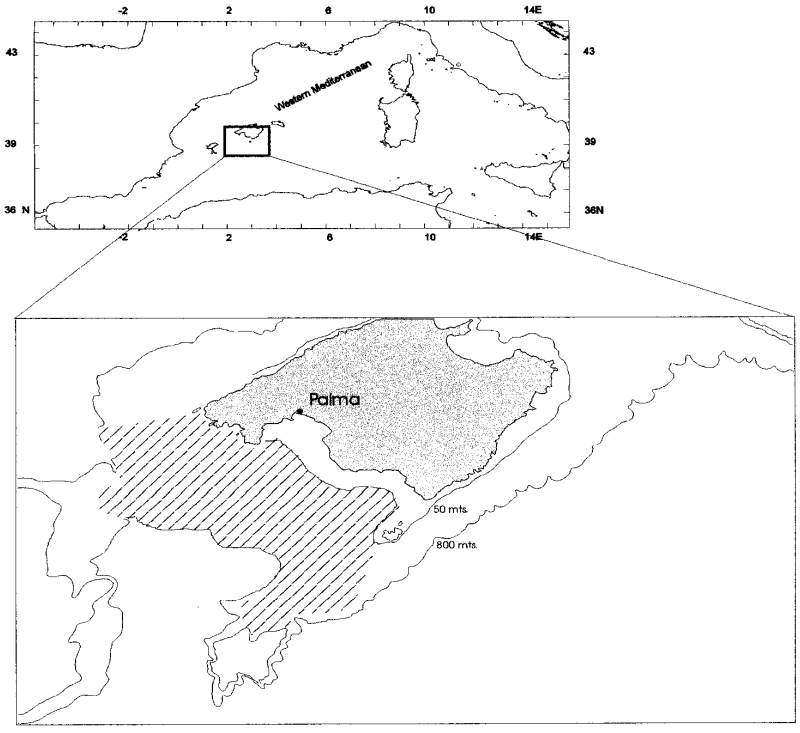

FIG. 1. – Fishing area of the Palma port trawl fleet.

TABLE 1. – Fishing mortalities estimated from VPA (Oliver *et al.*, 1995)

Age class	1983	1984	1985	1986	1987	1988	1989	1990	1991
0	0.001	0.023	0.038	0.001	0.000	0.004	0.001	0.000	0.000
1	0.478	1.657	1.367	1.172	0.583	0.712	1.008	0.393	0.165
2	1.028	1.007	1.236	1.738	1.036	1.084	1.199	0.702	0.350
3	0.619	0.879	1.708	1.421	0.629	0.922	0.548	0.651	0.717
4	0.449	0.790	1.115	1.343	0.584	0.433	0.273	0.484	0.518
5	0.433	0.482	0.489	0.958	0.655	0.382	0.101	0.298	0.249
6	0.319	0.287	0.090	0.441	0.320	0.249	0.136	0.084	0.330
7	0.000	0.263	0.243	0.201	0.194	0.000	0.639	0.161	0.060
8	0.000	0.178	0.350	0.350	0.350	0.000	0.350	0.350	0.392
9	0.000	0.350	0.350	0.000	0.000	0.000	0.350	0.000	0.000
Mean F	0.678	1.488	1.340	1.371	0.742	0.821	1.031	0.499	0.291

MATERIAL AND METHODS

Basic effort and catch data

Fleet capacity data were obtained from official fleet censuses. A total of 44 trawlers, with an average GRT of 47 tons and a nominal engine power of 249 HP, were considered.

Fleet activity and catch data by species of the Palma trawl fleet are available from the daily fish market receipts by trawler maintained by the fishermen's association or "Cofradía". A relational database was created which contains information by boat and fishing day. A total of 40,522 fishing days were analysed for the period 1983-1991, divided into 294,511 records, each including one report on species name, vessel code, day of capture and landed weight.

As basic effort, the unit number of fishing days was considered. It was not corrected for the number of hours fished per day, since they are quite constant due to legal constraints.

Fleet segmentation

Cluster analysis was performed from the daily landings by species and vessel to identify the fleet segments according to their fishing patterns. In a broad sense, taking into account data integrated on an annual time scale, these fleet segments could be considered as different métiers.

The database matrix included the annual landings of each vessel (44 units) by species (16 categories) during the study period. From the raw data, only demersal species or groups of species that appear regularly in the catches and can be considered as representative of the different exploited biotopes were selected. Afterwards, raw data were transformed into percentages, in order to diminish the differences among vessels that operate on the same fishing ground but with different fishing power. For clustering, UPGA algorithm was applied, considering Euclidean distances. The weight of discards of commercial demersal species is negligible in this fishery, so landing data can be considered as representative of total catches (Carbonell *et al*., 1997).

Fishing mortalities

The fishing mortalities on hake corresponding to the same period as the data base were available from VPA (Oliver *et al.*, 1995) (Table 1). The monitoring of the fishery is the same as described in Oliver *et al.* (1993).

Partial fishing mortalities by métier were calculated as:

$$F_{partial} = F_{total}\, C_{fleet}/C_{total}$$

where
F is total fishing mortality by year
C_{fleet} is the catch in weight by a métier

TABLE 2. – Annual catches (kg) by métier used to the F's partition.

Year	1983	1984	1985	1986	1987	1988	1989	1990	1991
Fleet 1	14461	36619	22214	15614	14764	20697	16696	6434	11733
Fleet 2	7328	37290	25020	24937	11347	11713	13548	14281	10975
Fleet 3	2942	7469	8287	6448	3389	5780	8993	6786	8697
Total catch	24731	81378	55521	46998	29501	38190	39237	27501	31405

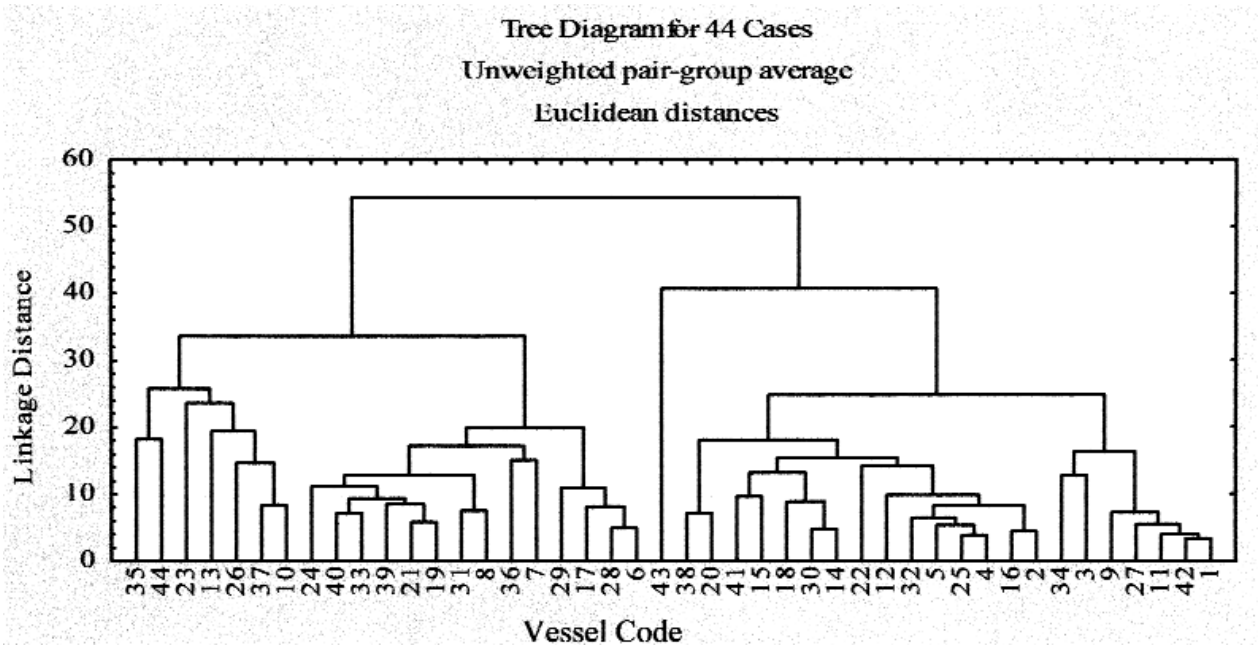

FIG. 2. – Cluster analysis based on the specific catch composition of landings of Palma fleet trawlers.

C_{total} is the total catch in weight.

Table 2 shows the annual catches by métier used to the F's partition.

From the fishing mortalities and the catch number by age, a weighted global F by year was calculated (Shepherd, 1983).

Relationships of fishing mortality vs. fishing effort

The relationships between fishing mortalities and fishing effort were explored by linear regressions between available fishing mortality values and different estimations of fishing effort. Several measures of fishing effort were considered, from the simpler number of vessels or total number of fishing days of the whole fleet to more accurate estimations of fishing effort aimed at hake populations, expressed in fishing days on upper slope and shelf muddy bottoms multiplied by GRT of the vessels. GRT values were chosen because they are more reliable than available official data on HP. However, the two values are highly correlated ($R^2 = 0.71$). The number of fishing days in which hake could be considered as a target species was calculated taking advantage of the facilities of the relational database to filter information according to several criteria, as species composition and their relative abundances by fishing day. In all cases both parameters were split by métier.

Catchability

Assuming that catchability coefficient q is the proportionality factor between fishing mortality and fishing effort,

$$F = q*f$$

where
F = total or partial -métier- fishing mortality
q = catchability coefficient
f = total or partial -métier- effort.

Annual q values were calculated considering those estimations of f which showed the highest correlation with available F values, and hence could be considered as estimates of effective fishing effort, both split by métier.

RESULTS

Fleet segmentation

The segmentation of the fleet carried out taking into account the average specific catch composition by vessel suggests the existence of at least four well-defined groups (Fig. 2). An isolated case was also detected. This vessel operated for only three months at the beginning of the study period, and its specific catch composition could not be considered as repre-

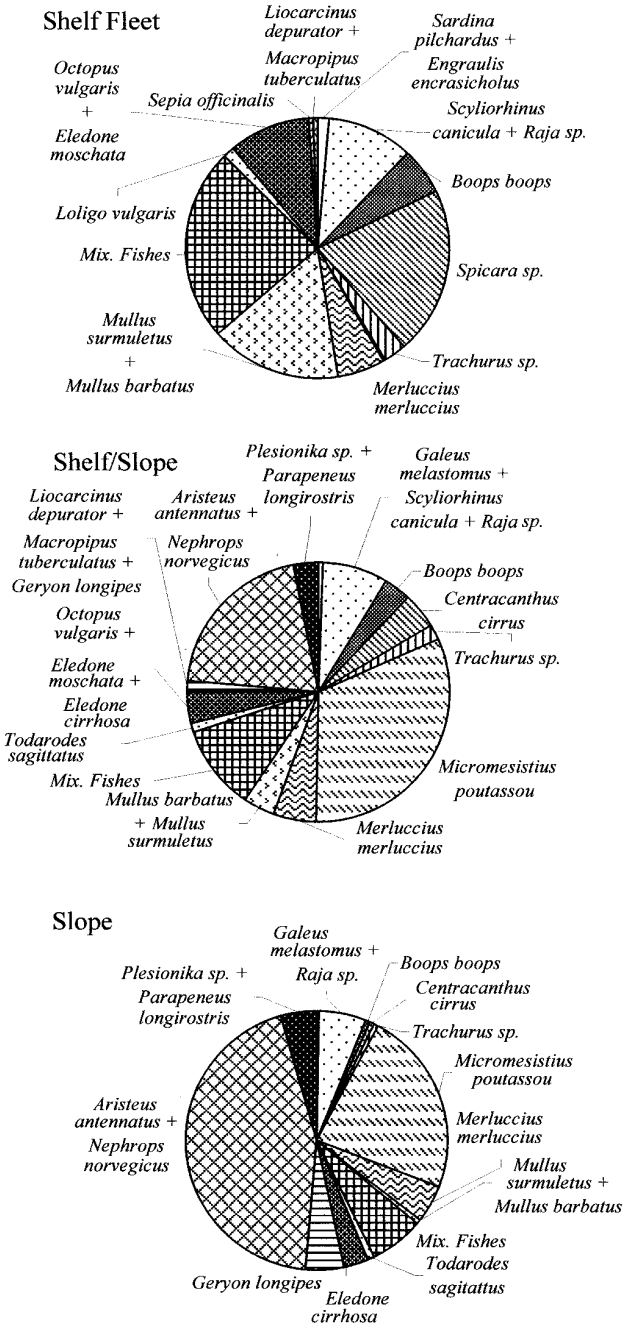

FIG. 3. – Catch composition by métier.

sentative of annual landings because of the seasonal variations. Two fleet groups represent opposite situations, 1) vessels fishing almost exclusively on slope, whose landings were composed of species inhabiting slope bottoms, and 2) smaller vessels that only exploited continental shelf fishing grounds—coralligenous or muddy bottoms—and their corresponding species representative of shallower waters. The other two groups were formed by vessels that worked indistinctly on soft bottoms of the continental shelf, on the upper slope or on deeper slope areas. Since the differences between these two groups were only quantitative, i.e. number of fishing days in one or another area, they were pooled and considered as a single group. The relative specific catch composition within each of these three métiers is shown in Figure 3.

The first métier operates on the inner shelf and included 14 vessels (average of 31 GRT and 150 HP). We called it the shelf fleet. Their catches are based mainly on picarel, red mullet, octopuses and a typical Mediterranean commercial category, a mixture of different fishes named "morralla". Moreover, a percentage of the fishing effort of this fleet is directed to shelf fishing grounds on muddy bottoms, where hake can be considered as the target species.

The second group, named the slope/shelf fleet, was composed of 15 vessels (average of 54 GRT and 270 HP). This is a fleet that can operate indistinctly on the deeper fishing grounds (500-800 m) targeting red shrimp, or on upper slope and deeper muddy shelf fishing grounds targeting Norway lobster, blue whiting or hake.

The third component included the 15 more powerful trawlers (average of 56 GRT and 320 HP), which operate almost exclusively on slope targeting red shrimp. Their catches usually include as bycatch some large hakes (>40 cm TL), but they only work incidentally on upper slope fishing grounds where hake can be considered the target species.

The average number of vessels operating simultaneously within each group was 7, 9 and 8 respectively.

Temporal evolution of fishing effort and hake landings

Despite the reduction of the number of trawlers and the limitation of the total HP and GRT of the trawl fleet at national and regional level, produced within the framework of effort reduction plans promoted by national and European Union authorities, the total fishing effort has risen during the study period in this particular area. This can be mainly attributed to the concentration of trawlers in the Palma port coming from other little fishing ports of Majorca island (Álvarez *et al*., 1999), possibly due to the better infrastructures of the former. Moreover, the parallel modernisation of fishing units allows them to operate in worse weather conditions, deeper fishing grounds and further from Palma. These conditions resulted in a higher number of fishing days

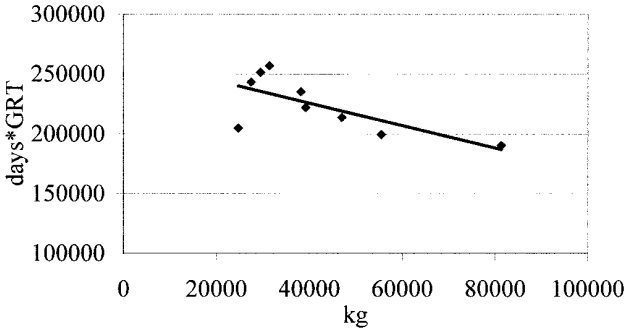

FIG. 4. – Relationship between total effort and hake landings (R^2 = 0.49; P=0.035).

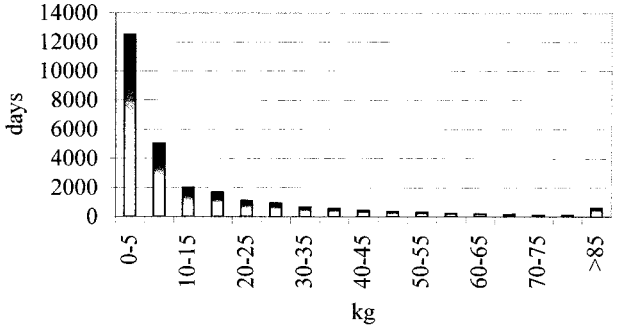

FIG. 7. – Frequency distribution of hake's landings in the studied period.

per vessel throughout the year and a more intensive exploitation of the red shrimp as a target species due to its higher economic value.

The evolution of total fishing effort of Palma trawl fleet seems to show an inverse relationship to that of hake landings (Fig. 4). As mentioned above, the trawlers can direct their effort to various fishing grounds, and the effort exerted more specifically on the hake population can vary independently of the overall effort of the fleet. This makes it necessary to know the percentage of fishing operations carried out in the fishing grounds where the main part of hake population is distributed, which are the muddy bottoms of the shelf and upper slope (Campillo *et al.*, 1989; Oliver and Massutí, 1995; Massutí *et al.*, 1996). On the coastal coral bottoms the presence of hake is almost null and in the deeper slope areas only the larger hakes, usually more than 3-4 years old and scarce, can be found available to the trawl gear.

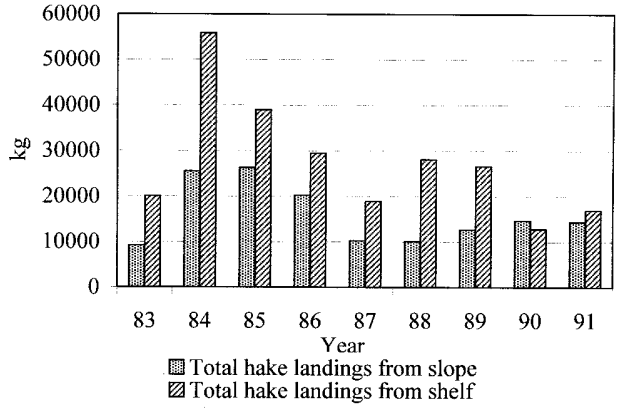

FIG. 5. – Hake landings from shelf or slope fishing grounds.

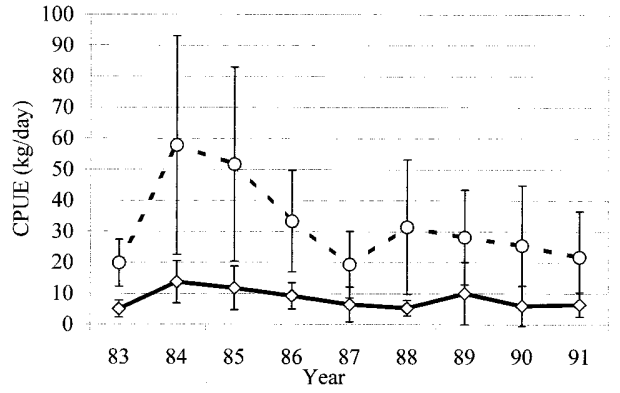

FIG. 6. – Hake CPUE (+/- s.d.) at slope (full line) and shelf (dotted line). Only positive hauls were considered.

Due to the unavailability of geo-referenced data about the daily spatial allocation of each trawler, an indirect method was used to estimate this figure. The relational database allows the days in which fishing operations were carried out in different fishing grounds to be identified and quantified. As a result of this analysis, Figures 5 and 6 show the proportion of hake landings coming from shelf or slope and the CPUE values in each area. It can be pointed out that, even taking into account the positive hauls only, the mean daily landing of hake from the slope is lower than 10 kg. The frequency distribution of daily hake landings by boat (Fig. 7) indicates that on more than 75% of days the hake landings were null (13,582 days) or lower than 10 kg (17,604 days). From these null or fairly unsuccessful hake fishing days, which are carried out in areas where this species is very scarce or absent, 12% correspond to the shelf fleet operating on coral bottoms only, and 82% to the slope or the shelf/slope fleets operating in deeper fishing grounds targeting red shrimp or Norway lobster. In this case the average daily landing of hake is 4.2 kg.

Taking into account these results, the effective effort on the hake population was estimated considering only the days on which hake landings were higher than 10 kg, which coincide with those fishing days on which the specific catch composition indicates that at least one haul was performed on the upper slope or shelf muddy bottoms. Then, the effort

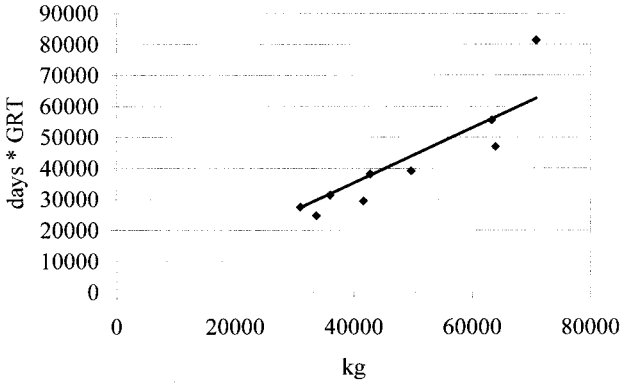

FIG. 8. – Effective effort on hake (fishing days with hake landings>10 kg*GRT) vs. hake landings (R^2=0,79; P<0.001).

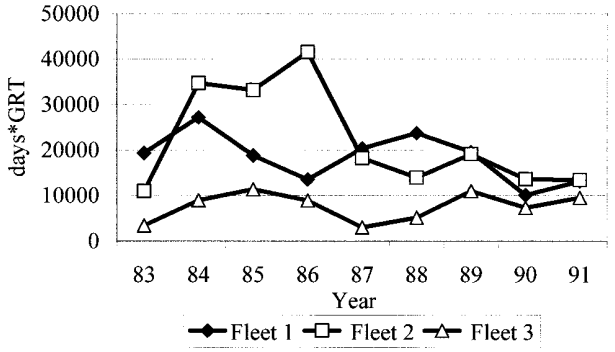

FIG. 9. – Effective effort on hake (fishing days with hake landings>10kg*GRT) by fleet or métier (1: shelf fleet; 2: shelf-slope fleet; 3: slope fleet)

evolution shows a significant positive relation to hake landings (Fig. 8). Effective effort on hake population split by fleet is shown in Figure 9.

Relationship between fishing effort and fishing mortality

The values of global fishing mortality per year for hake were related to the total annual effort of the Palma trawl fleet, showing an inverse relationship (Fig. 10). Again, this is consistent with the shift of the main target species during the analysed period to other species than hake. On the other hand, the estimated effective fishing effort on hake populations shows a close relationship with available fishing mortality values, with the shelf/slope fleet showing the best result and the slope fleet the worst (Fig. 11). As mentioned above, this last métier operates almost exclusively in deeper slope areas targeting red shrimp, where only some large specimens—usually fewer than 5 individuals—are captured. Therefore, the fishing mortality of hake attributable to this fleet is low. However, occasionally these vessels work in shallower areas of the slope, targeting mainly Nor-

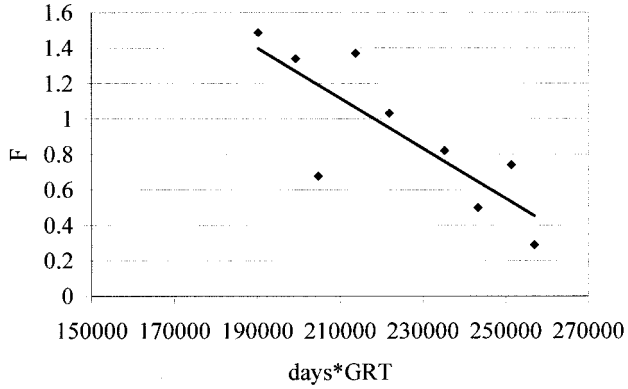

FIG. 10. – Fishing mortalities vs. total effort (R^2=0,66; P=0.008).

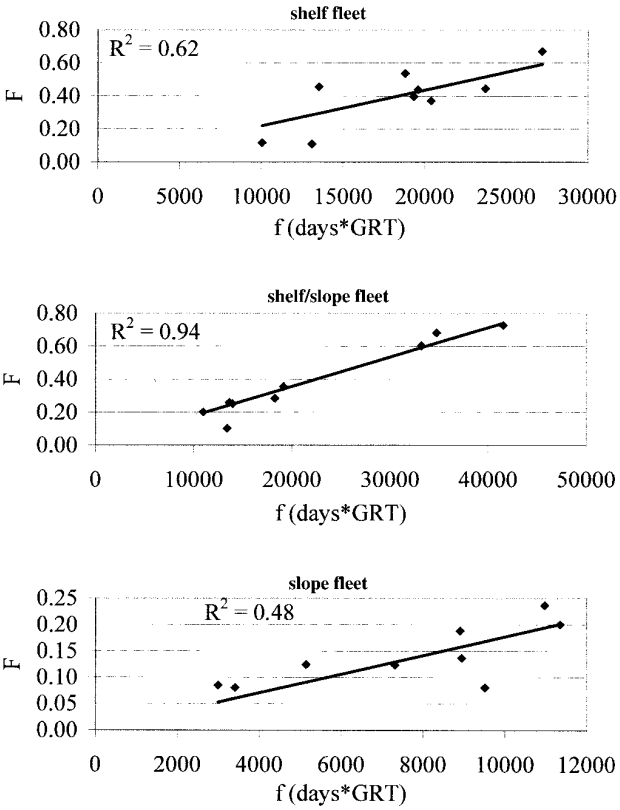

FIG. 11. – Relationships between F and effective effort (fishing days with hake landings>10kg*GRT) by métier (P<0.001 in the three cases).

way lobster, and in these fishing grounds hake is more abundant. According to our criteria these days were considered as effective effort on hake, but the lower densities of hake in these areas in comparison to the shelf fishing grounds would explain the lower correlation value showed by this fleet segment.

The shelf fleet usually works on shelf muddy bottoms where hake is more abundant, but not during the whole fishing day because a high percentage of hauls—these vessels can made several hauls per day—are performed on coralligenous bottoms.

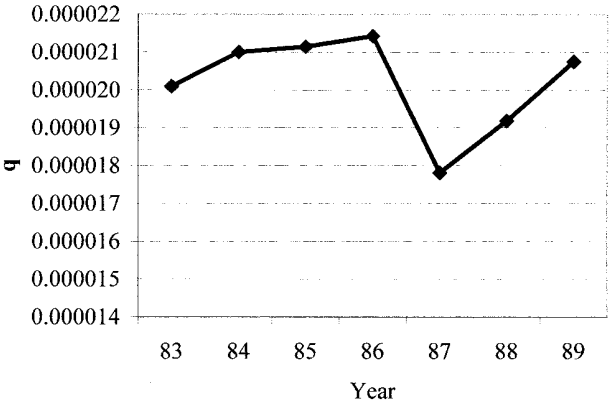

FIG. 12. – Evolution of catchability coefficient (q).

Therefore, considering as effort unit the fishing day and not the haul, a certain bias is introduced in the analysis that should explain the lower values of the correlation with the slope/shelf fleet. When this slope/shelf fleet chooses the hake as the target species instead of red shrimp, it exploits only the shelf/upper slope muddy bottoms where the density of hake is higher, which is consistent with the better result.

The wide range of effective fishing effort values suggests that hake was an alternative target species for the different métiers. Thus, hake would be heavily exploited by the shelf/slope métier only when a more valuable target species, such as the red shrimp, was scarce or not available. A similar behaviour should be applicable to the shelf métier, targeting hake on the mid-shelf when the economical revenues from the exploitation of coralligenous bottoms are lower.

Catchability

A value of q=0.00002 was estimated from the linear regressions between F and f. The temporal evolution of q values is shown in Figure 12. Considering that the last two values may be biased due to the arbitrary election of terminal F in the VPA, the catchability did not show any significant trend. This result suggests that both hake availability and fishing efficiency remained invariant during the studied period.

DISCUSSION

As Hilborn and Walters (1992) note, fleet dynamics is probably the most understudied subject in fisheries. Different types of multivariate analysis have been applied as effective quantitative methods to identify different fishing strategies (Murawski *et al*., 1983; Rocha *et al*., 1991; Rogers and Pikitch, 1992; Sobrino *et al*., 1996; Ward *et al*., 1996). This approach was considered necessary and suitable, since the heterogeneity of fishing practices within a multi-species fishery precludes any attempt to accurately assess the relationship between the total fishing effort of the fleet and the resulting fishing mortality exerted on the exploited stocks.

Our results point out the heterogeneity of the fishing practices in a typical multi-species Mediterranean trawl fishery. Cluster analysis based on disaggregated daily catch by species and vessel allowed the identification of three main métiers corresponding basically to a spatial gradient of fishing strategies, ranging from the more coastal activity to the slope zone, which is in accordance with a qualitative study on the demersal ichthyic communities in the same area (Massutí *et al*., 1996).

Recent studies considering a combination of different multivariate techniques have identified 11 métiers in the artisanal fishery off Tunisia (Jabeur *et al*., 2000) and a total of 20 métiers in 5 trawl fleets from the western Mediterranean (Álvarez *et al*., 2001). Moreover, the identification of métiers was a first step in selecting the best representative CPUE time series of hake catch rates through the application of General Linear Models (Goñi *et al*., 1999). As a consequence, the measures of total effort derived from this type of fishery have shown to be not appropriate for use with single stocks such as hake. However, the flexible relational database built on disaggregated information allowed different values of effort to be analysed. Their goodness can be objectively tested if fishing mortality values by métier are available (Murawski and Finn, 1986; Rocha *et al*., 1991).

The goal of this study was to select the best representative measure of effort on hake in the Palma de Mallorca-based trawl fishery. The significant values of effective effort on hake population were estimated when only the days on which hake landings were higher than 10 kg were considered. This was partly due to the fact that the effective effort data changed by a factor of three or more over the period of observation in the three métiers considered. At the same time, these CPUE values are obtained mainly when vessels operate on shelf and upper slope fishing grounds. Thus, the relevance of fishing location as a component of fishing strategies is highlighted. Fishers usually allocate fishing effort in a given area on the basis of prior information about the profitability determined by costs and expected benefits (Hilborn

and Ledbetter, 1979). On the other hand, no clear trends in catchability were found, which is in accordance with the underlying hypothesis in VPA models and indicative of stability of the fishing patterns on hake within the period studied.

Overall, some conclusions on management may be drawn from these results. Measures to reduce effort intend to reduce the amount of fishing. These measures are less directive in achieving a reduction of fishing mortality aimed at a particular stock, since it cannot always be predicted to which stock(s) the allowed effort will be directed. The analysis of the behaviour of individual vessels and the way fishing behaviour may affect fishing mortality can only be addressed when detailed data are available by trip and by haul. This would enable the catches by haul to be related to the specific unit of effort and gives information on its spatial distribution (Vignaux, 1996; Rijnsdorp *et al*., 1998). In the same context, the range of variations of effort could be of relevance given that comparatively large effort reductions, i.e. 20-30%, may be difficult to detect in terms of changes in fishing mortality.

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