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Relationships between fishing effort and fishing mortality in the trawl fishery for hake *Merluccius merluccius* off Majorca island.

F. Alvarez[1*], F. Alemany[1] and E. Ferrandis[2]

1. *Instituto Español de Oceanografía. Centro Oceanográfico de Baleares. Muelle Poniente s/n. 07080. Palma. Spain.*

2. *Universidad de Alicante. Dept. de Estadística. 03080. Alicante. Spain.*

1 Corresponding author: Tel. 34-971-401561; Fax: 34-971-404945; e-mail:federico.alvarez@ba.ieo.es*

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1. Introduction

Groundfish trawling is widely spread over the Mediterranean and traditionally has played an important socio-economic role in that 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 Horse Power (HP) of 300 (Oliver and Massutí, 1995; STCF, 1991). About 1230 units operate off harbours along the Spanish Mediterranean coast, one of which is Palma in the Majorca island. 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. The Palma port trawl fleet work on a 20 mile-long stretch at depths between 50 and 800 meters (Fig. 1). The smaller units exploit shallower fishing grounds between 50 and 200 meters of depth, having as target species stripped red mullet (*Mullus surmuletus*), european hake (*Merluccius merluccius*) and octopuses. The medium and large vessels generally work on the slope, further offshore, from 350 to 800 meters of depth. This pattern changes when unfavourable weather conditions force small units to stay in port and large units to operate close to shore. The species composition of the catch and the catch rates differ among these vessels and vary throughout the year.

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 trawl fishery studied has, as the main targets species, the following: rose shrimp (*Aristeus antennatus*), blue whiting (*Micromesistius poutassou*), picarel (*Spicara smaris*), stripped red mullet, octopus (*Octopus vulgaris*) and european hake. However, from the economic point of view, the main species are, in this order, rose shrimp, red mullet and european hake. Thus, hake can be considered as a target species.

Management regulations applied to the Spanish Mediterranean trawl fisheries include effort controls, as limitation of the duration of each trip (14 hours per day) and 5 trips per week, minimum mesh size and minimum size at capture. In some areas (Valencia, Cataluña) a one to two-month closure during spring-summer is established since 1991. The closure is intended to protect recruitment of hake and of other species of interest (Suau, 1967; Oliver and Massuti, 1995). However, administrative factors also play a role in setting its timing.

Due to the multispecific nature of Mediterranean fisheries, it has been traditionally difficult to gather long and reliable series of detailed catch data that would allow the carrying out of stock assessments. However, for hake exploited by the fleet of Palma, Yield per Recruit (Y/R), Virtual Population Analysis (VPA) and Length Cohort Analysis (LCA) have been performed for the period 1980-1991 (Oliver, 1991, 1993; P. Oliver, E. Massutí and O. Reñones, unpublished MS). Results indicated that hake suffered high exploitation rates at the recruit stage and the stock was considered to be overexploited.

For management purposes the relationships between fleet capacity, effort and the generated fishing mortality are important. If fishing mortality is closely linked to fishing effort – the underlying hypothesis in many VPA models – then to reduce fishing mortality one has to reduce fishing effort. In the same manner, if fishing effort would be linked to the capacity of a fleet, this would enable the definition of capacity levels that would generate a certain agreed target fishing mortality.

Fishing effort is defined as the product of fishing activity and fishing power. The fishing effort exerted by a fleet is the sum of these products over all fishing units in the fleet. Fishing activity is in units of time. Fishing power is the ability of a fishing unit to catch fish and is a complex function depending on vessel, gear and crew. However, since measures of fishing power may not be available, activity (such as hours or days fished) has often been used as a substitute for effort and called “nominal effort”. The consequence is that catchability, which expresses a variety of factors that determine the vulnerability of fish to capture, includes not only the availability and vulnerability of fish but also the power of the fishing gear to catch them.

The objective of this paper is to assess the relationships between fishing effort and fishing mortality for hake and to explore the catchability values. To do so, we will investigate the relationships between partial fishing mortality corresponding to the different trawl "métiers" (a combination of gear-fishing area-species) operating off Majorca, and its effort levels.

2. Material and methods

2.1 Effort and catch data

Effort and catch data by species on the Palma trawl fleet is available from the daily fish market receipts by boat, maintained by the fishermen association or "Cofradía"**.** A relational database was created (Access), which contains some information by trip. A total of 40522 trips were analysed for the period 1983-1991, divided over 294511 records including each one various data: species name, vessel code, day of capture and landed weight.

Effort is expressed as GRT*days. GRT values were chosen because they are more reliable than allowable official data of HP. However, both values are highly correlated (R^2 = .71). Effort was not corrected for the number of hours fished per day, since they are more or less constant due to legal constraints.

In order to consider mainly the differences in the spatial distribution of fishing effort, a cluster analysis (Statistica 4.5) was performed from the daily landings by species and boat to identify the "métiers". The database matrix included the annual landings by species (16 categories) and vessels (44 units) along the studied period. From the raw data, demersal species or groups of species that appear regularly in trawler catches and can be considered as representative of the various exploited biotopes were selected. Afterwards, raw data were transformed in percentages, in order to diminish the differences among boats 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 are negligible in this fishery, so landings data can be considered as representative of total catches (Carbonell et al., 1997).

2.2 Fishing mortalities

The fishing mortalities in the period 1980-1991 were estimated from VPA (P. Oliver, E. Massutí, O. Reñones, unpubl. MS) by using COHORT software programme ANACO (Mesnil, 1988). Partial fishing mortalities by “métier” are 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”
C_{total} is the total catch in weight

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

2.3 Catchability

Conventionally the relationship between F and nominal effort, f, is considered to be of the form.

$F = q*f$

Where

F = total (partial) instantaneous fishing mortality coefficient by “métier”
q = catchability coefficient
f = effort (days fished, GRT-days)

The catchability (q) is assumed to be constant. It is likely that q increases with time. Such possible trends have been examined by plotting q against time

3. Results and discussion

3.1 “Métiers”

Cluster analysis has allowed to distinguish among 3 types of “métiers”. Catch composition of each one of them is shown in Figure 2.

Considering an average value for the analysed period, the first component operates in coastal area and is composed by 7 trawlers (average 31 GRT and 150 HP). We called it 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", which are captured on coral bottoms. 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 component, named slope/shelf fleet, is composed by about 9 vessels (average 54 GRT and 270 HP). This is a fleet that can operate indistinctly on the deeper fishing grounds (500-800 m) targeting rose shrimp, or on upper slope and deeper muddy shelf fishing grounds, targeting Norway lobster (*Nephrops norvegicus*), blue whiting (*Micromesistius poutassou*) or hake.

The third component includes the more powerful trawlers (an average of 8 vessels of 56 GRT and 320 HP), which operates almost exclusively on slope targeting rose shrimp. Usually their catches includes as by catch some big hakes (>40 cm TL), but only incidentally work on upper slope fishing grounds where hake can be considered the target species.

3.1 **Temporal evolution of fishing effort and hake landings**

Despite the reduction of the number of trawlers and the limitation of the total HP of the trawl fleet at national and regional level, produced in the framework of effort reduction plans promoted by national and European Union authorities, the total fishing effort has raised during the studied period. This fact can be mainly attributed to the concentration of trawlers in the Palma port, coming from other little fishing ports of Majorca Island and due to the better infrastructures of the first one. Moreover, the modernisation of fishing units allows them to operate in worse wheather conditions, which results in a higher number of fishing days by vessel throughout the year.

The evolution of global fishing effort of Palma trawl fleet (Figure 3) does not have any direct relationship with that of hake catches, it even seems to present an inverse relationship (Figure 4). This is not a very surprising fact, because the trawlers can direct their effort to various fishing grounds, with different target species, and the effort exerted more specifically on hake populations can vary independently of the overall effort of the fleet. Therefore, if one pretends to analyse the q values for the hake fishery, it is necessary to determine the effective fishing effort exerted on hake. This fact implies knowing the percentage of fishing operations carried out in the fishing grounds where the main part of hake population is distributed: the muddy bottoms of the shelf and upper slope. On the coastal coral bottoms the presence of hake is almost null and in the deeper slope areas only the bigger hakes, more than 4 years old and very scarce, can be found available to the trawl gear.

Due to the unavailability of direct data (position references) about the daily spatial allocation of each trawler, an indirect method to estimate that figure was used. The elaborated relational database permitted to identify and to separate, depending on the specific composition of catches and taking into account all the allowable information on bathymetric distribution of species, the days in which fishing operations were carried out on coastal areas, on muddy bottoms of shelf, upper slope or in deeper areas of slope, more than 350 m depth. As a preliminary result of this analysis, Figures 5 and 6 show the proportion of hake landings coming from shelf or slope and the CPUE values at each area. It can be pointed out that, even taking into account only the positive hauls, the mean daily catches of hake from slope is lower than 10 kg. The frequency distribution of daily hake landings by boat (Figure 7) indicates that in more than the 75% of days the hake catches were null (13582 days) or lower than 10 kg (17604 days). From these null or little successful hake fishing days, which are carried out on areas where this species is very scarce or absent, 12% correspond to shelf fleet, when operates solely on coral bottoms, and 82% to the slope or the shelf/slope fleets, when operates on deeper fishing grounds targeting rose shrimp or norway lobster. In this case the average daily catches of hake are 4,2 kg.

Taking into account these results, the effective effort on hake population was estimated considering only the days in which hake catches were higher than 10 kg. Total effective effort is represented in Figure 3. Effective effort on hake population split by fleet is shown in Figure 8. Then the effort evolution presents a good correlation with hake catches (Figure 9).

3.2 Relationship between effective fishing effort vs. fishing mortality

From the fishing mortality by age class and year, global fishing mortalities for each year were calculated. These values were related to the total annual effort of Palma trawl fleet, showing an inverse relationship (Figure 10). This unexpected result can be explained considering that the fishing effort of Palma trawlers shifted during the analysed period to target species other than hake, as rose shrimp, more interesting from the economic point of view. Moreover, the modernisation of vessels allows to exploit more efficiently the fishing grounds of this late species, deeper and more distant of the port.

On the contrary, the estimated effective fishing effort on hake populations shows a close relationship with allowable fishing mortality values (Figure 11). Considering each fleet separately, the slope/shelf fleet presents the best results, and the slope fleet the worst (Figure 12). This last "métier" operates almost exclusively on areas where only some big specimens (usually less than 5 individuals) are captured. Therefore, the F attributable to this fleet is low. The shelf fleet works habitually on bottoms where hake is more abundant, but not all during the trip, because a high percentage of hauls (these vessels can carry out various hauls by trip) are performed on coral bottoms. So, considering as effort unit the trip and not the haul, we are introducing a certain bias in the analysis that explains the lower values of correlation. However, the slope-shelf fleet, when chooses the hake as target species instead of rose shrimp, exploits only the bottoms where the density of hake is high and it explains a better result.

3.3 Catchability

The slope of the lineal regressions between F and f can be considered as an estimation of q. In this case its value is 0.00002 (Figure 11). The temporal evolution of q values is showed in Figure 13. Considering that the two last values can be biased due to the arbitrary election of terminal F in the VPA, values of q did not show a trend during the studied period. Therefore, this is in agreement with the general assumption of a constant q in the relationship between F and f.

Acknowledgements

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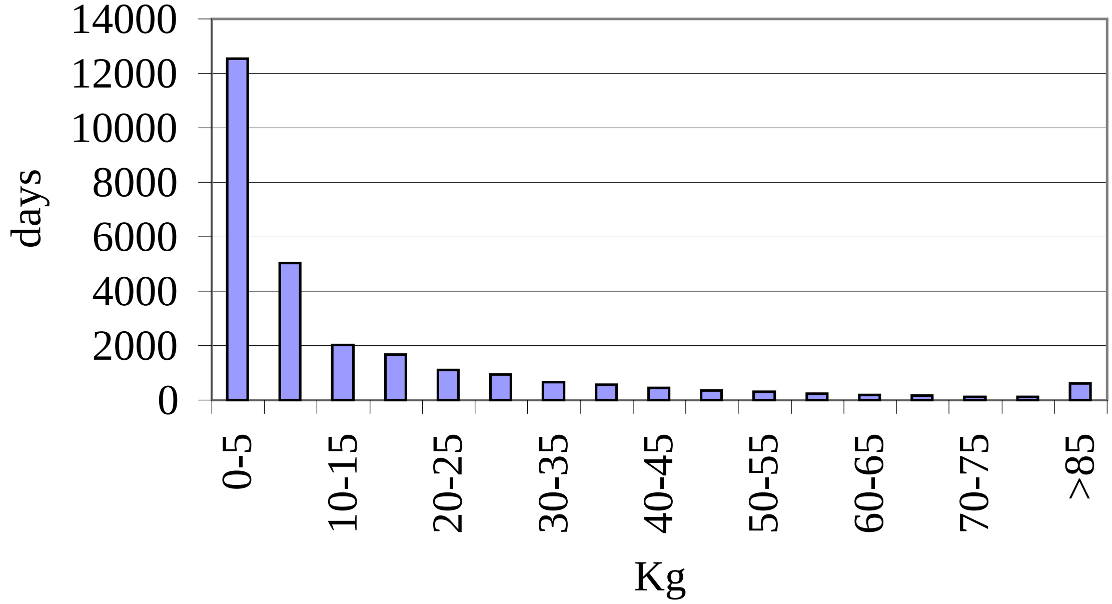

Figure 7.- Frequence distribution of hake's landings

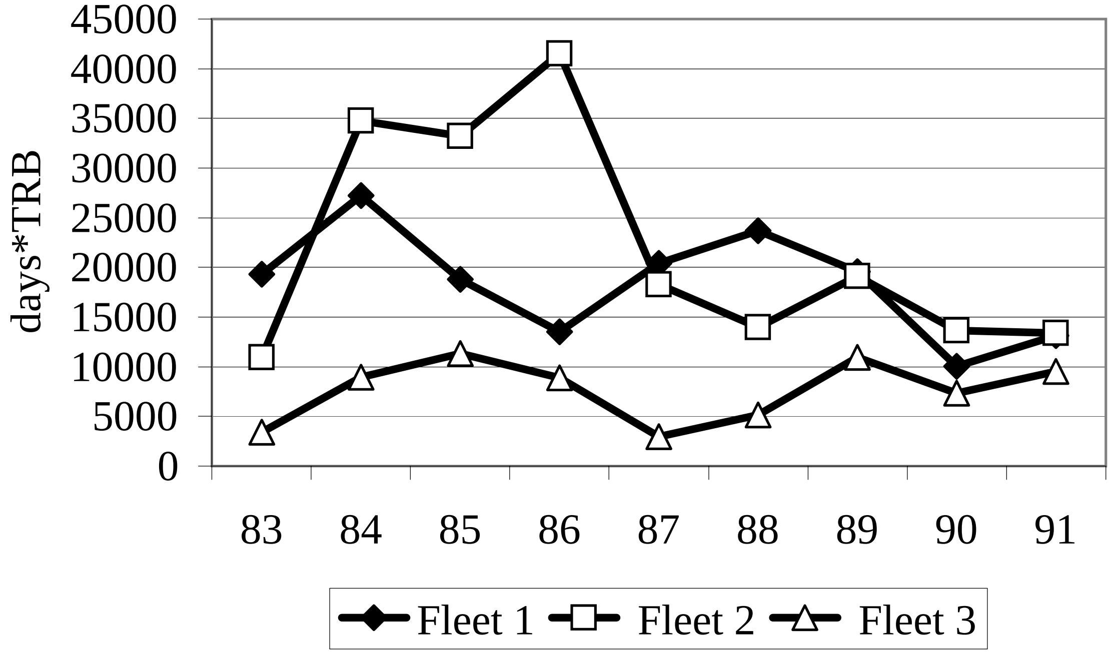

Figure 8.-Effective effort on hake (fishing days with catches>10kg) by sub-fleet or "métier"