Structure and spatio-temporal dynamics of artisanal fisheries around a Mediterranean marine protected area

Aitor Forcada, Carlos Valle, José L. Sánchez-Lizaso, Just T. Bayle-Sempere, and Fabio Corsi


Marine protected areas (MPAs) have been proposed and established throughout the world, but few studies have adequately assessed the spatial adaptations of fishers to the limitations imposed by their placement. The main objectives of this work were to identify and describe the characteristics of the artisanal fisheries around Tabarca Marine Reserve (western Mediterranean Sea) and to define their activity in space and time. Data were collected through questionnaires to fishers and onboard sampling. The artisanal fisheries were complex owing to the multispecific nature of the landings, the variety of gears involved, and their marked seasonality. All boats of the three harbours around the MPA were assessed, for a total of 32 boats. The fishers exploit 18 fishing grounds with eight gear types, for a total of 17 métiers. Mullus trammelnet, Sepia trammelnet, and sparid longline are the most frequently used métiers. The main factors determining the spatial distribution of the fishing effort are proximity to home harbour, habitat heterogeneity, and closeness to the MPA. Total fishing effort appeared slightly concentrated around the MPA, but each métier showed different patterns of effort distribution. Although the sparid gillnet and the sparid longline concentrated along MPA boundaries, the Sepia trammelnet and the Mullus trammelnet did not.

Keywords: fishing effort distribution, métier, MPA, small-scale fishery, spillover.

Received 6 April 2009; accepted 8 August 2009; advance access publication 26 October 2009.

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Introduction

Western Mediterranean fishing fleets include single-geart boats such as trawlers and purse-seiners, along with artisanal fishing vessels that use a variety of gears (Oliver, 2002). Artisanal fisheries represent 80% of the EU Mediterranean fleet (32 950 vessels), generating more than 100 000 jobs (COM, 2002). Along the coasts of Spain, artisanal fisheries are an important part of the social and economic sector, and along the Spanish Mediterranean, artisanal fisheries operate from 135 coastal locations, totalling 2251 vessels (54.2% of the Spanish Mediterranean fishing fleet) and 5402 artisanal fishers (Alarcón-Urbistondo, 2002; COM, 2002).

Artisanal fleets are generally small, and based in a multitude of ports and shelters from where they supply local markets directly (Alarcón-Urbistondo, 2002). Artisanal fishing activity is on the continental shelf (0–200 m deep), exploiting areas located within a few hours of the ports or beaches where the fishers are based (Colloca et al., 2004). The fisheries are characterized by a diversification of target species, gears and techniques, and by frequent changes in gear and technique use, spatially and seasonally, to optimize the catch and maximize profitability (Freire and García-Allut, 2000; Tzanatos et al., 2005, 2006). These characteristics increase the heterogeneity of the fishery and complicate assessment, monitoring and management of the sector.

To capture the heterogeneity, the concept of a “métier”, which is a combination of fishing gear, target species, area, and season, is used to characterize artisanal fisheries (Mesnil and Shepherd, 1990; Riseau, 1998). Métiers are homogeneous units that can be studied and interpreted individually. When assessing artisanal fisheries, a métier-based approach is not only useful for the design of stratified sampling surveys, but also for understanding the spatio-temporal pattern of effort allocation and the resulting catches (Tzanatos et al., 2006).

Usually, the identification of métiers is based on analysis of the species composition of large datasets of catch data, which are available from logbooks or landings data (e.g. Fernández and Esteban, 2003; Holley and Marchal, 2004; Jimenez et al., 2004; Ulrich and Andersen, 2004). However, in the Mediterranean, especially for artisanal fisheries, such information is seldom available and generally lacks key information, so diminishing its value for evaluating management actions. Spain censuses its active artisanal fleet in the Mediterranean Sea, but there is no exhaustive inventory of gears used, making it unlikely that the catch can be linked to a specific gear, so preventing métier identification.

The existing data on daily landings by boat therefore do not allow researchers to (i) precisely determine the métier used, (ii) distinguish simultaneous use of more than one métier, (iii) identify the fishing grounds from where the catch originates, (iv) quantify an appropriate measure of fishing effort (because the length and the number of fishing gears used vary from one vessel to another on a day-to-day basis), (v) obtain data on the composition...
of the catch at species level (species are landed either individually or as mixed categories; Fernández and Esteban, 2003), and (vi) estimate the total catch (for instance when fishers sell their catch in different harbours or directly to intermediaries or restaurants; Fernández and Esteban, 2003).

In the Mediterranean, as in other marine regions, fishery management has generally failed adequately to control fishing, so many of its resources are fully or overexploited (Farrugio and Papaconstantinou, 1998; Freire and García-Allut, 2000; FAO, 2007). Closures of fishing grounds, either temporarily (as with seasonal closing) or on a permanent basis (as with marine protected areas, MPAs), are increasingly advocated as a tool for ensuring the sustainable fishing of coastal resources (Francour et al., 2001; Freire et al., 2002). Such closures imply a clear redistribution of fishing effort. However, although MPAs have been proposed and implemented in many ecosystems, few studies have adequately assessed the spatial adaptations of fishers to their establishment (Wilcox and Pomeroy, 2003; Murawski et al., 2005; Goñi et al., 2006, 2008; Stelzenmüller et al., 2007, 2008). Several modelling studies indicate that the effectiveness of MPAs in rebuilding or maintaining populations of exploited species depends on the fishing effort in the area before the establishment of the MPA, as well as on the new spatial patterns of effort caused by displacement once the MPA is established (Babcock et al., 2005; Martell et al., 2005; Kellner et al., 2007). If, for example, fishing effort concentrates near the boundaries of an MPA after it is established, the effectiveness of the protection could be diminished (McClanahan and Kaunda-Arara, 1996; Halpern and Warner, 2003; Kellner et al., 2007). Therefore, understanding the spatio-temporal patterns of fishing-effort allocation around MPAs is essential for assessing their effectiveness.

The Tabarca Marine Reserve (Figure 1) was established to protect breeding stocks, to improve recruitment to neighbouring areas, and to restock marine species of commercial interest for artisanal fisheries (Ramos, 1985). The objectives of this work are to identify and describe the characteristics of the artisanal fisheries (fleet structure, métiers, catch composition, fishing grounds, fishing effort) taking place around the Tabarca Marine Reserve, and to locate their activity in space and time. Owing to the general characteristics of the artisanal fisheries and the limited information on landings data, we carried out a sampling scheme based on fisher questionnaires and onboard sampling to meet our research objectives.

**Material and methods**

**Study area**

The study area is located around Tabarca Marine Reserve (south-western Mediterranean, Spain), encompassing Alicante and Santa Pola bays (Figure 1). The coastal shelf is characterized by great environmental heterogeneity attributable to the co-occurrence of Posidonia oceanica meadows, and sandy and rocky seabeds. The area is exploited by three artisanal fleets; two of them, Alicante and Santa Pola, are based on the mainland, 16 and 5 km from the Marine Reserve, respectively. The third, Tabarca, is based inside the MPA.

The 1400-ha Tabarca Marine Reserve was created in 1986, and it is subdivided into three management zones (Ramos, 1985; Figure 1): (i) an Integral Reserve Area, where all activities except scientific research are forbidden; (ii) a Buffer Area, in which selective artisanal fishing gears (troll lines and trapnets that target pelagic species) are allowed; and (iii) a Transitional Area, in which stipulated selective fishing gears and recreational activities (e.g. swimming, diving, mooring of yachts) are permitted.

**Data collection**

For the study, we circulated questionnaires to fishers and carried out onboard sampling. Studies elsewhere using interview data show that this approach can produce a lot of information useful for assessing fisheries (Neis et al., 1999; Rocha et al., 2004). Fisher questionnaires were used to secure prior knowledge of the local fishery and the spatial distribution of fishing effort. Fishers from all the boats present in the three harbours were interviewed to obtain a complete overview of the fishery and the total fishing effort. In all, 32 interviews were conducted, 8 in Alicante, 21 in Santa Pola, and 3 in Tabarca. Information on fishing gear, target species, and seasonality were collected to identify the métiers used by the fishers, and the location and habitat characteristics of the different fishing grounds visited by the artisanal fisheries were identified. To assess the spatial distribution of fishing effort, the monthly frequency of use of each métier in each fishing ground was also gathered through the questionnaires. Official fleet data (tonnage, length, and horse power of the vessels) were obtained through the registries of the local maritime offices.

Onboard sampling was scheduled for 4 d per month, although the number of days sampled was usually less. By the end of the study, onboard sampling had been carried out over 77 days from May 2003 to March 2005. During the survey, 22 boats (6 from Alicante, 13 from Santa Pola, and 3 from Tabarca) were sampled, ~69% of the entire artisanal fishery. From this sampling scheme, 177 fishing sets (i.e. fishing samples that represented an individual fishing gear) were obtained. For each fishing set, the data collected included type of métier, fishing effort (length for nets or number of hooks for longlines), characteristics of the fishing ground (depth and type of substratum), total catch, and weight and market price by species. Catch per unit effort (cpue) was recorded per 500 m of net (for trammelnets, gillnets, and combined nets) or per 100 hooks (for longlines) in three ways: (i) abundance (individuals), (ii) weight (kg), and (iii) income (£).

**Data analysis**

The structure of the artisanal fleet by tonnage, horse power, and boat length was evaluated for each harbour. Using species cpue expressed as weight for each métier, a hierarchical cluster analysis, based on the Bray–Curtis dissimilarity index, was used to analyse differences in catch composition between the métiers sampled. Analysis of catch composition and fishing effort distribution was restricted to those métiers with greatest incidence in the fishery, and those targeting highly exploited, non-migratory, benthic or nektobenthic species having suitable habitats within the MPA.

To assess differences in selectivity or profitability among the métiers, differences in mean cpue (expressed as number of species, abundance, weight, and income) among the selected métiers were tested by one-way analysis of variance (ANOVA) and a Tukey test. Before the analysis, a Levene’s test was used to assess the homogeneity of the variance. Where there was significant variance heterogeneity, the data were transformed by $\sqrt{x + 1}$ or $\ln(x + 1)$. When transformations did not remove the heterogeneity, analyses were performed on the untransformed data but with the F-test $\alpha$-value set at 0.01 because ANOVA is robust to departures from this assumption (Underwood, 1997).
To identify the main species characterizing each métier by abundance, weight, and income, we used the similarity percentage analysis (SIMPER) routine included in PRIMER v6 software (Clarke and Gorley, 2006). From the results of that analysis, species with high values of similarity in terms of abundance and biomass within a given métier were assumed to characterize the specific métier. Species with high similarity scores in income provide the main revenue for the métier, and species with high similarity values in abundance and biomass but low for income were assumed to be consistent bycatches for that métier. Species that delivered large catches but low similarity scores only appeared episodically in the catch.

Using data from the questionnaires, the annual fishing effort for each selected métier and for total fishing effort was assessed. An effort index was calculated for each fishing ground to summarize the effort of each artisanal boat. Each boat’s contribution to the effort index of each fishing ground was estimated by multiplying its mean fishing effort in terms of each specific métier (length of nets, or number of hooks for longlines) by its frequency of use on the fishing ground. The value of the effort index for each fishing ground was subsequently expressed as a percentage of the total fishing effort for the study area. These values were incorporated in a geographic information system to obtain maps of fishing effort distribution and to assess spatial relationships between fishing effort, harbours, and the MPA.

Results
Artisanal fleet structure
Over the duration of the study, 51 artisanal fishing boats were listed in the official fleet register of Santa Pola, Alicante, and Tabarca (Figure 2a). However, some 40% of the boats were never present in the harbours during the study period; the exception was Tabarca, where the entire fleet was present. Some artisanal

![Figure 1. Map of the study area. The location of the harbours of Alicante, Santa Pola and Tabarca, and the Tabarca Marine Reserve are shown, along with its zonation (I: integral reserve area, II: buffer area, III: transitional area). Also shown are the distribution of the main habitats and the position of the fishing grounds used by the artisanal fisheries.](image-url)
boats showed mobility among harbours. The three boats registered in Tabarca generally used Santa Pola, except in summer when the fishers spent some days living on Tabarca Island. Of the boats registered at Santa Pola, two were permanently located in Alicante, and five temporarily used Alicante when fishing the grounds close to that port to save time and fuel.

The technical characteristics of the artisanal fleet do not differ among harbours. Boat ages range between 3 and 64 years (mean 22 years), and 53% are wooden, although modern vessels are constructed of polyester. Boat lengths average $8.63 \pm 0.35$ m (s.e.; Figure 2b). The artisanal fleet has a mean tonnage of $4.34 \pm 0.44$ grt (Figure 2c), and uses inboard diesel engines that average $51.71 \pm 7.20$ hp (Figure 2d). All are equipped with pulleys to recover the fishing gear, a radiophone, and an echosounder. The larger boats include global positioning system and radar. Crew size ranges from 1 to 3, mostly two per boat. Fishers exploit areas that can be reached in <2 h, returning to harbour every day, at the end of their trip. Fishing activity is carried out 5 days a week, and fishers sell their catch to intermediaries in markets located in the harbours, where landings data are also registered. Occasionally, fishers sell direct to restaurants, especially when they capture species of high market value.

**Métier identification**

In the study area, 17 métiers, using a total of eight types of fishing gear, were identified (Table 1). The bulk of the fleet used more than one métier, either within a single fishing day (Figure 3) or during a year (Figure 4). For the average fishing trip, each boat used $2.49 \pm 0.13$ (s.e.) fishing sets of $1.51 \pm 0.09$ métiers. During onboard sampling, we registered one trip in which a single boat used five fishing sets categorized as four different métiers. Over a 1-year period, the mean number of métiers used was $3.03 \pm 0.33$. We observed seasonal rotation in the use of the métiers, generally in relation to the abundance or catchability of the target species (Table 1). The average number of active métiers observed per month was $8.50 \pm 0.46$.

The main métiers used by the artisanal fleet were *Mullus trammlenet* and *Sepia trammlenet* (Table 1), and others of importance were sparid longline and *Solea trammlenet*. The use of each métier varied by harbour. During the study, the Alicante fleet fished with six métiers, but used mainly the *Mullus trammlenet* and the *Sepia trammlenet*. In Tabarca, the fleet used ten métiers, two of them (barrier traps traditionally used at Tabarca island) exclusively by that fleet because only boats from that harbour are allowed to fish with these métiers inside the MPA. The Santa Pola fleet used all métiers identified except barrier traps. Some gears such as *Penaeus trammlenet*, *Merluccius gillnet*, and *Octopus pots* were used exclusively by the Santa Pola fleet.

**Catch composition**

In all, 56 species belonging to 48 families were caught in the 177 fishing sets sampled (distributed in 13 métiers; Table 1). Most were fish, but two crustaceans (*Homarus gammarus* and *Palinurus elephas*) and three cephalopods (*Sepia officinalis*, *Loligo vulgaris*, and *Octopus vulgaris*) were recorded. The most represented family was the Sparidae, followed by the Labridae, with 16 and 10 species, respectively.

The species with highest market price were the crustaceans, followed by *Epinephelus marginatus*, *Sparus aurata*, and *Dicentrarchus labrax*. However, as catches of such species were relatively rare, other species with lower market prices and more captures (such as *Mullus surmuletus* and *Dentex dentex*) contributed more to the total income of the artisanal fishery. Owing to the multispecific character of the fishery, most of the species captured were commercialized. Discards were practically irrelevant, averaging just

![Figure 2](image-url)
### Table 1. Classification of métiers identified based on the fishing gear (sensu FAO, 1980).

<table>
<thead>
<tr>
<th>Métier and gear (FAO code)</th>
<th>Number of boats that use it</th>
<th>Number of fishing sets sampled</th>
<th>Target</th>
<th>Accessory species</th>
<th>Month</th>
<th>Habitat</th>
<th>Depth (m)</th>
<th>Soak time (h)</th>
<th>Mesh size (mm) or hook size (number)</th>
<th>Length of net (m) or number of hooks or pots</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Trammel nets</strong> (07.5.0)</td>
<td></td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Mullus trammelnet</td>
<td>25</td>
<td>44</td>
<td>M. surmuletus</td>
<td>M. barbatius, Scorpaena spp.</td>
<td>P, S</td>
<td>7–64 21</td>
<td>1–14 4</td>
<td>19–20 20</td>
<td>500–3 500 1 450</td>
<td></td>
</tr>
<tr>
<td>Solea trammelnet</td>
<td>6</td>
<td>9</td>
<td>Solea spp.</td>
<td>–</td>
<td>S</td>
<td>5–54 35</td>
<td>12–24 15</td>
<td>28–50 50</td>
<td>850–1 700 1 200</td>
<td></td>
</tr>
<tr>
<td>Palinurus trammelnet</td>
<td>2</td>
<td>3</td>
<td>P. elephas</td>
<td>H. gammaurus, S. scrofa</td>
<td>R</td>
<td>60–70 64</td>
<td>45–46 46</td>
<td>50–100 50</td>
<td>750–1 000 850</td>
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</tr>
<tr>
<td>Peneaus trammelnet</td>
<td>2</td>
<td>1</td>
<td>P. kerathurus</td>
<td>–</td>
<td>S</td>
<td>6–14 10</td>
<td>11–13 12</td>
<td>17–18 18</td>
<td>3 000</td>
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</tr>
<tr>
<td><strong>Gillnets</strong> (07.9.1)</td>
<td></td>
<td></td>
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<tr>
<td>Sarda gillnet</td>
<td>4</td>
<td>6</td>
<td>S. sarda</td>
<td>A. rochei, S. dumerili</td>
<td>P</td>
<td>7–21 16</td>
<td>21–24 22</td>
<td>–</td>
<td>50</td>
<td>600–1 000 750</td>
</tr>
<tr>
<td>Sparid gillnet</td>
<td>2</td>
<td>46</td>
<td>Sparidae</td>
<td>S. sarda, S. dumerili</td>
<td>R, P</td>
<td>5–63 20</td>
<td>12–24 19</td>
<td>44–100 50</td>
<td>500–2 700 750</td>
<td></td>
</tr>
<tr>
<td>Merluccius gillnet</td>
<td>2</td>
<td>2</td>
<td>M. merluccius</td>
<td>–</td>
<td>R</td>
<td>± 53</td>
<td>± 20</td>
<td>–</td>
<td>33</td>
<td>± 2 000</td>
</tr>
<tr>
<td><strong>Combined nets</strong> (07.6.0)</td>
<td></td>
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<tr>
<td>Sarda combined net</td>
<td>2</td>
<td>2</td>
<td>S. sarda</td>
<td>Sparidae, S. dumerili, A. rochei</td>
<td>P</td>
<td>9–16 14</td>
<td>21–23 22</td>
<td>50 (gill.) and 25 (tramm.)</td>
<td>900–1 000 950</td>
<td></td>
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<tr>
<td><strong>Longlines</strong> (09.3.0)</td>
<td></td>
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<tr>
<td><strong>Trolling lines</strong> (09.6.0)</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Bottom troll line</td>
<td>5</td>
<td>2</td>
<td>S. dumerili</td>
<td>E. marginatus, D. dentex</td>
<td>R, P</td>
<td>± 27</td>
<td>0.5–1</td>
<td>0.75–2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td><strong>Handlines</strong> (09.10)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Seriola handline</td>
<td>5</td>
<td>2</td>
<td>S. dumerili</td>
<td>C. hippurus</td>
<td>R</td>
<td>27–36 31</td>
<td>0.5–1 0.67</td>
<td>–</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Squid jig hook*</td>
<td>5</td>
<td>0</td>
<td>L. vulgaris</td>
<td>–</td>
<td>P, S</td>
<td>± 30</td>
<td>5–15 5</td>
<td>–</td>
<td>–</td>
<td>1</td>
</tr>
<tr>
<td><strong>Barrier traps</strong> (08.5.0)</td>
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</tr>
<tr>
<td>Seriola trapnet*</td>
<td>1</td>
<td>0</td>
<td>S. dumerili</td>
<td>S. sarda, A. rochei</td>
<td>P</td>
<td>0–10  –</td>
<td>– Months 200 and 66</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Atherina trapnet*</td>
<td>1</td>
<td>0</td>
<td>A. hepsetus</td>
<td>Sparidae juveniles, Serranidae</td>
<td>P</td>
<td>0–10  –</td>
<td>– Months 7 and 6</td>
<td>–</td>
<td>–</td>
<td>–</td>
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<td><strong>Pots</strong> (08.2.0)</td>
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<td></td>
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<tr>
<td>Octopus pots*</td>
<td>1</td>
<td>0</td>
<td>O. vulgaris</td>
<td>–</td>
<td>S</td>
<td>7–27 10</td>
<td>– Months</td>
<td>–</td>
<td>–</td>
<td>1 000</td>
</tr>
</tbody>
</table>

For each métier, the number of boats that use it, the number of fishing sets sampled, their target and accessory species, the season (no shading, without use; light grey shading, moderate use; dark grey shading, intensive use), habitat (P, P. oceanica seagrass; R, rocky substrata; S, sandy substrata), depth, soak time, and technical characteristics are reported.

*For métiers not sampled, their information has been completed from questionnaire data.
4.13% ± 0.64 (s.e.) of the total catch weight; mainly species of the Torpedinidae, small Labridae (Symphodus spp.), and small pelagics (Spicara spp., Boops boops, and Sardinella aurita).

The clustering of the métiers based on their catch data shows that all métiers used in the study area are separated at a dissimilarity level >50% (Figure 5). Sepia trammelnet, Mullus trammelnet, sparid gillnet, and sparid longline were the métiers selected for the subsequent analysis because of their prevalence in the fishery and because their target species are those ecologically most likely to benefit from the establishment of an MPA. Among these métiers, the greater selectivity of the métiers with larger mesh or hook size is reflected in the total number of species caught in each métier. Although the sparid longline and sparid gillnet caught 25 and 52 species, respectively, the Sepia trammelnet and the Mullus trammelnet caught 64 and 71 species, respectively. Métiers differed significantly in the mean number of species and number of individuals caught (Table 2). The Sepia trammelnet and the Mullus trammelnet (the less selective métiers) delivered significantly greater cpue in terms of number of species (Figure 6a) and individuals (Figure 6b), but by weight (Figure 6c), the cpue did not differ significantly among métiers. In contrast, the cpue calculated as income for the sparid gillnet was significantly greater than that of the other métiers (Figure 6d).

For the Sepia trammelnet (Figure 7a) and the Mullus trammelnet (Figure 7b), the largest catches by weight were recorded for their respective target species, but other species also contributed a significant portion of the catch of both. Mullus surmuletus contributed close to half the income of the Mullus trammelnet, but the income of the Sepia trammelnet was attributable to several species. The target species of the sparid gillnet (large sparids such as D. dentex, Diplodus sargus, and S. aurata), along with Seriola dumerili, constituted 47 and 43% of the catch by abundance and weight, respectively, and consistently provided the main income for that métier. This finding was also evidenced by the elevated similarity percentages (Figure 7c). The low similarity scores of Euthynnus alletteratus shows that it appeared sporadically in the catch, although it made an important contribution to the total catch of
Table 2. Summary of Levene’s test and one-way ANOVA for total cpue (expressed as number of species, individuals, kilogrammes, and income) among the selected métiers (Sepia trammelnet, Mullus trammelnet, sparid gillnet, and sparid longline).

<table>
<thead>
<tr>
<th>Cpue</th>
<th>Transformation</th>
<th>Levene’s test</th>
<th>d.f.</th>
<th>Sum of squares</th>
<th>Mean square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of species</td>
<td>–</td>
<td>0.147</td>
<td>Among groups</td>
<td>3</td>
<td>346.134</td>
<td>115.378</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Within groups</td>
<td>140</td>
<td>922.547</td>
<td>6.590</td>
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<td>11.346</td>
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<td></td>
<td>Total</td>
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<td>10 357.279</td>
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<tr>
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<td>Among groups</td>
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<td>9 884.696</td>
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<td>Within groups</td>
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<td>3 475.292</td>
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<td></td>
<td>Total</td>
<td>143</td>
<td>363 129.380</td>
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n = 144; d.f., degrees of freedom; F, F-ratio; P, level of significance (**p < 0.001). A dash (–) indicates no transformation.

^a No homogeneity of variance, the level of significance being *p < 0.01.

The sparid gillnet, Conger conger and Muraena helena were the most notable species for the sparid longline (Figure 7d), contributing the major share of the income of that métier, although they were not the target species and their market price is low.

Fishing effort distribution

In all, 18 fishing grounds were identified through the fisher questionnaires (Figure 1). The fishing grounds were mainly at depths <50 m, covering ~28 100 ha. Six of the fishing grounds are along the border of Tabarca Marine Reserve. The seabed of each is homogeneous, a combination of several habitats in different proportions. The deepest fishing grounds are mainly dominated by coralligenous and rocky substrata interspersed with detritic material.

The Tabarca and Santa Pola fleets were analysed together because both use Santa Pola as home base. They showed a different spatial distribution of total fishing effort from that of Alicante. Boats from Santa Pola/Tabarca used 16 fishing grounds (covering ca. 21 000 ha; Figure 8a), whereas boats from Alicante fished in just 9 (~17 000 ha; Figure 8b). Both fleets concentrated around their home harbour and shared some of the fishing grounds located in between. As a result, the fishing grounds located around Santa Pola, which hosts more artisanal boats, showed the greatest concentration of total fishing effort (24.79%; Figure 8c). The fishing grounds that surround the MPA accommodated 18.35% of the total fishing effort in the study area (Figure 8c), rising to 28.60% if only the total fishing effort of the Santa Pola/Tabarca fleet is considered (Figure 8a).

The Sepia trammelnet was used mainly in the coastal fishing grounds and showed the highest values of fishing effort around Santa Pola and Alicante (Figure 9). Only the Santa Pola/Tabarca fleet fished with this métier around the MPA, targeting two of the six fishing grounds that border the MPA (Figure 9a). Consequently, the Sepia trammelnet was the métier with the lower proportion of total fishing effort (12.29%) around the Tabarca Marine Reserve.

The fishing effort of the Mullus trammelnet was distributed through 13 fishing grounds (Figure 10), with fleets concentrating their effort around their respective harbours. The Alicante fleet fished with this métier exclusively in shallower areas (Figure 10b), whereas the boats from Santa Pola/Tabarca targeted fishing grounds with different depth ranges (Figure 10a). The Santa Pola/Tabarca fleet also fished in the six fishing grounds next to the MPA, concentrating 27.15% of its Mullus trammelnet effort around the MPA.

The sparid gillnet was only used by Santa Pola/Tabarca fishers. Although it was used in a wide range of depths, most of the effort was deployed between 30 and 50 m deep (Figure 11). The métier revealed the most concentrated fishing effort in the grounds next to the Tabarca Marine Reserve (53.62%), mostly along its northern and eastern limits.

The sparid longline was used in more fishing grounds than any of the other métiers (Figure 12). The Santa Pola/Tabarca fleet had the highest fishing effort for this métier in the Santa Pola and Freu fishing grounds (Figure 12a), whereas the Alicante boats concentrated more on the Morenes Forques fishing ground (Figure 12b). As a consequence, more than half the fishing effort of this métier (52.01%) was next to the MPA, especially along its northern and western limits (Figure 12c).

Discussion

Because of the mix of target species, highly diverse fishing gears, and marked seasonality, the artisanal fishery activity around the MPA was complex in terms of its dynamics. In general, the fishing boats used more than one fishing set from different métiers during a working day. In addition, fishers rotated métiers throughout the year to optimize yields, based on their knowledge of the seasonal variation in the behaviour and catchability of target species. Although our results show that the sparid gillnet is the most selective and profitable métier, the seasonal decrease in abundance of its target species explains why it is not the most used of the métiers. Also, the use of fixed fishing gears in coastal areas, where seasonal environmental variability and spatial heterogeneity are high, favours diversification of fishing tactics. Fishers have to choose the métiers over two time-scales: annually, when they purchase and/or prepare the gear, and daily, when they set out from their harbours to set the gear. The latter choice of métiers is based on several factors: recent catch and income, market demand, weather conditions, and information and rumours about the catches of other fishers. The versatility of the artisanal fleet relies on this annual and daily rotation of métiers, ensuring stability in total landings and sustained returns throughout the year. All these fishing strategies are typical of artisanal fisheries, including those of the Mediterranean Sea (Colloca...
et al., 2004; Tzanatos et al., 2006) and elsewhere (Freire and García-Allut, 2000).

Previous studies of the artisanal fisheries in the study area (Mas and Barcala, 1997; Alarcón-Urbistondo, 2002; Fernández and Esteban, 2003; García-Rodríguez et al., 2006) reached different conclusions. For example, métier identification and use on the part of the artisanal fishing fleet was not consistent among these studies, nor was the percentage use of each métier by each fishing boat. Of the differences, only a few are likely attributable to long-term variations in the use of specific métiers in the study area. For instance, we know that some métiers that target bivalves (*Chamelea gallina*, *Donax trunculus*, *Ruditapes decussatus*) with dredges (FAO code 04.1.0; FAO, 1980) or those that use pots (FAO code 08.2.0; FAO, 1980) to fish *M. helena* are no longer used by this artisanal fleet. On the other hand, the use of *Octopus* pots and *Merluccius* gillnets are both relatively new to the study area. The *Merluccius* gillnet was introduced in 1995 (García-Rodríguez et al., 2006), when boat length and horse power increased, allowing the exploitation of fishing grounds farther from shore where *M. merluccius* are found. Although we did observe the use of the *Merluccius* gillnet in our study, we only recorded two boats using this métier, as opposed to its widespread use as reported by other studies of the Santa Pola artisanal fleet (Fernández and Esteban, 2003; García-Rodríguez et al., 2006). These discrepancies are evidence of variable fishing tactics over the scale of a few years, resulting in changes to the artisanal fisheries. For this reason, periodic assessments are necessary for appropriate and valid management of the fisheries.

Information documented to date for the artisanal fisheries of the study area (Mas and Barcala, 1997; Alarcón-Urbistondo, 2002; Fernández and Esteban, 2003; García-Rodríguez et al., 2006) has limited utility in evaluating the impact of the Tabarca Marine Reserve as a management tool because of the imprecise units of fishing effort used in the earlier studies (days, gross tonnage, or horse power; Guerra-Sierra and Sánchez-Lizaso, 1998) and the mixed heterogeneous information used to define the real effort on the resources. To address this issue, future study of artisanal fisheries should assess the effort of individual métiers, using their basic unit (e.g. metres of net, or number of hooks). Direct onboard sampling allows effort to measure in adequate units while still allowing for more-precise evaluation of artisanal fishing activity, through a clearer understanding of the way fishers select and change métiers, and when and where each métier is used.

None of the earlier studies assessed the spatial distribution of artisanal fishing activity, a crucial parameter for effective management of coastal areas. Too often the major failure in traditional management has been the lack of attention paid to the dynamics or behaviour of the fishers, overlooking the fact that they are an integral part of the system (Freire and García-Allut, 2000). Our results show that artisanal fishing effort is not homogeneously distributed in the study area, but rather that fishing effort depends on proximity to the home harbour and to the MPA, and habitat heterogeneity. The distribution of the total fishing effort of the Santa Pola and Tabarca fleets is likely the result of a combination of métiers that concentrate around the MPA and of métiers that are less focused. The *Sepia* trammelnet and the *Mullus* trammelnet were used primarily close to the home harbour, demonstrating that fishers compromise between costs (distance from harbour) and benefits (expectations of improved yields; Caddy and Carocci, 1999). In addition, a small boat size limits travel distances to areas surrounding the home ports, especially in winter when bad weather may put boats at risk. Both issues seem to be particularly relevant to the Alicante artisanal fleet, which during our study always operated close to home.
Figure 7. Mean catch composition for métiers (a) Sepia trammelnet, (b) Mullus trammelnet, (c) sparid gillnet, and (d) sparid longline showing the mean proportion (in biomass, abundance, and income) of the 15 most important species in the total catch. Error bars show the standard error. Percentage contribution to the within-métier similarity of these species is also provided according to a SIMPER analysis, using a similarity level of 90%.
Figure 8. Spatial distribution of total fishing effort (including the activity of all métiers identified in the study area) of (a) the Santa Pola and Tabarca fleet, (b) the Alicante fleet, and (c) both fleets combined. Effort was estimated for each area by summarizing the frequency of use by each boat.

Figure 9. Spatial distribution of *Sepia* trammelnet effort of (a) the Santa Pola and Tabarca fleet, (b) the Alicante fleet, and (c) both fleets combined. Effort was estimated for each area by summarizing the frequency of use and the mean gear length of each boat.

Figure 10. Spatial distribution of *Mullus* trammelnet effort of (a) the Santa Pola and Tabarca fleet, (b) the Alicante fleet, and (c) both fleets combined. Effort was estimated for each area by summarizing the frequency of use and the mean gear length of each boat.
On the contrary, more than half the fishing effort of the sparid gillnet and the sparid longline by the Santa Pola and Tabarca fleets concentrated around the MPA. Suitable habitats for the species captured by these métiers (mainly *D. sargus*, *Diplodus vulgaris*, *D. dentex*, *S. aurata*, *Pagrus pagrus*, *Sciaena umbra*, *C. conger*, and *M. helena*) occur within the MPA, so the species and their yield benefit from the protection afforded by the reserve (Forcada, 2005). To this extent, previous studies in the Tabarca Marine Reserve evidenced a spillover showing a significantly decreasing gradient in fish biomass from the MPA boundaries (Forcada et al., 2005), along with larger catches near the MPA compared with more-distant fishing grounds (Forcada et al., 2009).

The concentration of fishing effort around the MPA indicates that fishers make better catches close to the Tabarca Marine Reserve, likely the result of biomass export from the MPA to the surrounding fishing grounds. Such an effect has also been seen around other MPAs (McClanahan and Mangi, 2000; Wilcox and Pomeroy, 2003; Murawski et al., 2005; Goñi et al., 2006, 2008; Stelzenmüller et al., 2007, 2008), but some other studies have given different explanations for the concentration of fishing effort around MPAs. Reasons given have been the non-selective redistribution of fishing effort after MPA creation (Halpern et al., 2004, Murawski et al., 2005), or an artefact attributable to the expectation of fishers for better catches along the boundaries even when the resources rates are locally depleted (McClanahan and Kaunda-Arara, 1996; McClanahan and Mangi, 2000; Wilcox and Pomeroy, 2003; Goñi et al., 2006). However, given that the Tabarca Marine Reserve was established more than 20 years ago, we can safely assume that, by now, the effort distribution we observed responds to real fishery benefits.

Although our results point towards a positive effect of the MPA on the surrounding fishing grounds, one should not ignore the effect of fishing effort distribution around the MPA. Some studies suggest that fishing activity intensification near the borders of the MPA has the potential to reduce catch rates and negate the ability of an MPA to meet its conservation and fisheries management goals (McClanahan and Kaunda-Arara, 1996; Walters, 2000; Halpern and Warner, 2003; Kellner et al., 2007), and that effort concentration in non-reserve areas can produce new impacts on species or habitats (Hilborn et al., 2004; Mangi and Roberts, 2007). Moreover fishing grounds located in coastal areas, as for the artisanal fleets studied, can lead to spatial interaction among fishers and other coastal activities (e.g. recreational fishing, tourism, aquaculture, diving). Therefore, efficient management should not be limited to controlling fishing effort and assessing its redistribution after MPA creation, but should focus too on understanding the spatio-temporal dynamics of artisanal fisheries, the resources they exploit, the conservation of key habitats, and their interaction with other activities (Freire et al., 2002).

**Figure 11.** Spatial distribution of sparid gillnet effort of the Santa Pola and Tabarca fleet. Effort was estimated for each area by summarizing the frequency of use and the mean gear length of each boat.

**Figure 12.** Spatial distribution of sparid longline effort of (a) the Santa Pola and Tabarca fleet, (b) the Alicante fleet, and (c) both fleets combined. Effort was estimated for each area by summarizing the frequency of use and the mean gear length of each boat.
Because of the income it generates, its selectivity, the scarcity of discards, and its low impact on marine habitats, artisanal fishing appears to be the most viable option to reduce the overexploitation caused by other Mediterranean fisheries (Farrugio and Papaconstantinou, 1998; FAO, 2007), and the same has been observed in other marine regions (Freire and García-Allut, 2000). However, the benefits of artisanal fisheries point to the need for further studies to understand their dynamics better in order adequately to manage the resources optimally. Our results indicate that although landings data are sometimes a good and substantial source of information, onboard evaluation of artisanal fisheries is required for correct identification of métiers, and its use. For instance, from our results, we can assume that the distance from home to the MPA determines the proportion of local fishers that can exploit the potential benefits of a protected area.

Our study has contributed to understanding the way fishers select and change métiers, and where and when they are used, detecting patterns of fishing effort concentration around Tabarca Marine Reserve. This is an important step towards assessing the fishery and selecting management approaches and can help to predict the outcome of future actions, such as increasing the size of an MPA or establishing a new one.

Acknowledgements
We acknowledge the cooperation of the fishers of Santa Pola, Alicante, and Tabarca. The research was financed by the EU DG Fisheries through project BIOMEX (QLRT-2001-00891). AF was supported by an FPI grant of the Generalitat Valenciana (CTBPRB/2003/146). We also thank the anonymous reviewers and the editor for their useful comments on the submitted manuscript.

References


