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# Size selectivity of trammel nets in southern European small-scale fisheries

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## Abstract

Trammel net size selectivity was studied for the most important métiers in four southern European areas: the Cantabrian Sea (Atlantic, Basque Country, Spain), the Algarve (Atlantic, southern Portugal), the Gulf of Cádiz (Atlantic, Spain) and the Cyclades Islands (Mediterranean, Aegean Sea, Greece). These métiers were: cuttlefish (*Sepia officinalis*) and soles (*Solea senegalensis*, *Microchirus azevia*, *Synaptura lusitanica*) in the Algarve and the Gulf of Cádiz, sole (*Solea solea*) in the Cantabrian Sea and mixed fin-fish in the Cyclades. In each area, experimental trammel nets of six different types (combinations of two large outer panel mesh sizes and three small inner panel meshes) were constructed. Fishing trials were carried out on a seasonal basis (four seasons in the Cantabrian Sea, Algarve and Cyclades and two seasons in the Gulf of Cádiz) with chartered commercial fishing vessels. Overall, size selectivity was estimated for 17 out of 28 species for which sufficient data were available. Trammel nets generally caught a wide size range of the most important species, with length frequency distributions that were skewed to the right and/or bi-modal. In many cases the length frequency distributions of the different nets were highly overlapped. The Kolmogorov–Smirnov test also showed that the large outer panel meshes generally had no effect in terms of size selectivity, while the opposite was true for the small inner panel ones. Six different selectivity models (normal scale, normal location, gamma, log-normal, bi-modal and gamma semi-Wileman) were fitted to data for the most abundant species in the four areas. For fish, the bi-modal model provided the best fits for the majority of the data sets, with the uni-modal models giving poor fits in most cases. For *Sepia officinalis*, where trammelling or pocketing was the method of capture in 100% of the cases, the logistic model fitted by maximum likelihood was judged to be more appropriate for describing the size selective properties of the trammel nets. Our results, which are among the first ones on trammel net selectivity in European waters, will be useful for evaluating the impacts of competing gear for the socio-economically important small-scale static gear fisheries.

*Keywords:* Trammel nets; Size selectivity; Cantabrian Sea; Algarve; Gulf of Cádiz; Cyclades Islands

## 1. Introduction

Trammel nets are widely used throughout the world in artisanal or small-scale fisheries to catch a variety of demersal species such as soles, sea breams, red mullets, skates, shrimps, lobsters and cuttlefish. In southern European countries trammel nets are among the most important gears, with different combinations of gear characteristics (mesh sizes, hanging ratios, net height, flotation), target species, fishing areas, depths, seasons and fishing strategy defining different trammel net métiers (Laurec et al., 1991; Ulrich et al., 2001; Salas and Gaertner, 2004). In the Algarve (southern Portugal), trammel nets were second in importance after longlines

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with 611 (18%) of a total of 3343 licences attributed to 1241 vessels in 2002 (Seruca, personal communication, DRPAS). In a study based on a fraction of the Basque Country's artisanal fisheries (boats with a total length less than 15 m), 56 out of a total number of 96 boats (58%) used trammel nets during part or all of the year (Puente et al., 2002).

Trammel nets consist of three walls of multifilament or monofilament netting, with a loosely hung, small mesh inner net between larger mesh netting. Hanging ratios for the inner net generally range between 0.3 and 0.5, while hanging ratios of the larger mesh outer panels are typically greater. Vertical slack, the ratio of the depth of the small-meshed inner panel to that of the large-meshed outer panels (Losanes et al., 1992a), is commonly between 1.5 and 2.0.

In addition to wedging, gilling and entangling (i.e., held by teeth, spines or other protrusions), trammel nets also catch fish and invertebrates in the pocket formed by the inner smaller mesh wall of netting being pushed through one of the larger mesh outer walls. This is known as trammelling or pocketing (Losanes et al., 1992b; Fabi et al., 2002). The catches of trammel nets depend primarily on the mesh size and vertical slack of the inner net (Purbayanto et al., 2000) with several studies reporting wider selection ranges with increasing inner net slackness (Kitahara, 1968; Koike and Takeuchi, 1985; Koike and Matuda, 1988; Salvanes, 1991; Losanes et al., 1992a,b). Trammel nets with a slackness of more than 1.5 are expected to be more effective in catching larger sized fish than gillnets of the same mesh size (Koike and Matuda, 1988).

Compared to gill nets, trammel net selectivity is relatively poorly studied. Trammel nets are generally considered to be less size selective than gill nets, with size frequency distributions frequently skewed to the right (Millner, 1985; Dickson, 1989; Fabi et al., 2002; Fitzhugh et al., 2002). The selectivity curve of trammel nets is domed but has a flatter shape than that for fin-fish caught with gill nets, as reported by authors who used the same methodology to fit the selectivity curve (Koike and Matuda, 1988; Losanes et al., 1992a). If a significant proportion of individuals, especially the larger ones, are pocketed or trammelled, then the selectivity curve may not fall to zero or even have a descending limb, implying that very few fish escape after coming into contact with the trammel net (Salvanes, 1991; Losanes et al., 1992b).

While there is a general consensus with regards to the form of gill net selectivity curves, this is not the case for trammel nets. Many authors have fitted uni-modal selectivity models to trammel net data. Thus, Fujimori et al. (1990, 1992) fit a skew-normal model, while Purbayanto et al. (2000) use Kitahara's (1968) method to fit a uni-modal model that was skewed to the right. Fujimori et al. (1996) also use Kitahara's (1968, 1971) method and report a dome-shaped selectivity curve that is flat on top. Losanes et al. (1992b) fit a bi-normal curve where the first component is assumed to correspond to fish that are essentially gilled or wedged, as in gill nets, and the second one to larger fish that are entangled or trammelled/pocketed. Matsuoka (1991) reports that trammel net selectivity for *Tilapia mossambica* is bi-modal, with wedging being a minor component compared to entangling. However, Matsuoka (1991) suggests that given the relatively poor fit of the bi-modal selectivity curve, trammel net selectivity may be tri-modal due to the capture of fish in the pocket.

Despite the importance of trammel nets for the small-scale fisheries in southern European waters, in terms of landings, commercial value, number of vessels and fishers, there have been few studies on the size selectivity this gear. Elsewhere we have examined the catch rates, catch species composition and métiers in southern European waters (Stergiou et al., 2006). In this paper our objectives were: (1) to study the size selectivity of the main métiers in four southern Europe areas: the Basque country (Atlantic, Spain), Algarve (Atlantic, southern Portugal), Gulf of Cádiz (Atlantic, Spain) and Cyclades (Mediterranean, Aegean Sea, Greece), (2) to evaluate the influence of outer panel mesh size on size selectivity, and (3) to investigate the effect(s) of catching mechanism(s) on size selectivity.

## 2. Materials and methods

### 2.1. Experimental fishing trials

In all four areas the most important trammel net métiers were identified on the basis of questionnaire surveys. In the Basque country and in the Algarve monofilament trammel net métiers were the most important while in the Gulf of Cádiz and in the Cyclades multifilament nets were the principal métiers. In the Basque country the *Solea solea* métier was chosen for the selectivity study while in the Algarve the *Sepia officinalis* and flatfish métier were the most important. The latter métier was also the most important in the nearby Gulf of Cádiz. Finally in the Cyclades, trammel nets for fin-fish, especially *Mullus surmuletus* and *Pagellus erythrinus,* were selected.

The trammel nets were constructed either by commercial enterprises or by the fishers contracted for the project according to design specifications appropriate for the selected métier. These design specifications were similar to those used by local fishers in terms of number of meshes deep, hanging ratios, lead line and floats. In all areas three inner panel mesh sizes and at least two outer panel mesh sizes were used, giving at least six combinations of outer and inner panel mesh size trammel nets. Inner panel stretched mesh sizes ranged from 40 to 48 mm in the Cyclades to 100–140 mm in the Algarve, while outer panel stretch mesh sizes ranged from 220 to 300 mm in the Cyclades to 600 and 800 mm in the Algarve (Table 1). Some differences between the gear parameters of the experimental trammel nets in each area were obtained due to constrictions in the mounting of the nets. The ranges of the main gear parameters are given in Table 1.

Normal fishing practices were followed in all four areas. In the Basque country the nets were generally fished for 24 h, except when bad weather did not allow gear retrieval. In

Table 1
Main characteristics of the trammel nets used, number of experimental trials and sampling depths in the four areas

| | Area | | | |
|---|---|---|---|---|
| | Basque | Algarve | Cádiz | Cyclades |
| Inner panel mesh sizes | 90, 100, 110 | 100, 120, 140 | 80, 90, 100 | 40, 48, 56 |
| Inner panel number of meshes | 33–40 | 40–50 | 20–30 | 60 |
| Outer panel mesh sizes | 500, 600 | 600, 800 | 300, 400 | 220/240, 240/260, 280/300 |
| Outer panel number of meshes | 3.5–4.5 | 3.5–5.5 | 2.5–3.5 | 7.5–8.5 |
| Twine type | Monofilament | Monofilament | Multifilament | Multifilament |
| Twine colour | Green | Green | Green | Yellow |
| Inner hanging ratio | 0.39–0.45 | 0.48–0.49 | 0.38–0.56 | 0.44–0.50 |
| Outer hanging ratio | 0.50–0.52 | 0.38–0.56 | 0.50 | 0.50 |
| Length of nets (m) | 6000 | 8900 | 6000 | 4500 |
| Sampling frequency | Seasonal | Seasonal | Autumn, spring | Seasonal |
| Total number of trials | 48 | 40 | 60 | 41 |
| Sampling depth | 20–80 | 15–100 | 10–30 | 10–80 |

Mesh sizes in millimetres (stretched), depths in metres.

the Algarve, the gears were set in the afternoon or evening before sunset and hauled after sunrise. In the Gulf of Cádiz, the fleets were fished before sunrise whereas hauling started around 9:00–9:30 a.m. In the Cyclades, the fleets were set either before sunrise or sunset and retrieved 1–2 h after sunrise and sunset, respectively. In all areas the different sets of nets were joined together by a footrope, leaving a 2 m gap between them so that fish are not led from one combination to the adjacent combination, thereby introducing error.

One to three members of each research group accompanied the fishermen in order to separate, identify and measure the catches coming on board. The catch was sorted according to the above mentioned combinations of inner/outer net panels. All fish, crustaceans and molluscs were measured (total length, disc width or mantle length) to the nearest mm. The way in which each fish, crustacean or mollusc was caught was also recorded: (a) gilled, (b) wedged and (c) trammelled or pocketed, i.e., entangled in the pocket formed when the small mesh inner panel is pushed through the larger mesh outer panel.

Experimental fishing trials were carried out on a seasonal basis during 1999–2000, at depths ranging between 20–80 m in the Basque country, 15–100 m in the Algarve, 10–30 m in the Gulf of Cádiz and 10–80 m in the Cyclades. Overall, 12 and 10 fishing trials per season were carried out in the Basque country and in the Algarve, respectively. In the Gulf of Cádiz, a total of 30 fishing trials took place in each of two seasons (spring and autumn). Finally, 41 fishing trials were carried out in Cyclades (8 in autumn, 7 in winter, 11 in spring and 15 in summer).

## 2.2. Size selectivity

The length frequency distributions for different inner/outer mesh combinations were compared with the Kolmogorov–Smirnov (K–S) test (Siegel and Castellan, 1988). The K–S test was used to evaluate differences between length frequency distributions due to season and to outer panel mesh size, guiding decisions concerning the pooling of data for the estimation of the selectivity parameters.

While there is a general consensus on the form of selection curves for gill nets, the same is not true for trammel nets. In the present study, trammel net selectivity parameters were estimated using the generalised extension of the SELECT method of Millar (1992), implemented in the GILLNET (Generalised Including Log-Linear N Estimation Technique) software (ConStat, 1998). In addition, the indirect method proposed by Wulff (1986) and Kirkwood and Walker (1986) was used to fit the logistic model. The methods are outlined below.

The general SELECT model (Millar and Fryer, 1999) assumes that the number of fish of length $l$ caught in mesh size $j(n_{lj})$ is determined by three processes: (a) the abundance of length $l$ fish contacting the combined gear ($\lambda_l$:); (b) the relative fishing intensity, which is the probability that a fish of length $l$ contacts gear $j$, given that it has come into contact with the combined gear ($p_j(l)$); and (c) the contact selection curve for given gear size $j(r_j(l))$. Since $\lambda_l$ is Poisson distributed, the number of length $l$ fish coming into contact with gear $j$ is also Poisson distributed with mean $p_i(l)\lambda_l$ (Feller, 1968; cited in Millar and Fryer, 1999) and $n_{lj}$ is Poisson distributed with mean $p_i(l)\ \lambda_l r_j(l)$: $n_{lj} \approx \mathrm{Pois}(p_i(l)\lambda_l r_j(l))$.

Comparative selectivity experiments do not allow the simultaneous estimation of $r_j(l)$ and $p_i(l)$ and therefore assumptions must be made about one or the other. Relative fishing intensities are usually assumed to be constant and the general model for analysing data from comparative fishing trials with gears of different dimensions is:

$$n_{lj} \approx \mathrm{Pois}(p_j \lambda_l r_j(l)).$$

The log-likelihood of $n_{lj}$ is:

$$\sum_l \sum_j \left\{ n_l \log_e[p_j \lambda_l r_j(l)] - p_j \lambda_l r_j(l) \right\}.$$

The $\lambda_l$ parameters (abundance) are eliminated from the maximisation problem in the SELECT method because proportions of the total catch for each length class and each gear are used ($y_{lj} = n_{lj}/n_{l+}$, where $n_{l+}$ is the total catch for each length class for all gears), thereby reducing the number of parameters. The proportions have a multinomial distribution with $n_{l+}$ trials and probabilities:

$$\phi_{lj} = \frac{p_j \lambda_l r_j(l)}{\sum_j p_j \lambda_l r_j(l)},$$

where $j = 1$ to $J$ (for $J$ mesh sizes). The log-likelihood for the proportions ($y_{lj}$) is:

$$\sum_l \sum_j n_{lj} \log_e (\phi_{lj}).$$

The parameters of six selection curves were estimated using GILLNET: normal location, normal scale, log-normal, gamma, bi-modal and gamma semi-Wileman:

$$\text{Normal location}: \quad \exp\left(-\frac{(l-km)^2}{2\sigma^2}\right)$$

$$\text{Normal scale}: \quad \exp\left(-\frac{(l-k_1 m_j)^2}{2k_2^2 m_j^2}\right)$$

Log normal :

$$\frac{m_j}{l m_1} \exp\left(\mu - \frac{\sigma^2}{2} - \frac{(\log(l) - \mu - \log(m_j/m_1))^2}{2\sigma^2}\right)$$

Gamma $(l, m; k, \alpha)$ :

$$\left(\frac{l}{(\alpha-1)km_j}\right)^{\alpha-1} \exp\left(\alpha - 1 - \frac{l}{km_j}\right)$$

Gamma semi-Wileman ($l$, $m$; $k$, $\alpha$, $c$): Gamma ($l$, $m$; $k$, $\alpha$) for $l < k(\alpha-1)m$; (Gamma ($l$, $m$; $k$, $\alpha$) + $c$)/(1 + $c$) for $l \geq k(\alpha-1)m$:

Bi-modal :

$$\exp\left(-\frac{(l-k_1 m_j)^2}{2k_2^2 m_j^2}\right) + c \exp\left(-\frac{(l-k_3 m_j)^2}{2k_4^2 m_j^2}\right).$$

Wulff (1986) introduces a flexible model for gear selectivity in which no assumptions are required concerning the efficiency of different gear sizes. Selectivity curves of different gear sizes are assumed to belong to the same family (e.g., normal, skew-normal, gamma probability distributions) and their similarity can be expressed by the relationship between gear size and parameters of the chosen model. As an example, Wulff (1986) models the optimum selectivity, the optimum length at capture, and the standard deviation as linear functions of mesh size in a skew-normal selectivity curve. Wulff (1986) shows that the parameters of the selectivity curve could be estimated by maximising the following maximum likelihood:

$$\sum_{l,m} \left[ c_{l,m} \ln \left( \frac{S_{l,m}}{\sum_m S_{l,m}} \right) \right],$$

where $c_{l,m}$ and $S_{l,m}$ are the catches and the selectivities for size classes $l$ and mesh sizes $m$. This is the same maximum likelihood proposed by Kirkwood and Walker (1986), who model gill net selectivity with a gamma distribution, with length at optimal selectivity proportional to mesh size, and with constant variance for all mesh sizes.

For *Sepia officinalis* the parameters of the logistic selectivity curve were also estimated using the NLP procedure in SAS (SAS Institute Inc., 1988, Hartman, no date). A series of models where the parameters $b$ and $L_{50}$ of the logistic model were a function of inner panel mesh size were fitted and the goodness of fit was evaluated by comparing the values of the maximum likelihood. These models were:

1. Proportional model. The parameters $b$ and $L_{50}$ of the logistic selectivity curve are both considered to be proportional to mesh size, $b = b_1 M_i$ and $L_{50} = b_2 M_i$, where $M_i$ is the inner panel mesh size.
2. Linear model. Both parameters, $b$ and $L_{50}$, are assumed to be linear functions of inner panel mesh size, $b = (b_1 M_i) + b_2$, and $L_{50} = (b_3 M_i) + b_4$.
3. $b$ constant and $L_{50}$ linear model. $b$ is assumed to be constant for each of the inner panel mesh sizes, while $L_{50}$ is considered to be a linear function of inner panel mesh size: $L_{50} = (b_3 M_i) + b_4$.

In the case of the GILLNET fittings, the following criteria were used to select the best model: (1) the critical level for goodness of fit was $P = 0.05$, (2) a small deviance that was similar in magnitude to the degrees of freedom, (3) small and randomly distributed deviance residuals, and (4) modal lengths that correspond to the modal lengths of the catch size distributions.

## 3. Results

### 3.1. Catch size frequency distributions

The most important species in terms of numbers caught in each area are given in Table 2. In all cases, the catches were dominated by relatively few species, with 4–11 species accounting for at least 60% of the total catch. The size selectivity was studied for all species shown in Table 1 but our results are restricted to the species for which it was possible to obtain meaningful parameter estimates and size selectivity curves.

Table 2
Species studied in the four areas and their contribution (% by numbers) to the total catch

| Species per area | % | Size range (cm) |
|---|---|---|
| Basque country | | |
| *Solea solea* | 19 | 16–51 |
| *Trisopterus luscus* | 12 | 13–37 |
| *Scomber scomber* | 9 | 25–49 |
| *Trachinus draco* | 8 | 13–37 |
| *Sardina pilchardus* | 6 | 13–35 |
| *Merluccius merluccius* | 6 | 14–71 |
| *Chelidonichtys lucernus* | 4 | 14–63 |
| Total | 64 | |
| Gulf of Cádiz | | |
| *Sepia officinalis* | 43 | 9–40 |
| *Solea senegalensis* | 8 | 11–43 |
| *Torpedo torpedo* | 7 | 12–44 |
| *Synaptura lusitanica* | 5 | 13–45 |
| Total | 63 | |
| Algarve | | |
| *Scomber japonicus* | 16 | 17–35 |
| *Sepia officinalis* | 13 | 13–44 |
| *Microchirus azevia* | 9 | 15–45 |
| *Trachinus draco* | 4 | 18–39 |
| *Phycis phycis* | 3 | 14–60 |
| *Scorpaena notata* | 3 | 8–21 |
| *Chelidonichthys obscurus* | 3 | 10–35 |
| *Pagellus acarne* | 3 | 14–35 |
| *Solea senegalensis* | 3 | 20–53 |
| *Chelidonichthys lastoviza* | 2 | 13–40 |
| *Merluccius merluccius* | 2 | 16–66 |
| Total | 61 | |
| Cyclades | | |
| *Mullus surmuletus* | 15 | 8–36 |
| *Pagellus erythrinus* | 14 | 10–38 |
| *Diplodus annularis* | 10 | 6–18 |
| *Scorpaena porcus* | 9 | 8–46 |
| *Spicara maena* | 7 | 8–28 |
| *Serranus cabrilla* | 7 | 10–24 |
| *Boops boops* | 5 | 8–26 |
| *Pagellus acarne* | 5 | 8–22 |
| *Trachurus mediterraneus* | 4 | 18–34 |
| *Symphodus tinca* | 2 | 11–27 |
| *Diplodus vulgaris* | 2 | 6–28 |
| Total | 80 | |

Size ranges are based on total length for fish and mantle length for *Sepia offininalis*.

### *3.1.1. Basque*

The length frequency distributions of the six of the seven most abundant species caught in the fishing trials are shown in Fig. 1. Data for *Merluccius merluccius* were not analysed due to the broad size range of the species and the poor representation of individuals in the size distributions (not shown). All mesh sizes caught a wide size range of the six species (Table 2, Fig. 1).

There was a significant difference between seasonal catch size distributions for the six species (K–S, $P < 0.05$) in the paired comparisons. For *Scomber scombrus* and *Sardina pilchardus* some of the paired comparisons were not possible due to the small number of individuals caught in some seasons.

With the exception of *Solea solea*, the length frequency distributions of all species for which selectivity was studied were highly overlapped (Fig. 1). In addition, all length frequency distributions were skewed to the right, with those of five species (*Solea solea, Scomber scombrus, Trachinus draco, Sardina pilchardus* and *Chelidonichthys lucernus*) being uni-modal and that of *Trisopterus luscus* clearly bi-modal, particularly in the case of the trammel nets using the 90/500 and 90/600 mm combinations (Fig. 1).

### *3.1.2. Algarve*

The length frequency distributions of the ten most abundant species caught are shown in Fig. 2. With the exception of *Scorpaena notata* (length range from 8 to 21 cm, Fig. 2f), all mesh size combinations caught a wide size range (Table 2, Fig. 2).

The length frequency distributions of 4 out of 10 species (*Microchirus azevia*, Fig. 2c; *Trachinus draco*, Fig. 2d; *Chelidonichthys lastoviza*, Fig. 2g; and *Merluccius merluccius*, Fig. 2j) for which selectivity was studied were highly overlapped, a fact also revealed by the K–S test which showed no significant difference ($P > 0.05$) between any of the paired comparisons. In contrast, for the remaining six species, length frequency distributions were also overlapping but with different modal lengths (Fig. 2a, b, e, f, h, and i) and significant differences (K–S, $P < 0.05$) for the majority of the paired comparisons. In addition, for six species the length frequency distributions were skewed to the right (Fig. 2a, c, e, g, h, and j) and for one species skewed to the left (Fig. 2i). None of the distributions showed evidence of bi-modality, although the wide size range for some species (e.g., *Phycis phycis*: Fig. 2e; *Merluccius merluccius*: Fig. 2j) and the considerable variability in numbers per length class may have obscured the modality pattern.

### *3.1.3. Gulf of Cádiz*

The length frequency distributions of *Sepia officinalis*, *Solea senegalensis*, *Synaptura lusitanica* and *Torpedo torpedo* for the two seasons are shown in Fig. 3. For all species and seasons, the length ranges caught were wide, ranging from 9 to 41 cm mantle length for *Sepia officinalis* (Fig. 3a and b), from 11 to 46 cm for *Solea senegalensis* (Fig. 3c and d), from 13 to 49 cm for *Synaptura lusitanica* (Fig. 3e and f) and from 12 to 48 cm for *Torpedo torpedo* (Fig. 3g and h).

The length frequency distributions of *Synaptura lusitanica* (Fig. 3e and f) and of *Torpedo torpedo* in the spring (Fig. 3g) were highly overlapped, a fact also revealed by the K–S test which found no significant difference ($P > 0.05$) for 18 out of 20 paired comparisons for the former and in 8 out of 10 comparisons for the latter. In contrast, for the remaining cases, length frequency distributions were also overlapping but with different modal lengths (Fig. 3a–d and h) and significant differences (K–S, $P < 0.05$) for the majority of the

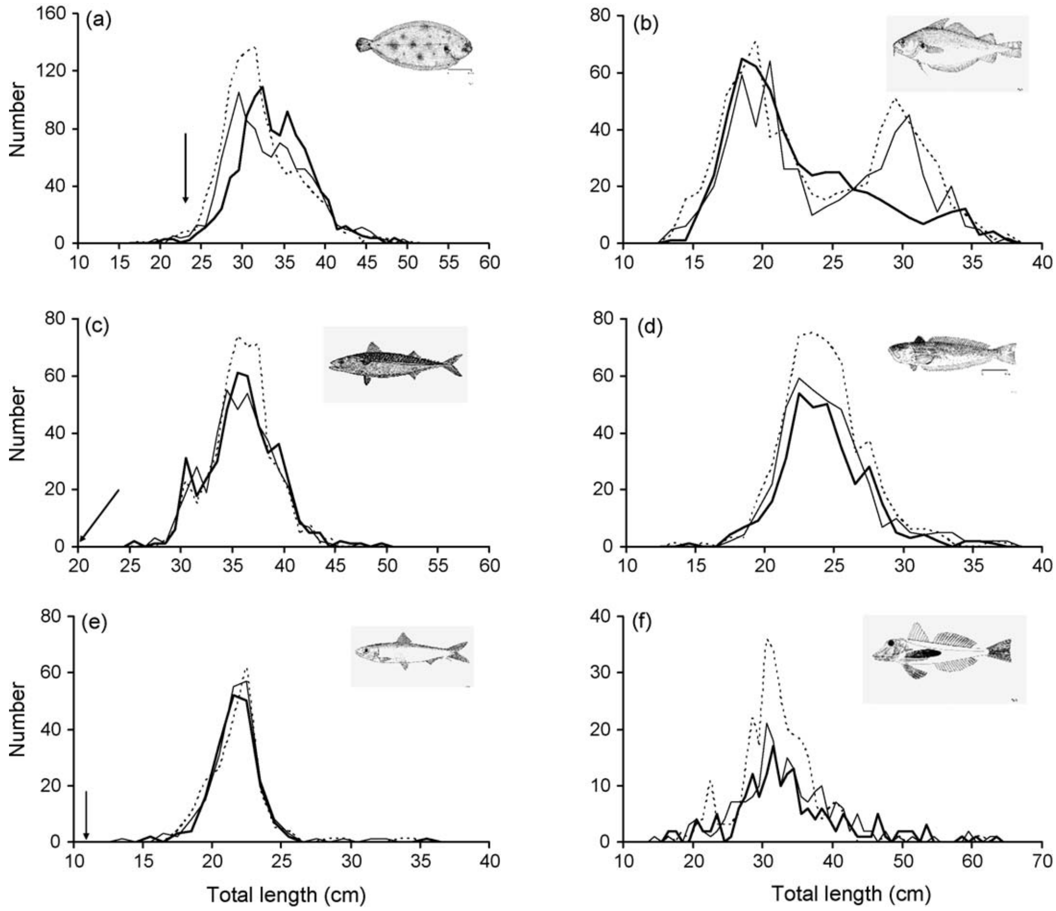

Fig. 1. Basque country. Catch size frequency distributions for pooled outer panel meshes (500 + 600 mm). (a) *Solea solea*, (b) *Trisopterus luscus*, (c) *Scomber scombrus*, (d) *Trachinus draco*, (e) *Sardina pilchardus*, and (f) *Chelidonichthys lucernus*. Dashed line: 90 mm inner panel mesh, continuous line: 100 mm inner panel mesh, bold line: 110 mm inner panel mesh. Arrows indicate the minimum landing sizes of the species.

paired comparisons. For *Sepia officinalis* and *Torpedo torpedo*, length frequency distributions were highly skewed to the right (Fig. 3a, b, g, and h).

### 3.1.4. Cyclades

In the Cyclades, the maximum sizes of the most important species were generally smaller compared to the other areas and consequently the size ranges were not as wide (Table 2, Fig. 4). In general, all mesh sizes caught overlapping length ranges, skewed to the right. Yet, the modal lengths of the species caught gradually increased with mesh size, a fact also indicated by the results of the K–S test ($P < 0.05$) for the majority of the paired comparisons.

## 3.2. Size selectivity

### 3.2.1. Basque country

The data were analyzed by season for all species due to the seasonal nature of the fishery (Stergiou et al., 2006), with separate analyses for each outer panel mesh size and combined outer panel mesh sizes for *Trachinus draco*, *Chelidonichthys lucernus* and *Scomber scombrus*. Because there were no differences in catch distributions due to outer panel mesh size (K–S, $P > 0.05$), the analyses for *Solea vulgaris* and *Trisopterus luscus* were based on pooled 500 and 600 mm outer panel mesh data.

For *Solea solea* the bi-modal model gave the best fit, with a smaller peak to the right of the main peak in each selectivity curve (Fig. 5a, Table 3). The Gamma–Wileman model gave the best fits for *Trachinus draco*, with selectivity curves being more similar in shape to logistic than uni-modal curves, showing a sharp increase in selectivity with size, followed by a leveling off for larger size classes (Fig. 5b, Table 3). Uni-modal selectivity curves fitted the *Chelidonichthys lucernus* data, although the estimated modal lengths were somewhat high. For the autumn 500, 600 and 500 + 600 mm combined data sets, the log-normal model was the best (Fig. 5c, Table 3). For the second most abundant species, *Trisopterus luscus*, the bi-modal model was best, with no other models fitting the winter data (Fig. 5d, Table 3). For both seasons the smaller peak in the selectivity curve corresponded to fish in the lower end of the size range. No fits were obtained with any model for the spring or summer data (Fig. 5d, Table 3). In general, most models could not be fitted for *Scomber scombrus* (Table 3) or were judged unsatisfactory based on the deviance residual plots. For *Sardina pilchardus* and *Merluccius merluccius*, no

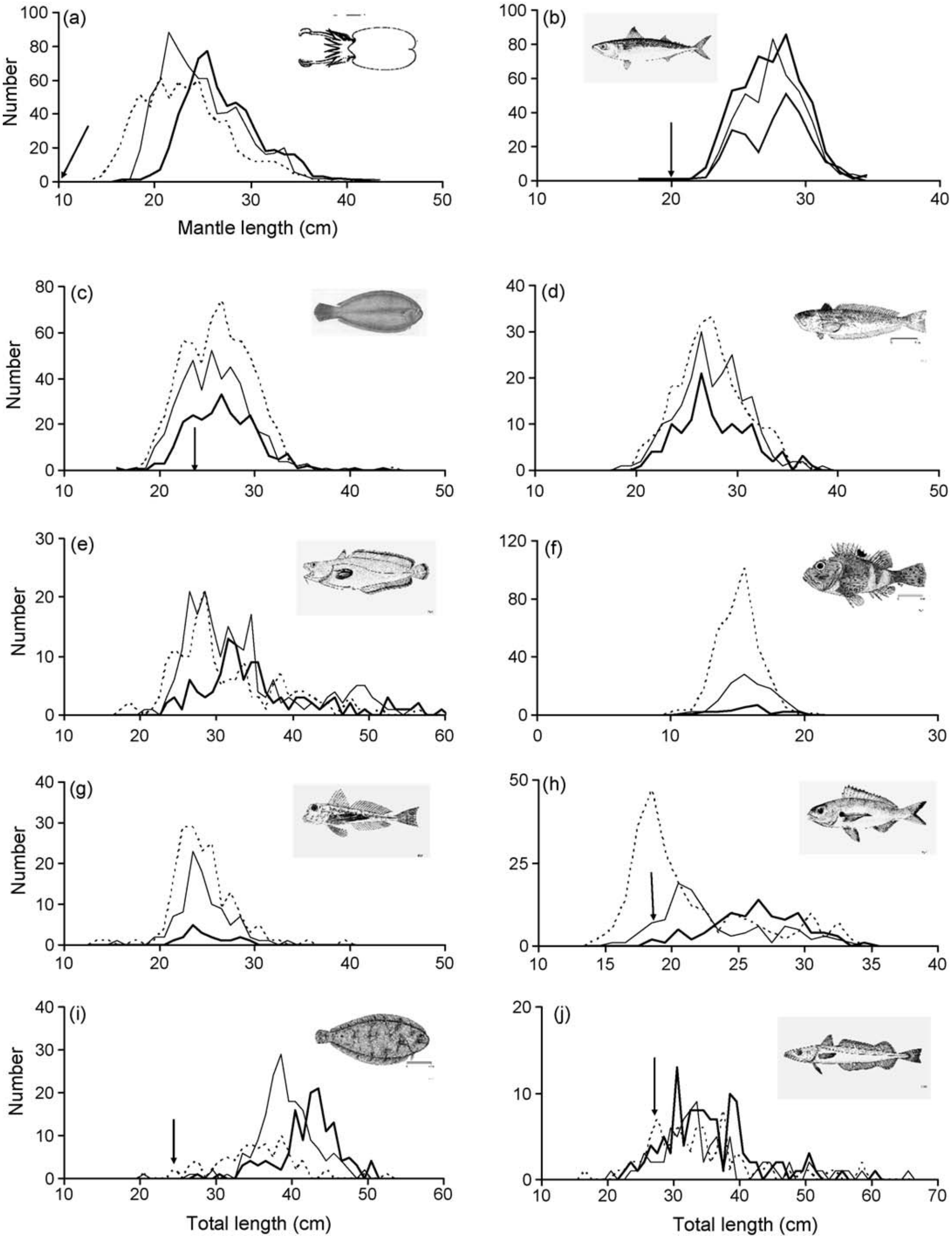

Fig. 2. Algarve. Catch size frequency distributions for 100, 120 and 140 mm inner panel mesh sizes. (a) *Sepia officinalis*, (b) *Scomber japonicus*, (c) *Microchirus azevia*, (d) *Trachinus draco*, (e) *Phycis phycis*, (f) *Scorpaena notata*, (g) *Chelidonichthys lastoviza,* (h) *Pagellus acarne*, (i) *Solea senegalensis*, and (j) *Merluccius merluccius*. Dashed line: 100 mm inner panel mesh, continuous line: 120 mm inner panel mesh, bold line: 140 mm inner panel mesh. Arrows indicate the minimum landing sizes of the species.

fits could be obtained with any of the models either because of highly overlapped and/or sparse data.

### *3.2.2. Algarve*

For *Sepia officinalis*, few of the GillNet models resulted in satisfactory fits (Table 4). For the 600 mm outer panel data only the gamma semi-Wileman model for fishing power proportional to mesh size gave a good fit ($P = 0.1142$) with a model deviance similar in magnitude to the degrees of freedom. As can be seen in Fig. 6a, the fitted Gamma semi-Wileman selectivity curves were asymptotic, suggesting that all individuals greater than the modal lengths were retained in the pocket formed by the small mesh inner panel pushed through the large mesh outer panel. The only model that gave reasonable fits for the 800 mm and the combined 600 and 800 mm outer panel data was the bi-normal

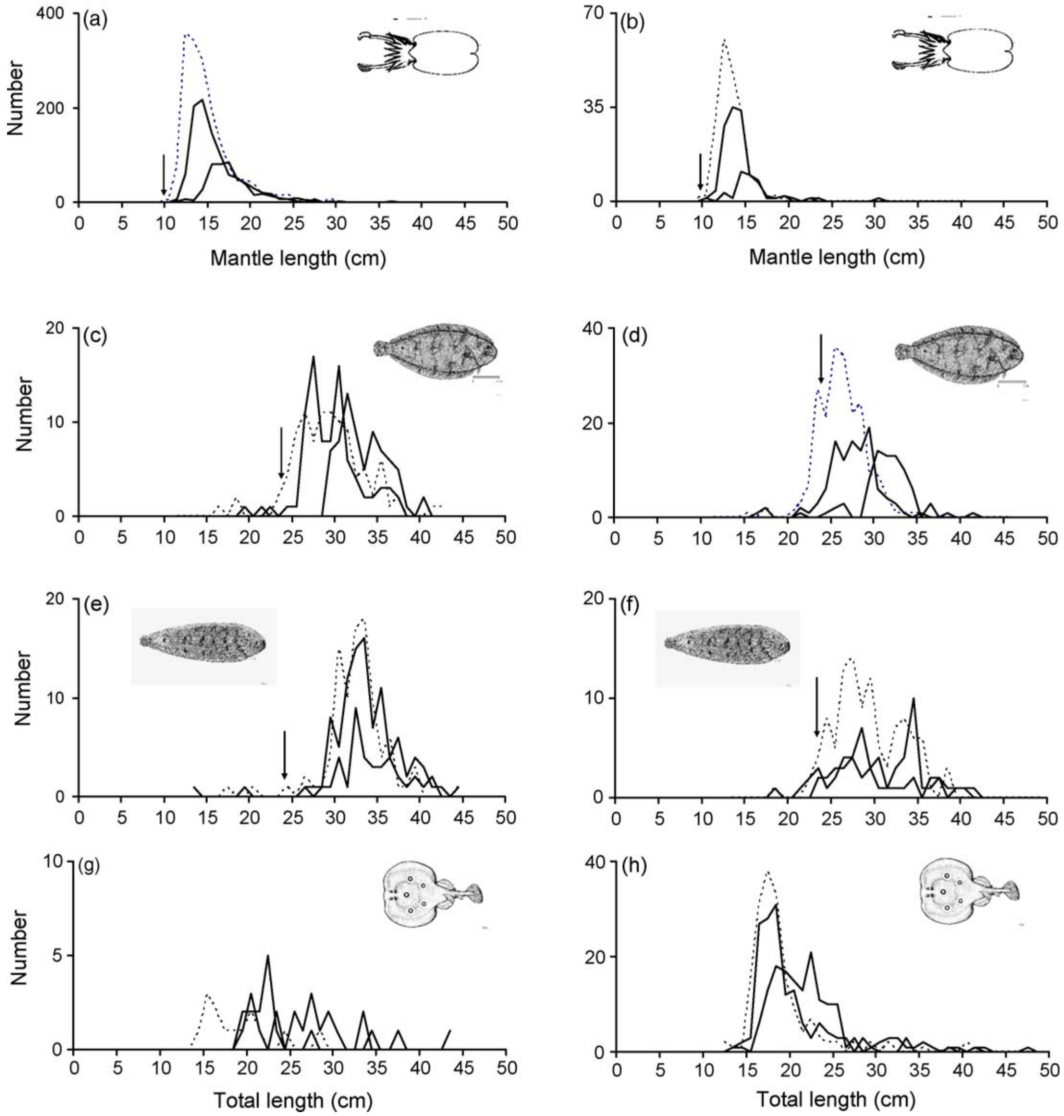

Fig. 3. Gulf of Cádiz. Catch size frequency distributions for pooled outer panel mesh (300 + 400 mm) data by season. *Sepia officinalis*: (a) spring, (b) autumn; *Solea senegalensis*: (c) spring, (d) autumn; *Synaptura lusitanica*: (e) spring, (f) autumn; *Torpedo torpedo*: (g) spring, (h) autumn. Dashed line: 80 mm inner panel mesh, continuous line: 90 mm inner panel mesh, bold line: 100 mm inner panel mesh. Arrows indicate the minimum landing sizes of the species.

model for equal fishing powers ($P = 0.1731$ and 0.0047) (Table 4, Fig. 6b and c).

The logistic model where both $b$ and $L_{50}$ are linear functions of mesh size gave the best fits for *Sepia officinalis* (Table 5). However, although the estimates of $L_{50}$ were similar for the three fits, there were significant differences between the models for the slope ($b$). There was a sharp increase in size selectivity with increasing inner panel mesh size (Table 5). Values for $L_{50}$ ranged from 14.6 to 16.1 cm for the 100 mm inner panel to 21.8–22.5 cm for the 140 mm one. The fitted selectivity curves for the simplest model ($b$, $L_{50}$ proportional to inner panel mesh size) are shown in Fig. 7.

For *Microchirus azevia*, *Trachinus draco*, *Scorpaena notata, Chelidonichthys obscurus* and *Chelidonichthys lastoviza* none of the models implemented in GillNet resulted in reasonable fits. For *Scomber japonicus* none of the models fitted any of the three data sets (600, 800 mm and combined outer panel data) ($P < 0.05$). For all these species no further attempts were made to fit the logistic model given the high overlap in the length frequencies and the results of the K–S test ($P > 0.05$), as well as because none of these species were exclusively caught by trammeling.

The estimated selectivity model parameters for the remaining four species are given in Table 4. In general, the bi-model gave the best fits. However, for some data sets no fits were obtained and for *Merluccius merluccius* 800 mm outer panel mesh size data, the log-normal model fitted best. *For Solea senegalensis, Phycis phycis and Pagellus acarne* significant proportions of the fish were gilled or wedged rather than trammeled/pocketed (43, 33 and 20%, respectively). Thus the first components of the selectivity curves correspond to fish that were gilled or wedged, while the second components

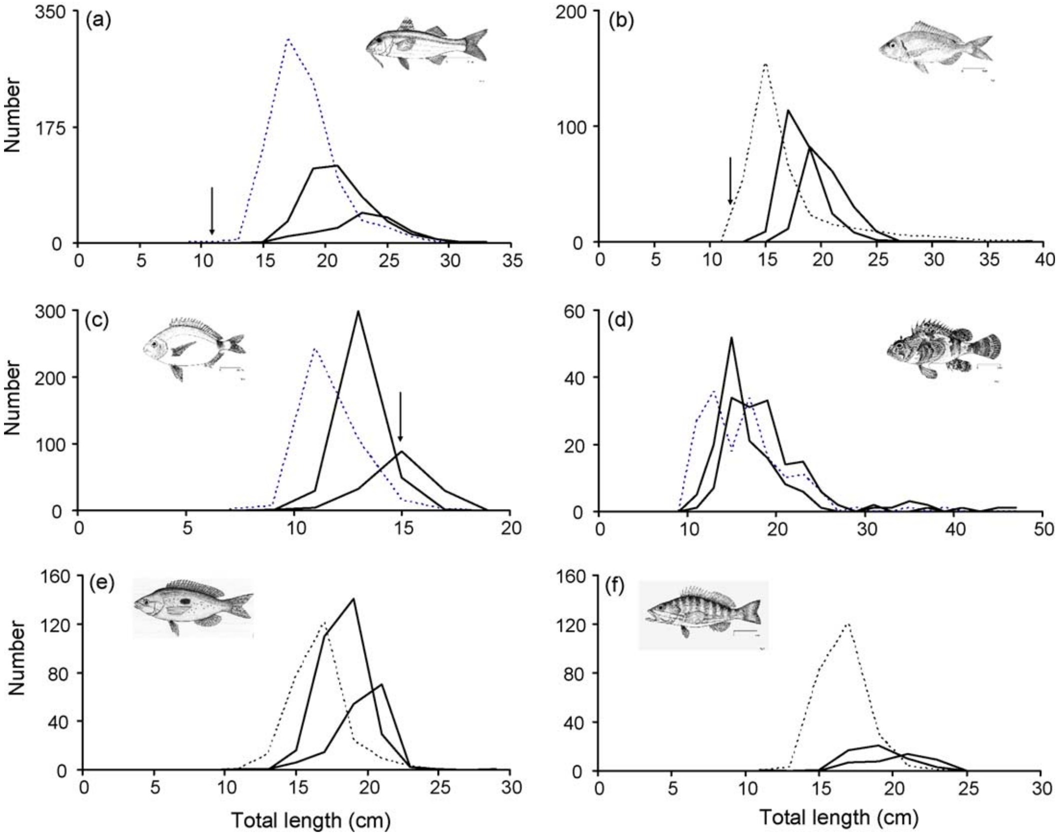

Fig. 4. Cyclades. Catch size frequency distributions for data pooled by season and outer panel mesh. (a) *Mullus surmuletus*, (b) *Pagellus erythrinus*, (c) *Diplodus annularis*, (d) *Scorpaena porcus*, (e) *Spicara maena*, and (f) *Serranus cabrilla*. Dashed line: 40 mm inner panel mesh, continuous line: 48 mm inner panel mesh, bold line: 56 mm inner panel mesh. Arrows indicate the minimum landing sizes of the species.

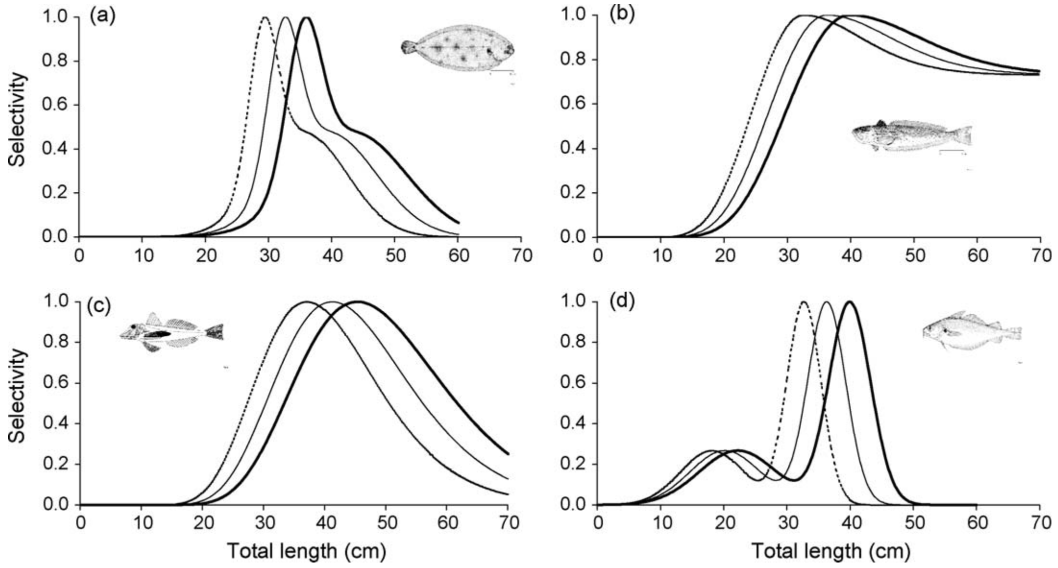

Fig. 5. Basque country. Best SELECT models by species. (a) *Solea solea*: bi-normal model, combined 500 and 600 mm outer panel data for all seasons, (b) *Trachinus draco*: Gamma–Wileman model, combined 500 and 600 mm outer panel data for summer, (c) *Chelidonichthys lucernus*: log-normal model, combined 500 and 600 mm outer panel data for autumn, and (d) *Trisopterus luscus*: bi-normal model, combined 500 and 600 mm outer panel data for autumn; dashed line: 90 mm inner panel mesh, continuous line: 100 mm inner panel mesh, bold line: 110 mm inner panel mesh.

Table 3
Basque country

| Species | Season | Mesh combinations (mm) | Model | Fishing power | Parameters | Model deviance | d.f. |
|---|---|---|---|---|---|---|---|
| *Solea solea* | Spring | 90, 100, 110/500 + 600 | Bi-modal | Equal | $(k_1, k_2, k_3, k_4, c) = (3.223, 0.318, 5.705, 1.542, 0.292)$ | 54.74 | 55 |
| | Summer | 90, 100, 110/500 + 600 | Bi-modal | Equal | $(k_1, k_2, k_3, k_4, c) = (3.135, 0.280, 3.803, 0.824, 0.495)$ | 25.96 | 55 |
| | Autumn | 90, 100, 110/500 + 600 | Bi-modal | $\alpha$ Mesh size | $(k_1, k_2, k_3, k_4, c) = (3.173, 0.215, 3.718, 0.555, 1.458)$ | 42.42 | 49 |
| | Winter | 90, 100, 110/500 + 600 | Bi-modal | $\alpha$ Mesh size | $(k_1, k_2, k_3, k_4, c) = (3.260, 0.212, 3.938, 0.731, 0.684)$ | 47.52 | 57 |
| | **Combined** | **90, 100, 110/500 + 600** | **Bi-modal** | **$\alpha$ Mesh size** | **$(k_1, k_2, k_3, k_4, c) = (3.239, 0.248, 3.955, 0.757, 0.685)$** | **62.62** | **67** |
| *Trachinus draco* | Summer | 90, 100, 110/500 | Gamma–semi-Wileman | $\alpha$ Mesh size | $(k, \alpha, c) = (0.306, 14.099, 8.467)$ | 36.98 | 35 |
| | Summer | 90, 100, 110/600 | Gamma–semi-Wileman | $\alpha$ Mesh size | $(k, \alpha, c) = (0.168, 21.029, 1.42E+15)$ | 25.97 | 35 |
| | **Summer** | **90, 100, 110/500 + 600** | **Gamma–semi-Wileman** | **$\alpha$ Mesh size** | **$(k, \alpha, c) = (0.247, 15.662, 2.72E+14)$** | **33.98** | **37** |
| *Chelidonichthys lucernus* | Autumn | 90, 100, 110/500 | Log-normal | Equal | $(m, s) = (3.656, 0.285)$ | 30.79 | 54 |
| | Autumn | 90, 100, 110/600 | Log-normal | Equal | $(m, s) = (3.702, 0.241)$ | 42.06 | 60 |
| | **Autumn** | **90, 100, 110/500 + 600** | **Log-normal** | **Equal** | **$(m, s) = (3.683, 0.261)$** | **46.78** | **70** |
| *Trisopterus luscus* | Autumn | 90, 100, 110/500 + 600 | Bi-modal | Equal | $(k_1, k_2, k_3, k_4, c) = (1.998, 0.674, 3.528, 0.266, 9.149)$ | 29.69 | 43 |
| | **Winter** | **90, 100, 110/500 + 600** | **Bi-modal** | **Equal** | **$(k_1, k_2, k_3, k_4, c) = (2.020, 0.557, 3.632, 0.300, 3.723)$** | **51.92** | **43** |

Best SELECT models and parameters for each species. d.f. is degrees of freedom. The models presented in Fig. 5 are in bold.

describe the selectivity associated with the larger fish that are trammeled/pocketed.

### 3.2.3. Gulf of Cádiz

Based on the results of the K–S tests, the analyses of the size selectivity of the various trammel nets was carried out by season, for each of the following species: *Sepia officinalis, Solea senegalensis, Synaptura lusitanica* and *Torpedo torpedo*. For *Sepia officinalis*, there were significant differences between the outer panels of 300 and 400 mm mesh (K–S, $P < 0.05$) and therefore the selectivity analysis was carried out separately for these panels.

As was the case for the Algarve, the gamma semi-Wileman and the bi-modal models resulted in the best fits for *Sepia officinalis* (Fig. 8a and b, Table 6). Following the same reasoning based on the method of capture, the logistic model was also fitted (Table 7). Although the values of the maximum likelihood function were very similar for both the

Table 4
Algarve

| Species | Mesh combinations (mm) | Model | Fishing power | Parameters | Model deviance | d.f. |
|---|---|---|---|---|---|---|
| *Sepia officinalis* | **100, 120, 140/600** | **Gamma–semi-Wileman** | **$\alpha$ Mesh size** | **$(k, \alpha, c) = (0.0533, 71.8619, 187.4136)$** | **63.39** | **51** |
| | 100, 120, 140/800 | Bi-modal | Equal | $(k_1, k_2, k_3, k_4, c) = (3.610, 0.342, 4.948, 0.998, 0.741)$ | 58.19 | 49 |
| | 100, 120, 140/600 + 800 | Bi-modal | Equal | $(k_1, k_2, k_3, k_4, c) = (3.644, 0.348, 5.039, 1.000, 0.879)$ | 81.00 | 51 |
| *Solea senegalensis* | 100, 120, 140/600 | Bi-modal | $\alpha$ Mesh size | $(k_1, k_2, k_3, k_4, c) = (6.280, 0.1403, 6.812, 1.113, 0.427)$ | 62.87 | 47 |
| | **100, 120, 140/800** | **Bi-modal** | **$\alpha$ Mesh size** | **$(k_1, k_2, k_3, k_4, c) = (6.306, 0.182, 6.898, 1.187, 0.392)$** | **35.96** | **43** |
| *Pagellus acarne* | **100, 120, 140/600 + 800** | **Bi-modal** | **Equal** | **$(k_1, k_2, k_3, k_4, c) = (3.756, 0.371, 6.903, 1.307, 2.151)$** | **42.98** | **37** |
| *Merluccius merluccius* | 100, 120, 140/600 | Bi-modal | $\alpha$ Mesh size | $(k_1, k_2, k_3, k_4, c) = (4.743, 1.092, 9.425, 2.456, 1.367)$ | 74.72 | 63 |
| | **100, 120, 140/800** | **Log-normal** | **$\alpha$ Mesh size** | **$(m, s) = (3.651, 0.548)$** | **76.30** | **62** |
| *Phycis phycis* | **100, 120, 140/600** | **Bi-modal** | **Equal** | **$(k_1, k_2, k_3, k_4, c) = (8.216, 0.742, 5.160, 0.922, 1.042)$** | **70.93** | **73** |

Best SELECT models and parameters per species. d.f. is degrees of freedom. The models presented in Fig. 6 are in bold.

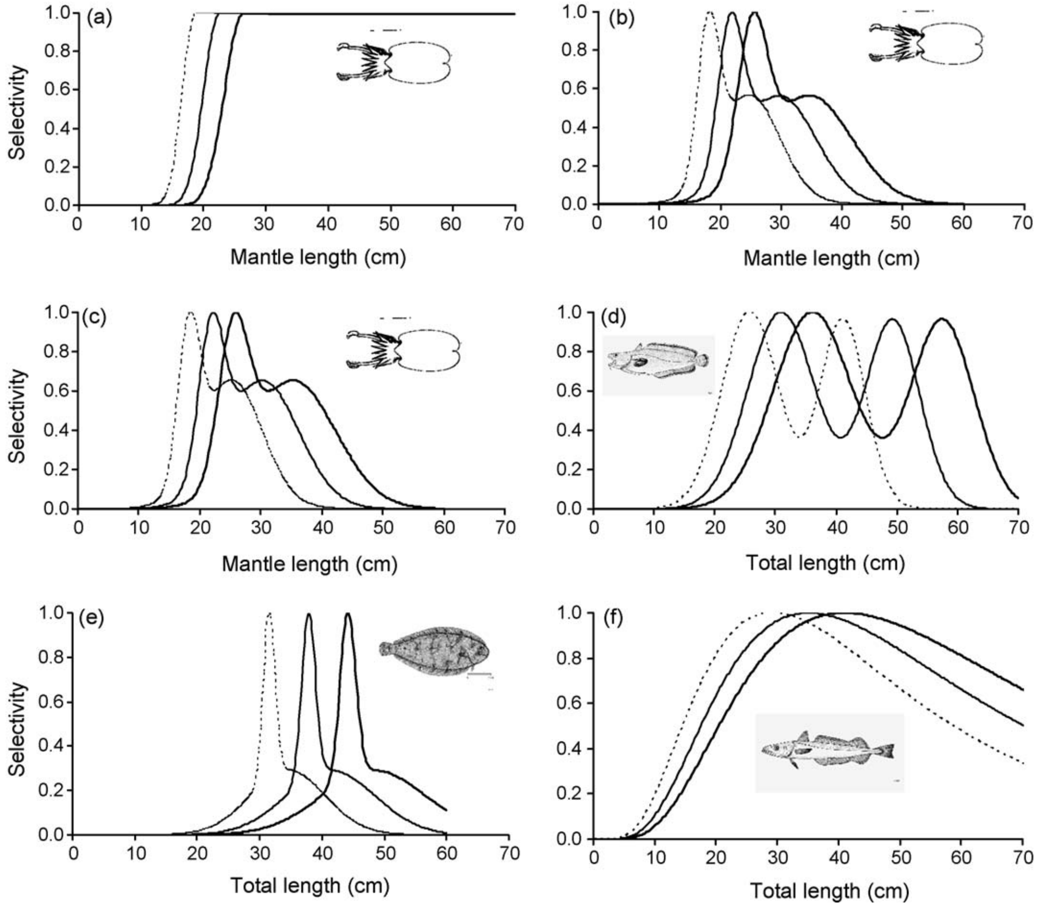

Fig. 6. Algarve. Best SELECT models by species. (a) *Sepia officinalis*: Gamma semi-Wileman, 600 mm outer panel mesh, (b) *Sepia officinalis*: bi-normal model, 800 mm outer panel mesh, (c) *Sepia officinalis*: bi-normal model, combined 600 + 800 mm outer panel meshes, (d) *Phycis phycis*: bi-normal model, 600 mm outer panel mesh, (e) *Solea senegalensis*: bi-normal model, 800 mm outer panel mesh, and (f) *Merluccius merluccius*: log-normal model, 800 mm outer panel mesh. Dashed line: 100 mm inner panel mesh, continuous line: 120 mm inner panel mesh, bold line: 140 mm inner panel mesh.

first and second models, the first model was chosen over the second one for being the most simple (three instead of four parameters). The estimated selectivity curves for *Sepia officinalis* for each net combination and season are given in Fig. 9.

For the other three species for which selectivity studies were carried out, the bi-normal model gave the best fit for *Solea senegalensis* (spring), *Synaptura lusitanica* (spring and autumn) and *Torpedo torpedo* (autumn) for the combined outer panel data (Table 6). The normal scale model gave the best fit for the autumn *Solea senegalensis* data while the gamma model was best for the spring *Torpedo torpedo* data (Table 6). For *Solea senegalensis* and *Synaptura lusitanica*, most of the fish were gilled or wedged rather than trammeled (86 and 91%, respectively) while 100% of the *Torpedo torpedo* were trammeled/pocketed. The fitted selectivity curves are shown in Fig. 8c–h.

### 3.2.4. Cyclades

For Cyclades, three data sets were used for each species. Data set 1 consisted of data for the 40/240, 48/260 and 56/300 mm trammel net combinations, while data set 2 of the 40/220, 48/240 and 56/280 mm ones. Because the larger outer panel meshes had little or no effect on size selectivity (K–S test, $P > 0.05$), the data for the three inner panel mesh sizes were combined for data set 3: 40/240 + 40/220, 48/260 + 48/240 and 56/300 + 56/280.

Although the bi-modal model was clearly the best for most of the species, with selectivity curves generally having a lower mode to the right of the main mode, the descending limbs of the selectivity curves for the largest inner mesh sizes tended to extend beyond the maximum observed sizes caught (Fig. 10, Table 8). For data sets for several species none of the uni-modal models in GillNet could be fit (data sets 1 and 2 for *Pagellus erythrinus*, all data sets for *Diplodus annularis*, *Scorpaena porcus*, and *Spicara maena*).

Finally, for *Serranus cabrilla* none of the models implemented in GillNet could be fitted to data sets 2 and 3. For data set 1, a variety of uni-modal as well as the bi-modal model could be fitted. However, the log-normal model was judged to be the best (Fig. 10f, Table 7). It is interesting to note that with the exception of *Scorpaena porcus* where 100% of the fish were caught in the pocket, significant proportions of all the other species were gilled or wedged: *Diplodus vulgaris*

Table 5
Algarve

| Season | Outer panel (mm) | Model | Inner panel mesh size (mm) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 100 | | 120 | | 140 | | Maximum likelihood |
| | | | $b$ | $L_{50}$ | $b$ | $L_{50}$ | $b$ | $L_{50}$ | |
| | | $b$, $L_{50}$ proportional | 0.839 | 15.9 | 1.006 | 19.1 | 1.174 | 22.3 | −1076.04 |
| | 600 | $b$ constant, $L_{50}$ linear | 1.156 | 16.1 | 1.156 | 19.2 | 1.156 | 22.2 | −1073.86 |
| | | $b$, $L_{50}$ linear | 6.044 | 14.6 | 3.455 | 18.6 | 0.866 | 22.5 | −1067.02 |
| | | $b$, $L_{50}$ proportional | 1.210 | 15.6 | 1.452 | 18.7 | 1.694 | 21.8 | −931.65 |
| All seasons | 800 | $b$ constant, $L_{50}$ linear | 1.596 | 15.3 | 1.596 | 18.6 | 1.596 | 21.8 | −930.83 |
| | | $b$, $L_{50}$ linear | 3.247 | 15.1 | 2.304 | 18.5 | 1.361 | 21.9 | −929.69 |
| | | $b$, $L_{50}$ proportional | 0.987 | 15.7 | 1.184 | 18.9 | 1.382 | 22.0 | −2009.78 |
| | All data | $b$ constant, $L_{50}$ linear | 1.336 | 15.8 | 1.336 | 18.9 | 1.336 | 22.0 | −2006.85 |
| | | $b$, $L_{50}$ linear | 4.401 | 15.1 | 2.729 | 18.6 | 1.057 | 22.1 | −1999.33 |
| | | $b$, $L_{50}$ proportional | 11.245 | 14.6 | 13.494 | 17.6 | 15.743 | 20.5 | −179.10 |
| | 600 | $b$ constant, $L_{50}$ linear | 25.309 | 13.9 | 25.309 | 17.2 | 25.309 | 20.5 | −187.00 |
| | | $b$, $L_{50}$ linear | 12.424 | 15.7 | 13.930 | 18.1 | 15.435 | 20.5 | −187.00 |
| | | $b$, $L_{50}$ proportional | – | – | – | – | – | – | – |
| Autumn | 800 | $b$ constant, $L_{50}$ linear | 1.428 | 10.0 | 1.428 | 15.7 | 1.428 | 21.3 | −194.21 |
| | | $b$, $L_{50}$ linear | 2.636 | 10.0 | 2.024 | 15.7 | 1.413 | 21.3 | −194.20 |
| | | $b$, $L_{50}$ proportional | 10.916 | 14.6 | 13.099 | 17.6 | 15.283 | 20.5 | −381.70 |
| | All data | $b$ constant, $L_{50}$ linear | 2.103 | 14.3 | 2.103 | 17.6 | 2.103 | 20.9 | −381.71 |
| | | $b$, $L_{50}$ linear | 12.607 | 15.2 | 13.174 | 17.9 | 13.741 | 20.5 | −381.70 |
| | | $b$, $L_{50}$ proportional | 0.718 | 16.2 | 0.862 | 19.4 | 1.006 | 22.7 | −749.08 |
| | 600 | $b$ constant, $L_{50}$ linear | 1.012 | 16.6 | 1.012 | 19.6 | 1.012 | 22.5 | −747.31 |
| | | $b$, $L_{50}$ linear | 4.249 | 15.2 | 2.496 | 19.0 | 0.742 | 22.7 | −742.88 |
| | | $b$, $L_{50}$ proportional | 2.044 | 15.8 | 2.453 | 19.0 | 2.862 | 22.1 | −602.56 |
| Winter | 800 | $b$ constant, $L_{50}$ linear | 2.664 | 15.1 | 2.664 | 18.7 | 2.664 | 22.3 | −601.84 |
| | | $b$, $L_{50}$ linear | 2.164 | 15.2 | 2.486 | 18.7 | 2.808 | 22.3 | −601.81 |
| | | $b$, $L_{50}$ proportional | 0.968 | 16.0 | 1.161 | 19.2 | 1.355 | 22.4 | −1359.97 |
| | All data | $b$ constant, $L_{50}$ linear | 1.289 | 15.8 | 1.289 | 19.1 | 1.289 | 22.4 | −1357.94 |
| | | $b$, $L_{50}$ linear | 4.190 | 15.1 | 2.608 | 18.9 | 1.026 | 22.6 | −1353.11 |

Logistic selectivity model parameters for *Sepia officinalis*. $b$ is the slope and $L_{50}$ is the mantle length at 50% selectivity.

(31%), *Diplodus annularis* (45%), *Mullus surmuletus* (60%), *Serranus cabrilla* (57%), *Spicara maena* (66%).

## 4. Discussion

In this study we estimated the size selectivity for the most important species participating in the trammel net catches of four southern European areas (i.e., Cantabrian Sea, Algarve waters, Gulf of Cádiz, Aegean Sea). Selectivity estimates were derived using the indirect method and based on a large range of inner panel mesh sizes, i.e., nine different mesh sizes ranging from 40 to 140 mm stretched. Overall, seven different selectivity models (i.e., normal scale, normal location, gamma, log-normal, gamma semi-Wileman, bi-modal, logistic) were applied to seasonal and annual data sets for 27 fish species and *Sepia officinalis* but estimates were only derived for 17 species.

Apart from *Sepia officinalis* and *Torpedo marmorata*, where trammelling or pocketing was the only method of capture, the vast majority of the fish species were caught by two or more methods (gilling, wedging and trammelling/pocketing). These combinations of capture mechanisms were reflected in the shapes of the size distributions (skewed to the right, bi-modal or multi-modal) and in the selectivity models that gave the best fits. Indeed, for fish, the bi-modal model was the best for 29 out of the 40 data sets (i.e., 72.5%). This is not surprising given the shape of the majority of the catch frequency distributions and where the two modes of the selectivity curve often correspond to two methods of capture. Thus, the smaller mode may correspond to the smaller individuals that are gilled or wedged and the larger mode is associated with the trammelling or pocketing of larger individuals. In contrast, the uni-modal selectivity models (i.e., normal scale, normal location, gamma, log-normal) generally proved unsuitable for these data. This was largely due to the wide range of sizes caught with the trammel nets, the typically skewed distributions and also possibly to over-dispersion. For many of the smaller species, part of the second component of the bi-modal selectivity curves for the largest inner panel mesh sizes extended beyond the length range of the corresponding catch. This is partly due to the principle

Table 6
Gulf of Cádiz

| Species | Season | Mesh combinations (mm) | Model | Fishing power | Parameters | Model deviance | d.f. |
|---|---|---|---|---|---|---|---|
| *Sepia officinalis* | Spring | 80, 90, 100/300 | Gamma–semi-Wileman | $\alpha$ Mesh size | $(k, \alpha, c) = (0.022, 82.720, 41.561)$ | 89.16 | 45 |
| | Spring | 80, 90, 100/400 | Bi-modal | Equal | $(k_1, k_2, k_3, k_4, c) = (1.815, 0.193, 3.225, 0.544, 7.284)$ | 161.19 | 43 |
| | **Spring** | **80, 90, 100/300 + 400** | **Gamma–semi-Wileman** | **$\alpha$ Mesh size** | **$(k, \alpha, c) = (0.032, 61.472, 50.263)$** | **191.08** | **51** |
| | Autumn | 80, 90, 100/300 | Bi-modal | Equal | $(k_1, k_2, k_3, k_4, c) = (1.852, 0.254, 3.342, 0.345, 1.326)$ | 27.47 | 21 |
| | Autumn | 80, 90, 100/400 | Bi-modal | Equal | $(k_1, k_2, k_3, k_4, c) = (1.622, 0.130, 2.355, 0.378, 1.657)$ | 22.77 | 19 |
| | **Autumn** | **80, 90, 100/300 + 400** | **Bi-modal** | **Equal** | **$(k_1, k_2, k_3, k_4, c) = (1.649, 0.148, 2.606, 0.458, 2.326)$** | **34.88** | **25** |
| *Solea senegalensis* | **Spring** | **80, 90, 100/300 + 400** | **Bi-modal** | **Equal** | **$(k_1, k_2, k_3, k_4, c) = (3.205, 0.188, 3.972, 0.629, 0.843)$** | **75.06** | **45** |
| | **Autumn** | **80, 90, 100/300 + 400** | **Normal scale** | **$\alpha$ Mesh size** | **$(k_1, k_2) = (3.448, 0.362)$** | **92.70** | **42** |
| *Synaptura lusitanica* | **Spring** | **80, 90, 100/300 + 400** | **Bi-modal** | **$\alpha$ Mesh size** | **$(k_1, k_2, k_3, k_4, c) = (4.041, 0.405, 4.558, 1.037, 0.752)$** | **48.72** | **43** |
| | **Autumn** | **80, 90, 100/300 + 400** | **Bi-modal** | **$\alpha$ Mesh size** | **$(k_1, k_2, k_3, k_4, c) = (2.530, 0.256, 4.468, 0.636, 39.510)$** | **37.42** | **39** |
| *Torpedo torpedo* | **Spring** | **80, 90, 100/300 + 400** | **Gamma** | **$\alpha$ Mesh size** | **$(\alpha, k) = (30.031, 0.148)$** | **55.26** | **46** |
| | **Autumn** | **80, 90, 100/300 + 400** | **Bi-modal** | **Equal** | **$(k_1, k_2, k_3, k_4, c) = (2.160, 0.270, 2.975, 1.057, 0.211)$** | **85.35** | **57** |

Best SELECT models and parameters per species. d.f. is degrees of freedom. The models presented in Fig. 8 are in bold.

of proportionality upon which the SELECT method is based and to the small number of inner mesh sizes used in each area. Ideally, indirect estimation of net selectivity parameters should be based on data from more than three mesh sizes and from individual sets in order to avoid over-dispersion due to pooling of data from different areas and/or times (Millar and Fryer, 1999). However, this was not possible in our study because of the insufficient numbers of individuals of even the most dominant species caught per set. In order to obtain sufficient numbers of individuals the amount of gear fished per trial would have to be increased considerably and more than one vessel would have to be used in each area.

For *Sepia officinalis*, which was exclusively caught by trammelling/pocketing, none of the uni-modal or bi-modal selectivity models implemented in the GillNet software were adequate for describing the size selectivity. However, the gamma semi-Wileman model did in some cases provide a good fit, resulting in selectivity curves that approximated the

Table 7
Gulf of Cádiz

| Outer | | | Inner panel mesh size (mm) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Season | Panel size (mm) | Model | $b$ | | | $L_{50}$ | | | Maximum likelihood |
| | | | 80 | 90 | 100 | 80 | 90 | 100 | |
| Spring | 300 | $b$ constant, $L_{50}$ linear | 1.672 | 1.672 | 1.672 | 11.4 | 13.6 | 15.7 | −1192.05 |
| | | $b$, $L_{50}$ linear | 1.762 | 1.702 | 1.641 | 11.4 | 13.6 | 15.8 | −1192.02 |
| | | $b$, $L_{50}$ proportional | −21.824 | −24.552 | −27.280 | 32.0 | 36.0 | 40.0 | −1480.81 |
| | 400 | $b$ constant, $L_{50}$ linear | 1.394 | 1.394 | 1.394 | 11.3 | 13.6 | 15.8 | 1550.57 |
| | | $b$, $L_{50}$ linear | 1.466 | 1.422 | 1.379 | 11.3 | 13.5 | 15.8 | 1550.55 |
| | | $b$, $L_{50}$ proportional | −7.031 | −7.910 | −8.789 | 34.9 | 39.2 | 43.6 | −1942.63 |
| | | $b$ constant, $L_{50}$ linear | 1.172 | 1.172 | 1.172 | 10.0 | 12.7 | 15.3 | −143.40 |
| Autumn | 300 | $b$, $L_{50}$ linear | 0.143 | 0.631 | 1.120 | 12.0 | 14.0 | 16.0 | −142.97 |
| | | $b$, $L_{50}$ proportional | −5.096 | −5.733 | −6.370 | 28.8 | 32.4 | 36.0 | −175.37 |
| | | $b$ constant, $L_{50}$ linear | 1.535 | 1.535 | 1.535 | 11.1 | 13.0 | 14.9 | −165.49 |
| | 400 | $b$, $L_{50}$ linear | 1.746 | 1.608 | 1.471 | 11.0 | 12.9 | 14.9 | −165.45 |
| | | $b$, $L_{50}$ proportional | −11.340 | −12.758 | −14.175 | 22.1 | 24.9 | 27.6 | −220.42 |

Logistic selectivity model parameters for *Sepia officinalis*. $b$ is the slope and $L_{50}$ is the mantle length at 50% selectivity.

Table 8
Cyclades

| Species | Mesh combinations (mm) | Model | Fishing power | Parameters | Model deviance | d.f. |
|---|---|---|---|---|---|---|
| *Spicara maena* | 40/240, 48/260, 56/300 | Bi-modal | α Mesh size | $(k_1, k_2, k_3, k_4, c)$ = (3.775, 0.316, 4.471, 1.246, 0.127) | 27.48 | 23 |
| | 40/220, 48/240, 56/280 | Bi-modal | α Mesh size | $(k_1, k_2, k_3, k_4, c)$ = (3.779, 0.296, 11.189, 2.516, 6.143) | 27.89 | 21 |
| | **40/(240 + 220), 48/(260/240), 56/(300/280)** | **Bi-modal** | **α Mesh size** | **$(k_1, k_2, k_3, k_4, c)$ = (3.770, 0.299, 5.524, 1.446, 0.233)** | **37.27** | **25** |
| *Pagellus erythrinus* | **40/240, 48/260, 56/300** | **Bi-modal** | **Equal** | **$(k_1, k_2, k_3, k_4, c)$ = (3.660, 0.344, 6.070, 1.218, 0.572)** | **45.83** | **37** |
| | 40/220, 48/240, 56/280 | Bi-modal | Equal | $(k_1, k_2, k_3, k_4, c)$ = (3.676, 0.306, 7.944, 1.579, 1.024) | 51.51 | 41 |
| *Mullus surmuletus* | 40/240, 48/260, 56/300 | Bi-modal | Equal | $(k_1, k_2, k_3, k_4, c)$ = (4.367, 0.468, 5.959, 1.009, 0.675) | 35.20 | 39 |
| | 40/220, 48/240, 56/280 | Bi-modal | Equal | $(k_1, k_2, k_3, k_4, c)$ = (4.306, 0.297, 5.506 0.834, 0.995) | 42.06 | 29 |
| | **40/(240 + 220), 48/(260/240), 56/(300/280)** | **Bi-modal** | **Equal** | **$(k_1, k_2, k_3, k_4, c)$ = (4.397, 0.432, 5.887, 0.965, 0.741)** | **49.82** | **41** |
| *Diplodus annularis* | 40/240, 48/260, 56/300 | Bi-modal | Equal | $(k_1, k_2, k_3, k_4, c)$ = (2.618, 0.163, 3.002, 0.522, 0.176) | 22.12 | 15 |
| | 40/220, 48/240, 56/280 | Bi-modal | Equal | $(k_1, k_2, k_3, k_4, c)$ = (2.671, 0.161, 3.101, 0.421, 0.380) | 11.43 | 17 |
| | **40/(240 + 220), 48/(260/240), 56/(300/280)** | **Bi-modal** | **Equal** | **$(k_1, k_2, k_3, k_4, c)$ = (2.640, 0.160, 3.053, 0.467, 0.267)** | **22.36** | **17** |
| *Scorpaena porcus* | **40/240, 48/260, 56/300** | **Bi-modal** | **Equal** | **$(k_1, k_2, k_3, k_4, c)$ = (3.164, 0.529, 7.434, 3.035, 0.549)** | **61.23** | **47** |
| *Serranus cabrilla* | **40/240, 48/260, 56/300** | **Normal scale** | **Equal** | **$(k_1, k_2)$ = (4.148, 0.398)** | **26.05** | **18** |

Best SELECT models and parameters per species. d.f. is degrees of freedom. The models presented in Fig. 10 are in bold.

shape of the logistic selectivity curve. Consequently, we fitted the logistic model by maximum likelihood, with the parameters $b$ and $L_{50}$ being functions of the inner panel mesh size, which was judged to be the most appropriate.

To the best of our knowledge, this is one of the first times that models other than the usual uni-modal or bi-modal models used in gill net selectivity studies have been used in trammel net size selectivity studies. The use of the logistic model to describe the size selectivity of trammel nets for *Sepia officinalis* is a particularly interesting result. In the case of species such as *Sepia officinalis*, which has no spines or outer body hard parts and where all individuals are caught in the pocket formed by the small mesh inner panel passing through one of the larger mesh outer panels, the type of selectivity is similar to "bag" type gear such as trawls or encircling gear such as seines. The very small individuals can pass through the trammel net but larger individuals are retained in the pocket and above a certain size, no individuals pass through the inner panel mesh and are all retained in the pocket. Akiyama et al. (2004) also fitted a logistic selectivity curve to squid (*Sepioteuthis lessoniana*) that were mostly caught by pocketing in a trammel net.

The size selectivity of a gear can be estimated directly if the population size structure is known or, as in our case, indirectly by comparing catch size distributions of nets of different mesh sizes (Hamley, 1975; Fujimori and Tokai, 2001). In the case where there are several methods of capture, such as gilling, wedging, and pocketing//tramelling, the fish caught with each mesh size can be classified accordingly and selectivity curves can then be fitted to the different catch components (Hamley and Regier, 1973; Fabi et al., 2002). However, this is often not practical given the difficulty and subjectivity in identifying the primary method of capture. Thus, fitting a bi-modal curve to the data for all fish captured, irrespectively of the method of capture, may be more correct (Losanes et al., 1992b).

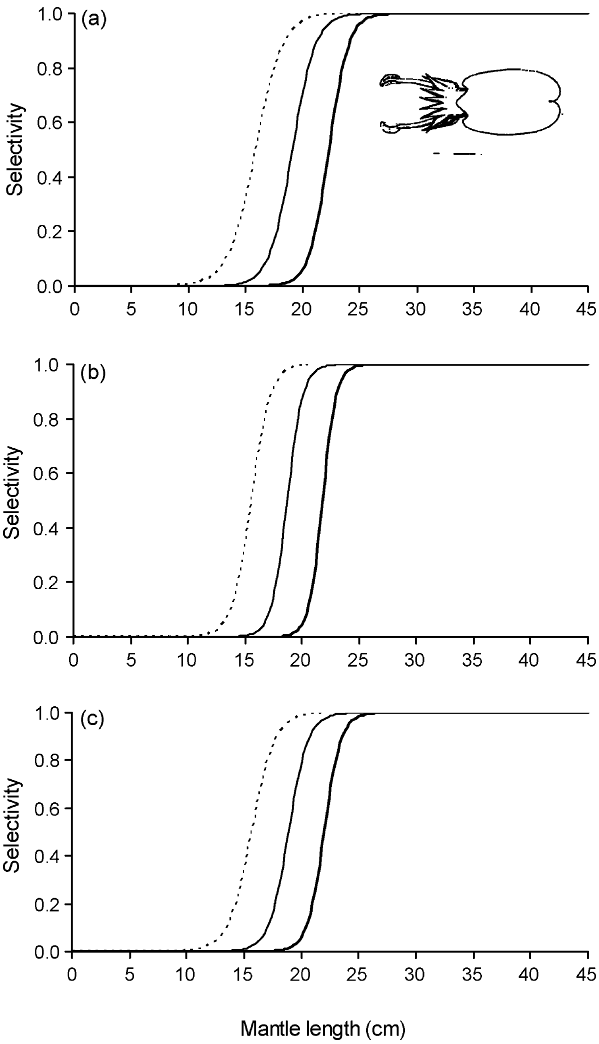

Fig. 7. Algarve. *Sepia officinalis*: logistic selectivity models fitted by maximum likelihood. (a) 600 mm outer panel mesh, (b) 800 mm outer panel mesh, and (c) combined 600 and 800 mm outer panel meshes. Dashed line: 100 mm inner panel mesh, continuous line: 120 mm inner panel mesh, bold line: 140 mm inner panel mesh.

Direct estimation of size selectivity for trammel nets has been reported by several authors (Fujimori et al., 1990, 1992; Matsuoka, 1991; Salvanes, 1991; Losanes et al., 1992b). Fujimori et al. (1990, 1992) fished a population of trout of known size structure in a large outdoor tank with a semi-trammel net and concludes that a skew-normal function adequately describes size selectivity. Matsuoka (1991) compares the size selectivity mechanisms of gillnets and trammel nets using *Tilapia mossambica* in indoor tanks, using a gillnet mesh size and trammel net inner panel mesh size of 48 mm, while the outer panel mesh size is 227 mm. Matsuoka (1991) expresses size selectivity as the sum of four components: gillnet wedging, gillnet entangling, additional wedging and entangling related to the outer panel. He uses normal and log-normal curves to describe the wedging and entangling components, respectively, and finds trammel net selectivity to be bi-modal, with wedging being a minor component when compared to entangling. The final selectivity curve of the trammel net shows almost no descending right-hand limb. Matsuoka (1991) concludes that in terms of selectivity, the entangling component alone was more logistic in shape than log-normal.

Salvanes (1991) uses a trammel net to sample a tagged group of *Gadus morhua* of known size composition and estimates absolute selectivity curves. She reports that the left side of the trammel net selectivity curves falls to zero as small fish pass through the inner panel mesh but the right side is skewed to the right and does not fall to zero as the larger fish are entangled.

The selectivity of trammel and semi-trammel nets is estimated directly by Losanes et al. (1992b) who carry out experimental fishing of a known population of trout in outdoor tanks. Losanes et al. (1992b) fit a bi-modal curve where the second component is assumed to correspond to larger fish that are entangled or trammelled/pocketed.

In the current study, the larger mesh outer panel had generally no significant effect on the size selectivity of the experimental trammel nets. This agrees with the results of Stergiou et al. (2006) who find that the outer panel mesh size does not significantly affect species selectivity and catch rates. In contrast, size selectivity was clearly a function of the smaller mesh of the inner panels, with modal length generally increasing with inner panel mesh size for many species. Other authors also report that the catches and the size selectivity of trammel nets depends primarily on the mesh size of the inner net (e.g., Kitahara, 1968; Koike and Takeuchi, 1985; Koike and Matuda, 1988; Salvanes, 1991; Purbayanto et al., 2000; Losanes et al., 1992a).

Vertical slack is reported to have no effect on the modes of the selectivity curves of trammel nets of the same mesh size (Koike and Matuda, 1988; Losanes et al., 1992a). Koike and Matuda (1988) carry out experiments with 5.1 cm inner mesh trammel nets with vertical slackness of 1.1, 1.5 and 2.0 and find that the selectivity curves for *Clupanodon punctatus* differ only in the steepness of the descending limb, reflecting the increase in selection range with greater slackness. Losanes et al. (1992a) fish gizzard shad with trammel nets with vertical slacks of 1.1, 1.5 and 2.0 and report that the master curves were all skewed to the right and had the same modal length/mesh size value of approximately 3.8. Thus, the ascending part of the selectivity curve of trammel nets is expected to be similar or the same for different values of vertical slack since it is determined primarily by the proportions of fish of different size classes that pass through the meshes. For sizes greater than the modal length, vertical slack does affect the slope of the descending limb. However, for values of vertical slack greater than 1.5, the differences in the descending limbs of the selectivity curve are minimal (Koike and Matuda, 1988; Losanes et al., 1992a).

The vertical slack of our experimental trammel nets generally ranged from 1.5 to 2.5 and this is reflected in the

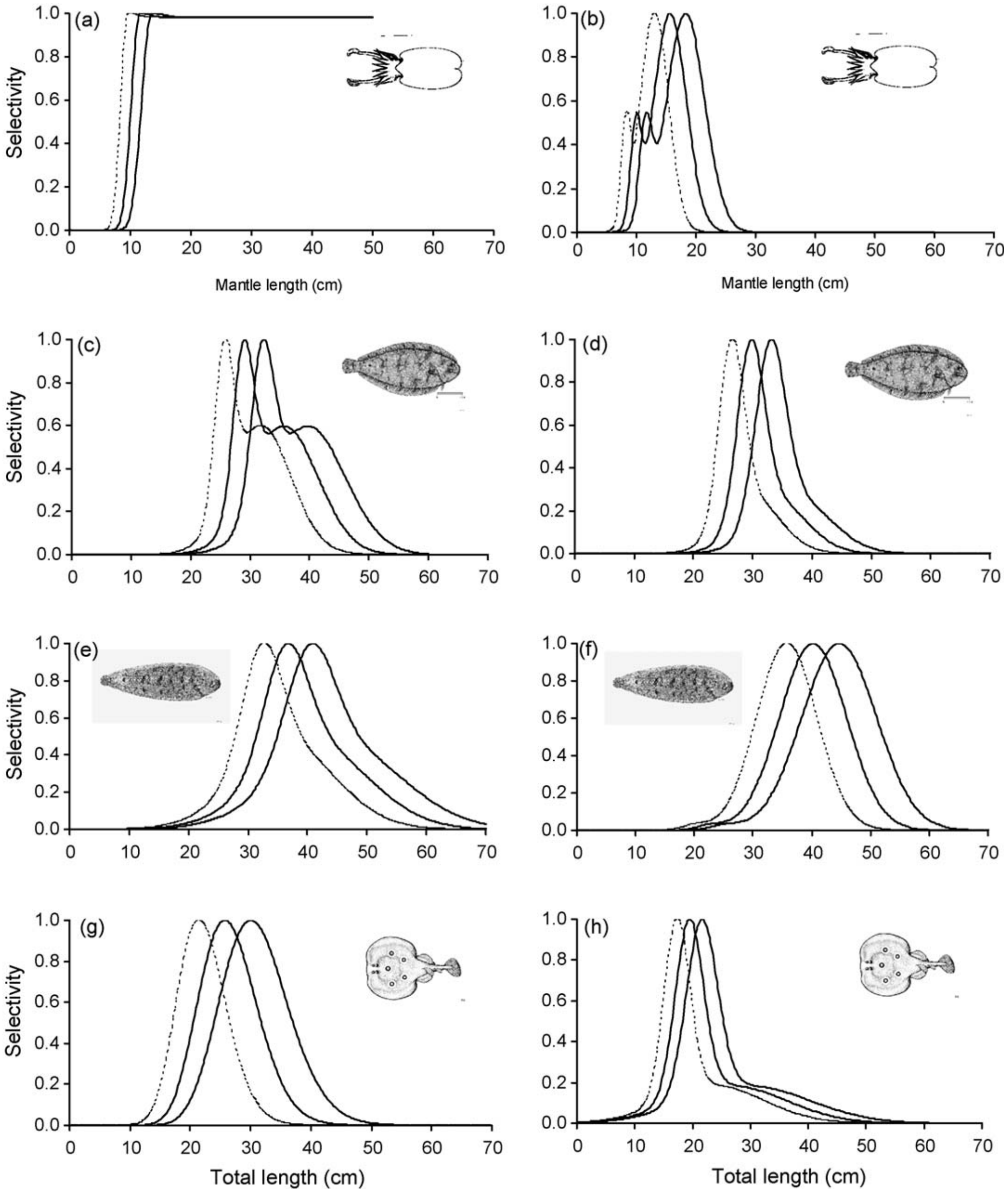

Fig. 8. Gulf of Cádiz. Best SELECT models by species, for pooled outer mesh data by season. (a) *Sepia officinalis*, Gamma semi-Wileman, spring, (b) *Sepia officinalis*, bi-normal model, autumn, (c) *Solea senegalensis*, bi-normal model, spring, combined 300 + 400 mm outer panels, (d) *Solea senegalensis*, normal model, autumn, combined 300 + 400 mm outer panels, (e) *Synaptura lusitanica*, bi-normal model, spring, combined 300 + 400 mm outer panels, (f) *Synaptura lusitanica*, bi-normal model, autumn, combined 300 + 400 mm outer panels, (g) *Torpedo marmorata*, Gamma model, spring, combined 300 + 400 mm outer panels, (h) *marmorata*, bi-normal model, autumn, combined 300 + 400 mm outer panels. Dashed line: 80 mm inner panel mesh, continuous line: 90 mm inner panel mesh, bold line: 100 mm inner panel mesh.

generally wide selection range of many species, especially for species such as *Phycis phycis* and *Merluccius merluccius*, which have a maximum size greater than 60 cm. In the case of *Sepia officinalis* with logistic type selectivity, vertical slack has no effect on the shape of the selectivity curve since there is no descending limb. For other species where uni-modal or bi-modal selectivity models are more appropriate, it is expected that there will be some influence of vertical slack on the shape of the selectivity curve but such an influence will be negligible.

In light of the state of the majority of living resources in European waters (ICES, 2003; OCEANA, 2004) and given the importance of static gears, particularly in small-scale fisheries, understanding the impact of different gears that compete for the same resources is vital for improved management and conservation (Demestre et al., 1997; Martin et al., 1999; Jabeur et al., 2000; Stergiou and Erzini, 2002). Management of heterogeneous fisheries often involves conflicts between resource users and the assessment of the impacts of each métier on the sustainability of the implicated fish-

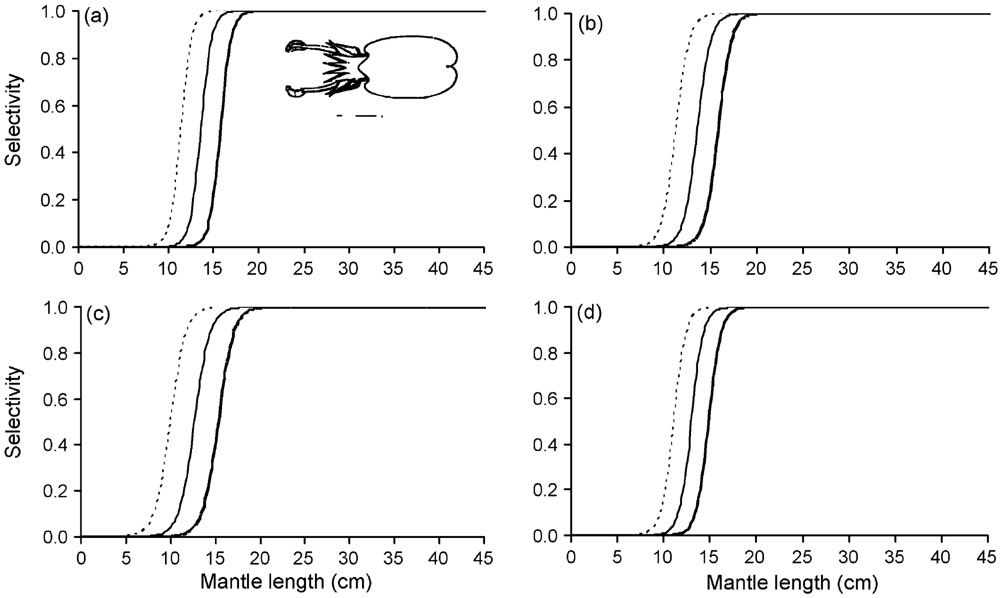

Fig. 9. Gulf of Cádiz. *Sepia officinalis* logistic selectivity models fitted by maximum likelihood. (a) Spring, 300 mm outer panel mesh, (b) spring, 400 mm outer panel mesh, (c) autumn, 300 mm outer panel mesh, and (d) autumn, 400 mm outer panel mesh. Dashed line: 80 mm inner panel mesh, continuous line: 90 mm inner panel mesh, bold line: 100 mm inner panel mesh.

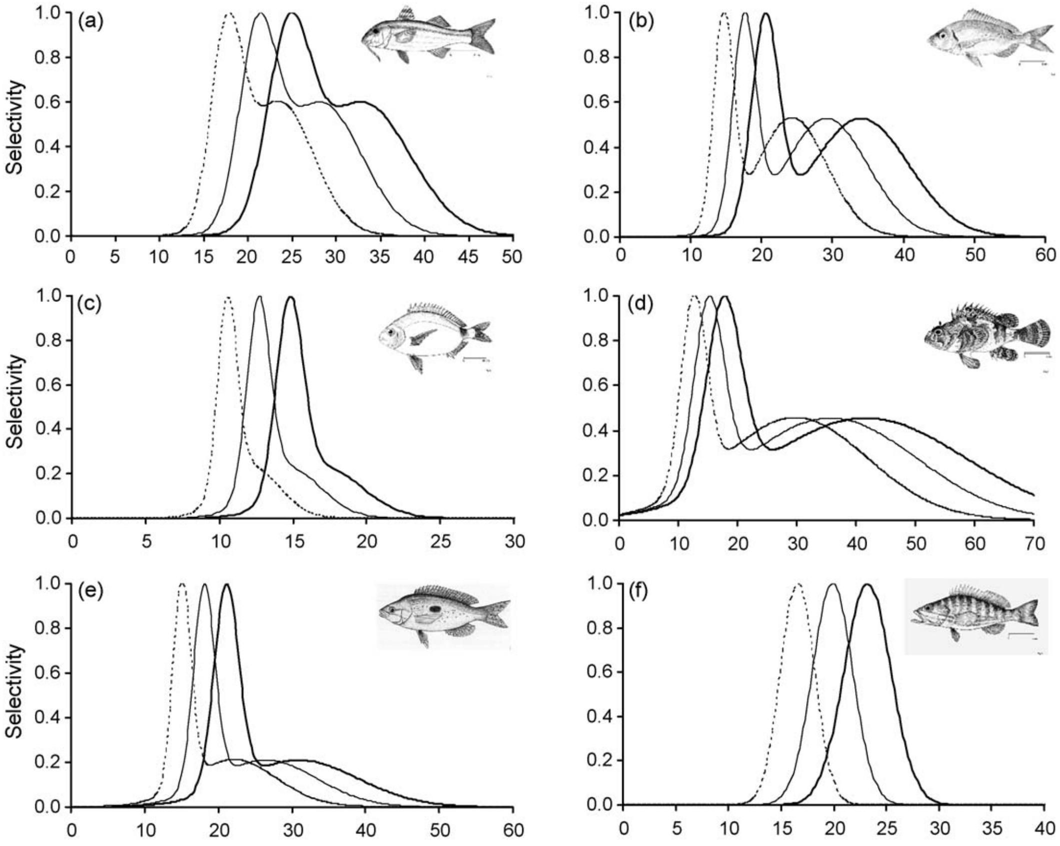

Fig. 10. Cyclades. Best SELECT models by species. (a) *Mullus surmuletus*, bi-normal model, data set 3, (b) *Pagellus erythrinus*, bi-normal model, data set 1, (c) *Diplodus annularis*, bi-normal, data set 3, (d) *Scorpaena porcus*, bi-normal, data set 1, (e) *Spicara maena*, bi-normal, data set 3, and (f) *Serranus cabrilla*, normal scale, data set 1. Data set 1: 40/240, 48/260 and 56/300 trammel nets; data set 2: 40/220, 48/240 and 56/280 trammel nets; data set 3: 40/240 + 40/220, 48/260 + 48/240 and 56/300 + 56/280 trammel nets.

eries (Gobert, 1992). There have been few studies on the selectivity of trammel nets in European waters. This study will provide a basis for evaluating the impacts of trammel nets in comparison with other gear such as longlines, gillnets and trawls that are also often used to catch the same species at different areas, depths and/or seasons (Stergiou et al., 2004).

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