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Selectivity of diamond and square mesh cod ends for horse mackerel (*Trachurus trachurus*), European hake (*Merluccius merluccius*) and axillary seabream (*Pagellus acarne*) in the shallow groundfish assemblage off the south-west coast of Portugal*

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SUMMARY: The effects of an increase in cod end mesh size from 65 to 70 and 80 mm and a change of mesh configuration from 65 mm diamond to 65 mm square mesh on the size selectivity of horse mackerel (*Trachurus trachurus*), hake (*Merluccius merluccius*) and axillary seabream (*Pagellus acarne*) of the shallow groundfish assemblage off the Portuguese southwest coast were evaluated. The increase in mesh size had a small but significant effect on size selectivity for the three species, while the change in mesh configuration led to a much more pronounced increase in the selectivity parameters. For horse mackerel, the L_{50} estimates ranged from 14.4 to 16.0 cm in the diamond mesh cod ends—values that are close to the minimum landing size of 15 cm. For hake, L_{50} of 17.0 and 18.3 cm were estimated for the 70 and 80 mm diamond cod ends respectively, while for the axillary seabream the L_{50} estimated was 13.9 cm for the 80 mm diamond mesh cod end. These values are well below the minimum landing sizes of 27 and 18 cm for these species. The corresponding estimates in the square mesh cod end were 21.9, 32.4 and 19.6 cm, with the loss of a high percentage (76%) of horse mackerel above the minimum landing size. For all the cod ends tested, the observed retention was presented as a function of maximum girth/mesh perimeter, which allowed a better understanding of the selection process for the species in study. Selectivity estimates for horse mackerel and hake were also compared to those obtained by Campos *et al.* (2003) for the same species in 1993 off the south coast, where they are captured as a by-catch in the crustacean fishery.

Key words: cod end selectivity, mesh size, mesh configuration, length-girth relationships, by-catch, *Trachurus trachurus, Merluccius merluccius*, *Pagellus acarne.*

RESUMEN: SELECTIVIDAD DE COPOS CON MALLA DE DIAMANTE Y CUADRADA PARA JUREL (*TRACHURUS TRACHURUS*), MERLUZA EUROPEA (*MERLUCCIUS MERLUCCIUS*) Y ALIGOTE (*PAGELLUS ACARNE*) EN LOS POBLAMIENTOS DE PECES DEMERSALES DE AGUAS SOMERAS FRENTE A LAS COSTAS DEL SUROESTE DE PORTUGAL. – Los efectos de un incremento en la dimensión de la malla del copo desde 65 a 70 y 80 mm, así como un cambio en su configuración entre malla de diamante de 65 mm y malla cuadrada de 65 mm han sido evaluados sobre la selectividad por talla del arte de arrastre para jurel (*Trachurus trachurus*), merluza europea (*Merluccius merluccius*) y aligote (*Pagellus acarne*) en los poblamientos de peces demersales de aguas someras frente a la costa del suroeste de Portugal. El incremento del tamaño de la malla ha tenido un efecto pequeño pero significativo sobre la selectividad por tamaños de las tres especies, mientras que el cambio de la configuración de la malla conlleva un incremento mucho más pronunciado en los parámetros de selectividad. En el caso del jurel, las estimaciones de la L_{50} oscilan entre 14.4 y 16.0 para los copos con malla de diamante; valores que se encuentran próximos a la talla mínima de desembarco de 15 cm. Para la merluza, la L_{50} estimada ha sido 17.0 y 18.3 cm para los copos de malla de diamante de 70 y 80 mm respectivamente, mientras que para el aligote la L_{50} estimada ha sido 13.9 cm para el copo de malla diamante de 80 mm. Los parámetros anteriores se encuentran por debajo de la talla mínima de desembarco de las dos especies (merluza: 27 cm; aligote: 18 cm). Las estimaciones de los parámetros correspondientes al copo de malla cuadrada han sido 21.9, 32.4 y

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19.6 cm para las tres especies respectivamente, con pérdida de un alto porcentaje (76%) de jurel por encima de la talla mínima de desembarco. En todos los copos analizados, la retención observada se ha expresado como una función de la relación perímetro máximo del pez/perímetro de la malla, lo cual permite un mejor entendimiento del proceso de selección de las especies estudiadas. Las estimaciones de parámetros de selectividad del jurel y de la merluza se han comparado igualmente con los obtenidos para estas especies en 1993 en aguas del sur de Portugal por Campos *et al.* (2003) en donde se capturan como *by-catch* en la pesquería de crustáceos.

Palabras clave: selectividad en el copo, dimensión de malla, configuración de malla, relación longitud/perímetro, by-catch, *Trachurus trachurus, Merluccius merluccius, Pagellus acarne.*

INTRODUCTION

The horse mackerel *Trachurus trachurus*, the axillary seabream *Pagellus acarne* and the European hake *Merluccius merluccius* are three commercially important species of the shallow ground fish assemblage of southern Portuguese waters (Gomes *et al.*, 2001). A number of other commercially valuable species, including seabreams and cephalopods, as well as some species with no commercial value and therefore discarded, are also included in this group. This assemblage extends over the southwest and southern continental coasts of Portugal at depths to approximately 120 m, and is exploited by the coastal bottom finfish trawling fleet. A total of 14 licensed fishing vessels are registered within this area, for which the legal cod end mesh size is 65 mm.

There are no studies quantifying the discard rates for the finfish trawlers fishing off the south west coast. However, mean discard rates per trip of 62% were estimated for the bottom finfish trawlers operating off the south coast in 1995-96 (Borges *et al.*, 2001), which target the same groundfish assemblage. The main reasons identified for discarding were the low or null commercial value of some species such as the longspine snipefish *Macroramphosus scolopax*, while for commercially valuable species most discards consisted of undersized fish.

Given scientific evidence pointing to overfishing of most demersal stocks in region 3, in which the Portuguese continental coast is included, the increase in cod end mesh size from 65 to 80 mm was proposed by the EC in 1991, but not subsequently adopted. Following this proposal, an evaluation of the consequences of increasing the cod end mesh size and changing mesh configuration was carried out by the Portuguese Institute for Fisheries and Sea Research - IPIMAR in the bottom trawl fishery off the south-west coast of Portugal. In the present study, some of the results obtained are presented for the horse mackerel, the European hake and the axillary seabream and are compared to those obtained for the first two species (Campos *et al.*, 2003) when captured as a by-catch in the crustacean fishery off the south coast.

MATERIAL AND METHODS

Data collection

The data in this paper were collected between 9 and 20 May 1992 off the south-west coast of Portugal on board the R/V "Noruega", a stern trawler of 47.5 m length and 1500 HP belonging to IPIMAR. A total of 28 hauls (Fig. 1) carried out during daylight hours at depths of 45 to 100 m approximately, the depth range normally exploited by the finfish fleet, were chosen from a total of 42 valid hauls between Sesimbra and Arrifana. Haul duration was one hour for all hauls, at a constant trawling speed of about 3.5 kn. Three diamond mesh cod ends of 65 mm (8 hauls), 70 mm (5 hauls) and 80 mm (8 hauls) nominal mesh size and a square mesh cod end of 65 mm mesh size (7 hauls) were tested.

The trawl used in the experiments is similar to the one quoted as FGAV019 in Leite *et al.* (1990). Changes introduced in the latter gear design mainly concerned a general increase in the mesh size of the different panels, while maintaining the same overall dimensions. The gear was made of polyethylene, was approximately 47 m long (excluding cod end), and had a circumference of 566 meshes of 140 mm at the footrope level. It was rigged with a 55.4 m length footrope made of 18 mm steel cable covered with 24 mm polyethylene, 25 m sweeps with 22 mm diameter, 16 m legs of steel of 16 mm diameter, and steel otter boards of 4.3 m^2 and 650 kg.

Trawl geometry was recorded using Scanmar acoustic equipment, including depth, height, spread and trawl speed sensors. Vertical opening was about 3.1 m, and wing end and door spread 26.5 and 71.0 m respectively, at 3.5 kn.

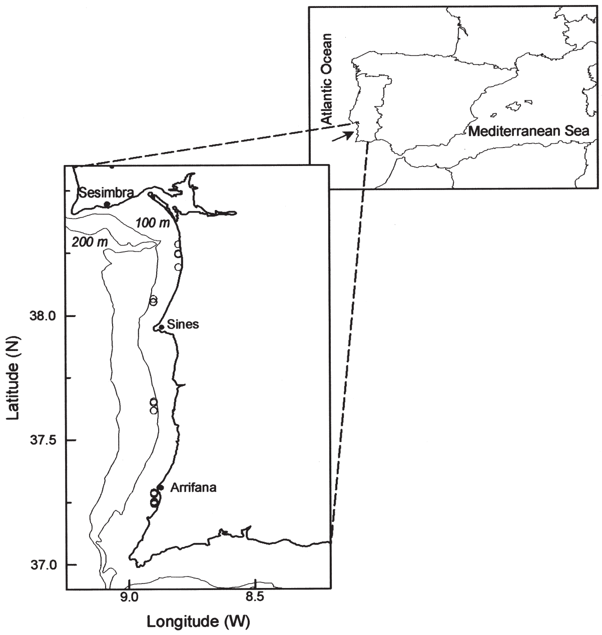

Fig. 1. – Location of selectivity hauls.

Cod end dimensions are shown in Table 1 for the four cod ends used. All cod ends were made of 2.5 mm single braided polyethylene, except for the square mesh cod end for which 2.0 mm twine was used. Cod end effective mesh sizes were measured during the surveys as the inside stretched mesh size using a calliper, due to the unavailability of an ICES gauge as recommended by Pope *et al.* (1975). The perimeter (given by number of meshes round times mesh size) of the diamond mesh cod ends was kept constant in order to achieve a similar mesh opening in all the experimental cod ends, since this is a variable which can affect selectivity to a large extent (Robertson and Ferro, 1988; Reeves *et al.*, 1992; Galbraith *et al.*, 1994). Due to their particular shape, square meshes always have the same (maximum) opening. Although selection factors (SF = L_{50}/mesh size) were calculated using the effective mesh size value, for practical reasons the nominal value will be referred to throughout.

The covered cod end method (Pope *et al.*, 1975) was used to assess escapement from the cod ends. The cover was made of single twisted PA 20 mm mesh size and 1.5 mm twine thickness. In order to minimise the possible masking effect of cod end meshes, the general dimensions of the covers were 1.5 times the width and the length of the cod ends, as proposed by Stewart and Robertson (1985) for covers when large catches are not expected.

After hauling up, catches from both the trawl cod end and cover were handled separately on board and weighed. Identification was almost always carried out to the species level and the weights registered for each species, both for the cod end and the cover. Total length was measured to the centimetre below for commercially valuable fish species. The whole catch was measured in all hauls for hake, captured in lower quantities, while horse mackerel and axillary seabream were sub-sampled in some of the hauls. In this case random samples were taken from the cod end, the cover or both, and the length class frequencies were then estimated by scaling up the sub-sampled frequencies by the ratio of the total weight to the sub-sample weight.

In order to determine girth/length relationships, maximum girth (unconstricted) and total length were measured, to the millimetre, in samples of 1017 individuals for horse mackerel, 260 for hake and 534 for axillary seabream.

Selectivity analysis

The probability r(l) that a fish of length l is retained, given that it entered the cod end, was modelled by means of the logistic selection curve

$$r(l) = \frac{\exp(v_1 + v_2 l)}{1 + \exp(v_1 + v_2 l)}$$

where $\hat{v} = (v_1\ v_2)^T$ is the maximum likelihood estimator of the vector of selectivity parameters. Estimation of $\hat{v}$ and the respective variance matrix R

TABLE 1. – Details of cod ends. Standard errors are in brackets; D, diamond mesh; S, square mesh.

Cod end mesh size (mm) Nominal	65D	70D	80D	65S
Measured	63.5 (1.54)	69.4 (2.26)	79.2 (1.74)	63.3 (1.90)
Nº of measurements	100	100	50	50
Dimensions (nº of meshes)				
width	115	106	93	64*
length	154	143	125	308*

* number of bars

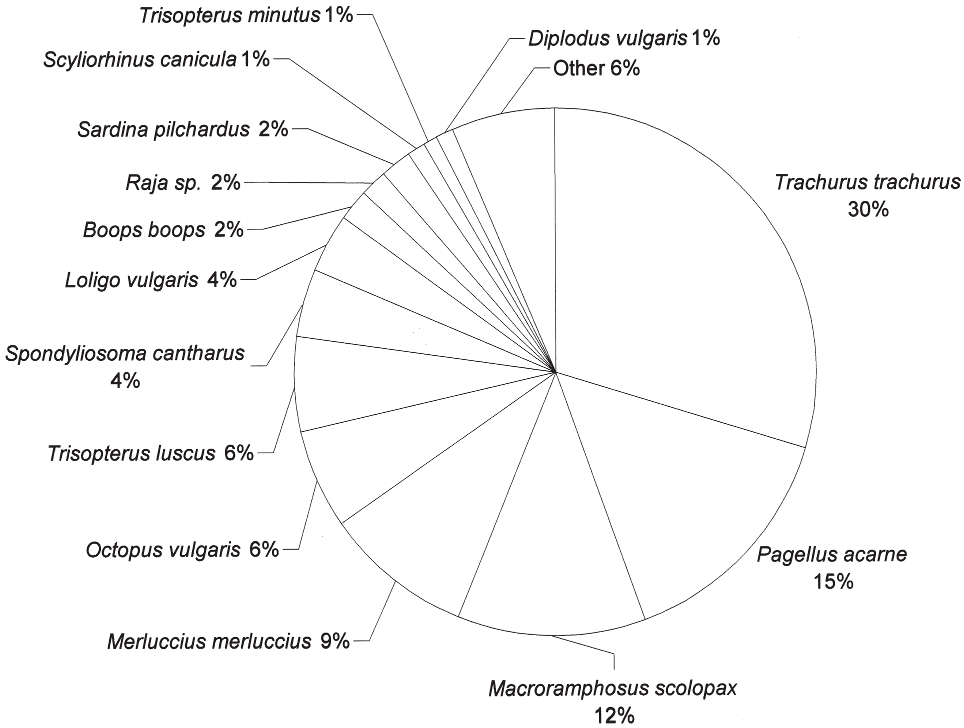

Fig. 2. – Species composition by weight, in cod end + cover (all hauls combined).

are described in Fryer (1991) and Millar and Fryer (1999).

For all the species in study, $\hat{v}$ was estimated based on the total number of individuals for each length class across all hauls within the same cod end, since the number of hauls for which the selectivity could be separately estimated was too low to estimate mean curves taking into account between-haul variation following the methodology of Fryer (1991). The selectivity parameters were estimated using the software CC 2000 (*ConStat*, DK).

A likelihood ratio test (McCullagh and Nelder, 1991) was carried out in order to determine whether the selection curves estimated for the different cod ends were statistically different from each other. In the present case, the ln-likelihoods resulting from fitting independent selection curves for each pair of contiguous mesh sizes were summed up, then a single curve was fitted to the data of both mesh sizes and the corresponding ln-likelihood was assessed.

W^2 = 2 * [ln-likelihood (mesh size A) + ln-likelihood (mesh size B) - ln-likelihood (mesh size A + mesh size B)] is approximately $\chi^2_{(\alpha,\, dof)}$, where dof is given by the change in the number of parameters estimated when fitting the curves, if the null hypothesis, H_0, of no differences between curves is correct.

RESULTS

Horse mackerel was the most abundant species, together with the axillary seabream representing 45% of the total biomass in the catches (cover + cod end, Fig. 2), followed by the longspine snipefish *Macrorhamphosus scolopax,* a species with no commercial value that is discarded (12%), and by the European hake with 9%. Cephalopods and other seabreams accounted for 10 and 7% respectively of the total biomass.

Horse mackerel (*Trachurus trachurus*)

Horse mackerel was captured in large numbers within a length range of 6 to 34 cm approximately, with the mode at 17 cm, although the vast majority of the catches were found to be included in a much narrower range of 15 to 20 cm, for all mesh sizes (Fig. 3). In the 70D codend mesh size, where a higher proportion of larger individuals was caught, a second mode can be noticed at 22 cm. Fig. 4 shows the selectivity curves plotted together with the observed retention values in all mesh sizes. The 65 and 70 mm diamond mesh curves are almost coincident, the L_{50} estimates being 14.4 and 14.7 cm while the SRs were 3.3 and 2.9 cm respectively (Table 2). These

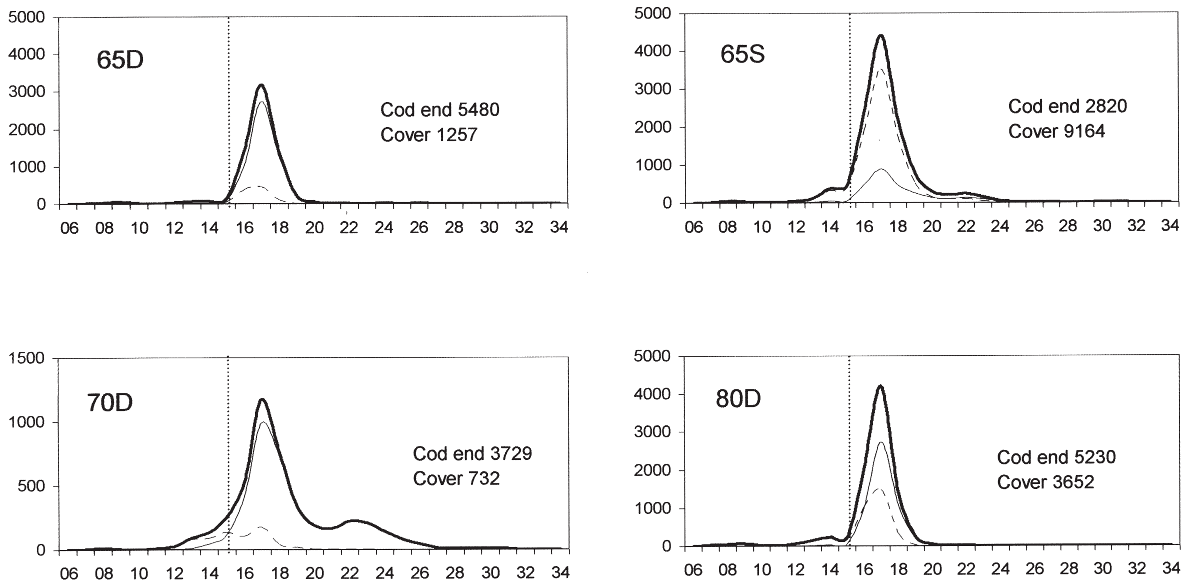

Fig. 3. – *Trachurus trachurus* (horse mackerel). Size structure of the populations that entered the diamond cod ends (D) and the square mesh cod end (S). X-axis – length (cm). Y-axis – numbers. Thin line corresponds to length frequency in cod end, dashed line in cover and thick line to total numbers. Dotted vertical line indicates the minimum landing size MLS.

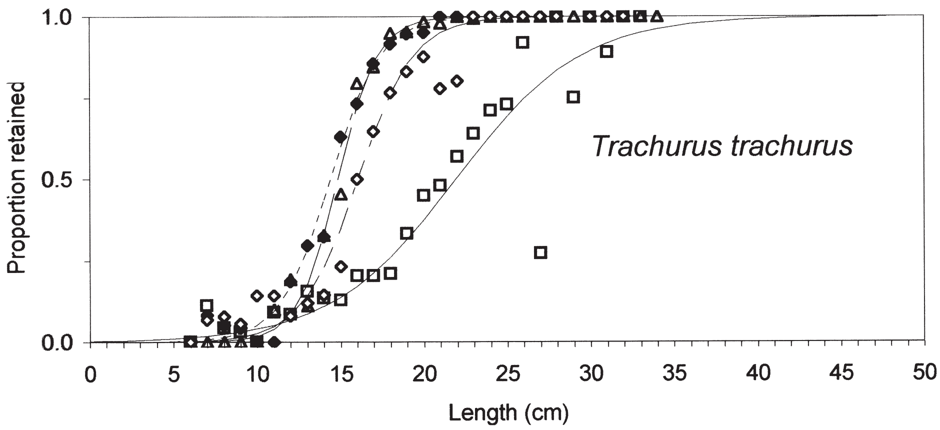

Fig. 4. – Selectivity curves for *Trachurus trachurus* (horse mackerel) based on pooled data, together with observed retention in the four cod ends. —- 65D; - - - 70D; - · - · - 80D; — 65S. Observed retention is expressed as black lozenges (65D), triangles (70D), white lozenges (80D) and squares (65S).

figures indicate that a 5 mm increase from the currently used mesh size of 65 mm has virtually no consequences in improving cod end selectivity. When the 80 mm diamond mesh was used, the L_{50} increased to 16.0 cm, while the selection range was 3.7 cm, slightly higher than for the other diamond mesh cod ends. If the selection factors are examined, a decrease is noticeable with the increase in mesh size from 2.3 to 2.1 and 2.0, indicating that horse mackerel did not make use of the greater escapement areas made possible by larger mesh sizes. On the other hand, the selectivity was much higher for the 65S cod end, as shown by the L_{50} estimate of 21.9 cm and SF of 3.8, while the SR estimate of 8.3 cm is also considerably higher.

The percentage of undersized horse mackerel that was retained is relatively low in all mesh sizes, about 20% for the 65 and 70D diamond cod ends, dropping to 11-12% when the mesh size is increased to 80 mm or the square mesh configuration is adopted (Table 2). However, the fraction of undersized individuals that entered the cod end was extremely low in all cod ends (4 to 7% of the total numbers) and estimation of the left branch of the selection curves was based on a low number of individuals, except for the 65S cod end. Conversely, while the losses of fish above MLS are about 15% for the smaller mesh size cod ends, they increase significantly for the 80D and 65S cod ends (37 and 76% respectively).

TABLE 2. – Selectivity parameter estimates for the three species in study in diamond meshes (D) and square mesh (S).The numbers in cod end and cover below and above the minimum landing size (MLS) are shown. v_1 and v_2 are the estimated selectivity parameters; R, the respective variance matrix; L_{25}, L_{50} and L_{75}, lengths at 25, 50 and 75% retention respectively; CI, confidence intervals for L_{50} and SR.

	Trachurus trachurus				*Merluccius merluccius*				*Pagellus acarne*			
Selectivity estimates	65D 8 hauls	70D 4 hauls	80D 6 hauls	65S 7 hauls	65D 8 hauls	70D 4 hauls	80D 8 hauls	65S 6 hauls	65D 8 hauls	70D 5 hauls	80D 8 hauls	65S 7 hauls
Retained												
<MLS	55	62	75	80	1527	380	1267	54	1479	87	1084	353
>=MLS	5425	3667	5155	2740	346	90	327	54	736	654	412	1614
Escapees												
<MLS	233	229	590	591	97	82	288	620	279	10	714	2229
>=MLS	1024	503	3062	8573	4	0	2	123	8	22	76	1179
v_1	-9.519	-11.269	-9.487	-5.802	-	-12.635	-9.547	-8.662	-	-	-4.155	-12.054
v_2	0.662	0.765	0.592	0.265	-	0.742	0.522	0.267	-	-	0.299	0.615
R_{11}	0.255	0.651	0.408	0.160	-	2.553	0.471	0.648	-	-	0.215	1.425
R_{12}	-0.0153	-0.0396	-0.0243	-0.0090	-	-0.1397	-0.0226	-0.0243	-	-	-0.0135	-0.0761
R_{22}	0.00090	0.00243	0.00146	0.00051	-	0.00770	0.00110	0.00090	-	-	0.00099	0.00412
L_{50} (cm)	14.4	14.7	16.0	21.9	-	17.0	18.3	32.4	-	-	13.9	19.6
L_{25} (cm)	12.7	13.3	14.2	17.8	-	15.5	16.2	28.3	-	-	10.2	17.8
L_{75} (cm)	16.0	16.2	17.9	26.1	-	18.5	20.4	36.5	-	-	17.6	21.4
CI L_{50} (cm)	14.2-14.6	14.5-15.0	15.9-16.2	21.1-22.8	-	16.5-17.5	17.9-18.7	30.6-34.2	-	-	13.4-14.4	19.1-20.1
SR (cm)	3.3	2.9	3.7	8.3	-	3.0	4.2	8.2	-	-	7.4	3.6
CI SR (cm)	3.0-3.6	2.5-3.3	3.2-4.2	6.8-9.8	-	2.2-3.7	3.6-4.7	6.3-10.2	-	-	5.8-8.9	2.8-4.4
SF	2.3	2.1	2.0	3.5	-	2.5	2.3	5.1	-	-	1.8	3.1
Deviance	17.1	63.5	70.2	103.6	-	8.9	16.2	16.0	-	-	18.5	276.2
df	21	27	24	26	-	30	32	18	-	-	16	22
p-value	0.71	0.00	0.00	0.00	-	1.00	0.99	0.59	-	-	0.30	0.00

European hake (*Merluccius merluccius*)

Hake were captured in much lower numbers than the previous species, ranging in size from approximately 15 to 40 cm (Fig. 5). In the 65 mm diamond and square mesh cod ends a modal class can be observed at 22 cm, while in the 80 mm diamond cod end the distribution tends to be bimodal, with two close modes of similar abundance (21 and 24 cm). In the 70 mm cod end, where the size distribution is somewhat irregular, a higher proportion of smaller individuals was captured, showing a first mode at 18 cm and a second one, which is less distinct, at 22 cm.

Selectivity parameters were not estimated for the 65D cod end since the observed retention proportions were mostly concentrated above 0.7 (Fig.6). For the 70 and 80D cod ends the L_{50} estimates were very similar, 17.0 and 18.3 cm respectively, while for the 65S cod end the estimate was much higher (32.4 cm). The SR estimates were also lower for the 70 and 80D cod ends (3.0 and 4.2 cm respectively),

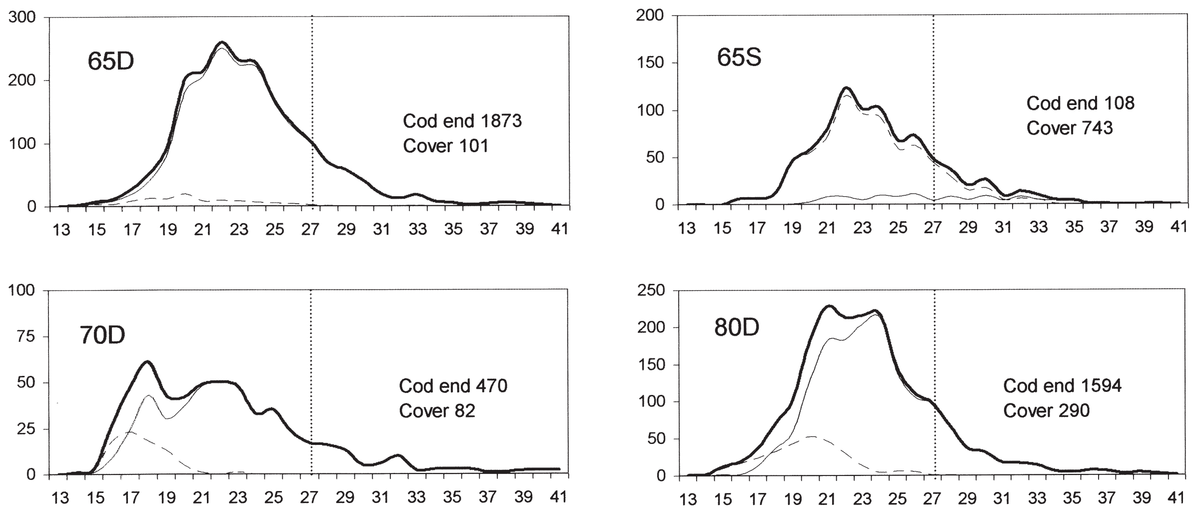

FIG. 5. – *Merluccius merluccius* (European hake). Size structure of the populations that entered the diamond cod ends (D) and the square mesh cod end (S). X-axis – length (cm). Y-axis – numbers. Thin line corresponds to length frequency in cod end, dashed line in cover and thick line to total numbers. Dotted vertical line indicates the minimum landing size MLS.

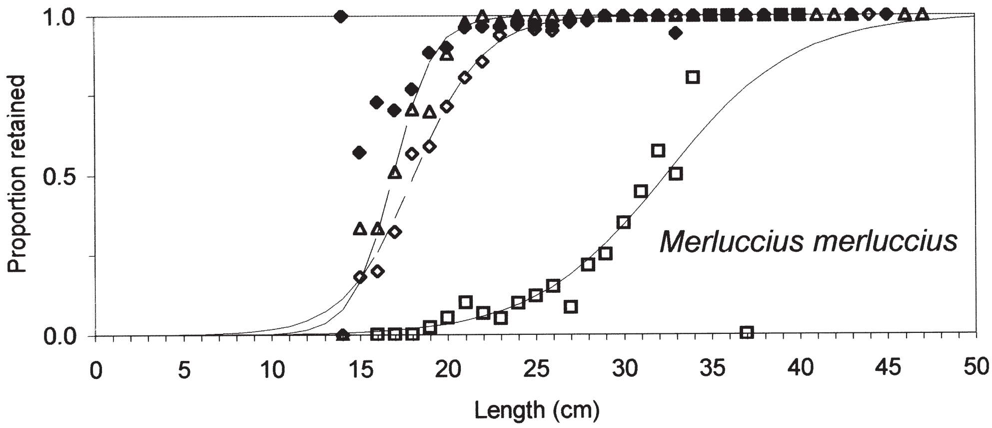

FIG. 6. – Selectivity curves for *Merluccius merluccius* (European hake) based on pooled data, together with observed retentions in the four cod ends. - - - 70D; -·-·- 80D; —— 65S. Observed retention is expressed as black lozenges (65D), triangles (70D), white lozenges (80D) and squares (65S).

when compared to the square mesh cod end estimate of 8.2 cm (Table 2). This difference in SR values, resulting from a much sharper slope for the diamond mesh codends, denotes the very different selective properties of the two mesh configurations.

The 65S curve was estimated based on an observed range of retention values that do not cover the interval between 0 and 1 (Fig. 6). The selectivity estimates are based mainly on the length classes from 15 to 30 cm, where escapement was high, since catches of larger individuals were extremely rare. This data structure contributed to the much higher estimate of SR, as well as to the wider confidence intervals for L_{50} and SR when compared to diamond cod ends.

The retention of undersized fish (Table 2) was around 80% in the 70 and 80 mm diamond cod ends, while in the 65 mm square mesh cod end most small fish escaped but a loss of 70% was observed for commercial sized catches.

Axillary seabream (*Pagellus acarne*)

Axillary seabream ranging from approximately 12 to 35 cm were captured (Fig.7). For the 65 and 80 mm diamond mesh cod ends the greater part of the catches were concentrated in the length classes from 14 to 17 cm. The size distributions are clearly bimodal, with the first mode, by far the most abundant, at 15 cm, while a second one, with much lower numbers of individuals, is found at 18 cm. For the other two cod ends the size structure of the catch differed substantially, with the capture of a higher fraction of bigger individuals from 17 to 22 cm. While the mode remained at 15 cm in the 65S cod end, in

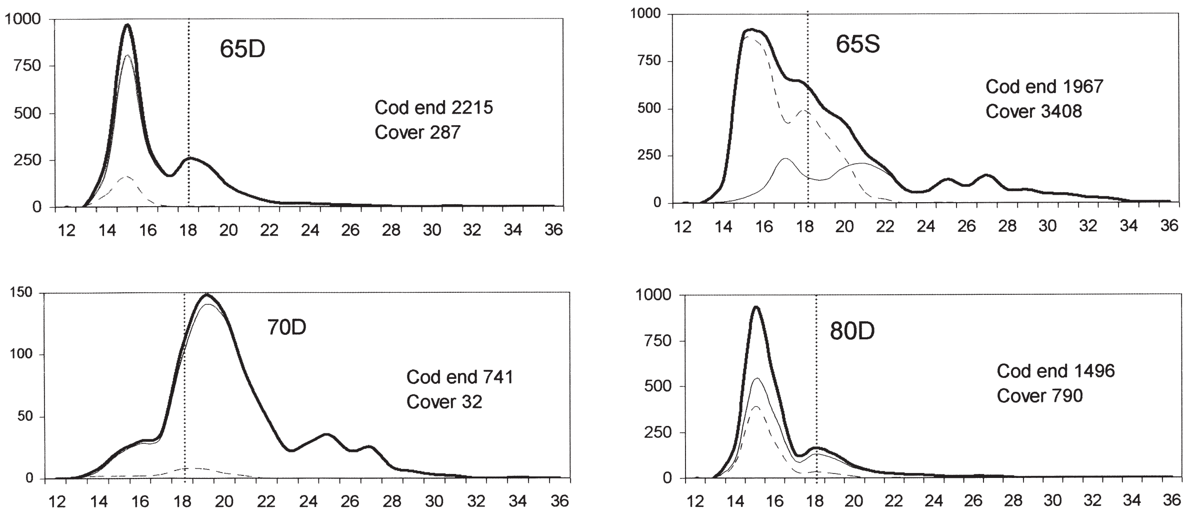

FIG. 7. – *Pagellus acarne* (axillary seabream). Size structure of the populations that entered the diamond cod ends (D) and the square mesh cod end (S). X-axis – length (cm). Y-axis – numbers. Thin line corresponds to length frequency in cod end, dashed line in cover and thick line to total numbers. Dotted vertical line indicates the minimum landing size MLS.

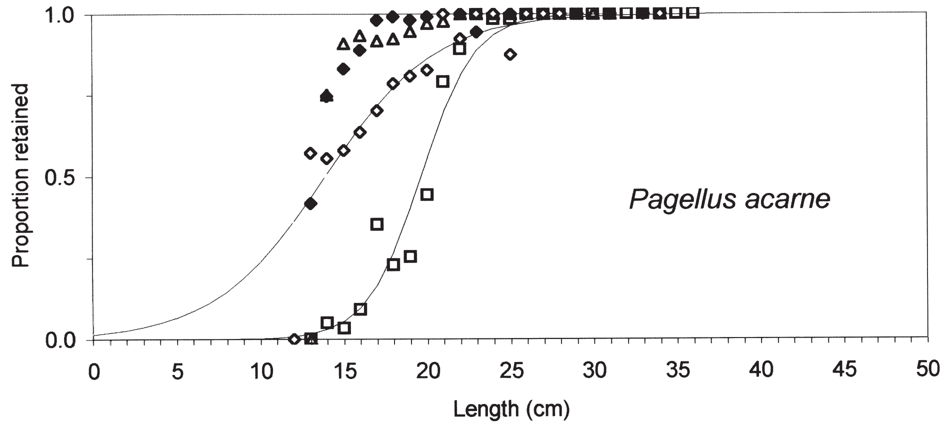

Fig. 8. – Selectivity curves for *Pagellus acarne* (axillary seabream) based on pooled data, together with observed retentions in the four cod ends. -·-·-80D; — 65S. Observed retention is expressed as black lozenges (65D), triangles (70D), white lozenges (80D) and squares (65S).

the 70D cod end there was a shift towards 19 cm, together with lower abundance of the smaller individuals from 14 to 16 cm.

It should be noted that although the catches in the 70D cod end were lower for all species in study, which can partly be attributed to the lower number of hauls carried out with this mesh size, they are particularly low for the axillary seabream.

For both the 65 and 70D cod ends even the smaller length classes were almost completely retained, and therefore selectivity estimates are not presented for these cod ends, while for the 80D and 65S cod ends (Fig. 8) the L_{50} estimates were 13.9 and 19.6 cm and the selection ranges 7.3 and 3.6 cm respectively (Table 2). Similarly to what was observed for the other species, the use of a square mesh cod end resulted in a significant improvement in the selectivity, as shown by the difference in the respective selection factors (1.8 and 3.6).

In the 80 mm diamond cod end a retention of 60% was observed for undersized fish, while the use of the square mesh resulted in the loss of 42% of all fish above the MLS.

The results of the likelihood ratio test for comparing the selection curves of pairs of mesh size/configuration cod ends fitted for each species are given in Table 3. At the 0.01 level of significance, the only case for which the null hypothesis of no difference between mesh sizes was accepted was for horse mackerel, for which the 65D curve was compared to the 70D, while for all the other pairs of mesh sizes significant differences were always found (p-value < 0.001).

TABLE 3. – Results of the likelihood ratio test comparing pairs of selection curves.

	mesh sizes	significance
Trachurus trachurus	65D/70D	0.041
	70D/80D	<0.001
	80D/65S	<0.001
Merluccius merluccius	70D/80D	<0.001
	80D/65S	<0.001
Pagellus acarne	80D/65S	<0.001

Girth selectivity

The maximum girth/total length relationships estimated for the three species are presented in Table 4 and plotted in Figure 9. For horse mackerel and hake these relationships are very close to those estimated in June 1999 by Fonseca *et al.* (unpublished data) for the west coast of Portugal, while for the axillary seabream it is close to that reported by Santos *et al.* (1995) for the south coast. For all species girth is highly correlated with length, as shown by the high values of the coefficient of determination (see Table 4). For the same length, the maximum

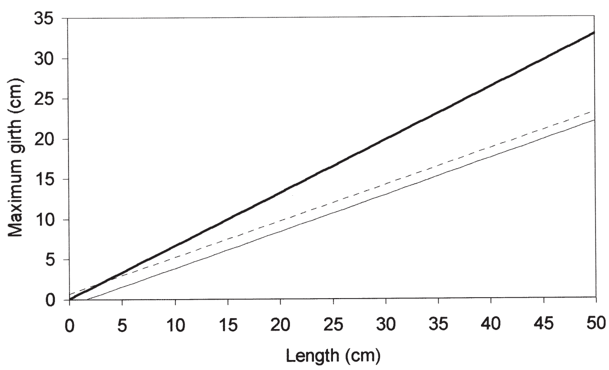

FIG. 9. – Maximum girth-total length relationships for the species in study. Thin line – *Merluccius merluccius* (European hake); dashed line – *Trachurus trach*urus (horse mackerel); thick line – *Pagellus acarne* (axillary seabream).

TABLE 4. – Maximum girth-total length relationships.

	G_{max}	r^2	N	L_t (cm)
Trachurus trachurus	$0.449 * L_t + 0.713$	0.865	1017	14.2 - 33.8
Merluccius merluccius	$0.455 * L_t - 0.732$	0.937	260	16.0 - 75.0
Pagellus acarne	$0.656 * L_t + 0.081$	0.947	534	15.5 - 34.5

girth attains its lowest value for hake and the highest one for the axillary seabream. In addition, a higher increase in girth with length is observed for axillary seabream than for the other two species, which explains the lower SR estimate in the square mesh cod end as a result of a steeper curve.

Considering the high correlation between the two dimensions it was possible to plot the retention proportion versus G_{max}/mesh perimeter (where G_{max} was directly obtained from the retention-at-length plots), without much concern for the fact that with such a procedure the girth variance for a given length is not taken into account (Fig. 10). This type of plot allowed the direct comparison of the retention proportions in all cod ends for the three species by bringing the corresponding maximum girths to the same scale.

DISCUSSION

The three species studied are considerably different from the morphological point of view and in size range, and consequently differences are expected in their behaviour towards the fishing gear in general and to the increase in cod end mesh size or change in mesh configuration in particular.

Despite these differences, common general selection patterns can be identified for horse mackerel and hake. Both these species have diamond mesh cod end size selection curves with much steeper slopes than those found for the square mesh cod end, while for the axillary seabream the opposite can be observed. However, common selection patterns do not mean similar selectivity. In fact, there is a large between-species difference in how horse mackerel and hake of the same length use the opportunity of escape offered by an increase in mesh size or a change in mesh configuration. For the same mesh size, the horse mackerel has a consistently higher retention (lower selectivity) than hake of the same length. This difference is particularly striking when the change in mesh configuration is considered. Similar considerations can apply to the retention for axillary seabream when compared to hake.

The explanation for the differences in size selectivity found for the three species in study is not

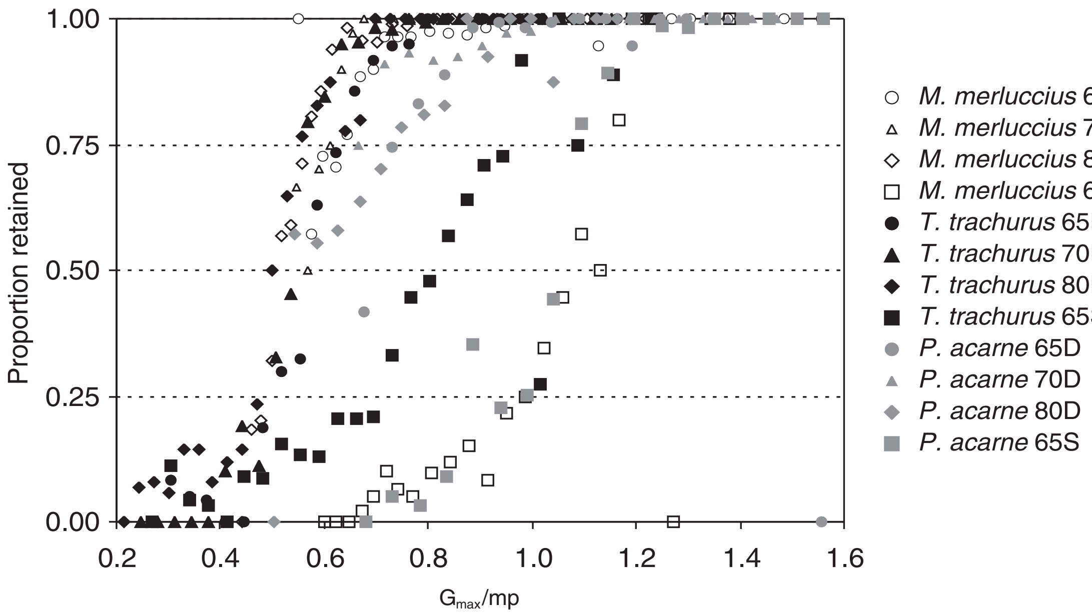

Fig. 10. – Observed retention values for the three species in all cod ends as a function of G_{max}/mesh perimeter.

straightforward. Since the work of Baranov (1948), it is widely assumed that the probability of retention is primarily determined by the relationship between the body shape and mesh opening, although it is usually expressed as a function of body length, which is easier to measure. Considering that in these data length was highly correlated with maximum girth, selectivity-at-length was converted into selectivity-at-girth, looking for a better explanation of the selection patterns observed, since girth gives a better approximation to fish shape.

If the maximum body girth alone was the critical dimension for these species when attempting to escape through the meshes, then it would be expected that fish of the same body girth escape from the same type of cod end (diamond mesh *vs.* square mesh) in a similar way, irrespective of the species. However, this was not observed, since it becomes evident that, for the same value of G_{max}/mp, escapement is lower for hake, increasing slightly for horse mackerel and more significantly for axillary seabream within the diamond mesh cod ends. The retention started at G_{max}/mp values of between 0.3 and 0.4, and attained 100% at G_{max}/mp = 0.7 for horse mackerel and hake, while for axillary seabream no individuals were captured with G_{max}/mp < 0.5, which corresponded to 50% retention, while full retention was achieved for individuals with G_{max}/mp = 1. The first two patterns are somewhat different from that found by Tokai *et al.* (1994) and Liang *et al.* (1999) for diamond cod ends in Japanese waters, in which the retention started at approximately G_{max}/mp of 0.5 and attained its maximum at 1.0 for most of the species studied.

The retention patterns are quite different for the square mesh cod ends, in which horse mackerel retention starts approximately at a G_{max}/mp of 0.4 and attains its maximum around 1.0, for a fish length of 26 cm corresponding to a girth equal to the mesh perimeter, while for hake and axillary seabream all fish with G_{max}/mp < 0.8 escaped and they could escape even at girths higher than the respective mesh perimeters, corresponding to fish lengths larger than 29 and 19 cm respectively.

This suggests that escapement through the cod end meshes has certainly depended to some extent on other factors besides the maximum girth, such as body shape and stiffness, swimming ability and reaction to the gear panels. Hake and axillary seabream can probably fit better to square meshes than horse mackerel due to the fact that their bodies are softer and more compressible, although their body proportions are somewhat different, particularly the hake which is more round-shaped. This feature probably contributes to explaining the higher retention for hake in the diamond cod ends when compared to the other two species. Differences in escape behaviour can also be responsible for part of the variability observed, with Figure 10 suggesting a more active escape behaviour for the axillary seabream. Although this hypothesis is subject to confirmation by direct observation of the catch process, it is in accordance with observations by Tokaç *et al.* (1998), who report heavy meshing of axillary seabream in cod ends that is compatible with active escape behaviour.

For horse mackerel, L_{50} estimates in this study are around the minimum landing size of 15 cm for the 65 and 70D cod ends, and slightly higher for the 80D. An acceptable balance between the retention of undersized individuals and the escape of commercial sized fish was therefore achieved with the smaller mesh sizes.

Both hake and axillary seabream L_{50} estimates for the diamond mesh cod ends are well below the MLS of 27 and 18 cm respectively. The difference is particularly high for hake (about 9/10 cm, for the 70 and 80 mm cod ends), resulting in extremely high retention of undersized fish. For the 65 mm square mesh cod end, the L_{50} (32.4 cm) is considerably higher than the MLS, thus allowing for the escapement of most of the small fishes but resulting in major losses of commercially sized individuals. For the axillary seabream, the L_{50} in the 80D cod end was 13.9 cm, with a high retention of undersized fish, while the use of the square mesh resulted in the loss of an appreciable fraction of fish above the MLS.

Previous results on selectivity for horse mackerel and hake can be found in Campos *et al.* (2003), where these species were captured as a by-catch in crustacean fishing grounds off the Potuguese south coast, at depths from 150 to 700 m, using diamond mesh cod ends of 55, 60 and 70 mm and a square mesh cod end of 55 mm. For horse mackerel, the SF was 3.1 and 3.9 in the 70D and 55S cod ends respectively, corresponding to L_{50} estimates of 21.9 and 21.7 cm. These latter values are similar to those obtained in the present study for the 65 mm square mesh, suggesting that the selectivity for horse mackerel in the finfish trawling is much lower than in the crustacean trawling. A similar situation, although less evident, is found for hake, for which there are previous data only for the 55 and 60 mm diamond mesh cod ends with a SF of 2.9, which is higher than the SFs of 2.5 and 2.3 estimated herein for the 70 and 80D cod ends.

These differences in selectivity for both species are certainly related to a large extent to the fact that distinct fish assemblages are exploited at different depth ranges. The observed differences in the overall catch composition, as well as in length composition, can explain part of the variability within the selectivity results. This is particularly valid for hake, for which differences in length composition were found between experiments, with a higher fraction of smaller fish together with a lower number of larger individuals being captured in the crustacean fishing grounds. For horse mackerel, a similar length distribution was observed in both experiments, although the catches by the finfish trawl were much higher.

Moreover, differences in the trawl design between experiments have most likely affected the cod end geometry and mesh opening in the diamond mesh cod ends, contributing to differences in selectivity. While the cod end perimeter was kept constant (and equal to the perimeter of the trawl rear panel) in order to ensure the same mesh opening within each trawl, it was different between trawls due to differences in trawl design, and differences in the cod end mesh opening, which were not controlled, probably occurred between experiments.

Another hypothesis for the explanation of the differences between experiments can arise from the experimental method itself. Since in the present experiments, unlike those for crustaceans in 1993 (Campos *et al*., 2003), no hoops were used in the cover, the eventual occurrence of a masking effect can be raised. However, as explained in previous section, the cover used was especially designed to prevent its collapse over the cod end. Furthermore, the analysis of selectivity data for the square mesh cod end showed that both hake and axillary seabream escaped through meshes at a girth higher than mesh perimeter, which is not in accordance with a masking effect.

Selectivity data for axillary seabream in Portuguese waters were obtained for the first time during the present experiments. However, Tokaç *et al.* (1998), in selectivity trials in the Aegean Sea using diamond and square mesh cod ends, reported higher selectivity for this species in the diamond cod ends (SF between 2.95 and 3.22, corresponding to L_{50} estimates of 10.61 to 14.16 cm), but at the same time found non-significant differences in selectivity between diamond and square mesh cod ends of the same mesh size. Once more, differences in selectivity between those data and data presented in this work could be related to differences in length composition and range of mesh sizes tested (smaller fish from 10 to 15 cm and cod end mesh sizes from 36 to 44 mm in their experiments), as well as differences between cod end material (polyamide versus polyethylene in the present work) and cod end geometry and mesh opening, particularly with respect to the diamond cod ends.

CONCLUSIONS

In conclusion, the results from the present study, although concerning only three of the many commercial species captured in the finfish trawl *métier*, are a good example of the difficulty in managing multi-species fisheries based simply on mesh size regulations.

It is suggested that, for horse mackerel, the most captured species during these experiments, the current minimum legal mesh size of 65 mm is adequate. On the other hand, data for hake and axillary seabream reveal a worrying scenario, since for both species even the increase of the minimum mesh size to 80 mm, while keeping the diamond configuration, is too small to prevent the capture of an extremely high proportion of fish below the respective MLSs.

The change in mesh configuration to 65 mm square mesh would lead to the escapement of a high percentage of horse mackerel larger than the MLS (about 76%), while for hake and axillary seabream the use of square mesh codends would contribute to a drastic decrease in the catch of undersized fish, but concurrently, there would be an unacceptable loss of fish of commercial size.

The different responses of the three species in relation to the change in mesh size or mesh configuration within this experiment can be associated with differences in morphology, swimming endurance and behaviour, while gear-dependent factors, such as cod end dimensions, twine thickness and construction, as well as operational factors, (trawling speed, catch size, etc.), can help to explain differences between experiments. Still, the relationship between body shape and mesh opening is a key factor, and the consequences of an increase in mesh opening by reducing the number of meshes round the cod end should be evaluated for Portuguese trawl fisheries. It is suggested that although maximum girth is a useful dimension to take into account in selectivity studies, it is still not the most adequate for the description of the selection process, since it does not express the fish shape in an accurate manner. A more realistic representation of the selection process would most probably be achieved by considering, as do Efanov *et al.* (1987) and Liang *et al.* (1999), a coefficient based on the relationship between the height and the width at the region of maximum girth, and its relation to mesh size and mesh opening.

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