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Comparison of diamond- and square-mesh codends in the hake (*Merluccius merluccius* L. 1758) trawl fishery of the Adriatic Sea (central Mediterranean)

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SUMMARY: A traditional codend (40 mm diamond mesh) and an experimental codend (40 mm square mesh) made of 2.6 mm diameter knotless PA netting were tested on a commercial trawl net on a sandy-muddy bottom (~70 m depth) of the Adriatic sea in order to assess the size selectivity of European hake (*Merluccius merluccius*) and the reduction of the discards in a demersal multi-species trawl fishery. The catch was sorted as target species and bycatch and the selectivity with respect to European hake was investigated using the covered codend method. The square-mesh codend allowed a reduction of about 37% of the fraction discarded at sea. The mean catch obtained with the experimental codend was lower than that obtained with the traditional codend (about 14 kg per haul) but the short-term economic losses were low (~12%). The square-mesh codend was also more selective than the traditional codend, giving the juveniles of European hake a good chance of escape: the mean selection length (L_{50}) was 7.60 cm in DM and 12.98 cm in SM. Moreover, the mesh configuration did not affect the gear's performance. Thus, the square-mesh codend could be an easy, inexpensive and useful solution for a more sustainable management of the resources in Adriatic multi-species fishery.

Keywords: discards, square mesh, *Merluccius merluccius*, Adriatic Sea, fishery management, selectivity, bottom trawl.

RESUMEN: Comparación de la malla de rombo y cuadrada en la pesquería de arrastre de la merluza (*Merluccius merluccius* L. 1758) en el mar Adriático (Mediterráneo central). – Se han probado copos de malla tradicional (rombo de 40 mm) y una malla experimental (cuadrada de 40 mm), hechas en fibra de 2.6 mm de diámetro sin nudo en PA, en una red de arrastre comercial sobre fondos fangosos (~ 70 m de profundidad) en el Adriático, con el fin de conocer la talla de selectividad de la merluza (*Merluccius merluccius*) y la reducción de los descartes en una pesquería demersal mutiespecífica. La captura fue separada en especies objetivo y especies acompañantes. Para conocer la selectividad de la merluza se utilizó el método del sobrecopo. El copo de malla cuadrada obtuvo una reducción del 37% de la fracción descartada al mar. La captura media obtenida mediante el copo experimental fue menor que la obtenida con el copo tradicional (14 kg por lance aproximadamente), pero las pérdidas económicas a corto plazo fueron bajas (~ 12%). El copo de malla cuadrada fue también más selectivo que el copo tradicional, dando a los juveniles de merluza mayor probabilidad de escape; la talla de selección (L_{50}) fue de 7.60 cm en malla de rombo y 12.98 cm en malla cuadrada. La configuración de la malla no afectó el funcionamiento del arte. De este modo, el copo de malla cuadrada podría representar una fácil, barata y práctica solución para conseguir una gestión más sostenible de los recursos en la pesquería multiespecífica del Adriático.

Palabras clave: descarte, malla cuadrada, *Merluccius merluccius*, mar Adriático, gestión pesquera, selectividad, arrastre de fondo.

INTRODUCTION

Bycatch has become a priority issue for global fisheries management during the last two decades. Most of the interest has focused on demersal trawl fisheries because conventional otter trawls are generally non-selective fishing gears and therefore catch a wide range of unwanted species and undersized individuals. Bycatch is a particularly important issue in multi-species fisheries such as that of the Adriatic sea (eastern Italy), where several species are found together at the same time and in the same place (Pranovi *et al.*, 2000; Coll *et al.*, 2007; Sanchez *et al.*, 2007). In this area the bottom trawl may simultaneously catch target species, such as whiting (*Merlangius marlangus*), Norway lobster (*Nephrops norvegicus*), hake (*Merluccius merluccius*), squid (*Loligo vulgaris*), short-finned squid (*Illex coindetii*), monkfish (*Lophius* spp.), red mullet (*Mullus barbatus*) and other species. Most of them attain different sizes when fully grown, have different shapes and behaviours and have different Minimum Landing Sizes (MLS). In addition to the target species the codend retains large quantities of non-target organisms (an overview of the quantity of discards in the world's marine fisheries is made by Kelleher, 2005); this affects the habitat at an ecosystem level, influencing the prey-predator relationship and the food web (Kaiser and Spencer, 1994; Jennings and Kaiser, 1998; Ramsay *et al.*, 1998; Coll *et al.*, 2007). Traditionally the Mediterranean bottom trawl codend is made of small diamond meshes (minimum mesh opening of 40 mm stretched until 30/06/08 established by EC REG. 1967/06), resulting in a fishing gear that is not particularly selective. Therefore, the capture of unwanted species and immature and undersized fishes is considerable. Studies carried out in the Mediterranean Sea (Spain, Greece, Turkey and Italy) have shown that the use of a square-mesh codend can reduce the catch of juvenile specimens and also the bycatch and discard of the bottom trawl net (Petrakis and Stergiou, 1997; Stergiou *et al.*, 1997; Tokaç *et al.*, 1998; Bahamon *et al.*, 2006; Guijarro and Massutí, 2006; Ordines *et al.*, 2006; Sardà *et al.*, 2006).

The main aim of this paper is to evaluate the effectiveness of a square-mesh codend for reducing both catches of young hakes and discards. To this end a traditional 40 mm diamond mesh (DM) codend and an experimental 40 mm square-mesh (SM) PA codend were tested in the Adriatic sea multi-species fishery, where the hake is one of the main target species.

MATERIAL AND METHODS

Data collection

Data were collected during demersal trawl trials carried out on board the commercial fishing vessel

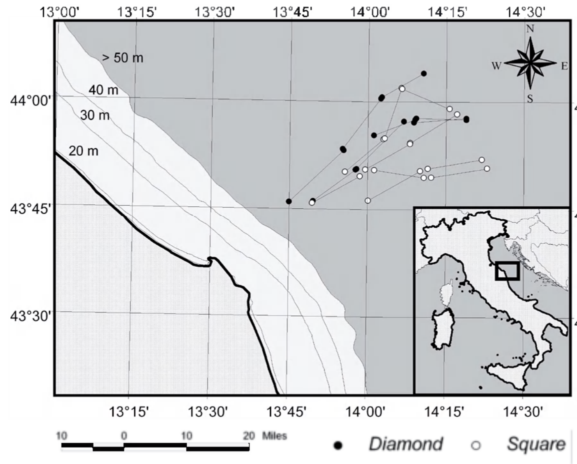

Fig. 1. – Location of the fishing trials.

"Orizzonte" (engine power of 600 hp, overall length (LOA) of 21.5 m and gross tonnage of 82 GT) between 27 February and 20 March, 2006. The trials at sea were done in this period because the hake was one of the main target species for local fishermen and all the size frequencies were represented in the population (Jukic and Arneri, 1984; Arneri and Morales, 2000). Sampling was conducted in the central Adriatic Sea, at approximately 70 m depth on a sandy-muddy bottom (Fig. 1); this area is commonly exploited during winter by local bottom trawlers.

The two tested codends (experimental and traditional) were rigged on the same commercial bottom trawl net for a total of 18 valid hauls. The traditional polyamide (PA) diamond-mesh netting codend (R4227tex, 2.6 mm twine diameter) had 310 meshes on its circumference and its stretched length was about 6 m. The mesh opening (42.8 mm) was measured in wet conditions with the OMEGA mesh gauge (Fonteyne, 2005). The experimental square-mesh shaped codend was obtained from the same PA netting panel used to prepare the traditional codend. The dimensions of the two codends (length and circumference) were the same, with the aim of evaluating just the influence of the different mesh configurations on selectivity rather than that of other parameters such as materials or dimensions.

The tests were performed following the covered codend technique (Wileman *et al.*, 1996) and a cover with a nominal mesh size of 10 mm was used. The cover was supported by circular hoops to hold the cover clear of the codend and minimise the masking effect (Main and Sangster, 1991). The rigging of the net and all the other components of the gear coincided with the common commercial practices used in the central Adriatic bottom trawl fishery.

Gear performances were monitored using acoustic sensors (door spread, horizontal and vertical net openings), electronic strain gauges (to measure the warp strength) and underwater force sensors (to measure net drag) to evaluate the possible influence of different mesh configurations. Tow duration was about 2 h for all the hauls and towing speed ranged between 3.7 and 3.8 knots in accordance with the practices commonly employed in the Adriatic Sea.

Once the net was hauled onboard, the codend and cover catch were analysed separately. The catch was sorted into the categories target species (European hake *M. merluccius*, monkfish *Lophius* spp, red mullet *M. barbatus* and cuttlefish *Sepia officinalis*) and bycatch (discarded catch plus incidental catch). An *Independent sample t-test* was done to evidence statistical differences between the different categories for each main commercial species and for the total catch. The statistical significance of the results (p-level) was represented by an asterisk with $p<0.05$ and two asterisks with $p<0.01$.

The species belonging to each category were classified at the minimum level and their abundance was standardised as mean catch in weight (grams) and number per hour of tow.

The *proportion retained* of the principal target species in weight and number was also computed; this index is the ratio between the weight (and number) of individuals of a certain species caught in the codend and the weight (and number) of the individuals of the same species potentially present in the swept area (which is the sum of the codend and cover catch). Moreover, for the main commercial species the *percentage of discard* in both weight and number was computed: the *percentage of discard* is the ratio between the weight (and number) of the individuals of a species caught in the codend and discarded and the total weight of the same species in the codend. Also in this case an *Independent sample t-test* was done to evidence statistical differences.

The *Commercial Catch Efficiency*,

$$CCE[\%] = \frac{\sum C}{\sum C + \sum D},$$

where C is the commercial part of the catch and D is the discard, was also evaluated. The composition in weight of the retained species of two codends was finally investigated using non-metric multidimensional scaling (MDS; Brodgar, 2000) based on Bray-Curtis similarity matrices of square-root transformed data.

Selectivity data analysis

The total length of European hake was taken to the nearest 0.5 cm to calculate the selection parameters and to evaluate the influence of different mesh configurations on individuals below the MLS (20 cm for EU Regulation 1967/06).

For each haul, the retention probability $r(l)$ in the codend, which is the probability of a fish of length l being retained once it has entered the codend (Wileman *et al.*, 1996) was modelled by means of the logistic selectivity curve and $\hat{\upsilon} = (\upsilon_1, \upsilon_2)^T$ was the vector of the selectivity parameters.

The effect of sub-sampling in individual hauls was corrected according to Millar (1994). Fryer's model (1991) was used to investigate the between-haul variation of the selectivity parameters υ_1 and υ_2 by mesh configuration, allowing the estimation of mean curves for the two different codend meshes.

Finally, the selectivity data were modelled according to Fryer (1991) by estimating the individual contribution of some explanatory variables on the selectivity parameters. All possible linear expressions of the selectivity parameters as functions of the explanatory mesh configuration (m_i) and codend catch size (c_i) were tested. Catch size was adjusted as a continuous variable, while mesh configuration was adjusted as a two-level factor. The choice of the model best describing the data was based on the lowest value for Akaike's Information Criterion (AIC; Akaike, 1973; Fryer and Shepherd, 1996), defined as $AIC = -2 \cdot \log likelihood + 2 \cdot np$, where np is the number of parameters. The haul-by-haul maximum likelihood estimation of the selectivity parameters for individual hauls was carried out using the software CC2000 (ConStat, 1995). Models, including between-haul variation, were estimated using the software ECModeller (ConStat, 1995) which implements the REML *(REsidual Maximum Likelihood)* approach proposed by Fryer (1991).

RESULTS

Gear performance

The use of two different mesh configurations in the codend did not affect the behaviour of the bottom trawl net. No significant differences were detected in the total drag and net drag. Moreover, the power needed to tow the net and the fuel consumption of the

TABLE 1. – Gear performances recorded during trials at sea. DM: diamond mesh; SM: square mesh; P: power [kW]; FC: fuel consumption [kg/h]; TD: total drag; ND: net drag [kgf]; HO: horizontal opening [m]; VO: vertical opening [m]; DO: doors opening [m]. Means ± standard errors are reported.

Type of codend	P	FC	TD	ND	HO	VO	DO
DM	154.1±12.7	47.9±2.6	2611.2±168.3	1777.5±138.9	17.7±1.8	1.3±0.0	90.4±9.1
SM	164.4±34.1	50.4±6.5	2684.5±254.8	1782.1±215.5	17.7±1.5	1.3±0.1	89.6±7.7

TABLE 2. – Mean catch in weight (grams) and number per hour of tow of the main target species divided by categories commercial (CM), discard (D) and cover (CV). DM: diamond mesh; SM: square mesh. W: weight; N: number. * = 0.01<p<0.05; ** = p<0.01.

Taxa		DM						SM					
		Codend				Cover		Codend				Cover	
		CM		D				CM		D			
		W	N	W	N	W	N	W	N	W	N	W	N
Little squid	*(Alloteuthis media)*	62	7.6	36	6.4	6	2.4	26	2.8	20	3.0	1166**	22.1**
Scaldfish	*(Arnoglossus laterna)*	17	2.0	236	51.2	40	17.3	8	0.7	82**	17.2**	150**	56.6**
Tub gurnard	*(Chelidonichthys lucernus)*	692	5.1	10	0.2	-	-	238**	1.5**	11	0.1	-	-
Atlantic spotted flounder	*(Citharus linguatula)*	15	1.1	42	6.1	5	0.6	11**	0.6	41	4.1	16	3.1*
Curled octopus	*(Eledone* spp)	1801	6.4	3	0.3	6	0.5	1331	4.8	2	0.1	14	0.6
Shortfin Squid	*(Illex coindetii)*	1055	7.1	25	1.4	1	0.1	727	8.9	47	3.0	64*	5.2*
European Squid	*(Loligo vulgaris)*	608	7.8	-	-	-	-	212*	2.0*	-	-	-	-
Monkfish	*(Lophius* spp)	1050	3.6	-	-	-	-	1338	3.7	-	-	-	-
European hake	*(Merluccius merluccius)*	17100	153.6	235	15.8	27	4.7	12258	92.2*	184	10.6	173**	23.5**
Red mullet	*(Mullus barbatus)*	2715	78.5	50	3.3	38	2.4	1997	45.1	37	1.9	240*	14.5*
Norway lobster	*(Nephrops norvegicus)*	257	2.3	-	-	-	-	723	15.4	3	0.3	3	0.6*
Pink shrimp	*(Parapenaeus longirostris)*	601	92.1	194	50.9	16	6.1	568	87.0	84	20.0	96	20.5
Atlantic mackerel	*(Scomber scombrus)*	974	10.6	-	-	-	-	930	10.0	19	0.3	-	-
Cuttlefish	*(Sepia officinalis)*	4998	13.2	3	1.0	-	-	3747	9.9	-	-	-	-
Poor cod	*(Trisopterus m. capelanus)*	786	28.0	174	16.0	20	1.6	329**	10.1**	130	9.2	220**	15.3**
John Dory	*(Zeus faber)*	125	0.1	-	-	0	0.1	161	0.4	-	-	-	-
Other species		498	2.9	16747	475.2	590	131.4	1981	4.5	9817**	272.9*	2979**	472.7**
Total categories		33353	422.0	17754	627.9	750	167.1	26584	299.5	10477**	342.8	4070**	634.6
Total catch		51107						37061**					

boat were very similar with the two tested codends mounted on the same net (Table 1). The mean values of the geometrical parameters monitored with the acoustic sensors were: horizontal opening 18 m, vertical opening 1.3 m and door spread 90 m. This means that at a mean speed of 4 knots the water flow inside the net was about 47.3 m^3/sec.

Catches

The mean catches for each category (commercial, discard and cover catch) obtained with the two codends are shown in Table 2. The traditional diamond-mesh codend catch was generally higher than that of the experimental codend, as observed from the mean catch of the target species in both weight and number (Table 2). The traditional codend caught an average of 14 kg/h more than the experimental one and the statistical analysis showed a significant difference (p=0.031). Nevertheless, taking into account the different catch categories, it can be observed that the difference in total catch was mainly due to the discarded portion of the traditional codend catch, which was significantly higher (p=0.002) than that observed for the square-mesh codend. The commercial fraction was also more abundant in the traditional codend catch but in this case the difference was not statistically significant (p=0.178); the commercial catch of both codends was dominated, in terms of weight, by the two main target species, the hake and the cuttlefish (Table 2). On the other hand, the escapees retained by the cover were more abundant with the square-mesh codend (4.07 kg/h against 0.75 kg/h), and this difference was highly significant (p<0.01).

Figure 2 shows the percentage of the different catch categories with respect to total catch: the mesh configuration (diamond or square) does not seem to influence the commercial fraction of the catch in weight (65% in both codends). On the other hand, very large differences were detected for the discard (34% with the diamond-mesh codend and 25% with

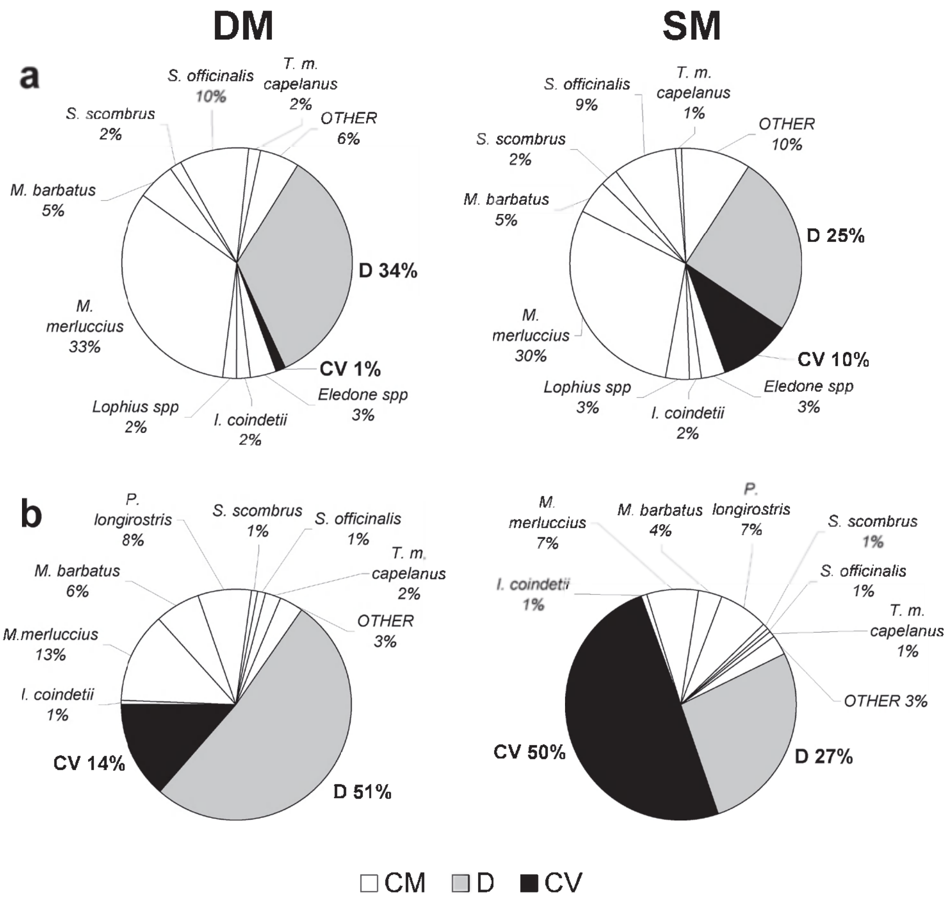

FIG. 2. – Percentage in weight (a) and number (b) of the different categories to the total catch. The main commercial species are reported. CM: commercial; D: discard; CV: cover. DM: diamond mesh; SM: square mesh.

the square-mesh codend) and for the cover catch (1 and 10% respectively). The corresponding graphs in number (Fig. 2) confirm and emphasise these differences: in particular the cover represented 14 and 50% of the total for the traditional and the experimental codend, respectively. The discrepancy between biomass and abundance can be explained by the fact that the individuals that escaped from the experimental codend were either juveniles or very small.

The index computed to evaluate the *proportion retained* by the traditional codend was very high in both weight (99%) and number (86%, Table 3): most of the individuals living in the swept areas (considering practically null the escapees under the foot rope in the Italian bottom trawl) had a really low possibility of escape. The experimental codend showed a high *proportion retained* in weight (90%) but not in number (50%); this means that the square-mesh codend was effective on the catch of large individuals and gave the smallest individuals a good chance of escape.

The square-mesh codend did not imply a high short-term economic loss; in fact, the catches of the main commercial species of fishes (hake, monkfish), crustaceans (deep water rose shrimp, Norway lobster, penaeid shrimp), and cephalopods (cuttlefish; Table 3) obtained with two codends were always very high, in many cases reaching 100% (all the individuals entering the codend were caught). The traditional codend was more effective at retaining the following species: European common squid (*Alloteuthis media* L. 1758), scaldfish (*Arnoglossus laterna* Walbaum, 1792), Atlantic spotted flounder (*Citharus linguatula* L. 1758) and poor cod (*Trisopterus minutus capelanus* L. 1758). These species are marketable, but their economic value is generally low. The mean gain obtained during the sea trials was €512 and €449 per haul for the diamond- and the square-mesh codends, respectively, with a short-term loss of about 12%. The difference was mainly due to the larger number of hake and red mullet retained in the diamond-mesh codend; however, other species with a low commercial value (*T. minutus capelanus*, *Chelidonichthys lu-*

TABLE 3. – *Proportion retained* in weight (PR_W), in number (PR_N) and *percentage of discard* in weight (FD_W) and number (FD_N) of diamond (DM) and square (SM) mesh codends. All the values are represented as percentages. * = 0.01<p<0.05; ** = p<0.01.

TAXA MAIN COMMERCIAL SPECIES		DM PR_W	PR_N	FD_W	FD_N	SM PR_W	PR_N	FD_W	FD_N
Little squid	*(Alloteuthis media)*	94	85	37	46	28**	21**	43	52
Scaldfish	*(Arnoglossus laterna)*	86	75	93	96	37**	24**	92	96
Tub gurnard	*(Chelidonichthys lucernus)*	100	100	1	4	100	100	4	7
Atlantic spotted flounder	*(Citharus linguatula)*	91	93	73	85	77**	60*	79	88
Curled octopus	*(Eledone* spp)	100	94	0	5	99	90	0	3
Shortfin Squid	*(Illex coindetii)*	100	99	2	17	92	70*	6	25
European Squid	*(Loligo vulgaris)*	100	100	0	0	100	100	0	0
Monkfish	*(Lophius* spp*)*	100	100	0	0	100	100	0	0
European hake	*(Merluccius merluccius)*	100	97	1	9	98**	81**	1	10
Red mullet	*(Mullus barbatus)*	99	97	2	4	89*	76**	2	4
Norway lobster	*(Nephrops norvegicus)*	100	100	0	0	100	96	0	2
Pink shrimp	*(Parapenaeus longirostris)*	98	96	24	36	87*	84	13	19
Atlantic mackerel	*(Scomber scombrus)*	100	100	0	0	100	100	2	3
Cuttlefish	*(Sepia officinalis)*	100	100	0	7	100	100	0	0
Poor cod	*(Trisopterus m. capelanus)*	98	96	18	36	68**	56**	28	48
John Dory	*(Zeus faber)*	100	71	0	0	100	100	0	0
OTHER SPECIES		97	78	97	99	80**	37**	83	98
TOTAL		99	86	35	60	90**	50**	28	53

cernus and *Mullus barbatus*) showed highly significant differences in the *proportion retained,* affecting the final economic gain (Table 3).

The parameter *percentage of discard* (Table 3) is related to the species caught but discarded for different reasons (because they are damaged or undersized, or because the individuals were ignored during the sorting on deck). The index, in both number and weight, was always very low for the main commercial species and close to 100% for species of very limited commercial interest; in fact no statistical differences were detected for the main commercial species.

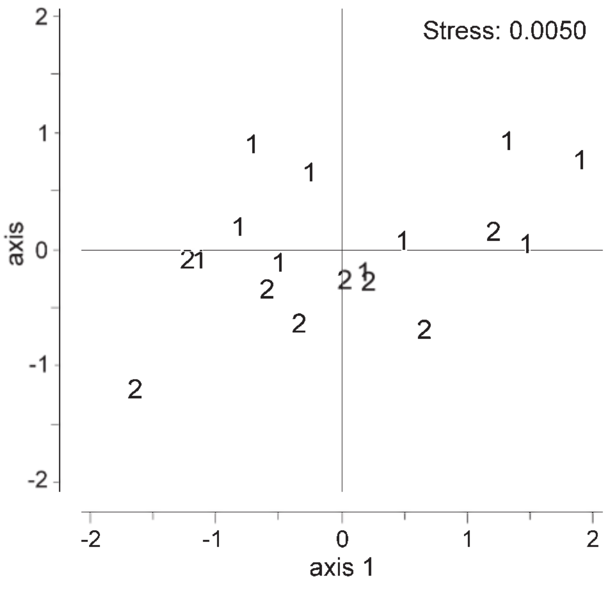

FIG. 3. – MDS plot representing the species retained by square (1) and diamond (2) mesh codends.

The values of the parameter *CCE* [%] (*Commercial Catch Efficiency*) computed for the two codends were very similar and the difference was not statistically significant (p=0.704). The traditional codend exploited 84.2% of the total catch while the experimental one exploited 85.4%.

The MDS analysis of the retained species revealed a rather distinct separation between square–mesh (1) and diamond-mesh (2) codends (Fig. 3) and confirmed the previous results.

Species abundance

In the sampling area a total of 76 and 74 species were obtained with the traditional and experimental codends, respectively, confirming the homogeneity of the explored area.

The mean numbers of species per haul obtained with the two codends for the three categories (commercial, discard and total) were not statistically different. A mean of 45.4 and 44.8 taxa per haul were caught with traditional and experimental codends, respectively (p=0.806). The mean number of commercial species caught with the square-meshed codend (16.1) was very similar to that observed with traditional codend (15.8). On the other hand, high significant differences (p<0.01) were recorded for the portion of the catch retained in the covers. A mean of 34.9 species per haul were able to escape from the experimental codend against 25.5 species per haul from the traditional codend.

TABLE 4. – Direct estimate of the selectivity parameters of *M. merluccius* for the traditional (DM) and experimental (SM) codends. Mean values and respective confidence intervals (CI) of retention length at 50% (L_{50}) and selection range (SR) are reported. The best fitting *alpha* parameters and standard deviation (in brackets) derived from the model are also indicated. υ_1 and υ_2: maximum likelihood estimators of the selectivity parameters; *{R}*: variance matrix measuring the within-haul variation; *{D}*: measures the between-haul variation in the parameters {υ}. α is the vector that determines the direction and magnitude of the influence of the explanatory variables on selectivity parameters (L_{50} and SR). * = 0.01<p<0.05; ** = p<0.01

		L_{50} Mean	L_{50} CI	SR Mean	SR CI	υ_{i1}	υ_{i2}	{R} R_{i11}	{R} R_{i12}	{R} R_{i22}	dof	p-val	t-Value
DM	Estimated parameters	7.70	(5.62, 8.83)	3.66	(2.6, 6.71)	-4.619	0.600	0.2550	-0.0241	0.0025			
	Mean curve Fryer	7. 60		4.01		-4.168	0.548	0.2387	-0.6447	1.7450	9	0.000**	
	{D}							0.2273	-0.2154	0.4558			
SM	Estimated parameters	12.74	(9.06, 15.98)	4.73	(1.87, 6.69)	-5.917	0.464	0.0976	-0.0065	0.0005			
	Mean curve Fryer	12.98		3.65		-7.809	0.602	2.8843	-2.3544	1.9657	15	0.000**	
	{D}							0.3365	-0.2620	0.2513			
Alpha parameters	α_1(L_{50}, Constant)	7.45	(0.575)	0.57							28	0.000**	12.958
	α_2 (SR, Constant)	3.77	(0.394)	0.39							28	0.000**	9.555
	α_3 (L_{50}, Mesh)	5.49	(0.495)	0.49							28	0.000**	11.102

Selectivity of European hake

The sizes of the hakes caught with the traditional codend ranged between 6 and 38 cm (modal class 24 cm), while those caught with the experimental codend had the same modal class (24 cm) but a wider range (5-47 cm). The mean number of individuals per haul caught with diamond- and square-mesh codends was 297 and 179, respectively. Moreover, the size of the individuals retained in the cover of the experimental codend ranged between 4 and 19.5 cm. This is very important because the minimum landing size for the European hake is established as 20 cm by EU Regulation 1967/06, so all the individuals escaping from the codend were below the MLS. The selection ratio (the ratio between the number of individuals in the cover and the total number) computed for the diamond-mesh codend was 3%, showing a very low possibility of escape for the individuals living in the swept area. On the other hand, the selection ratio

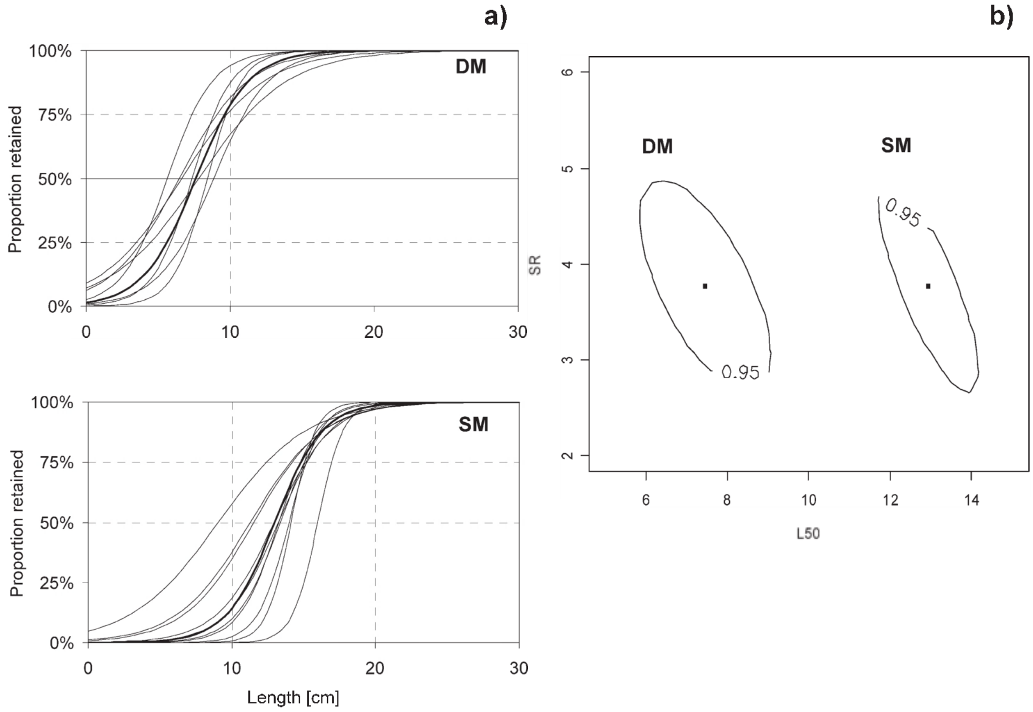

FIG. 4. – *Merluccius merluccius* (European hake). a) Selectivity curves for individual hauls (thin lines) and mean curve (thick line) according to Fryer (1991). b) Confidence regions (95%) for expected mean REML values of Selection Range (*pred.SR*) plotted against the 50% retention length (*pred.*L_{50}) calculated by the best model, based on the lowest value of Akaike's Information criterion (AIC). DM: diamond mesh; SM: square mesh.

of the square-mesh codend reached 21%, allowing a good chance of escape for most small individuals. Individual hauls and mean selectivity curves for both codends are explained graphically in Figure 4. It can be noticed that the square-mesh codend positively affects the L_{50}. The direct estimate of the selectivity parameters computed during covered codend trials and the mean curve obtained using the methodology proposed by Fryer are shown in Table 4.

The expected L_{50}, calculated using Fryer's model (Table 4), significantly declined from 12.98 ± 0.58 cm to 7.60 ± 0.48 cm (p<0.01) when the DM codend replaced the SM codend, while the selection range (SR) increased from 3.65 ± 0.50 cm to 4.01 ± 0.68 cm but the difference in this case was not statistically significant (p=0.433).

The *alpha* parameters estimated following Fryer's model (1991), along with their standard deviations and *t-values*, which give an idea of the relative importance of the variables in the models, are given in Table 4. The model which best describes the data, based on the lowest value of Akaike's Information Criterion-AIC (Fryer and Shepherd, 1996), was:

$$E\begin{pmatrix} L_{50} \\ SR \end{pmatrix} = \begin{pmatrix} \alpha_1 + \alpha_3 m_i \\ \\ \alpha_2 \end{pmatrix}$$

Of the two external variables, mesh configuration (m_i) was found to play a constantly high significant role (p<0.001) in between-haul variation. In particular the use of the square-mesh codend seems to positively affect the selectivity parameter L_{50} (α_3=5.490). The *SR* seems not to depend on the two variables. To calculate the expected L_{50} and *SR* and to compare the two codends, a mean catch of 43.4 kg (the mean of codend catch) and a towing time of 120 minutes were used in the model. Predicted values computed on the basis of the model showed an increase in L_{50} from 7.45 (DM) to 12.94 cm (SM), while no evident differences were detected for the SR.

DISCUSSION

The present study provides information on the performances of 40 mm diamond-mesh and 40 mm square-mesh codends in Adriatic sea waters. It highlights the problem regarding the very poor selection of the traditional diamond mesh used by bottom trawlers in multi-species fisheries of the Mediterranean sea, as has already been shown in recent studies (Bahamon *et al.*, 2006; Guijarro and Massutí, 2006; Ordines *et al.*, 2006; Sardà *et al.*, 2006).

The different mesh configurations did not seem to influence the gear performance and the general behaviour of the net and, consequently, the net drag which influences some very important economic parameters such as fuel consumption.

The study showed that square meshes allowed a reduction of the bycatch. In particular the experimental codend allowed a reduction of about 37% in weight of the fraction discarded at sea. Moreover, the square-mesh codend allowed a larger number of specimens to escape: about 50% of the individuals encountered in the swept area escaped from the codend, while the traditional codend retained almost all the specimens, giving the juveniles a very low chance of escape. Nevertheless, the different mesh configurations did not influence the commercial fraction of the catch, which represented the same percentage in weight in both codends. The *proportion retained* confirmed that both codends had a very high effectiveness on the catch of the main commercial species (hake, monkfish, cuttlefish, Norway lobster, and deep-water pink shrimp). In the western Mediterranean very similar results were recently obtained by Guijarro and Massutí (2006): in fact they found no significant difference in the catch composition and yield of the diamond- and square-mesh codend, while the discard was more abundant in the traditional codend. On the basis of market prices it was possible to estimate the short-term economic losses of experimental codend at 12%, and this loss was mainly because of the escape of young European hakes from the square-mesh codend. Other authors (Bahamon *et al.*, 2006) found that the economic losses of fishery on the slope (~400m) were less than on the continental shelf (~400 m) but in the central Adriatic sea it was impossible to evaluate the influence of different fishing grounds. In the present study other economic losses concerned some species with a scant commercial value (*C. lucernu*s, *M. barbatu*s, *T. minutus capelanus*). Ordines *et al.* (2006) obtained similar results in the western Mediterranean sea; they found that the square-mesh codend would not lead to a reduction in the yield of either the main target species or the remaining commercial categories, except for *Spicara smaris*.

The square-mesh codend described in the paper also allowed a larger range of species to escape, as observed in other studies (Stergiou *et al.*, 1997;

Campos *et al.*, 2003; Hendrickson, 2005; Broadhurst *et al.*, 2006).

The present study, as already explained, showed that the diamond-mesh codend retains almost all the encountered biomass; this is a great problem in some areas of the Adriatic sea characterised, for example, by the facies "*Turritella*" or "*Anadara*". Bottom trawlers often catch large quantities of *Turritella turritella*, a small Gastropod, or *Anadara demiri,* an allochthonous bivalve, both of which are very common and abundant in certain areas. In these cases, catching of *T. turritella* and *A. demiri* causes serious problems: it blocks the codend meshes, negatively affecting the selectivity process, causing skin damage to the species caught in the codend, and increasing the power and fuel needed to tow the net (the water cannot easily flow out of the codend).

The analysis of selectivity showed that the experimental codend positively affected L_{50} of *M. merluccius*; the square-mesh codend increased the size of escapement, as observed in many other studies carried out recently in the Mediterranean sea (Petrakis and Stergiou, 1997; Tokaç *et al.*, 1998; Bahamon *et al.*, 2006; Guijarro and Massutí, 2006; Ordines *et al.*, 2006; Sardà *et al.*, 2006). The authors have found some differences in the L_{50} of *M. merluccius* but several factors such as material, twine diameter, presence of knots, mesh dimension, number of meshes at the circumference, towing duration and towing speed could justify these differences. For example, Bahamon *et al.* (2006) obtained for the square-mesh codend an L_{50} lower than that computed by Sardà *et al.* (2006), but Bahamon *et al.* performed their tests with a 5 mm diameter knotted PE-netting in the codend, while Sardà *et al.* used the same material without knots and with a different twine diameter. Campos *et al.* (2003) tested codend with a mesh opening from 55 to 70 mm (DM) while Petrakis and Stergiou (1997) carried out the trials with a mesh opening of 14 and 20 mm. Guijarro and Massutí (2006) obtained very high values of L_{50} with the diamond mesh but they carried out their tests at sea at lower a speed (2.5 knots) than that of the other studies. Thus, direct comparison of the L_{50} obtained from different studies should be made with caution.

From the selectivity analysis it was noted that the square-mesh codend seems not to protect the individuals of hake below the MLS (20 cm), but the curves are strongly shifted to the right compared with those obtained with the traditional codend. This means that the catch of the experimental codend is focused on a holder portion of the hake's population, giving the juveniles a good chance of escape.

In conclusion, the traditional codend leads to a large quantity of bycatch and juveniles, causing serious problems for the management of fisheries and resources. Therefore, the diamond-mesh codend should be replaced with more acceptable and responsible solutions to guarantee the right balance between fisheries resources and the level of permitted fishing. In according with Sardà *et al.*, 2006 the results described in this paper allowed us to conclude that the square-mesh codend is not a definitive solution to the problem of low selection properties of the traditional bottom trawl net, but it could be a reasonable, simple and inexpensive solution for a more sustainable management of the resources in the Adriatic, at least in certain multi-species fishing grounds and seasons.

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REFERENCES

Akaike, H. – 1973. Information theory and an extension of the maximum likelihood principle. In: B.N. Petrov and F. Csaki, (eds.), *Second International Symposium on Information Theory*, pp. 267-281. Budapest, Akademia Kaido.

Arneri, E. and B. Morales-Nin. – 2000. Aspects of the early life history of European hake from the central Adriatic. *J. Fish. Biol.,* 53: 1155-1168.

Bahamon, N., F. Sardà and P. Suuronen. – 2006. Improvement of trawl selectivity in the NW Mediterranean demersal fishery by using a 40 mm square mesh codend. *Fish. Res.,* 81: 15-25.

Broadhurst, M.K., R.B. Millar, M.E.L. Wooden and W.G. Macbeth. – 2006. Optimising codend configuration in a multi-species demersal trawl fishery. *Fish. Manage. Ecol.,* 13: 81-92.

Brodgar. – 2000. *Software package for Multivariate Analysis and Multivariate Time Series Analysis.*

Campos, A., P. Fonseca and K. Erzini. – 2003. Size selectivity of diamond and square mesh codends for four by-catch species captured in the crustacean fishery off the Portuguese south coast. *Fish. Res.,* 60: 79-97.

Coll, M., A. Santojanni, I. Palomera, S. Tudela and E. Arneri. – 2007. An ecological model of the Northern and Central Adriatic Sea: analysis of ecosystem structure and fishing impacts. *J. Mar. Sci.*, 67: 119-154.

ConStat. – 1995. *CC selectivity program.* Gronspaettevej 10, DK-9800 Hjorring, Denmark.

EC-1967. – 2006. Council Regulation concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea. *Off. J. of the European Union*. L409, 75 pp.

Fonteyne, R. – 2005. Protocol for the Use of an Objective Mesh Gauge for Scientific Purposes. *ICES Coop.Res Rep.* 1-14.
Fryer, R.J. – 1991. A model of between-haul variation in selectivity. *ICES J. Mar. Sci.*, 48: 281-290.
Fryer, R.J. and J.G. Shepherd. – 1996. Models of codend size selection. *J. North. Atl. Fish. Sci.*, 19: 51-58.
Guijarro, B. and E. Massutí. – 2006. Selectivity of diamond- and square-mesh codends in the deepwater crustacean trawl fishery off the Balearic Islands (western Mediterranean). *ICES J. Mar. Sci.*, 63: 52-67.
Hendrickson, L. – 2005. Effectiveness of a square-mesh escape panel in reducing finfish bycatch in a small-mesh bottom trawl used in the longfin inshore squid (*Loligo pealeii*) fishery. *U.S. Dep. Commer., Northeast Fish. Sci. Cent. Ref. Doc.* 05-05.
Jennings, S. and M.J. Kaiser. – 1998. The effects of fishing on marine ecosystems. *Advances in Marine Biology,* 34: 201-351.
Jukic, S. and E. Arneri. – 1984. Distribution of hake (*Merluccius merluccius*, L.) striped mullet (*Mullus barbatus*, L.) and pandora (*Pagellus erythrinus*, L.) in the Adriatic Sea. *FAO Fish. Rep.*, 290: 85-91.
Kaiser, M.J. and B.E. Spencer. – 1994. Fish scavenging behaviour in recently trawled areas. *Mar. Ecol. Prog. Ser.,* 112: 41-49.
Kelleher, K. – 2005. Discards in the world's marine fisheries. An update. *FAO Fish. Tech. Pap.* No. 470. Rome, FAO.
Main, J. and G.I. Sangster. – 1991. A different approach to covered codend selection experiments. *Scot. Fish. Work. Paper* No 4/91.
Millar, R.B. – 1994. Sampling from trawl gears used in size selectivity experiments. *ICES J. Mar. Sci.*, 51: 293-298.
Ordines, F., E. Massutí, B. Guijarro and R. Mas. – 2006. Diamond vs. square mesh codend in a multi-species trawl fishery of the western Mediterranean: effects on catch composition, yield, size selectivity and discards. *Aquat. Living Resour.*, 19: 329-338.
Petrakis, G. and K. Stergiou. – 1997. Size selectivity of diamond and square mesh codends for four commercial Mediterranean fish species. *ICES J. Mar. Sci.*, 54: 13-23.
Pranovi, F., S. Raicevich, G. Franceschini, M.G. Farrace and O. Giovanardi. – 2000. Rapido trawling in the northern Adriatic Sea: effects on benthic communities in an experimental area. *ICES J. Mar. Sci.*, 57: 517-524.
Ramsay, K., M.J. Kaiser and R.N. Hughes. – 1998. Responses of benthic scavengers to fishing disturbance by towed gears in different habitats. *J. Exp. Mar. Biol. Ecol.,* 224: 73-89.
Sánchez, P., P. Sartor, L. Recasens, A. Ligas, J. Martin, S. De Ranieri and M. Demestre. – 2007. Trawl catch composition during different fishing intensity periods in two Mediterranean demersal fishing grounds. *Sci. Mar.,* 71(4): 765-773.
Sardà, F., N. Bahamon, B. Molí and F. Sardà-Palomera. – 2006. The use of a square mesh codend and sorting grids to reduce catches of young fish and improve sustainability in a multi-species bottom trawl fishery in the Mediterranean. *Sci. Mar.*, 70(3): 347-353.
Stergiou, K.I., C.Y. Politou, E.D. Christou and G. Petrakis. – 1997. Selectivity experiments in the NE Mediterranean: the effect of trawl codend mesh size on species diversity and discards. *ICES J. Mar. Sci.*, 54: 774-786.
Tokaç, A., A. Lök, Z. Tosunŏglu, C. Metin and R.S.T. Ferro. – 1998. Cod-end selectivities of a modified bottom trawl for three fish species in the Aegean Sea. *Fish. Res.*, 39: 17-31.
Wileman, D.A, R.S.T. Ferro, R. Fonteyne and R.B. Millar. – 1996. Manual of methods of measuring the selectivity of towed fishing gears. *ICES Coop. Res. Rep.* 215, Copenhagen, 1-126.

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