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ScienceDirect
Fisheries Research 81 (2006) 15–25
FISHERIES RESEARCH
www.elsevier.com/locate/fishres

Improvement of trawl selectivity in the NW Mediterranean demersal fishery by using a 40 mm square mesh codend

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Received 26 January 2006; received in revised form 12 May 2006; accepted 26 May 2006

Abstract

Commercial fishing trials with 40 mm diamond (DM40) and square (SM40) mesh codends made of 5 mm diameter knotted PE-netting were conducted in July 2005 on the continental shelf (∼100 m) and upper slope (∼400 m) of the Catalan Sea (NW Mediterranean) to assess the size selectivity of European hake (*Merluccius merluccius*), Norway lobster (*Nephrops norvegicus*), poor cod (*Trisopterus minutus*) and greater forkbeard (*Phycis blennoides*) in the demersal multi-species trawl fishery. In total, 28 tows were done using the standard covered codend method. For all four species, the SM40 showed a significantly higher mean selection length (L_{50}) than the DM40. For hake the L_{50} was 16.0 cm in SM40 and 10.1 cm in DM40; the corresponding figures were 13.0 cm versus 9.2 cm for poor cod and 14.9 cm versus 9.8 cm for greater forkbeard. For Norway lobster, DM40 did not show any size-selectivity whereas SM40 produced a L_{50} of 22 mm. The selection range (SR) between DM40 and SM40 was not significantly ($p > 0.05$) different for any of the three fish species. Our trials indicate that substantial improvement in size-selectivity for these commercially important species is achieved by switching from the conventional 40 mm diamond mesh codend to a 40 mm square mesh codend. Our analysis also suggests that by using a 40 mm square mesh codend the short-term economic losses of commercial species, compared to the losses of 40 mm diamond mesh codend, will be low in the slope fishery (less than ∼5% of the total catch value), whereas in the continental shelf losses could be up to ∼30% of the total catch value.

Keywords: Codend selectivity; Multi-species trawl fishery; Diamond mesh; Square mesh; European hake; Norway lobster

1. Introduction

The overall fishing effort of trawling fleets on the Mediterranean Iberian coast has increased during the last two decades (Irazola et al., 1996; Bas, 2002; Bas et al., 2003; Lleonart and Maynou, 2003). Structural and Cohesion Funds from the European Commission have promoted the construction of new and more powerful trawlers; thereby the pressure on the overexploited marine resources has increased substantially both on the shelf and in deeper waters. Species showing signs of overexploitation include European hake (*Merluccius merluccius*), Norway lobster (*Norway lobster*) (Recasens et al., 1998; Sardà, 1998; Lombarte et al., 2000; Lleonart and Maynou, 2003) and red shrimp (*Aristeus antennatus*) (Demestre and Lleonart, 1993; Demestre and Martin, 1993).

The current 40 mm diamond mesh codend enforced in the NW Mediterranean demersal trawl fishery produces catches with large amounts (one third of the total captured biomass) of discards composed of commercially important species below the legal minimum landing size (MLS) and of non-commercial species (Sánchez et al., 2004; Martín et al., 1999). This suggests that the selectivity of the present legislated codend is not adequate. To improve the overall exploitation pattern in the demersal trawl fishery, the General Fisheries Commission for the Mediterranean (GFCM) and the European Commission have suggested a general introduction of a 40 mm square mesh codend to replace the present 40 mm diamond mesh codend in the Mediterranean fishery (GFMC, 2001; Doc 11853/05 PECHE 165). Relatively little scientific work, however, has been done to assess the

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doi:10.1016/j.fishres.2006.05.020

selectivity of a 40 mm square mesh codend in the highly variable multi-species conditions prevailing in the Mediterranean trawl fishery (Stewart, 2002). Moreover, most selectivity studies performed so far in the Mediterranean apply to codends made of polyamide (PA) netting (e.g., Sardà et al., 1993; Stergiou et al., 1997a,b; Petrakis and Stergiou, 1997; Tokaç et al., 1998; Guijarro and Massuti, 2006). Tokaç et al. (2004) compared the selectivity of PA and polyethylene (PE) codends and showed that in general, the PA codends produce much higher mean selection length that the corresponding PE codend. Codends made of stiffer and thicker PE-netting are becoming more popular in the Mediterranean demersal fishery; for instance, the majority of the Spanish demersal trawlers fishing in the Mediterranean are now using PE-codends. No relevant comparison of the selective performance of 40 mm diamond and square mesh codends made of PE-netting in the highly multi-species Mediterranean demersal fishery can be made on the basis of published literature.

The objective of this work is to compare the selectivity of 40 mm diamond mesh (DM40) and 40 mm square mesh (SM40) PE codends (a) in a typical north-western Mediterranean shelf fishing ground where hake is one of the major target species and (b) in the upper continental slope where Norway lobster is an important target species. Potential economic losses that would be experienced by fishermen on the introduction of a 40 mm square mesh codend are assessed.

2. Materials and methods

2.1. Field experiments

The experiment was conducted in July 2005 on board the commercial trawler "Nova Marisin" (1000 HP, LOA 24.1 m) on commercial fishing grounds at depths of about 100 m (shelf) and 400 m (upper slope) in the Catalan Sea, NW Mediterranean (Fig. 1). The trawl was a typical commercial bottom trawl used in the NW Mediterranean demersal fishery. Rigging and the overall performance (door spread, mouth opening, and towing depth) of the gear during the experimental tows were monitored using Scanmar acoustic sensors.

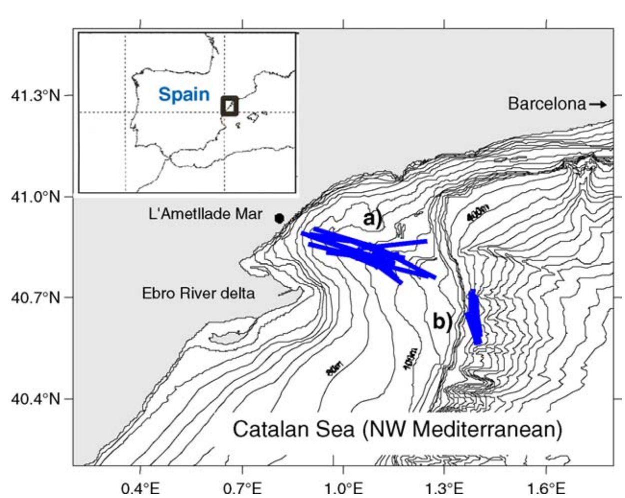

Fig. 1. Study area. Straight lines indicate trawl transects performed: (a) on the continental shelf fishing ground and (b) on the slope fishing ground.

The standard covered codend method (Wileman et al., 1996) was used to assess the selectivity of the codends (Fig. 2). The braided single twine knotted PE-netting was similar in both codends (diameter 5 mm, nominal mesh size 42 mm); in the square mesh codend the netting was rigged in square mesh configuration. The average mesh opening of the experimental codends was 40.3 mm ± 0.3 S.E. (10 meshes daily measured as wet with a wedge). The length of the codends was about 1.5 m and there were no lifting bags around the codends (commercial standard). The diamond mesh codend had 230 meshes and square mesh codend 140 meshes (bars) in circumference (meshes in the selvedges are not included). The 6 m codend extension was made of 40 mm diamond mesh codend (PA 3 mm) and the number of meshes around was 200 (commercial standard). The total length of the cover was 11.7 m and it was made of 15 mm (stretched mesh) knotless black diamond mesh PA netting, except the conical front part (sleeve) that was made of 40 mm mesh. The cover enclosed the codend and the extension. Hence, we measured the combined selectivity of the extension and the codend, as would be the case in the commercial fishery. Two plastic (PVC) hoops were used to keep the cover rigid and off the codend netting during the tow; the diameter of the front hoop was 1.6 m and rear hoop 1.9 m.

A total of 28 tows were carried out; 19 tows were made on the continental shelf at an average depth of 88 m, and 9 tows on the upper continental slope at an average depth of 405 m (Table 1). The towing speed varied between 3.3 and 3.9 knots. On the shelf, the warp length was 420 m, door spread 85–95 m and the mean effective towing duration 86 min. On the slope, warp length was 1200 m, door spread 90–95 m and the mean effective towing duration 116 min. Sweep length was 200 m in all hauls. Trawl headline height varied between 3 and 4 m.

In total, 27 commercially exploited species were recorded in the experimental catches (Fig. 3). On the continental shelf, the most common species encountered were European hake, gurnard (*Eutrigla gurnardus*), spotted flounder (*Citharus linguatula*), and horned octopus (*Eledone cirrhosa*) representing 54% of the total weight of commercial species. Norway lobster represented only about 2% of the total weight in the shelf catches. On the upper continental slope, Norway lobster, European hake, blue whiting (*Micromesistius poutassou*), and greater forkbeard (*Phycis blennoides*) represented 65% of the total weight of commercial species (Fig. 3). It is noteworthy that the relative high quantity of hake in catches on the upper slope is mainly due to the relatively low number but large size of individuals (ca. 30–50 cm).

The total length (TL) of fish was measured to the nearest cm. With Norway lobster, the carapace length (CL) was measured to the nearest mm. Other recorded species were

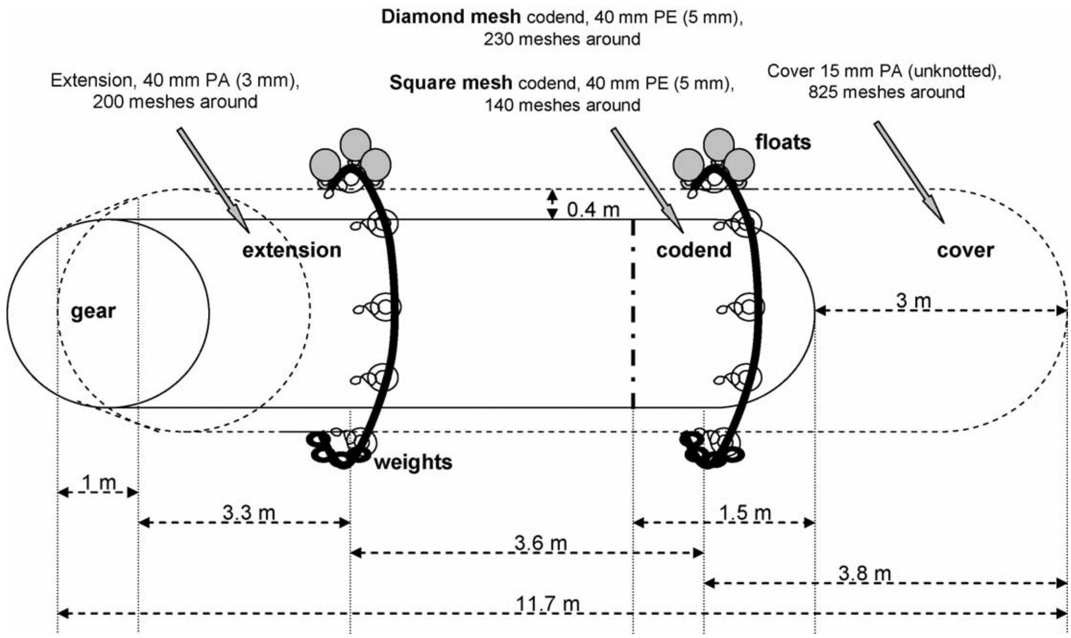

Fig. 2. Schematic illustration of the experimental gear.

considered to be accompanying commercial species (i.e., marketable by-catch).

2.2. Analysis of size selectivity

Selectivity analyses were performed only on those species caught with sufficient frequency and in sufficient numbers, i.e., European hake, Norway lobster, poor cod (*Trisopterus minutus capelanus*) and greater forkbeard. Logistic selection curves for individual hauls were fitted on the basis of the model: $r_i(l) = \exp(a_i + b_i l)/[1 + \exp(a_i + b_i l)]$, where $r(l)$ is the probability that a fish of length l that has entered the net will be retained by the net. The parameters a_i and b_i were estimated by maximising the log-likelihood function (Tokai, 1997), assuming that the proportions observed are binomially distributed. Parameters a and b were used to calculate the mean selection length $L_{50} = -a \times b^{-1}$, and the selection range $\mathrm{SR} = L_{75} - L_{25} = 2 \times \ln(3) \times b^{-1}$. Covariance matrices provided the standard errors for individual a and b parameters. Most individual selectivity curves showed over-dispersion as indicated by significant p-values in the Chi-square statistics (Table 2), suggesting a failure in the assumption that fish behaved independently (Millar et al., 2004). The over-dispersion was corrected by multiplying the original standard errors by the square root of this estimate (Millar et al., 2004) (Table 2).

Between-haul variability for target species shown by DM40 and SM40 was assessed using the fixed and random (mixed) effects selectivity model (Fryer, 1991). The total catch weight (i.e., catch in the codend and the cover), the total catch weight in the codend, and the towing duration were fixed variables in the model. The statistical difference between selectivity parameters was estimated using the adjusted z-score Wald's test.

2.3. Economic losses

Short-term economic losses caused by fishing with the SM40 and DM40 were estimated separately for the continental shelf and upper slope fishery. Mean commercial values for the four main target species and the accompanying commercial species were obtained from daily official invoices of the vessel. In the Mediterranean fishery, fish a few centimetres below the official MLS are often marketed. Therefore, we calculated economic losses based on minimum commercial sizes of 18 cm for hake (MLS 20 cm), and 10 cm for both the poor cod (MLS 11 cm) and greater forkbeard (no official MLS); for Norway lobster we used 18 mm (MLS 20 mm). The size frequencies of main target species (in the catches) were used to calculate weight of undersized and marketable individuals using the allometric length–weight (L–W) equation $W = a \times L^b$. The parameters in the equation (a, b) were obtained from Fishbase (Froese and Pauly, 2005).

3. Results

3.1. Selectivity parameters

The SM40 showed significantly higher L_{50} than the DM40 for all four species analysed (Fig. 4, Tables 2 and 3). The L_{50} for hake obtained with the DM40 was 10.1 cm (Table 3). That is about 10 cm below the minimum landing size of this species (MLS 20 cm). With SM40 the L_{50} was 16.0 cm, i.e., signif-

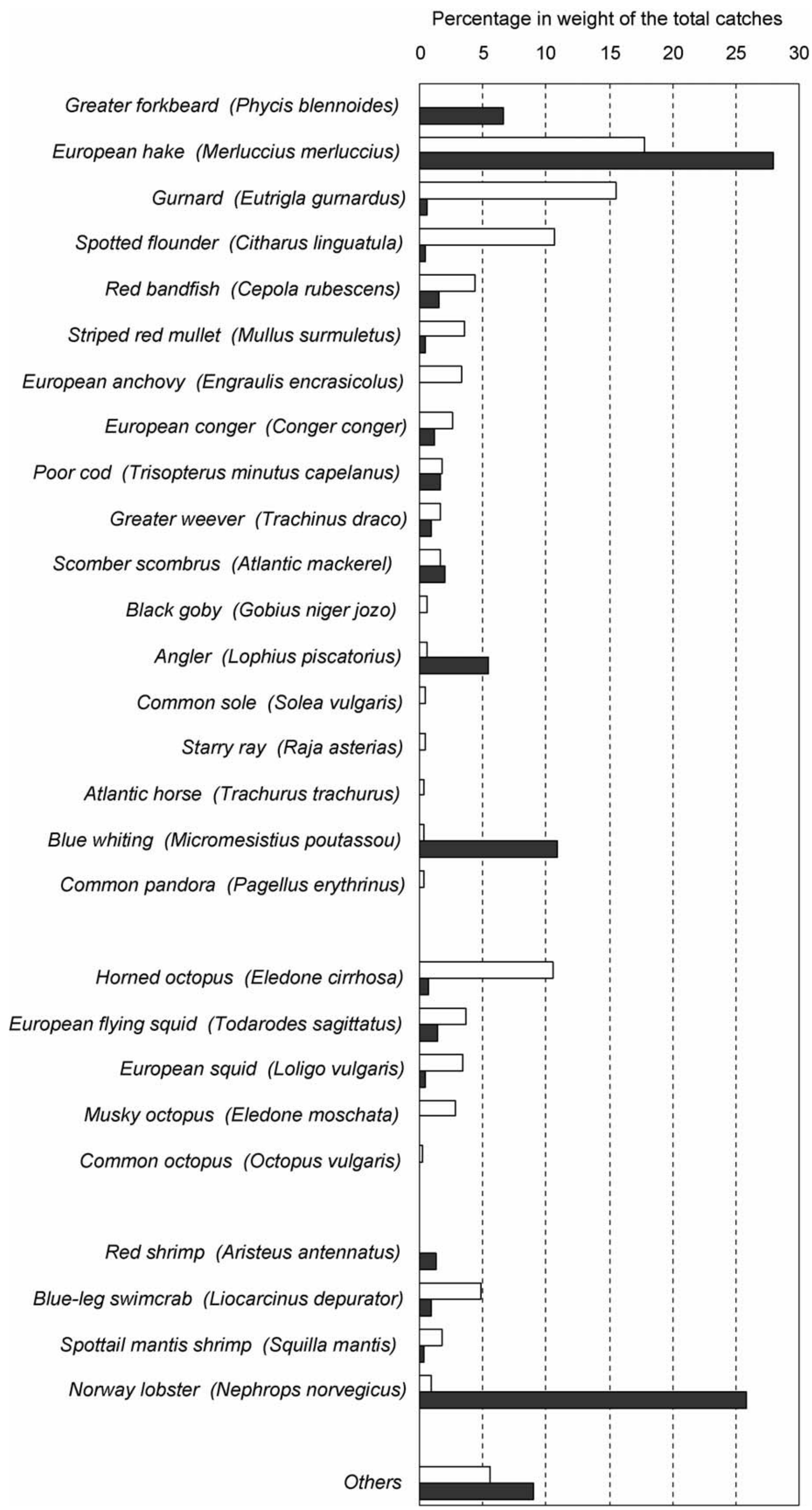

Fig. 3. Commercial species composition and weight percentage of each species relative to the total catches on the continental shelf (white bars) and the upper slope (black bars) fishing grounds.

Table 1
Details of tows performed in the shelf and slope fishing grounds

Haul no.	Mean depth (m)	Date	Towing time	Towing duration (min)	Total codend catch (kg)	Total cover catch (kg)	Percentage escaped
Continental shelf							
Diamond mesh codend							
1	80	04.07.05	8:07	15	70	33	32
2	101	04.07.05	9:50	100	206	144	41
3	84	04.07.05	12:02	65	137	102	43
4	90	04.07.05	14:12	85	114	60	35
5	62	05.07.05	8:32	65	170	84	33
6	77	05.07.05	10:15	90	146	50	26
7	80	05.07.05	12:57	115	105	50	32
8	79	05.07.05	14:42	85	96	28	23
Square mesh codend							
9	77	06.07.05	8:30	60	82	78	49
10	91	06.07.05	10:42	85	95	93	50
11	97	06.07.05	12:31	63	71	96	58
12	91	06.07.05	14:23	106	65	94	59
13	101	07.07.05	8:33	67	92	80	47
14	102	07.07.05	10:38	77	108	77	42
15	101	07.07.05	12:21	103	55	60	52
16	91	07.07.05	14:47	35	84	60	42
34	66	18.07.05	8:38	137	151	390	72
35	88	18.07.05	11:17	94	111	230	67
36	108	18.07.05	13:42	84	112	126	53
Upper slope							
Diamond mesh							
39	384	20.07.05	10:04	68	95	23	20
40	402	20.07.05	12:51	162	116	25	18
41	421	21.07.05	10:02	65	90	30	25
42	430	21.07.05	12:48	157	126	25	17
Square mesh codend							
31	397	14.07.05	9:58	117	38	20	34
32	411	14.07.05	12:36	133	104	35	25
33	428	15.07.05	10:03	67	55	30	35
37	366	19.07.05	9:59	118	66	44	40
38	408	19.07.05	12:47	155	78	44	36

Towing time is the median towing time of the haul. Time is local time (GMT + 01:00).

icantly higher ($p < 0.001$) than with DM40 (Table 3). The selection range (SR) of hake with SM40 (3.2 cm) and with DM40 (3.1 cm) did not differ significantly ($p = 0.53$). The codend catch weight significantly affected the SR of hake; therefore, the codend catch weight was included in the selectivity model to estimate the parameters (Table 3). For poor cod (MLS 11 cm), the L_{50} was significantly lower ($p < 0.001$) with DM40 (9.2 cm) than with SM40 (13.0 cm), whereas the SR did not differ ($p = 0.46$) (Table 3).

DM40 did not show any selectivity for Norway lobster (MLS 20 mm) whereas SM40 gave a L_{50} value of 22 mm and SR of 6.5 mm (Table 3). The L_{50} of greater forkbeard (MLS not regulated) was significantly higher ($p < 0.01$) with the SM40 (15.0 cm) than with the DM40 (9.8 cm). The SR in DM40 and SM40 showed no significant difference for greater forkbeard ($p = 0.97$).

3.2. Percentages escaped

On the continental shelf, the total weight of fish escaping from the SM40 (into the cover) was around the same as the total weight caught in the codend (i.e., the mean percentage of escapees ± the standard deviation was 54.6 ± 3.0). The mean percentage of escapees with the DM40 was around one third (33.0 ± 2.4) of the total quantity of fish entering the gear (Table 1).

On the upper slope, the total quantity of fish escaping from the codends was generally lower than in the continental shelf, the mean percentage of escape (by weight) being 34.3 ± 2.5 for the SM40 and 19.7 ± 1.9 for the DM40 (Table 1).

3.3. Economic losses

Norway lobster had the highest average market price (€27 kg^{-1}) and hake the second highest (€9 kg^{-1}). The individuals of these species escaped from the SM40 at similar percentages (5.7 ± 0.4 and 5.5 ± 1.3, respectively). Poor cod and forkbeard had substantially lower market prices (around €1.4 and €1.3 kg^{-1}) and they escaped in larger percentages than Norway lobster and hake from the SM40 (87.1 ± 4.5 and 52.3 ± 15.0, respectively). The mean prices of accompanying commercial species varied widely between €1.1 and

Table 2
Selectivity parameters for individual hauls

Haul no.	L50	SR	*a*	*b*	R_{i11}	R_{i12}	R_{i22}	Model deviance	d.f.	*p*-Value
Continental shelf										
European Hake										
Diamond mesh codend										
1	9.5 ± 0.9	3.6 ± 0.3	−5.765	0.608	0.2890	−0.0253	0.0023	20.2	18	0.32
2	9.9 ± 0.5	3.0 ± 0.1	−7.207	0.726	0.1257	−0.0112	0.0010	86.2	20	0.00
3	11.1 ± 0.5	2.4 ± 0.1	−10.110	0.913	0.2119	−0.0185	0.0016	86.1	17	0.00
4	10.2 ± 0.7	4.0 ± 0.3	−5.622	0.550	0.1418	−0.0118	0.0010	87.1	21	0.00
5	10.0 ± 0.7	3.4 ± 0.2	−6.531	0.655	0.2042	−0.0174	0.0015	58.1	19	0.00
6	9.4 ± 0.9	2.6 ± 0.2	−7.904	0.844	0.5659	−0.0534	0.0051	90.1	21	0.00
7	8.4 ± 1.1	4.6 ± 0.5	−3.098	0.369	0.1557	−0.0128	0.0011	137.0	18	0.00
8	10.0 ± 0.7	3.1 ± 0.4	−7.187	0.719	0.2679	−0.0231	0.0021	110.7	21	0.00
Square mesh codend										
9	16.5 ± 0.7	4.1 ± 0.2	−8.838	0.536	0.1364	−0.0087	0.0006	107.3	16	0.00
10	15.0 ± 0.7	3.8 ± 0.2	−8.742	0.582	0.1740	−0.0118	0.0008	156.5	22	0.00
11	15.2 ± 0.7	3.0 ± 0.2	−11.076	0.729	0.2701	−0.0184	0.0013	82.5	18	0.00
12	16.6 ± 1.0	3.4 ± 0.2	−10.771	0.648	0.3913	−0.0246	0.0016	23.3	20	0.28
13	15.6 ± 0.9	3.1 ± 0.2	−10.995	0.704	0.3755	−0.0247	0.0016	31.8	18	0.02
14	15.3 ± 0.8	2.2 ± 0.1	−14.949	0.978	0.5766	−0.0378	0.0025	22.5	21	0.37
15	14.9 ± 1.6	4.4 ± 0.5	−7.498	0.503	0.6081	−0.0392	0.0026	42.0	13	0.00
16	16.5 ± 0.8	3.1 ± 0.2	−11.536	0.701	0.3397	−0.0206	0.0013	92.4	20	0.00
34	16.5 ± 0.6	2.4 ± 0.1	−15.027	0.911	0.2825	−0.0170	0.0010	124.0	17	0.00
35	16.6 ± 0.5	3.1 ± 0.1	−11.611	0.701	0.1424	−0.0092	0.0006	149.2	23	0.00
36	16.6 ± 0.6	3.0 ± 0.1	−12.278	0.740	0.1768	−0.0120	0.0008	116.3	25	0.00
Poor cod										
Diamond mesh codend										
2	9.4 ± 0.4	2.7 ± 0.1	−7.262	0.785	0.0934	−0.0097	0.0010	39.7	7	0.00
5	8.9 ± 0.9	4.3 ± 0.5	−4.587	0.517	0.2284	−0.0261	0.0031	25.4	5	0.00
6	9.2 ± 0.5	1.4 ± 0.1	−14.857	1.623	0.6624	−0.0715	0.0078	57.9	8	0.00
7	9.0 ± 0.6	2.9 ± 0.2	−6.906	0.768	0.2341	−0.0247	0.0027	67.3	12	0.00
8	9.3 ± 0.9	3.8 ± 0.4	−5.332	0.576	0.2696	−0.0278	0.0030	67.6	8	0.00
Square mesh codend										
10	11.0 ± 2.6	5.2 ± 1.4	−4.633	0.421	1.2316	−0.1197	0.0119	5.6	5	0.34
11	13.1 ± 1.3	2.3 ± 0.3	−12.435	0.948	1.4209	−0.1293	0.0119	5.8	9	0.76
12	13.7 ± 1.2	3.1 ± 0.3	−9.857	0.720	0.6975	−0.0650	0.0062	22.1	8	0.00
15	11.7 ± 1.6	2.1 ± 0.3	−11.917	1.022	2.5734	−0.2532	0.0252	7.0	7	0.43
34	14.1 ± 1.4	2.4 ± 0.3	−12.778	0.907	1.5952	−0.1347	0.0115	7.3	7	0.39
Upper slope										
Norway lobster										
Square mesh codend										
31	23.5 ± 3.6	5.6 ± 0.7	−9.240	0.393	1.9684	−0.0706	0.0026	44.0	24	0.01
32	21.7 ± 2.2	6.4 ± 0.5	−7.412	0.341	0.5724	−0.0212	0.0008	92.2	28	0.00
33	21.7 ± 3.5	7.6 ± 1.0	−6.253	0.288	1.0117	−0.0360	0.0013	14.4	26	0.97
37	21.6 ± 3.9	7.4 ± 1.1	−6.406	0.296	1.3406	−0.0486	0.0018	52.1	21	0.00
38	22.4 ± 1.9	5.4 ± 0.4	−9.060	0.405	0.5938	−0.0224	0.0009	121.9	26	0.00
Greater forkbeard										
Diamond mesh codend										
39	9.7 ± 1.6	3.1 ± 0.4	−6.775	0.700	1.3209	−0.1088	0.0091	16.9	8	0.03
40	10.8 ± 1.9	3.6 ± 0.5	−6.681	0.618	1.3045	−0.1037	0.0084	13.2	8	0.10
41	9.9 ± 1.5	1.3 ± 0.2	−17.409	1.763	7.3335	−0.6816	0.0638	7.8	9	0.56
42	9.5 ± 1.2	2.4 ± 0.3	−8.567	0.899	1.1424	−0.0991	0.0087	7.5	11	0.75
Square mesh codend										
31	14.6 ± 1.4	2.3 ± 0.3	−13.732	0.943	1.7598	−0.1254	0.0090	6.0	7	0.54
32	14.3 ± 1.0	3.9 ± 0.3	−7.969	0.558	0.3185	−0.0230	0.0017	43.6	10	0.00
33	14.6 ± 1.7	3.2 ± 0.3	−10.063	0.689	1.4241	−0.1012	0.0073	5.5	9	0.79
37	16.2 ± 1.4	2.4 ± 0.2	−15.078	0.933	1.6116	−0.1084	0.0074	17.2	10	0.07
38	15.0 ± 1.2	3.4 ± 0.3	−9.747	0.650	0.6288	−0.0437	0.0031	8.6	9	0.47

L_{50} and SR are the selectivity parameters. *a* and *b* are the parameters in the selectivity equation. R_{ixx} are values in the covariance matrix. d.f. indicates the degree of freedom. The *p*-value indicates the significance of the model deviance.

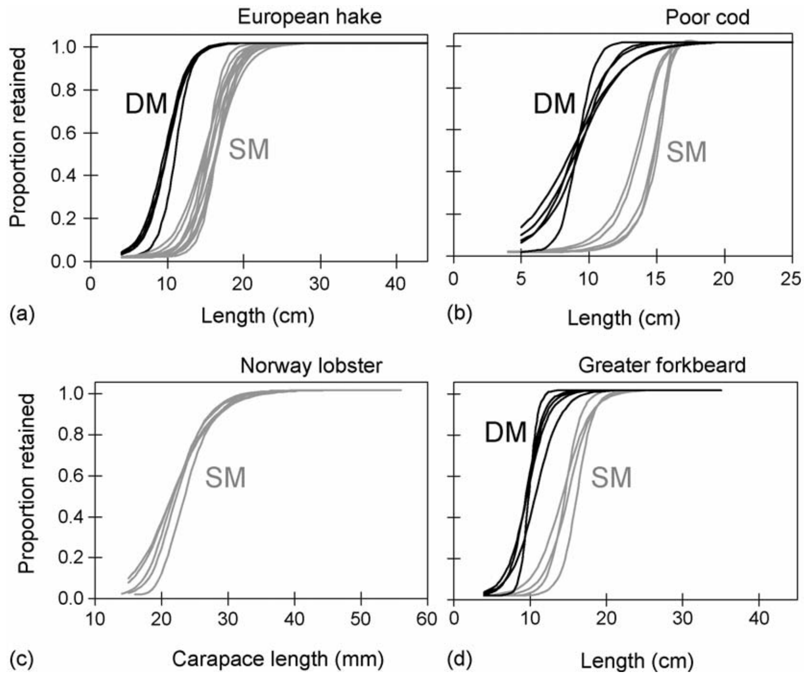

Fig. 4. Selectivity curves for four species caught on the continental shelf (a and b) and the upper slope (c and d) when using the 40 mm diamond mesh codend (DM, black lines) and the 40 mm square mesh codend (SM, grey lines).

€14.6 kg^{-1}. They were included in the analysis of economic losses (Tables 4 and 5).

The gross economic loss on the continental shelf with the SM40 was between 14 and 34% (Table 4). With the DM40, the losses were between 2 and 3% (Table 5), and this loss was mainly because of the escape of accompanying species. Hence, on the continental shelf the economic loss by switching from the DM40 to SM40 varies between 12 and 32%.

On the slope fishing ground, the estimated economic losses with the SM40 were between 3 and 5%, and this was mainly due to escape of small Norway lobster and forkbeard (Table 4), while with the DM40 the losses would be between 1.3 and 1.6% mainly due to escape of greater forkbeard and

Table 3
Selectivity parameters for target species obtained with the fixed and random effect model by Fryer (1991)

Selectivity estimates	Continental shelf				Upper slope			
	European hake		Poor cod		Norway lobster		Greater forkbeard	
MLS	20 cm		11 cm		20 mm		not regulated	
Codend	DM40	SM40	DM40	SM40	DM40	SM40	DM40	SM40
Number of valid hauls	8	11	5	5	4	5	4	5
Total no. of individuals in codend	11366	4059	2747	419	3996	4968	2091	974
Total no. of individuals in cover	2994	7242	2917	12373	18	557	234	2502
L_{50}	10.1	(16.0) 16.0	9.2	13.0	–	22.0	9.8	(14.8) 15.0
SR	3.1	(4.8) 3.2	3.0	3.0	–	6.5	2.6	(1.7) 3.0
Standard deviation of L_{50}	0.2	(0.2) 0.2	0.2	0.6	–	0.5	0.7	(0.5) 0.4
Standard deviation of SR	0.2	(0.6) 0.2	0.5	0.6	–	0.5	0.5	(0.5) 0.3
SR/L_{50}	0.3	(0.3) 0.2	0.3	0.2	–	0.3	0.3	(0.1) 0.2
Degree of freedom	14	19	8	7	–	8	6	7
p-Value L_{50}	<0.01	<0.01	<0.01	<0.01	–	<0.01	<0.01	<0.01
p-Value SR	<0.01	<0.01	<0.01	<0.01	–	<0.01	<0.01	<0.01
p-Values for covariates								
(Catch weight in codend + cover) × (L_{50})	ns	ns	ns	ns	–	ns	ns	ns
(Catch weight in codend + cover) × (SR)	ns	ns	ns	ns	–	ns	ns	ns
(Catch weight in codend) × (L_{50})	ns	ns	ns	ns	–	ns	ns	ns
(Catch weight in codend) × (SR)	ns	0.01	ns	ns	–	ns	ns	0.02
(Towing duration) × (L_{50})	ns	ns	ns	ns	–	ns	ns	ns
(Towing duration) × (SR)	ns	ns	ns	ns	–	ns	ns	ns

ns: non-significant p-value, higher than 0.05. In parenthesis are given the selectivity estimates without accounting significant covariates.

Table 4
Economic losses estimated for catches with the SM40 codend in the continental shelf and upper slope fishing ground

Haul no.	Species	Fish sold		Fish escaped		Economic losses	
		Weight (kg)	Total value (€)	Weight (kg)	Total value (€)	Per species (%)	Per haul (%)
Continental shelf							
9	European hake	22.6	203.4	2.7	16.0	3	15
	Poor cod	0.1	0.1	1.8	1.7	2	
	By-catch	43.0	249.5	17.9	60.4	11	
10	European hake	21.8	195.8	0.7	4.0	1	16
	Poor cod	0.6	0.9	0.7	0.6	1	
	By-catch	33.3	193.4	21.3	72.0	15	
11	European hake	16.8	151.1	0.3	1.8	0	21
	Poor cod	2.6	15.4	7.8	7.5	8	
	By-catch	25.1	145.9	22.0	74.3	19	
12	European hake	10.5	94.2	1.2	7.3	2	26
	Poor cod	1.0	1.4	4.8	4.6	5	
	By-catch	25.7	149.5	21.6	72.8	22	
13	European hake	11.6	104.0	1.5	9.2	2	25
	Poor cod	0.0	0.0	1.7	1.7	1	
	By-catch	32.3	252.3	20.2	105.9	22	
14	European hake	30.9	277.8	0.3	1.7	0	18
	Poor cod	0.1	0.2	6.5	6.2	6	
	By-catch	29.6	231.3	19.5	102.0	16	
15	European hake	8.9	79.8	0.7	4.1	2	34
	Poor cod	0.9	1.3	3.3	3.2	4	
	By-catch	11.6	90.3	15.2	79.5	31	
16	European hake	33.9	305.3	1.6	9.7	2	17
	Poor cod	0.0	0.0	4.4	4.2	4	
	By-catch	17.3	135.6	15.2	79.5	15	
34	European hake	58.0	521.6	5.6	33.8	3	26
	Poor cod	0.8	1.2	15.1	14.5	5	
	By-catch	55.8	368.0	51.4	262.6	22	
35	European hake	29.4	264.3	1.0	5.8	1	24
	Poor cod	1.1	1.5	40.0	38.4	19	
	By-catch	56.3	370.8	30.3	155.2	19	
36	European hake	27.6	248.8	0.5	3.0	0	14
	Poor cod	4.9	7.0	28.7	27.5	23	
	By-catch	68.9	454.5	16.6	84.8	10	
Upper slope							
31	Norway lobster	15.3	417.6	0.8	14.9	3	4
	Greater forkbeard[a]	3.0	4.0	3.0	2.6	10	
	By-catch	3.3	35.1	2.2	3.9	1	
32	Norway lobster	34.1	930.0	2.2	39.2	3	4
	Greater forkbeard[a]	8.3	10.9	6.4	5.6	9	
	By-catch	16.0	171.4	3.8	6.8	1	
33	Norway lobster	19.4	527.7	1.1	20.4	3	3
	Greater forkbeard[a]	3.0	4.0	2.3	2.0	8	
	By-catch	9.4	136.2	0.3	0.3	0	
37	Norway lobster	11.2	305.4	0.7	12.9	2	5
	Greater forkbeard[a]	2.2	3.0	8.3	7.3	19	
	By-catch	30.7	323.7	7.9	15.5	2	
38	Norway lobster	36.6	997.3	2.3	41.8	3	5
	Greater forkbeard[a]	5.5	7.3	4.7	4.1	6	
	By-catch	15.8	166.4	7.9	15.5	1	

[a] The L_{50} obtained with the DM40 was used as a reference instead of MLS, as MLS is not regulated.

Table 5
Economic losses estimated for catches performed with the DM40 codend in the continental shelf and upper slope fishing ground

Haul no.	Species	Fish sold		Fish escaped		Economic losses	
		Weight (kg)	Total value (€)	Weight (kg)	Total value (€)	Per species (%)	Per haul (%)
Continental shelf							
1	European hake	8.6	77.4	0.0	0.0	0	2
	Poor cod	0.3	0.4	0.3	0.0	0	
	By-catch	31.5	182.5	1.6	5.0	2	
2	European hake	40.3	363.1	0.0	0.0	0	3
	Poor cod	12.0	17.3	3.2	0.0	0	
	By-catch	51.5	298.7	7.1	21.8	3	
3	European hake	31.3	281.5	0.0	0.0	0	3
	Poor cod	1.0	1.4	1.1	0.0	0	
	By-catch	39.7	230.4	5.0	15.4	3	
4	European hake	32.2	290.0	0.0	0.0	0	2
	Poor cod	0.0	0.1	1.2	0.0	0	
	By-catch	38.8	224.9	3.0	9.1	2	
5	European hake	23.1	207.9	0.0	0.0	0	3
	Poor cod	1.5	2.2	0.7	0.0	0	
	By-catch (lobster)	103.5	457.6	6.9	19.3	3	
6	European hake	20.9	188.4	0.0	0.0	0	2
	Poor cod	4.8	6.9	0.9	0.0	0	
	By-catch (lobster)	66.2	292.6	4.1	11.5	2	
7	European hake	19.2	172.9	1.2	0.0	0	3
	Poor cod	5.4	7.8	1.1	0.0	0	
	By-catch (lobster)	41.3	182.5	4.1	11.5	3	
8	European hake	32.2	289.9	0.0	0.0	0	2
	Poor cod	3.1	4.5	0.6	0.0	0	
	By-catch	18.4	81.3	2.3	6.4	2	
Upper slope							
39	Norway lobster	21.5	585.0	0.0	0.0	0	1
	Greater forkbeard[a]	6.3	8.3	0.4	0.4	2	
	By-catch	35.2	130.0	3.0	10.2	1	
40	Norway lobster	30.2	822.8	0.1	1.8	0	1
	Greater forkbeard[a]	3.8	5.0	0.5	0.4	2	
	By-catch	37.8	139.4	3.3	11.1	1	
41	Norway lobster	19.5	531.0	0.0	0.0	0	2
	Greater forkbeard[a]	9.6	12.7	0.1	0.1	1	
	By-catch	9.6	50.9	3.3	9.6	2	
42	Norway lobster	19.4	527.9	0.0	0.8	0	1
	Greater forkbeard[a]	12.7	16.7	0.4	0.3	1	
	By-catch	33.2	175.3	2.7	8.0	1	

[a] The L_{50} obtained with the DM40 was used as a reference instead of MLS, as MLS is not regulated.

accompanying species (Table 5). Hence, the relative losses with the SM40 will be between 2 and 4%, i.e., substantially less than in the shelf fishery.

4. Discussion

Our trials demonstrate that a significant improvement in selectivity for European hake, Norway lobster, poor cod and greater forkbeard can be achieved by switching from the current 40 mm diamond mesh codend to a 40 mm square mesh codend. The estimated L_{50} for hake with the square mesh codend (16.0 cm) is closer to the current minimum landing size (MLS = 20 cm) and significantly higher than that of diamond mesh codend (L_{50} = 10.1 cm). Clearly, the 40 mm square mesh codend would represent a marked improvement in the harvesting pattern of this commercially important species. However, it is notable that the length of first maturity of hake in the Western Mediterranean is estimated by different authors to be between 22 and 32 cm for males and 30 and 39 cm for females (Recasens et al., 1998; Froese and Pauly, 2005). Hence, a substantially higher mesh size than 40 mm in the square mesh codend would be required if the spawn-at-least-once rule was to be satisfied for this species.

Our selectivity parameters for hake are close to those presented by Guijarro and Massuti (2006); L_{50} = 11.6 cm with

40 mm diamond mesh, and 15.3 cm with 40 mm square mesh codend) although they used a codend made of thinner PA netting, both of which should increase selectivity compared to our case (see also Tokaç et al., 2004). However, Guijarro and Massuti (2006) operated on the deepwater trawling grounds off the Balearic Islands where juvenile hake are scarce. Their selectivity analysis for hake was restricted to that from pooled data due to the low number of small hake.

The selectivity parameters we estimated for Norway lobster in the 40 mm square mesh (L_{50} = 22 mm, SR = 6.5 mm) are close to those reported from the Aegean Sea by Stergiou et al. (1997b) where a 40 mm square mesh codend (twisted PA) produced a L_{50} of 24.0 mm and SR of 5.9 mm.

It is noteworthy that in our trials, the 40 mm diamond mesh codend did not show any selectivity for Norway lobster. This is in accordance with Guijarro and Massuti (2006) who did not have any selectivity for Norway lobster in their trials with a 40 mm diamond mesh codend (made of twisted 3 mm PA). However, in the Aegean Sea, Stergiou et al. (1997b) showed with a 40 mm diamond mesh codend (twisted PA) a L_{50} of 22.8 mm and SR of 9.5 mm for Norway lobster. Comparison of these results, however, is difficult because only nominal mesh sizes are reported in the papers.

For the greater forkbeard, our estimates of L_{50} are somewhat lower than those shown by Guijarro and Massuti (2006). We estimated for the 40 mm diamond mesh codend a L_{50} of about 9.8 cm whereas Guijaro and Massuti obtained a mean value of 12.0 cm. For the 40 mm square mesh codend, our L_{50} estimate is 14.8 cm whereas that of Guijaro and Massuti is 16.2 cm (in their autumn trials). In their spring trials, however, the estimate was 13.7 cm. It appears that seasonal differences may require more attention. For poor cod, no comparable selectivity data exist.

Our assessment indicated that in the deeper slope fishing grounds (∼400 m depth) economic losses would be substantially smaller than in the shallower shelf grounds due to a smaller number of commercial species. Our estimate of economic losses in the slope fishery are very similar to those estimated by Guijarro and Massuti (2006) when introducing a 40 mm square mesh codend in deepwater trawl fishery off the Balearic Islands (1–2%).

Relatively high economic losses (12–33%) estimated for the 40 mm square mesh codend in the shallow fishing grounds (depths < 100 m) are due to the escape of a high number of accompanying species with a relatively high commercial value. These losses may result in substantial resistance by the fishing industry against accepting such a codend. However, for many species a square mesh codend would reduce the discards and the sorting work on deck. Clearly, there is a need to identify the potential longer term benefits by a full analysis.

In conclusion, our study indicates that a 40 mm square mesh codend would help to improve the overall exploitation pattern in the Mediterranean multi-species trawl fishery (see also Guijarro and Massuti, 2006; Stergiou et al., 1997b). A potential advantage of a square mesh codend is that it may be less affected by the twine type than a diamond mesh codend; hence it may be less susceptible to measures by fishermen to negate the selectivity improvement. However, we acknowledge that a square mesh codend would not be efficient for all commercial species, such as many high bodied fish and flatfish (e.g., Petrakis and Stergiou, 1997). This demonstrates the difficulty of improving size-selection in a highly multi-species fishery. The same mesh opening is not suitable for all species; it will always be too large for some species and too small for others. To enable a more effective reduction of non-target species and optimal size-selection for target species, species selectivity should be developed in concert with size-selectivity (e.g., Valdemarsen and Suuronen, 2003; Sardà et al., 2004, 2005; Fonseca et al., 2005). However, it is important to realize that any increase in fleet selectivity would increase the average age-at-first-capture for the vast majority of commercially important species even if a precise optimum is not achieved for all species. Assuming that most of the escapees will survive, this is likely to be advantageous for the stocks.

Acknowledgements

We are very grateful to the skippers and crew of "Nova Marisin" for the invaluable assistance in performing the fishing trials. Mr. Santiago Salom (Artes de Pesca Salom, S.L.) is acknowledged for his valuable contribution in the construction of the experimental gears. Dr. Dick Ferro offered valuable help in designing the codend cover and gave useful comments on the manuscript. Dr. M. Coll and Mr. T. Cruz assisted in the fieldwork. This study was financially supported by the European Commission, Contract SSP8-CT-2003/501605 (NECESSITY). This paper, however, does not reflect the Commission's view and does not anticipate its future policy in this area.

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