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Selectivity of flexible size-sorting grid in Mediterranean multispecies trawl fishery

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ABSTRACT: The demersal multispecies trawl fishery in the western Mediterranean Sea has a poor selectivity; large numbers of juvenile fish are caught when using the legislated 40-mm diamond mesh cod end. The selectivity of a flexible sorting grid with 20-mm bar spacing (BS20) installed in front the conventional trawl cod end was investigated. The standard covered cod end method was used. Data was adequate for analyzing the selectivity of European hake *Merluccius merluccius*, poor cod *Trisopterus minutus*, greater forkbeard *Phycis blennoides* and Norway lobster *Nephrops norvegicus*. The selectivity of the 20-mm sorting grid was compared with the performance of 40-mm diamond (DM40) and square mesh (SM40) cod ends. The effect of a guiding funnel on the performance of the grid (BS20-f) was also explored. Finally, the potential changes in yield per recruit (Y/R) and biomass per recruit (B/R) after implementing a sorting grid were explored. An overall improvement in the 50% selection length (L_{50}) with all four species was substantial when comparing the BS20 to the DM40. Higher improvement in L_{50}s was achieved when the grid was equipped with the guiding funnel. When comparing the performance of the BS20-f to the SM40, there was no marked difference in L_{50}s. The Y/R and B/R, however, are substantially higher with BS20-f for poor cod and about the same for European hake. BS20 compared to SM40 achieved lower Y/R and B/R for all four species; the smallest difference was observed for Norway lobster. Further development is required if the sorting grid is to be introduced into commercial fisheries.

KEY WORDS: **cod end selectivity, European hake, forkbeard, multispecies trawl fishery, Norway lobster, poor cod, sorting grid, square mesh.**

INTRODUCTION

The current 40-mm standard diamond mesh cod end enforced in the demersal trawl fishery in the Mediterranean Sea shows very poor size selectivity for most target species.[1–4] For instance, the 50% selection length (L_{50}) of European hake *Merluccius merluccius* is approximately 10 cm with the standard cod end,[5] which is only about half of the current official minimum landing size of 20 cm, and about one-third of the size at first maturity.[6] Several commercially exploited species are overexploited and discarding of young fish is a common practice.[4,5,7–9] Clearly, the capture of immature fish should be reduced markedly.

Relatively little scientific work has been done to improve the selectivity and exploitation pattern in the Mediterranean multispecies demersal fishery. Most work has been done to test the effect of increasing cod end mesh size or using a square mesh cod end.[2,5,10–12] Some preliminary trials have been carried out with rigid sorting grids inserted in front of the trawl cod end,[13–15] but no commercial applications exist. On the other hand, sorting grids have been intensively studied and tested in many northern European fisheries for releasing juveniles.[16–18] Nevertheless, in spite of the extensive amount of work done, only a few fisheries use grids in the size sorting function; the most remarkable are the sorting grids developed in Norway and used in the Barents Sea demersal trawl fishery.

A potential advantage of a sorting grid is that the bar spacing of a grid is constant throughout the tow, regardless of towing speed and catch size. Another advantage is that practically all the fish can be forced into contact with a grid and the small fish pass quickly through it because the grid can be installed so that it completely crosses their way. These factors are generally considered to allow effective selection performance. There are also

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some indications that a cod end equipped with a sorting grid has a sharper selectivity curve than a conventional cod end with corresponding 50% selection length,[16,18] although this effect has not been demonstrated conclusively.[19] Further, survival of fish that escape from a sorting grid may be higher than that of fish escaping through a cod end mesh.[20]

Generally, various types of handling problems associated with rigid sorting grids have resulted in industry resistance. Recent development of flexible, lighter and more user-friendly sorting grids offers opportunities for more practical operation. In particular, new polyurethane polymers allow substantial operational flexibility.[21]

Improving size selection in multispecies bottom trawl fisheries is expected to reduce excessive fishing mortality of juveniles and produce an overall positive impact on fish stocks.[22,23] A short-term result of introducing effective selectivity in a fishery would likely be reduction in the yield per recruit,[24,25] although a compensation of losses would be obtained with time as the stock biomasses and yield per recruit increase.[25,26] The overall effects of improving the size selection on commercial species and the whole ecosystem, however, have remained unclear as the species interactions with the environment are complex and scarcely documented.[23,27–29]

In this study we have explored whether a flexible sorting grid with 20-mm bar spacing installed in front of the conventional trawl cod end would be practical and improve the overall selectivity in the highly multispecies western Mediterranean demersal trawl fishery. We also explored the effect of a guiding funnel on the selectivity performance of the grid. Finally, we assessed the potential changes in yield per recruit (Y/R) and biomass per recruit (B/R) after implementation of a sorting grid. We compared our results with a parallel study[5,25] performed in the same area aimed at improving the size selection of the species with a 40-mm square mesh cod end.

MATERIALS AND METHODS

Field experiments

In total 14 tows were conducted in July 2005 on board the commercial trawler Nova Marisin (1000 HP, length over all [LOA] 24.1 m) on commercial fishing grounds in the Catalan Sea, NW Mediterranean Sea (Fig. 1). Eight tows were made at depths of 70–110 m (continental shelf) and six tows at 400–440 m (upper slope). A typical commercial NW Mediterranean bottom trawl was used in the experiments. The towing speed varied between 3.3 and 3.9 knots. The overall performance of the gear (door spread, mouth opening and towing depth) during the tows was monitored using acoustic sensors (Scanmar AS, Asgardstrand, Norway). The mean effective towing duration was 82 min (range 68–90 min).

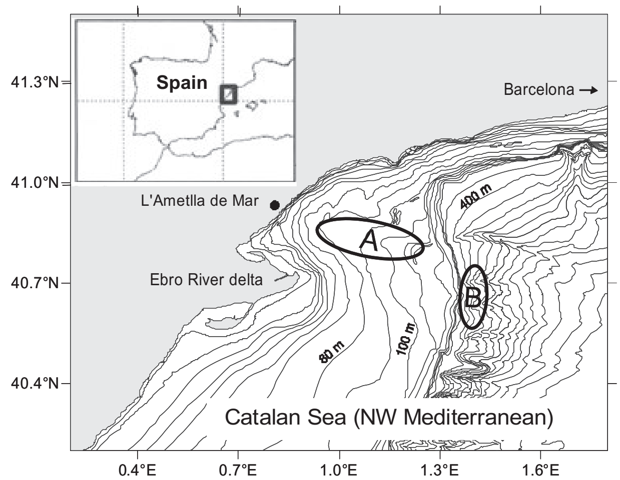

Fig. 1 Study area for selectivity experiments conducted in the multispecies trawl fishery on the continental shelf (A) and the upper slope (B) in the NW Mediterranean Sea.

The flexible sorting grid was made of black polyurethane polymers. The grid was 130 cm high and 90 cm wide, and its rigging angle was 35° (Fig. 2). The bar spacing was 20 mm. In the lower part of the grid (20% of total area) was an opening where the fish and other organisms guided by the grid could enter into the cod end. Smaller fish escaped through the bars and swam out through the hole made in the netting panel behind the grid. These fish were caught in the cover. The grid was fitted into a special 5-m netting section installed in front of the cod end. This section was made of 40-mm polyamide (PA) netting and had 197 surrounding meshes. In four of eight tows conducted on the continental shelf, a guiding panel (funnel) was installed in front of the grid (Fig. 2). A guiding funnel was not used in the tows conducted on the continental slope. The cod end was made of a braided single twine, knotted polyethylene (PE) netting with 5-mm twine diameter and nominal diamond mesh size of 42 mm. The length of the cod end was 1.5 m (commercial standard).

The standard covered cod end method[30] was used to assess the selectivity. 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), which was made of 40-mm mesh (Fig. 2).[5] The

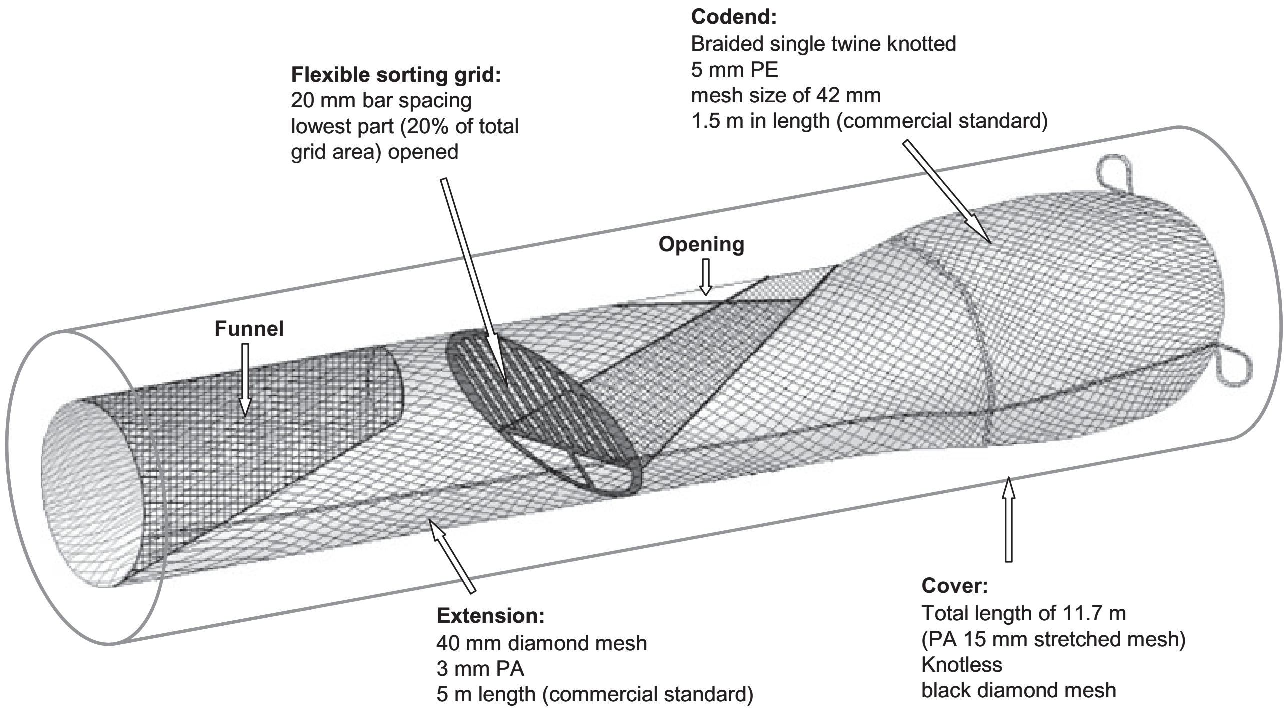

Fig. 2 Scheme of the sorting grid installed in front of the cod end. The funnel used in some tows on the continental shelf is shown in front of the grid. PA, polyamide; PE, polyethylene.

cover enclosed the grid and the cod end; hence, the selectivity measured in this study describes the combined selectivity of the grid and the cod end. Two plastic (PVC) hoops were used to keep the cover rigid and approximately 40 cm off the cod end netting during the tow; the diameter of the front hoop was 1.6 m and rear hoop, 1.9 m.

Catch sampling focused on most frequent and abundant commercial species. On the shelf, the main target species were European hake and poor cod *Trisopterus minutus*, and on the slope Norway lobster *Nephrops norvegicus* and greater forkbeard *Phycis blennoides*. 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. When catches were too large to measure each fish, we sampled similar fractions from the cod end and cover.[31] Other commercial species occurred in relatively small numbers, and therefore were not included in the selectivity analysis. Mean percentages of fish escaping the net were estimated from total cod end and cover catch weight by haul.

Assessment of selectivity

In order to determine the 50% selection length (L_{50}) and the selection range (SR) of European hake, Norway lobster, poor cod and greater forkbeard by haul, a standard logistic model was used: $r(l) = \exp(a + b \times l)/[1 + \exp(a + b \times l)]$, where $r(l)$ is the probability that a fish of length l entering the net will be retained by the net. The parameters a and b were estimated by maximizing the log-likelihood function,[32] assuming that the proportions observed are binomially distributed. These parameters were used to calculate the 50% selection length $L_{50} = -a/b$ and the selection range $SR = L_{75} - L_{25} = 2 \times \ln(3)/b$. Covariance matrixes provided the standard errors for parameters a and b. Between-haul variability shown by sorting grid with funnel (BS20-f) and without funnel (BS20) was assessed using the fixed and random (mixed) effects selectivity model.[33]

Long-term effects of implementing sorting grid

We performed a transition analysis to assess long-term effects on yield per recruit (Y/R) and biomass per recruit (B/R) using VIT software.[34] First, we ran a virtual population analysis to estimate mortalities by age produced by the BS20-f and BS20 using the same biological parameters set for the species in the experiment with SM40 (Fig. 3).[25] We assumed steady-state recruitment and constant fishing effort. The program estimates size-at-age from the

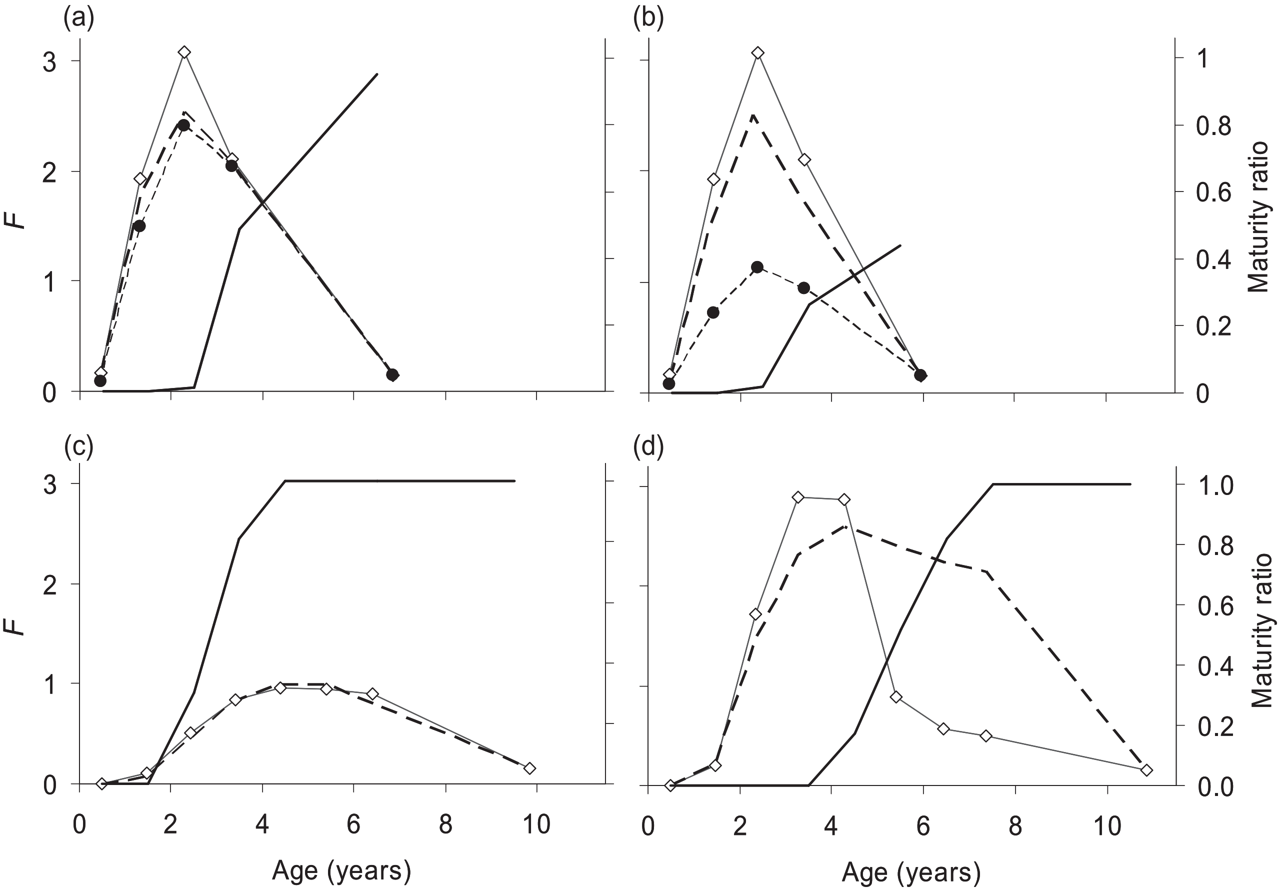

Fig. 3 Fishing mortalities (*F*) by age produced by sorting grid with funnel (●, BS20-f) and without funnel (broken line, BS20), compared with the current fishing mortalities produced with legislated 40-mm diamond mesh cod end (◇, DM40) for (a) European hake, (b) poor cod, (c) Norway lobster and (d) greater forkbeard. Maturity ratios[25] are indicated for comparison with fishing mortalities (solid line).

length distributions according to von Bertalanffy growth curves. The size frequencies were divided into age classes by intervals to determine fishing mortalities (*F*)-at-age. Distributions-at-age were then reconstructed using the general biological parameters of each species.[25] We then ran simulations of Y/R and B/R by shifting current fishing mortalities with DM40[25] to fishing mortalities produced with the BS20. Details of the transition analysis are described in Lleonart and Salat.[34]

RESULTS

Selectivity of BS20

The onboard use of the light and flexible sorting grid did not cause any practical handling problems. The grid could easily be wound onto the net drum. Some problems were encountered with the accumulation of small fish in the netting corners of the grid section. Individual haul selectivity showed significant intrahaul variability for European hake, poor cod and Norway lobster but not for greater forkbeard (Table 1).

Improvement in 50% selection length of all three fish species was obtained with the grid (without a guiding funnel) when compared with the 40-mm diamond mesh cod end (Table 2, Fig. 4). The L_{50}s of European hake (13.2 cm), poor cod (11.8 cm), and greater forkbeard (10.9 cm) are approximately 3, 3 and 1 cm higher than L_{50}s observed with the DM40. A marked improvement in L_{50} is also reached for Norway lobster (with DM40 there is almost no escape).

Marked differences were found in the selectivity performance of the grid equipped with and without the guiding funnel (Table 2). The mean L_{50} of European hake and poor cod was substantially higher with a guiding funnel (17.2 and 14.6 cm, respectively) than without a guiding funnel (13.2 and 11.8 cm, respectively). Further, the selection

Table 1 Selectivity parameters for individual hauls using sorting grid with guiding funnel (BS20-f) and without guiding funnel (BS20)

Haul No.	L_{50}	*SR*	*a*	*b*	R_{i11}	R_{i12}	R_{i22}	Model deviance	AIC	d.f.	*P*
Continental shelf											
European hake											
BS20-f											
17	17.7 ± 1.6	6.1 ± 0.6	−6.381	0.361	0.3135	−0.0190	0.0012	19.1	77	16	0.26
18	16.5 ± 0.7	4.3 ± 0.2	−8.475	0.513	0.1451	−0.0089	0.0006	49.0	114	22	0.00
19	18.0 ± 1.2	8.0 ± 0.6	−4.926	0.274	0.1152	−0.0067	0.0004	27.2	95	17	0.06
20	16.9 ± 0.9	6.6 ± 0.4	−5.663	0.335	0.0910	−0.0054	0.0003	100.5	164	23	0.00
BS20											
21	14.7 ± 6.6	4.1 ± 0.5	−4.879	0.331	0.1281	−0.0084	0.0006	68.9	126	17	0.00
22	12.7 ± 4.5	3.8 ± 0.3	−6.160	0.483	0.1770	−0.0131	0.0010	32.6	83	19	0.03
23	12.1 ± 6.0	3.0 ± 0.6	−4.429	0.365	0.2243	−0.0156	0.0011	46.5	91	17	0.00
24	13.0 ± 7.5	3.4 ± 0.6	−3.805	0.292	0.1494	−0.0094	0.0006	36.9	94	16	0.00
Poor cod											
BS20-f											
18	15.5 ± 1.8	3.6 ± 0.6	−9.439	0.609	1.1918	−0.1078	0.0100	32.0	58	6	0.00
19	13.0 ± 1.7	2.4 ± 0.4	−11.811	0.909	2.4075	−0.2141	0.0193	14.5	37	4	0.01
20	14.3 ± 1.5	3.5 ± 0.4	−9.078	0.636	0.8977	−0.0775	0.0068	22.5	55	8	0.00
BS20											
21	12.9 ± 1.9	3.6 ± 0.9	−9.078	0.636	0.7697	−0.0763	0.0077	22.5	41	8	0.00
22	11.8 ± 1.2	2.4 ± 0.4	−6.683	0.568	0.4511	−0.0431	0.0042	31.8	62	7	0.00
23	11.1 ± 1.5	3.5 ± 0.7	−5.002	0.449	0.4678	−0.0454	0.0045	23.2	53	6	0.00
24	11.9 ± 1.8	3.0 ± 0.5	−8.810	0.742	1.8579	−0.1750	0.0168	2.3	27	5	0.80
Upper slope											
Norway lobster											
BS20											
25	20.5 ± 5.0	9.5 ± 1.7	−4.7235	0.2309	1.3353	−0.0482	0.0018	27.3	55	21	0.16
26	19.2 ± 5.2	11.6 ± 2.2	−3.6338	0.1896	0.9672	−0.0353	0.0013	46.9	71	23	0.00
27	22.1 ± 2.3	6.4 ± 0.6	−7.6249	0.3449	0.6556	−0.0241	0.0009	78.6	90	26	0.00
38	19.5 ± 7.8	9.8 ± 2.7	−4.3774	0.2246	3.0936	−0.1065	0.0037	33.1	44	23	0.08
29	24.9 ± 4.0	7.5 ± 1.0	−7.3176	0.2935	1.3473	−0.0461	0.0016	75.2	88	24	0.00
30	17.0 ± 4.3	10.9 ± 1.6	−3.4188	0.2014	0.7336	−0.0249	0.0009	131.9	94	28	0.00
Greater forkbeard											
BS20											
25	10.6 ± 2.5	5.8 ± 1.1	−4.0163	0.3793	0.9027	−0.0702	0.0056	11.4	42	12	0.50
26	11.1 ± 2.9	8.8 ± 2.0	−2.7713	0.2492	0.5269	−0.0403	0.0032	10.7	51	12	0.55
27	9.7 ± 1.5	4.8 ± 0.6	−4.4264	0.4541	0.4894	−0.0386	0.0031	12.0	52	11	0.36
38	10.9 ± 2.5	7.7 ± 1.6	−3.1134	0.2865	0.5228	−0.0429	0.0036	4.4	43	10	0.93
29	10.7 ± 2.2	7.1 ± 1.2	−3.3215	0.3098	0.4753	−0.0368	0.0029	10.6	50	10	0.39
30	12.0 ± 1.4	4.3 ± 0.5	−6.0783	0.5062	0.5066	−0.0380	0.0029	15.0	56	11	0.18

a and *b*, parameters in logistic equation.
AIC, Akaike information criterion.
d.f., degrees of freedom.
L_{50} and *SR*, selectivity parameters ± standard error.
P, significance of the model deviance.
R_{ixx}, values in covariance matrix.

Table 2 Selectivity parameters obtained for target species using sorting grid with guiding funnel (BS20-f) and without guiding funnel (BS20) relative to parameters reported with diamond mesh cod end (DM40)[5] and square mesh cod end (SM40)[5]

Selectivity estimates	Continental shelf								Upper slope					
	European hake				Poor cod				Norway lobster			Greater forkbeard		
Cod end	BS20-f	BS20	DM40	SM40	BS20-f	BS20	DM40	SM40	BS20	DM40	SM40	BS20	DM40	SM40
Number of valid hauls	4	4	8	11	3	4	5	5	6	4	5	6	4	5
No. individuals in cod end	1872	2384	11 366	4059	168	450	2747	419	3710	3996	4968	1712	2091	974
No. individuals in cover	3339	1522	2 994	7242	2361	1314	2917	12 373	441	18	557	701	234	2502
L_{50}	17.2	13.2	10.1	16	14.6	11.8	9.2	13.0	20.5	–	22.0	10.9	9.8	15.0
SR	6.2	3.6	3.1	3.2	3.6	3.1	3.0	3.0	9.3	–	6.5	6.4	2.6	3.0
Standard deviation of L_{50}	0.3	0.6	0.2	0.2	0.7	0.4	0.2	0.6	1.1	–	0.5	0.3	0.7	0.4
Standard deviation of *SR*	0.8	0.2	0.2	0.2	0.3	0.3	0.5	0.6	0.8	–	0.5	0.7	0.5	0.3
SR/L_{50}	0.36	0.27	0.31	0.20	0.25	0.26	0.33	0.23	0.45	–	0.30	0.59	0.27	0.20
Degree of freedom	6	6	14	19	4	6	8	7	10	–	8	10	6	7
Minimum landing size	20 cm				11 cm				20 mm CL			not regulated		

CL, carapace length.
L_{50} and *SR*, selectivity parameters.

range (*SR*) for European hake was much higher with the guiding funnel (6.2 cm) than without the guiding funnel (3.6 cm), but for poor cod it remained about the same (3.6 and 3.1 cm, respectively).

The mean percentage of fish (total weight) escaping the net equipped with a grid using a guiding funnel was 51%. These results were similar to those obtained with the SM40 (48%) and much higher than for the DM40 (29%).[5]

Y/R and B/R when switching to sorting grid

On the continental shelf, there would in the long run be an increase of 55 and 40% in the Y/R of European hake and poor cod, respectively, when introducing a sorting grid equipped with a guiding funnel (BS20-f, Fig. 5). The BS20 without a guiding funnel would produce less improvement in the Y/R (30% for hake and 10% for poor cod). On the upper slope, only a slight (<10%) improvement in Y/R would be obtained with the introduction of the BS20 for Norway lobster and greater forkbeard (Fig. 5). During the first year after introducing the grid, there was a substantial reduction in Y/R for the three fish species.

The use of BS20 with a guiding funnel on the continental shelf increased the B/R of European hake and poor cod by more than 100 and 200%, respectively (Fig. 5). The BS20 without a guiding funnel made the B/R of all species increase less than 55%. In the upper slope, the improvement in B/R of Norway lobster and greater forkbeard was less than 10%.

DISCUSSION

Our trials demonstrate that substantial improvement in size-selectivity of European hake, poor cod, greater forkbeard and Norway lobster can be achieved by adding a 20-mm sorting grid in front of the current 40-mm diamond mesh cod end.[5] The estimated 50% selection length for hake (17 cm) with the sorting grid equipped with a guiding funnel is close to the current minimum landing size (20 cm) and noticeably higher than that of the 40-mm diamond mesh cod end (L_{50} = 10 cm). A 20-mm sorting grid would represent a marked improvement in the harvesting pattern of this commercially important species. However, it is notable that the length at first maturity of hake in the Western Mediterranean is approximately 22–32 cm for males and 30–39 cm for females, according to Recasens *et al.*[6] and Froese and Pauly available from http://

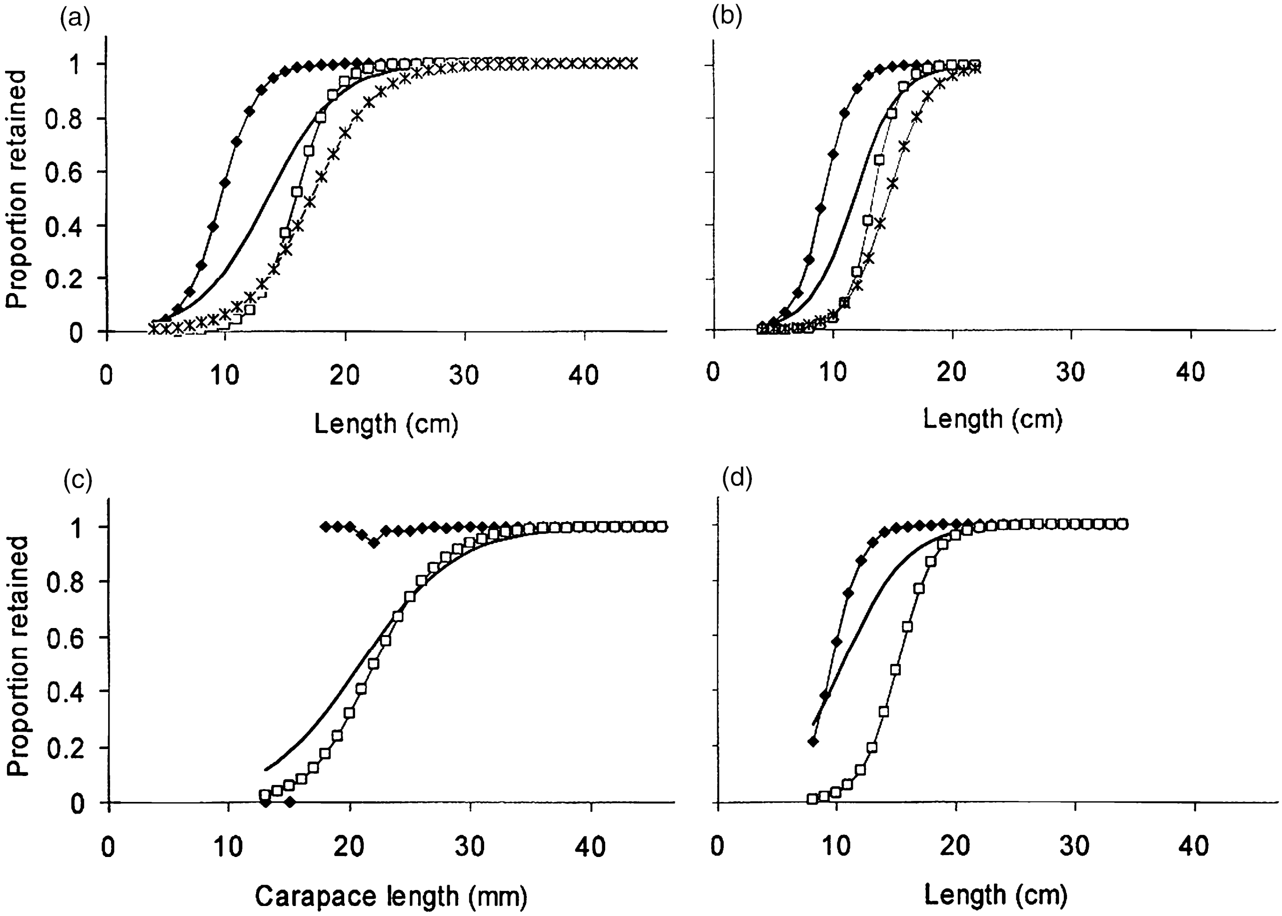

Fig. 4 The 50% selection curves for (a) European hake, (b) poor cod, (c) Norway lobster and (d) greater forkbeard with 40-mm diamond mesh (◆, DM40) and 40-mm square mesh (□, SM40) cod ends (Bahamon *et al.*[5]), and 20-mm sorting grid with funnel (*, BS20-f) and without funnel (solid line, BS20) from the present work. Diamond mesh cod end was not selective for Norway lobster; therefore, no selectivity curve was fitted (◆, observations).

Table 3 Variation of proportions in weight (%) of Y/R and B/R at sixth year after introducing 20-mm sorting grid with guiding funnel (BS20-f) and without guiding funnel (BS20), and a 40-mm square mesh cod end (SM40)[†‡]

	European hake			Poor cod			Greater forkbeard		Norway lobster	
	BS20-f	BS20	SM40	BS20-f	BS20	SM40	BS20	SM40	BS20	SM40
Y/R	54	35	55	38	11	20	8	30	5	7
B/R	100	61	120	210	25	85	10	35	4	5

†Results for simulations after introducing an SM40, after Bahamon *et al.*[25]
‡Current proportions were compared from model simulations run with the same program (VIT)[25] and using the same biological parameters.

www.fishbase.org (ver. 10/2005). Hence, a substantially larger bar space in the grid would be required if the spawn-at-least-once rule was to be satisfied for this species.

Flexibility in the grid design was a marked practical improvement compared with the earlier rigid sorting grids.[13] However, the long-term mechanical strength and durability for repeated bending may be a concern. Excessive flexibility and lower stiffness of the grid bars may also result in variation of bar spacing.[21]

Our experiments suggest that the performance of the grid is highly sensitive to the existence of a funnel to guide the fish against the grid. The guiding funnel tested markedly affected the 50% selection length and the selection range of hake.

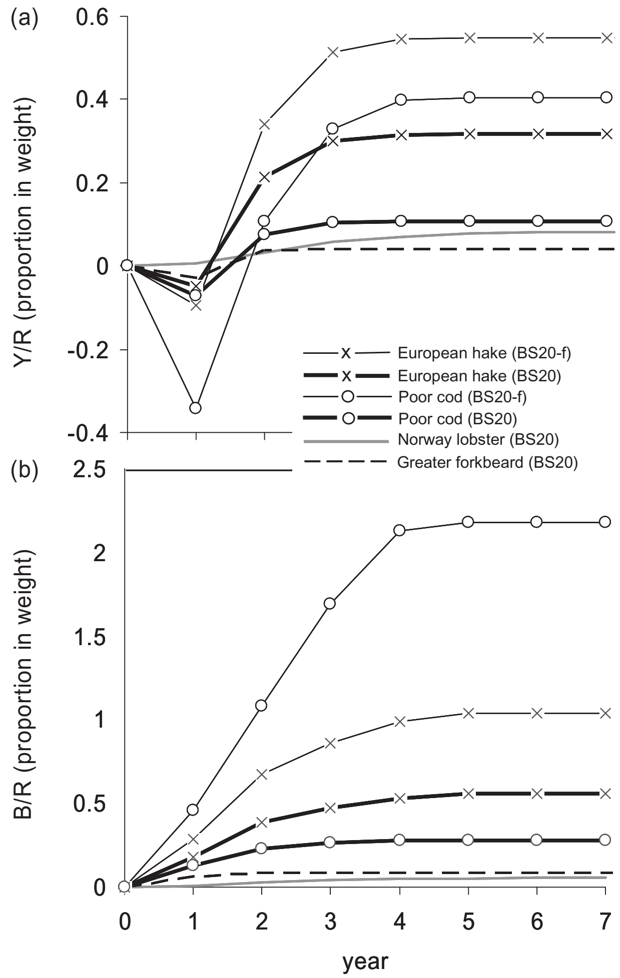

Fig. 5 Effects on the (a) yield per recruit (Y/R) and (b) biomass per recruit (B/R) for the selected target species after introducing a sorting grid with funnel (BS20-f) and without funnel (BS20).

This is likely related to hydrodynamic[35] and behavioral factors. Nevertheless, it is not clear why the selection range of hake increased so strongly when the funnel was used. Guiding funnels often cause problematic water turbulence in front of the grid and may thereby cause serious problems in the selectivity performance.[17,22] Various species and size-groups will likely react in different ways. Detailed underwater video observations are necessary to clarify these behavioral features. Clearly, further research is required in the design of the guiding funnel used in front of the sorting grid.

The 50% selection length for European hake and poor cod when using the 20-mm sorting grid equipped with a guiding funnel was slightly higher than that of the 40-mm square mesh cod end, but slightly lower without a guiding funnel (Fig. 4). When comparing the performances of SG20-f and SG20 to SM40, there was no marked difference in L_{50}s.[5] The selection range, however, generally appears to be narrower with the square mesh cod end.[5]

The evaluated species showed a different response when comparing the model simulations of Y/R and B/R after introducing the 20-mm grid (BS20-f) and the 40-mm square mesh cod end.[25] The Y/R and B/R of European hake was about the same for the two sorting devices (Table 3), while for poor cod, substantial improvements of Y/R and B/R were observed (Table 3). In contrast, the grid without the guiding funnel (BS20) produced Y/R and B/*R* values lower than those produced with the square mesh cod end; the smallest difference was observed for Norway lobster (Table 3).

Although the first-year effect of introducing a sorting grid on yield per recruit would be negative for all fish species (European hake, poor cod and greater forkbeard), the long-term effects on yield and biomass per recruit would be positive for the four target species (the three fish species plus Norway lobster). However, survival of escaped fish[36] is an issue that remains to be investigated.

CONCLUSION

The flexible grid tested in this study would help to improve the overall exploitation pattern in the Mediterranean multispecies trawl fishery. We acknowledge, however, that a sorting grid would not be efficient for all commercial species. In a highly multispecies fishery, no single solution is suitable for all species.[37] 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.[14,15,22] However, 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. Further development work is required if the sorting grid is to be introduced into commercial fishery.

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