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Reduction of Unwanted By-Catch in the Portuguese Crustacean Trawl Fishery Through the Use of Square Mesh Windows

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Abstract: The utility of square mesh windows as by-catch excluders when placed either in the trawl upper belly or at the top of the cod-end is examined for a number of species captured off the Portuguese south coast. Data were obtained for the blue whiting, *Micromesistius poutassou* (Risso, 1826), the boarfish, *Capros aper* (L.), the horse mackerel, *Trachurus trachurus* (L.), the blue jack mackerel, *Trachurus picturatus* (Bowdich, 1825), the chub mackerel, *Scomber japonicus* Houttuyn, 1782, the European hake, *Merluccius merluccius* (L.) and the rose shrimp, *Parapenaeus longirostris* (Lucas, 1846). Active escape behaviour was evidenced for blue whiting and blue jack mackerel, these being the only species escaping in significant amounts, particularly when the square mesh window was placed on the top of cod-end (54 and 48%, in weight, respectively). For the remaining fish species, the data suggest the need for appropriate stimuli in order to improve escape behaviour. The losses of shrimps were equal for both window locations (about 11%, in weight).

Key words: Trawl selectivity, by-catch reduction devices, square mesh windows, *Micromesistius poutassou*, *Capros aper*, *Trachurus trachurus*, *Trachurus picturatus*, *Scomber japonicus*, *Merluccius merluccius*, *Parapenaeus longirostris*, portuguese continental waters

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INTRODUCTION

Following the research on full square mesh codends during the 1980's (Robertson and Stewart, 1988), the use of Square Mesh Windows (SMWs) as trawl By-catch Reduction Devices (BRDs) has been extensively examined since the early 90's, with a particular emphasis in the European Union countries, for Norway lobster, *Nephrops norvegicus* L., in trawl fisheries (Arkley, 1990; Ulmestrand and Larsson, 1991; Briggs, 1992; Thorsteinsson, 1992; Briggs and Robertson, 1993; Robertson and Shanks, 1994) and later in Australia, for prawns (Broadhurst and Kennelly, 1995, 1996, 1997; Broadhurst *et al*., 1996). They have been recognized as preferential zones of escape, when placed in the cod-ends or in other strategically chosen sections of trawls, by creating visual stimuli (Glass *et al*., 1993) and by modifying the water flow inside the trawl (Broadhurst *et al*., 1999) thus enhancing fish escape behaviour.

More recently, besides their use in crustacean targeted fisheries to exclude the fish by-catch species, such as haddock, *Melanogrammus aeglefinus* (L.), whiting, *Merlangius merlangus* (L.), cod, *Gadus morhua* L., or blue whiting, *Micromesistius poutassou* (Risso 1827) (Armstrong *et al*., 1998; Madsen *et al*., 1999; Campos and Fonseca, 2004), SMWs have been tested in squid fisheries also for

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fish by catch reduction (Hendrickson, 2005; Scandrol *et al*., 2006). Furthermore, SMWs use in flatfish and roundfish targeted fisheries, both for excluding juveniles or other fish bycatch, has been subject of an intensive research work (Madsen *et al*., 1998; Graham and Kynoch, 2001; Madsen *et al*., 2002; Graham *et al*., 2003; Madsen and Staehr, 2005; Madsen *et al*., 2006).

Their effectiveness as BRDs first made their use mandatory in Irish and UK *Nephrops* fisheries, being subsequently incorporated in the European Union legislation for that species, as top windows (Council Regulation 850/98) or cod-end side windows for Baltic Sea cod fisheries (Council Regulation 3362/94 and Council Regulation No. 48/99).

The exclusion of fish by-catch in the crustacean trawl fishery off the coast of Algarve (south Portugal), by using a 100 mm square mesh window alone mounted in the upper belly before the cod-end joining row, was previously addressed by Campos and Fonseca (2004) during a short experiment in May 1994. Blue whiting, *Micromesistius poutassou* (Risso, 1826) was the only species for which active escape behaviour was recorded, attaining a mean escape rate of 67% of the total weight per haul. For the rose shrimp, *Parapenaeus longirostris* (Lucas, 1846), one of the target species in this fishery, high losses were reported with 24% of escapees above the minimum landing size of 24 mm. These results, although based on a small number of hauls, suggest that the often considerable amount of low or non-commercially valuable fish by-catch in crustacean trawling may be reduced by the use of square mesh windows, provided that losses of target species are minimized. For this purpose, further trials were carried out placing the windows either in the top belly of the trawl or on the top of the cod-end. Data herein presented describe the effectiveness of both arrangements in the exclusion of the main by-catch species, along with losses of shrimps.

MATERIALS AND METHODS

The data were collected during an experiment carried out off the south coast of Portugal from 14 -21 April 1998, on board the R/V Noruega from IPIMAR, a 1500 HP stern trawler. Altogether, 23 valid hauls with duration of 1 h each were carried out during the day in rose shrimp fishing grounds, between Lagos in the west and Tavira in the east, at depths from 200 to 375 m (Fig. 1). The trawl used

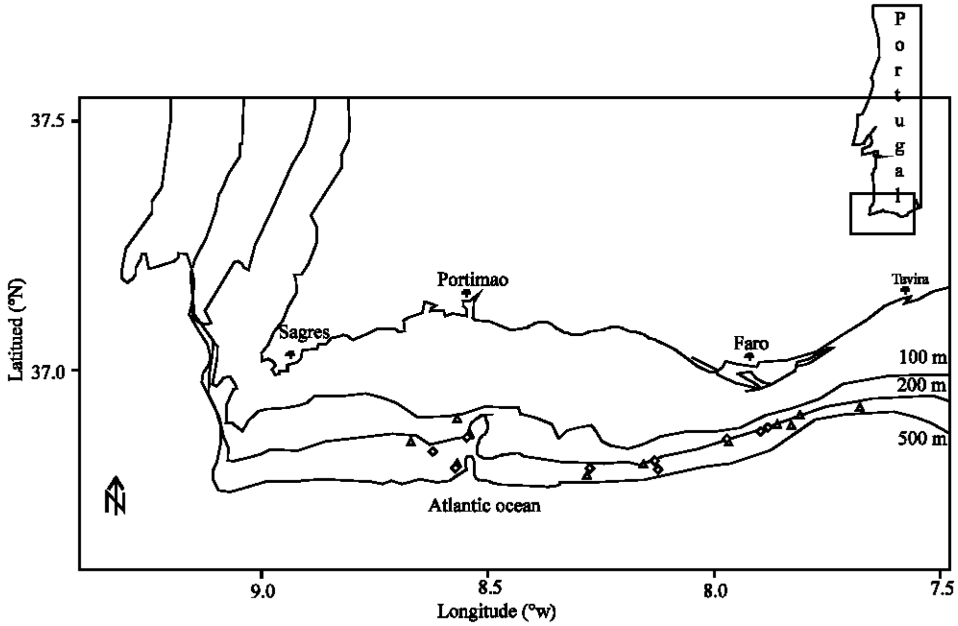

Fig. 1: Location of the fishing hauls. SMW1 (△); SMW2 (◇)

(Fig. 2) was made up of twisted polyethylene, had a length of about 48.5 m from the wing tips to the cod-end joining row and a circumference of 608 meshes of 140 mm at the footrope level. Headline height ranged from 2.4-2.7 m and wingend spread from 21-27 m, as measured by Scanmar sensors, when the trawl was rigged with 100 m bridles and Portuguese Sounete otterboards of 650 kg each. Trawling speed was approximately 3.0-3.3 knots. A cod-end made of 20 mm mesh size twisted polyamide was used in order to retain the entire catch size range.

Two different windows of 100 mm mesh size made of white twisted PA 2.0 mm diameter were tested. Technical drawings of the square mesh windows and details of the installation are given in Fig. 3. In the first 12 hauls, a window with dimensions of 37×60 bars in width and length, respectively

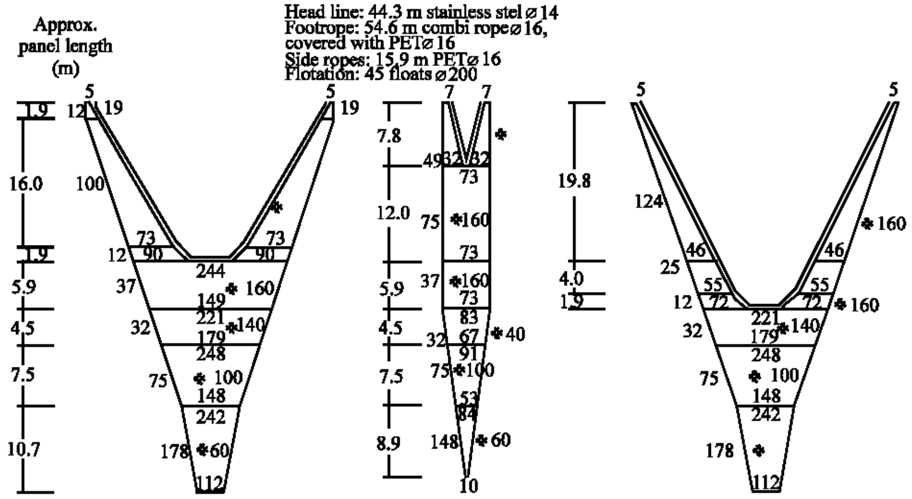

Fig. 2: Technical drawing of the trawl

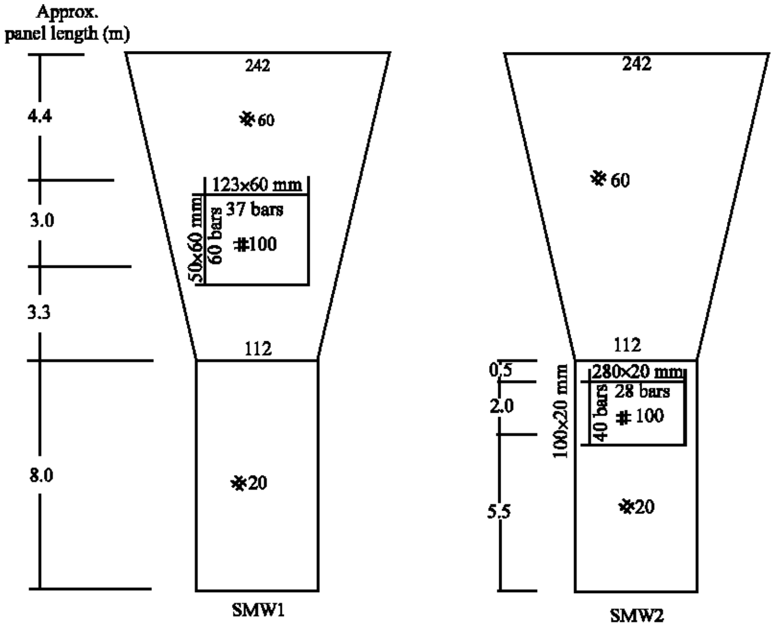

Fig. 3: Technical drawing of the square mesh windows and their instalation in the trawl

was placed in the upper belly 3.3 m before the cod-end (SMW 1), while in the following 11 hauls (SMW 2) a smaller window of 28×40 bars was placed in the cod-end top panel, 0.5 m after the cod-end joining row. The control of the number of individuals escaping through the square mesh windows was achieved by means of a top cover of 45 mm mesh size in twisted PET, according to technical specifications in Wileman *et al*. (1996). The cover ended in a collecting bag of the same characteristics as the cod-end.

After hauling up, catches from cod-end and cover were handled separately and weighed. Carapace length and total length were measured for rose shrimp and for the most important fish species (except the boarfish, *Capros aper* (L.)), to the millimetre and centimetre below, respectively. For horse mackerel, *Trachurus trachurus* (L.), blue jack mackerel, *Trachurus picturatus* (Bowdich, 1825), chub mackerel, *Scomber japonicus* Houttuyn, 1782 and European hake, *Merluccius merluccius* (L.), the whole catch was always measured, while for the remaining species, caught in greater numbers, sub-sampling was carried out in most of the hauls. The length class frequencies for each species in sub-sampled hauls were estimated by scaling up the measured frequencies in the sub-samples (cod-end and cover) by the inverse of the sampling proportions.

A Wilcoxon rank-sum test (Conover, 1980) was used to evaluate the significance of the differences between the escape proportions (in weight and in number) for the species studied, for the two groups of hauls, herein referred to as SMW1 and SMW2.

RESULTS

General information on the hauls and catches can be found in Table 1. Blue whiting was the most important species in weight in most hauls, particularly those for depths below 300 m, followed by the horse mackerel, which was significantly caught only in a small number of hauls. A large catch of boarfish was recorded only once, while the remaining species were scarcely represented in the catches. Rose shrimp, for which catches in numbers were high, accounted for just a small percentage of the total catch weight in 16 out of the 23 hauls carried out (Table 1).

Table 1: Fishing yields (kg h^{-1}) by haul, for the most important species

				Fishing yields (kg h^{-1})							
Window	Haul N°	Date	Average depth (m)	Total	Rose shrimp	Blue whiting	Boarfish	Horse mackerel	European hake	Mackerel	Blue jack mackerel
SMW1	1	14 Apr. 98	225	595	1.3	39.0	449.0	50.3	19.0	32.0	4.3
	2	15 Apr. 98	241	102	2.7	2.1	26.7	17.2	22.5	23.3	3.3
	3	15 Apr. 98	321	419	3.6	152.0		200.4	23.5	29.8	8.9
	4	15 Apr. 98	225	173	2.3	19.3	33.4	49.4	26.7	29.1	5.3
	5	16 Apr. 98	304	112	2.6	103.0		3.5	1.6	1.8	
	6	16 Apr. 98	373	59	2.5	56.0			0.8		
	7	16 Apr. 98	262	100	8.9	18.0	70.1	0.3	3.0		
	8	16 Apr. 98	213	19	9.4	0.2		0.9	2.0	6.1	
	9	17 Apr. 98	212	106	39.0	36.0		0.3	30.5		
	10	17 Apr. 98	255	68	24.0	6.0		0.2	37.4		
	11	18 Apr. 98	341	370	4.1	365.0		0.6			
	12	18 Apr. 98	284	51	22.2	7.9		0.9	20.0	0.4	
SMW2	13	19 Apr. 98	218	136	18.5	46.0	34.0	2.3	29.6	5.1	
	14	19 Apr. 98	204	28	9.4	9.8		3.3	5.4	0.1	
	15	19 Apr. 98	217	54	25.5	2.3		4.4	20.7	0.7	
	16	19 Apr. 98	252	56	8.5	2.1	42.8	0.5	2.1		
	17	20 Apr. 98	364	17	2.9	11.8			0.9		
	18	20 Apr. 98	300	31	7.9	20.3		0.3	2.5		
	19	20 Apr. 98	324	173	2.2	162.0		5.6	3.5		
	20	20 Apr. 98	253	581	2.9	483.0		78.1	10.2	0.2	6.5
	21	20 Apr. 98	228	233	5.5	196.0		17.2	13.2		1.3
	22	21 Apr. 98	236	206	4.1	91.0		71.0	12.8	7.9	11.0
	23	21 Apr. 98	343	166	2.4	127.5		30.8	2.0	1.5	1.7

Figure 4 shows the length frequency distributions in the cod-end and cover for the different species, together with the observed escape proportions, using pooled data from the two groups of hauls corresponding to the different window positions (SMW1 and SMW2). The length distributions for all species were approximately the same in both groups, while changes in the abundance between groups can be seen for blue whiting, caught in much greater numbers in SMW2 hauls and for both the horse mackerel and the mackerel, for which catches were much greater in SMW1.

Relatively low percentages of blue whiting and blue jack mackerel escaped (27 and 20% in weight, respectively) when the square mesh window was placed in the trawl rear belly, before the cod-end (SMW1), while 11% escapement was recorded for rose shrimp (Table 2). The use of the square mesh

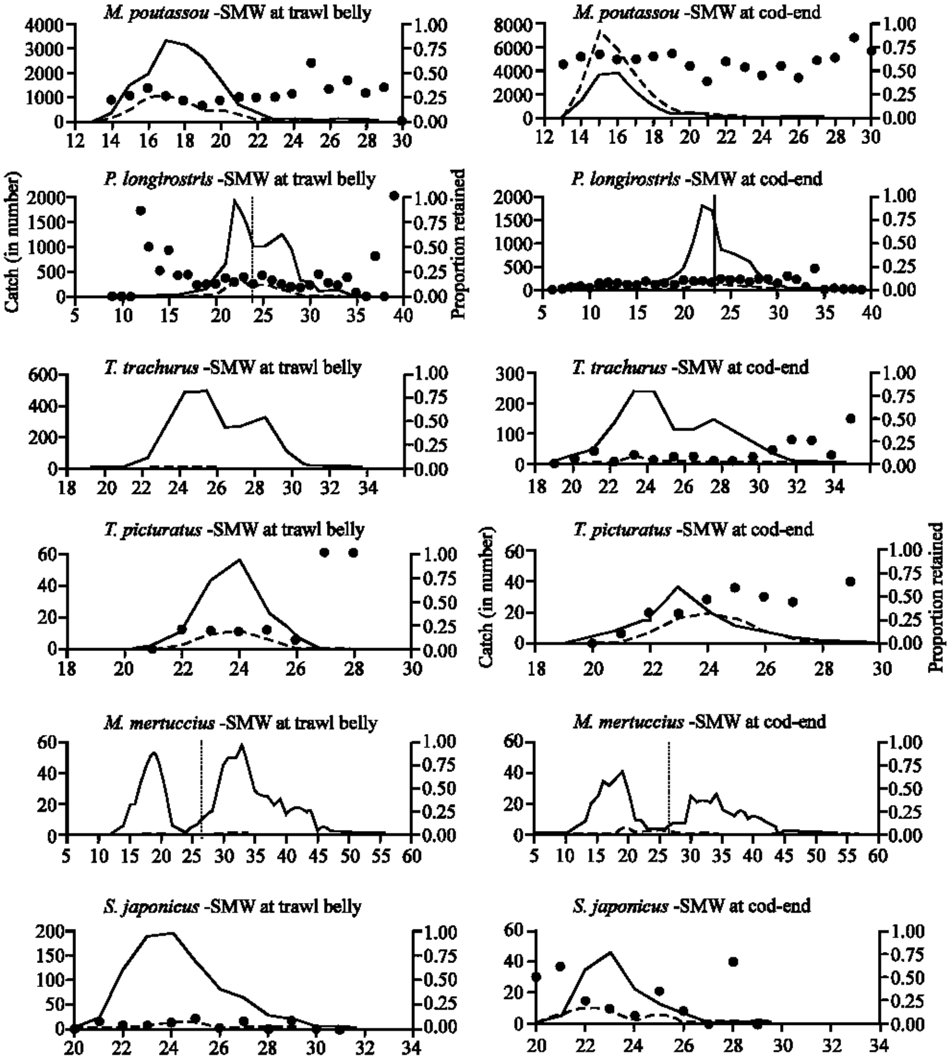

Fig. 4: Size structure of the populations captured along with observed escape proportions. Thin lines correspond to fish retained in the cod-end and dashed lines to fish escaping through the square mesh windows. Dotted vertical lines represent the minimum landing size MLS

Table 2: Average catch percentages excluded through the square mesh window, when it was placed in the rear belly (SMW1) and at cod end (SMW2). Coefficients of variation are in brackets. For blue whiting and boarfish there is N° MLS, while all horse mackerel, chub mackerel and blue jack mackerel caught were above the respective MLS's

Groups	N° hauls		Retained	Escapees	Total catch	Average escape (%)
Rose shrimp						
SMW1	12	Total n°	11373.0	2082.0	13455.0	11.1 (69%)
		<MLS	4992.0	1033.0	6025.0	9.3 (103%)
		≥MLS	6381.0	1049.0	7430.0	10.8 (73%)
		kg	104.7	17.7	122.5	11.0 (63%)
SMW2	11	Total n°	10379.0	1037.0	11416.0	7.9 (50%)
		<MLS	6614.0	581.0	7195.0	8.6 (107%)
		>=MLS	3765.0	456.0	4221.0	9.1 (52%)
		kg	80.5	9.2	89.7	10.6 (63%)
Blue whiting						
SMW1	10	Total n°	15562.0	4815.0	20377.0	26.8 (47%)
		kg	627.5	174.7	802.2	26.6 (46%)
SMW2	9	Total n°	13866.0	23281.0	37147.0	54.0 (31%)
		kg	472.3	675.1	1147.4	53.5 (25%)
Boarfish						
SMW1	4	kg	546.0	33.0	579.0	3.6 (64%)
SMW2	2	kg	68.0	8.8	76.8	12.1
Horse mackerel						
SMW1	5	Total n°	2327.0	16.0	2343.0	0.8 (127%)
		kg	318.5	2.3	320.8	1.0 (115%)
SMW2	5	Total n°	1293.0	95.0	1388.0	8.0 (38%)
		kg	189.2	13.4	202.6	8.0 (40%)
European hake						
SMW1	7	Total n°	721.0	12.0	733.0	1.4 (103%)
		<MLS	207.0	3.0	210.0	1.9 (196%)
		≥MLS	514.0	9.0	523.0	1.3 (107%)
		kg	177.5	2.0	179.5	1.0 (104%)
SMW2	6	Total n°	454.0	23.0	477.0	5.8 (66%)
		<MLS	218.0	14.0	232.0	8.0 (119%)
		≥MLS	236.0	9.0	245.0	3.9 (140%)
		kg	87.8	4.0	91.8	5.3 (78%)
Chub mackerel						
SMW1	5	Total n°	846.0	48.0	894.0	7.6 (115%)
		kg	116.8	3.5	120.3	3.3 (89%)
SMW2	2	Total n°	111.0	28.0	139.0	22.9
		kg	10.5	2.5	13.0	21.5
Blue jack mackerel						
SMW1	4	Total n°	145.0	34.0	179.0	20.7 (49%)
		kg	17.8	3.9	21.7	19.7 (46%)
SMW2	4	Total n°	111.0	73.0	184.0	46.3 (54%)
		kg	12.0	8.6	20.6	48.2 (53%)

window in the cod-end (SMW2) substantially improved these figures for both fish species, with average escape percentages of 54 and 48%, without increasing the escapement for the rose shrimp. Boarfish, one of the potentially most abundant bycatch species in shallower waters, presented only 4% exclusion for SMW1 increasing to about 12% for SMW2. These figures are not surprising since this species has previously shown both a lack of escaping behaviour and a body shape poorly adapted to the square mesh configuration (Campos and Fonseca, 2004). Horse mackerel and hake escape in both situations was almost negligible (1% in SMW1 increasing to 8.0 and 5.3% for SMW2, respectively). Finally, the chub mackerel which had an escape percentage of 3% for SMW 1 attained 22% in the more confined space of the cod-end (SMW2).

High between-haul variability in exclusion was found for most species in both windows settings, particularly for SMW1, as indicated by the values for the coefficients of variation in Table 2. The existence of a relationship between the escape percentages and species catch size (in number) for the different hauls was investigated within both groups. For blue whiting, the most captured species, the percentage excluded was found to be significantly ($R^2 = 0.53$, $p<0.05$) related to the logarithm of catch

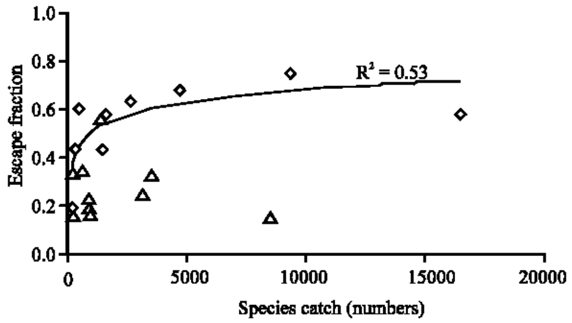

Fig. 5: Relationship between the escape proportion of blue whiting and catch size in the two groups of hauls SMW1 (△) and SMW2 (◇). R^2 for SMW2 was found to be significant (p-value = 0.026)

Table 3: Results of Wilcoxon rank-sum test comparing escapement in the two groups of hauls

	N° hauls		p-value	
Species	SMW1	SMW2	Number	Weight
Rose shrimp	12	11	0.4865	0.9759
Blue whiting	10	9	0.0015	0.0021
Horse mackerel	5	5	0.0079	0.0079
European hake	7	6	0.0260	0.0373
Blue jack mackerel	4	4	0.0571	0.0571

size, for SMW2 (Fig. 5). No clear relationship between escapement and catch size was found for SMW1. For the remaining species, much lower catches were obtained and therefore such correlations were not estimated.

Table 3 shows the results of Wilcoxon rank-test comparing the exclusion in the two groups of hauls. Significant differences ($p<0.05$) between groups, both in numbers and weight, were found for blue whiting, as well as for horse mackerel and hake, while for blue jack mackerel the estimated p-values were close to the confidence limit of $\alpha = 0.05$.

DISCUSSION

For all species except the rose shrimp, escapement through the window increased when it was placed on top of the cod-end. This suggests that most fish entering the net with the window placed in the trawl belly passed below it without making any attempt to escape, while in the more confined space of the cod-end a greater proportion of individuals either reacted to or was forced into direct contact with the square meshes. On the other hand, as has long been recognized (Boddeke, 1996; Hannah *et al*., 2003) shrimps are poor swimmers, showing no active escape behaviour. They are taken passively towards the codend, only displaying a reaction (jumping in a random direction) when they come into contact with the mesh panels. This (lack of) behaviour results in a selection essentially by passive filtering, which contributes to explaining the similar escape rates in both situations.

Blue whiting and blue jack mackerel were the only species that apparently exhibited active escape behaviour, which was enhanced when the square mesh window was placed in the top of the cod-end. For the remaining species escapement was in general low in both situations, although for horse mackerel and hake significant differences were found between SMW1 and SMW2. Chub mackerel was an exception with a low escape rate of 3% in SMW1 and a considerable increase to about 22% in SMW2. Even though the relatively low catches may have contributed to this poor outcome, the results obtained were somewhat unexpected for horse mackerel and chub mackerel, two pelagic species with a good swimming performance, particularly the former, for which there are experimental evidences regarding the effectiveness of square mesh panels (Briggs, 1992; Campos and Fonseca, 2003; Campos *et al*., 2003). The relatively small size of the individuals captured in these experiments (thus weaker swimmers), together with the absence of visual stimuli due to low light levels at deep waters, may explain the poor results for those species. For hake, the lack of escape behaviour confirms previous observations in Namibian waters for two closely related species *Merluccius capensis* (Castelnau, 1861) and *Merluccius paradoxus* (Franca, 1960) (B. Isaksen, IMR, Norway, pers. comm.).

The high between-haul variability in escapement observed for most species was probably a consequence of the low yields. Nevertheless, the variability was generally smaller for SMW2, suggesting that the smaller space available within the codend promotes a more uniform fish escape behaviour. For blue whiting, the positive correlation between the proportion of escapees and catch (in number), when the window was placed on top of the cod-end, suggests that the schooling behaviour may play an important role in the effectiveness of BRDs. Similar observations were made by Campos and Fonseca (2004) for boarfish escaping from a window placed in the trawl belly. No clear size-dependence was found in escapement, indicating that the 100 mm square mesh window is too large to induce a differential escape by length for these species within the length range captured. The exception was the blue jack mackerel for which a clear pattern was noticed for SMW2, with a higher escape proportion (of up to about 0.6) for larger individuals. Although based on small numbers of individuals, this pattern suggests that the larger, more active, individuals have a higher chance of contacting the square mesh window and thus swimming across it.

Comparison of the present results for SMW1 with those previously reported by Campos and Fonseca (2004), where the characteristics and the position of the window were similar, evidences a higher escapement for all the common species (rose shrimp, blue whiting, horse mackerel and boarfish) in the early experiment. It is thought that gear-related characteristics may be on the basis of such differences. The lower vertical opening of the trawl used in early experiments (about 1 m less) and thus the more confined space in the rear area, most certainly increased the probability of contact with the square mesh window, thereby enhancing escapement.

CONCLUSIONS

Overall results indicate that the square mesh windows tested were of little efficiency as by-catch reduction devices, except for blue whiting and the blue jack mackerel for the SMW mounted on top of the cod-end. Furthermore, the 11% loss (in weight) of rose shrimp, although not too high compared to what was noticed in other crustacean fisheries where square mesh windows were introduced, will probably be perceived as unacceptable by fishermen. On the other hand, escapement was not generally observed to be size-dependent, indicating that the window mesh size was too large for the exclusion of undersized commercial fish by-catch, while retaining those above minimum landing size. The higher vertical opening of the trawl tested in these experiments, possibly decreasing the probability of contact with the square mesh window, can partially explain the poor results obtained in excluding by-catch. It is suggested that better results for the small pelagic species could be obtained with top cod-end windows placed in low opening trawls similar to that used by Campos and Fonseca (2004). Furthermore, testing of cod-ends using alternative window designs and placement should be considered.

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