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Research Article

Relative efficiency of square-mesh codends in an artisanal fishery in southern Brazil

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ABSTRACT. The relative efficiency of two square-mesh codend designs with the same circumference (~2 m) but different mesh sizes and materials (32 mm polyethylene-PE and 30 mm polyamide-PA) was tested in an artisanal shrimp trawl fishery in Paraná, southern Brazil. The two square-mesh codends were hauled alternately with a 26 mm diamond-shaped mesh codend (control) in a twin gear configuration. Although not significant, the mean numbers of total bycatch were reduced by 16.6 and 10.0% with the 32 and 30 mm square-mesh codends, respectively. The results indicate significant improvement in size selectivity for some species (*Xiphopenaeus kroyeri* and *Stellifer rastrifer*). The operational changes tested can be a suitable technical solution for reducing the capture of immature organisms in the shrimp trawl fishery in Paraná, Brazil.

Keywords: discards, shrimp fishery, bycatch reduction devices, square-mesh, size selection, fisheries management, southern Brazil.

Eficiencia relativa de copos de malla cuadrada en una pesquería artesanal del sur de Brasil

RESUMEN. La eficiencia relativa de dos diseños de copos con malla cuadrada con la misma circunferencia (~2 m) pero diferentes tamaños de malla y materiales (32 mm de polietileno-PE y 30 mm de poliamida PA) ha sido evaluada en una pesquería de arrastre artesanal de camarón en Paraná, sur de Brasil. Los dos copos de malla cuadrada fueron arrastrados alternativamente con un copo de malla de 26 mm en forma de diamante (control) en una configuración de doble arrastre. Aunque no es significativo, el número medio de la captura incidental total se redujo en 16,6 y 10,0% en los copos de malla cuadrada de 32 y 30 mm, respectivamente. Los resultados indican que se logra una significativa mejora en la selectividad por tamaño medio de algunas especies (*Xiphopenaeus kroyeri* y *Stellifer rastrifer*). Los cambios operacionales evaluados pueden representar una solución técnica adecuada para reducir las capturas de organismos inmaduros en la pesquería de arrastre de camarón en Paraná, Brasil.

Palabras clave: descarte, pesca del camarón, dispositivos de reducción de capturas incidentales, malla cuadrada, selección por tamaño, gestión pesquera, sur de Brasil.

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INTRODUCTION

Southern Brazilian artisanal trawl fisheries are noteworthy for their large catches of seabob shrimp (*Xiphopenaeus kroyeri*). This penaeid species, globally ranked among the top five wild-caught penaeids (Gillett, 2008), has typically 10- to 30-mm carapace length CL and accounts for more than 5,000 ton harvested each year in Brazil (IBAMA, 2005). Bottom trawling for shrimp is one of the most common fishing practices in the southern region of Brazil (Andriguetto-Filho *et al*., 2009) and like most penaeid-trawl fisheries worldwide, owing to the small meshes used, it is responsible for the retention of large quantities of unwanted organisms (collectively named 'bycatch'; Hall, 1996) that are consequently discarded.

Southern Brazilian artisanal trawlers discard all of their bycatch, which mainly comprises small teleosts (*e.g.* sciaenids) and brachyurids (Silva *et al.*, 2011).

In recent years, concerns about the impact on stocks of important bycatch species by penaeid trawls have resulted in efforts at improving selectivity, as a part of an ecosystem-based approach to fisheries management (Cochrane, 2002). An inexpensive and simple modification to improve the selectivity of some penaeid trawls involves changing only the configuration of mesh in the codend by hanging conventional diamond-shaped mesh on the bar - termed “square-mesh” (*e.g.* Broadhurst & Kennelly, 1994; Macbeth *et al.*, 2004). Codends made entirely by square meshes are bycatch reduction devices (BRDs) that separate species based on their size - mechanical separation.

Most of the studies describing the development of BRDs for penaeid trawls have originated from developed countries (Broadhurst, 2000). Gillett (2008) states that landed bycatch tend to be much higher in poor tropical countries than in developed countries. Since developing countries greatly contribute towards total global bycatch estimates (Kelleher, 2005), it is of the greatest importance to develop and apply BRDs in these fisheries.

Our aim in this paper was to conduct an experiment with two designs of square-mesh codends under normal fishing operations in southern Brazil to investigate their potential for reducing catches of unwanted organisms, while maintaining the catches of the retained shrimps. This study is the first of its kind in a Brazilian artisanal trawl shrimp fishery.

MATERIALS AND METHODS

The experiment was done during four fishing days in February 2010 off the coast of Paraná, Brazil (25º40’S, 48º30’W) (Fig. 1), using a fibreglass canoe (10 m) powered by a single cylinder 16 kW diesel engine. The two trawls were constructed from 26 mm polyamide-PA mesh throughout the wings and body with 8.8 mm headline and foot rope (see Silva *et al.*, 2011 for a description of the gear and vessels). Zippers (Burazchi S146R) measuring 1.5 m in length were attached to the posterior trawl body to facilitate changing codends. The tow duration was chosen based on conventional fishing practice in the region which is between 30 and 60 min. All hauls were 30 min in duration; done between 07:00 and 13:00 h across sandy bottoms (7-16 m) at ~0.5-0.8 m s^{-1} and manoeuvred by hand. The locations and directions of the tows were decided by local fishers to guarantee conventional fishing practices.

A control diamond-shaped mesh and two square-mesh codends were constructed for the experiment (Fig. 2). The control codend represented existing conventional 26 mm polyamide-PA diamond-mesh designs (1.5 mm twine diameter) used in the artisanal penaied-trawl fishery of southern Brazil. The two treatment codends were made of 32 mm polyethylene-PE (4.0 mm twine diameter) and 30 mm polyamide-PA (1.5 mm twine diameter) square-mesh. The two square-mesh designs were alternately compared against the conventional diamond-mesh codend, rigged in a twin-gear configuration (one on each side of the vessel). Three replicates were done on each day providing a total of 12 hauls for each paired comparison, randomly allocated to each trawl (to eliminate any trawl bias).

After each haul, the contents of each codend were emptied into separate trays and the total weights of *X. kroyeri*, teleosts and brachyurids (and therefore total bycatch) were recorded onboard. The total bycatch and a subsample (n = 50) of *X. kroyeri* were then collected from each codend, stored on ice, separated by species, measured (to the nearest 0.5 cm) and weighted in the laboratory.

After preliminary tests for normality (Shapiro-Wilk´s W test) and for homogeneity of variances (Levene´s test), all variables were analysed with two-tailed, paired *t*-tests ($P < 0.05$), when necessary data were ln(x + 0.1) transformed. Size frequencies of *X. kroyeri* and two abundant key teleosts (*Stellifer rastrifer* and *Selene setapinnis*) were combined across all tows and compared between the square-mesh and their respective control codends using two-sample Kolmogorov-Smirnov tests ($P < 0.01$). Mean sizes of each species (Carapace length (CL) for *X. kroyeri* and Total length (TL) for *S. rastrifer* and *S. setapinnis*) were estimated for each haul and compared between control and square-mesh codends using two-tailed, paired *t*-tests ($P < 0.05$).

RESULTS

Seabob shrimp comprised approximately 75% (in number) of the total catches from the three codends. In total, 46 species (38 teleosts, 1 elasmobranch and 7 crustaceans) were recorded, although more than 70% of the bycatch (in number) comprised only two brachyurids (*Callinectes ornatus* and *Hepatus pudibundus*) and two teleosts (*Stellifer rastrifer* and *Selene setapinnis*) (Table 1). The species composition was consistent with that typically observed in the fishery.

There were no significant differences in terms of weight and number of bycatch retained between

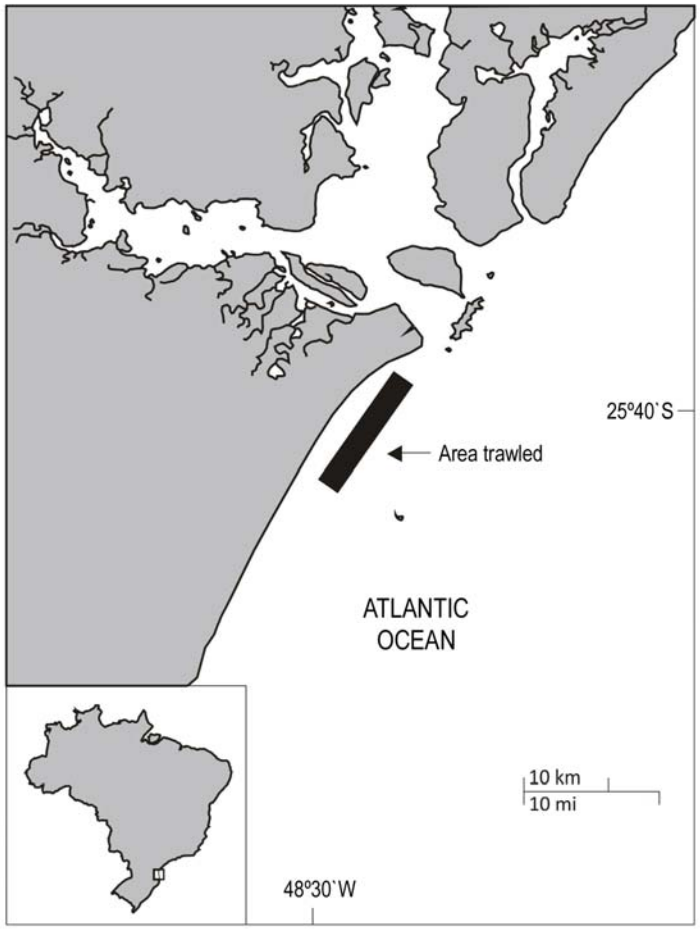

Figure 1. Map showing the location of the coast of Paraná and the area trawled during the experiment.

Figura 1. Mapa mostrando la localización de la costa de Paraná y el área de arrastre durante el experimento.

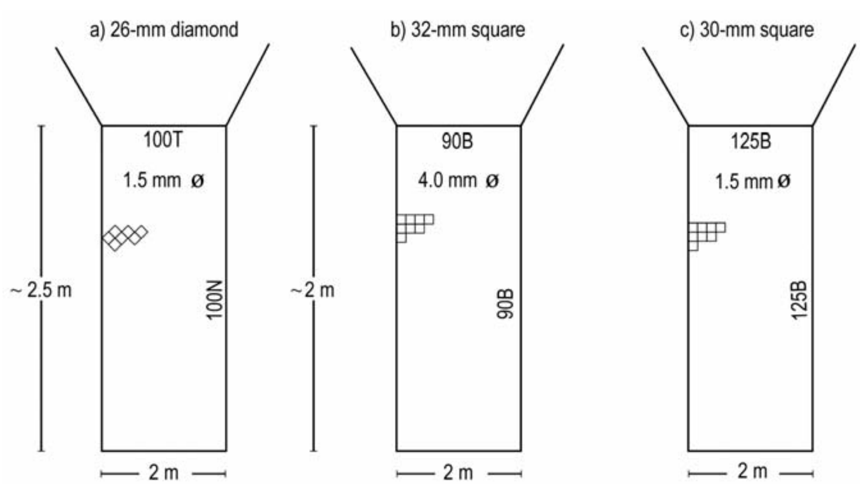

Figure 2. Diagrammatic representation of a) the control 26 mm diamond-shaped mesh polyamide-PA codend, b) the 32 mm square-mesh (22.5 mm outside bar) polyethylene-PE codend, and c) the 30 mm square-mesh (16 mm outside bar) polyamide-PA codend used in the experiment (T: transversals, B: bars, N: normals).

Figura 2. Diagrama de a) copo control de malla diamante de 26 mm de poliamida-PA, b) copo de malla cuadrada de 32 mm (22.5 mm barra externa) de polietileno-PE y c) copo de malla cuadrada de 30 mm (16 mm barra externa) de poliamida-PA usados en los experimentos (T: transversales, B: barras, N: normales).

Table 1. Numbers (n) of organisms caught with the control and square-mesh codends during the four days of experiment and their scientific and common names.

Tabla 1. Números (n) de los organismos capturados con los copos controle y de malla cuadrada al largo de los cuatro días de experimento y sus respectivos nombres científico y común.

Family	Scientific name	Common name	n
Crustaceans			
Penaeidae	*Xiphopenaeus kroyeri*	Seabob shrimp	30909
Aethridae	*Hepatus pudibundus*	Flecked box crab	1115
Leucosiidae	*Persephona punctata*	Purse crab	372
Majidae	*Libinia ferreirae*	Spider crab	24
Portunidae	*Arenaeus cribrarius*	Speckled swimcrab	719
	Callinectes danae	Dana swimming crab	318
	Callinectes ornatus	Shelligs	3564
Teleosts			
Achiridae	*Trinectes microphthalmus*	Sole	10
	Trinectes paulistanus	Slipper sole	41
Ariidae	*Aspistor luniscutis*	Sea catfish	3
	Cathorops spixii	Madamango sea catfish	182
Carangidae	*Chloroscombrus chrysurus*	Atlantic bumper	44
	Hemicaranx amblyrhynchus	Bluntnose jack	9
	Oligoplites saliens	Castin leatherjacket	39
	Selene setapinnis	Atlantic moonfish	585
	Selene vomer	Lookdown	22
	Trachinotus carolinus	Florida pompano	3
Clupeidae	*Chirocentrodon bleekerianus*	Dogtooth herring	39
Cynoglossidae	*Symphurus tessellatus*	Tongue fish	2
Engraulidae	*Anchoa* spp.		3
	Cetengraulis edentulus	Atlantic anchoveta	11
	Lycengraulis grossidens	Atlantic sabretooth anchovy	8
Ephippidae	*Chaetodipterus faber*	Atlantic spadefish	5
Gerreidae	*Diapterus rhombeus*	Silver perch	1
Haemulidae	*Conodon nobilis*	Barred grunt	90
	Pomadasys corvinaeformis	Roughneck grunt	20
Paralichthyidae	*Citharichthys spilopterus*	Bay whiff	9
Polynemidae	*Polydactylus virginicus*	Barbu	35
Pristigasteridae	*Pellona harroweri*	American coastal pellona	161
Sciaenidae	*Bairdiella ronchus*	Ground croaker	78
	Ctenosciaena gracilicirrhus	Barbel drum	2
	Cynoscion jamaicensis	Jamaica weakfish	18
	Isopisthus parvipinnis	Bigtooth corvina	165
	Larimus breviceps	Shorthead drum	81
	Menticirrhus americanus	Southern kingcroaker	8
	Menticirrhus littoralis	Gulf kingcroaker	3
	Micropogonias furnieri	Whitemouth croaker	30
	Paralonchurus brasiliensis	Banded croaker	171
	Stellifer brasiliensis	Drum	236
	Stellifer rastrifer	Rake stardrum	1837
Sphyraenidae	*Sphyraena guachancho*	Guachanche barracuda	1
Stromateidae	*Peprilus paru*	American harvestfish	2
Tetraodontidae	*Sphoeroides testudineus*	Checkered puffer	5
Trichiuridae	*Trichiurus lepturus*	Largehead hairtail	57
Triglidae	*Prionotus punctatus*	Bluewing searobin	1
Elasmobranches			
Narcinidae	*Narcine brasiliensis*	Brazilian electric ray	1

control and square-mesh codends. However, compared to the control, the 32 and 30 mm square-mesh codends retained fewer total bycatch by 16.6 and 10.0%, respectively (*P* > 0.05; Fig. 3b, Table 2). The catches of *X. kroyeri* were not significantly reduced, despite the 32 and 30 mm square-mesh codends having reduced the weights by 4.0 and 3.4% and the numbers by 6.7 and 9.6%, respectively (Fig. 3a, Table 2). Although not significant, the 32 and 30 mm square-mesh codends also reduced the numbers of total fish by 24.0 and 29.9% (Fig. 3c, Table 2). Compared to the control, the 32 mm square-mesh codend caught fewer *S. rastrifer* and *S. setapinnis* (11.5 and 21.4%, respectively) and reduced the weight of *S. setapinnis* by 26.6%, while the 30 mm square-mesh codend caught fewer *S. rastrifer* (in terms of weight and number, 14.4 and 40.9%) (Figs. 3d-3e). Further, none of the square-mesh codends were effective in terms of reducing the catches of brachyurids (Table 2).

Two-sample Kolmogorov-Smirnov tests detected significant differences in the size-frequency distributions of *X. kroyeri* and *S. rastrifer* (*P* < 0.01; Fig. 4a-4b) between the control and the 32 and 30 mm square-mesh codends. There were no significant differences in size-frequencies of *S. setapinnis* between the control and square-mesh codends (Kolmogorov-Smirnov test, *P* > 0.05, Fig. 4c).

Compared to the control, the 32 mm codend caught individuals of *X. kroyeri* with a significantly higher mean carapace length (*P* < 0.05, Table 2, Fig. 5a). Both square-mesh codends (32 and 30 mm) caught significantly bigger individuals of *S. rastrifer* in terms of mean total length, comparing to the control codend (*P* < 0.01, Table 2, Fig. 5b). No other significant differences in terms of mean size between the control and square-mesh codends were detected (*P* > 0.05, Table 2, Figs. 5a and 5c).

Table 2. Summary of two-tailed paired *t*-test comparing catches of *X. kroyeri*, total bycatch, brachyurids, total fish, *S. rastrifer* and *S. setapinnis* and mean sizes of *X. kroyeri*, *S. rastrifer* and *S. setapinnis* between control and square-mesh codends (32 and 30 mm). n = 12. ** Significant differences at *P* < 0.01. * Significant differences at *P* < 0.05, n: number, w: weight, CL: carapace lenght, TL: total length.

Tabla 2. Resumen del teste *t* apareado con dos colas comparando las capturas de *X. kroyeri*, bycatch total, brachyurids, total de peces, *S. rastrifer* y *S. setapinnis* y los tamaños medios de *X. kroyeri*, *S. rastrifer* y *S. setapinnis* entre los copos control y de malla cuadrada de 32 y 30 mm. n = 12. ** Diferencia significativa con *P* < 0,01. * Diferencia significativa con *P* < 0,05; n: número, w: peso, CL: longitud del caparazón, TL: longitud total.

Weight/Number	Control *vs* 32 mm		Control *vs* 30 mm	
	Paired t-value	*P*	Paired t-value	*P*
X. kroyeri (w)	0.213	0.833	-0.042	0.967
X. kroyeri (n)	0.369	0.715	0.224	0.825
Total bycatch (w)	-0.102	0.920	-0.083	0.935
Total bycatch (n)	1.326	0.198	0.857	0.401
Brachyurids (w)	0.345	0.733	-0.523	0.606
Brachyurids (n)	0.629	0.536	-0.163	0.872
Total fish (w)	-0.674	0.507	-0.226	0.823
Total fish (n)	1.805	0.085	1.503	0.147
S. rastrifer (w)	-1.930	0.067	-0.261	0.797
S. rastrifer (n)	0.155	0.879	1.531	0.140
S. setapinnis (w)	1.207	0.240	0.640	0.529
S. setapinnis (n)	1.117	0.276	0.753	0.459
X. kroyeri (CL)	2.201	0.037 *	2.201	0.058
S. rastrifer (TL)	2.110	4.82^{-7} **	2.101	9.25^{-6} **
S. setapinnis (TL)	2.110	0.793	2.086	0.416

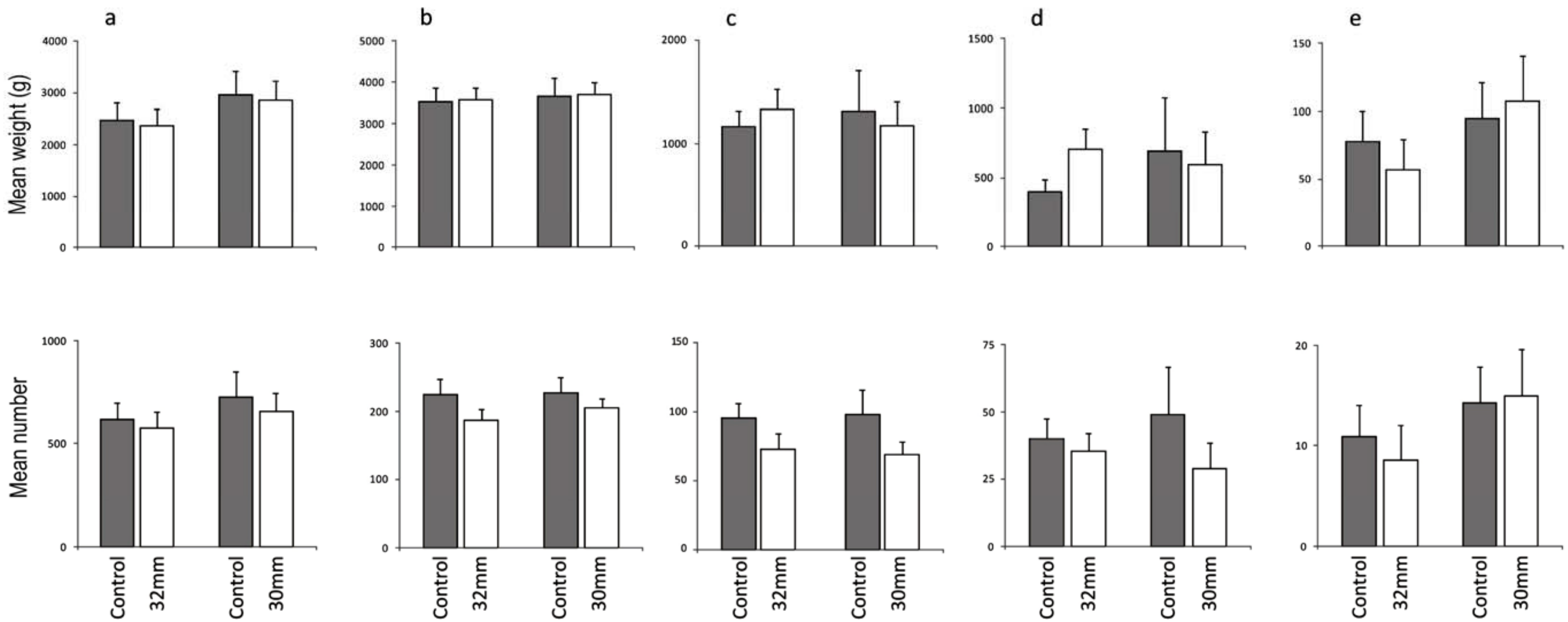

Figure 3. Differences in mean catches ± SE 30 min^{-1} between control (shaded histograms) and square-mesh codends (32 and 30 mm) for the weight and number of a) *Xiphopenaeus kroyeri*, b) total bycatch, c) total fish, d) *Stellifer rastifer* and e) *Selene setapinnis* captured during the experiment.

Figura 3. Diferencias en las capturas medias ± ES 30 min^{-1} entre los copos control (histogramas sombreados) y de malla cuadrada (32 y 30 mm) para el peso y número de a) *Xiphopenaeus kroyeri*, b) *bycatch* total, c) total de peces, d) *Stellifer rastifer* y e) *Selene setapinnis* capturados durante el experimento.

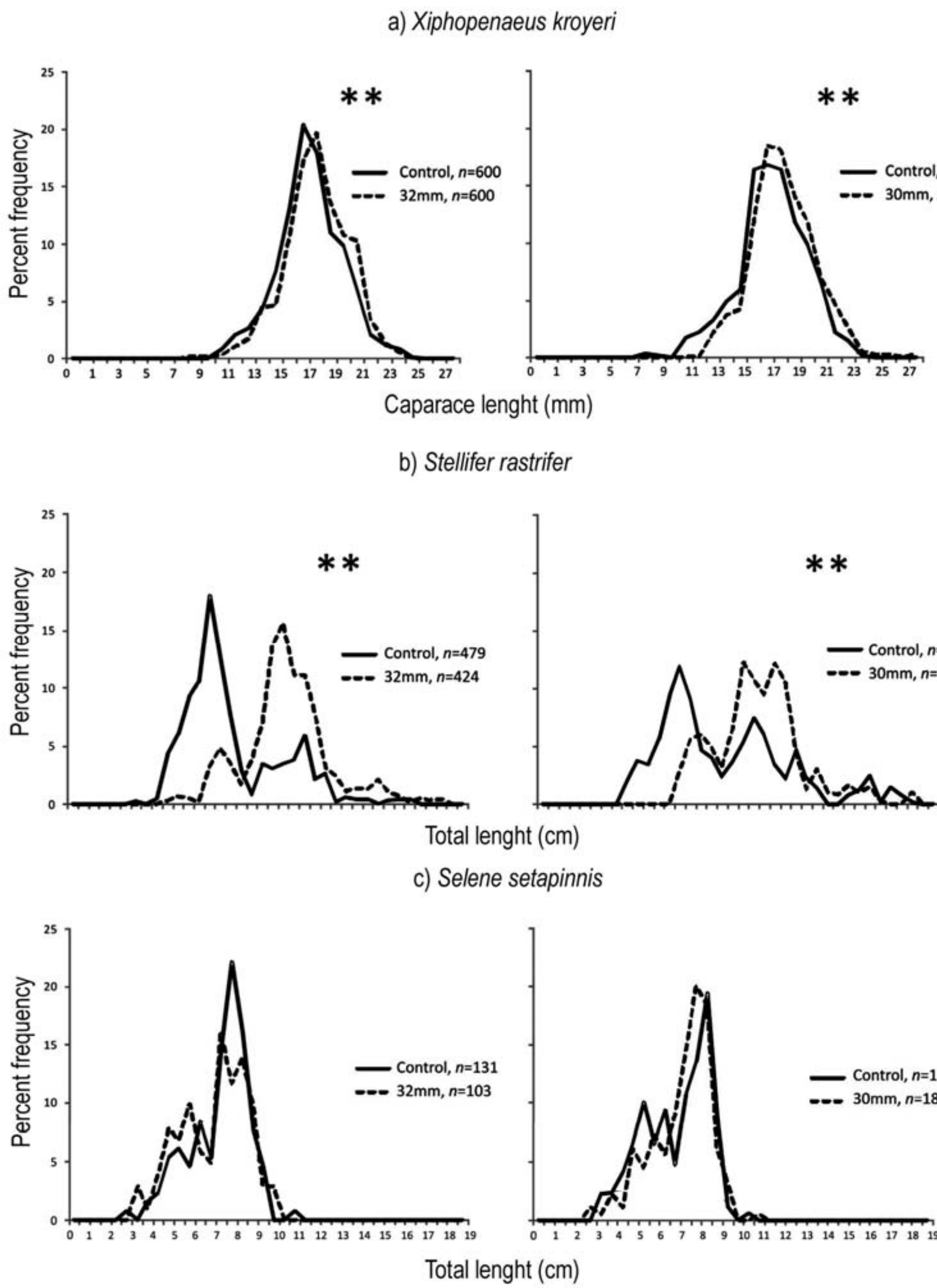

Figure 4. Size-frequency distributions of a) *Xiphopenaeus kroyeri*, b) *Stellifer rastrifer*, and c) *Selene setapinnis* captured with the control and square-mesh codends (32 and 30 mm) during the experiment. ** Significant differences at $P < 0.01$.

Figura 4. Distribuciones de frecuencia de tamaño de a) *Xiphopenaeus kroyeri*, b) *Stellifer rastrifer*, y c) *Selene setapinnis* capturados con los copos control y de malla cuadrada (32 y 30 mm) durante el experimento. ** Diferencia significativa con $P < 0{,}01$.

DISCUSSION

Although the reduction of total bycatch in terms of number and weight was not significant, the results of this experiment tend to support the wide utility of square-mesh codends for releasing small fish and penaeids from trawls, as shown by Bahamon *et al*. (2006), Macbeth *et al*. (2007) and Broadhurst *et al*. (2010). Both the 32 and 30 mm square-mesh codends performed similarly without significantly affecting the catches of *Xiphopenaeus kroyeri*.

Comparing with the control, the 30 mm codend caught fewer total fish and *Stellifer rastrifer* than the 32 mm square-mesh codend (Figs. 3c-3d). Such an

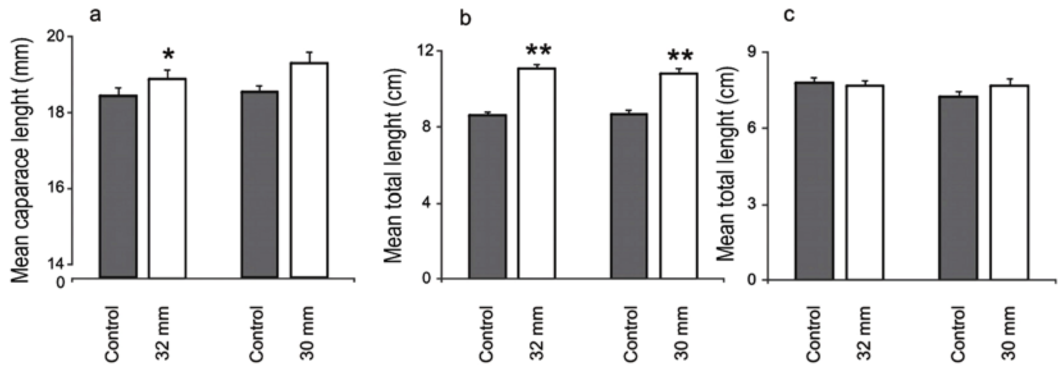

Figure 5. Mean sizes ± SE 30 min^{-1} (between hauls) of: a) *Xiphopenaeus kroyeri*, b) *Stellifer rastrifer*; and c) *Selene setapinnis* captured with the control and square-mesh codends (32 and 30 mm). ** Significant differences at $P < 0.01$, * Significant differences at $P < 0.05$.

Figura 5. Tamaños medios ± ES 30 min^{-1} (entre arrastres) de: a) *Xiphopenaeus kroyeri*, b) *Stellifer rastrifer*; y c) *Selene setapinnis* capturados con los copos control y de malla cuadrada (32 y 30 mm). ** Diferencia significativa con $P < 0,01$, * Diferencia significativa con $P < 0,05$.

apparent negative relationship between selection and mesh size may have been caused because the thick twine diameter of the 32 mm codend resulted in the meshes being more closed and maybe more visible and therefore dissuading escape attempts (Sala *et al.*, 2007). This result may also reflect species-specific behaviour, swimming ability and twine bending stiffness (Herrmann & O´Neill, 2006).

Due to the small sizes of the organisms caught in the fishery, the square-mesh codends had no substantial benefit in terms of reducing the weight of total bycatch; however, although not significant, the reduction in the number of unwanted organisms caught was appreciable. Moreover, there was evidence of an associated dependence of species morphology with the mechanisms by which the square-mesh codends select the catches. Specifically, compared to the conventional codend, both the square-mesh designs contributed to some improvement towards trawl performance which was due to the escape of small individuals of *Stellifer rastrifer*. The significant size-selectivity of *S. rastrifer* may be possibly due to their relatively fusiform body, while *S. setapinnis* has a strongly compressed body (Figs. 4b-4c; Figs. 5b-5c).

Other studies have shown the utility of square-mesh codends to increase and maintain lateral mesh openings in demersal trawls (Broadhurst *et al.*, 2004, 2010; Macbeth *et al.*, 2007). Due to this fact, the square meshes allow more small fishes and penaeids to escape than the diamond-meshes. In this study, the 30 and 32 mm square-mesh codends caught individuals of *S. rastrifer* with a significant higher mean total length than individuals from the control (Fig. 5b); similarly, the 32 mm square-mesh codend caught seabob shrimp with a significant higher mean carapace length than the control codend (Fig. 5a) which indicates the escape of small fishes and shrimps through the square meshes. Moreover, comparing to the diamond-mesh codends, the square-mesh codends are the best alternative in terms of minimising the damage of escapees, as proved by Farmer *et al.* (1998).

As observed in many of the world´s shrimp-trawl fisheries (*e.g.* Liggins *et al.*, 1996; Kennelly *et al.*, 1998; Sala *et al.*, 2008) fish that comprise bycatches are usually quite small (< 20 cm long) and often juveniles. Seabob shrimp is a smaller species of penaeid (usually < 10 cm long) and, as bycatch fish species have a similar size it may be possible to reduce more effectively bycatches by a behavioural separating mechanism. For example, a square-mesh panel “strategically” positioned in the codend separates species based on the characteristic escape response of fishes to trawls (see Broadhurst, 2000 for a review).

Like other studies (*e.g.* Macbeth *et al.*, 2005) the data suggest that the codends made of diamond-mesh used in the fishery are less selective than the square-mesh codends tested and, since the catches of seabob shrimp were not affected, it should be feasible to use larger sizes of mesh. Further research is required, therefore, to explore the utility of different operational changes in the fishing gear configurations in the fishery. Additionally, future experiments should be replicated under different operational conditions (*e.g.* longer hauls) and in different periods of the year to encompass changes in the size structure of the species in order to modify the codends design and improve the efficiency of the artisanal penaeid trawl nets. Additionally, given that there were few (if any) negative impacts to the fishing operation associated with using square-mesh codends and the netting materials are locally available, enforcing the use of square-mesh codends in the southern Brazilian artisanal penaeid fishery would be a suitable technical solution to reduce the capture of immature fish. Assuming most of these escaping individuals survive (Broadhurst *et al*., 2006), such a management option should translate to a reduction in impacts on the stocks of key species.

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