Lat. Am. J. Aquat. Res., 37(2): 221-230, 2009
DOI: 10.3856/vol37-issue2-fulltext-9

Research Article

Improved interspecific selectivity of nylon shrimp (*Heterocarpus reedi)* trawling in Chile

Dante Queirolo[1], Mauricio Ahumada[1], Erick Gaete[1], Víctor Zamora[1], Roberto Escobar[1] Ivonne Montenegro[1] & José Merino[1]
[1]Escuela de Ciencias del Mar, Pontificia Universidad Católica de Valparaíso
Casilla 1020, Valparaíso, Chile

ABSTRACT. In order to improve the inter-specific selectivity of a new bottom trawl design for demersal crustaceans, an experimental attempt was carried out to compare the shrinkage effect in length of net structure accessories, particularly shorter bridles and sweeps, based on previous studies on escape behavior of gadiform fishes. For this purposes, an experimental fishing for nylon shrimp (*Heterocarpus reedi*) was carried out on board of two trawler vessels. The results showed no significant differences in catch per unit of fishing effort (CPUE) for the target species between gears and significant reductions ($p < 0.05$) for the most important by-catch species (*Merluccius gayi*) with the modified gear. In fact, the average CPUE for *M. gayi* decreased 5.6 kg h^{-1} (19.2%) and 35.7 kg h^{-1} (47.5%) for each vessel.

Keywords: by-catch, interspecific selectivity, trawl, nylon shrimp, *Heterocarpus reedi*, Chile.

Mejoramiento de la selectividad interespecífica en arrastre de camarón nailon (*Heterocarpus reedi*) en Chile

RESUMEN. Con la finalidad de mejorar la selectividad interespecífica de un nuevo diseño de red de arrastre de fondo de crustáceos demersales, se efectuó una experiencia destinada a probar el efecto del acortamiento de la longitud de las estructuras anexas de la red, específicamente estándares y malletas, basado en investigaciones similares respecto del comportamiento de escape de peces gadiformes. Para ello, se realizó una pesca experimental de camarón nailon (*Heterocarpus reedi*) con dos embarcaciones arrastreras. Los resultados mostraron que el arte de arrastre modificado, respecto del tradicional, presentó rendimientos de pesca (CPUE) sin diferencias significativas para el recurso objetivo y disminuciones significativas (valor $p < 0,05$) en la principal especie de fauna acompañante, *Merluccius gayi*, cuyos rendimientos de pesca promedio disminuyeron 5,6 kg h^{-1} (19,2%) y 35,7 kg h^{-1} (47,5%) en cada nave.

Palabras clave: fauna acompañante, selectividad interespecífica, arrastre, camarón nailon, *Heterocarpus reedi*, Chile.

Corresponding author: Dante Queirolo (dante.queirolo@ucv.cl)

INTRODUCTION

Trawl fishing is controversial subject worldwide, attributed with low intra- and interspecific catch selectivity, as reported by various fisheries (Madsen *et al*., 2002; King *et al*., 2004; Broadhurst *et al*., 2006). Modified fishing gears, such as nets or attached structures (bridles, sweeps or otter boards), have been studied in an attempt to generate information that would make commercial fishing compatible with the need to decrease its negative externalities (Kvalsvik *et al*., 2006; Revill *et al*., 2006).

In Chile, trawl fishing is used by the fleet targeting demersal crustaceans, particularly nylon shrimp (*Heterocarpus reedi*), yellow squat lobster (*Cervimunida johni*), squat lobster (*Pleuroncodes monodon*), and red royal shrimp (*Haliporoides diomedeae*) in the central part of the country (Escuela de Ciencias del Mar, 2003). The fleet has reported a variety of by-catch species during its operations (Acuña *et al*., 2005), which has led to technological changes in the form of design modifications intended to decrease catches of non-target organisms (Melo *et al.*, 2008).

Therefore, in this study, we shortened two structures connected to the net – sweeps and bridles – in order to verify the expected improvement in the gear's interspecific selectivity due to its lower herding surface for ichthyic species (Engas & Godo, 1989). We carried out experimental fishing trips targeting nylon shrimp (*H. reedi*), a resource whose catches have been associated with a variety of by-catch species, notably fishes such as *Merluccius gayi* and *Hippoglossina macrops*, amongst others (Escuela de Ciencias del Mar, 2003).

MATERIALS AND METHODS

In order to evaluate the interspecific selectivity of bottom-trawling gear for demersal crustaceans in the nylon shrimp (*Heterocarpus reedi*) catch, we carried out experimental fishing trips in December 2007 off Coquimbo, Chile (29º10'S-32º10'S), on traditional fishing grounds for this resource and following the fleet's normal operating regime (Fig. 1). We used a trawl net designed at the Pontificia Universidad Católica de Valparaíso in a project funded by the Fishery Research Fund (FIP No. 2006-20). This design was evaluated via dynamic simulation (computer program DynamiT), a test tunnel (Fisheries and Marine Institute, Newfoundland, Canada), and commercial fishing operations for demersal crustaceans (Melo *et al.*, 2008).

Two trawling vessels from the nylon shrimp fleet participated in the study: the LM "Isabel S" (17.9 m, 350 HP) and the LM "Amancay I" (14.9 m, 325 HP). Both used nets made according to the following design: panels of intertwined polyethylene (PE) multifilaments with an 80 mm mesh size in the upper panel, a 54 mm mesh size in the lower panel, and 56 mm mesh size in the tunnel and codend (Fig. 2). The panels were joined with structural polypropelene ropes (PP) twisted at $\phi = 20$ mm. The upper line was 28.8 m and made of a mixed Hercules-type cable ($\phi = 16$ mm); 16 buoys ($\phi = 200$ mm, 3 kg buoyancy) were distributed along the upper line. The lower line, which attaches to the footrope, was 32.9 m long and was made of polyamide (PA) rope ($\phi = 16$ mm).

During the tests, we used two configurations of annexed structures (sweeps and bridles) that differed in length. For the "traditional" design, the structures were identical in length to those normally used by the fleet (two 13 m bridles attached to a 10 m sweep). The "modified" design consisted of two five meters bridles

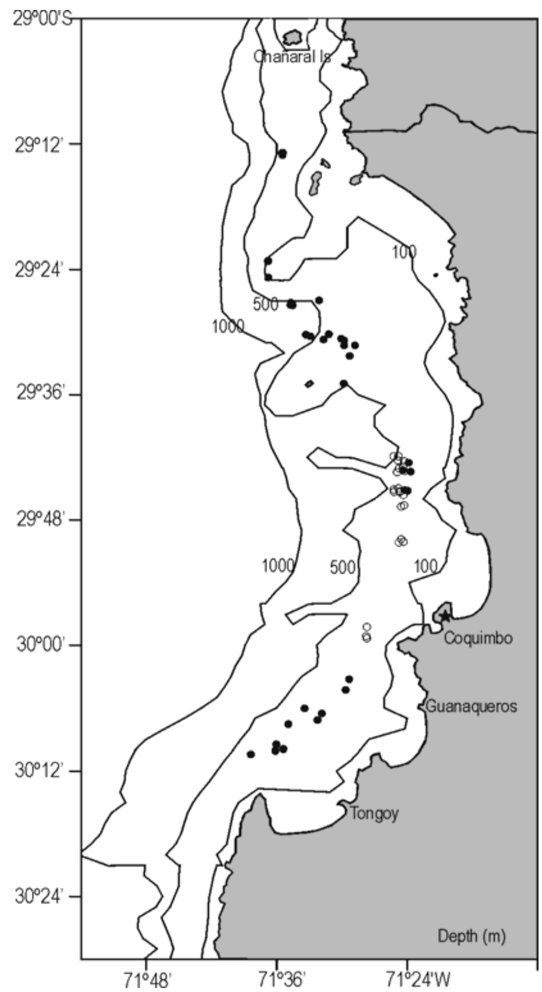

Figure 1. Tow locations for the experimental fishing. White: "Amancay 1", black: "Isabel S".

Figura 1. Ubicación de los lances realizados durante la pesca experimental. Blanco: "Amancay I", negro: "Isabel S".

attached to a one meter sweep (Fig. 3). These structures were made of steel cables: $\phi = 16$ mm for the upper bridles and $\phi = 19$ mm for the lower bridles and sweeps.

Each fishing configuration used the otter boards normally used in commercial fishing; that is, made of steel, with a horizontal V design, and a total approximate weight of 350 kg. The standard commercial footropes, consisting of a chain in the middle section ($\phi = 13$ mm) covered with a panel of net and mixed PA-PP rope ($\phi = 50$ mm), were also used for all configuretions. The section of the footrope corresponding to the net doors varied by vessel: on the "Amancay I", one meter sections of steel cable covered with a mixed PA-PP rope were alternated with one meter sections of steel cable with rubber discs ($\phi = 100$ and 150 mm)

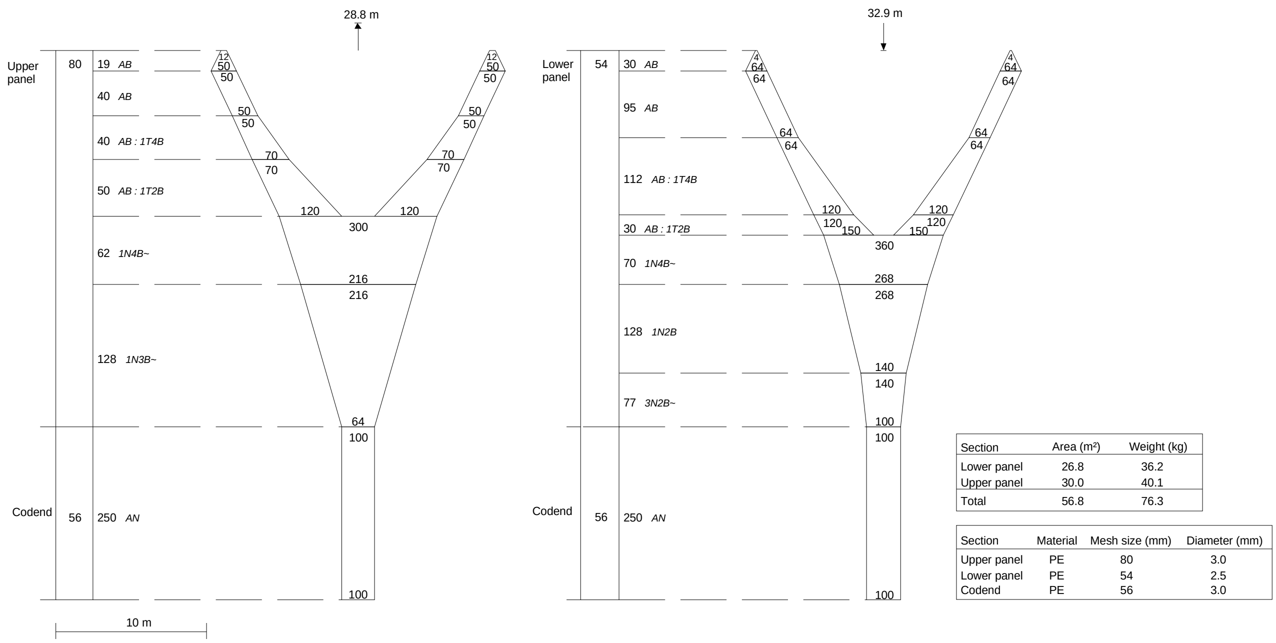

Figure 2. Crustacean trawl design utilized during experimental fishing.

Figura 2. Plano de la red de arrastre de crustáceos utilizada durante la pesca experimental.

whereas, on the "Isabel S", only steel cable covered with a mixed PA-PP rope was used in the doors (Fig. 4).

The work was carried out in two stages. First we monitored the behavior of the two types of fishing gear and then we compared their catch rates (CPUE). The initial monitoring of the net in commercial fishing operations was done on board the "Isabel S" with electronic instruments, specifically the Trawlmaster system (Notus Electronics Ltd.); this uses acoustic sensors to obtain information regarding the wing-end spread (WES). We contrasted hypotheses to verify both normality and equality of the frequency distributions from the WES records (H_0: $F_1 = F_2$ and H_a: $F_1 \neq F_2$) for each design used. This was done with the non-parametric Kolmogorov-Smirnov test (Conover, 1999) using the SPSS computer program (version 10.0).

The second stage involved comparing the two designs in terms of their catch rates. We recorded the operational information associated with each fishing tow for each vessel: the initial and final position via GPS, estimated length (h) or the lapse between the braking of the setting cable winch and the beginning of net retrieval, and the initial and final depth of the marine floor according to the echosounder on each vessel.

The net was monitored and catch rates with both types of gear were compared in commercial *H. reedi* fishing grounds and following the normal operational regime of each vessel. The species caught in each tow were identified using field identification guides. Later, the catches of target and by-catch species were estimated (kg). This was done by placing the specimens on trays, of which four units were sampled and weighed with an electronic scale. The total catch (kg) was estimated considering the average weight obtained and the number of trays counted.

In order to analyze the information from the catch rates in terms of the CPUE, we considered the estimation of the *i-th* tow of the *j-th* species, for design *k* (traditional or modified) on the *l-th* vessel, expressed as catch per hour of trawling:

$$CPUE_{ijkl} = Catch_{ijkl} \cdot Trawling\ time_{ijkl}^{\ -1}$$

We estimated the average CPUE and the variability of the data in terms of the coefficient of variation (CV% = $100\,\bar{x}\ \sigma^{-1}$). Moreover, we verified the significance of the effect that the net design and vessel had on the CPUE, considering the catch rates of both the target resource (*H. reedi*) and the species that made up the greatest percentage of the catch by weight with respect to the total catch during fishing.

For this, we used a multiple regression fit that considered the inclusion of two dummy variables: "vessel" (X_1) and "design" (X_2). We took the traditional

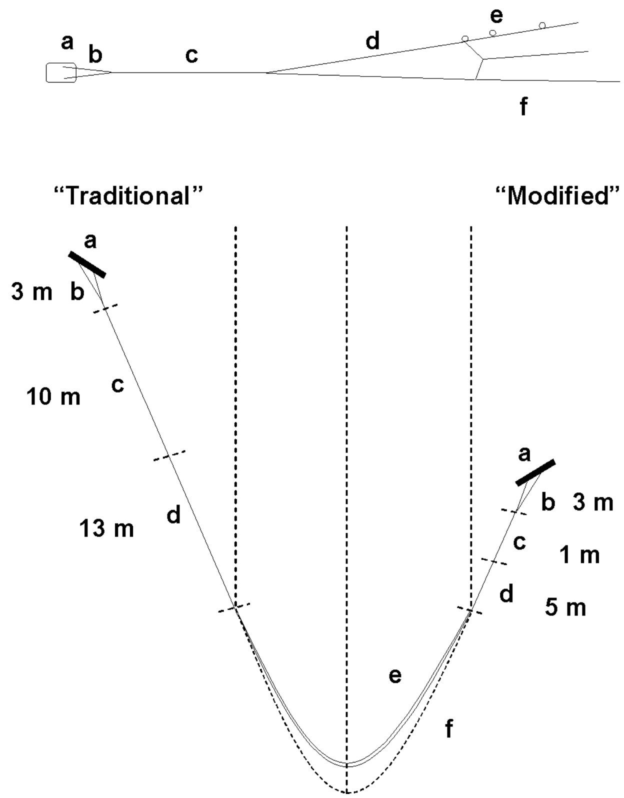

Figure 3. Diagram of traditional and modified designs used in the experimental fishing. a: Otter boards, b: Door legs, c: Sweep, d: Bridles, e: Headline, f: Footrope.

Figura 3. Esquema de los diseños “Tradicional” y “Modificado” utilizados en la pesca experimental. a: Portalón, b: Patas de gallo, c: Malleta, d: Estándares, e: Relinga superior, f: Borlón.

design and the vessel “Isabel S” to be standards ($X_i = 0$), following:

$$CPUE_{ijkl} = \hat{\alpha}_0 + \hat{\alpha}_1 \cdot X1_{ijkl} + \hat{\alpha}_2 \cdot X2_{ijkl} + \varepsilon_{ijkl}$$

In order to determine the effect of the vessel and the net design on the CPUE, we contrasted the individual hypotheses of the regression parameters following H_0: $\alpha_i = 0$ and H_a: $\alpha_I \neq 0$ (Gujarati, 2004), using $p < 0.05$ to estimate the significance of the test.

RESULTS

The net was monitored during 14 tows done on board the “Isabel S”, whereas catch rates from 55 tows were used to compare the two net designs. In this stage, 34 tows were done on board the “Isabel S” (at 327-452 m depth) and 21 on the “Amancay I” (at 375-425 m depth). Twenty-eight tows were done using the modified gear (shorter sweeps and bridles), whereas 27 tows were done with the traditional gear (normally used by the fleet) (Table 1).

The monitoring of the net used by the “Isabel S” allowed us to determine an average wing-end spread of 14.5 m for the traditional and 15.3 m for the modified design. Considering the results of the Kolmogorov-Smirnov test, we rejected both hypotheses of normality in the WES records for the traditional (D = 0.177, $p < 0.05$) and modified (D = 0.165, $p < 0.05$) designs and those of equality in the frequency distributions of the WES for both designs (D = 0.394, $p < 0.05$).

On our experimental fishing trips, we identified 22 taxa in the catch. These weighed a total of 45.6 ton: 24.9 ton caught with the traditional gear and 20.7 ton with the modified gear. The global catch, disaggregated by vessel, was 17.3 ton for the “Amancay I” and 28.3 ton for the “Isabel S” (Table 2). In terms of the percentage in weight, the largest fraction was made up of crustaceans (85.6%), followed by bony fishes (13.6%) (Tables 3 and 4).

The catch of the target species (*H. reedi*) was 37.2 ton, or 81.4% of the total catch in weight. The main by-catch species, in terms of weight, were South Pacific hake (*Merluccius gayi*) (4.0 ton, 8.8%), bigeye flounder (*Hippoglossina macrops*) (1.7 ton, 3.7%), yellow squat lobster (*Cervimunida johni*) (0.9 ton, 2.2%), and armored box crab (*Mursia gaudichaudi*) (0.8 ton, 1.7%). These five species constituted 98.2% of the total catch in weight throughout the investigation (Tables 3 and 4).

The average CPUE, in terms of the total catch, was 474.5 (kg h^{-1}) (CV = 49.8%). By design type, 522.2 kg h^{-1} (CV = 51.9%) were caught with the traditional gear and 428.6 kg h^{-1} (CV = 445%) with the modified gear. Comparing this indicator between vessels revealed an average CPUE for the “Amancay I” of 417.0 kg h^{-1} (CV = 29.0%) and for the “Isabel S” of 510.1 kg h^{-1} (CV = 55.1%) (Table 2).

The average catch rate for *H. reedi* was 379.6 kg h^{-1} (CV = 58.1%). Using the modified design, we estimated an average catch rate of 347.8 kg h^{-1} (CV = 49.2%) and, with the traditional design, 412.6 kg h^{-1} (CV = 63.3%). In the case of the “Amancay I”, the average CPUE was 347.9 kg h^{-1} (CV = 27.3%) and, for the “Isabel S”, it was 399.1 kg h^{-1} (CV = 67.7%) (Table 5). In this sense, no significant differences were found for the CPUE of the target resource associated with vessel or design ($p > 0.05$) (Table 6).

The average catch rate of South Pacific hake (*M. gayi*), the main by-catch species, revealed a CPUE of

Table 1. Number of tows and trawl duration (h) by vessel and design utilized during the experimental fishing.
Tabla 1. Número de lances y tiempo de arrastre (h) por nave y tipo de diseño utilizado durante la pesca experimental.

Vessel	Number of tows			Trawl duration (h)		
	Modified design	Traditional design	Total	Modified design	Traditional design	Total
Amancay I	11	10	21	20.3	22.3	42.6
Isabel S	17	17	34	29.9	27.2	57.0
Total	28	27	55	50.2	49.5	99.6

Table 2. Total catch (kg) and CPUE (kg h^{-1}), by vessel and design utilized in the experimental fishing.
Tabla 2. Captura total (kg) y CPUE (kg h^{-1}), por nave y diseño utilizado en la pesca experimental.

	Vessel	Modified design	Traditional design	Total
Total catch (kg)	Amancay I	8,182.2	9,205.6	17,387.8
	Isabel S	12,541.1	15,731.8	28,273.0
	Total	20,723.3	24,937.4	45,660.8
Total CPUE (kg h^{-1})	Amancay I	411.7	422.8	417.0
	Isabel S	439.5	580.6	510.1
	Total	428.6	522.2	474.5

29.1 and 75.1 kg h^{-1} with the traditional design and 23.5 and 39.4 kg h^{-1} with the modified design on the "Amancay I" and "Isabel S", respectively (Table 5). Based on the fit of the model, the average estimated CPUE was dependent both on the design and the vessel used during the tows ($p < 0.05$). For this species, we determined an average decrease of 5.6 kg h^{-1} (19.2%) on the "Amancay I" and 35.7 kg h^{-1} (47.5%) on the "Isabel S" with the modified design (Table 6).

For *H. macrops* and *M. gaudichaudi*, only the vessel was found to have a significant influence on the average CPUE. No significant differences were found in the catch rates when using the two different fishing gear designs. In the case of *C. johni*, the vessel and the design failed to show significant differences in the CPUE (Table 6).

DISCUSSION

Several studies have been done with the aim of improving the interspecific selectivity of bottom trawling nets, specifically attempting to reduce the by-catch in fishing operations and, thereby, discarding. These studies have covered specific selection mechanisms such as grids or escape panels in several sections of the net (Broadhurst *et al*., 2002; Bahamon *et al*., 2006; Kvalsvik *et al*., 2006) as well as the modification of the net's annexed structures such as bridles or sweeps (Engas & Godo, 1989), opting for simpler alternatives, as done herein.

The monitoring of the wing-end spread (WES) through electronic instruments was used to determine the average values (14.5 and 15.3 m) for the traditional (long annexed structures) and modified (short annexed structures) designs; these values have an absolute difference of 5.5%. In spite of this, the rejection of the hypotheses of a normal data distribution and the equality of the WES frequency distributions for both designs, according to the Kolmogorov-Smirnov test, raise questions as to the factors that explain the changes in the WES and the effect it has on the CPUE. Munro & Somerton (2002) indicate the same effect in a study of the efficiency of flat fish catches with trawl nets after modifying the length of the bridles.

Catch rates by species revealed significant differences ($p < 0.05$) in relation to both the vessel and the type of design used. Thus, the variable "vessel" affected the CPUE of three main by-catch species (*M.*

Table 3. Percentage of catch in weight with respect to the total catch (%RT) of the main species retained in the experimental tows (%RT ≥ 0.1). 1: Crustacea, 2: Osteichthyes, 3: Chondrichthyes. M: “Modified” design, T: “Traditional” design.

Tabla 3. Porcentaje de la captura en peso respecto al total (%RT) de las principales especies retenidas en los lances experimentales (%RT ≥ 0,1). 1: Crustáceos, 2: Osteíctios, 3: Condrictios. M: Diseño “Modificado”, T: Diseño “Tradicional”.

Group	Species	Scientific name	Design	Catch			% RT
				“Amancay I”	“Isabel S”	Total	
1	Nylon shrimp	*Heterocarpus reedi*	M	6,883.5	10,120.5	17,004.0	37.2
			T	7,749.0	12,421.5	20,170.5	44.2
2	South Pacific hake	*Merluccius gayi*	M	469.1	1,059.8	1,528.9	3.3
			T	648.0	1,849.5	2,497.5	5.5
2	Bigeye flounder	*Hippoglossina macrops*	M	181.3	639.3	820.6	1.8
			T	102.8	747.0	849.8	1.9
1	Yellow squat lobster	*Cervimunida johni*	M	156.2	364.6	520.8	1.1
			T	309.4	154.3	463.7	1.0
1	Armored box crab	*Mursia gaudichaudi*	M	345.8	62.2	408.0	0.9
			T	267.1	87.0	354.1	0.8
2	Cardinalfish	*Epigonus crassicaudus*	M	1.7	145.0	146.6	0.3
			T	1.7	328.1	329.8	0.7
2	Aconcagua grenadier	*Coelorhynchus aconcagua*	M	35.7	69.2	104.9	0.2
			T	53.9	51.8	105.7	0.2
3	Dusky catshark	*Halaelurus canescens*	M	21.0	17.2	38.2	0.1
			T	28.0	25.6	53.6	0.1
1	Mantis shrimp	*Pterygosquilla armata*	M	32.4	5.5	37.9	0.1
			T	31.5	9.9	41.4	0.1
1	Squat lobster	*Pleuroncodes monodon*	M	0.0	14.0	41.5	0.1
			T	0.0	0.0	0.0	0.0
		Total		17,318.1	28,172.0	45,490.1	

gayi, *H. macrops*, *M. gaudichaudi*) without significant influence on the catch rate of nylon shrimp (*H. reedi*). The above may be a result of factors influencing the performance of the fishing net, including: the size and operation of the otter boards or differences in the design of the footrope used by each vessel. Differences in catch rates could also be attributable to the own characteristics of fishing grounds (Fig. 1).

Thus, it should be noted that, in spite of the multiplicity of these factors, a significant reduction was still seen in the average *M. gayi* CPUE when using the modified design on both vessels ($p < 0.05$). At the same time, no significant differences were detected in the CPUE for the target species (*H. reedi*) or for the remaining principle by-catch species (*C. johni*, *H. macrops*, *M. gaudichaudi*) ($p > 0.05$).

These results are consistent with several studies on trawling, with lower catch rates for the by-catch associated with shorter annexed structures (e.g., bridles or sweeps) (Strange, 1984; Engas & Godo, 1989). In all cases, the results are attributed fundamentally to decreased catch rates of ichthyic species such as Atlantic cod (*Gadus morhua*), Pacific cod (*Gadus macrocephalus*), or haddock (*Melanogrammus aeglefinus*), in general, gadiform species.

The significantly lower CPUE for *M. gayi* with the modified design (short annexed structures: 5-m bridles and 1-m sweeps) is largely explained by the gear’s decreased herding capacity and the lower proportion of fish located between otter boards (Somerton, 2003, 2004). Moreover, the fish being herded are more likely to escape, as they are able to exit the gear through the front section since the annexed structures are shorter. We cannot reject the possibility that alterations in the hydrodynamic performance of the net could be manifested in the differences detected in the WES frequency distributions.

M. gayi is reported to be the main by-catch species of the *H. reedi* fishery. Estimates made in commercial fishing from 1998 to 2001 indicate that its catch in

Table 4. Percentage of catch in weight with respect to total catch (%RT) of the remaining species retained in the experimental tows (%RT < 0.1). 1: Crustacea, 2: Osteichthyes, 3: Chondrichthyes, 4: Mollusca, 5: Agnatha. M: "Modified" design, T: "Traditional" design.

Tabla 4. Porcentaje de la captura en peso respecto al total (%RT) de las restantes especies retenidas en los lances experimentales (%RT < 0,1). 1: Crustáceos, 2: Osteíctios, 3: Condrictios, 4: Moluscos, 5: Agnatos. M: Diseño "Modificado", T: Diseño "Tradicional".

Group	Species	Scientific name	Design	Catch			% RT
				"Amancay I"	"Isabel S"	Total	
3	Hooktooth dogfish	*Aculeola nigra*	M	0.4	18.8	19.2	< 0.1
			T	0.0	17.6	17.6	< 0.1
1	Lemon crab	*Cancer porteri*	M	16.0	3.2	19.2	< 0.1
			T	5.8	4.2	10.0	< 0.1
4	Jumbo flying squid	*Dosidicus gigas*	M	5.0	15.0	20.0	< 0.1
			T	5.0	0.0	5.0	< 0.1
1	Red royal shrimp	*Haliporoides diomedeae*	M	0.7	0.1	0.8	< 0.1
			T	0.1	20.1	20.1	< 0.1
4	Octopus	*Octopus* sp.	M	0.7	0.9	1.6	< 0.1
			T	0.1	4.8	4.9	< 0.1
2	Eel	*Ophichthus* sp.	M	2.5	3.5	6.0	< 0.1
			T	2.5	5.5	8.0	< 0.1
5	Fourteen-gill hagfish	*Eptatretus polytrema*	M	2.0	1.0	3.0	< 0.1
			T	0.5	2.0	2.5	< 0.1
3	Largenose catshark	*Apristurus nasutus*	M	0.0	0.8	0.8	< 0.1
			T	0.0	2.8	2.8	< 0.1
3	Yellownose skate	*Dipturus chilensis*	M	0.4	0.4	0.8	< 0.1
			T	0.0	0.0	0.0	< 0.1
1	Spider crab	*Libidoclaea granaria*	M	0.3	0.0	0.3	< 0.1
			T	0.2	0.0	0.2	< 0.1
4	Snail	Unidentified gastropod	M	0.0	0.0	0.0	< 0.1
			T	0.2	0.2	0.3	< 0.1
2	Pink cusk-eel	*Genypterus blacodes*	M	0.0	0.2	0.2	< 0.1
			T	0.0	0.0	0.0	< 0.1
		Total		42.4	101.1	143.5	

weight represented between 18% and 24% of the catch in weight of *H. reedi* (Escuela de Ciencias del Mar, 2003), whereas, in the present study, by-catch makes up 12.4% with traditional gear, revealing seasonal and/or spatial differences that are probably associated with the dynamics of the resources.

However, no significant reduction was observed in the CPUE for *H. macrops* when using the modified trawling gear. This could be related to the different types of stimulus that trawling induces in this species and *M. gayi*, as well as the configuration adopted by the bridles during trawling, which could affect flat fishes (Somerton, 2003). Main & Sangster (1981a, 1981b) indicate that, for gadiform species such as *G. morhua*, *G. macrocephalus*, and *M. aeglefinus*, the triggering factor for herding is visual in nature, generated by the action of otter boards, bridles, sweeps, and the cloud of sediments produced by trawling.

The lack of significant differences in the CPUE of the main crustacean species captured is explained by its low mobility as well as its scarce or null escape reaction to the trawl net. Thus, the shortening of the annexed structures generates highly specific improved selectivity, specifically decreasing the *M. gayi* fishing yield.

Likewise, we detected differences in the CPUE variability per tow in *C. johni* and *M. gaudichaudi* between fishing vessels. In the case of *C. johni*, the differences could be attributed to the low number of tows in which the species was caught (< 50%) (Table 6).

Tabla 5. CPUE (kg h^{-1}) promedio y coeficiente de variación (%) para la especie objetivo, fauna acompañante y total, por nave y diseño utilizado durante la pesca experimental.

Table 5. Average CPUE (kg h^{-1}) and coefficient of variation (%) for the target species, by-catch, and total catch by vessel and design utilized during the experimental fishing.

Vessel	Species	CPUE (kg h^{-1})		
		Modified design	Traditional design	Total
Amancay I	*Heterocarpus reedi*	342.9 (33.2%)	353.4 (21.2%)	347.9 (27.3%)
	Merluccius gayi	23.5 (24.5%)	29.1 (27.9%)	26.2 (28.2%)
	Hippoglossina macrops	10.3 (201.7%)	5.4 (250.1%)	7.9 (219.0%)
	Cervimunida johni	10.4 (267.5%)	17.3 (301.3%)	13.7 (294.0%)
	Mursia gaudichaudi	31.4 (41.3%)	26.7 (54.5%)	29.2 (46.7%)
	Total	411.7 (31.4%)	422.8 (27.8%)	417.0 (28.9%)
Isabel S	*Heterocarpus reedi*	350.9 (57.9%)	447.3 (72.2%)	399.1 (67.7%)
	Merluccius gayi	39.4 (66.5%)	75.1 (57.2%)	57.2 (68.9%)
	Hippoglossina macrops	23.1 (76.5%)	27.4 (88.6%)	25.2 (83.3%)
	Cervimunida johni	12.7 (318.1%)	6.5 (199.1%)	9.6 (309.4%)
	Mursia gaudichaudi	3.7 (208.6%)	5.1 (103.3%)	4.4 (148.3%)
	Total	439.5 (51.2%)	580.6 (54.9%)	510.1 (55.1%)

Table 6. Estimated values, significance, and confidence limits (95%) for the main species by vessel and design utilized in the experimental fishing, according to the regression model. (*) Significant coefficients ($p < 0.05$).

Tabla 6. Valores estimados, significancia y límites de confianza al 95% para las principales especies capturadas, por nave y diseño empleado en la pesca experimental, según modelo de regresión. (*) Coeficientes significativos (p < 0,05).

Species	Coefficient	n	Estimated (kg h^{-1})	p	Lower limit (kg h^{-1})	Upper limit (kg h^{-1})
Heterocarpus reedi	Intercept	55	430.9	< 0.001	334.3	527.6
	Vessel ($\hat{\alpha}_1$)		-49.7	0.421	-172.6	73.3
	Design ($\hat{\alpha}_2$)		-63.7	0.289	-183.1	55.8
Merluccius gayi	Intercept	55	69.3	< 0.001	56.6	82.1
	Vessel ($\hat{\alpha}_1$)		-30.5	< 0.001 (*)	-46.7	-14.2
	Design ($\hat{\alpha}_2$)		-24.2	0.003 (*)	-39.9	-8.4
Hippoglossina macrops	Intercept	47	29.2	< 0.001	19.4	38.9
	Vessel ($\hat{\alpha}_1$)		-15.4	0.020 (*)	-28.4	-2.4
	Design ($\hat{\alpha}_2$)		-4.4	0.469	-16.6	7.8
Cervimunida johni	Intercept	21	31.8	0.138	-11.1	74.7
	Vessel ($\hat{\alpha}_1$)		-0.7	0.976	-49.4	47.9
	Design ($\hat{\alpha}_2$)		-3.9	0.871	-53.0	45.2
Mursia gaudichaudi	Intercept	53	4.2	0.068	-0.3	8.7
	Vessel ($\hat{\alpha}_1$)		24.5	< 0.001 (*)	18.8	30.2
	Design ($\hat{\alpha}_2$)		0.9	0.737	-4.6	6.5

With both designs, the CPUE for *H. macrops* varied more on the tows done with the "Amancay I" than those done with the "Isabel S". Given the behavior of the flat fishes studied herein, such differences can be attributed to the different types of footrope used on each vessel or even the different fishing grounds worked by each vessel (Fig. 4).

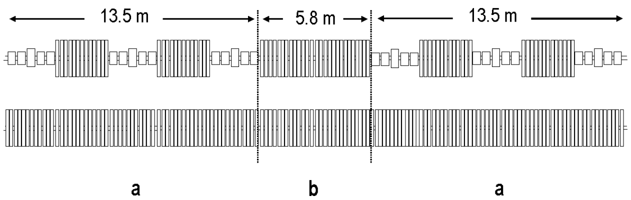

Figure 4. Diagram of the footrope design used by the vessels "Amancay I" (upper) and "Isabel S" (lower). a: wings, b: central section (mouth).

Figura 4. Esquema del diseño de borlones usados por las naves "Amancay I" (superior) e "Isabel S" (inferior). a: alas de la red, b: sección central (boca).

In the future, more in-depth analyses of the effect that the reduced length of the annexed structures have on the catch should tackle the size-at-catch composition of the by-catch, given the varied swimming capacity of different-sized specimens (Wardle, 1993). Engas & Godo (1989) report a lower proportion of small-sized *G. morhua* and *M. aeglefinus* individuals in the catch when using nets with longer annexed structures.

Future research should also incorporate matters related to how the fishing area, given possible changes in the spatial availability of the resources, and the length of the tows influence the CPUE. Similarly, new studies should consider variations in the wing-end spread of the fishing nets and their effect on the CPUE due to operational or design factors.

Finally, the results of the present study can be projected to the multi-specific crustacean Chilean trawl fishery, which also encompasses species as yellow squat lobster (*C. johni*), squat lobster (*P. monodon*) and red royal shrimp (*H. diomedeae*). Although results have shown that the use of shorter bridles and sweeps could reduce impacts of bottom trawling in Chile, namely inter-specific selectivity, further research should focus on intra-specific selectivity and interference with the marine floor.

ACKNOWLEDGMENTS

The authors express their gratitude to Alejandro Karstegl (SUBPESCA) for the support that has given in this initiative. We also thank to skippers Olliver Riegel and Víctor Olivares, besides of crews of the vessels "Isabel S" and "Amancay I", for their good disposition and help to make field experiments. We are especially grateful to Guido Plaza and Exequiel González for their helpful comments and suggestions, and two anonymous reviewers for constructive criticisms of the manuscript draft. The present research was partially financed by the Fisheries Research Fund (FIP) under project FIP No 2006-20: 'Redesign of the crustacean trawl nets'.

REFERENCES

Acuña, E., J.C. Villarroel, M. Andrade & A. Cortés. 2005. Fauna acompañante en pesquerías de arrastre de crustáceos de Chile: implicancias y desafíos desde la perspectiva de la biodiversidad. In: E. Figueroa (ed.). Biodiversidad marina: valoración, usos y perspectivas ¿Hacia dónde va Chile? Editorial Universitaria, Santiago, 586 pp.

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

Broadhurst, M., M. Kangas, C. Damiano, S. Bickford & S. Kennelly. 2002. Using composite square-mesh panels and the Nordmore-grid to reduce bycatch in the Shark Bay prawn-trawl fishery, Western Australia. Fish. Res., 58: 349-365.

Broadhurst, M., P. Suuronen & A. Hulme 2006. Estimating collateral mortality from towed fishing gear. Fish Fish., 57: 180-218.

Conover, J. 1999. Practical non parametric statistics. Wiley, John & Sons, New York, 596 pp.

Engas, A. & O. Godo. 1989. The effect of different sweep lengths on the length composition of bottom-sampling trawl catches. J. Cons. Int. Explor. Mer, 45: 263-268.

Escuela de Ciencias del Mar (ECM). 2003. Evaluación de dispositivos de reducción de fauna acompañante en las pesquerías de crustáceos demersales. Inf. Téc. FIP-IT/2001-23: 304 pp.

Gujarati, D. 2004. Econometría. McGraw-Hill, México, 972 pp.

Kvalsvik, K., I. Huse, O. Misud & K. Gamst. 2006. Grid selection in the North Sea industrial trawl fishery for Norway pout: Efficient size selection reduces by-catch. Fish. Res., 77: 248-263.

King, S., R. Hannah, S. Parker, K. Matteson & S. Berkeley. 2004. Protecting rockfish through gear design: development of a selective flatfish trawl for the U.S. west coast bottom trawl fishery. Can. J. Fish. Aquat. Sci., 61: 487-496.

Madsen, N., R. Holst & L. Foldager. 2002. Escape windows to improve the size selectivity in the Baltic cod trawl fishery. Fish. Res., 60: 223-235.

Main, J. & G.I. Sangster. 1981a. A study of the sand clouds produced by trawl boards and their possible effect on fish capture. Scott. Fish. Res. Rep., 20: 1-20.

Main, J. & G.I. Sangster. 1981b. A study of the fish capture process in a bottom trawl by direct observations from a towed underwater vehicle. Scott. Fish. Res. Rep., 23: 1-23.

Melo, T., C. Hurtado, D. Queirolo, E. Gaete, I. Montenegro, V. Zamora, J. Merino & R. Escobar. 2008. Rediseño de las redes de arrastre de crustáceos. Inf. Téc. FIP-IT/2006-20: 144 pp.

Munro, P.T. & D.A. Somerton. 2002. Estimating net efficiency of a survey trawl for flatfishes. Fish. Res., 55: 267-279.

Revill, A., G. Dunlin & R. Holst. 2006. Selective properties of the cutaway and several other commercial trawls used in the Farne Deeps North Sea *Nephrops* fishery. Fish. Res., 81: 268-275.

Somerton, D.A. 2003. Bridle efficiency of a survey trawl for flatfish: measuring the length of the bridles in contact with the bottom. Fish. Res., 60: 273-279.

Somerton, D.A. 2004. Do Pacific cod (*Gadus macrocephalus*) and walleye Pollock (*Theragra chalcogramma*) lack a herding response to the doors, bridles and mudclouds of survey trawls? ICES J. Mar. Sci., 61: 1186-1189.

Strange, E. 1984. Review of the fishing trials with Granton and Saro deep Sea Trawl Gear 1963-1967. Scot. Fish. Work. Pap., 8: 1-59.

Wardle, C. 1993. Fish behaviour and fishing gear. In: T. Pitcher (ed.). Behaviour of teleost fishes. Chapman & Hall, London, pp. 608-642.

Received: 17 September 2008; Accepted: 15 April 2009