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Queirolo, Dante; Wahrlich, Roberto; Molina, Rodrigo; Munari-Faccin, José Ricardo; Pezzuto, Paulo Ricardo

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Research Article

Industrial double rig trawl fisheries in the southeastern and southern Brazil: characterization of the fleet, nets and trawl simulation

Dante Queirolo[1], Roberto Wahrlich[2], Rodrigo Molina[1]
José Ricardo Munari-Faccin[2] & Paulo Ricardo Pezzuto[2]
[1]Escuela de Ciencias del Mar, Pontificia Universidad Católica de Valparaíso, Valparaíso, Chile
[2]Universidade do Vale do Itajaí, Centro de Ciências Tecnológicas da Terra e do Mar, Itajaí, SC, Brasil
Corresponding author: Dante Queirolo (dante.queirolo@pucv.cl)

ABSTRACT. The industrial double rig trawl fisheries are an important extractive activity in the southeastern and southern Brazil where near 300 vessels participate, targeting their catch to the sea-bob shrimp, pink shrimp and demersal fishes, such as flatfishes and monkfish. In order to advance in the fishery management, a general characterization of the trawl fleet operating in the area was done, identifying the patterns of nets used and the hydrodynamic performance of the nets observed by means of dynamic simulation. 194 vessels of Santa Catarina State and 130 vessels from other areas, mainly built in steel and wood, were identified. The largest size, tonnage, and capacity, correspond to those vessels working upon demersal and oceanic fishes. On the other hand, the most abundant vessels were those working upon pink shrimp (230 vessels). Regarding the nets, different patterns were identified according to the catch of target species; the smaller nets were used to catch shrimps (sea-bob and pink shrimp) and the largest were used to catch fishes. Mixed nets were also identified, characterized by similar dimensions of nets to catch fish but with mesh sizes of shrimp nets. From the simulations, different performance functions were adjusted according to each founded pattern; these functions will serve to calculate net's spread, their shape relationship, and the hydrodynamic drag forces.

Key words: sea-bob shrimp, pink shrimp, demersal fishes, double rig trawl, dynamic simulation, Brazil.

Pesquerías industriales de arrastre con tangones en el sudeste y sur de Brasil: caracterización de la flota, redes y simulación dinámica

RESUMEN. Las pesquerías industriales de arrastre con tangones son una importante actividad extractiva en el sudeste y sur de Brasil donde participan cerca de 300 embarcaciones dirigiendo su captura a camarón siete barbas, camarón rosa, y peces demersales como peces planos y pejesapo. Para avanzar en el manejo pesquero, se realizó una caracterización general de la flota de arrastre que opera en el área, identificando los patrones de las redes usadas y el desempeño hidrodinámico de las redes observado mediante simulación dinámica. Se analizaron 194 embarcaciones del Estado de Santa Catarina y 130 embarcaciones de otras áreas, construidas principalmente de acero y madera. Las embarcaciones de mayor tamaño, tonelaje y capacidad correspondieron a aquellas que trabajan sobre peces demersales y peces oceánicos. La mayor cantidad de embarcaciones opera sobre camarón rosa (230 embarcaciones). Respecto a las redes, se identificaron diferentes patrones de acuerdo a las especies objetivo de captura; las redes más pequeñas fueron usadas para la captura de camarones (camarón siete barbas y camarón rosa) y las de mayor tamaño para la captura de peces. También se identificaron redes mixtas, caracterizadas por dimensiones similares a las redes para capturar peces pero con tamaño de malla de redes camaroneras. A partir de las simulaciones se ajustaron diferentes funciones de desempeño conforme a los patrones particulares de cada tipo de red. Estas funciones servirán para calcular la abertura de las redes, su relación de forma y las fuerzas hidrodinámicas de arrastre.

Keywords: camarón siete barbas, camarón rosa, peces demersales, redes tangoneras, simulación dinámica, Brasil.

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INTRODUCTION

Trawl fishery has been used in the southeastern and southern Brazil since the 1940's (Peruzzo, 2006). In the 1960's, the trawl fishery activity increased due to the stimulus of the production perspectives of two species of coastal shrimps as pink shrimp (*Farfantepenaeus* spp.) and sea-bob shrimp (*Xiphopenaeus kroyeri*), and fishes from the Sciaenidae family, especially in wide areas of the continental shelf close to the regions of the southeastern and southern Brazil (Yesaki & Bager, 1975; Diegues, 1983; Valentini *et al*., 1991a, 1991b; Haimovici, 1997).

From 1980's, the demersal fisheries with single and double rig trawlers were concentrated on the continental shelf between south of the Paraná State and the southern limit of the Brazilian EEZ (Exclusive Economic Zone). At the same time, an important part of the double rig trawl fleet, originally designed to the pink shrimp fishery, also occupied the coastal area of Río Grande do Sul State to catch the Argentine red (*Pleoticus muelleri*) and Argentine stiletto (*Artemesia longinaris*) shrimps, as well as demersal fishes, such as flatfishes (Haimovici, 1997; Perez *et al*., 2007). During the following ten years, a diversification of trawl fishery targets was produced, especially in double rig trawl fishery, intensified by the identification of a wide number of fisheries of previously underutilized resources, including crustaceans and shellfishes (Perez & Pezzuto, 1998; Perez, 2000; Perez *et al*., 2007).

At the beginning of this millennium, the double rig trawl fleet expanded their operations to the border of the shelf and upper slope grounds, exploiting resources like the pink cusk-eel (*Genypterus brasiliensis*), Brazilian codling (*Urophycis mystacea*), Argentine hake (*Merluccius hubbs*), monkfish (*Lophius gastrophysus*), flatfish (*Paralichthys* spp.), Argentine squid (*Illex argentinus*) and arraias rays (Rajidae spp.) up to *ca.* 500 m depth (Perez *et al*., 2001, 2009; Perez & Pezzuto, 2006). During this period, this area was also occupied by foreign stern trawlers which developed two different strategies. Part of the fleet operated between 250-500 m, exploiting basically the same resources above, while some units went even deeper (*i.e.*, 700-800 m depth), in order to catch the valuable deep-water shrimps, *Aristaeopsis edwardsiana*, *Aristaeomorpha foliacea* and *Aristeus antillensis* (Pezzuto *et al*., 2006; Dallagnolo *et al*., 2009).

By the year 2000, 529 double rig trawlers, 163 pair trawlers, and 12 single trawlers were operating in the southeastern and southern Brazil (Perez *et al*., 2001). Between 1996-2004, this fleet annually disembarked around 88,700 ton, which represented nearly 37% of the total fishing production recorded in the southeastern and southern Brazil (Valentini & Pezzuto, 2006). Between 2000-2009, the ports of Santa Catarina registered landings of 237-370 double rig trawlers, 27-59 pair trawlers and 23-42 single trawlers (UNIVALI/ CTTMar, 2010), concentrating, therefore, a significant part of the trawling fleet in the region.

In the southeastern and southern Brazil, an important artisanal and industrial fishing activity upon different species of commercial interest is carried out, in particular pink shrimp, sea-bob shrimp (*Xiphopenaeus kroyeri*), and demersal fishes such as flatfishes and monkfish, among others (Pezzuto & Benincá, 2015). These activities are mainly performed through double rig bottom trawl nets, a common fishing practice in this area, where an interaction with different species is recognized. Some of these species are commercially used by the fleet and some others are discarded (Haimovici & Mendonça, 1996; Andriguetto-Filho *et al*., 2009; Silva *et al*., 2012).

Accordingly, a necessary base to understand the interaction of the fishing fleets and the ecosystem is the knowledge of the trawls and performance patterns used since they have a direct impact on the fishing output of the fleet, and from here, to know the productivity of the fishing effort and the state of conservation of the commonly exploited fishing resources (Salthaug & Godø, 2001). Usually, an indicator of the fishing effort used in trawl fisheries corresponds to the time and duration of the trawling (Kotwicki *et al*., 2001); however, this effort unit is not related to the technological features of the trawl that produces the fishing mortality. For this reason, it is recognized the need for an effort indicator that includes the time and trawl speed, and also the size of the trawl nets used, which determines the net spread and allows to evaluate the stock based in data that depend of the operation of the fishing fleet (Pezzuto *et al*., 2008).

The direct measurement of the trawl net performance is a complex task since it requires the use of sensors for the wing-end spread, the door spread and the height of the net's mouth, which are limited and difficult to operate. In some cases, portable equipment can be used to carry out a net characterization, but this requires a specific sampling design during some fishing days. In order to advance on the knowledge of the hydrodynamic performance of trawl nets, it is known that the use of dynamic simulation tools provides a valid approach with an acceptable level of error during design and evaluation stages (Vincent, 1999; Queirolo *et al*., 2009; Nguyen *et al*., 2015). Essentially, the most advanced knowledge stages require the use of supplementary hydrodynamic performance tools, such as the use of flume tanks and direct measurements in the sea according to the specific objectives (Winger *et al*., 2006).

Since there is a need to advance in the management of double rig trawl net fishery, the purpose of this research is to: a) characterize the fleet using this catch system in the southeastern and southern Brazil, b) identify the patterns of the nets used, and c) characterize their hydrodynamic performance through dynamic simulation.

MATERIALS AND METHODS

Fleet characterization

The physical characterization of the double rig trawl fleet was carried out from the official data available in the Registro Geral da Pesca (RGP) (General Fishing Registry) of the Ministério da Pesca e Aquicultura (MPA) of Brazil (Ministry of Fisheries and Aquaculture of Brazil). For this, in April 2013, the database of the authorized vessels of the Sistema Nacional de Informação da Pesca e Aquicultura/Sistema Informatizado do Registro Geral da Atividade Pesqueira (SINPESQ/SisRGP) (National System of Fishing and Aquaculture Information/Computerized System of the General Registry of Fishing Activities) was consulted. Specially, the database of the authorized vessels for catching: a) pink shrimp and by-catch; b) sea-bob shrimp and by-catch; c) demersal fishes (coastal trawl), and d) demersal fishes (oceanic trawl, involving vessels working both with single and double rig trawl between 250 and 500 m depth) was consulted. The interest data were, among others: the name of the vessels, registry number (RGP), total length of the hull (m); tonnage (AB), engine power (Hp), material of the hull and district (according to the residence of the ship-owner).

The work basis considered only those units identified as industrial vessels, excluding artisanal boats under 20 AB. As a significant part of the industrial bottom trawl fleet in Brazil operating from Santa Catarina State harbors (southern Brazil), were mostly focused on this paper. Vessels were identified as pertaining to this State if they were: a) included in the registries either of the SINDIPI (Shipowner's and Fishing Industry Union of Itajaí and Region) or SINDIFLORIPA (Florianópolis' Fishing Industry Union), regardless the shipowner State of residence, and b) not registered in both Unions but appeared in the RGP as being based in SC.

Net characterization

Double rig trawl nets used by the industrial fleet working from the ports of Itajaí and Navegantes (SC) were also analyzed. Nine netters were interviewed resulting in the identification of 26 net designs which were identified and characterized. The nets were classified according to the designation used by the netters as per the catch's target species, corresponding to pink shrimp, sea-bob shrimp, fishes and mixed nets. During the interviews, the available nets were inspected for registering their specific structure characteristics (length of headlines, type and construction of materials, diameters, etc.), and meshes (type and construction of yarns, mesh size, yarn diameter, number of meshes, cuts, etc.), from where layouts of the nets were drawn. The ratio D/L is commonly associated to the drag resistance of trawls, therefore the average value of D/L for each net was calculated proportionally from the yarn diameter (D) and mesh size (L) from all sections of each net. Those nets that were not available for inspection were characterized according to their length (headrope and footrope) and mesh size in the body and the cod end.

Dynamic simulation

In order to study the hydrodynamic performance of the representative industrial double rig trawl nets used in the region, the DynamiT software developed by IFREMER was used, to help to the conception and optimization of trawl gears (Vincent & Marichal, 2006). DynamiT is based on the Finite Element Method (FEM) and the simulation process consists of four stages: a) input of net data in the software, including dimensions and characteristics (number of meshes, mesh size, yarn diameter, type of material), or that basically corresponds to a net layout; b) input of the net associated structures, specially, ropes and their properties (type of material, diameter and length), floats (if they correspond) and trawl doors (dimensions, resistance coefficient, spread coefficient, individual weight); c) union of the components aforementioned and their relation to the vessel, and d) simulation according to the operation parameters of the net, haul depth and trawl speed.

To support the analysis, the information of eight double rig trawl nets chosen from the 26 identified models were used, prioritizing the most representatives for the catch of each target species. The trawl operations of each chosen net were simulated with a speed of 2, 2.5 and 3 knots. Due to software limitations, simulations corresponded to individual nets; however, double rig trawl, as the fleets uses simultaneously two identical nets, results of the simulation about hydrodynamic drag were multiplied by 2.

The length of the bridles used in most simulations was 60 m. The warp length was changed according to the average operation depth of each net type (sea-bob shrimp is more coastal than pink shrimp). After each simulation, the following results were obtained: door and wing-end spreads (DS and WS), total drag (drag force, DF) and headline height in the mouth (HH).

Generalization of trawl net performance

Once the dynamic simulations of the eight trawl nets were finished, a general analysis of these nets was performed in order to obtain patterns for the other nets in the fleet. Equations were calculated to generalize the estimation of wing-end spread (*WS*) as well as the drag force (*DF*). As variables, the headrope length (*HL*) of the nets and the drag speed (*s*) were used. Although some authors suggest specific approximations to calculate the drag force (*e.g.*, Koyama (1974) and Chi (1988)), in this research, we used two relations that simplify the results interpretation and their application to other trawl nets, with similar characteristics in size and manufacture. These equations were: $WS = a\ HL + b\ s$, $DF = a\ WS\ s^b$ and $DF = a\ HL\ s^b$, where a and b are the adjustment parameters of each equation.

RESULTS

Fleet characterization

In the southeastern and southern Brazil, the industrial double rig trawl fleet amounted 324 vessels, 194 belonging to SC State, and 130 to other states. According to the authorized catch species, 57 vessels target demersal fishes, 10 oceanic fishes, 230 pink shrimp and 27 sea-bob shrimp (Table 1). With the exception of the sea-bob shrimpers, that are mostly wooden boats, other SC vessels exhibit an inverse pattern, with steel hulls being more frequent. On the other hand, vessels from other states of the SE/S are mostly made of wood.

Vessels with a larger size, tonnage and power correspond to those operating in deeper areas for oceanic fishes, having an average of 23.3 m LOA, 91.5 GT and 325 HP (Table 1). Those vessels oriented to the sea-bob shrimp are the smallest, both in Santa Catarina (16.9 m LOA, 42.5 GT and 180 HP) as in the other states (15.8 m LOA, 26 GT and 210 HP) (Table 1). Most vessels are authorized to catch pink shrimp (118 in Santa Catarina and 112 in other states); these vessels are similar in dimensions and characteristics.

Net characterization

The characterization of the nets was made according to the target species, being classified by: i) nets for fish, ii) nets for pink shrimp, iii) nets for sea-bob shrimp, and iv) mixed nets. In the first group, flatfish, clingfish, or other demersal fishes, 13 nets were inspected. They were made of polyethylene (PE) twisted yarn. Nine nets have two panels, and four have four panels and they use a lateral panel to improve the vertical height of the net. The headrope and footrope lengths varied from 17.4 to 28.2 m and from 19.4 and 31.5 m, respectively The mesh size ranged between 90 and 120 mm, measured from knot to knot, while in the cod end, 90 mm double yarn meshes were identified (Table 2).

Regarding pink shrimp nets, five models were inspected. PE twisted yarn was the main material used, but in some cases, the use of polyamide (PA) yarn was observed. The headrope length varied between 13.7 and 23.2 m, while the footrope length varied between 16.5 and 26.3 m. The body of the nets was conformed by variable size meshes ranging between 40 and 50 mm, while in the cod end, multifilament PA material ranging between 30 and 44 mm was used (Table 2).

In the body of the sea-bob shrimp nets, PE twisted yarn and PA monofilament yarn were used. Some nets were exclusively made of PE. The headrope length varied between 15.4 and 23.2 m, while the footrope length varied between 17 and 25.4 m. The body of the nets revealed meshes of variable size ranging between 36 and 50 mm, while in the cod end, 30 mm multifilament PA meshes were used (Table 2).

During the interviews, the existence of multiple-use nets called "mixed nets" was confirmed. These nets are used to catch shrimp as well as fish. Due to this, the mixed nets have similar dimensions to fish nets, with variable headrope and footrope length ranging of 17.5-19.4 m and 20.3-23.6 m, respectively. Regarding the material, PE twisted yarn was preferred, but in some cases monofilament PA was used. In the cod ends, a construction pattern similar to the nets for pink shrimp with multifilament PA of 30 to 44 mm from was used (Table 2).

Finally, the average values of D/L of trawl nets fluctuated between 0.020 and 0.037 being slightly higher in the case of nets used in shrimp fisheries (sea-bob and pink shrimp) because the mesh sizes in both cases are lower (Table 2).

Performance patterns according to dynamic simulation

From the 26 nets characterized in the previous stage, eight nets were selected for a detailed performance analysis through dynamic simulation. Performance of three nets for demersal fishes, two for pink shrimp, two for sea-bob shrimp and one mixed net were simulated under the same use conditions of an industrial fleet in terms of footrope and warp length, amount of floats and trawl doors (Table 3). The average values of D/L of the trawl nets used for dynamic simulation fluctuated in a narrow range (0.023-0.031), which validate that the drag resistance obtained can be compared. All nets were simulated under speeds of 2, 2.5 and 3 knots.

The first performance indicator used in the analysis corresponded to the aspect relation of the net's mouth,

Table 1. General characteristics of double rig trawl vessels involved in the industrial fishery operating from Santa Catarina (n = 324).

Fleet / Permission	n	Hull material (%)			Vessel length (m)		Gross tonnage		Horse power	
		Wood	Iron	Fiber	Median	Min-Max	Median	Min-Max	Median	Min-Max
Santa Catarina										
Demersal fishes	46	28	72	-	22.0	16.2 - 26.4	83.0	38 - 118	325	180 - 385
Oceanic fishes	10	10	90	-	23.3	19.2 - 25.1	91.5	73 - 131	325	290 - 425
Pink shrimp	118	38	62	-	20.0	14.9 - 24.2	61.1	26 - 108	270	110 - 425
Sea-bob shrimp	20	95	5	-	16.9	13.9 - 18.3	42.5	27 - 49	180	90 - 360
Other states										
Demersal fishes	11	73	27	-	21.4	17.3 - 23.6	65.0	39 - 98	291	180 - 485
Pink shrimp	112	56	43	1	20.2	14.9 - 27.0	64.5	26 - 112	290	115 - 427
Sea-bob shrimp	7	100	-	-	15.8	13.6 - 17.3	26.0	24 - 49	210	180 - 270

Table 2. General characteristics of double rig trawl nets (n = 26) used in industrial fishery, according to the information provided by netters from Itajaí and Navegantes. PE: polyethylene. PA: polyamide. The number of nets is shown in parentheses.

Fishery	n	Net material (n)	Mesh size (mm)		Headline length (m)	Footrope length (m)	Range of $\overline{D/L}$
			Body panels	Codend			
Demersal fishes	13	PE (13)	90 - 120	90	17.4 - 28.2	19.4 - 31.5	0.022 - 0.031
Pink shrimp	5	PE (4); PE-PA (1)	40 - 50	30 - 44	13.7 - 23.2	16.5 - 26.3	0.023 - 0.033
Seabob shrimp	4	PE (2); PE-PA (2)	36 - 50	30	15.4 - 23.2	17.0 - 25.4	0.027 - 0.037
Multispecies	4	PE (3); PE-PA (1)	50 - 60	30 - 44	17.5 - 19.4	20.3 - 23.6	0.020 - 0.028

Table 3. Characteristics of the nets used in dynamic simulation (n = 8) according to the target fishery. PE: polyethylene. PA: polyamide.

Fishery	Nets			Structures			Floats (n)	Doors	
	Material	Area (m^2)	D/L	Bridles (m)	Warp (m)	Headline (m)		Area (m^2)	Weight (kg)
Demersal fishes	PE	29.5	0.026	60 - 75	225 - 240	23.4	3	1.13	150
	PE	32.0	0.025	60	940	28.2	5	1.13	150 - 170
	PE	34.1	0.029	60	440	20.9	2 - 5	1.13	150
Pink shrimp	PE-PA	11.8	0.023	60	440	14.6	0	1.28	120
	PE-PA	22.4	0.030	60	440	17.2	0	1.13	150
Sea-bob shrimp	PE-PA	10.8	0.029	60	140	15.4	1	0.93	90
	PE-PA	16.7	0.031	60	150	21.5	0	0.93	90
Multispecies	PE	18.3	0.023	60	440	19.0	0	1.28	120

this is, the proportion between the mouth height and the wing-end spread. It was verified the existence of a consistent pattern showing that, the height magnitude of the nets used to catch sea-bob shrimp, pink shrimp and the mixed nets ranges between 10.5 and 13.1% of the wing-end spread according to the trawl speed used (Table 4). This allows classifying these as low height nets. This percentage is lower than the one observed in nets for demersal fishes, where the mouth height is higher and represents between 17.3 and 26.6% of the wing-end spread (Table 4), corresponding to higher vertical height nets. In all cases, the mouth height is higher when the trawl speed is low due to the lesser force of the trawl doors spread.

The same performance pattern was verified through the relation between the door spread and the headrope length, varying between 55.3% and 63.7% for nets used to catch sea-bob shrimp, pink shrimp and mixed nets, corresponding to nets with a big horizontal spread. On the other hand, the nets for fishes have an inferior door spread that varies between 46.6 and 47.8% of the headrope length according to the trawl speed (Table 4).

Table 4. Performance of trawls, expressed in terms of percentage between: a) headline height in the mouth (HH) and wing-end spread (WS), and b) door spread (DS) and headline length (HL). Mean ± standard deviation.

Relation	Trawl speed (kn)	Fishery			
		Demersal fishes (n = 3)	Pink shrimp (n = 2)	Sea-bob shrimp (n = 2)	Mixed (n = 1)
HH/WS	2.0	26.6 ± 8.9	11.1 ± 2.2	13.1 ± 1.6	12.4
	2.5	21.1 ± 8.6	10.8 ± 2.7	12.3 ± 0.8	11.8
	3.0	17.3 ± 7.8	10.5 ± 2.6	11.9 ± 0.9	10.5
DS/HL	2.0	46.6 ± 9.3	57.7 ± 14.5	55.3 ± 13.7	58.4
	2.5	47.6 ± 6.8	59.9 ± 15.0	58.5 ± 13.6	61.6
	3.0	47.8 ± 4.3	61.9 ± 15.9	60.7 ± 14.2	63.7

Calculation of the wing-end spread

It was verified that the wing-end spread of nets depends not only of the headrope length but also of the trawl speed (Fig. 1). However, according to the differences in performance observed through dynamic simulation, independent linear regressions were adjusted for: i) pink shrimp, sea-bob shrimp and mixed nets with a headrope length (HL) between 14 and 22 m (Eq. 1); ii) nets for demersal fishes with headrope length between 20 and 24 m (Eq. 2), and iii) nets for fishes with a headrope length of 28.2 m (Eq. 3). The equations correspond to:

Nets for pink shrimp, sea-bob shrimp and mixed nets (HL between 14 and 22 m)

$$WS=0.288\ HL+1.95\ s \quad R^2=0.43 \qquad (1)$$

Nets for fishes with a HL between 20 and 24 m

$$WS=0.296\ HL+1.04\ s \quad R^2=0.70 \qquad (2)$$

Nets for fishes with a 28.2 m HL.

$$WS=0.359\ HL+2.17\ s \quad R^2=0.93 \qquad (3)$$

Calculation of the hydrodynamic resistance

From the dynamic simulation, the transmitted forced in trawl nets were calculated according to a known dimension of the net (wing-end spread or headrope length), and in relation to the used trawl speed. To generalize the relationship of the total hydrodynamic resistance and these variables, two equations were adjusted: i) one depending of the WS and the trawl speed (Eq. 4) and ii) the other depending of the HL and the trawl speed (Eq. 5). The last one showed the best adjustment (R^2 = 0.85) (Fig. 2). In this way, it can be determined that for the analyzed nets, regardless of the target species, the better estimates for hydrodynamic resistance can be obtained from the headrope length.

- Hydrodynamic resistance according to the WS and the trawl speed

$$DF=23.73\ WS\ s^{1.29} \quad R^2=0.76 \qquad (4)$$

- Hydrodynamic resistance according to the HL and the trawl speed

$$DF=15.78\ HL\ s^{0.93} \quad R^2=0.85 \qquad (5)$$

DISCUSSION

The four double rig trawl fleets that were inspected presented different physical characteristics. In general, the trawl vessels working in the slope (oceanic trawl) and on demersal fishes of the continental shelf showed a slightly bigger size in comparison with pink shrimp vessels, which also operates in the middle and outer shelf. All of these are by far larger in size and power than the fleet working in shallower waters and closer to the coast for catching sea-bob shrimp.

The fleets of Santa Catarina and the other states are relatively homogeneous in terms of length; however, the tonnage of Santa Catarina's fleet is bigger in vessels catching demersal fishes as well as sea-bob shrimp. The tonnage differences can be explained by the hull construction material, since the vessels of Santa Catarina are mainly made of steel while the vessels from other states are mostly made of wood. In general, the Santa Catarina fleet seems to have maintained its physical characteristics relatively unchanged during the last 14 years, at least in terms of total length and engine power. In fact, mean values calculated for all vessels, irrespective of their target species, were 20.7 m and 295.2 Hp in 1999 (Perez *et al*., 2007) and 20.5 m and 282.3 Hp in 2002 (UNIVALI/CTTMar, 2003). These values conform with the limits reported in Table 1, and approximate to the features showed mainly by pink shrimp vessels that are, by far, are the most numerous in the region.

The analysis of the fleet nets, operating from Itajaí and Navegantes, showed that the net's size for shrimps (pink and sea-bob shrimps), demersal fishes and mixed nets differ, with the latter been larger, in spite of which, the values of the mesh sizes and $\overline{D/L}$ ratio of the mixed

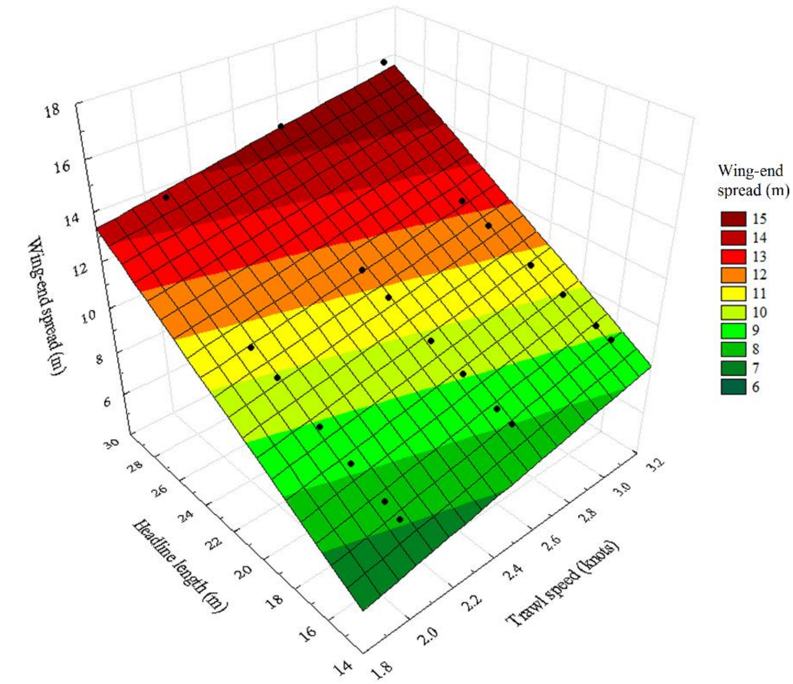

Figure 1. Wing-end spread of trawl nets according to the headrope length and the trawl speed.

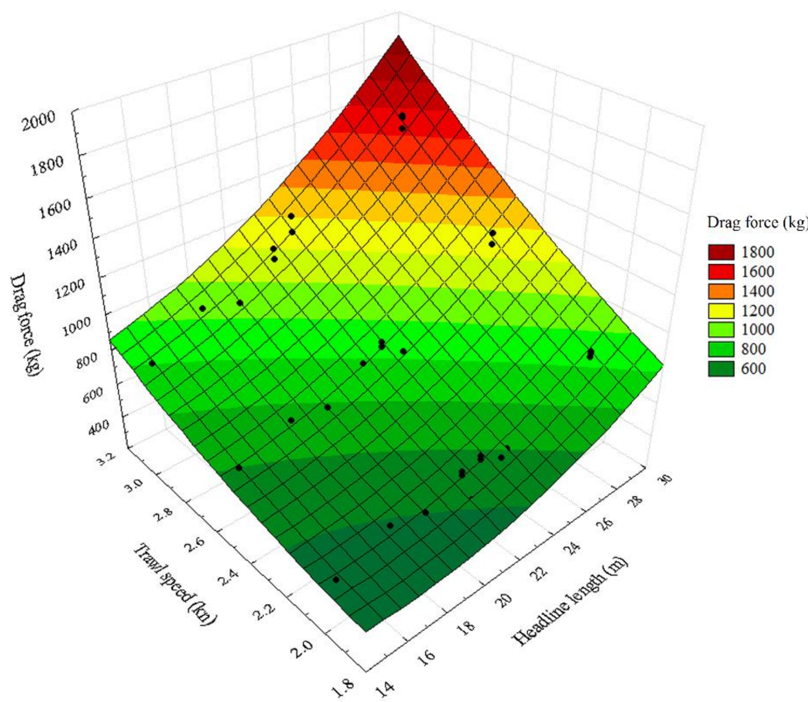

Figure 2. Trawl nets hydrodynamic resistance according to headrope length and trawl speed. The drag force corresponds to a simulation of an independent net.

and shrimp nets are equal, being possible to corroborate that their name reflects a combination of other nets patterns.

In relation to the simulation of the trawl nets, the results correctly reflect the expected trend of the hydrodynamic performance, especially due to the increase of the wing-end spread, the door spread and the drag force according to a greater trawl speed. Similarly, the vertical spread performs inversely to the increase of speed, since the nets reduced significantly in height by increasing the speed from 2 to 3 knots.

All of this confirms that the dynamic simulation of trawl nets is becoming a more important option for the study of trawl nets, and it must be complemented with other sources of information, either through direct measurements or the use of scale models (Queirolo *et al*., 2009; Nguyen *et al*., 2015).

In this research, four types of trawl nets were used, differenced according to the target fishery; that is, pink shrimp, sea-bob shrimp, demersal fishes and mixed. Although this determines a great difference for users, when analyzing the performance patterns among the nets, it can be observed that differences are relatively small, and basically occur due to the progressive changes of the net designs to be adapted to other fisheries. A mixed net can be used not only for fishes but also for shrimps, while a net for sea-bob shrimps probably evolved from a net for pink shrimps. This explains that the proportions and general performance of the nets allow to be represented through general equations.

Regarding to the wing-end spread (WS), a variable that largely determines the catch of a trawl net, a variation between 35% and 65% of the headrope length was determined, with an average value of 51%, which is within the spread range for bottom trawl nets (Martini, 1986). In general, it is known that the WS can be calculated in a static way from the length of the headrope, representing between 50% and 70% of its length (WS = [0.5-0.7]*HL) (Okonski & Martini, 1987). However, the operation variables, as the trawl speed, are decisive in the magnitude of the WS in bottom trawl nets, the same was observed in this research. It was demonstrated that the trawl speed (operational variable) as well as the headline length (design variable) explain the WS of the nets, considering different equations according to the shape and size of the nets. From these equations, it can be identified that the independent effect of the WS ranges between 28.8% and 35.9% of the headrope length.

The dynamic simulation of the sea-bob shrimp nets presented a lower hydrodynamic resistance than the pink shrimp nets at the same trawl speed. Although the general dimensions are very similar, there are differences in the construction of the nets, especially in the yarns, which are thinner in the former nets, however it does not affect the $\overline{D/L}$ ratio that fluctuated in a narrow range. The differences in terms of wing-end spread are low, allowing to recognize that the sea-bob shrimp nets presented a nearly optimal mechanical (resistance) and operational performance (wing-end spread), requiring field tests to verify the accuracy of these results.

When considering the mouth height of the net in the global analysis, there is a clear difference of target resources between nets. Thus, the nets with a low mouth height in relation to the wing-end spread, correspond to shrimp nets (pink shrimp and sea-bob shrimp), as well as mixed nets. In this way, it is possible to conclude, on the basis of its performance, that mixed nets are mainly oriented to catch shrimps, fish being secondary species. The same can be observed from the similarity in terms of the wing-end spread in relation to the length of the headrope. The nets for fishes clearly show a mouth height that represents around 20% of the wing-end spread, while the shrimp and mixed nets present a mouth height of almost 10% of the wing-end spread.

In terms of the hydrodynamic resistance of the fishing gear, it was possible to adjust an equation depending of the headrope length and the trawl speed that could have an important role in the future of the trawl fishery. As long as advances are made in the measurements of fuel consumption of the fleet (*i.e*., using flow meters), it will be possible to associate that consumption to the hydrodynamic resistance (Broadhurst *et al*., 2013), and thus to have the specific figures of the technological improvements (*i.e.*, reduction in yarn diameter) on the reduction of the used fuel by trawl hour or swept area.

Horizontal opening of bottom trawl nets are one of the key variables to be known when conducting direct biomass assessments with the swept area method (Gunderson, 1993; Sparre & Venema, 1997). Therefore, while not discarding the validity of obtaining future accurate in situ measurements, the equations obtained in the present study represent an important contribution in this direction, producing reasonable opening estimates from relatively well-known features of the nets and fleets. In addition, thousands of commercial tows have been monitored by observers in the region, resulting in an extensive database of catch data which are fully available for analysis. Part of them have been used by Sant`Ana & Perez (2016), to demonstrate that geostatistical models can produce unbiased biomass estimations for demersal resources, even when using information from commercial fishing trips, where effort allocation does not follow any previously scientifically determined sample design. Thus, as suggested by cost-benefit analysis conducted by Sant`Ana (2013), combining the present results with detailed commercial fishing data and statistical modelling may represent an alternative low-cost strategy for conducting future biomass assessments, especially as compared to scientific surveys, which are often very difficult to implement due to economic and logistic constrains.

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