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Research Article

Multiple strategies developed by bottom trawlers to exploit fishing resources in deep areas off Brazil

Martin Coachman Dias[1] & José Angel Alvarez Perez[2]
[1]Independent Fisheries Consultant
[2]Grupo de Estudos Pesqueiros, Centro de Ciências Tecnológicas da Terra e do Mar
Universidade do Vale do Itajaí, Itajaí, SC, Brazil
Corresponding author: Martin Coachman Dias (martindias@vmdpesca.com.br)

ABSTRACT. Since the early 2000s, codling, hake and blackfin goosefish became main components in the landings of double-rig and stern trawlers fishing in the slope off the south and southeast coasts of Brazil. Because these stocks are known to be little resilient, the heterogeneous and unpredictable fishing regime has been regarded as biologically and ecologically unsafe. In this article, we examine the fishing strategies developed by the Brazilian trawl fleet when fishing deep water fish between 2007 and 2009. Slope fish resources were primarily exploited under four fishing tactics. On Tactic 1 landings comprised mainly hake and blackfin goosefish, with trawlers concentrating their fishing effort on the fishing grounds located in the upper slope (300-350 m depth) in central and northern areas. Two other strategies (Tactics 3 and 4) were similar to each other, with trawlers occupying fishing grounds on the upper slope (350 m) along the whole area. Catches were dominated by codling, representing at least 50% of the fish landed. A fourth strategy (Tactic 2) concentrated in shallow fishing grounds (100 m) along the whole coast, reported only small landings of deep water species (less than 20%). We characterized five different fleets based on the number of fishing trips that vessels dedicated to each strategy. During the study period, 34-37 vessels have undertaken fishing trips primarily in slope fishing grounds, however a few vessels (10-14) also fished for coastal species (Tactic 2). From 11 to 22 vessels fished regularly as coastal trawlers, operating opportunistically on slope grounds. Management of the deep water trawl fishery should take into consideration the number of trawlers specialized in targeting deep-water resources and the behaviour of opportunistic trawlers occasionally fishing in the slope.

Keywords: fishing strategy, multiple strategies fleets, deep-water fishery, target *métier* analysis.

Estrategias múltiples desarrolladas por arrastreros de fondo para explotar recursos pesqueros en aguas profundas de Brasil

RESUMEN. Desde comienzos de los años 2000, la brótola, la merluza y el rape pescador se convirtieron en los principales componentes de los desembarques de las flotas de arrastre doble y de arrastre por popa, que operó en el talud de la costa sur y sureste de Brasil. Debido a que estos stocks son conocidamente poco resilientes, el heterogéneo e impredecible régimen de pesca ha sido considerado como biológico y ecológicamente poco seguro. En este artículo, examinamos las estrategias de pesca desarrolladas por la flota de arrastre brasilera en la extracción de peces de aguas profundas entre 2007 y 2009. Los peces de aguas profundas fueron principalmente explotados mediante cuatro estrategias de pesca. En la Táctica 1, los desembarques incluyeron principalmente merluza y rape pescador, con los arrastreros concentrando su esfuerzo en las zonas de pesca localizadas en el talud superior (300-350 m) de las áreas central y norte. En otras dos estrategias (Tácticas 3 y 4), similares entre sí, operaron arrastreros en toda el área de las zonas de pesca localizadas en el talud superior (350 m). Las capturas fueron predominantemente brótola, que representó al menos el 50% del desembarque. Una cuarta estrategia (Táctica 2), que se concentró en zonas de pesca poco profundas (100 m) a lo largo de toda la costa, reportó solo bajos desembarques de especies de aguas profundas (<20%). Se caracterizaron cinco flotas diferentes, basados en el número de viajes de pesca que los buques realizaron bajo cada estrategia. Durante el periodo de estudio, 34-37 buques realizaron viajes de pesca mayoritariamente en zonas localizadas en

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Corresponding editor: Carlos A. Arfelli

el talud, sin embargo, unos pocos buques (10-14) también pescaron especies costeras (Táctica 2). Entre 11 y 22 buques pescaron de manera regular como arrastreros costeros y de aguas profundas, operando de manera oportunista en el talud. El manejo de la pesca de arrastre de aguas profundas debiera tomar en consideración el tamaño de la flota compuesta por arrastreros especializados en recursos de aguas profundas y en el comportamiento de aquellos que ocasionalmente pescan en el talud.

Palabras clave: estrategias de pesca, flotas de estrategias múltiple, pesquerías de aguas profundas, análisis de objetivo *métier*.

INTRODUCTION

Exploitation of living and non-living resources in deep areas of Brazil has increased in the past 20 years paralleling global trends and raising both economic benefits and environmental pressures over pristine marine ecosystems of the SW Atlantic (Morato *et al*., 2006; UNEP-WCMC, 2007; Arana *et al.*, 2009). The development of demersal fisheries was central to this process attaining maximum levels of activity between 2000 and 2007 when both national and foreign vessels operated in the southern sectors of Brazilian EEZ. The latter were authorized to fish in Brazilian waters as part of a national deep-sea fishing development policy, allowing increasing catches of a few valuable finfish and shellfish species, namely: blackfin goosefish (*Lophius gastrophysus*), hake (*Merluccius hubbsi*), codling (*Urophycis mystacea*), argentine squid (*Illex argentinus*), deep-sea crabs (*Chaceon* spp.) and deep-sea shrimps (Family Aristeidae). By 2008, as this policy expired and foreign vessels were no longer active, most of these stocks had exhibited strong abundance oscillations and signs of overfishing (see Perez *et al*., 2009a for review).

After this so called “gold-rush” fishing episode, exploitation of slope resources continued to present-day, principally through the gradual establishment of a regular bottom trawl fishing regime down to 500 m depths. Codling, hake and blackfin goosefish became main components of slope trawling landings, which have oscillated annually between 5,000, 2,000 and 3,000 ton respectively (MPA, 2012). Sustainability of these catches remains uncertain, as stocks abundance has not been regularly assessed. Yet, general studies on the trawling effort dynamics and patterns of bycatch demonstrated that impacts on benthic ecosystems have increased, either through an expansion of the spatial footprint and the area disturbed by trawl nets, or by the incidental mortality impinged on nearly 30 teleost and elasmobranch species, the majority of them highly vulnerable to current fishing regimes (Port *et al*., 2016; Visintin, 2015).

Management efforts in the region included the establishment of fishing permits specific for slope trawling, limitation of fishing effort and capacity, and the definition of bathymetric limits (Perez & Pezzuto, 2006; Perez *et al*., 2009a). Only the former measure, however, was actually implemented in 2011 (Brasil, 2011), which has not prevented a much larger and unauthorized fleet to access demersal resources concentrated on slope grounds off southeastern and southern Brazil. These are ‘generalist’ trawlers that operate in different areas of the continental shelf and exploit a variety of finfish and shellfish species, as a strategy to improve their economic performance each year (Perez *et al*., 2001; Pezzuto & Mastella-Benincá, 2015). They tend to concentrate effort over unmanaged stocks (*e.g*., scallops *Euvola ziczac*, Pezzuto & Borzone, 1997; squids *Doryteuthis plei*, Perez, 2002, among others) and have largely contributed to the uncontrolled exploitation of slope resources (Perez & Pezzuto, 2006). Such heterogeneous and unpredictable fishing regime has been regarded as biologically and ecologically unsafe, considering that resilience of slope ecosystems and stocks is generally low (Koslow *et al*., 2002; Norse *et al*., 2012).

An additional problem arises from the fact that mixed interests in different species aggregations, as often observed in multi species/multi fleet fisheries, which may affect the catch and effort data introducing errors in the calculation of single stock abundance indices (He *et al*., 1997; Biseau, 1998). Overcoming such difficulties has usually required the use of the composition of catch to identify ‘fishing tactics’ (or *métiers*) within the pool of fishing operations carried on during a certain period of time, and the subsequent quantification of vessels that share annually the same tactics, *i.e*., sharing the same ‘fishing strategy’ (He *et al*., 1997; Biseau, 1998; Holley & Marchal, 2004; Wiff *et al*., 2008). Fishing tactics have been characterized by a combination of target species, fishing area, gear, and time of the year (Laloë & Samba, 1991; Laurec *et al*., 1991; Holley & Marchal, 2004; Ulrich & Andersen, 2004). We apply this approach to identify a typology of fishing tactics adopted by trawlers that reported slope resources in their catches off southern and southeastern Brazil. The primary aims are (a) to identify within this typology, tactics fully (or highly) dedicated to these resources, and (b) to identify groups of trawlers (fleets) that most persistently adhere to those tactics (considered slope ‘specialized’ trawlers). We expect these results to allow inferences about fishing capacity being built on slope resources after the period of foreign slope fishing, as elements, not only critical to guide sustainable fishing regimes over targeted stocks, but also relevant in the context of the development of an "area-based" fishing management model, currently debated as an alternative for demersal fisheries off southeastern and southern Brazil (Rosso & Pezzuto, 2016).

MATERIALS AND METHODOS

Data collection

Fishing data were recorded from 2007 to 2009 at the landing sites through interviews with skippers, as part of a routine industrial fishing sampling program conducted at the harbors of Santa Catarina State, Brazil (Perez *et al*., 1998), or retrieved from available logbooks. Because these harbors host nearly 60% of the fleet operating off southeastern and southern Brazil, and records annually 50-95% of the landings of slope resources (Perez *et al*., 2001; UNIVALI/CTTMar, 2010), the analyzed data set was assumed to be representative of the overall fishing patterns in this area. Recorded variables included total catch landed (discriminated by species or 'categories', *i.e.* group of species, in kg), fishing effort (number of days fishing, number of tows per day and duration of tows in hours), fishing grounds visited (informed by skippers through geographical coordinates or geographical landmarks), and depth (in meters). The information reported was reviewed by experienced analysts who compared them to long term trends of fishing areas and depths visited by trawlers, common species in the catch, catch values and trip duration etc. When records diverged significantly from these trends they were considered "unreliable" and eliminated from the database. Additionally, when more than one source of information was available for a single fishing trip, these were crosschecked for consistency and eliminated when sources diverged greatly.

Addressing the slope trawl fishery required a selection of all fishing trips that captured slope resources by using a range of tactics, varying from trips that conducted occasional deep tows within a mostly coastal operation, to those fully directed at slope areas. Because depth was not normally reported on a tow-by-tow basis, slope fishing trips could not be efficiently selected using such information. Therefore, a fishing trip selection criterion was adopted based on reported catches of at least one of three species: blackfin goosefish (*Lophius gastrophyus*), hake (*Merluccius hubbsi*) and codling (*Urophycis mystacea*). These species comprise most landings and have been shown to be major targets in the slope areas of southeastern and southern Brazil (Perez & Pezzuto, 2006). A total of 1,315 fishing trips that landed at least one of the three-abovementioned species were selected, being 1,100 trips carried out by 212 double rig trawlers and 215 trips by 40 stern trawlers (Table 1). Twenty-nine vessels switched their fishing gears between trips, and were considered in both gear categories.

Preparation of data collected for geographical analysis of fleet dynamics involved assigning total catch (kg), fishing effort (total trawled hours) and landings per unit effort (LPUE in kg h^{-1}) to a 30'x30' geographical grid based on the fishing area information provided by the skippers. Fishing trips that operated in more than one unit of the grid had their fishing data divided equally among all units visited. This approach allowed mapping the distribution of the fishing effort along the South and Southeast coast. Three main areas (North - north of the 25.5ºS; Central - between 25.5º and -25.9ºS and South - south of the 29.5ºS) created and in the analysis of fleet dynamics. No spatial data was available in 2009.

Definition of the typology of fishing tactics

The total number of selected fishing trips were arranged in a matrix $M_{i,j}$ with the *i* and *j* indexes referring to a fishing trip and a species landed in the trip, respectively (He *et al*., 1997; Wiff *et al*., 2008). The latter included the three-abovementioned species and a fourth category formed by the sum of all other landed species within a fishing trip. "Fishing tactics" were defined according with groups of fishing trips with similar proportions of the selected species and "other species", as revealed by a cluster analysis. This analysis required initially the construction of a dissimilarity matrix calculated using the Manhattan method. Subsequently three dendrograms were constructed, one for each year, grouped with the complete linkage method. Groups were delimited in the dendrograms by cutting at the 0.95 dissimilarity index.

Fishing tactics (groups of fishing trips with similar catch composition) were described by *i*) the total catches and relative proportion of the species in landings; *ii*) temporal (seasonal) patterns of fishing trips; *iii*) fishing areas and depths and *iv*) catch rates (LPUE). The identified typology of fishing tactics was finally grouped in "Slope" or "Continental Shelf" tactics (see results), depending on their adherence to slope resources throughout the year.

Target *métier* analysis

Directionality levels of each tactic to the main fishing resources of the slope areas were accessed by an adaptation of 'target *métier*' technique developed by Biseau (1998). In this procedure, the proportion of each

Table 1. Summary of the fishing trips separated by fishing tactics and year, presenting the number of fishing trips performed in each bathymetric and latitudinal stratum, the number of vessels that performed fishing trips during the study period and the total catch (in ton and %) for species evaluated. CS: continental shelf, SB: shelf break, SL: slope, DR: double rigs trawlers, ST: stern trawlers. Numbers between parentheses refer to the number of double rig trawlers that also have operated as stern trawlers.

		Number of fishing trips by depth			Number of fishing trips by area			Number of vessels		Total catch (ton)						
	Year	CS	SB	SL	North	Central	South	DR	ST	Codling	%	Hake	%	Blackfin goosefish	%	Total
Tactic 1	2007	5	12	30	21	31	3	17	1 (1)	151.1	5	268.6	26	248.9	46	668.6
	2008	1	2	14	11	6	2	9	1 (0)	128.0	3	227.2	16	37.1	8	392.3
	2009	13	2	10	-	-	-	21	1 (1)	125.6	3	264.9	13	21.6	3	412.1
Total		19	16	54	32	37	5	40	3 (3)	404.7	4	760.7	17	307.6	19	1,473.0
Tactic 2	2007	165	91	17	20	139	132	91	17 (12)	169.1	6	140.3	14	83.8	15	393.2
	2008	175	107	13	46	117	123	98	20 (9)	211.9	6	131.4	9	141.0	32	484.3
	2009	211	136	11	-	-	-	106	21 (5)	240.0	5	233.4	11	155.5	23	628.9
Total		551	334	41	66	256	255	185	37 (24)	621	5	505.1	11	380.3	23	1,506.4
Tactic 3	2007	2	8	26	1	10	18	14	0	752.0	27	53.6	5	27.3	5	832.9
	2008	1	20	52	13	32	27	23	3 (3)	1,643.0	43	268.8	19	89.1	20	2,000.9
	2009	3	40	75	-	-	-	37	0	2,550.8	54	424.7	20	243.7	36	3,219.2
Total		6	68	153	14	42	45	47	3 (3)	4,945.8	44	747.1	17	360.1	22	6,053.0
Tactic 4	2007	13	50	82	20	78	39	44	3 (3)	1,714.4	62	555.2	55	186.0	34	2,455.6
	2008	16	62	84	63	65	34	58	2 (2)	1,845.0	48	767.7	55	179.3	40	2,792.0
	2009	7	27	98	-	-	-	37	0	1,813.4	38	1,183.5	56	249.1	37	3,246.0
Total		36	139	264	83	143	73	89	5 (5)	5,372.8	47	2,506.4	55	614.4	37	8,493.6
Total		612	557	512	195	478	378	212	40 (29)	11,344.3	-	4519.3	-	1,662.4	-	17,526.0

species biomass in the total landing of each trip within a fishing strategy and year was calculated, and values were rounded into integers. These proportions (varying from 1 to 100%) were considered as 'qualification levels' (QL). The frequency of fishing trips where each species had the same QL was calculated and a species-specific cumulative frequency curve was built for each of the studied years. The patterns of directionality of a given tactic to a particular species were established from the shape of these curves: 'incidental species', 'targets' and 'massive targets'. In the former, characterized by logarithmic-shaped curve, the majority of fishing trips reported small proportions of the considered species in the total catch (low QLs are most frequent). The latter represented the opposed situation, *i.e.* a positive exponential-shaped curve and showed that most fishing trips reported large proportions of the considered species in the catches (high QLs are more frequent). Finally 'target' species were identified by a rather linear trajectory, and the fishing trips were well distributed among the different QLs.

Definition of Fleets/ Strategies

The adherence of different vessels to each tactic, and their flexibility/ability to change tactics throughout the year (Ulrich & Andersen, 2004), was quantified by calculating the proportion of trips that each vessel conducted under each fishing tactic, according to Equation 1, where $P_{a,i}$ refers to the proportion (%) of fishing trips carried by a vessel "a" under a tactic "i"; $n_{a,i}$ represents the number of fishing trips carried by "a" under tactic "i" and N_a the total of trips conducted by vessel "a".

$$P_{a,i} = \frac{n_{a,i}}{Na} * 100 \quad (1)$$

'Fleets' were defined as groups of trawlers that shared similar strategies, *i.e.* "Slope Fleet" (SF) and the "Continental Shelf Fleet" (CSF) comprised vessels that carried out 100 % of their fishing trips under slope and continental shelf tactics, respectively. These were 'specialized' trawlers (*sensu* Ulrich & Andersen, 2004). A "Preferential Slope Fleet" (PSF) and a "Preferential Continental Shelf Fleet" (PCSF) comprised vessels that carried on at least 66 % of their fishing trips under the Slope and Continental Shelf tactic, respectively. A "Double Strategy Fleet" (DSF) was characterized by vessels that adopted Slope and Continental Shelf tactics in similar proportions. These were 'polyvalent' trawlers (*sensu* Ulrich & Andersen, 2004). The five fleets ('strategies') were sized and compared between years.

RESULTS

Identification of fishing tactics

Dendrograms separated the total number of fishing trips into four groups, consistently noted in the three years analyzed (Fig. 1). The first identified group (Tactic 1) comprised 77 fishing trips where hake was the main catch component representing, on average, 50% of the landed biomass (Fig. 2). Blackfin goosefish landings were also significant in 2007, but its contribution to total landings reduced in subsequent years. Together, the three slope species contributed with nearly 75% of the total biomass landed by this group in the study period. Tactic 2 comprised the largest number of fishing trips (726) where hake, codling and the blackfin goosefish were minor components contributing, on average, to less than 10% of the biomass landed by each trip (Fig. 2). Codling was a major component of landings in Tactic 3. The species contributed to over 75% the total biomass landed by the 172 fishing trips under this tactic. Together, hake and blackfin goosefish accounted for another 15% of the landings. The fourth identified group (Tactic 4) comprised 340 fishing trips, equally distributed between the three years considered. As observed in Tactic 3, codling was a major component of the landings. However, this species was seen in lower proportions than those observed in fishing trips of Tactic 3. On the other hand, hake, blackfin goosefish and other non-discriminated species had greater participation in the landed catch of the fishing trips, contributing with around 20%, 5% and 25%, respectively (Fig. 2).

Tactic 1 included fishing trips conducted mostly in the upper slope and shelf break of Central and North areas between 100 and 350 m depths (Figs. 3, 4). In 2008 fishing trips concentrated in deeper areas, whereas in 2009 they dispersed along this depth range in association with an increase in the contribution of species other than hake, codling and blackfin goosefish to the total landed catch (Table 1, Fig. 2). Fishing trips occurred year round with no particular seasonality (Fig. 5). The 'target *métier*' analysis indicated that hake was a consistent target of this group, especially in 2008. In 2009 50% of the landings reported catches in which the hake contributed with more than 50% of the weight landed. The species only did not feature as a target in 2007, when it could be considered an incidental species. Other species oscillated between targets and incidental species during the three years analyzed (Fig. 6). A total of 40 double rig trawlers and three stern trawlers operated under this fishing tactic (Table 1).

Tactic 2 presented a smooth oscillation between years and included fishing operations concentrated in

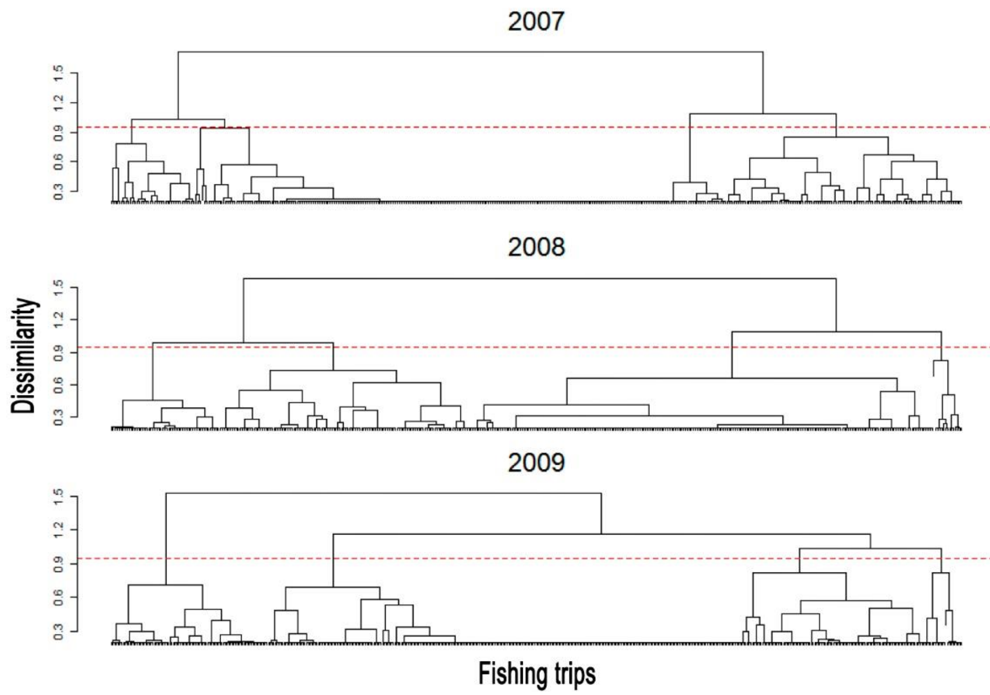

Figure 1. Dendrograms produced by cluster hierarchical analysis applied over the fishing trips carried by the south and southeastern Brazilian trawl fleet between 2007 and 2009. Dashed red lines represent the arbitrary cuts at 0.95 dissimilarity index.

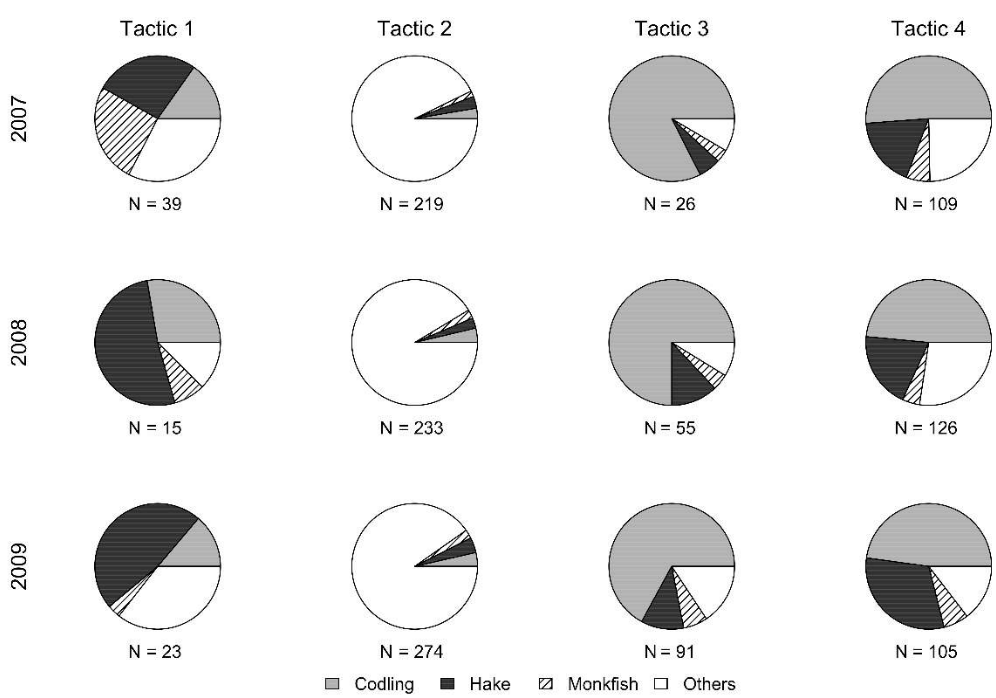

Figure 2. Mean proportion of deep-water demersal fishes (codling, hake and blackfin goosefish) in the total catch of fishing trips conducted by four fishery strategies (groups) identified on cluster analysis between 2007 and 2009.

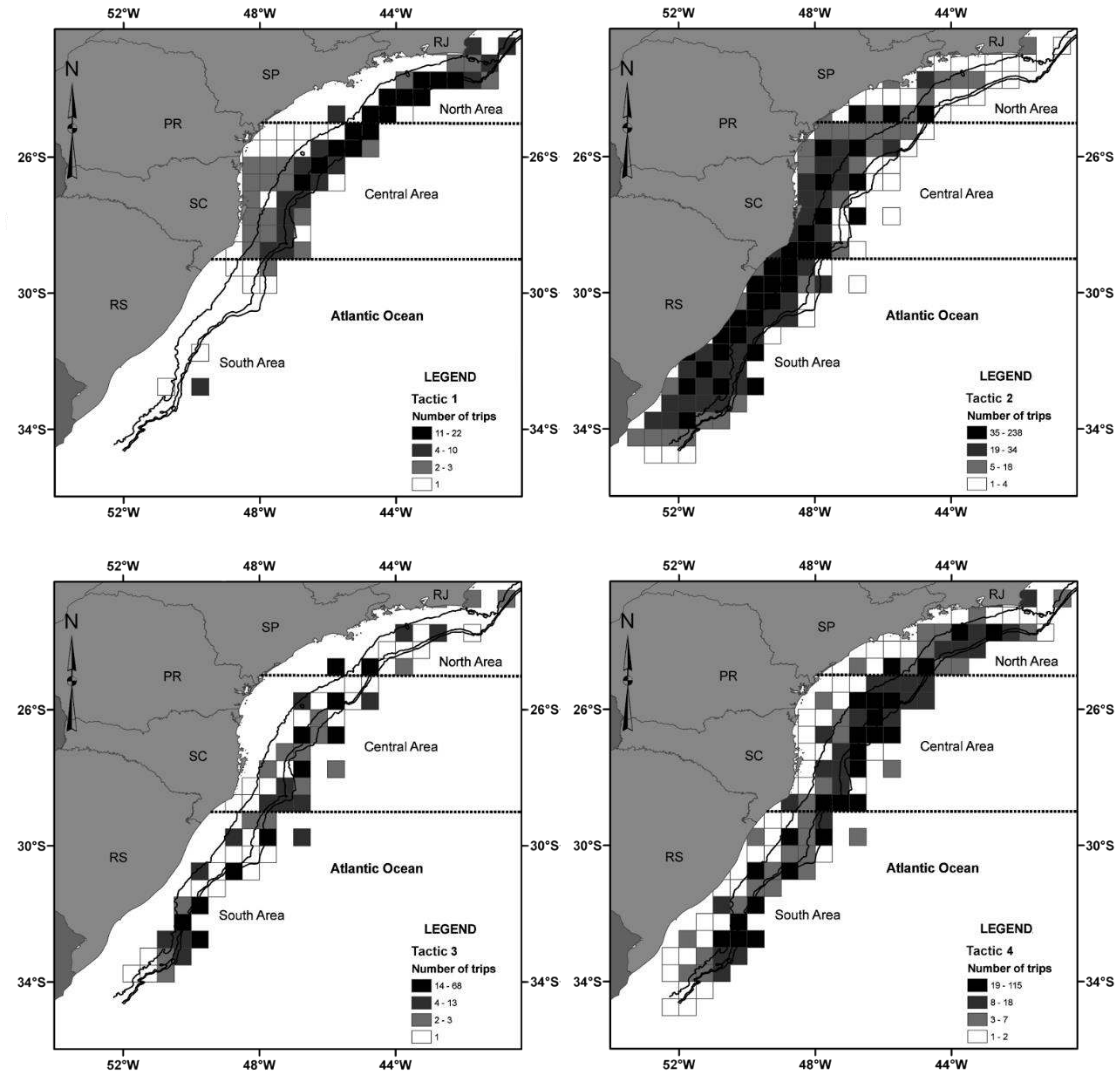

Figure 3. Spatial distribution of fishing effort (number of trips per square) conducted by each group. Data represents only 2007 and 2008 years.

the continental shelf (depths shallower than 100 m). Trips were more frequent in the second and third trimesters and were conducted along the entire latitudinal range, although more frequently in Central and South areas (Table 1, Figs. 3-5). Tactic 2 was formed by 185 double rig and 37 stern trawlers (Table 1). In these operations, blackfin goosefish, codling and hake were consistently characterized as 'incidental species' (Fig. 6).

Tactics 3 and 4 were similar and comprised fishing trips chiefly conducted in the upper slope and shelf break, oscillating around 300 and 400 m depths (median values, Table 1 and Figs. 3, 4). Operations were widely distributed throughout the year and along the latitudinal range although, fishing trips under Tactic 4 tended to concentrate in the Central area and during the first half of the year (Fig. 5). The codling oscillated between a 'target' and a 'massive target' in both tactics, and hake appeared as a target to Tactic 4. Contrastingly, catches of blackfin goosefish were always incidental (Fig. 6). Tactics 3 and 4 comprised 47 and 85 double rig trawlers and 3 and 5 stern trawlers, respectively (Table 1).

Catch rates (kg h^{-1}) of slope fishes by Tactic 2, which used primarily shelf areas, were expectedly low (Fig. 7). Nevertheless, because this tactic comprises a massive number of fishing trips (726 fishing trips - see Fig. 2), their combined landings attained 1,506 ton of the slope fish species during the study period, nearly 10% of total landings (Table 1). This contribution was highest for the blackfin goosefish, reaching 15-30% of annual landings, and lowest for codling (5-6%).

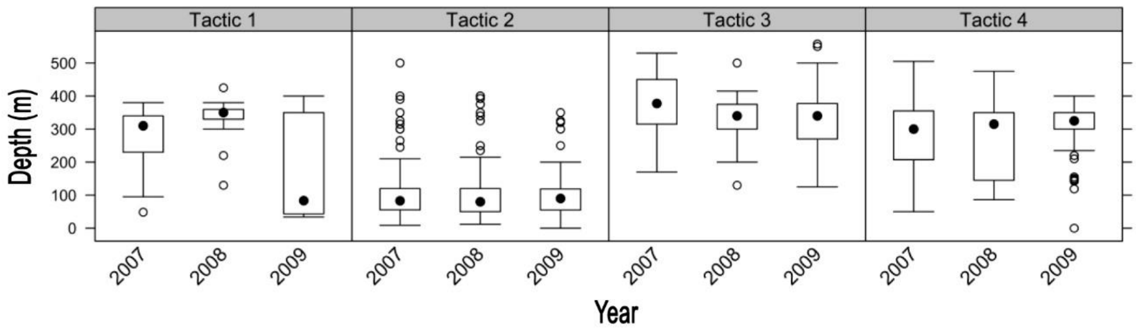

Figura 4. Distribution for the depth operations showed in the boxplot. Black points represent the median values, boxes the first and third quartiles. Boxplots are discriminated for groups and years.

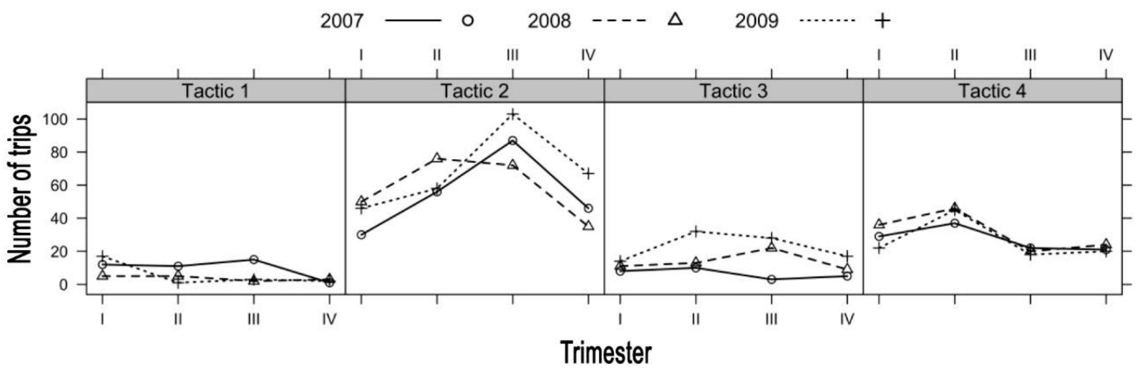

Figure 5. Number of fishing trips conducted into each group compared between trimesters and years.

Catch rates of fishing trips under Tactic 1 varied widely among species and years, probably in association with the dynamic behavior of trawlers throughout the study period (see above). It produced the highest catch rates of hake when compared to other tactics, with a particular peak in 2008, when median values reached over 40 kg h^{-1} (Fig. 7). Hake landings remained stable, above 220 ton, during the three consecutive years, contributing annually to 13-26% of the total landed biomass of the species (Table 1). During the three consecutive years these landings were greatly surpassed by the increasing landings of fishing trips under tactics 3 and 4.

Catch rates of codling obtained by Tactic 1 were highest in 2008 when reached a median value around 40 kg h^{-1}, but remained generally lower that the ones obtained by tactics 3 and 4 (Fig. 7), which also reflected in small contributions for annual landings of this species (3-5%) (Table 1). Catch rates of blackfin goosefish obtained by Tactic 1 were highest in 2007 (median = 15 kg h^{-1}) (Fig. 7) when it contributed to 46% of total landings of the species (Table 1). These catch rates decreased in subsequent years, as did total catches. Despite concentrating fishing effort in slope areas, this tactic contributed generally little to exploitation of slope fishes. This was mainly due to the reduced number of trawlers and fishing trips under this tactic (Fig. 2).

During most years, Tactics 3 and 4 landed above 1,500 ton of codling, their main target, contributing together to 91% of all landed catch of this species (Table 1). Catch rates obtained by Tactic 3 were higher than those observed for Tactic 4. However, they tended to decrease over the years, with median values varying from 100 to 75 kg h^{-1}. In Tactic 4, catch rates remained constant oscillating around 50 kg h^{-1} (Fig. 7). Hake had a discrete contribution in Tactic 3, with less than 800 ton caught in the three years summed. This represented around 17% of the total biomass landed of this species. On the other hand, 2500 ton of hake were landed by fishing trips under Tactic 4, over 50% of the total biomass landed by trawlers from 2007 to 2009. Blackfin goosefish catch rates were generally similar in both tactics (around 5 kg h^{-1}).

Tactics 3 and 4 landed jointly the bulk of biomass of slope fishes during the study period. That basically reflects the elevated catch rates obtained by trawlers operating frequently under these tactics, in association with a large number of fishing trips.

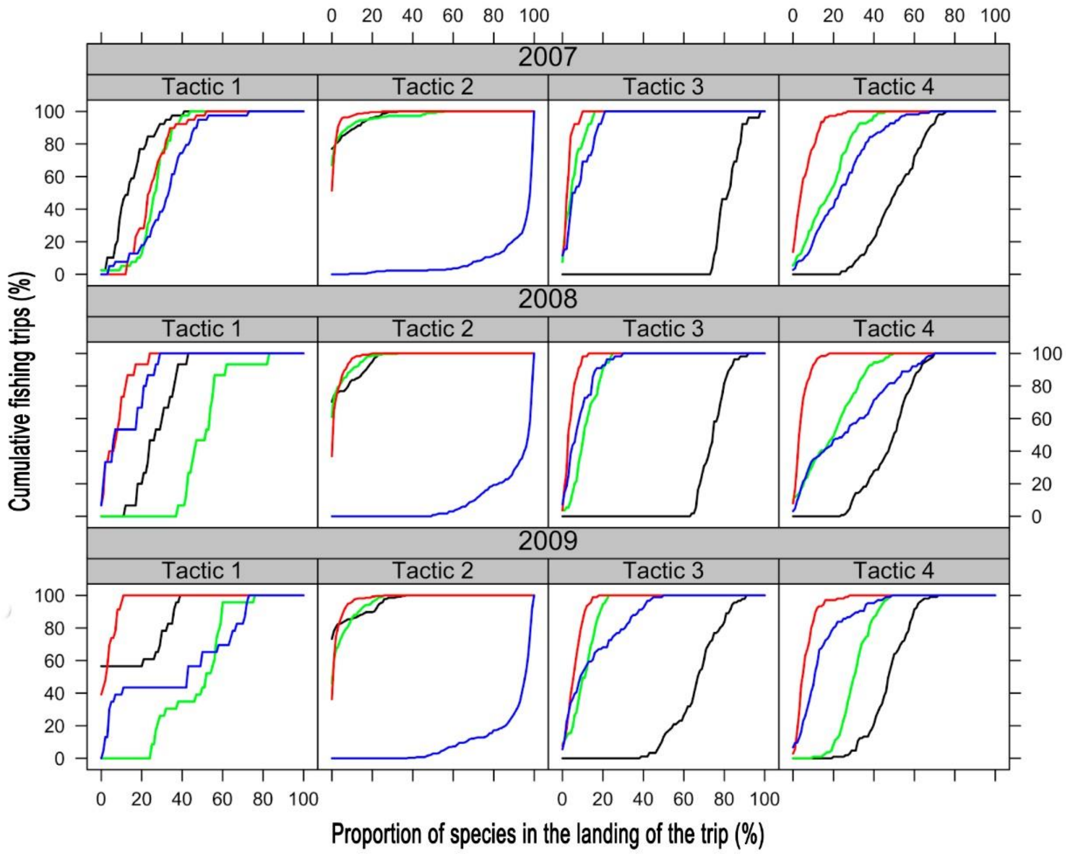

Figure 6. Cumulative relative frequency of fishing trips by the proportion of codling (black line), hake (green line), blackfin goosefish (red line) and other (blue line) indiscriminate species in the landings of the fishing trips. Data are discriminated by each fishing strategy (Tactics) and year.

Definition of fleets/strategies

Five fleets (strategies) were differentiated by the combination of tactics adopted to exploit slope fishes off southeastern and southern Brazil (Fig. 8). CSF was by far the largest one, representing more than 50% of the total number of trawlers and with a maximum of 92 units observed in 2009. This fleet operated preferentially under the shelf tactic (Tactic 2) and included no more than 7 units recorded in 2008. The number of vessels that adopted inshore and offshore tactics equally (DSF) was highly variable, with 14, 22 and 11 units, observed in 2007, 2008 and 2009, respectively. DSF comprised more vessels in years when CSF comprised fewer vessels. Trawlers that fished exclusively or preferably on the shelf (PCSF and CSF) reached from 67 to 97 units between 2007 and 2009 (Fig. 8).

The fleet that fished exclusively with tactics 1, 3 and 4 (SF), characterized by slope fishing operations, included no more than 30 units varying little in size during the study period. The fleet which fished preferably on the slope, but occasionally adopted shelf trawling tactics (PSF), ranged from 10 to 14 vessels in 2008 and 2009, respectively. Considering that these were strategies of trawlers most dedicated to slope fishing, the total size of the fleet operating in slope areas off southeastern and southern Brazil may have attained 44 units during the study period (Fig. 8).

DISCUSSION

Blackfin goosefish, codling and hake were the major drivers of the trawl fishing expansion to the slope areas off southeastern and southern Brazil (Perez *et al.*, 2009a). This expansion begun during the foreign vessel fishing period (2000-2007) and continued thereafter through the development of tactics focused on the maximization of catches of these resources. Trawl fishing data available from 2007 to 2009 revealed a typology of tactics adopted by nearly 250 vessels whose features may, in principle, be related to patterns of distribution and abundance of the main target species.

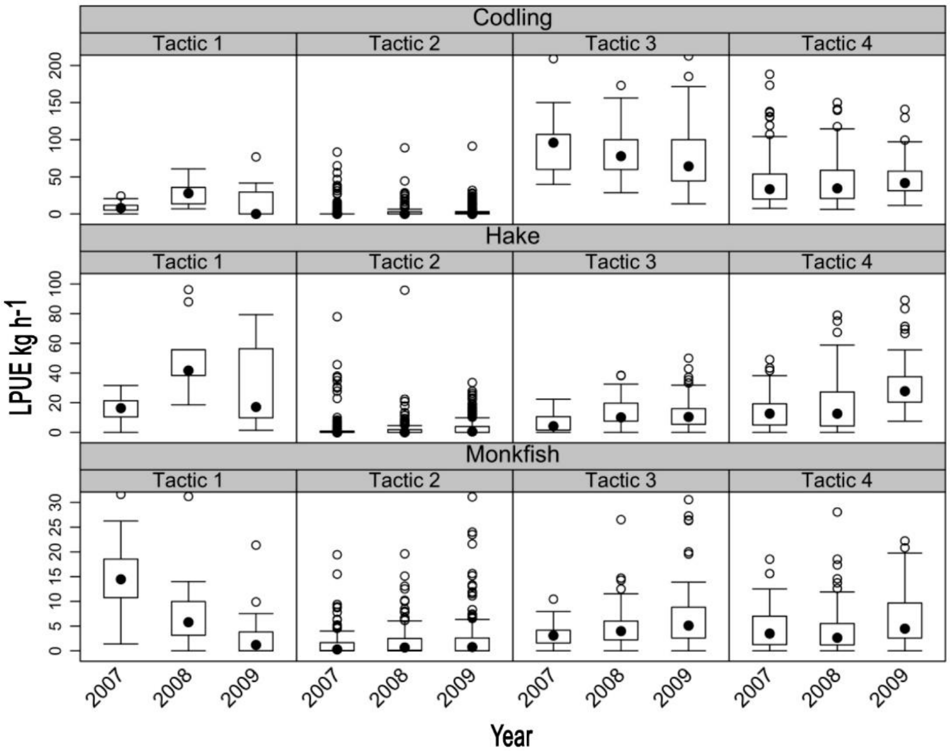

Figure 7. Boxplot representing the fishing catch rates (LPUE in kg h^{-1}) of fishing trips conducted under each fishing strategy (Tactics) from 2007 to 2009.

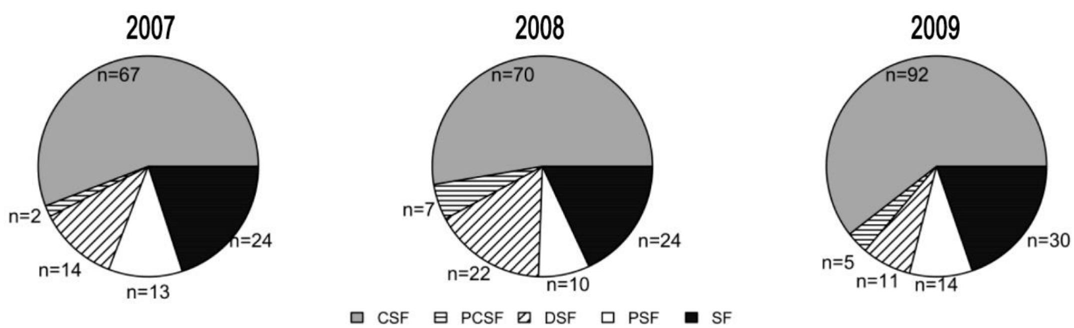

Figure 8. Pie chart comparing the size of each specific fleet. Numbers in the charts refers to the number of vessels registered into each fleet. SF: slope fleet; PSF: preferential slope fleet; DSF: double strategy fleet; PCSF: preferential continental shelf fleet and CSF: continental shelf fleet.

Densities of all three species escalate at depths greater than 200 m (Haimovici *et al.*, 2009). Yet, they also occur over the shelf up to 50-60 m depths. Blackfin goosefish and codling tend to concentrate south of 27°S, whereas two nuclei of elevated densities of hake have been found, one north of 26°S and another south of 32°S (Haimovici *et al.*, 2009). These possibly correspond to two geographically isolated stocks (Vaz-dos-Santos *et al.*, 2009). Three tactics (1, 3 and 4) concentrated on depths where slope fish densities are highest (200-500 m). Jointly, they comprised 45% of the fishing trips that reported landings of blackfin goosefish, hake and codling and contributed to 91% of their combined landed biomass during the study period. One of them (Tactic 4) characterized a broader occupation of the slope areas, highest fishing effort (nearly 1/3 of all fishing trips) and produced highest catches of hake and codling. The two other tactics reflected some level of specialization to hake (Tactic 1) and codling (Tactic 3) exploitation. The former was clearly directed at the northern sectors of the slope, where concentrations of the so called 'southeastern stock' (Vaz-dos-Santos *et al.*, 2009) has been available to trawl fishing throughout the year and exploited by operations of both national and foreign trawlers since 2000 (Perez & Pezzuto, 2006; Perez *et al.*, 2009b). Interestingly, blackfin goosefish was a bycatch component of all three tactics.

Nearly 10% of the landings of the three selected slope fish during the study period were attributed to operations of trawlers under a 'coastal' tactic (Tactic 2). These were either retained catches of blackfin goosefish, hake and codling available in shallower areas, or derive from occasionally deep trawls conducted during regular fishing trips. The former case is particularly relevant to blackfin goosefish exploitation regime since nearly 1/3 of the landed biomass was obtained by the shelf trawls. These catches usually comprise only young and immature fish bathymetrically segregated from larger individuals that concentrate on the slope (Valentim *et al.*, 2007), and their potentially high fishing mortality rate may affect adult stock resilience on the slope fishing grounds. Encompassing a significant number of fishing trips during the study period, Tactic 2 could be further subdivided into new 'coastal' tactics, provided that this analysis is expanded to shelf and shelf break species. Previous reviews on the trawl fleet dynamics off southeastern and southern Brazil revealed both historical and ongoing fishing tactics focused at both fish (*e.g.*, flatfish *Paralichthys* spp.) and shellfish (*e.g.*, pink shrimp *Farfantepenaeus* spp., argentine stiletto shrimp *Artemesia longinaris*, argentine red shrimp *Pleoticus muelleri*, scallop *Euvola ziczac*, long-fin squid *Doryteuthis plei*) (Pezzuto & Borzone, 1997; Perez & Pezzuto, 1998; Perez, 2002; Perez *et al.*, 2007).

A specialized 'slope fleet' encompassed annually 34-37 vessels, approximately 15% of all trawlers that reported catches at the harbors of Santa Catarina during the study period (UNIVALI/CTTMar, 2010). It comprises a subset of the numerous trawl fleet operating regularly off southeastern and southern Brazil (Perez *et al.*, 2001), which has 'naturally' adapted, both technologically and operationally, to thrive year round on slope fishes. In a sense, they correspond to the slope trawl fleet envisioned by scientifically-based assessments conducted before 2006, spread along the entire southeastern and southern Brazilian coast between the 250-500 m isobaths and targeting hake and codling concentrations (Perez & Pezzuto, 2006). Yet they also developed contrasting features, most notably a) the prevalence of double rig trawls, as opposed to the presumably more efficient stern trawls; b) the regular harvesting of the blackfin goosefish stock, although not as a main target; c) the regular discarding of the silver John dory (*Zenopsis conchifera*) regarded as a potential target at that time; d) the great quantity of vessels, nearly two-fold the number initially recommended (17) based on estimations of annual sustainable catches of hake, codling and silver John dory (Perez *et al.*, 2009a).

Consequences of such divergences and perspectives of long-term sustainability of the developing trawl fishing regime on the slope are uncertain. Blackfin goosefish and hake stocks have sustained stable landings until recently (2011) and close to the estimated MSY (blackfin goosefish ~2,500 ton; hake ~2,215 ton) (Perez, 2006; UNIVALI/CTTMar, 2013). Yet, because latest biomass assessments date back to 2008, little can be concluded about temporal trends of their abundance in the fishing areas. On the other hand, a risk analysis using landing information recorded in 2010-2011 and criteria based on fish species capacity to regenerate biomass ('productivity') and their 'susceptibility' to bottom trawling, indicated that nearly ¼ of all fish species landed by the slope fleet could be considered highly vulnerable to overfishing (Visintin, 2015). Blackfin goosefish, codling and hake featured among these species as well as the pink cusk-eel (*Genypterus brasiliensis*) and several rays within the family Rajidae. Evidences for an increasing occupation and disturbance of slope benthic ecosystems by trawl nets have also been revealed from the offshore expansion of trawling effort between 2003 and 2011 and the total area swept by trawlers in the slope area (Port *et al.*, 2016).

A relatively small fraction of trawlers adopted a 'polyvalent' strategy moving widely between continental shelf and slope fishing grounds. These could be interpreted as vessels undergoing a transitional strategy during the study period, *i.e.* searching for better profit opportunities, following positive experiences obtained by slope trawlers. Alternatively, however, they could encompass a set of vessels led by skippers originally licensed to catch pink shrimp or coastal demersal fish (mostly sciaenids) but that freely operate in multiple unmanaged stocks available locally and/or seasonally to versatile double rig trawls. Whereas such strategy tends to improve annual economic performance (Pezzuto & Mastella-Benincá, 2015), it has a potential to erratically add a variable amount of fishing effort to that imposed each year by slope trawlers on slope stocks.

Generalists' and 'specialist' fishers play an important role in the development of new fisheries (Branch *et al.*, 2006). The former are normally associated to versatile vessels/ fishing technologies that allow them to operate in a variety of fisheries switching target species as opportunity arises (McKelvey, 1983). They are particularly adapted to instability, both ecological and economic, and tend to enter new fisheries more easily because they aim at short-term gains despite the involved risks (*e.g.*, they can always switch back to a species target or move to a new one) (Branch *et al*., 2006). In that sense they tend to become the founders of new fisheries and, in time, be substituted by vessels that will specialize in harvesting the targeted species, and aim at steady economic returns. Well-established fisheries will be primarily operated by specialist fishers. Under a common-property regime, however, generalists may enter and exit these fisheries erratically from year to year, driven by stochastic variations in the stocks abundance and prices. By doing so they add effort to that exerted annually by specialists vessels, diluting their annual returns (McKelvey, 1983). Common-property operations will eventually end up having excessive total effort as composed by a variable mix of specialist and generalist fishers. Because such unstable regime can impede specialist fishers to perceive short-term investments restraints, only management measures, such as license limitation, could lower the risks of economic (*i.e.*, wasteful capitalization) and biologic overexploitation (McKelvey, 1983). The latter will increase if the target species are valuable, ease to fish at low costs, and live long and grow slowly (Branch *et al*., 2006).

The slope trawl fisheries off southeastern and southern Brazil, as characterized by the fleet monitored between 2007 and 2009, seem to comprise such mix of fisheries. Its development, after the end of the foreign fishing episode, may have included operations of generalist trawlers usually engaged in coastal fishing tactics. Throughout the past decade, however, the growing number of slope trawlers, augmented annually by an uncontrolled entry of versatile double-rig trawlers under generalist strategies, may have enhanced the potential to overfish the little productive and highly vulnerable slope fish (Perez, 2006; Visintin, 2015). In that sense, limitation of permits to the specialist 'slope trawl' trawlers only, numerically restricted by sustainable annual yields, seems mandatory in order to prevent future overfishing and to promote conservation o slope benthic ecosystems. That seems equally valid to other fisheries developing in the slope areas, such as the gill net fisheries (Pio *et al*., 2016).

Separation of multispecies/multifleet fisheries into distinct management units may not be simple particularly when the level of technical interactions is high (*e.g*., Ulrich & Andersen, 2004). However a promising approach has emerged from the insertion of demersal fisheries into a spatial management plan for the region (Rosso & Pezzuto, 2016). As noted by Holley & Marchal (2004), however, the approach utilized in this study to identify fishing tactics and strategies does not allow results to be extrapolated to other time periods. Sequential analyses using longer and more recent time series are critical to contribute to the development of these new management initiatives.

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