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Research Article

Spatial management units for industrial demersal fisheries in Southeastern and southern Brazil

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ABSTRACT. Most fishing management systems in the world have long assessed and managed single-stocks over very large areas. The increasing use of the oceans and the problems faced by many fisheries have increased the trend to focus on spatial-based fisheries management. Most of the Brazilian industrial fisheries concentrate in the so-called "southeastern-south region" (SE/S), a large jurisdictional area exceeding 1600 km of latitudinal extent, along which industrial demersal fishing vessels operate quite unrestrictedly, resulting in large overlapping in their catch composition and fishing areas. Despite being essentially multi-specific, management of these fisheries is focused on a few target-species, with poor results in terms of sustainability. This paper aimed at identifying possible future spatial fishing management units for the region, based on the distribution of demersal stocks, depth, bottom characteristics and fishing dynamics from double-rig, pair and stern trawlers, bottom gillneters, bottom longliners and octopus potters which were landed in Santa Catarina harbors (southern Brazil) between 2010 and 2012. Based on these data and information from existing literature, six potential spatial units were proposed at coastal (<30 m depth), shelf (southeastern and southern sectors) (30 to 100 m), shelf break (100 to 250 m) and slope areas (>250 m). This new scheme represents a step forward in designing a final spatial management model for the SE/S industrial fisheries, improving a previous model published in the early 2000`s and conforming, in general, to the three main subdivisions recognized for the South Brazil Large Marine Ecosystem.

Keywords: fishing management, marine spatial planning, demersal fisheries, industrial fisheries, ecosystem approach in fisheries, southeastern-south Brazil.

Unidades de manejo espacial para las pesquerías demersales de la región sureste y sur de Brasil

RESUMEN. En el mundo la mayoría de los sistemas de manejo de pesquerías han evaluado y manejado stocks únicos en extensas áreas. El aumento del uso de los océanos y los problemas enfrentados por muchas pesquerías han generado un enfoque creciente de atención en el manejo pesquero basado en áreas. La mayor parte de las pesquerías industriales brasileñas se concentra en la llamada "región sureste y sur" (SE/S), una gran área jurisdiccional que excede 1600 km de extensión latitudinal, donde los buques pesqueros involucrados en las pesquerías demersales industriales operan casi sin restricción, resultando en una gran superposición en la composición de capturas y áreas de pesca. Al ser éstas esencialmente multi-específicas, el manejo de estas pesquerías se basa en un grupo pequeño de especies objetivo con resultados pobres en términos de sustentabilidad. El artículo busca identificar posibles unidades de manejo pesquero espacial para la región, sobre la base de la distribución de los stocks demersales, profundidad y tipos de fondo, así como también en la dinámica de las flotas de arrastre dobles, arrastre simple, arrastre por parejas, enmalle de fondo, palangre de fondo y trampas para pulpo, las que desembarcaron sus capturas en los puertos de Santa Catarina (sur de Brasil) entre 2010 y 2012. Basado en estos datos y en información obtenida en la literatura, se propusieron seis unidades espaciales de manejo en la zona costera (<30 m de profundidad), plataforma continental (sectores sur y sureste, 100-250 m) y talud continental (>250 m). Este nuevo esquema representa un avance en el desarrollo de un mo-

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delo de manejo espacial para las pesquerías industriales del SE/S, mejorando un modelo anterior publicado a inicios del 2000 y se ajusta en general, a las tres principales subdivisiones reconocidas para el Gran Ecosistema Marino del Sur de Brasil.

Palabras clave: manejo pesquero, planificación espacial marina, pesquerías demersales, pesquerías industriales, enfoque ecosistémico en la pesca, sureste y sur de Brasil.

INTRODUCTION

For a long time, most fishing management systems in the world has assessed and managed single-stocks over very large areas (Palumbi, 2004; Wilen, 2004; Claudet *et al*., 2006). The boundaries between these jurisdictional zones were frequently defined with no correlation with biological, oceanographic and/or human use patterns, mainly due to the scarcity of meaningful information available to the managers at the time of their definition (Wilen, 2004; Norse, 2010). The combination of the structure and processes of the biological components (and the respective environmental drivers) with management actions, has been viewed as a prerequisite for the sustainable management (Reiss *et al*., 2009, 2010).

This is especially true when moving from a single-species to an ecosystem approach in fisheries, in which a coherent space delimitation is of paramount importance. The increasing uses of the ocean and the problems faced by many fisheries (Norse, 2010; Jentoft & Knol, 2014), have increased the focus on spatial-based fisheries management, including, the formulation and enforcement of no-take areas, spatial zoning of fleet access, spatial restrictions of gear use and spatial user rights and/or catch quotas (Wilen, 2004; Pipitone, 2012; Rassweiler *et al*., 2012). In general, such strategies restrict the unlimited mobility of fishermen, a feature that fosters sequential overfishing (Berkes *et al*., 2006; Norse, 2010), and indiscriminate habitat exploitation (Bax *et al*., 1999).

Most of the Brazilian industrial fisheries concentrate in the so-called "Southeastern-South region" (hereafter named SE/S region), a large management area exceeding 1600 km of latitudinal extent, ranging from 18º20'S to the border with Uruguay. In general, vessels are authorized to operate along this entire region, eventually, with some bathymetric restrictions depending on the specific license. Besides the quite unrestricted spatial regime, management of the demersal fisheries conducted in this area has traditionally focused on a few (generally overexploited) target-species, in spite of most of these fisheries are highly multi-specific (Pezzuto & Benincá, 2015). This scenario has produced a substantial overlapping in catch composition and fishing areas exploited by hundreds of vessels (Perez *et al*., 2001; Valentini & Pezzuto, 2006; Kolling *et al*., 2008; Imoto, 2014; Pezzuto & Benincá, 2015; Dias & Perez, 2016; Pio *et al*., 2016) leaving fishing resources and ecosystem at risk.

In the last 15 years, several authors have pointed out the need of changing the management of demersal fisheries in SE/S Brazil from a species-based to a spatial-based approach (*e.g.*, Perez *et al*., 2001; Okubo-da-Silva, 2007; Kolling *et al*., 2008; Pezzuto & Benincá, 2015). Under this approach, the region should be divided in smaller spatial management units, designed according to the respective biological assemblages (including the different stocks), bottom characteristics, depth, fleet dynamics and technical considerations. Fleets should only be allowed to operate inside one or a few units, following specific management measures.

Regarding bottom trawl and gillnet fisheries, Perez *et al*. (2001) published a first formal proposal in this direction, suggesting the subdivision of the SE/S region in six new management units, bordered by the latitudes 22º52`S and 29º20`S and the 100 m isobath. In the present paper we expand this proposal, by: a) adding bottom longliners and octopus potters to the analyzed fleets, b) including bottom characteristics as a new variable, c) considering recent data reflecting the expansion of the regional industrial fisheries to the slope, as occurred mostly after the late 1990`s and early 2000`s (see review in Perez *et al*., 2009), and d) improving the identification of management units through a multivariate approach.

MATERIALS AND METHODS

Fishing and bottom data

Fishing data were provided by the Santa Catarina Industrial Fishing Statistical Program, developed by UNIVALI (University of Vale do Itajaí) since 2000. Effort, fishing areas and landings per "species" were collected through skippers' interviews, logbooks and/or sales records from 5,977 fishing trips conducted by industrial double-rig, pair and stern trawlers, bottom gillnetters, bottom longliners and octopus potters that landed in Santa Catarina harbors between January 2010 and December 2012. "Species" here refers to the commercial designations used by the local industry to identify fishing products. A "species" may correspond, therefore, to a single biological species (not necessarily from a unique stock), or to a complex of two or more biological species, eventually pertaining to different genera or families.

The data used to characterization benthic habitat were derived from a database structured in GIS (Geographic Information System), accumulated between 1970 and 2002 and provided by the CPRM - Geological Survey of Brazil (Companhia de Pesquisa de Recursos Minerais) (Bizzi *et al*., 2003).

Identification of main fishing grounds

The 35 most important demersal species landed in Santa Catarina were selected for this study (Table 1). They were chosen by identifying, for each fleet, the items that contributed cumulatively to 95% of the total biomass landed during the study period. Following the procedures adopted by the Fishing Statistical Program, the study area was divided into geographic grid squares of 30`x30`of resolution. For each fleet, the total number of trips recorded in the period in each grid square was calculated. Several grid squares were frequently visited by each vessel during a single trip. Considering that catch information is recorded per trip and not per tow, the presence of determined species in the landings was interpreted as resulting from catches obtained in all grid squares exploited by a vessel in a single trip. This procedure necessarily produces some biases in the data; for instance, coastal resources may appear as been caught also in the slope in case of a vessel exploiting both areas during a single trip. In order to overcome this problem, the frequency of occurrence of each species was calculated per grid square considering all trips of all fleets, and the respective 40 percentile was determined. Grid squares where the frequency of a species was lower than the respective 40 percentile, had its frequency changed to zero, emphasizing therefore, the identification of the main "core" areas in the species distribution.

Cluster analysis (Clarke & Warwick, 1994) was used to identify fishing grounds according to the respective species associations. The data matrix of the frequency of occurrence of the several species (considering all trips of all vessels) in the corresponding grid squares was standardized by the total values, and the Bray-Curtis index was chosen to measure the similarity between the objects (*i.e*., grid squares). Grouping was performed by using the group average method. Grid squares not visited by the fleets during the study period were eliminated from the analysis. A SIMPER (*Similarity Percentage*) analysis was used in order to identify the main species contributing to each group (*i.e*., fishing ground) (Clarke, 1993).

The Cluster and SIMPER analysis were carried out by R computational program using the vegan package (R Development Core Team, 2015) and software PRIMER 7.0.10 (Plymouth Routines in Multivariate Ecological Research) (trial version) (Clarke & Gorley, 2015), respectively.

Spatial distribution of fishing effort and species

Maps representing the spatial distribution of the fishing effort (*i.e*., total number of trips recorded per grid square between 2010 and 2012) were produced for each fleet using *Spatial Join* tool in ESRI® ArcGIS™ software. The respective percentage of trips (and biomass landed) recorded in each fishing ground was then calculated as well as the relative frequency of occurrence and the relative contribution of each group to the total biomass landed of each species. Both results were organized in tables.

Benthic habitat characterization

Bottom samples were originally classified in the CPRM database in 11 qualitative categories, which were secondarily grouped in the present study as: calcareous algae; sand and biodetritic gravel (including the original sand/biodetritic gravel and biodetritic/mud); muddy-sand; sand (including fine, medium and coarse sand); mud; gravel (including gravel and shells) and reef. The original geographical coordinates of each bottom sample were centered in the respective grid square. The percentage of occurrence of each bottom type was calculated for each group (fishing ground), in order to describe its main bottom characteristics, using *Spatial Join* tool in ESRI® ArcGIS™ software.

In addition, each geographic grid square was classified semi-quantitatively in five depth levels. The classification was based on Perez & Pezzuto (2006) and Haimovici *et al*. (1994), with small modifications. The following levels were defined: a) Level 1: coastal areas from 0 to 30 m depth; b) Level 2: inner continental shelf (30 to 100 m); c) Level 3: shelf break (100 to 250 m); d) Level 4: upper slope (250 to 500 m); e) Level 5: lower slope (depths exceeding 500 m). Grid squares covering more than a single bathymetric stratum were assigned to the stratum presenting the largest area.

Relationship between species and environmental variables

The relationship between the distribution of the 35 species (response variables) and depth, latitude and bottom types (explicative variables) was investigated by using Canonical Correspondence Analysis (CCA) (Ter Braak & Smilauer, 2002). The inclusion of the environmental variables in the model was performed through a forward selection procedure followed by a

Table 1. Vernacular and scientific names of the demersal fishery resources analyzed in this study. *Not included in the multivariate analysis.

Resource	Vernacular name	Scientific name	Family
Fishes	Acoupa weakfish	*Cynoscion acoupa*	Sciaenidae
	American harvestfish	*Peprilus paru*	Stromateidae
	Argentine croaker	*Umbrina canosai*	Sciaenidae
	Argentine hake	*Merluccius hubbsi*	Phycidae
	Bluewing searobin	*Prionotus puctatus*	Triglidae
	Brazilian codling	*Urophycis brasiliensis, U. mystacea*	Phycidae
	Brazilian flathead	*Percophys brasiliensis*	Percophidae
	Castaneta	*Nemadactylus bergi*	Cheilodactylidae
	Catfish		Ariidae
	Codling	*Urophysis mystacea*	Phycidae
	Dusky grouper	*Epinephelus marginatus*	Serranidae
	Flounder	*Paralichthys* spp.	Paralichthydae
	Grey triggerfish	*Balistes capriscus*	Balistidae
	Jamaica weakfish	*Cynoscion jamaicensis*	Sciaenidae
	King weakfish	*Macrodon ancylodon*	Scianidae
	Largehead hairtail	*Trichiurus lepturus*	Trichiuridae
	Monkfish	*Lophius grastrophysus*	Lophiidae
	Pink cusk-eel	*Genypterus brasiliensis*	Ophidiidae
	Red porgy	*Pagrus pagrus*	Sparidae
	Sand flounder	*Paralichthys isosceles, P. triocellatus*	Paralichthydae
	Sandperch	*Pseudopercis numida*	Mugiloididae
	Sea trout	*Cynoscion* spp.	Sciaenidae
	Silver John dory*	*Zenopsis conchiffera*	Zeidae
	Skate	*Rioraja agassizii, Atlantoraja castelnaui, Psammobatis* spp., *Sympterygia* spp., *Dipturus* spp., *Atlantoraja platana*	Rajidae
	Southern kingcroaker	*Menticirrhus* spp.	Sciaenidae
	Stripped weakfish	*Cynoscion guatucupa*	Sciaenidae
	Tilefish	*Lophalatilus villarii*	Branchiostegidae
	Tomtate grunt	*Haemulon aerolineatum*	Haemulidae
	Whitemouth croaker	*Micropogonias furnieri*	Sciaenidae
Crustaceans	Argentine red shrimp	*Pleoticus muelleri*	Penaeidae
	Argentine stiletto shrimp	*Artemesia longinaris*	Penaeidae
	Deep-sea crabs*	*Chaceon ramosae, Chaceon notialis*	Geryonidae
	Deep-sea shrimps*	*Aristaeopsis edwardsiana, Aristaeomorpha foliacea Aristeus antillensis*	Aristeidae
	Pink-shrimp	*Farfantepenaeus paulensis, F. brasiliensis*	Penaeidae
	Sea-bob shrimp	*Xiphopenaeus kroyeri*	Penaeidae
	Striped soldier shrimp	*Plesionika edwardsii*	Pandalidae
Molluscs	Argentine squid*	*Illex argentinus*	Ommastrephidae
	Octopus	*Octopus vulgaris, Eledone massyae*	Octopodidae
	Squid	*Loligo plei, L. sanpaulensis*	Loliginidae

significance test ($P < 0.05$) conducted after 499 Monte Carlo permutations. Only depth, latitude, sand, gravel and calcareous algae bottom types were retained in the analysis.

This analysis was carried out by R computational program using the vegan package (R Development Core Team, 2015).

RESULTS

Identification of main fishing grounds

At a 13% level of similarity, the cluster analysis identified three main faunal components, which reflected the major bathymetric domains of the study area: a) coastal; b) shelf and c) slope grounds (Fig. 1).

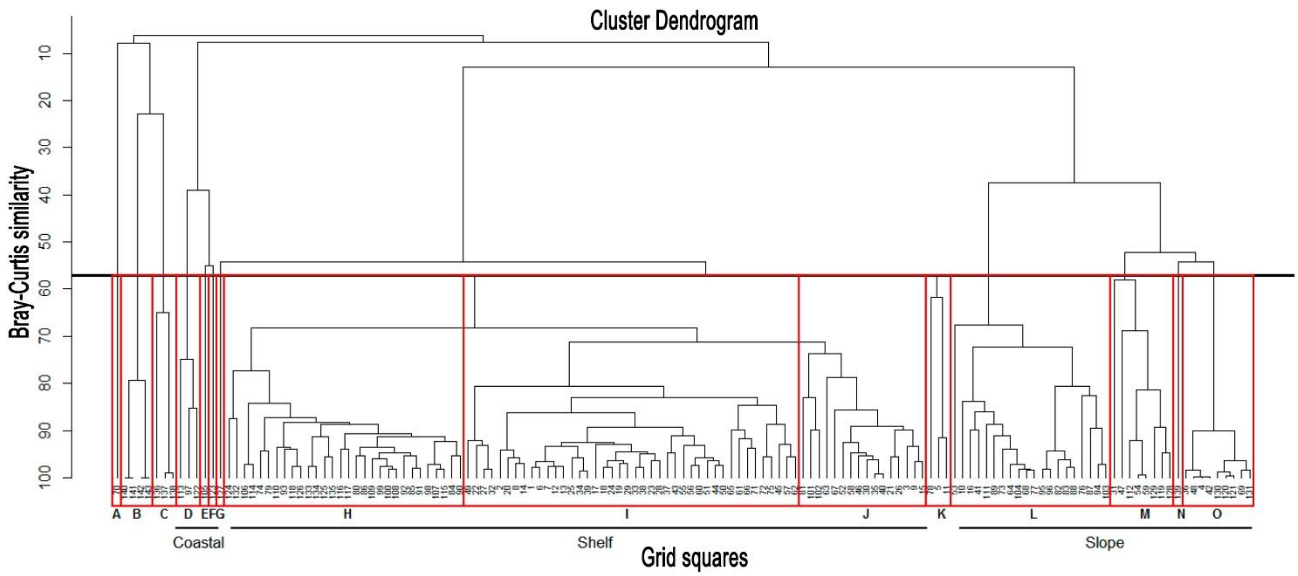

Figure 1. Cluster analysis results obtained from the grid squares of the similarity of the total occurrence of demersal resources (absolute frequency), considering together all fleets and the entire study period. Highlighted the cutoff level of 57% similarity used to define the groups and subgroups of grid squares (the latter indicated by the letters).

At a higher similarity level however (57%), six new spatially consistent groups emerged (Fig. 2):

Northern Group: including the grid squares situated at the northern limit of the study area (off Rio de Janeiro State) and extending from the coast to the shelf break. The group was composed by subgroups "B" and "C" (Fig. 2). Pink-shrimp was the single species contributing to subgroup "B" (96%), while the subgroup "C" consisted of five species (Table 2).

Coastal Group: including subgroups "D", "E" and "F", ranged from northern São Paulo (23°30'S, 45°30'W) to center Paraná (25°00'S, 48°30'W) in areas shallower than 25 m depth (Fig. 2). Only sea-bob shrimp contributed to this group (93%) (Table 2), with an average similarity of 78.4%.

Northern Inner Continental Shelf: it was formed by subgroups "G" (a single grid square) and "H', extending mostly between 25 and 100 m depth from central Santa Catarina State (27°S) to southern Rio de Janeiro (23°S) (Fig. 2). Sixteen species contributed to the group (Table 2).

Southern Inner Continental Shelf: composed by subgroup "I". It is located southward from 27°S, mostly from the coast to 100 m depth (Fig. 2). The SIMPER analysis showed that 16 resources contributed to this group (Table 2).

Shelf Break: formed only by subgroup "J" which includes a series of contiguous grid squares situated southern from 28°S, between 100 and 250 m depth, and some other isolated areas found in northernmost areas (Fig. 2). Showing an average similarity of 83.5%, sixteen species were reported contributing to this group (Table 2).

Slope: four subgroups were enclosed in the slope group ("L", "M", "N" and "O"), corresponding to fishing grounds deeper than 100 m in the northern and 200 m in the southern portions of the study area (Fig. 2). According to SIMPER, five different species contributed to the whole group (Table 2). As subgroup "N" was represented by a single grid square (Fig. 2), SIMPER analysis was not able to identify any species contributing to its formation (Table 2).

Subgroups "A" and "K" (1 and 3 grid squares, respectively) (Fig. 2) located respectively in coastal areas of Santa Catarina and Rio Grande do Sul, were not associated to any particular major group. The latter was formed by nine species (Table 2).

Spatial distribution of fishing fleets

Most of the trips conducted by the demersal fleets operating from Santa Catarina harbors were carried out in areas corresponding to the inner continental shelf, shelf break and slope (Table 3). Accordingly, the same areas produced the major part of the landings in biomass (Table 4). Operations of the double-rig trawlers and bottom gillnetters exhibited the broadest distribution of trips along the study area, in spite of the latter concentrated more than 50% of their trips in the northern inner continental shelf. Pair and stern trawlers, otherwise, operated mostly in the southern shelf. Effort

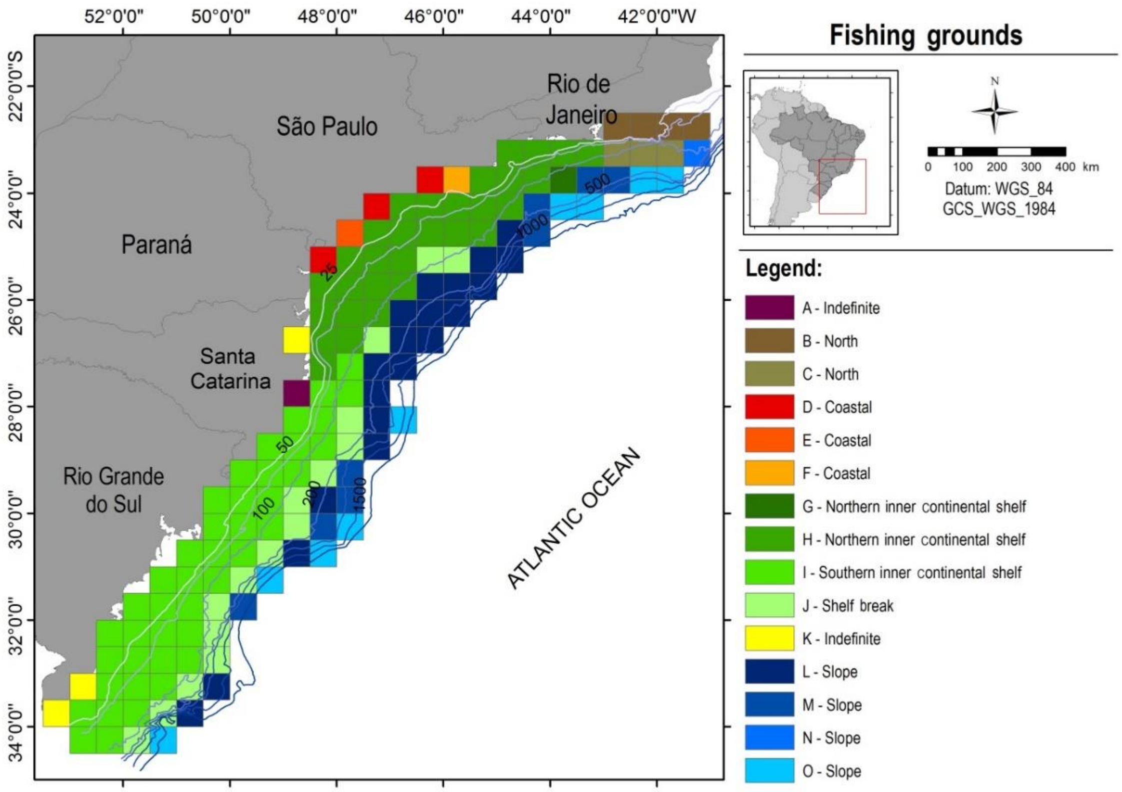

Figure 2. Geographic distribution of the groups and subgroups of grid squares (*i.e.*, geographical areas of 30`x30`resolution) as resulting from the cluster analysis, based on the similarity in the composition of the respective demersal fishing resources.

from bottom longliners were nearly equally spreaded in this same area, the shelf break and slope. Finally, more than 90% of the trips conducted by vessels targeting octopus occurred in the inner continental shelf (Table 3, Fig. 3). The area corresponding to the southern inner continental shelf was the most important in terms of biomass landed for all fleets, excepting for the bottom gillnetters, whose landings were similar in the northern inner continental shelf and southern inner continental shelf (Table 4).

Spatial distribution of the demersal resources

As the use of the northern area by the fleets was only marginal (Table 3), resources caught in this area showed both small frequency of occurrence (Table 5) and low contribution to the total landings (Table 6). An exception was the striped soldier shrimp landings, which represented 37.0% (Table 6). A similar pattern was observed in the coastal area, where sea-bob shrimp was by far the main species either in terms of frequency of occurrence and in biomass landed (Tables 5 and 6).

The inner continental shelf and the shelf break showed the highest diversity, as all 35 species were recorded in trips conducted along these areas, many of them showing high frequency of occurrence (Table 5) and/or high participation in the total biomass landed (Table 6). In the southern inner continental shelf, 20 of the 35 selected resources revealed contributions in the landings from 58.4 to 97.7%, denoting the high importance of the area to the Santa Catarina fleets. More than 95% of the landings of acoupa weakfish, sea trout and Argentine red and Argentine stiletto shrimps came from this area (Table 6). On the other hand, landings of pink-shrimp (80.4%), sea-bob shrimp (78.1%) and squid (83.0%) came mainly from the northern inner continental shelf (Table 6). Tomtate grunt and whitemouth croaker showed a quite balanced production in both areas (Table 6). In general, resources caught in the northern inner continental shelf showed a higher importance in terms of frequency of occurrence than in terms of biomass landed, probably reflecting an unequal biological productivity between those areas. For instance, frequencies of catfish in the northern and southern inner continental shelf represented respectively, 50.9% and 38.1%, while their biomass landed showed an inverse pattern, totaling 10.8% and 58.4% in the same areas (Tables 5 and 6).

Castaneta, codling and pink cusk-eel were the most frequent resources in the shelf break (Table 5).

Table 2. Results of SIMPER analysis with group, subgroup, name and percentage of each species composing the subgroups. Subg. = Subgroups; Contrib. (%) = Percentage of contribution; NICS: Northern Inner Continental Shelf; SICN: Southern Inner Continental Shelf.

Group	Subg.	Species	Contrib. (%)
Northern	B	pink-shrimp	96.0
	C	pink-shrimp	26.7
		soldier striped shrimp	21.7
		codling	19.1
		octopus	17.6
		sandperch	8.6
Coastal	D	sea-bob shrimp	93.0
	E	-	-
	F	-	-
NICS	G	-	-
	H	whitemouth croaker	14.6
		bluewing searobin	14.3
		skate	9.0
		American harvestfish	8.0
		catfish	6.5
		Brazilian codling	5.9
		Jamaica weakfish	5.7
		pink-shrimp	4.9
		stripped weakfish	4.9
		sand flounder	4.2
		Argentine croaker	3.0
		octopus	2.9
		Argentine hake	2.5
		flounder	2.4
		monkfish	2.0
SICS	I	bluewing searobin	0.4
		whitemouth croaker	10.0
		Brazilian codling	8.2
		stripped weakfish	8.2
		skates	7.8
		Argentine croaker	7.3
		flounder	7.3
		American harvestfish	4.6
		Brazilian flathead	4.2
		sand flounder	4.1
		Jamaica weakfish	3.9
		monkfish	3.7
		southern kingcroaker	3.2
		largehead hairtail	2.7
		catfish	2.6
		grey triggerfish	2.3
Shelf Break	J	skate	9.4
		bluewing searobin	9.0
		monkfish	8.8
		sand-flounder	7.9
		Argentine hake	7.3
		Argentine croaker	6.5
		stripped weakfish	6.0
		Brazilian codling	6.0
		pink cusk-eel	5.8
		whitemouth croaker	5.4
		Brazilian flathead	4.3
		codling	3.5
		flounder	3.5
		largehead hairtail	3.1
		Jamaica weakfish	2.5
		catfish	2.1
Slope	L	monkfish	20.3
		Argentine hake	20.1
		codling	19.1
		pink cusk-eel	18.9
		tilefish	13.1
	M	codling	37.2
		pink cusk-eel	36.8
		tilefish	24.1
	N	-	-
	O	codling	60.2
		tilefish	39.9
-	A	-	-
-	K	whitemouth croaker	21.2
		bluewing searobin	17.7
		American harvestfish	13.3
		Brazilian flathead	10.7
		Jamaica weakfish	6.9
		Southern kingcroaker	6.6
		stripped weakfish	5.2
		flounder	4.7
		Argentine croaker	4.4

However, Argentine croaker, Argentine hake, bluewing searobin, catfish, monkfish, red porgy, sand flounder added to the three former species were the most important resources in terms of biomass landed (Table 6). Argentine hake, codling, monkfish, pink cusk-eel, sandperch and tilefish were caught mostly in slope grounds (Table 6), in spite of several of these species had exhibited high frequencies of occurrence out of this area (Table 5).

Characterization of benthic environment

A minimum of one and a maximum of 1,336 sediment samples were available for each of the 199 grid squares of the study area. About 60% of them presented more

Table 3. Percentage of the total number of trips carried out by the industrial demersal fleets landing in Santa Catarina between 2010 and 2012, broken down into groups and subgroups identified in the cluster analysis. DT: double-rig trawl, PT: pair trawl, ST: stern trawl, BL: bottom longline, BG: bottom gillnet, OP: octopus pot, NICS: northern inner continental shelf, SICS: southern inner continental shelf.

Fleets	Group/Subgroup																		
		Northern			Coastal				NICS			SICS	Shelf break		Slope				
	A	B	C	Total	D	E	F	Total	G	H	Total	I	J	K	L	M	N	O	Total
DT	0.1	0.3	1.0	1.4	0.7	0.6	0.2	1.5	0.2	34.2	34.5	36.0	9.9	0.4	12.7	2.2	0.1	1.4	16.4
PT	0.0	-	-	-	0.1	0.2	0.0	0.3	0.0	13.0	13.1	81.9	2.9	1.8	-	-	-	-	-
ST	-	-	-	-	-	-	-	-	-	2.4	2.4	66.9	26.3	0.2	3.2	0.7	-	0.2	4.2
BL	-	-	-	-	-	-	-	-	-	1.6	1.6	35.8	31.7	-	25.2	5.7	-	-	30.9
BG	0.2	0.2	0.5	0.7	0.1	0.2	0.3	0.6	0.4	53.3	53.6	39.9	3.3	0.9	0.5	0.1	-	0.1	0.7
OP	-	-	-	-	-	-	-	-	-	50.9	50.9	40.6	6.6	-	1.9	-	-	-	1.9

Table 4. Percentage of the landings (kg) recorded by the industrial demersal fleets landing in Santa Catarina between 2010 and 2012, broken down into groups and subgroups identified in the cluster analysis. DT: double-rig trawl, PT: pair trawl, ST: stern trawl, BL: bottom longline, BG: bottom gillnet, OP: octopus pot, NICS: northern inner continental shelf, SICS: southern inner continental shelf.

Fleets	Group/Subgroup																		
		Northern			Coastal				NICS			SICS	Shelf break		Slope				
	A	B	C	Total	D	E	F	Total	G	H	Total	I	J	K	L	M	N	O	Total
DT	0.1	0.1	0.9	1.0	0.6	0.5	0.2	1.2	0.1	14.0	14.1	37.5	18.5	0.3	22.0	2.9	0.2	2.1	27.3
PT	0.0	-		-	0.0	0.0	0.0	0.1	0.0	8.3	8.3	84.6	5.1	1.9	-		-	-	-
ST	-	-	-	-	-	-	-	-	-	2.2	2.2	61.1	33.2	0.1	2.7	0.5	-	0.1	3.3
BL	-	-	-	-	-	-	-	-	-	1.8	1.8	50.9	38.4	-	7.7	1.2	-	-	8.9
BG	0.1	0.2	0.5	0.7	0.0	0.2	0.1	0.3	0.2	45.4	45.7	45.3	3.3	1.0	2.7	0.6	-	0.3	3.6
OP	-	-	-	-	-	-	-	-	-	23.9	23.9	55.2	20.9	-	0.1	-	-	-	0.1

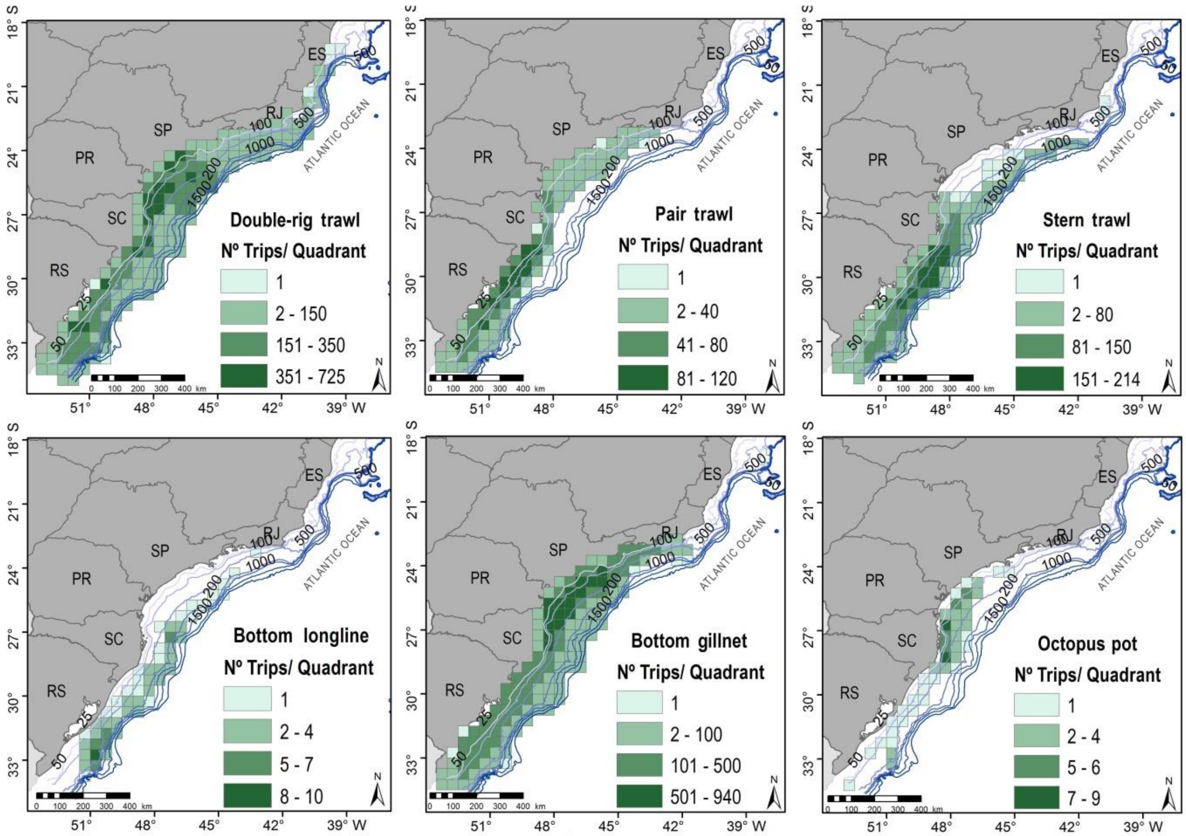

Figure 3. Spatial distribution of the industrial demersal fleets landing in Santa Catarina between 2010 and 2012. Values are number of trips recorded in geographical areas of 30’x30’ resolution. ES: Espírito Santo, RJ: Rio de Janeiro, SP: São Paulo, PR: Paraná, SC: Santa Catarina, RS: Rio Grande do Sul.

than 30 samples. Sand, muddy-sand and mud were much more frequent than reefs, gravel, sand with biodetritic gravel and calcareous algae (Table 7).

In general, samples classified as gravel and sand with biodetritic gravel were more frequent in the northern and slope areas. Muddy bottoms showed higher frequencies in the shelf break and slope grounds, although it also appeared in many sediment samples from the inner continental shelf. Calcareous algae and reefs occurred punctually in the northern, coastal and slope grounds. Sand and muddy-sand samples were largely distributed along the whole study area (Table 7).

Relationship between demersal resources and environmental variables

High correlations between species distribution and environment variables (latitude, depth and sand, gravel and calcareous algae bottom types) were found in the first and second axis (0.783 and 0.894, respectively) of the Canonical Correspondence Analysis (CCA). The former axis was highly correlated with depth and the latter with latitude (Fig. 4).

Codling and tilefish were positively correlated with depth, showing no clear association with latitude. Their occurrence probably is associated to gravelly or even muddy (a bottom type opposed to the sand along a granulometric gradient) bottoms (Fig. 4). Argentine hake, monkfish, pink cusk-eel, sandperch and striped soldier shrimp were also correlated with depth, but on a more intermediate position along the first axis. The latter species showed a clear trend towards a northern distribution while the other species were positioned near to the first axis, suggesting a wider latitudinal distribution. Harder bottoms (calcareous algae and gravel) and/or with low sand content (*i.e.*, muddier) were mostly associated to these resources (Fig. 4).

Sea-bob shrimp, pink-shrimp, squid, catfish, American harvestfish, Jamaica weakfish, octopus, whitemouth croaker and bluewing searobin were negatively correlated with both depth and latitude (Fig. 4). Argentine red shrimp, Argentine stiletto shrimp, sea trout, acoupa weakfish, king weakfish and tomtate grunt were also negatively correlated with depth, but exhibited positive correlation with latitude (*i.e.*, a southernmost distribution) (Fig. 4). In both cases, resour-

Table 5. Frequency of occurrence (%) of the main 35 demersal resources exploited by the industrial fleets in the SE/S region, per group and subgroup identified in the cluster analysis. NICS: northern inner continental shelf, SICS: southern inner continental shelf.

	Resources	Group/subgroup																		
			Northern			Coastal				NICS			SICS	Shelf break		Slope				
		A	B	C	Total	D	E	F	Total	G	H	Total	I	J	K	L	M	N	O	Total
Fishes	Acoupa weakfish	0.1	-	-	-	0.6	0.2	0.1	0.9	-	5.9	5.9	89.1	2.5	1.3	0.2	-	-	-	0.2
	American harvestfish	0.2	0.2	0.3	0.5	0.1	0.2	0.2	0.5	0.3	45.0	45.3	47.2	5.1	1.0	0.3	0.1	-	0.0	0.4
	Argentine croaker	0.1	0.2	0.3	0.4	0.0	0.1	0.1	0.2	0.2	17.4	17.6	66.0	11.8	0.8	2.2	0.5		0.3	3.0
	Argentine hake	0.1	0.1	0.7	0.8	0.0	0.1	0.1	0.2	0.3	26.9	27.2	32.5	16.3	0.3	17.4	3.0	0.1	2.0	22.5
	Bluewing searobin	0.1	0.2	0.4	0.6	0.1	0.2	0.2	0.4	0.3	38.3	38.6	47.8	8.5	0.7	2.5	0.5	0.0	0.3	3.3
	Brazilian codling	0.1	0.1	0.2	0.4	0.1	0.1	0.1	0.3	0.2	29.0	29.1	59.2	8.6	0.7	1.3	0.3	0.0	0.1	1.7
	Brazilian flathead	0.0	0.2	0.4	0.6	0.1	0.1	0.1	0.3	0.2	17.1	17.2	65.1	12.8	0.6	2.5	0.6	0.0	0.3	3.4
	Castaneta	0,1	-	-	-	-	-	-	-	-	0,7	0,7	70,5	24,8	0,5	2,5	0,4	-	0,5	3.4
	Catfish	0.1	0.3	0.6	0.9	0.1	0.3	0.3	0.7	0.4	50.5	50.9	38.1	8.0	0.6	0.6	0.2	-	0.1	0.9
	Codling	-	0.0	1.3	1.3	0.0	0.0	-	0.0	0.5	9.2	9.6	13.0	22.3	0.1	41.7	7.0	0.3	4.7	53.7
	Dusky grouper	0.7	-	-	-	-	-	-	-	-	28.0	28.0	67.8	2.1	1.4	-	-	-	-	-
	Flounder	0.1	0.1	0.2	0.3	0.0	0.1	0.1	0.2	0.1	16.8	16.9	70.9	8.5	0.9	1.6	0.4	0.0	0.2	2.2
	Grey triggerfish	0.0	0.2	0.3	0.5	0.1	0.2	0.1	0.4	0.2	27.1	27.3	61.6	6.9	0.7	1.7	0.5	-	0.3	2.5
	Jamaica weakfish	0.1	0.2	0.4	0.6	0.1	0.2	0.2	0.5	0.3	41.2	41.5	48.3	7.2	0.8	0.7	0.2	-	0.1	1.0
	King weakfish	0.2	-	-	-	1.2	0.6	0.3	2.2	-	14.0	14.0	78.2	2.6	2.4	0.2	0.1	-	0.0	0.4
	Largehead hairtail	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.3	0.1	12.7	12.9	64.1	15.8	0.8	4.9	0.8	-	0.4	6.1
	Monkfish	0.1	0.1	0.8	1.0	0.0	0.1	0.1	0.2	0.3	20.1	20.3	42.7	16.0	0.3	15.0	2.6	0.1	1.7	19.4
	Pink cusk-eel	-	0.1	1.1	1.2	0.0	0.0	0.0	0.0	0.4	14.3	14.7	28.1	21.2	0.2	27.3	4.4	0.1	2.8	34.6
	Red porgy	0.0	0.1	0.3	0.4	0.0	0.1	0.2	0.3	0.3	27.5	27.8	55.9	12.0	0.7	2.1	0.5	-	0.2	2.9
	Sand flounder	0.1	0.1	0.6	0.7	0.1	0.1	0.1	0.3	0.3	27.3	27.6	46.5	14.1	0.4	8.1	1.4	0.1	0.8	10.3
	Sandperch	-	-	1.7	1.7	0.0	0.0		0.1	0.7	24.3	25.0	28.1	17.7	0.3	23.0	2.4	0.2	1.6	27.2
	Sea trout	0.3	-	0.1	0.1	0.4	0.3		0.7	0.1	16.9	17.0	75.5	4.4	1.5	0.4	0.2		0.1	0.6
	Skate	0.1	0.2	0.6	0.9	0.1	0.1	0.1	0.3	0.3	32.0	32.3	47.0	11.1	0.5	6.1	1.1	0.0	0.6	7.8
	Southern kingcroaker	0.0	0.1	0.1	0.2	0.4	0.3	0.1	0.8	0.1	18.1	18.2	68.9	8.8	1.1	1.6	0.3	-	0.1	2.0
	Stripped weakfish	0.1	0.1	0.3	0.4	0.1	0.1	0.1	0.3	0.2	22.3	22.5	64.3	9.6	0.8	1.5	0.4	-	0.2	2.1
	Tilefish	-	-	0.5	0.5	0.0	0.0	-	0.0	0.3	6.9	7.1	17.5	17.2	0.1	45.8	6.9	0.1	4.8	57.6
	Tomtate grunt	0.1	-	-	-	0.1	-	-	0.1	-	13.8	13.8	79.5	4.3	1.7	0.4	0.1	-	-	0.5
	Whitemouth croaker	0.1	0.2	0.4	0.7	0.1	0.2	0.2	0.5	0.3	40.6	40.9	50.0	6.2	0.8	0.6	0.2	0.0	0.1	0.9
Crustaceans	Argentine red shrimp	0.7	-	-	-	0.3	0.1	0.2	0.6	-	7.6	7.6	89.7	0.6	0.5	0.3	-	-	-	0.3
	Argentine stiletto shrimp	0.6	-	-	-	0.0	0.1	-	0.1	-	5.1	5.1	92.8	0.6	0.4	0.4	-	-	-	0.4
	Pink-shrimp	0.0	0.8	1.2	2.1	0.0	0.0	0.0	0.1	0.3	71.6	71.9	17.7	5.0	0.5	2.3	0.3	0.0	0.1	2.7
	Sea-bob shrimp	-	-	-	-	11.6	9.3	2.7	23.6	-	73.6	73.6	1.6	0.3	0.7	0.2	-	-	-	0.2
	Striped soldier shrimp	-	0.1	6.8	6.9	-	0.1	-	0.1	1.4	37.7	39.0	3.1	18.9	0.1	26.1	4.1	0.9	0.8	31.9
Molluscs	Octopus	0.0	0.5	0.9	1.4	0.1	0.1	0.0	0.3	0.2	41.9	42.1	43.4	8.2	0.4	3.4	0.5	0.0	0.2	4.1
	Squid	0.2	0.6	0.7	1.4	0.2	0.2	0.1	0.4	0.3	52.1	52.3	32.9	4.8	2.0	4.6	0.8	0.1	0.5	6.0

Table 6. Percentage of landings (kg) of the main 35 demersal resources exploited by the industrial fleets in the SE/S region, per group and subgroup identified in the cluster analysis. NICS: northern inner continental shelf, SICS: southern inner continental shelf.

	Resources	Group/subgroup																		
			Northern			Coastal				NICS			SICS	Shelf break		Slope				
		A	B	C	Total	D	E	F	Total	G	H	Total	I	J	K	L	M	N	O	Total
Fishes	Acoupa weakfish	0.0	-	-	-	0.0	0.0	0.0	0.0	-	1.5	1.5	97.5	0.3	0.7	0.0	-	-	-	0.0
	American harvestfish	0.2	0.0	0.1	0,1	0.1	0.1	0.0	0.2	0.1	28.3	28.3	67.0	2.3	1.8	0.0	0.0	-	0.0	0.1
	Argentine croaker	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	2.2	66.4	29.0	0.6	1.4	0.2	-	0.1	1.7
	Argentine hake	0.0	0.0	0.7	0.7	0.0	0.0	0.0	0.0	0.2	4.2	4.5	7.7	30.0	0.0	44.4	6.8	0.4	5.4	57.0
	Bluewing searobin	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.1	0.0	11.0	11.1	61.5	22.6	0.3	3.5	0.6	0.0	0.2	4.3
	Brazilian codling	0.0	0.0	0.6	0.6	0.0	0.1	0.0	0.1	0.1	16.0	16.1	63.3	10.1	0.2	8.6	0.6	0.0	0.3	9.6
	Brazilian flathead	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.0	2.3	2.3	89.0	6.7	0.3	0.9	0.2	0.1	0.1	1.2
	Castaneta	0.0	-	-	-	-	-	-	-	-	0.2	0.2	65.4	28.2	0.2	4.5	0.4	-	1.1	6.0
	Catfish	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.1	0.0	10.7	10.8	58.4	29.1	0.5	0.2	0.7	-	0.0	0.9
	Codling	-	0.0	0.3	0.4	0.0	0.0	-	0.0	0.1	1.8	1.9	3.3	35.9	0.0	48.0	6.2	0.2	4.2	58.5
	Dusky grouper	0.0	-	-	-	-	-	-	-	-	6.8	6.8	80.6	11.0	1.6	-	-	-	-	-
	Flounder	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	1.9	1.9	89.2	6.9	0.6	0.9	0.3	0.0	0.1	1.4
	Grey triggerfish	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	2.5	88.1	4.9	0.4	1.6	1.1	-	1.2	4.0
	Jamaica weakfish	0.1	0.0	0.1	0.1	0.2	0.1	0.0	0.4	0.0	21.6	21.6	69.2	4.5	3.7	0.3	0.1	-	0.0	0.4
	King weakfish	0.0	-	-	-	0.2	0.1	0.0	0.3	-	7.7	7.7	89.1	0.6	2.1	0.0	0.0	-	0.0	0.1
	Largehead hairtail	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.1	0.0	11.5	11.5	72.8	11.9	1.2	1.9	0.3	-	0.1	2.4
	Monkfish	0.0	0.0	2.5	2.5	0.0	0.0	0.0	0.0	0.2	2.8	3.0	13.9	26.5	0.0	41.1	6.7	0.7	5.6	54.0
	Pink cusk-eel	-	0.1	1.7	1.8	0.0	0.0	0.0	0.0	0.5	9.6	10.1	9.3	21.7	0.0	48.3	6.2	0.3	2.3	57.1
	Red porgy	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.1	0.1	13.9	14.0	57.0	23.5	0.4	3.4	0.9	-	0.8	5.0
	Sand flounder	0.1	0.1	1.1	1.2	0.0	0.1	0.0	0.1	0.2	15.0	15.2	48.0	23.7	0.2	9.5	1.4	0.2	0.5	11.6
	Sandperch	-	-	2.5	2.5	0.0	0.0	-	0.0	0.5	6.1	6.6	25.8	17.7	0.9	43.9	1.4	0.8	0.4	46.6
	Sea trout	0.0	-	0.0	0.0	0.0	0.0	-	0.0	0.0	1.5	1.5	97.7	0.5	0.2	0.0	0.1	-	0.0	0.1
	Skate	0.0	0.1	0.3	0.4	0.0	0.0	0.0	0.0	0.1	9.1	9.2	65.4	18.1	0.4	5.4	0.7	0.0	0.4	6.5
	Southern kingcroaker	0.0	0.0	0.0	0.1	0.2	0.2	0.0	0.4	0.0	15.3	15.3	76.3	5.6	1.2	0.6	0.2		0.2	1.0
	Stripped weakfish	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	3.2	85.3	9.4	0.9	0.7	0.3	-	0.1	1.1
	Tilefish	-	-	0.2	0.2	0.0	0.0	-	0.0	0.1	2.5	2.6	8.2	10.9	0.0	70.7	4.6	0.1	2.7	78.1
	Tomtate grunt	0.2	-	-	-	0.1	-	-	0.1	-	41.6	41.6	55.1	0.3	2.6	0.0	0.0	-	-	0.0
	Whitemouth croaker	0.1	0.2	0.5	0.7	0.1	0.2	0.1	0.3	0.2	43.7	43.9	50.6	3.1	1.1	0.1	0.0	0.0	0.0	0.2
Crustaceans	Argentine red shrimp	0.6	-	-	-	0.0	0.0	0.2	0.2	-	3.6	3.6	95.1	0.2	0.2	0.1	-	-	-	0.1
	Argentine stiletto shrimp	0.3	-	-	-	0.0	0.0	-	0.0	-	2.0	2.0	97.5	0.1	0.1	0.0	-	-	-	0.0
	Pink-shrimp	0.0	1.4	1.6	3.1	0.0	0.0	0.0	0.0	0.2	80.2	80.4	11.6	3.7	0.6	0.6	0.0	0.0	0.0	0.7
	Sea-bob shrimp	-	-	-	-	9.5	7.5	2.9	19.9	-	78.1	78.1	1.4	0.1	0.3	0.1	-	-	-	0.1
	Striped soldier shrimp	-	0.0	36.9	37.0	-	0.0	-	0.0	0.9	14.4	15.3	0.9	14.9	0.0	21.8	3.8	5.0	1.3	31.9
Molluscs	Octopus	0.0	0.2	0.6	0.8	0.0	0.0	0.0	0.0	0.0	31.9	32.0	53.9	11.8	0.2	1.1	0.1	0.1	0.0	1.3
	Squid	0.0	0.2	0.2	0.4	0.0	0.0	0.0	0.0	0.0	82.9	83.0	7.2	0.9	7.2	1.1	0.1	0.0	0.1	1.3

Table 7. Percentage of occurrence of the bottom types in the subgroups identified in the cluster analysis. NICS: northern inner continental shelf, SICS: southern inner continental shelf.

Fishing Ground	Calcareous algae	Sand/Biodetritic gravel	Muddy-sand	Sand	Gravel	Mud	Reef
A - Indefinite	0.0	3.4	27.1	42.4	6.8	20.3	0.0
B - Northern	0.9	6.8	19.8	54.2	7.3	10.6	0.4
C - Northern	0.2	12.9	29.1	28.6	8.9	20.3	0.0
D - Coastal	0.0	1.9	35.2	33.3	0.0	27.8	1.9
E - Coastal	0.0	0.0	0.0	100.0	0.0	0.0	0.0
F - Coastal	0.0	3.7	40.7	15.4	1.2	38.9	0.0
G - NICS	0.0	3.4	10.2	3.4	6.8	76.3	0.0
H - NICS	0.0	8.0	24.0	38.5	2.7	26.7	0.1
I - SICS	0.0	4.6	23.6	21.5	1.9	47.9	0.4
J - Shelf break	0.0	6.8	14.4	6.6	3.8	67.2	1.1
K - Indefinite	0.0	5.6	16.7	34.8	2.4	40.4	0.0
L - Slope	0.7	13.2	22.9	8.2	7.2	45.5	2.2
M - Slope	0.0	19.1	18.7	20.7	9.4	32.1	0.0
N - Slope	5.3	19.7	27.6	17.1	3.9	25.0	1.3
O - Slope	0.0	12.9	11.6	26.5	15.0	34.0	0.0

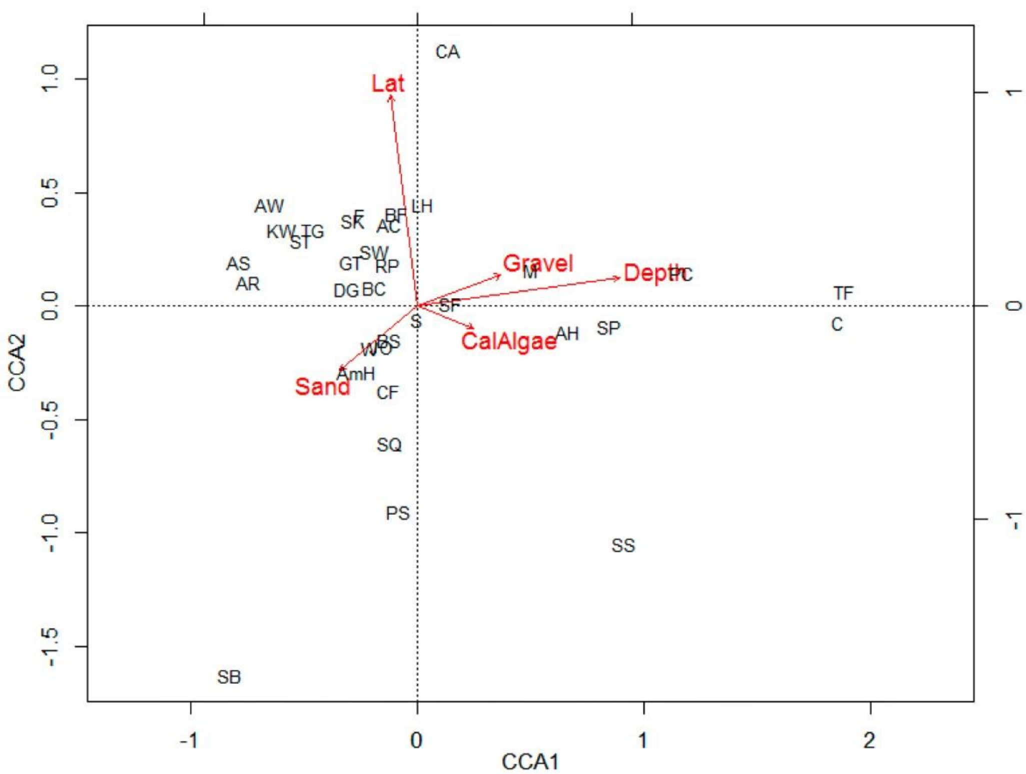

Figure 4. Plot of the Canonical Correspondence Analysis results among depth, latitude and bottom types (environmental variables) and demersal resources distribution (response variables). Lat: latitude, CalAlgae: Calcareous algae, AC: Argentine croaker, AH: Argentine hake, AmH: American harvestfish, AR: Argentine red shrimp, AS: Argentine stiletto shrimp, AW: acoupa weakfish, BC: Brazilian codling, BF: Brazilian flathead, BS: bluewing searobin, C: codling, CA: castaneta, CF: catfish, DG: dusky grouper, F: flounder, GT: grey triggerfish, J: Jamaica weakfish, KW: king weakfish, LH: largehead hairtail, MF: monkfish, O: octopus, PC: pink cusk-eel, PS: pink-shrimp, RP: red porgy, S: skate, SB: sea-bob shrimp, SF: sand flounder, SK: southern kingcroaker, SP: sandperch, SQ: squid, SS: striped soldier shrimp, ST: sea trout, SW: stripped weakfish, TF: tilefish, TG: tomtate grunt, W: whitemouth croaker.

ces seemed to be related to sandy and/or muddy-sand bottoms (Fig. 4).

Fishing management units

The integration of biological, fishery and environmental data, either analyzed in the present study as available in the literature (see discussion), resulted in six main areas, from which future spatial fishing management units could evolve (Table 8, Fig. 5).

North unit: comprises a small sand, muddy-sand and muddy area situated between southern and central parts of Rio de Janeiro state (23°45'-22°30'S). Octopus, pink-shrimp, striped soldier shrimp, codling and sandperch compose the main species assemblage of this unit, exploited mostly by double-rig trawlers and bottom gillnetters (Table 8, Fig. 5).

In addition, while pertaining to the SE/S region, grid squares between 22°30'S and 18ºS were not included in the present analysis (and neither in the North unit), given the scarcity of fishing records available from the studied fleets.

Coastal unit: situated in shallow waters between 25º30'S (central Paraná) and 23º25'S (northern São Paulo) up to 30 m depth. This area is characterized by muddy-sand, muddy, and, in smaller proportions, by sandy bottoms, where the sea-bob shrimp fishery conducted by double-rig trawlers dominates (Table 8, Fig. 5). Given the limited availability of data concerning fishing operations conducted in shallow waters by the studied fleets, it is very likely that these latitudinal limits are artificially underrepresented.

Southeastern shelf unit (based on the northern inner continental shelf group): delimited by latitudes ~28°S (Cabo de Santa Marta; southern Santa Catarina) and ~23°S (Cabo Frio, southern Rio de Janeiro), from 30 to 100 m depth (Table 8, Fig. 5). Sand, mud and muddy-sands are the dominant bottoms (Table 8).

Whitemouth croaker (southeastern stock), squid, octopus, pink-shrimp, Brazilian codling, catfish, bluewing searobin, skate, American harvestfish, Jamaica weakfish e sand flounder compose the main species assemblage of this unit, sharing the last seven species with the Southern shelf unit. Octopus pot, double-rig trawl, bottom gillnet and pair trawl were the main fleets operating in the area (Table 8).

Southern shelf unit (based on the southern inner continental shelf group): extending from 28ºS to the southern limit of the Brazilian Economic Exclusive Zone from the coast to 100 m depth (Fig. 5), the area is covered by mud, muddy-sand and sand, and is exploited mostly by trawlers (double-rig, pair and stern) and gillnetters. From the main 24 resources caught in the area, 17 are dominant (Table 8).

Shelf break unit: it was identified in the cluster analysis as a continuous area bordering only the southern continental shelf; however, this unit seems to extend uninterruptedly up to São Paulo state (23°25'S) in depths ranging from 100 to 250 m (Table 8, Fig. 5).

Muddy bottoms dominate in this sector, where bottom longliners, bottom gillnetters and double-rig and stern trawlers are the main fleets operating (Table 8). Sandperch, striped soldier shrimp, pink cusk-eel, bluewing searobin, skate, sand flounder and Brazilian codling were the main resources exploited in the shelf break. The last four species are shared with both southeastern and southern shelf units, while the pink cusk-eel occurs also in the slope (Table 8).

Slope unit: extends for areas exceeding 250 m depth situated from 23°35'S (northern São Paulo) to the southern limit of the Brazilian EEZ (Table 8, Fig. 5). Bottom types are quite heterogeneous in the area. Codling, tilefish, monkfish, Argentine hake and pink cusk-ell were the main slope resources identified in the present study (Table 8).

DISCUSSION

A critical point in tropical fisheries analysis as the one developed in the study area is their multispecific feature, and the fact that the same species is exploited by different fishing gears in distinct phases of its life cycle. Usually, a fleet explores several stocks, and several fleets compete by the same resources (Sparre & Venema, 1997). Under this scenario, the adoption of operational units, hereby called fishing management units, could be useful to reduce such complexity in the management process, through the identification of homogeneous groups of vessels associated with assemblages of resources and bottom types (Accadia & Franquesa, 2006).

Despite being considered a single jurisdictional area for fishing management purposes, the large SE/S region cannot be regarded as a homogeneous system deserving, therefore, a more regionalized approach. However, in determining the size of the management units, scale turns a fundamental issue. For fishing management purposes, excessively larger scales may turn management unsuccessful, as critical details may be lost, while excessively finer scales can make monitoring and enforcement impractical (Bax *et al*., 1999; Norse, 2010). When proposing new spatial management units for the SE/S region, we have adopted a megahabitat scale (100s of km) (Bax *et al*., 1999). This option was justified by: a) either the studied fleets as most of the exploited resources, are highly movable; b) the generally plain, soft-bottom and opened shelf is

Table 8. Spatial management units proposed for the SE/S Brazil industrial demersal fisheries, as resulting from data from the present study and information from the literature. *Values are mean frequencies (%) of occurrence of the bottom types in the respective quadrants. **Resources for which spatial regulations are enforced in the region.

Management unit	Depth (m)	Latitudinal limits	Main resources	Bottom types*	Main fleet
Northern	All depths	23°35'-22°30'S	Pink-shrimp, sandperch, octopus, striped soldier shrimp, codling	Sand (40.4%) Muddy-sand (24.9%) Mud (15.8%)	Double-rig trawl Bottom gillnet
Coastal	Up to 30	25°30'-23°25'S	Sea-bob shrimp	Muddy-sand (38.8%) Mud (35.6%) Sand (21.0%)	Double-rig trawl
Southeastern shelf	30-100	28°-23°S	Pink shrimp, squid, octopus, Brazilian codling, catfish, bluewing searobin, whitemouth croaker (stock Northern), skate, American harvestfish, Jamaica weakfish, sand flounder	Sand (38.2%) Mud (27.2%) Muddy-sand (23.9%)	Octopus pot Double-rig trawl Bottom gillnet Pair trawl
Southern shelf	Up to 100	28°-34°S	Argentine stiletto shrim, Argentine red shrimp, Brazilian codling, catfish, Southern kingcroaker, Argentine croaker, bluewing searobin, tomtate grunt, whitemouth croaker (stock Southern), skate, largehead hairtail, dusky grouper, Jamaica weakfish, American harvestfish, flounder, sand flounder, stripped weakfish, castaneta; red porgy, grey triggerfish, sea trout, acoupa weakfish, king weakfish, Brazilian flathead	Mud (47.9%) Muddy-sand (23.6%) Sand (21.5%)	Bottom gillnet Pair trawl Double-rig trawl Stern trawl
Shelf break	100-250	23°25'-34°00'S	Sandperch, striped soldier shrimp, pink cusk-eel, bluewing searobin, skate, sand flounder, Brazilian codling	Mud (67.2%) Muddy-sand (14.4%)	Bottom longline Stern trawl; Double-rig trawl
Slope	>250	23°35'-34°00'S	Codling, tilefish, pink cusk-eel, silvery John dory**, Argentine hake**, deep-sea crabs**, deep-sea shrimps**, monkfish**, Argentine squid**	Mud (37.7%) Muddy-sand (20.1%) Sand (15.9%) Sand/biodetritical gravel (15.6%)	Bottom longline Double-rig trawl Stern trawl Trap (crab) Bottom gillnet (monkfish)

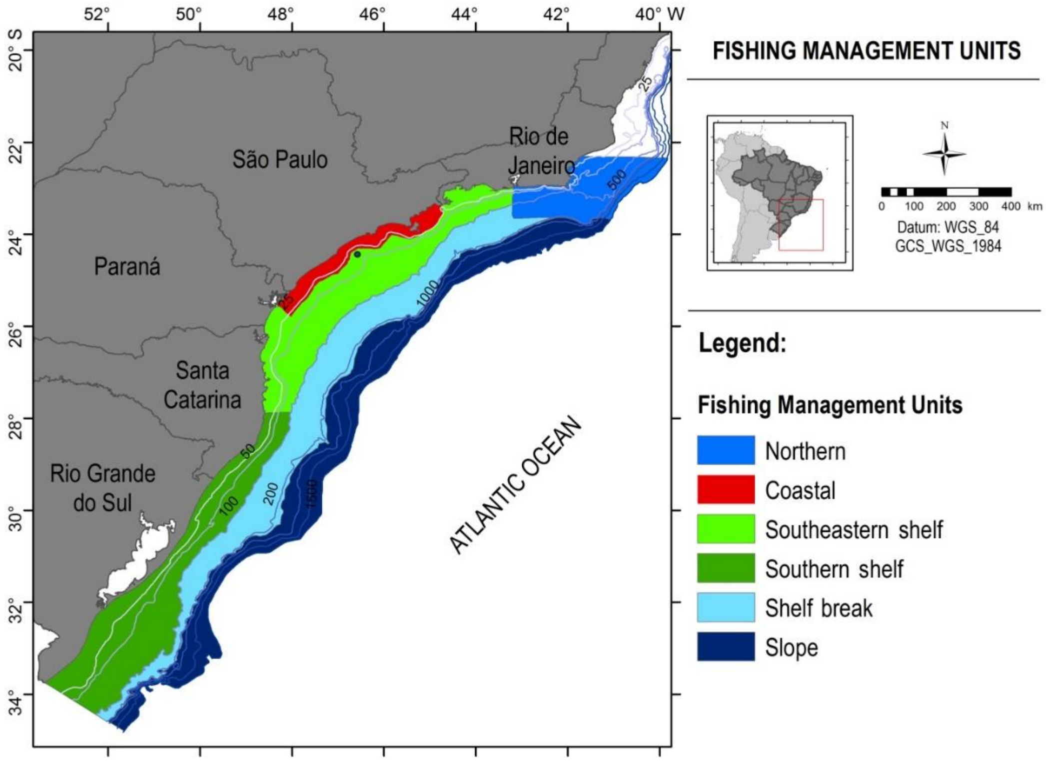

Figure 5. Map of the spatial management units proposed for the SE/S Brazilian industrial demersal fisheries, as resulting from data from the present study and information from the literature.

mostly submitted to large scale oceanographic processes; c) fishing data have a quite poor spatial resolution; and d) structural and operational limitations of the Brazilian fishing management authorities turn unfeasible dealing with an excessively large number of management units. Therefore, the six management areas defined in such geographic scale are discussed below.

North unit: includes either shallow as deep fishing grounds, resulting in a highly diverse assortment of species exploited, as the narrowing of the shelf in the region (Cooke *et al.*, 2007) makes it possible for the vessels to reach great depths in a short navigation time. Therefore, in the same fishing trip the fleet is able to exploit either coastal species as deeper ones.

Bottom characteristics seem also to exert strong influence in the North unit design. Northern from Cabo Frio (~22°52'S) the shelf bottom is highly heterogeneous, being dominated by gravel, gravelly sand and calcareous algae, while sand areas remain confined to coastal areas (Martins *et al.*, 1972; Figueiredo Jr. & Madureira, 2004; Figueiredo Jr. & Tessler, 2004). Most trawlable areas are therefore confined to southernmost latitudes, while passive gears tend to prevail over the more irregular bottoms predominating towards the north (Muehe & Garcez, 2005). In addition, while pertaining to the SE/S region, grid squares between 22°30'S and 18°S were not included in the present analysis (and neither in the North unit), given the scarcity of fishing records available from the studied fleets, probably resulting from the long distance to the Santa Catarina harbors. Consequently, this management area must be seen as provisional, depending on a reassessment based on fishing data from São Paulo and Rio de Janeiro fleets.

Coastal unit: given the limited availability of data concerning fishing operations conducted in shallow waters by the studied fleets, it is very likely that the latitudinal limits proposed for this small management unit are artificially underrepresented. In fact, extensive exploitation of sea-bob shrimp (the main species identified in the coastal unit) by double-rig trawlers is known to occur from Espírito Santo to southern Santa Catarina (Perez *et al.*, 2001; Valentini & Pezzuto, 2006). Therefore, in the Perez *et al.* (2001) model a coastal (*i.e.*, < 30 m depth) management sector extending along all this area was proposed. This should be considered in the future as more detailed data become available.

Southeastern shelf unit: it is inserted in the Southeastern Brazil Bight. The region is characterized by oceanographic processes such as coastal upwellings and sub superficial nutrient-rich cold water intrusions during the austral summer, the formation of meanders and eddies by the Brazil Current and the presence of relatively cold and less saline waters from the south during the winter (Castro *et al*., 2006; Rossi-Wongtschowski *et al*., 2006). The coastline is very indented in several sectors. Shelf width and depth gradient vary between 70 and 230 km and 1:600 to 1:1,300 respectively, and the shelf break lies on the 120 to 180 m isobaths (Corrêa & Villwock, 1996; Mahiques *et al*., 2010). Although the sand, mud and muddy-sands are the dominant bottoms, their distribution are not homogeneous in the area. Northward from 24ºS there is a complex sedimentary mosaic, while southward the sediment distribution is comparatively more homogeneous (Mahiques *et al*., 2010).

Southern shelf unit: previously separated from the northern shelf unit by the cluster analysis in the parallel 27ºS, the existence of either distinct oceanographic patterns as latitudinal changes in the structure of some stocks justify moving this limit to a southernmost position. Morphologically very homogeneous (Corrêa & Villwock, 1996), the southern shelf width varies from 100 to 200 km and its break lies between 100 and 180 m depth (Mahiques *et al*., 2010). Low gradients ranging from 1:600 to 1:1,000 are also typical in the area (Figueiredo Jr. & Tessler, 2004; Mahiques *et al*., 2010). The shelf is alternately influenced throughout the year by tropical (Brazil current) and sub-Antarctic (Malvinas current) waters flowing in opposite directions. In shallower sectors, they are also strongly influenced by low salinity and nutrient-rich waters originating from La Plata River and Patos Lagoon discharges (Castro *et al*., 2006). The seasonal transport of nutrient enriched waters increases the primary and secondary productivity in the region, showing a comparatively high fishing potential of demersal resources (Rossi-Wongtschowski *et al*., 2006; Haimovici *et al*., 2007). This fact explains, in part, the concentration of fishing effort (and catches) in this region, as showed by most of the studied fleets.

Despite the wide geographic distribution showed by most of the resources caught in this unit, their catches were more abundant in this area. In addition, there is evidence that the transition zone between the southeastern and southern shelf separates different stocks which have been identified at least for Argentine hake (Vaz-dos-Santos *et al*., 2009), king weakfish (Rodrigues *et al*., 2014), Argentine croaker (see references in Haimovici *et al*., 2006) and whitemouth croaker (Vazzoler, 1991; Vasconcellos *et al*., 2015). This fact reinforces the need of considering the southeastern and southern areas as different management units.

Shelf break unit: originally identified in the cluster analysis as a discontinuous sector probably due to the methodological limitations related both to the coarse resolution of the fishery data and the high mobility of the fleets, this unit should instead to be considered as a continuous area extending along from 100 to 250 m along most of the study area. On the other hand, by sharing several species with other management units (Table 8), it probably constitutes a transitional area. Dominated by muddy bottoms, it is known that hard bottoms (not clearly identified in the present analysis by scale and data limitations) are concentrated also between 100 and 500 m in front of Santa Catarina State, potentially excluding the operation of trawlers in favor of longliners in some areas (Figueiredo Jr. & Tessler, 2004).

Slope unit: bottom types and morphology are quite heterogeneous in the area, influencing the operation of the different fishing fleets. Hence, while some areas have been regarded as non-trawlable due to the high slope gradient (1:13 to 1:8) and/or to the presence of hard bottoms, others have been successfully exploited by either double-rig as stern trawlers, given their gentler declivity and suitable sedimentary coverage (1:132 to 1:190) (Figueiredo Jr. & Tessler, 2004).

Besides the species analyzed in the present study, deep-sea crabs (*Chaceon* spp.), deep-sea shrimps (Aristeidae) (Pezzuto *et al*., 2006; Dallagnolo *et al*., 2009), silver John dory (*Zenopsis conchifera*) and Argentine squid (*Illex argentinus*) (Perez *et al*., 2009) (Tables 1 and 8), whose landings were not available for the study period, should also be included among the slope resources.

Determined mostly from fishing-derived data, three of the six management units proposed in the present study have their boundaries conforming to the subdivisions of the so-called South Brazil Large Marine Ecosystem. Large Marine Ecosystems (LME) are "large marine areas of approximately 200,000 km^2 or larger, adjacent to the continents in coastal waters where primary productivity is generally higher than in open ocean areas" (Sherman & Hempel, 2009). Based in four ecological criteria (*i.e*., bathymetry, hydrography, productivity and trophic relations), a total of 64 LMEs have been identified along the World Ocean, which account for nearly 80% of the world capture of marine fish (Sherman & Hempel, 2009). Following such criteria, three LMEs have been recognized along the Brazilian coast: a) North Brazil Shelf; b) East Brazil Shelf; and c) South Brazil Shelf (Sherman & Hempel, 2009). The latter LME extends from 22ºS (Rio de Janeiro) to 34ºS (Rio Grande do Sul states) (basically including the SE/S region) and has been subdivided in three smaller sub-areas as follows: a) Southeastern Bight (23°-28°S), characterized by seasonal upwellings and cold intrusions; b) South Shelf (28°-34ºS), affected by estuarine outflows; and c) slope and oceanic system, influenced by mesoscale eddies (Gasalla, 2007 *apud* Heileman & Gasalla, 2009). As can be clearly observed, such sub-areas coincide precisely with the boundaries of the Southeastern shelf, Southern shelf and Slope spatial management units proposed in the present study, while the Shelf Break unit denotes a bathymetric transition among them. Produced by different approaches, such similarity points to the robustness of the divisions proposed here.

In general, the present findings corroborate also some aspects of the model from Perez *et al*. (2001) as: a) it identifies a coastal unit focused mainly on the sea-bob shrimp fishery; and b) it establishes two major latitudinal boundaries in the SE/S, despite some slight differences in their respective locations and respective bathymetric ranges. Otherwise, one of the most remarkable contrast between the two models, refers to the management of the outer shelf and slope areas. In the Perez *et al*. (2001) proposal, a single bathymetric limit separating shallower from deeper fisheries was established over the 100 m depth contour. Here we evidenced the need of a more detailed approach in the deeper areas, by recognizing two sectors (shelf break, from 100 to 250 m and slope, >250 m) distributed along the full latitudinal extent of the study area. Developing more significantly since late 1990's and early 2000's, deep-water fisheries were extensively monitored in the region during the period (see review by Perez *et al*., 2009) providing, in recent years, a much better understanding about resources distribution and respective potentials. Paradoxically, despite its recent history, efforts in assessment and management of deep-water fisheries in Brazil were comparatively more intense than to "traditional" coastal fisheries. Consequently, in some aspects the spatial approach considered here have already been implemented in the SE/S slope sector, where some fisheries have been space-regulated in terms of target-species, by-catches, TACs, effort limitations and technical measures (Brasil, 2008a, 2008b, 2008c, 2009). It is necessary to expand such approach to the shelf and coastal water demersal fisheries, for which several authors (*e.g*., Okubo-da-Silva, 2007; Imoto, 2014; Pezzuto & Benincá, 2015) have described spatial patterns that reinforce the need to change the present management scenario focused on target-species and unrestrictedly mobility.

The present study represents a step forward in designing a final spatial management model for the SE/S industrial fisheries, as could be evidenced, among other aspects, by the improvements over the previous model (*i.e*., Perez *et al*., 2001) and its correspondence with the South Brazil LME configuration. However, it presents some shortcomings that should be eliminated before a final design be accepted. For example, given the proximity of the isobaths either in the slope as in some parts of the shelf break, the coarse spatial resolution of the fishing data available, and the quite punctual distribution of coarse/consolidate bottoms in the region, relevant features in the mesohabitat scale (*i.e*., 10s km; *sensu* Bax *et al*., 1999) could not be identified in this present study. In addition, vessels landing in Santa Catarina are not fully representative of the fleets operating from other harbors of the SE/S, where technological and operational differences could produce different information about fishing strategies and catches.

Future refinements to the present model should benefit from considering other relevant biological, environmental, economic and social features regarding the regional fisheries and stocks. However, concerning fishing data, it should be considered, at least: a) landings from other harbors, for a better understanding of the fishing dynamics, especially in the northernmost areas; b) fine-scale satellite vessel monitoring system data (Jennings & Lee, 2012); and c) seasonal patterns in the fishery activity, as they could influence significantly the spatial effort allocation with time. In spite of these limitations, we expect that the present study can serve as a new base to subsidizing the future spatial planning of the fishing activity in the SE/S Brazil.

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