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Research Article

Biomass and fishing potential yield of demersal resources from the outer shelf and upper slope of southern Brazil

Manuel Haimovici[1], Luciano Gomes Fischer[2], Carmem L.D.B.S. Rossi-Wongtschowski[3], Roberto Ávila Bernardes[3] & Roberta Aguiar dos Santos[4]
[1]Instituto de Oceanografia, Fundação Universidade Federal de Rio Grande, FURG
[2]Pós Graduação em Oceanografía Biológica, FURG
[3]Instituto Oceanográfico da Universidade de São Paulo, IOUSP
[4]Instituto Chico Mendes, ICMBio, Ministério do Meio Ambiente

ABSTRACT. The relative abundance and fishing potential of the commercially valuable fishes and cephalopods with marketable size was assessed using two seasonal bottom trawl surveys performed in 2001 and 2002 on the outer shelf and upper slope (100-600 m depth) off the coast of southern Brazil. These surveys were part of REVIZEE, a national program designed to assess the fishery potential within the Economic Exclusive Zone. Of the 228 fish and cephalopod species caught during the surveys, only 27 species and genera were considered to be of commercial interest. Commercial-sized individuals of these species made up 52.3% of the total catch. The total biomass was estimated to be 167,193 ton (± 22%) and 165,460 ton (± 25%) in the winter-spring and summer-autumn surveys, respectively. The most abundant species were the Argentine short-fin squid *Illex argentinus*, a species with highly variable recruitment, followed by the Argentine hake *Merluccius hubbsi*, the gulf-hake *Urophycis mystacea*, and the monkfish *Lophius gastrophysus*. The latter three were intensively fished prior to the surveys, as well as the beardfish *Polymixia lowei* and silvery John dory *Zenopsis conchifera*, both relatively abundant but with a very low market value. The potential yield of the demersal fish species, not considering *Illex argentinus*, estimated with the Gulland equation for a mean natural mortality of M = 0.31, was 20,460 ton. When considering only *Merluccius hubbsi*, *Urophycis mystacea*, and *Lophius gastrophysus*, the potential yield decreased to 6,625 ton. The surveys showed that the fishery potential of the outer shelf and upper slope was substantially lower than that of the inner shelf. Therefore, this environment should be carefully monitored to avoid overfishing and fast depletion.

Keywords: demersal fishes, stock assessment, biomass, Brazil.

Biomasa y rendimiento potencial pesquero de recursos demersales de la plataforma externa y talud superior del sur de Brasil

RESUMEN. Se evaluó la abundancia relativa y el potencial pesquero de peces y cefalópodos de especies y tamaños de valor comercial en dos muestreos estacionales con redes de arrastre de fondo realizados en los años 2001 y 2002 sobre la plataforma externa y talud superior, 100 a 600 m de profundidad, a lo largo del extremo sur de la costa brasilera, como parte de un programa nacional de evaluación del potencial pesquero de la Zona Económica Exclusiva (Programa REVIZEE). Del total de 228 especies de peces y cefalópodos capturados, sólo 27 especies y géneros fueron considerados de interés comercial. Los tamaños comercializables de estas especies representaron 52,3% de la captura total. La biomasa total estimada fue de 167.193 ton (± 22%) y 165.460 ton (± 25%) en los muestreos de invierno-primavera y verano-otoño respectivamente. Las especies más abundantes fueron el calamar argentino *Illex argentinus*, especie de reclutamiento muy variable, seguido de la merluza argentina *Merluccius hubbsi*, la brótola de profundidad *Urophycis mystacea*, el pez sapo o rapé *Lophius gastrophysus*, estas últimas intensamente explotadas en la época de los levantamientos, así como también *Polymixia lowei* y *Zenopsis conchifera*, ambas relativamente abundantes pero de escaso valor comercial. El rendimiento potencial de especies demersales excluido *Illex argentinus,* estimado a través de la ecuación de Gulland para un coeficiente de mortalidad natural medio de M = 0,31, fue de 20.460 ton. Cuando sólo

Merluccius hubbsi, Urophycis mystacea y *Lophius gastrophysus* fueron considerados, el potencial disminuye a 6.625 ton. Los mustreos mostraron que el potencial pesquero de la plataforma continental externa y el talud superior es substancialmente inferior al de la plataforma interna, por lo tanto, este ambiente debe ser cuidadosamente controlado para evitar la sobrepesca y rápida depleción.

Palabras clave: peces demersales, evaluación, biomasa Brasil.

Corresponding author: Manuel Haimovici (docmhm@furg.br)

INTRODUCTION

Exploratory bottom trawl surveys provide important information on the distribution and abundance of potential fish resources (Saville, 1977). Density estimates based on research surveys are subject to bias due to several factors, including the gear and its rigging, trawl depth, time of day, distribution, fish behavior and size, and others (Gunderson, 1993). More realistically, bottom trawl surveys produce relative abundance indices rather than absolute estimates, and potential yield must be carefully inferred. However, at the initial stages of fishery development, such surveys can be helpful, providing rough estimates of the biomass and the potential yield of the assessed resources (Gulland, 1983).

Industrial fisheries in southern Brazil began in the late 1940s following the same development pattern observed worldwide in the second half of the 20th century (Yesaki & Bager, 1975). For two decades, bottom trawling expanded almost exclusively over the inner shelf at depths under 100 m and it peaked in the early 1970s (Haimovici *et al*., 1989; Valentini *et al*., 1991). Due to the combination of new fishing technologies, cheap fuel, elevated fish abundances, and increasing market demands, catches have decreased steadily since then, despite increased efforts (Haimovici, 1998). Fishing on the outer shelf for demersal fishes with bottom trawls or bottom gill-nets began off the state of Rio Grande do Sul in the mid-1980s, targeting elasmobranches and flatfishes (Haimovici, 1997). In the late 1990s, this effort expanded along the outer shelf off Santa Catarina State and, later, over the entire southern region (Perez & Pezzuto, 2006). Intense fishing on the upper slope started soon after, when large foreign fishing vessels with the capacity for onboard processing and freezing were authorized to fish on the upper slope (Perez *et al*., 2003).

It is possible to contextualize Brazilian exploratory fishing by research vessels and the development of commercial fisheries as follows: early exploratory fishing to assess the demersal fishing potential on the outer shelf and slope started in the 1950s and 1960s onboard Portuguese, Japanese, and German research vessels. In the 1970s, the national fishery agency (SUDEPE), with support from the United Nations agency (PNUD), developed a series of surveys with large commercial bottom trawlers. These surveys were continued in the 1980s with the research vessel Atlântico Sul of the Federal University of Rio Grande (FURG). The main results of these surveys, including unpublished reports, were summarized in Haimovici *et al*. (2007). More recently, two seasonal bottom trawl surveys were performed in 2001 and 2002 as part of the Brazilian governmental program REVIZEE: Assessment of the Sustainable Yield of the Economic Exclusive Zone (Haimovici *et al*., 2008).

This paper focuses on the distribution, relative abundance, and fishing potential of the main commercially valuable species on the outer shelf and upper slope of southern Brazil based on data obtained during the REVIZEE surveys. These surveys coincided with the rapid development of trawling and gillnet fishing on the upper slope and provided useful data on the distribution, seasonality, and yields of the demersal fish resources vulnerable to such gears.

MATERIAL AND METHODS

Study area

The study area included southern Brazil's outer shelf and slope between Cabo Frio (23°S) and Chui (34°35'S) (Fig. 1). Along this area, the shelf width ranged from 140 to 180 km, narrowed to 90 km along Cabo de Santa Marta Grande (29ºS), attained a maximum width of 250 km along the southeastern Brazilian Bight, and narrowed again to 50 km in Cabo Frio. The area encompassed by the 100 to 600 m isobaths covered 152,354 km^2 (Table 1). Bottom sediments on the outer shelf were mostly mud rich in silts and clay, although large patches with biodetritic sediments and sand were found near the shelf break and along Cabo Frio; on the slope, muddy sediments were dominant (Martins *et al*., 1976; Figueiredo & Madureira, 2004). The most remarkable hydrographic characteristics on the shelf were the seasonal variation of the water temperature and water column stratification, which was strong in summer and weak or non-existent in winter (Castro & Miranda, 1998). Another important feature

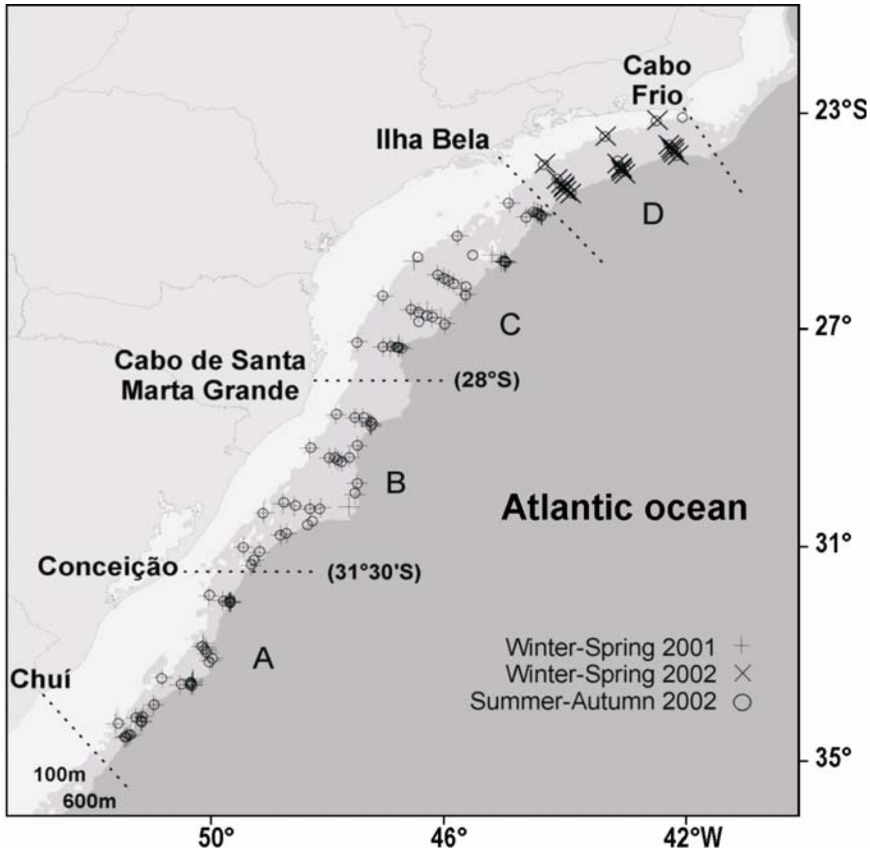

Figure 1. The study area and haul positions in the REVIZEE trawl surveys along the outer shelf and upper slope in southern Brazil.

Figura 1. Área de estudio y posición de los arrastres en el levantamiento pesquero del programa REVIZEE realizado en la plataforma externa y talud superior del sur de Brasil.

Table 1. Areas and number of hauls at each depth and latitude stratum in the REVIZEE bottom trawl surveys on the outer shelf and upper slope in southern Brazil (2001-2002) in winter-spring (w-s) and summer-autumn (s-a).

Tabla 1. Áreas y número de lances en cada estrato de profundidad y latitud en los muestreos pesqueros de arrastre de fondo del Programa REVIZEE realizados en la plataforma externa y talud superior del sur de Brasil (2001-2002) in invierno-primavera (w-s) y verano-otoño (s-a).

Stratum	A (Chuí – Conceição)			B (Conceição - Santa Marta Grande)			C (Santa Marta Grande - Ilha Bela)			D (Ilha Bela - Cabo Frio)		
	34°35'S - 31°30'S			31°30'S - 28°00'S			28°00'S - 24°24'S			24°24'S - 23°00'S		
	Areas	Hauls		Areas	Hauls		Areas	Hauls		Areas	Hauls	
Depth (m)	km^2	w-s	s-a	km^2	w-s	s-a	km^2	w-s	s-a	km^2	w-s	s-a
100-149	7,524	6	5	16,723	8	9	17,124	6	4	14,961	5	6
150-199	7,869	4	4	15,284	4	3	20,354	6	4	8,110	2	5
200-299	2,237	5	4	6,456	7	6	5,762	4	3	3,121	3	2
300-399	1,247	5	4	3,460	3	4	2,450	4	5	1,857	1	6
400-600	3,340	10	10	6,529	6	6	5,141	15	11	2,805	9	10
Total	22,217	30	27	48,452	28	28	50,830	35	27	30,855	20	29

at latitudes over 30ºS was a shelf front that shifted northward in the cold season and southward in the warm months, separating the cold, less salty Subantarctic Surface Waters of the shelf from the warmer, saltier Shelf Subtropical Waters (Piola *et al*., 2000). On the upper slope, the Brazil Current ran southward in the upper layers and the Malvinas Current ran northward, meeting at a front that shifted seasonally in the north-south direction and was known as the western boundary of the Subtropical Convergence. Beneath the Brazil Current, the South Atlantic Central Waters (SACW) had temperatures between 10ºC and 17ºC and, below these, between 400 and 600 m, a mixture of SACW and Antarctic Intermediate Waters were found with bottom temperatures ranging from 4ºC to 10ºC.

Vessels and gears

Due to the large extension of the area under investigation, two research vessels were used: the R/V Soloncy Moura (26 m, 600 HP) from the Brazilian Environmental Agency (IBAMA) and the R/V Atlântico Sul (39.5 m, 860 HP) from the Federal University of Rio Grande (FURG).

Both vessels were geared with Engel Star Ballon trawl nets with 439 meshes of 160 mm stretched between opposite knots in the mouth and 27 mm in the codend. The groundrope had a "rockhopper" of rubber discs (300, 200, and 130 mm in diameter) in its central 20.8 m with two lateral extensions of 9.8 m each; considering the 75 mm rubber discs, this totalled 40.4 m. The otter doors (550 kg rectangular Engel Hydro) were connected to the wings of the net by 5-m-long lengthening bridles and to the winch cables with 50-m bridles. These nets were similar to those used in commercial fishing on the upper slope by otter trawlers, although the mesh size in the codend was smaller in this study.

Sampling

The surveys were performed almost simultaneously, with the R/V Atlântico Sul operating from August to September 2001 and March to April 2002 between 28ºS and 34º35'S, and the R/V Soloncy Moura cruising from August to October 2001 and from February to April and in late June 2002 between 23ºS and 28ºS. Overall, 224 effective fishing hauls were performed between Cabo Frio and Chuí at depths between the 100 m and 600 m isobaths: 113 hauls were done in winter and spring 2001 and 2002 and 111 in summer and autumn 2002 (Table 1). After each tow, the fishes and cephalopods in the catch were classified, counted, and weighed. For large catches, random samples of 30 kg of small fish and cephalopods were classified and the number and weight of each species was recorded. For most of the tows, the length composition of the samples of all the species was also recorded. The total catch in number and weight and the mean weight for each haul was calculated for all species (Haimovici *et al*., 2008).

The main scope of the surveys was to study the distribution and abundance of the whole fish fauna vulnerable to bottom trawls without much previous knowledge about the distribution pattern of each species (Haimovici *et al*., 2008). In this situation, systematic sampling was recommended to cover the whole study area (Saville, 1977; Gunderson, 1993); this was done by distributing the fishing stations along profiles perpendicular to the coastline, 55 miles apart and in depth ranges of 100-149, 150-199, 200-299, 300-399, and 400-600 m. Some depth ranges were not well represented along the profiles with sharp slopes, whereas additional stations were included to better represent larger areas in depth ranges with milder slopes. For the biomass analysis, hauls were grouped into four latitudinal areas named A to D from south to north (Fig. 1). Combining latitudinal and depth ranges, 20 strata were defined (Table 1). The surface of each stratum was calculated graphically with ArcView 3.2 Software, integrating the polygons determined by the latitudinal transects and isobaths obtained from the GEBCO (General Bathymetric Chart of the Oceans) database (http://www.gebco.net) and complemented with data from acoustic surveys of the REVIZEE Program (Madureira *et al*., 2005).

Since the codends of the nets used for the bottom trawl surveys had smaller mesh than those used in commercial fishing, the samples included fishes weighing less than the minimum marketable weight (MMW). The MMW values for the main species in the catch were obtained from the literature or personal communications (Table 2). As the scope of this paper is to estimate the commercial biomass and potential yield for each of the main species, only hauls in which the mean weight was over the MMW were included. This assumption was necessary because the size composition of all species for all hauls was not always available. Preliminary tests showed that the hauls in which the mean weight was under the MMW had a very small fraction in weight over the MMW and those in which the mean weight was over the MMW had only a small fraction of the catch smaller than the marketable size.

Density and biomass estimates

Densities were calculated as catch per unit of areas (CPUA) in kg km^{-2}. The swept areas were estimated by multiplying the distances between the beginning and the end of the hauls recorded by the satellite posi-

Table 2. Minimum marketable individual weight (MMW) and minimum marketable total length or mantle length (MMTL) of the main commercially important species caught in the REVIZEE bottom trawl surveys on the outer-shelf and upper-slope in southern Brazil (2001-2002).

Tabla 2. Peso mínimo de peces y calamares con valor comercial (MMW) y peso mínimo largo total o del manto (MMTL) de las principales especies capturadas en los muestreos de arrastre de fondo del Programa REVIZEE en la plataforma externa y talud superior del sur de Brasil (2001-2002).

Species	% of hauls with mean weight over MMW	MMW (g)	MMTL (mm)	Reference
Illex argentinus	83	100	180	Haimovici *et al*. (2006a)
Urophycis mystacea	98	100	250	Haimovici *et al*. (2006b)
Merluccius hubbsi	85	100	250	Haimovici *et al*. (1993)
Lophius gastrophysus	100	350	290	Haimovici (*pers. observ.*)
Zenopsis conchifera	67	350	280	Haimovici (*pers. observ.*)
Polymixia lowei	91	100	200	Rossi-Wongtschowski (*pers. observ.*)

tioning system and the width of the swept area calculated as 18.18 m or 45% of the length of the groundrope based on Alverson & Pereyra (1969). Geometry and net gearing, towing speed, and fish behavior can affect catchability (q); since none of these effects could be measured, a value of 1 was attributed to q as suggested by Alverson & Pereyra (1969) and Fogarty (1985).

The mean densities (kg km^{-2}) D_i of each species i in each survey were calculated by weighing the mean densities in each stratum by the fraction of the total area of each stratum A_e (eq. 1). The variances of the mean density of each species in each stratum $\bar{S}^2_{D_i}$ were calculated by weighing the variances in each stratum S_{Die} divided by the number of samples and multiplied by the square of the fraction of the area of each stratum (eq. 2).

$$D_i = \sum_e D_{ie}\left(\frac{A_e}{A}\right) \quad (1)$$

$$\bar{S}^2_{D_i} = \sum_e \frac{S^2_{Die}}{n_e}\left(\frac{A_e}{A}\right)^2 \quad (2)$$

The biomass of each species in each survey was calculated as the sum of the products of the densities for the areas of all strata (eq. 3), and the total variances were calculated by multiplying the variances in each stratum by the respective squared areas.

$$B_i = \sum_1^e A_e\, D_{i.e} \quad (3)$$

$$\mathrm{var}\, B_i = \sum_1^e A_e{}^2\, \bar{S}^2_{Die} \quad (4)$$

The 90% confidence intervals of the biomass estimates were calculated based on Student's "t" distribution for α = 0.1 and $\boldsymbol{\nu}$ degrees of freedom (Zar, 1984) according to equations (5) and (6).

$$IC_{\alpha\%} = B_i \pm t_{\alpha,\nu}\sqrt{\bar{S}^2_{Die}} \quad (5)$$

$$\nu = \sum_e (n_e - 1) \quad (6)$$

Potential yield

Potential yield was calculated under the assumption that the maximum growth in mass of a population occurs at intermediate levels of abundance and is related to the population's natural mortality. In its simplest form, populations can be assumed to grow following a logistic model in which maximum growth occurs when the biomass halves the virginal biomass (B_∞) and fishing mortality (F) equals the natural mortality (M) (Graham, 1935). Provided unbiased estimates of virginal biomass and natural mortality are available, an approximation of the maximum equilibrium yield (Y_{max}) can be calculated by the formula Y_{max}= M (X B_∞) (Gulland, 1971). The value of 0.5 for X, originally proposed by Gulland, was considered to be too high for most long-living species (Beddington & Cooke, 1983; Walters & Martell, 2002); thus, we used a value of 0.4 in our calculations.

Natural mortality was calculated separately for each of the five most abundant commercially valuable fishes; this was inferred from the longevity equation proposed by Hoenig (1983) based on longevity estimated from growth studies (Table 3). A common value of M = 0.31 was calculated, weighing M estimates for each species or group of species by its contribution in weight to the catch of those species.

RESULTS

The list of fishes and cephalopods caught in the REVIZEE bottom trawl surveys off southern Brazil included 228 species (Haimovici *et al*., 2008); few of them were of commercial interest. To select those species, we examined the marine fisheries landing reports for the southern states of Brazil (IBAMA, 2007). We also examined the literature and databases such as FISHBASE (Froese & Pauly, 2009) to find additional species that are commercially fished in other regions. This filtering resulted in 27 species and genera of interest (Table 4).

The overall catch from both surveys was 32,715 kg, and the total catch of the 27 selected species was 24,946.3 kg (76.5%), 17,418 kg (52.9%) of which complied with the adopted size selection criteria (Table 4). Six species (*Illex argentinus*, *Urophycis mystacea*, *Merluccius hubbsi*, *Polymixia lowei*, *Zenopsis conchifera*, *Lophius gastrophysus*) accounted for 77.8% of the catch with commercial value; another 9.8% consisted of other bony fishes and 12.4% were cartilaginous fishes.

The total biomass of commercial sizes for marketable species was estimated to be 167,193 ton (± 22%) in the winter-spring survey and 165,460 ton (± 25%) in the summer-autumn survey. However, if squids are excluded, the winter-spring biomass was 16% higher (158,281 ton) than the biomass estimated during the summer-autumn survey (136,813 ton). In the winter-spring survey, bony fishes were 13% and elasmobranches 26% more abundant than in the summer-autumn survey (Table 5).

The total biomass of commercial sizes of marketable species was calculated by depth and latitude strata in both seasons (Fig. 2). On the outer shelf, biomass decreased from higher to lower latitudes in both surveys; elasmobranches were more abundant in the south (areas A and B), where commercial-sized *Illex argentinus* were absent. On the upper slope, biomass was higher in the central areas (B and C) in winter-spring and, in area B, in summer-autumn, and both bony fish and *I. argentinus* biomasses were larger. Elasmobranches were more abundant on the outer shelf than on the upper slope and in the southern area of the study.

Overall density was 27% higher in the summer-autumn survey. On the outer shelf, it was much higher in the south, particularly in winter-spring. On the upper slope, the difference was smaller but densities were still higher in the south. Both biomass and densities of commercially valuable fishes from the outer shelf were lower than those on the upper slope (Table 6).

Illex argentinus

The mean mantle length of the Argentine short-fin squid *Illex argentinus* landed by commercial fishing was over 160 mm for males and 180 mm for females (Haimovici *et al*., 2006a), corresponding to approximately 100 g. In the surveys, 83% (in weight) of the

Table 3 Hoenig (1983) equation-based estimates of the natural mortalities of the main commercially important species caught in the REVIZEE bottom trawl surveys on the outer-shelf and upper-slope in southern Brazil (2001-2002). Other fishes include Elasmobranchii, Sciaenidae and Paralichthyidae.

Tabla 3. Mortalidad natural, estimada mediante la ecuación de Hoenig (1983), de las principales especies de interés comercial capturadas en los muestreos de arrastre de fondo del programa REVIZEE en la plataforma externa y talud superior del sur de Brasil (2001-2002). "Other fishes" incluye Elasmobranchii, Sciaenidae and Paralichthyidae.

Species	% of the catch	Maximum age	Mortality estimate	Reference for maximum age
Urophycis mystacea	9	14	0.30	Haimovici *et al*. (2006b)
Merluccius hubbsi	17	12	0.35	Vaz-dos-Santos & Rossi-Wongtschowski (2005)
Lophius gastrophysus	7	18	0.23	Lopes (2005)
Zenopsis conchifera	19	15	0.28	Duarte-Pereira *et al*. (2005)
Polymixia lowei	25	10	0.42	Rossi-Wongtschowski (*pers. observ*.)
Other fishes	23	10 - 40	0.20	

Table 4. Total catch and catch in hauls with mean weight over minimum marketable weight (MMW) of the commercially valuable species in the REVIZEE bottom trawl surveys on the outer shelf and upper slope in southern Brazil (2001-2002).

Tabla 4. Captura total y en los lances en los cuales el peso medio fue superior al menor peso comercializable (MMW) de las especies de interés comercial en los levantamientos pesqueros del programa REVIZEE realizados en la plataforma externa y talud superior del sur de Brasil (2001-2002).

	Under MMW (kg)	Over MMW (kg)	% of total catch
Teleosts			
Polymixia lowei	383	3,445	19.8
Zenopsis conchifera	1,240	2,553	14.7
Merluccius hubbsi	411	2,316	13.3
Urophycis mystacea	24	1,292	7.4
Lophius gastrophysus	0	1,113	6.4
Umbrina canosai	51	651	3.7
Prionotus punctatus	26	430	2.5
Paralichthys isosceles	145	230	1.3
Trichiurus lepturus	1,734	169	1.0
Genypterus brasiliensis	3	163	0.9
Beryx splendens	178	58	0.3
Helicolenus lahillei	996	0	0.0
Trachurus lathami	536	0	0.0
Ariomma bondi	479	0	0.0
Thyrsitops lepidopoides	341	0	0.0
Loligo plei	175	0	0.0
Mullus argentinae	118	139	0.8
Other teleosts	7,796	0	0.0
Elasmobranches			
Atlantoraja cyclophora	0	461	2.6
Atlantoraja platana	0	390	2.2
Squalus mitsukurii	0	349	2.0
Squalus megalops	39	167	1.0
Mustelus schmitti	23	152	0.9
Atlantoraja castelnaui	0	165	0.9
Squatina argentina	0	156	0.9
Squatina guggenheim	0	147	0.8
Squatina punctata	0	32	0.2
Cephalopods			
Illex argentinus	598	2,841	16.3
Total	15,297	17,418	100.0

squids caught were over this size (Table 5). In the winter-spring survey, commercial-sized squids were concentrated between Solidão and Cabo de Santa Marta Grande at over 400 m depth, with an estimated biomass of 8,912 ton (± 106%). In summer-autumn, squid biomass increased sharply to 28,647 ton (± 62%) and larger densities were found in the 300 to 600 m depth range between Chuí and Cabo de Santa Marta Grande (Fig. 2). Specimens under the commercial size occurred mainly in the upper 300 m (Haimovici *et al*., 2008). Wide confidence intervals for the biomass were due to large catches in only a few hauls. The aggregated nature of the distribution of this school-forming squid was also observed in acoustic surveys by Madureira *et al*. (2005), who estimated total biomasses of *I. argentinus* as high as 31,742 ton in April and May 1997.

As are all species of the genera, *I. argentinus* is a fast-growing, short-lived species with highly variable interannual abundance (Rodhouse *et al*., 1998); for a review, see Perez *et al*. (2009). Recorded commercial landings in 2002 reached 2,601 ton, far higher than in the previous and following years (Fig. 3). It is very likely that the high proportion of *I. argentinus* in the catch of the autumn 2002 survey corresponded to an exceptionally high recruitment.

Urophycis mystacea

The size distribution of commercial landings of the gulf-hake *Urophycis mystacea* in southern Brazil included fishes over 100 g and 250 mm TL (Haimovici *et al*., 2006b). In the surveys, 98% (in weight) of the gulf-hake caught exceeded this size (Table 5). This species does not seem to form dense schools; rather, it was caught in a large number of hauls but without outstanding individual catches. For this reason, biomass estimates were relatively precise compared with those of other species: 8,583 ton (± 24%) in winter-spring and 11,204 ton (± 41%) in summer-autumn (Table 3). Larger catches occurred in the southern area in both seasons at depths over 150 m and further north at depths over 300 m (Fig. 2).

Urophycis mystacea is a relatively slow-growing species that lives at least 14 years and reaches sexual maturity between three and six years (Martins & Haimovici, 2000; Haimovici *et al*., 2006b). This species was part of the bycatch of the bottom longline fishery that has targeted the wreckfish *Polyprion americanus* since the 1970s (Haimovici *et al*., 2003). Landings statistics of *Urophycis brasiliensis* and *U. mystacea* were not differentiated in most states. Pooled landings of both species were a little above 2,000 ton from 1996 to 2000, increased sharply to 6,013 ton and 8,192 ton in 2002, and decreased slowly in the follo-

Table 5. Biomass estimates of the commercial size fraction of the important species in the REVIZEE bottom trawl surveys on the outer shelf and upper slope in southern Brazil (2001-2002) in winter-spring (w-s) and summer-autumn (s-a). The 90% confidence intervals are shown as percentage of the estimated biomasses

Tabla 5. Biomasas estimadas de las especies y tamaños de interés comercial en los levantamientos de arrastre de fondo del programa REVIZEE realizados en la plataforma externa y talud superior del sur y sudeste de Brasil (2001-2002) en invierno-primavera (w-s) y verano-otoño (s-a). El intervalo de 90% de confianza está expresado como porcentaje de la biomasa.

Depth ranges Areas		Shelf 100-199 m 92,555 km^2	Upper slope 200-600 m 42,168 km^2	Total area 100-600 m 134,724 km^2	± IC 90% biomass
Total commercial biomass	w-s	92,398	74,795	167,193	22%
	s-a	69,167	96,292	165,460	25%
Illex argentinus	w-s	5	8,907	8,912	106%
	s-a	0	28,647	28,647	62%
Merluccius hubbsi	w-s	3,079	11,376	14,455	43%
	s-a	3,111	12,968	16,078	32%
Zenopsis conchifera	w-s	6,456	21,760	28,216	61%
	s-a	242	20,760	21,003	87%
Urophycis mystacea	w-s	3,049	5,535	8,583	24%
	s-a	5,453	5,751	11,204	41%
Polymixia lowei	w-s	0	14,854	14,854	85%
	s-a	15	17,713	17,728	69%
Lophius gastrophysus	w-s	9,993	6,002	15,994	27%
	s-a	5,213	5,758	10,971	23%

Table 6. Mean densities (kg km^{-2}) of pooled commercially important species in the REVIZEE bottom trawl surveys on the outer shelf and upper slope in southern Brazil (2001-2002).

Tabla 6. Densidades medias (kg km^{-2}) de las especies de importancia comercial en los muestreos pesqueros de arrastre de fondo del Programa REVIZEE realizados en la plataforma externa y talud superior del sur de Brasil (2001-2002).

	Latitudinal strata A and B		Latitudinal strata C and D		All latitudinal strata		Total
	100-199 m	200-600 m	100-200 m	200-600 m	100-200 m	200-600 m	
Area (km^2)	31,952	38,719	37,655	44,029	69,607	82,749	152,355
Winter-Spring surveys (2001-2002)	2,143	1,059	0,636	0,767	0,829	0,904	0,904
Summer-Autumn surveys (2002)	1,485	1,642	0,577	0,743	0,782	1,164	1,164

wing years (Fig. 3). If we assume that landings of *U. brasiliensis* remained stable at 2,000 ton, those of *U. mystacea* peaked at approximately 6,000 ton in 2002 and decreased in the following years.

Merluccius hubbsi

Commercial landings of the Argentine hake *Merluccius hubbsi* in southern Brazil considered fish over 100 g and 250 mm (Haimovici *et al*., 1993). In the

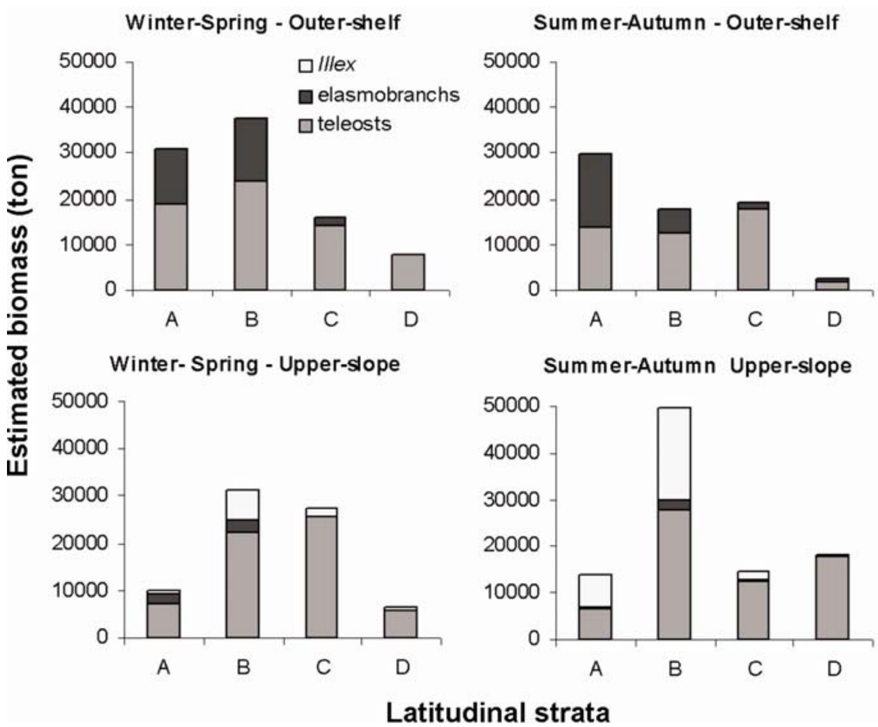

Figure 2. Estimated biomass of marketable species (tons) on the outer shelf and upper slope in the bottom trawl REVIZEE surveys in southern Brazil (2001-2002) (A-D are latitudinal strata defined in the text).

Figura 2. Biomasa estimada de especies de valor comercial (ton), en los levantamientos de arrastre de fondo del programa REVIZEE en el sur de Brasil realizados en la plataforma externa y talud superior (2001-2002). (A-D estratos latitudinales definidos en el texto).

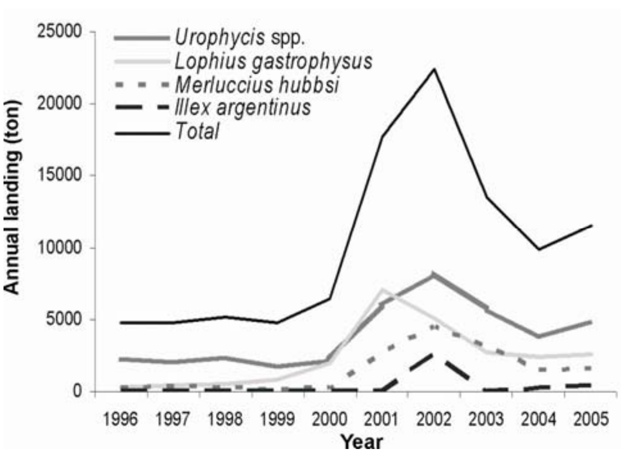

Figure 3. Annual landings (tons) of the main species in bottom trawl and bottom gillnet catches on upper-slope of southern Brazil (Valentini & Pezzuto, 2006; IBAMA, 2007).

Figura 3. Desembarques anuales (ton) de las principales especies demersales del talud superior de la flota de arrastreros de fondo y de enmalle de fondo de la pesca en el sur de Brasil (Valentini & Pezzuto, 2006; IBAMA, 2007).

surveys, 85% (in weight) of the species caught were over this size. Biomass estimates were 14,445 ton (± 43%) in winter-spring and 16,078 ton (± 32%) in summer-autumn, with nearly 3/4 caught on the upper slope (Table 5). The largest concentrations of this species were found in the southern and northern parts of the study area at depths over 300 m (Fig. 4). However, smaller than commercial-sized specimens were far more abundant numerically and occurred in catches at all latitudes and in all depth ranges, particularly on the outer shelf (Haimovici *et al*., 2008).

Annual landings of Argentine hake were below 300 ton until 2001; these were fished mostly off Rio de Janeiro and in Rio Grande do Sul in the years with a strong influence of cold waters from the Malvinas Current (Haimovici, 1997). Landings increased sharply in 2001 to 2,654 ton, peaked at 4,479 in 2002, and decreased to 1,565 by 2005 (Fig. 3).

Polymixia lowei

Commercial landings of the beardfish *Polymixia lowei* are rare and no information is available on its marketing. Occasionally, trawlers fishing on the upper slope

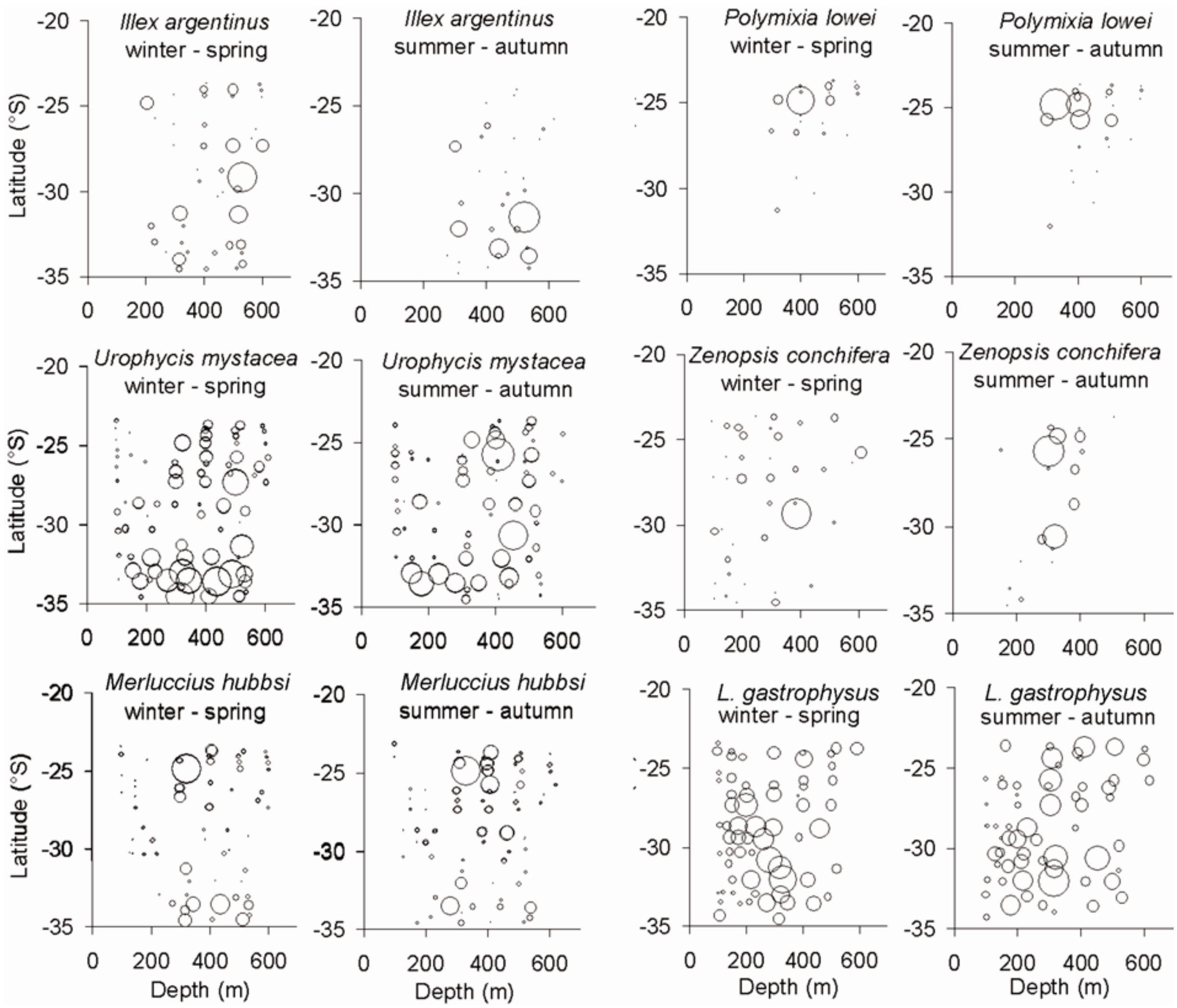

Figure 4. Densities (kg km^{-2}) of the commercial size catches of *Illex argentinus*, *Urophycis mystacea, Merluccius hubbsi, Polymixia lowei*, *Zenopsis conchifera* and *Lophius gastrophysus* captured in winter-spring (left) and summer-autumn (right) REVIZEE surveys (2001-2002) by depth and latitude in southern Brazil. For each species and survey, the diameters of the largest circles represent the largest densities.

Figura 4. Densidades (kg km^{-2}) de ejemplares de tamaño comercial de *Illex argentinus*, *Urophycis mystacea, Merluccius hubbsi, Polymixia lowei*, *Zenopsis conchifera* y *Lophius gastrophysus* capturados en invierno-primavera (izquierda) y verano-otoño (derecha) por profundidades y latitudes en los muestreos pesqueros del programa REVIZEE en el sur de Brasil (2001-2002). Para cada especie los diámetros de los círculos representan las mayores densidades.

obtain large catches of specimens over 100 g and 200 mm total length; these specimens bring low prices when landed because, according to the fishermen, they have too many spines. In the surveys, 91% (in weight) of the *P. lowei* caught were over this size and the potential commercial biomass estimates were 14,827 ton (± 63%) in winter-spring and 17,721 ton (± 85 %) in summer-autumn (Table 5). Wide confidence intervals occurred due to large catches in a few hauls; this species was very abundant in a few hauls at depths over 300 m between 23ºS and 26ºS (Fig. 4). Specimens smaller than the commercial size were more frequent to the south of Cabo de Santa Marta Grande in the 150 to 300 m depth range and at all latitudes between 300 and 400 m (Haimovici *et al.*, 2008). The maximum total length of this species is under 300 mm and its biology is poorly known.

Zenopsis conchifera

The silvery John dory *Zenopsis conchifera* is a benthopelagic species with low commercial value that is caught incidentally by large foreign trawlers on the upper slope (Perez *et al*., 2003). Due to its laterally compressed body and large dermal bones along the body, only large specimens are adequate for filleting. Thus, only samples in which the mean weight of the fishes was over 350 g were considered for biomass estimates with commercial value. In the surveys, 67% (in weight) of the *Z. conchifera* caught were over this size and biomass estimates were 28,216 ton (± 61%) in winter-spring and 21,003 ton (± 87%) in summer-autumn (Table 5). As large catches occurred in only a few hauls, the estimated confidence intervals of the biomass were large. Higher densities of commercial-sized *Z. conchifera* were found at 300 to 400 m depth in all seasons in Cabo de Santa Marta Grande region and also along Ilha Bela in summer-autumn (Fig. 4). Specimens smaller than the commercial size occurred mostly over the shelf break (Haimovici *et al*., 2008).

Lophius gastrophysus

The monkfish *Lophius gastrophysus* was the fish with the highest commercial value among the frequently caught species. This fish has a very large head and specimens under 350 g are not considered to be of commercial interest and are not usually landed (Schwingel & Andrade, 2002). As few of the *L. gastrophysus* caught were smaller than this size, all their catches were considered to have commercial value. The winter-spring biomass was estimated to be 15,994 ton (± 27%), with 9,993 ton caught on the outer shelf and 6,002 ton on the upper slope; the summer-autumn biomass was 10,971 ton (± 23%), of which 47.5% were caught on the outer shelf (Table 5). The monkfish was caught along all the study area in both surveys. Larger densities were found in both surveys between Conceição and (area B) and also between Cabo de Santa Marta Grande and Cabo Frio (areas C and D) in summer-autumn (Fig. 4). The smallest specimens, of low commercial value, occurred mostly on the outer shelf and shelf break and the largest ones on the upper slope at depths between 250 and 550 m (Haimovici *et al*., 2008**)**.

The monkfish was exploited on the outer shelf of Rio de Janeiro by the local industrial fishing fleet for decades. Landings increased sharply due to the foreign gillnet fleet that operated from 1999 to 2002 all along the upper slope of southern Brazil (Perez *et al*., 2002; 2005). Total landings peaked at 7,094 ton in 2001 and 5,129 ton in 2002 and decreased to around 2,500 ton in the later years (Fig. 3).

Fishing potential estimates

Gulland's formula was used for the first appraisal of the potential yield of the demersal fish resources vulnerable to bottom trawls on the outer shelf and upper slope of southern Brazil. This approach is not adequate for short-lived species with highly variable recruitment and abundance such as *Illex argentinus*. Therefore, the values of this species were not included in the analysis.

The biomasses estimated from the surveys cannot be considered to be unexploited stocks (Bo) since the outer shelf has been fished for years and landings of Argentine hake, gulf-hake, and monkfish, which were low until 2000, increased to around 13,500 ton in 2001 and 15,800 in 2002 (Fig. 3). Furthermore, the gulf-hake has been caught as bycatch of the bottom longline fishery since the 1970s (Peres & Haimovici, 1998; Haimovici *et al*., 2004). Similarly, elasmobranches have been caught on the outer shelf by diverse gears since the 1980s (Vooren & Klippel, 2005). Thus, our best choice for the exploitable biomass (exB_o) was the biomass estimate of commercially valuable fishes in the 2001 winter-spring survey, excluding *I. argentinus* (149,369 ton) and including the recorded catches of the most important species in 2001 (13,500 ton), for a total of around 165,000 ton.

The potential yield of commercially valuable species was: $Y = 0.4 \cdot 0.31 \cdot 165{,}000$ ton = 20,460 ton. However, 12.4% of the total commercial size of marketable fish biomass were elasmobranches (*Squatina* spp. and other legally protected species), which have slow growth rates and low reproductive potential. Two potentially marketable species, *Polymixia lowei* and *Zenopsis conchifera*, which represented 18.3%, are presently discarded or have very little value. Thus, only three of the species (Argentine hake, gulf-hake, monkfish) are, at present, targeted by commercial fishing on the upper slope and their potential yield may provide a more realistic estimate of the fishing potential of the demersal fishes vulnerable to trawls in this environment. Their pooled biomass in the winter-spring survey was 39,033 ton. When added to the 13,500 ton of these species caught in 2001, the total was 53,433 ton. Their common natural mortality was also estimated at 0.31 and their potential yield was: $Y = 0.4 \cdot 0.31 \cdot 53{,}433$ ton = 6,626.

DISCUSSION

The overall picture revealed by the surveys is that the demersal fish densities and fishery potential of the outer shelf and upper slope of southern Brazil is lower than that of the inner shelf and the same depth ranges farther south off Uruguay and Argentina but higher than in central and northeastern Brazil (MMA, 2006). This result is not unexpected since it agrees with the differences in productivity of the corresponding environments (Castello & Odebrecht, 2001). The influence of the nearby richer waters to the south is corroborated by the higher densities in the southern half of the study area. This pattern was also observed for fishes vulnerable to bottom longlines (Haimovici *et al*., 2004). However, the lower biomass and densities of commercially valuable fishes on the outer shelf (as compared to the upper slope; Fig. 3) may have another explanation: very intense fishing on the shelf over the last forty years could have reduced the abundance of species occurring on both the inner and outer shelf such as sciaenids, red porgy, flatfishes, and elasmobranches (Haimovici, 1997; Haimovici *et al*., 2006c). Commercially valuable species have also been fished on the upper slope but for a far shorter period of time.

The pooled recorded catch of Argentine hake, gulf-hake, and monkfish was 13,761 ton in 2001, 15,800 ton in 2002, and 9,413 ton in 2003. These values were respectively 107%, 138%, and 42% above the common potential yield, estimated to be 6,625 ton. This may have reduced their exploitable biomass substantially. In fact, reported landings of Argentine hake, gulf-hake, and monkfish in later years decreased to a fraction of those from 2001-2002. In part, this decrease coincided with the exit of most of the foreign fishing vessels in the former years (Perez *et al*., 2009).

The estimates of the potential yield presented in this paper were subject to a considerable bias. Underestimates of the swept area due to both gear and fish behavior may have led to underestimates of the standing biomass. Additionally, incomplete landing reports affected the proposed correction factor. Considering that all three species were already exploited before the surveys and based on life story parameters, Perez (2006) concluded that sustainable yields for Argentine hake, gulf-hake, and monkfish should not be over 10% of the virginal exploitable biomass. His estimate does not differ substantially from our results based on bottom trawl survey biomass estimates.

Presently, over 700 industrial fishing boats are operating along southern Brazil (unpublished data, Fisheries and Aquaculture Ministry), including trawlers and gill-net fishing boats. Despite being smaller than the foreign fishing boats and having poor fishing and processing technology, many of these could fish on the upper slope. However, the cost-benefit relationship does not appear to be attractive to most of them. For this reason, we believe that the abundance of these species and their fishing potential is likely to be far lower than expected in previous years and unlikely to have been as high as expected or higher than that reported in this paper.

Theoretically, the fourth important fishing resource, *Illex argentinus*, with an estimated biomass of over 26,000 ton in the summer-autumn 2002 survey, could yield over 10,000 ton if an escape of 40% was allowed, as recommended in the literature (Beddington, 1990). However, this yield would demand a very high fishing effort in a very short fishing season, which is not economically feasible. In fact, landings of the short-fin Argentine squid only reached 2,500 ton in 2002 and were far lower in the previous and following years (Fig. 3). If managed, *I. argentinus* could be fished opportunistically, with high yields in some years and none in most of the others.

The surveys did not reveal substantial new fishing resources vulnerable to bottom trawls between 100 and 600 m depth and showed limited potential of those already exploited; in fact, this potential was substantially lower than that on the inner shelf. Therefore, this environment cannot be considered to be a "new frontier" for the expansion of fishing, and exploitation must be carefully controlled to avoid overfishing.

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