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Review

Deep-water fisheries in Brazil: history, status and perspectives

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ABSTRACT. The recent development of deep-water fisheries off Brazil is reviewed from biological, economic, and political perspectives. This process has been centered in the southeastern and southern sectors of the Brazilian coast (19°-34°S) and was motivated by the overfishing of the main coastal resources and a government-induced vessel-chartering program. Shelf break (100-250 m) operations by national hook-and-line and trawl vessels intensified in the 1990s. Around 2000-2001, however, foreign-chartered longliners, gillnetters, potters, and trawlers started to operate in Brazilian waters, leading the occupation of the upper slope (250-500 m), mostly targeting monkfish (*Lophyus gastrophysus*), the Argentine hake (*Merluccius hubbsi*), the Brazilian codling (*Urophycis mystacea*), the wreckfish (*Polyprion americanus*), the Argentine short-fin squid (*Illex argentinus*), the red crab (*Chaceon notialis*), and the royal crab (*Chaceon ramosae*). Between 2004 and 2007, chartered trawlers established a valuable fishery on deep-water shrimps (family Aristeidae), heavily exploiting the lower slope (500-1000 m). Total catches of deep-water resources varied annually from 5,756 ton in 2000 to a maximum of 19,923 ton in 2002, decreasing to nearly 11,000 ton in 2006. Despite intensive data collection, the availability of timely stock assessments, and a formal participatory process for the discussion of management plans, deep-water stocks are already considered to be overexploited due to limitations of governance.

Keywords: deep-water fishery, stock assessment, fishery management, southwest Atlantic, Brazil.

Pesquerías de aguas profundas en Brasil: historia, situación actual y perspectivas

RESUMEN. El reciente desarrollo de la pesca profunda en Brasil fue revisado desde perspectivas biológicas, económicas y políticas. Este proceso se ha centrado en los sectores sureste y sur de la costa de Brasil (19°-34°S) y fue motivado por la sobrepesca de los principales recursos costeros en conjunto con una política gubernamental de arriendo de buques pesqueros. Las operaciones de pesca sobre el borde de la plataforma (100-250 m) por buques palangreros y arrastreros se intensificaron en la década del 90. Sin embargo, entre 2000 y 2001 empezaron a operar buques arrendados para la pesca con palangre, red de enmalle, nasas y arrastre en aguas brasileras y lideraron el proceso de ocupación del talud superior (250-500 m) dirigido principalmente a la captura del rape (*Lophyus gastrophysus*), merluza argentina (*Merluccius hubbsi*), brótola de profundidad (*Urophycis mystacea*), chernia (*Polyprion americanus*), calamar argentino (*Illex argentinus*), cangrejo rojo (*Chaceon notialis*) y cangrejo real (*Chaceon ramosae*). Entre 2004 y 2007, buques arrendados establecieron una valorada pesquería de langostinos de profundidad (Familia Aristeidae) y explotaron intensamente los fondos del talud inferior (500-1000 m). Las capturas totales de recursos de aguas profundas variaron anualmente de 5.756 ton en 2000 a un máximo de 19.923 ton in 2002, decayendo a cerca de 11.000 ton en 2006. No obstante, que fueron recolectados datos pesqueros en forma intensas, estuviesen disponibles oportunamente evaluaciones de stock y se haya llevado a cabo un proceso formal de discusión participativa de planes de manejo para estas pesquerías, los stocks de aguas profundas han sido considerado en situación de sobrepesca debido a limitaciones de gobernabilidad.

Palabras clave: pesca profunda, evaluación de stock, manejo pesquero, Atlántico sudoccidental, Brasil.

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INTRODUCTION

The first records of demersal fishing beyond the continental shelf waters of the Atlantic date back to the 1960s when Soviet trawlers began to operate on the northern mid-Atlantic ridge (Troyanovsky & Lisovsky, 1995). This deep-water fishery, however, throve from the 1980s onwards as the abundance of shelf resources declined greatly and important technological and market limitations were overcome (Piñeiro *et al*., 2001; Gordon *et al*., 2003). Headed by French trawlers, a multispecies, deep-water fishery was established at depths of 800 to 1600 m during the 1990s, mostly in the northeast Atlantic (Charuau *et al.*, 1995; Iglesias & Paz, 1995; Gordon, 2001; Piñeiro *et al*., 2001; Lorance & Dupuoy, 2001). Nearly ten years later, fishing activity on slope grounds began to emerge as a pattern off the Brazilian coast in the tropical and subtropical southwest Atlantic (Perez *et al*., 2003).

The Brazilian Economic Exclusive Zone (EEZ) encompasses an area of 3.5 million km^2, mostly bathed by southwest Atlantic waters; roughly 25% (911,000 km^2) of this area is occupied by the continental shelf. Since its early development in the 1960s, a large-scale demersal fishery has been restrained to the inner shelf and is sustained by a few coastal resources, most notably shrimps (*i.e. Farfantepenaeus* spp.), spiny lobsters (*Panulirus* spp.), and groundfish of the families Sciaenidae (*i.e. Micropogonias furnieri*, *Cynoscion* spp., *Macrodon ancylodon*, *Umbrina canosai*), Pimelodidae (*i.e. Brachyplatystoma vaillantii*), Lutjanidae (*i.e. Lutjanus* spp.), and others (see Paiva *et al*., 1996 and Haimovici *et al*., 2006a for reviews). For nearly 40 years, deep-water fishing was essentially scientific or restricted to hand-line operations over slope grounds and seamounts targeting rockfish (Paiva *et al*., 1996; Peres & Haimovici, 1998). In addition, Soviet trawlers explored the Martin Vaz (20-21°S, 36-39°W) and Rio Grande Rise (28°-35°S, 20°-38°W) seamounts in the 1980s (Clark *et al*., 2007). Despite a few government efforts to map the ocean floor and assess potential resources, commercial fishing was generally considered unproductive and uneconomical beyond the shelf break (Haimovici *et al*., 1994; Haimovici, 2007).

At the end of the 1990s, a new scientific program set out to assess fishing potential in the Brazilian EEZ (REVIZEE Program; Anon, 2006a). By then, however, fishing was already expanding to the outer continental shelf and slope due to economic losses experienced by the industrial fleet, both overcapitalized and facing major reductions in the abundance of their main targets (Perez *et al.*, 2001). Concurrent to this natural process and to the REVIZEE scientific exploration, in 1998, the Brazilian fishing authorities decided to catalyze the commercial occupation of the EEZ through a foreign vessel-chartering program. This program allowed national companies to operate in Brazilian waters with foreign vessels specialized in oceanic and deep-water fisheries provided that (a) these operations were intensely monitored by observers and satellite VMS (Vessel Monitoring System) and (b) that the data generated on commercial stocks, fishing and processing technology, and international market opportunities were made available to the government in order to subsidize a national policy on fishing in deep and oceanic areas. From 2000 onwards, unprecedented commercial exploration began of fishing grounds 200 to 1000 m deep, revealing the existence of profitable resources, efficient technologies, and international market demands (Perez *et al.*, 2003). During the past six years, however, deep-water fishing has also come into conflict with traditional fishing practices and raised great concerns as to the sustainability of fragile stocks and deep ocean habitats as a whole.

The present review intends to describe the development of the deep-water fishery off the Brazilian coast from biological, economic, and political perspectives, addressing the lessons learned in this new phase of Brazil's fishing history and analyzing its prospects for the future.

MONITORING AND DATA SOURCES

The deep-water fishery developed off the coast of Brazil could possibly be the most intensely monitored fishing activity in the country. Besides the use of official data collection instruments (*i.e.* logbooks), observers and VMS programs were implemented for the first time in order to enforce the legal obligations of the chartered fleet. These programs were formerly structured and conducted as part of a scientific cooperation agreement established between the Brazilian government and the University of "Vale do Itajaí" (Santa Catarina, southern Brazil). In 2005, after a period of development and adjustments, these programs have become national policies and are incorporated into the agenda of the Special Secretariat of Aquaculture and Fishery, the Ministry of the Environment and Natural Resources, and the Brazilian Navy.

Between 2000 and 2007, 311 fishing trips of the chartered fleet were fully observed and monitored by satellite VMS. Data on fishing position, depth, and catch/bycatch from over 35,800 fishing sets conducted by trawlers, bottom gillnetters, bottom longliners, and potters were recorded and stored in a data bank (Table 1). Observers also collected biological samples of these catches and recorded biometric data (size, sex, and maturity, depending on the species) for around 713,810 individuals of the main target species (Table 1). Supplementary data was obtained during the same period from landings of deep-water operations conducted in the harbors of Santa Catarina State by the national fleet as reported by skippers in logbooks or during harbor interviews at the time of the landings. These data were extracted from the Santa Catarina State industrial fishing statistical service (www.univali.br/gep) and included biometric data taken from national gillnetters, stern trawlers, and double rig trawlers. Parallel sources of fishing and biological data have also originated from surveys conducted as part of the REVIZEE program (*e.g.*, Cergole *et al.*, 2005; Costa *et al.*, 2005; Rossi-Wongtschowski *et al.*, 2006) and fishery statistical systems operated in the states of Rio Grande do Sul, São Paulo, and Rio de Janeiro.

Because deep-water fishing activity off the Brazilian coast is relatively recent, fishing data time-series have been of limited use for stock assessments. This limitation has been compensated, however, by the availability of a robust geo-referenced catch, effort, and biological data base provided by observed commercial operations and scientific surveys. In addition, in the laboratory, biological samples have further provided detailed information on the reproduction, age, and growth of some studied species. This combination of information has been critical for building an empirical framework for recommending, discussing, and implementing management plans for deep-water resources (Anon, 2005, 2006b, 2007).

DEEP-WATER FISHING GROUNDS

The continental margin off the Brazilian coast has been subdivided into five sectors: northern, northeastern, central, southeastern, and southern (Fig. 1) (Rossi-Wongtschowski *et al.*, 2006). The continental shelf is wider in the northern, southeastern, and southern sectors, where it has been intensely occupied and exploited by traditional demersal fisheries (mostly trawling) during the past 40 years (see Haimovici *et al.*, 2006a for review). Deep-water fishing activities have concentrated on the slope grounds of the southeastern and southern sectors. This area is highly undulated and morphologically characterized by the occurrence of several seaward protrusions and submarine canyons between 100 and 1000 m depth (Figueiredo Jr. & Madureira, 2004). The depth gradient is gentle (1:132 – 1:190) along a large central feature known as the Brazilian Bight between 29°S and 24°S, becoming steeper north of 23°S (1:10) and south of 32°S (1:13) (Figueiredo Jr. & Tessler, 2004) (Fig. 1). The slope floor is generally covered by mud, but there are areas where nodules of calcareous algae and beach rocks concentrate, predominantly north of 26°S. In addition, deep-water coralline reefs have been mapped along the lower slope of southeastern sector (20°-24°S), some of them hundreds of meters long, tens of meters wide, and up to 15 to 20 m high (see Pires, 2007 for review).

Seamounts have been of secondary importance for deep-water fishing activity off the Brazilian coast. These structures ascend from the slope and ocean basin floor throughout the Brazilian EEZ (Rossi-Wongtschowski *et al.*, 2006). Particularly dense and accessible seamount concentrations are found in the central and northeastern sectors, most notably as part of the Ceará Plateau, Fernando de Noronha Chain, and Vitória-Trindade Chain. Hand-line fishing and trawling have been reported on seamounts of these chains (Fonteles-Filho & Ferreira, 1987; Martins *et al.*, 2005; Clark *et al.*, 2007). In 1982-1984 and 2000-2002, Soviet/Russian vessels also reported trawling on seamounts of the Rio Grande Rise area, outside the Brazilian EEZ (Clark *et al.*, 2007).

FLEET DYNAMICS

Deep-water fisheries off Brazil rely on four basic fishing gears: hook-and-line (operated as hand-lines, vertical lines, and long-line settings), bottom gillnets, pots, and bottom trawls (Perez *et al.*, 2003). The national fleet participated in the occupation of deep areas basically with longliners and trawlers, the former a practice recorded almost along the entire Brazilian coast at least since the 1960s (Peres & Haimovici, 1998) and the latter expanding to slope grounds by the end of the 1990s (Perez *et al.*, 2001) (Table 2). Chartered vessels operated with both gears mentioned above but also introduced the use of deep-water gillnets and traps in the Brazilian EEZ (Perez *et al.*, 2003; Wahrlich *et al.*, 2004). Besides fishing technology, the deep-water chartered vessels also introduced other novel technological practices to the national vessels, including on board fish handling, processing, packing, and freezing (Wahrlich *et al*, 2004). Absorbing these practices were also important steps allowing the national industry to access EU and Asian seafood markets in the short term (Soares & Scheidt, 2005). Chartered fishing operations intensified from 2000 onwards, becoming gradually scarce between 2004 and

Table 1. Summary of Brazilian deep-water fishing data collected between 2000 and 2007. Chartered fleet data were collected by on board observers for all the fishing operations conducted during this period. National fleet data originated from logbooks and interviews with skippers in the harbors of Santa Catarina State. S. trawl: stern trawl; D.R. trawl: double rig trawl. * data from the national fleet includes coastal and deep-water resources.

Tabla 1. Resumen de los datos de pesca en aguas profundas de Brasil, obtenidos entre 2000 y 2007. Los datos de la flota arrendada fueron obtenidos por observadores a bordo en todas las operaciones de pesca realizadas en ese periodo. Los datos de la flota nacional provienen de las bitácoras de pesca y entrevistas a los capitanes de buques pesqueros en los puertos del Estado de Santa Catarina. S. trawl: arrastreros por popa; D.R. trawl: arrastreros duplos. *datos de la flota nacional que también incluye capturas de recursos costeros.

	Chartered fleet					National fleet				Total
Fishing Gear	Pot	Gillnet	Longline	S. trawl	Total	Gillnet	S. trawl	D.R. trawl	Total	
Number of vessels	8	10	4	15	37	11	42	374	416	453
Number of monitored trips	111	79	7	114	311	122	878	10,840	11,718	12,029
Number of monitored hauls	10,037	3,947	476	21,400	35,860	-	-	-	-	35,860
Total landed catch (t)*	6,601	5,770	300	8,988	21,659	1,411	32,054	146,726	180,191	201,850
Number of sampled inds.										
Lophius gastrophysus	-	157,656	-	55,268	212,924	4,492	1,238	11,237	16,967	229,891
Merluccius hubbsi	-	-	-	15,238	15,238	-	201	2,731	2,932	18,170
Urophycis mystacea	-	-	-	-	-	904	225	2,855	3,984	3,984
Zenopsis conchifera	-	-	-	20,769	20,769	-	-	-	-	20,769
Polyprion americanus	-	-	190	-	190	-	-	-	-	190
Epinephelus nigritus	-	-	-	1,271	1,271	-	-	-	-	1,271
Aristaeopsis edwardsiana	-	-	-	161,408	161,408	-	-	-	-	161,408
Aristaeomorpha foliacea	-	-	-	76,220	76,220	-	-	-	-	76,220
Aristeus antillensis	-	-	-	25,977	25,977	-	-	-	-	25,977
Chaceon notialis	65,645	-	-	-	65,645	-	-	-	-	65,645
Chaceon ramosae	126,518	1,543	-	1,988	130,049	-	-	-	-	130,049
Illex argentinus	-	-	-	4,119	4,119	-	787	4,492	5,279	9,398
Total (ton)					713,810				29,162	742,972

Source: UNIVALI

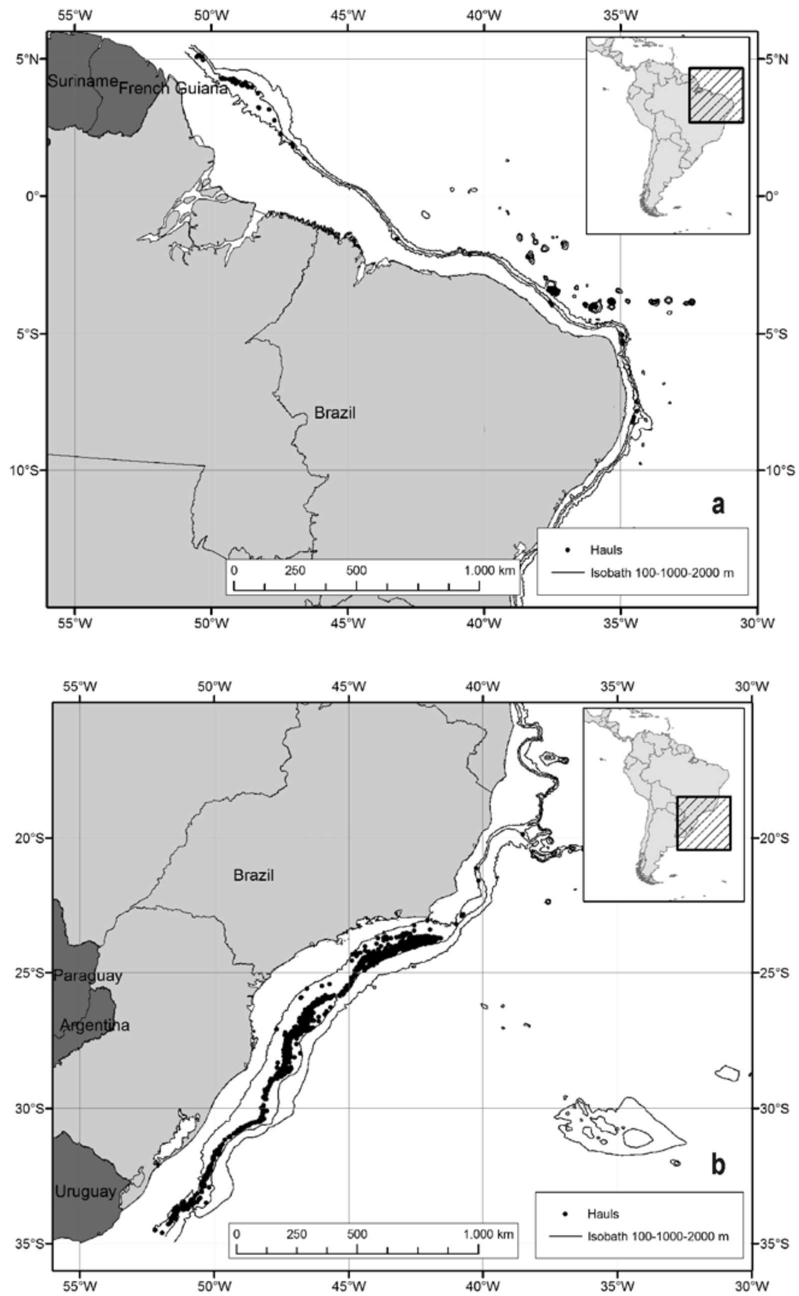

Figure 1. Continental margin off Brazil, SW Atlantic. a) northern and northeastern sectors, b) central, southeastern, and southern sectors. Dots represent fishing hauls conducted by the chartered trawlers. Chartered gillnetters, potters, and longliners operated in the same slope areas as those occupied by trawlers (see the lower map) but are not represented for clarity.

Figura 1. Margen continental de Brasil, Atlántico sudoccidental. a) sectores norte y nordeste, b) sectores centro, sureste y sur. Los puntos representan lances de pesca realizados por arrastreros arrendados. Los buques de pesca de la flota arrendada que operan con enmalle, nasas y palangres operan en la misma área que los arrastreros, representados en el mapa inferior, pero no fueron incluidos para mayor claridad.

2007 as many foreign vessels moved away from the Brazilian EEZ. During this period, slope areas were shared by national and foreign vessels, the former predominating since 2004 (Table 2).

Deep-water fishing operations of the national fleet involved the occupation of the shelf break (100-250 m) and upper slope grounds (250-500 m) of the southeastern and southern sectors (Perez *et al.*, 2002a; Perez & Pezzuto, 2006). These patterns were attributed to the (a) depth-limitations of fishing gear operations, (b) proximity of traditional fishing grounds, (c) proximity of known markets for the country's large urban centers (*i.e.* São Paulo, Rio de Janeiro), (d) limited autonomy at sea, (e) low-capacity fish conservation systems, and (f) latitudinal restrictions of fishing authorizations. These factors did not influence the chartered fleet, which, in contrast, was required to occupy areas off the shelf break (> 200 m) and explored a variety of habitats in a wide latitudinal and depth range (Fig. 2). In general, however, most operations concentrated south of 18°S; 96% of the hauls were conducted in the central, southeastern, and southern sectors (Table 3). Operations started off over the shelf break in 2000, rapidly expanding to completely occupy the upper slope between 2001 and 2002. Thereafter, fishing began on the lower slope (> 500 m) grounds, where the majority of deep-water fishing has taken place, centered on the 750 m isobath. By the end of 2007, over 97% of all deep fishing hauls conducted by chartered vessels off Brazil occurred below 250 m depth; the lower slope (>500 m) was the deep area most heavily exploited by foreign vessels (65.7% of conducted hauls) (Table 3).

Hook and line fishing

Hand-line fishing off Brazil was first a coastal activity in the central sector, specifically off the southern coast of Bahia State and the Abrolhos Archipelago (17°25'-18°10'S, 38°33'-39°37'W). In the 1970s, the fleet expanded its activity towards the slope grounds of the southeastern and southern coasts (200-600 m depth) and changed its technology to vertical lines and finally bottom long-line (Peres & Haimovici, 1998). By the end of the 1990s, hand-line and long-line fleets were operating on slope grounds to the north and south of 29°S, respectively. The former targeted the tilefish (*Lopholatilus villarii*), snowy grouper (*Epinephelus niveatus*), sandperch (*Pseudopercis numida*), and catfish (*Genidens barbus*); whereas the latter targeted mainly the wreckfish (*Polyprion americanus*), but also produced important catches of Brazilian codling (*Urophycis mystacea*), red porgy (*Pagrus pagrus*), and pink cusk-eel (*Genypterus brasiliensis*) (Ávila-da-Silva & Arantes, 2007; Haimovici *et al.*, 2007).

Four chartered long-line vessels operated off the southern sector of the Brazilian EEZ, three of them in 2000 and one between January and June of 2001 (Table 2). A total of 476 hauls were conducted during seven fishing trips, all of which targeted wreckfish concentrations south of 30°S and between 159 and 800 m (Fig. 2). In addition, these trips also landed important catches of pink cusk-eel, the school shark (*Galeorhinus galeus*), and tilefish (Table 4) (Perez *et al.*, 2003). Because the national long-line fleet already heavily exploited wreckfish fishing grounds, regulations were implemented in 2001 that forced these vessels to explore deeper areas of the lower slope. The enforcement of these regulations stimulated foreign longliners to abandon the Brazilian EEZ within the year.

Bottom gillnet fishing

Deep-water gillnets were introduced in Brazil following similar experiences conducted off east Canada in the early 1990s (Kulka & Miri, 2001) and principally, the "rascos" operations in the deep areas of the NW Iberian Peninsula and Cantabric Sea (Bruno *et al.*, 2001). The fishery started off in 2001 with two vessels and increased to a maximum of ten in 2002, most of them originating from Spain (Wahrlich *et al.*, 2004) (Table 2). These vessels conducted 79 fishing trips (3,947 hauls), quickly occupying the upper slope grounds, between 200 and 500 m depth along the entire southeastern and southern sectors of the Brazilian coast (Fig. 2) (Perez *et al.*, 2002a). The monkfish *Lophius gastrophysus* was the targeted species, representing numerically 40.7% of the entangled organisms. Catches of royal crabs (*Chaceon ramosae*), spider crabs (Majidae), beard fish (*Polimixia lowei*), silvery John dory (*Zenopsis conchifera*), Brazilian codling, Argentine hake (*Merluccius hubbsi*), wreckfish, angel shark (*Squatina argentina*), and various skates (Rajidae) were also important and, except for monkfish, most were discarded (Perez & Wahrlich, 2005).

In mid-2002, following the preliminary assessments of monkfish and innumerable conflicts with national trawlers, government regulations prohibited foreign gillnetters to operate south of 21°S. That action defined the termination of chartered gillnet operations off Brazil, although a small national fleet continued the fishery. Composed of no more than five licensed units, this fleet assimilated the fishing technology and the international markets introduced by the chartered vessels (Wahrlich *et al.*, 2004).

Table 2. Temporal distribution of national and foreign (chartered) deep-water fishing activity off Brazil. Slope trawling has been fragmented into shelf break, upper slope, and lower slope operations.

Tabla 2. Distribución temporal de la actividad pesquera en aguas profundas realizadas por la flota nacional y extranjera (arrendada) en Brasil. Los arrastres en el talud fueron clasificados como operaciones efectuadas en el borde de la plataforma y en el talud superior e inferior.

Only national vessels | Only foreign vessels | National + foreign vessels

	1980-1990	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Longline	Only national vessels	Only national vessels	Only national vessels	National + foreign vessels	National + foreign vessels	Only national vessels	Only national vessels	Only national vessels	Only national vessels	Only national vessels	Only national vessels
Gillnet				Only foreign vessels	Only foreign vessels	National + foreign vessels	Only national vessels	Only national vessels	Only national vessels	Only national vessels	Only national vessels
Pot		Only foreign vessels	Only foreign vessels	Only foreign vessels	Only foreign vessels	Only foreign vessels	Only foreign vessels	Only foreign vessels	National + foreign vessels	National + foreign vessels	National + foreign vessels
Trawl- shelf break	Only national vessels	Only national vessels	Only national vessels	Only national vessels	Only national vessels	Only national vessels	Only national vessels	Only national vessels	Only national vessels	Only national vessels	Only national vessels
Trawl- upper slope			Only national vessels	National + foreign vessels	National + foreign vessels	National + foreign vessels	National + foreign vessels	Only national vessels	Only national vessels	Only national vessels	Only national vessels
Trawl- lower slope						Only foreign vessels	National + foreign vessels	National + foreign vessels	National + foreign vessels	National + foreign vessels	National + foreign vessels

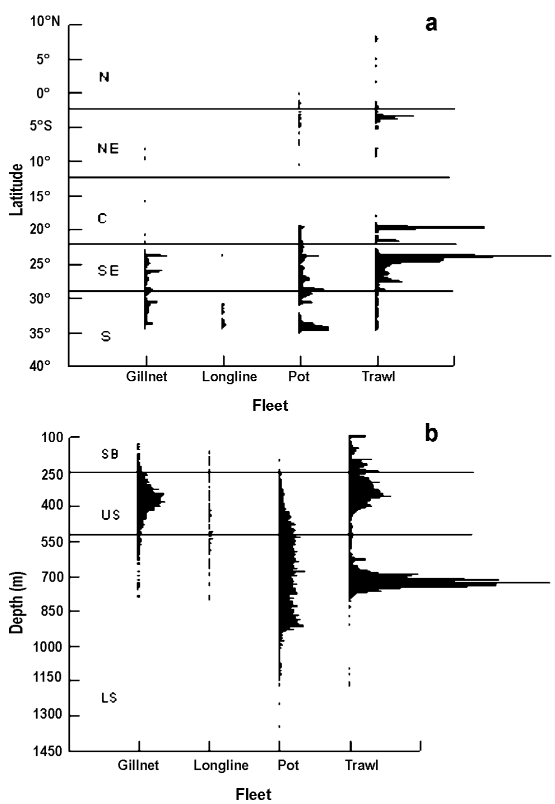

Figure 2. a) Latitudinal and b) depth distribution of hauls conducted by the chartered vessels on slope areas off Brazil from 2000 to 2007. LS: lower slope, US: upper slope, SB: shelf break.

Figura 2. a) Distribución latitudinal, y b) batimétrica de los lances de pesca realizados por buques arrendados en las áreas del talud de Brasil en el periodo 2000-2007. LS: talud inferior, US: talud superior, SB: borde de la plataforma.

Pot fishing

The first episode involving pot fishing for deep-water crabs was recorded in 1984-1985, when two chartered Japanese vessels operated off the southernmost extreme of the Brazilian EEZ (Lima & Branco, 1991). This activity began again in 1998 when another Japanese vessel initiated operations in precisely the same area as part of the government-induced chartering program (Perez *et al.*, 2003). On both occasions, the species targeted was the red crab (*Chaceon notialis*), a stock whose distribution extends southwards to Uruguayan waters, where a similar pot fishery has existed since the 1990s (Defeo & Masello, 2000). The same single vessel continued to exploit the red crab off Brazil until 2007, operating on the upper and lower slope (200 to 900 m depths) south of 33°S (Pezzuto *et al.*, 2006a).

Between 2001 and 2002, another four chartered pot vessels initiated their operations off southern Brazil flying the flags of Russia, Spain, and the UK. These vessels directed their efforts at another deep-water crab, the royal crab (*Chaceon ramosae*); concentrations of this resource had been revealed by incidental gillnet catches on board chartered vessels in 2001 (Perez & Wahrlich, 2005). Operations concentrated on the lower slope (500-900 m depth) within a major fishing area bounded by the parallels 27°S and 30°S (Fig. 2). In 2003, this area was expanded northward with the establishment of a new fishing ground off southeastern Brazil between 19°S and 25°S. Said expansion coincided with the entry of another two vessels from Spain and one from the USA, increasing the royal crab chartered pot vessel fleet to a maximum of

Table 3. Spatial distribution of deep-water fishing hauls conducted by the foreign chartered fleet off Brazil between 2000 and 2007. Hauls are grouped by fishing gears, depth strata (and seamounts), and sectors of the Brazilian coast. Numbers in parentheses represent the proportion (%) of hauls conducted by gear in each depth strata and sector. In the last line, the number in parentheses represents the proportion of hauls conducted by fishing gear.

Tabla 3. Distribución espacial de los lances de pesca en aguas profundas realizados por la flota extranjera arrendada en Brasil entre 2000 y 2007. Los lances fueron agrupados según método de pesca, estratos batimétricos (y montes submarinos) y sectores de la costa de Brasil. Los números entre paréntesis representan el porcentaje (%) de lances realizados por método de pesca en cada estrato batimétrico y sector. En la última línea los números entre paréntesis representan proporciones de lances realizados de acuerdo al método de pesca.

	Longline	Gillnet	Pot	Trawl	Total
Depth strata					
Shelf break (100-250) m	6 (13.0)	37 (1.1)	4 (0.1)	612 (2.7)	659 (2.0)
Upper slope (250-500) m	9 (19.6)	3186 (92.3)	628 (9.5)	5634 (24.8)	9457 (28.9)
Lower slope (> 500) m	28 (60.9)	230 (6.7)	5925 (90.0)	15360 (67.7)	21543 (65.7)
Seamounts	0 (0.0)	0 (0.0)	0 (0.0)	965 (4.3)	965 (2.9)
Coastal sector					
North	0 (0.0)	0 (0.0)	19 (0.3)	55 (0.2)	74 (0.2)
Northeast	0 (0.0)	6 (0.2)	57 (0.9)	1221 (5.4)	1284 (3.9)
Central	0 (0.0)	10 (0.3)	292 (4.4)	3850 (17.0)	4152 (12.7)
Southeast	4 (8.7)	2294 (66.4)	4498 (68.3)	17438 (76.9)	24134 (74.0)
South	42 (91.3)	1143 (33.1)	1715 (26.1)	123 (0.5)	3023 (9.2)
Total	46 (0.1)	3453 (10.5)	6581 (20.1)	22687 (69.2)	32767 (100.0)

seven units operating simultaneously off Brazil. In the following four years, all the vessels exploited both the southeastern and southern fishing grounds but gradually abandoned Brazilian waters by 2007. Altogether, the chartered pot fleet operating on the southeastern and southern Brazilian slope (on both *Chaceon* species) totaled eight vessels that conducted 111 fishing trips and completed 10,037 hauls (Table 1).

From 1999 to 2007, national vessels attempted the pot fishery for deep-water crabs on two known occasions. The first was in 2004-2005 and took place off southern Brazil on board one vessel built for deep-water crab fishing; this attempt ended abruptly with a wreck. Another incursion has been reported since 2006 off the coast of Ceará in the northeast sector of the Brazilian coast. There, one vessel formerly used for coastal lobster fishing has presumably exploited a third species of the genus *Chaceon*, the golden crab *C. fenneri*, at depths of 600 to 800 m (Carvalho *et al.*, 2009).

Trawl fishing

Trawling on the slope areas off Brazil intensified since 1999 as a consequence of both the expansion of traditional fishing areas of the national fleet and the operation of foreign trawlers chartered to explore deep grounds within the Brazilian EEZ (Perez *et al.*, 2001, 2003). Together, both national and foreign trawlers have concentrated their efforts in the southern and southeastern sectors of the Brazilian coast, exploiting

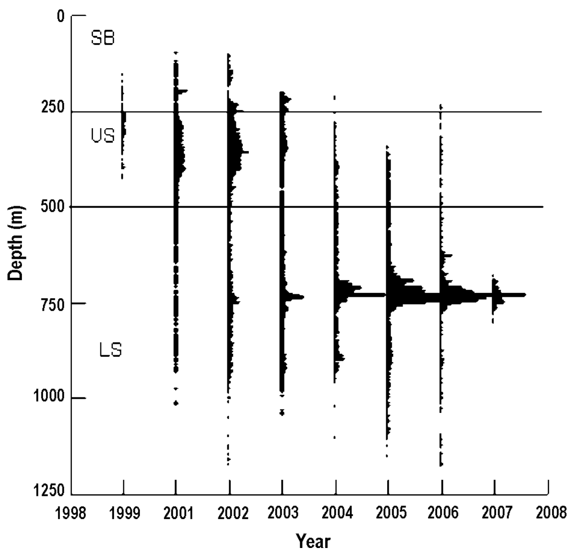

Figure 3. Bathymetric distribution of hauls conducted by chartered vessels on slope areas off Brazil by year from 2000 to 2007. LS: lower slope, US: upper slope, SB: shelf break.

Figura 3. Distribución batimétrica de los lances de pesca realizados anualmente por buques arrendados en las áreas de talud de Brasil, años 2000 a 2007. LS: talud inferior, US: talud superior, SB: borde de la plataforma.

three discrete bathymetric strata: shelf break, (100-250 m), upper slope (250-500 m), and lower slope (> 500 m) (Perez & Pezzuto, 2006; Perez *et al.*, 2009a) (Table 2).

National trawlers used two types of trawl gear on the slope grounds: the double rig trawl traditionally used in the pink shrimp fisheries on the continental shelf and the stern trawl conducted by modified double rig trawlers and designed specifically to operate in deeper areas (Perez *et al.*, 2002a; Perez & Pezzuto, 2006). Between 2001 and 2003, landings from 1,511 fishing trips conducted on slope areas off southeastern and southern Brazil by 255 double rig trawlers and 44 stern trawlers were recorded in the harbors of Santa Catarina State. In that period, these operations accounted for 27.8% of all fishing trips conducted with both types of gears in the state and 41.8% of all catches landed by them. The Argentine hake and Brazilian codling were the main targets of both types of trawlers (Table 4). Monkfish and the Argentine squid have also been important catch components, the latter restricted to winter months (July-September). Whereas these species were dominant in catches obtained on the upper slope, in shallower grounds of the shelf break, the catches were highly multispecific and included a variety of shellfish, finfish, and elasmobranchs, namely soldier shrimps (*Plesionika* spp.), flounders (*Paralichthys isosceles*, *P. triocellatus*), pink cusk-eel, and deep-water skates (Table 4).

A fleet composed of 37 chartered trawlers operated on deep areas off the Brazilian coast since 2000, completing, by 2007, 311 fishing trips and 35,860 trawls at depths of 100 to 1,173 m in the northern, northeastern, southeastern, and southern sectors of the Brazilian coast (Tables 1 to 3).

In southeastern and southern Brazil, a preliminary "exploratory phase" of chartered trawling was established between late 2000 and mid-2001, when two large vessels flying the flags of Portugal and the Republic of South Korea conducted long fishing trips between 100 and 400 m depth (Perez *et al.*, 2003; Perez *et al.*, 2009a). By the end of 2001, the results of the preliminary exploration gave way to an "upper slope directed phase" characterized by the intense exploitation of two latitudinal strata, 23°S-25°S and 26°S-29°S, both between 250 and 400 m deep. This phase included the operations of seven trawlers, most of them originating from Spain, that targeted Argentine hake concentrations on the upper slope off southeastern Brazil. Catches of the Argentine squid were also particularly important in this period, along with the monkfish, silvery John dory, and Brazilian codling, the latter usually discarded due to the lack of an international market (Table 4). After sharing the upper slope and most of its demersal resources with the national fleet for nearly one year, most chartered trawlers left Brazilian waters by the end of 2002 (Perez *et al.*, 2009a).

Chartered trawling off Brazil continued, however, through the operation of another set of foreign vessels that established a third and still ongoing fishing phase directed at the lower slope and valuable concentrations of aristeid shrimps: *Aristaeopsis edwardsiana* (scarlet shrimp), *Aristeomorpha foliacea* (giant red shrimp), and *Aristaeus antillensis* ("alistado" shrimp) (Table 4) (Pezzuto *et al.*, 2006b; Perez *et al.*, 2009a). Two Spanish trawlers initiated this phase in late 2002-2003, establishing an intense fishing regime in a limited area bounded by the 24-26°S parallels and 700-750 m isobaths. In mid-2004, another five trawlers from Spain, Mauritania, and Senegal started operations within the same limited area mentioned above, moving gradually to new productive grounds to the north (19°30'-20°S) and, in 2005, to the south of 26°S (Pezzuto *et al.*, 2006b; Dallagnolo *et al.*, 2009). This phase directed at the lower slope was the longest to be sustained by chartered trawlers off Brazil, but it also declined in 2007 when most vessels abandoned Brazilian waters due to poor catch rates. Throughout this phase,

Table 4. Landing composition of deep-water fishing operations off Brazil. "Main target-species" are species that generally compose more than 10% of the landed biomass and are always listed as targets. "Secondary target species" are species that compose from 1 to 10% of the landed biomass. "Valued bycatch" are species that represent less than 1% of the landed biomass but are generally retained for commercialization. Sources for landing composition of national longliners and handliners: Ávila-da-Silva & Arantes (2007), Haimovici & Velasco (2007), and Haimovici *et al.* (2007).

Tabla 4. Composición de los desembarques correspondiente a las operaciones de pesca realizadas en aguas profunda en Brasil. "Main target-species" son especies que componen más del 10% de la biomasa desembarcada y siempre son nombradas como "objetivo" de la pesca. "Secondary target species" son especies que componen el 1-10% de la biomasa desembarcada. "Valued bycatch" son especies que componen menos de 1% de la biomasa de los desembarques, pero que en general son retenidos para su comercialización. Fuentes para la composición de los desembarques de barcos de palangre: Ávila-da-Silva & Arantes (2007), Haimovici & Velasco (2007) y Haimovici *et al.* (2007).

M = Main target-species; S = Secondary target-species; V = Valued bycatch

	Stern trawl - Shelf break	DR Trawl - Shelf break	Stern trawl - Upper slope	DR Trawl - Upper slope	Stern trawl - Upper slope	Stern trawl - Lower slope	Stern trawl - Seamount	Gillnet	Gillnet	Handline	Longline	Longline	Pot
	National	National	National	National	Chartered	Chartered	Chartered	National	Chartered	National	National	Chartered	Chartered
Crustaceans													
Aristaeomorpha foliacea						M							
Aristaeopsis edwardsiana					V	M							
Aristeus antillensis						M							
Chaceon fenneri													M
Chaceon notialis													M
Chaceon ramosae					V	S			S				M
Metanephrops rubellus		S											
Plesionika longirostris		S											
Scyllarides deceptor		V											
Mollusks													
Illex argentinus	V	V	M	M	M	S							
Octopus vulgaris	V	V											
Elasmobrachs													
Atlantoraja, Dipturus spp.	S	S	V					S	S				
Carcharhinus spp.								V					
Galeorhinus galeus											S	S	
Isurus oxyrinchus												S	
Rhinobatos spp.	S	V	V										
Squalus spp.		V						V					
Squatina argentina	V	V	V						V				
Teleosts													
Conger orbignyanus	V	V										V	
Cynoscion guatucupa	S	S	V										
Epinephelus nigritus							M			M			
Epinephelus niveatus											S		
Genidens barbus										S	S		
Genypterus brasiliensis	S	S	S		V	V					S	S	
Helicolenus dactylopterus	V	V						V				V	
Lophius gastrophysus	S	S	S	S	S	S		M	M				
Lopholatilus villarii	V	V	V		V			V	S	M	M	S	
Merluccius hubbsi	S	M	M	M	M	S		V	V			S	
Micropogonias furnieri	S	V											
Mullus argentinae	V	V											
Pagrus pagrus										S	V	V	
Paralichthys spp.	S	S			V								
Polimixia lowei		V											
Polyprion americanus	V				V			V	V		M	M	
Prionotus punctatus	S	S	S	S									
Pseudopercis spp.										M		V	
Trichiurus lepturus					S								
Umbrina canosai	M	S	S	S									
Urophycis mystacea	M	M	M	M	S	S		M	S		S	S	
Zenopsis conchifera	V	V	S		M	V							

two national trawlers, one imported and another adapted to slope trawling, were also recorded in the fishing areas off southeastern Brazil.

Chartered deep-sea trawling was also attempted in the northern and northeastern sectors of the Brazilian coast. Nearly 226 trawls were conducted between 428 and 1,158 m deep off the coast of Amapá State (47-50°W) in late 2002, where productive concentrations of *A. edwardsiana* and *A. antillensis* were found (Pezzuto *et al.*, 2006b). Additionally, a few trips by one chartered trawler were directed towards the flat tops of the seamounts making up the Ceará Plateau and Fernando de Noronha Chain. These seamounts rise from nearly 1,000 m at the base to 200 m at the top, where the gentle topography was found suitable for trawling. Catches in these areas were mostly composed of the Warsaw grouper (*Epinephelus nigritus*), whose catch rates decreased rapidly to unprofitable levels (Table 4). These areas have been abandoned ever since (Perez *et al.*, 2009a).

Other fisheries

In 2003, a national pot fishery directed at the common octopus *Octopus vulgaris* developed in the southeastern sector of the Brazilian coast, with a maximum of 29 vessels operating in 2005. This fleet decreased to around 14 units in 2007, but substantial activity of illegal vessels has been reported, mostly off southern Brazil. Pot operations have concentrated on the outer shelf, although a considerable proportion of catches have originated from shelf-break areas (100-200 m deep) (Ávila-da-Silva & Tomás, 2007).

In 2005, one vessel chartered for squid jigging conducted one experimental trip off southeastern and southern Brazil. This attempt was highly unsuccessful but may have been affected by the fact that the vessel did not operate during the winter months (July-September), when trawl catches of Argentine squid are highest (Perez *et al.*, 2009a).

FISHERIES DEVELOPMENT AND SUSTAINABILITY

Considering the year 2000 as a the reference for the start of a deep-sea fishing phase in Brazil, total landed catches of the main demersal "deep-sea" resources reported for the southeastern and southern sectors of Brazil, where this activity has concentrated, varied annually from 5,756 ton in 2000 to a maximum of 19,923 ton in 2002, decreasing to nearly 11,000 ton in 2006 (Table 5). These annual figures have represented 2 to 8% of the total catch landed annually in this period (Valentini & Pezzuto, 2006). In this section, the main deep-water resources exploited off Brazil are presented along with existing descriptive information on historical catches (Table 5), abundance patterns and stock assessments (Table 6), and management/conservation measures (Table 7).

Wreckfish, *Polyprion americanus* (Bloch & Schneider, 1801)

The wreckfish is a large-sized serranid that constituted the main target of the hook-and-line fisheries, particularly those established between 100 and 500 m deep south of 30°S. Sparse catch records of this species date back to 1973, but a series of nominal catches has been available from 1986 onwards (Valentini & Pezzuto, 2006). Until 2004, annual reported landings oscillated around 700 to 800 ton (Table 5). These figures, however, may not be totally realistic considering that landing records may be contaminated by two other serranids (*Epinephelus niveatus* and *E. flavolimbeatus*) and that there has been a historical trend of unreported catches, particularly during the first half of this period (Haimovici & Peres, 2005). These authors estimated that landings declined nearly 79% since 1989 (dropping from 2,200 ton in that year to less than 460 ton in 2002), in association with abundance reductions ranging from 57 to 94%, according to CPUE time-series analysis. Part of this reduction has been attributed to a significant increment in fishing mortality during the 1990s as the result of (a) the rising demands of international markets and (b) increased fishing power through the dissemination of the use of long-line settings in the fleet.

The species is long-lived. Catches include females and males as old as 76 and 62 years, respectively. Maturation is reached for the first time after nine to 10 years-of-age in both sexes and spawning occurs on localized areas off southern Brazil (Peres & Haimovici, 2003). In these areas, most of the local stock is highly vulnerable to the long-line directed fishery as well as unintentional mortality from slope trawling and monkfish gillnetting (Peres & Klippel, 2003; Perez & Wahrlich, 2005). Given the combination of these K-strategy features and the important biomass reductions mentioned previously, the Brazilian stock has been included, justifiably so, on the IUCN "red list" and Brazilian authorities imposed a moratorium since 2005 (Tables 6 and 7) (Cornish & Peres, 2003).

Monkfish, *Lophius gastrophysus* Ribeiro, 1915

The monkfish is a lophiiform widely distributed along the Brazilian shelf and slope. It is traditionally a valuable component of the catches obtained by double

Table 5. Annual landings (ton) of deep-water resources in southeastern and southern Brazil between 2000 and 2006. Brazilian codling includes two species: *Urophycis brasiliensis* (coastal) and *U. mystacea* (deep-water).

Tabla 5. Desembarques anuales (ton) de recursos de aguas profundas en el sureste y sur de Brasil entre 2000 y 2006. "Brazilian codling" incluye dos especies: *Urophycis brasiliensis* (costera) y *U. mystacea* (aguas profundas).

Species		Year							Total
		2000	2001	2002	2003	2004	2005	2006	
Teleosts									
Brazilian codling	*Urophycis* spp.	1,901.3	5,991.7	7,847.0	5,273.6	3,491.2	4,547.8	4,825.0	33,877.6
Tilefish	*Lopholatilus villarii*	533.2	709.2	597.6	572.5	545.2	560.8	717.0	4,235.5
Argentine hake	*Merluccius hubbsi*	225.8	2,653.4	3,708.8	3,042.4	1,417.8	1,564.5	1,950.5	14,563.2
Silver john dory	*Zenopsis conchifera*	0.0	0.0	82.5	147.1	42.3	85.1	31.0	388.0
Monkfish	*Lophius gastrophysus*	1,934.4	7,063.9	5,073.1	2,556.3	2,410.7	2,544.6	2,516.5	24,099.5
Crustaceans									
Royal crab	*Chaceon ramosae*	2.0	593.6	1,252.3	746.0	849.9	494.5	171.4	4,109.7
Red crab	*Chaceon notialis*	1,157	1,183.6	1.089.0	1,377.7	1,092.5	675.7	302.8	5,899.8
Scarlet shrimp	*Aristaeopsis edwardsiana*	0.0	0.0	13.0	58.9	81.6	182.6	99.3	435.4
Giant red shrimp	*Aristaeomorpha foliacea*	0.0	0.0	0.0	4.6	14.9	42.6	51.7	113.8
Alistado shrimp	*Aristeus antillensis*	0.0	0.0	0.3	0.5	5.5	15.8	5.4	27.5
Molluscs									
Argentine squid	*Illex argentinus*	2.7	13.6	2,600.7	31.2	158.3	453.1	292.5	3,552.1
Total		5,756.4	18,209.0	19,923.0	13,810.8	10,109.9	11,167.1	11,028.1	91,302.1

Sources: IBAMA/DF, IBAMA/RJ, CEPSUL/IBAMA, CEPERG/IBAMA, IP-APTA and CTTMar/UNIVALI.

rig trawling along the coast of Rio de Janeiro State. In 2001, an important cycle of commercial exploitation of the species began in Brazil and peaked in the following year, when over 150 trawlers and nine chartered vessels operating with bottom gillnets landed 7,094 ton (Table 5) (Perez *et al.*, 2002a, 2003; Perez & Pezzuto, 2006). This fishing regime continued during most the following year, with landings of 5,129 ton, but changed in 2003 as the chartered vessels abandoned Brazilian waters. Since then, exploitation has been maintained mostly by double rig trawlers along with a few vessels of the national fleet transformed to fish with the new gillnet technology (Wahrlich *et al.*, 2004). Landings decreased to roughly 50% from 2002 to 2003, remaining stable around 2,500 ton ever since (Table 5).

Through data collected from national and chartered operations, catch-at-size, general linear models, and depletion models were combined in order to provide both pristine biomass and abundance index estimates for 2001 (Table 6) (Perez *et al.*, 2005). Landing statistics indicated that fishing removed approximately 16% of the 62,776 ton of total estimated biomass and approximately 32% of the spawning stock. Alternatively, variations in the abundance indices suggested a more severe 30-60% biomass reduction in the main fishing grounds off southern Brazil throughout 2001. The latter scenario was favored by the establishment of a conservative reference point and the Gulland's equation was used to predict a maximum sustainable yield (MSY) of 2,500 ton per year, or nearly 4% of the total biomass (Perez *et al.*, 2002b). A later assessment combining life-history parameters and population models (Kirkwood *et al.*, 1994; Perez, 2006) estimated an MSY for the species of around 6% virginal biomass and suggested that the former recommended annual catch was conservative enough to sustain the fishery at biologically safe levels. Notwithstanding, in 2002, as biomass reductions in the fishing areas reached nearly 50% of the 2001 levels, a lower annual catch (1,500 ton, nearly 2.5% of the virginal biomass) was recom-

Table 6. Abundance estimators, methods for stock assessment, reference points, and the status of deep-water fisheries/stocks exploited in southeastern and southern Brazil. t: year, B_0: virginal or initial biomass, C: catch, Cref: catch in the year of reference, E: exploitation rate.

Tabla 6. Estimadores de abundancia, métodos de evaluación del stock, puntos de referencia y estado de las pesquerías de aguas profundas/stocks explotados en el sureste y sur de Brasil. t: año, B_0: biomasa inicial o virginal, C: captura, Cref: captura en el año de referencia, E: tasa de explotación.

Stocks	Abundance estimators/ indicators	Stock assessment methods	Reference points (limits)	Stock status
Elasmobranchs				
Galeorhinus galeus	-	-	-	Risk of extinction (1)
Teleosts				
Helicolenus lahillei	-	Z; M; S (2)	-	Under-exploited (2)
Lophius gastrophysus	Swept area (3),VPA, Depletion, GLM (4)	Gulland's equation (4)	$0.06B_{2001}$ (5); GLM_t/GLM_0; GLM_t/GLM_{MSY} (4, 6)	Overexploited (4, 7)
Lopholatilus villarii	VPA (8)	Thompson & Bell *(8)*	$F_{0,1}$; F_{max} (8)	Overexploited (8)
Merluccius hubbsi	Swept area (3), GLM (7)	Kirkwood *et al*., 2004 (5)	$0.1B_{2002}$ (5)	Fully exploited/ overexploited (5,7)
Polyprion americanus	-	Ct/Cref; CPUEt/CPUEref (10)	-	Colapsed (10)
Urophycis mystacea	Swept area (9,3), GLM (7)	Kirkwood *et al*., 2004 (5)	$0.1B_{2002}$ (5)	Fully exploited/ overexploited (9,5)
Zenopsis conchifera	Swept area (3)	Kirkwood *et al*., 2004 (5)	$0.1B_{2002}$ (5)	Unknown
Crustaceans				
Aristaeopsis Edwardsiana	Swept area, GLM (11)	Kirkwood *et al*., 2004 (11)	B_t/B_0; B_t/B_{MSY}; $CPUE_t/CPUE_0$; $CPUE_t/CPUE_{MSY}$; GLM_t/GLM_0; GLM_t/GLM_{MSY} (11)	Overexploited (11)
Aristaeomorpha foliacea	Swept area, GLM (11)	Kirkwood *et al*., 2004 (11)	B_t/B_0; B_t/B_{MSY}; $CPUE_t/CPUE_0$; $CPUE_t/CPUE_{MSY}$; GLM_t/GLM_0; GLM_t/GLM_{MSY} (11)	Unknown
Aristeus antillensis	Swept area, GLM (11)	Kirkwood *et al*., 2004 (11)	B_t/B_0; B_t/B_{MSY}; $CPUE_t/CPUE_0$; $CPUE_t/CPUE_{MSY}$; GLM_t/GLM_0; GLM_t/GLM_{MSY} (11)	Unknown
Chaceon notialis	EFA, GLM, CPUE (12, 13)	Gulland's equation (12)	B_t/B_0; B_t/B_{MSY}; $CPUE_t/CPUE_0$; $CPUE_t/CPUE_{MSY}$; GLM_t/GLM_0; GLM_t/GLM_{MSY} (13)	Fully exploited (13)
Chaceon ramosae	EFA, GLM, CPUE (12, 8)	Gulland's equation (12)	B_t/B_0; B_t/B_{RMS}; $CPUE_t/CPUE_0$; $CPUE_t/CPUE_{RMS}$; GLM_t/GLM_0; GLM_t/GLM_{RMS} (13)	Fully exploited/ Overexploited (13)
Molluscs				
Illex argentinus	Swept area (14)	-	-	Unknown
Octopus vulgaris	VPAe (15, 16)	$B_t/Catch_t$ (16)	-	Under-exploited (16)

(1) Vooren & Klippel (2005), (2) Bernardes *et al*. (2005b), (3) Haimovici *et al*. (2008), (4) Perez *et al*. (2005), (5) Perez (2006), (6) Perez *et al*. (2002b), (7) Perez (2007a), (8) Ávila-da-Silva & Haimovici (2005), (9) Haimovici *et al*. (2006b), (10) Haimovici & Peres (2005), (11) Dalagnollo (2008), (12) Pezzuto *et al*. (2006a), (13) Pezzuto *et al*. (2006b), (14) Haimovici *et al*. (2006c), (15) Tomás (2002), (16) Tomás & Petrere Jr. (2005).

mended (Anon, 2007). This MSY was used to define a TAC (Total Allowable Catch) as one of the elements of a management plan discussed and agreed on by fishing authorities in 2002-2003 (Table 7). This plan also included the definition of a bottom gillnet fleet of no more than nine units, a maximum of 1,500 nets per vessel, 280 mm mesh size (stretched), and no-fishing areas, among other measures (Perez *et al*., 2002b; Anon, 2005).

Since the beginning of the monkfish production cycle, however, landed catches have been systematically higher than the maximum recommended catches (Table 5). That pattern is regarded to be the main cause of the major biomass reduction in 2002 and the stabilization at biologically insecure levels thereafter (Perez, 2007a; Anon, 2007).

The monkfish was exploited throughout the southern and southeastern regions between the 100-600 m isobaths. Brazilian trawlers concentrated their activities on the shelf break (at 100-200 m) and chartered gillnet vessels in deeper areas of the upper slope (at 300-400 m). Because the stock size-structure is affected by the bathymetric gradient across the slope and both fishing gears differ markedly in mesh-size, trawler mortality concentrated on young, immature specimens (mostly males), whereas gillnet fishing tended to affect mostly large adult females, which are dominant in areas deeper than 300 m. After 2002, as chartered vessels no longer operated in the Brazilian EEZ, the deep fraction of the stock tended to be less affected than the one exploited by trawlers on the shelf break (Valentim *et al.*, 2007). In recent years, trawlers targeting monkfish off southern Brazil have tended to occupy deeper areas of the slope and to include large individuals in their catch. These individuals also have predominated in the catches of the small national gillnet fleet (Anon, 2007).

Argentine hake, *Merluccius hubbsi* Marini, 1933

The Argentine hake is a benthopelagic gadiform of the family Merluccidae that occurs in the SW Atlantic shelf and slope waters from 22° to 55°S. The highest densities occur over the Patagonian Shelf where the species has long sustained an important trawl fishery (Bezzi *et al.*, 2004). Catches in Brazilian waters have mostly occurred in the southern sector and have been historically associated with the northward penetration of juveniles from the Patagonian stocks, particularly during years when the influence of the cold Malvinas/Falkland Current waters in the Brazilian EEZ was intense (Haimovici *et al.*, 1994). From 1990 onwards, important catches have been reported off the coast of Rio de Janeiro State, in the southeastern sector; these come from what appears to be a distinct stock whose distribution is associated with the local upwelling of cold South Atlantic Central Waters (Vaz-dos-Santos & Rossi-Wongstchowski, 2005; Haimovici *et al.*, 2008). This “Brazilian” stock has constituted one of the main targets of the slope trawling fishery conducted since 2000, both by national and foreign trawlers (Perez *et al.*, 2003; Perez & Pezzuto, 2006; Perez *et al*, 2009a). The species also appeared amongst the most important components of the deep-water gillnet catches obtained by the chartered fleet in 2001-2002, although nearly 87% of these catches were discarded in the monkfish-oriented operations (Perez & Wahrlich, 2005).

Annual landings through the 1980s and 1990s have been mostly under 1,000 ton (Valentini & Pezzuto, 2006). In 2001, landings reached 2,653 ton, almost 10 times the levels recorded in the previous years, increasing to over 3,000 ton in 2002 and 2003 (Table 5). Chartered trawlers contributed with 38.4% (1,018 ton) and 52.7% (1,953 ton) of the total landings in 2001 and 2002 respectively. In 2003, nearly 90% of the 3,042 ton landed were produced by national double rig trawler operations (Perez *et al.*, 2009a). After 2003, annual landings were cut in half and stabilized around 1,400-1,500 ton (Table 5).

Surveys conducted by the REVIZEE Program reported the highest densities between 250 and 550 m depths and within two latitudinal strata: one in the southernmost extreme of the Brazilian EEZ (33-34°S) and another in the southeastern sector (23-25°S) (Haimovici *et al.*, 2008). The latter was the concentration primarily exploited by both national and foreign trawlers, with the largest catches being obtained at depths of 300 to 400 m (Perez & Pezzuto, 2006; Perez *et al.*, 2009a). A direct swept area assessment estimated a total of 21,924 ton (± 5,922.2 95%CI) of Argentine hake in the southeastern sector in 2002, and an MSY of 2,215 ton (corresponding to 10% of the total stock biomass) was estimated based on life-history parameters (Table 6) (Haimovici *et al.*, 2008; Perez, 2006). Between 2001 and 2003, catches were well above the estimated MSY and the total biomass decreased nearly 50% from 2003 onwards (Perez, 2007a; Anon, 2007). Vaz-dos-Santos & Rossi-Wongstchowski (2005) further demonstrated that catches of the trawl fishery were highly concentrated on immature males and females (1-2 years old). These authors also estimated a 0.58 fishing mortality rate (F) that clearly surpassed the F_{MSY} levels as defined by Perez (2006). All the above assessments converge into a scenario of overfishing that calls for an urgent upper slope trawling management plan (Table 7).

Table 7. Management elements of the deep-water fisheries in southeastern and southern Brazil. Logbooks and VMS: 100% coverage. Observers: 100% coverage. Exceptions are indicated in specific cases.

Tabla 7. Elementos utilizados en el manejo de las pesquerías de aguas profundas en el sureste y sur de Brasil. Bitácoras a bordo y VMS: 100% de cobertura. Observadores: 100% de cobertura, Excepciones están indicadas en casos específicos.

	Bottom longline	Double-rig trawl (shelf break)	Bottom trawl (upper slope)	Bottom trawl (lower slope)	Gillnet	Trap	Trap	Trap
Management plan	No	2008	2008	Now implementing	2008	2008	2005	Now implementing
Target and accessory species	*Polyprion americanus* (*); *Lopholatilus villarii; Pseudopercis numida; Epinephelus niveatus; Urophycis mystacea; Galeorhinus galeus; Genypterus brasiliensis; Helicolenus lahillei*	Multispecies (**)	*Urophycis mystacea; Merluccius hubbsi; Zenopsis conchifera; Illex argentinus*	*Aristaeopsis edwardsiana; Aristaeomorpha foliacea; Aristeus antillensis*	*Lophius gastrophysus*	*Chaceon notialis*	*Chaceon ramosae*	*Chaceon fenneri*
Fleet size	Unlimited	Unlimited among coastal pink-shrimp trawlers	17 (< 600 HP)	2	9	2	2	1
Area	Brazilian EEZ	18º20' S to the Southern limit of the Brazilian EEZ; 100-250 m depth	18º20' S to the Southern limit of the Brazilian EEZ; 250-500 m depth	18º20' S to 28º30'; 500-1000 m depth	21º' S to the Southern limit of the Brazilian EEZ; > 250 m depth	32º S to the Southern limit of the Brazilian EEZ; > 200 m depth	19º S to 30º S; > 500 m depth	NE coast > 200 m depth
Fishing season	Jan-Dec	March - May	Jan-Dec	Jan-Dec	Jan-Dec	Jan-Dec	Jan-Dec	Jan-Dec
TAC	No	No	No	60 ton.year^{-1}. Individual (not-transferable) quotas of 7.5 ton.trimester^{-1}	1.500 ton.year^{-1}	735 ton. year^{-1}	420 ton.year^{-1}	No
Effort limits	No	No	No	No	Up to 1000 nets.vessel^{-1} (maximum net length: 50 m)	No	Up to 900 traps.vessel^{-1}	
Minimum legal sizes	Yes, species-specific	No	No	No	No	No	No	No
Gear restrictions	No	Double-rig trawl	Stern trawl; minimum cod-end mesh size 90 mm stretched	Stern trawl; minimum cod-end mesh size 60 mm stretched	Minimum mesh size 280 mm stretched; nets tagged with vessel register	Mesh size 120 mm stretched; escape panels; traps tagged with vessel register	Mesh size 120 mm stretched; escape panels; traps tagged with vessel register	Mesh size 120 mm stretched; escape panels; traps tagged with vessel register
By-catch limits	No	*Lophius gastrophysus* (5%); other coastal species*** (15% of the total catch)	*Chaceon* spp. (5%); *Lophius gastrophysus* (5%); Aristeidae shrimps (1% of the total catch)	*Chaceon* spp. (15%); *Lophius gastrophysus* (5% of the total catch).	*Lopholatilus villari* (5%); *Chaceon* spp. (5% of the total catch)	No	No	No

Exclusión areas	No	SE and S (****)	SE and S (****)	SE (****); seamounts; coral bottoms; areas N of 21ºS when catches of *A. antillensis* attain 4.4 ton	SE and S (****)	Spawning time/area: August to December; < 600 m depth	Spawning time/area: January to June; < 700 m depth	No
Rotation of harvestable areas	No	No	No	N and S from the exclusion area SE	No	No	No	No
Catch or processing limits	No	No	No	No	No	Mutilation (only claw processing) prohibited	Mutilation (only claw processing) prohibited	Mutilation (only claw processing) prohibited
Control	Logbooks; VMS	Logbooks; VMS; Obser-vers (20% coverage)	Logbooks; VMS; Observers (50% coverage)	Logbooks; VMS; Observers	Logbooks; VMS; Observers	Logbooks; VMS; Observers	Logbooks; VMS; Observers	Logbooks; VMS; Observers

* Under moratory.
** *Plesionika* spp., *Parapenaeus americanus; Rioraja agassizzi; Altantoraja cyclophora; A. castelnaui; A. platana; Sympterygia bonapartei; S. acuta; Genypterus brasiliensis; Paralichthys isosceles; P. triocellatus; Illex argentinus; Metanephrops rubellus; Mullus argentinae; Polymixia lowei; Helicolenus dactylopteru; Zenopsis conchifera.*
*** mainly *Cynoscion striatus; Micropogonias furnieri; Umbrina canosai* and *Macrodon ancylodon.*
**** Exclusions areas named SE and S are defined, respectively, by the following coordinates: 23º40'S/44º00'W-24º15'S/45º00'W-24º26'S/43º30'W-25º0 0'S/44º30'W and 29º00'S/48º35'W-29º00'S/47º40'W-30º00'S/49º20'W-30º00'S/47º40'W.

Brazilian codling, *Urophycis mystacea* (Ribeiro, 1903)

The Brazilian codling is another gadiform of great importance for the development of a deep-water fishery off Brazil. The species occurs over the slope throughout the entire latitudinal range of the southeastern and southern sectors of the Brazilian coast. High densities have been reported south of 30°S, where the species concentrates below the 150 m isobath, and also in some areas to the north of 30°S, although always deeper than 300 m (Haimovici *et al.*, 2008). This gadid was a major target of slope trawling conducted by national vessels between 2001 and 2003, contributing 30.7% and 17.8% of the catches landed by double rig and stern trawlers, respectively (Perez & Pezzuto, 2006). Its proportion in the catches tended to be even higher on trips conducted in areas deeper than 250 m south of 29°S. In the catches of chartered trawlers, *U. mystacea* was regarded as incidental, possibly because operations were concentrated in the northern extreme of the southeastern sector of the Brazilian coast, an area where the species is less abundant (Perez *et al.*, 2009a). In addition, most chartered trawlers have usually discarded this species as it lacked international markets. Between 1997 and 1998, Haimovici & Velasco (2007) reported that the Brazilian codling was relatively important in the landings of the long-line fleet operating off southern Brazil, pointing out that catches could be even higher than the figures recorded at the landings since the species was frequently used as bait for higher-priced species such as the wreckfish. In fact, the species was among the most abundant in the catches with long-lines, vertical lines, and traps conducted on the slope off southern Brazil under the REVIZEE program and also in commercial catches obtained by chartered longliners in 2000-2001 (Perez *et al.*, 2003; Haimovici *et al*., 2004; Bernardes *et al.*, 2005a). In the chartered gillnet fishery for monkfish, the Brazilian codling was one of the major components, although less than 25% of these catches were estimated to be actually retained and processed (Perez & Wahrlich, 2005). Recently, as the national deep-water gillnet fishery for monkfish expanded to deeper areas of the slope, catches of *U. mystacea* have also increased and been landed as valuable bycatch. The species is undoubtedly one of the most abundant components of the demersal habitats of the slope off southeastern and southern Brazil, and it is also one of the most intensely fished, both intentionally and non-intentionally, by several fishing methods (Haimovici *et al.*, 2006a).

Landed catches of the Brazilian codling have been historically pooled with those of a shallow-water cogeneric species: *U. brasiliensis* (Valentini & Pezzuto, 2006). Nevertheless, a three-fold increase in the landings recorded since 2001 has been attributed to catches of the slope form (*U. mystacea*) as a consequence of the trawl fishery's expansion to deeper areas (Perez & Pezzuto, 2006). Total landings oscillated between 5,000 and 7,000 ton between 2001 and 2003, declining in the subsequent years (Table 5). Estimates derived from the landing composition in the harbors of Santa Catarina State, where *U. mystacea* has been found since 2003, indicate that between 70 and 80% of these figures correspond to catches of this species.

Following the same estimation procedures previously described for the Argentine hake, an MSY of 1,182.4 ton has been estimated for this species, that is 9.5% of the total biomass available in fishing areas of southeastern and southern Brazil in 2002 (12,446 ton ± 4,605.0 ton 95% CI) (Perez, 2006; Haimovici *et al.*, 2008). Even considering that reported landings overestimate *U. mystacea* total catches (see above), it has been demonstrated that these have greatly surpassed, at least since 2001, the limits estimated as potentially sustainable (Table 6) (Anon, 2007). Significant biomass reductions have been observed in 2004-2005, possibly as the outcome of an unsustainable fishing regime (Perez, 2007a). Similar conclusions have been drawn by Haimovici *et al.* (2006b), who argued that the species was probably subjected to excessive exploration rates (0.5-0.6) in 1997-1998, even before the slope trawling expansion in Brazil. The species is to be considered, along with the Argentine hake, in the upper slope trawling management plan (Table 7).

Silvery John dory, *Zenopsis conchifera* (Lowe, 1852)

This benthopelagic zeiform is distributed in shelf break and slope areas worldwide. Fishing surveys conducted off southeastern and southern Brazil since the 1970s have indicated a moderate potential for commercial exploitation, although this is generally hampered by the uncertain availability of favorable markets for this species (Haimovici *et al.*, 1994). The recent survey conducted under the REVIZEE program revealed that the species is concentrated at depths of 200 to 400 m, particularly in two latitudinal strata: 29-30°S and 23-25°S (Haimovici *et al.*, 2008). Commercial catches were recorded for the first time in those areas by chartered trawlers during the 2000-2001 exploratory phase (Perez *et al.*, 2003; Perez *et al.*, 2009a). After that, in general, the species was still caught abundantly by these trawlers although it was usually discarded (Perez *et al.*, 2009a). This may also have contributed to the small volumes recorded at the landing sites of the national trawlers that operate on the slope grounds (Table 5).

In 2002, the biomass and calculated MSY were 38,876 ton (± 24491.9 ton 95% CI) and 4,895.5 ton (12.5% of total biomass), respectively (Table 6) (Perez, 2006; Haimovici *et al.*, 2008). Whereas landings indicate that the stock has been largely underexploited (Table 5), the indirect impact may be significant given the considerable biomass that was likely discarded by national trawlers operating on the slope off southeastern and southern Brazil, where the species is highly vulnerable (Haimovici *et al.*, 1994; Perez *et al.*, 2009a). The species is also considered to be a target in the upper slope trawling management plan (Table 7).

Red crab, *Chaceon notialis* Manning & Holthuis, 1989

Following the development of a directed fishery in Uruguayan waters since 1995 (Defeo & Masello, 2000), the exploitation of the red crab *C. notialis* started in Brazil in 1998, when the Japanese factory vessel Kinpo Maru No. 58 was chartered by a national company. The vessel was closely monitored by observers and VMS since 2000, making available all the fishing and biological data needed for describing and analyzing this valuable, new deep-water fishery. Between 2000 and 2004, red crab catches oscillated around 1,130 ton year^{-1} (Table 5) and were entirely exported to Asia as frozen processed crabs. After attaining a maximum of 1,377.7 ton in 2003, catches declined continuously until 2007, when the permit for Kinpo Maru No. 58 was cancelled by the national fishing authorities.

The application of the Effective Fishing Area Method (Defeo *et al.*, 1991; Arena *et al.*, 1994) and Gulland's Formula (Pezzuto *et al.*, 2002) for the "Brazilian" part of the stock (33°00'S and 34°40'S) allowed the virginal biomass and the MSY to be estimated at 17,117.8 ton (16,453.6-7,779.0 CI95%) and 1,027 ton per year, respectively (Table 6). A management plan for the red-crab fishery was established in May 2005 (Pezzuto *et al*, 2006a) and included, *inter alia*, a total allowable catch of 1,050 ton live weight year^{-1}, a maximum number of permits (2 vessels), and a minimum mesh size of 110 mm (stretched) in the pots (Table 7). Unregulated catches surpassed MSY in most years (Table 5) and, therefore, by the end of 2005, the stock biomass was reduced to nearly 60% of its original levels (Pezzuto *et al.*, 2006a).

Females naturally contributed 67 to 77% of the biomass exploited in Brazil and most of the catches were composed of immature individuals. Spawning seems to be localized both in space and time; in Brazil, ovigerous females were found concentrated at depths lower than 600 m, mostly from July to December (Pezzuto *et al.*, 2006b), following the same pattern previously reported for Uruguayan waters (Defeo *et al.*, 1992). A review of the red crab management plan has been recently agreed on and was implemented in 2008 (Table 7). The main changes in the original rules include a TAC reduction to 735 ton year^{-1}, a fishing ban in areas shallower than 600 m during the second half of the year, and a minimum mesh size in the pots of 120 mm (stretched).

Royal crab, *Chaceon ramosae* Manning, Tavares & Albuquerque, 1989

Unlike *Chaceon notialis*, which was exploited in Brazil by a single pot vessel, the fishery for *Chaceon ramosae* started in 2001 and soon expanded to a fleet of up to eight foreign processor vessels chartered by national companies. The species was also the most abundant and valuable bycatch item of several chartered gillnetters and trawlers that targeted other deep-sea resources, namely monkfish and aristeid shrimps (Perez & Wahrlich, 2005; Pezzuto *et al.* 2006c).

In the first year of exploitation, catches of royal crabs summed 593.6 ton and exhibited a 2-fold increase in 2002 (Table 5). Catches declined in 2005 and 2006 as a direct response to lower catch rates and successive reductions in the number of vessels in the fishery, which was interrupted by the end of 2006 (Pezzuto *et al.*, 2006b). In 2002, stock biomass and MSY were estimated to be 11,636.4 ton (11,271.5-12,007.7 ton CI 95%) and 593.5 ton, respectively (Table 6) (Pezzuto *et al.*, 2002, 2006a). A management plan for the royal-crab fishery was only established in May 2005 and included, *inter alia*, a total allowable catch (600 ton live weight year^{-1}), a maximum number of permits (3 vessels) and pots per vessel (900 units), and minimum mesh size in the pots (100 mm stretched) (Table 7). Delayed management was critical for the species, as catches surpassed the suggested TAC in most of the years and especially in 2002, when they were 211% higher than the MSY. In 2005, the stock biomass was reassessed at 44-48% of the 2001 levels (Pezzuto *et al.*, 2006b).

Males naturally predominated the catches and ovigerous females were concentrated in areas shallower than 700 m from January to June (Pezzuto *et al.*, 2006b); more than 50% of the males and females caught between 2001 and 2005 were sexually immature (Pezzuto & Sant'Ana, 2009). The management plan for the royal crab fishery was recently reviewed in light of the new findings regarding stock biomass levels and biological characteristics of the species (Table 7). The newly established measures include: a) a 33% reduction, either in the TAC or the maximum number of permits, b) the closure of areas shallower than 700 m during the first half of the year in order to protect ovigerous females from fishing, and c) increasing the minimum mesh size in the pots from 100 to 120 mm (stretched).

Golden crab, *Chaceon fenneri* (Manning & Holthuis, 1984)

The golden crab *Chaceon fenneri* was first reported in the Brazilian EEZ by Sankarankutty *et al.* (2001) based on survey samples taken along the northeastern coast (1.5-4.0°S; 34.0-42.0°W). Previously known only in the northwestern Atlantic (Manning & Holthuis, 1989), the species supports a directed fishery in the United States (Erdman & Blake, 1988). Exploitation for golden crabs in Brazil has been very incipient as compared to royal and red crabs, supposedly due to operational and/or commercial limitations experienced by most of the foreign vessels which, besides targeting the latter species, conducted some exploratory fishing on the northeastern coast as well. A preliminary management plan has been recently discussed for this species, although adequate data on distribution, fishing potential, and biological characteristics are virtually inexistent (Table 7). Most information on this stock has been made available very recently, as fishing operations of a national pot vessels that entered the fishery have been continuously monitored. Carvalho *et al.* (2009) summarizes the preliminary results of this study.

Scarlet shrimp, *Aristaeopsis edwardsiana* (Johnson, 1867)

The scarlet shrimp (*carabinero shrimp*) is an aristeid shrimp distributed in slope areas worldwide. This is a high-valued deep-water species that has been commercially exploited by trawl fisheries at low latitudes of both the East and West Atlantic (Dallagnolo *et al.*, 2009). Off Brazil, it has been the main target of the lower slope trawl fishery phase conducted by chartered vessels since 2003 (Pezzuto *et al*, 2006c; Perez *et al.*, 2009a). The main concentrations have been exploited in the southeastern sector, between 22 and 26°S and from the 700 to 750 m isobaths. After 2004, fishing exploration continued within these bathymetric boundaries but expanded latitudinally to productive areas in the central and southern sectors of the Brazilian coast. Concentrations were also identified in northern Brazil, off the coast of Amapá State, where fishing was mostly exploratory (Pezzuto *et al*, 2006c; Perez *et al.*, 2009a).

Annual catches increased from 13.0 ton in 2002 to a maximum of 182.6 ton in 2005, declining to 19.9 ton in 2007 (Table 5). Through the use of commercial catch rate data and swept area procedures, a total exploitable biomass of 865.0 ton was estimated within the fishing areas south of 19°S in 2002 (Table 6). This biomass, regarded as virginal, was reduced by 41 to 49% by 2007 due to an intense trawling effort concentrated on spatially limited fishing grounds (Dallagnolo, 2008). Considerations of the species' life-history (Kirkwood *et al.*, 1994) allowed the definition of an MSY of around 6% of the virginal biomass or approximately 2.5 ton. Taking the total biomass at MSY as a limit reference point, it was concluded that the recent state of the scarlet shrimp stock has been biologically unsafe, demanding short-term restoration management actions (Table 6).

Biological data have shown that males attain smaller sizes (maximum 72 mm carapace length) than females (maximum 106 mm carapace length). Sexual maturity was reached at 57-59 mm and 47.7 mm carapace length in males and females, respectively. The reproductive cycle is annual, with most activity concentrated in the second half of the year. The catch size-structure was dominated by females and included limited proportions (15-24%) of immature individuals (Anon, 2007). A management plan for this fishery has been recently proposed, including the other two aristeid shrimps (see below) as target species but using the scarlet shrimp fishing potential to limit annual catches (Table 7) (Dallagnolo, 2008).

Giant red shrimp, *Aristaeomorpha foliacea* (Risso, 1827)

The giant red shrimp (*moruno shrimp*) was the second most abundant aristeid shrimp caught by chartered trawlers on the lower slope off Brazil (Pezzuto *et al.*, 2006c). Catches were generally associated with the chartered trawling activity directed at the larger, more abundant scarlet shrimp. Nevertheless, the species was found to dominate catches in particular fishing grounds of the southeastern and central sectors, principally in later years as densities of scarlet shrimp decreased (Dallagnolo *et al.*, 2009). Total giant red shrimp catches increased continuously until 2005 and 2006, peaking at 42.6 and 51.7 ton, respectively, and then declining to 7.7 ton in 2007 (Table 5).

Densities increased continuously on the slope off southeastern Brazil from 2002 to 2007, as estimated by commercial catch rate analysis. In this sector, the mean exploitable biomass peaked in 2007 at 205.6 ton (Dallagnolo, 2008). Off the central sector of the Brazilian coast, a maximum of 86.5 ton of exploitable biomass was estimated in 2006, declining by approximately 46% in 2007, possibly in response to harvest rates as high as 22-53.6% in 2005-2006. The estimated MSY for the giant red shrimp was 15-19% and 17-20% of the exploitable biomass for females and males, respectively (Table 6) (Dallagnolo, 2008). The largest males in the catches attained 62 mm and the largest females 91 mm carapace length. Maturity was reached, on average, in males and females with carapaces of 46 mm and 29 mm long, respectively, and reproduction was found to be continuous in the fishing grounds throughout the year. Immature individuals have been rare in the catches (Anon, 2007).

Alistado shrimp, *Aristeus antillensis* A. Milne Edwards & Bouvier, 1909

The alistado shrimp was a minor component among the aristeid shrimps exploited off Brazil, accounting for approximately 5% of the total catches reported between 2000 and 2007. The species was known to occur in the western Atlantic as far south as French Guiana, where it has been exploited along with the scarlet shrimp (Guéguen, 2001). Chartered trawlers reported this species in the northern sector of the Brazilian coast, but commercial concentrations have been detected and exploited principally off central Brazil (Pezzuto *et al.*, 2006c; Dallagnolo *et al.*, 2009). Catches between 2005 and 2006 were considerably lower than those reported for the other shrimps, peaking in 2005 at 15.8 ton (Table 5). A mean virginal biomass of 49.8 ton was estimated for the fishing grounds of the central sector in 2004. This biomass was reduced by nearly half until 2007, particularly after a maximum harvest rate of 32% exerted by chartered trawlers in 2005 (Dallagnolo, 2008). The latter author also estimated an MSY for the species in 19-22% of the exploitable biomass. The alistado is the smallest of aristeid shrimps exploited off Brazil; samples measured on board have included males and females as large as 55 and 67 mm carapace length. Catches have been greatly skewed towards large-sized females (Anon, 2007).

Argentine short-fin squid, *Illex argentinus* (Castellanos, 1960)

Illex argentinus is an ommastrephid squid distributed in the southwest Atlantic from the coast of Rio de Janeiro State to southern Argentina. On the Patagonian shelf and around the Falkland/Malvinas Islands, the species sustains one of the largest cephalopod fisheries in the world (Haimovici *et al.*, 1998). Off Brazil, despite being regarded as a potential slope-water fishing resource since the 1970s (see review in Haimovici *et al.*, 2007), records of commercial catches were scarce until the beginning of the chartered trawler operations in 2000 (Perez *et al.*, 2003; Perez *et al.*, 2009a). In austral winter 2002, a South Korean chartered trawler produced, in four complete fishing trips off southern Brazil, a total of 1,400 ton, the largest catches ever recorded in Brazilian waters. These catches were concentrated in a relatively small area off the "Santa Marta Grande" Cape between 26 and 29°S and the 250 and 500 m isobaths (Perez *et al.*, 2009a) and were followed by operations of national trawlers. These trawlers contributed nearly 13% of the total reported landings in 2002 (2,600 ton) (Perez & Pezzuto, 2006). After that episode, annual landings were greatly reduced and sustained basically by national trawlers at around 100-400 ton per year (Table 5). These catches were obtained off southern Brazil below 250 m depth and have been highly seasonal, concentrated in late winter-early spring (September-October) (Perez & Pezzuto, 2006).

Trawl surveys conducted under the REVIZEE program estimated relative abundances much higher than those obtained by previous surveys off southern Brazil (Haimovici *et al.*, 2006c, 2008). This pattern could be attributed to abundance fluctuations, a natural characteristic of this annual species (Haimovici *et al.*, 1998, 2006c). In addition, size and maturity data, as obtained in both scientific and commercial catches, related productive areas and fishing episodes to the austral winter northward migrations of Patagonian stocks spawning over the lower slope of southern Brazil (Perez *et al.*, 2009b). Other concentrations of smaller mature males and females occur throughout the year over the shelf break, but they have not been targeted by the slope trawling fishery. Whereas the ecological aspects involved in such migrations are not fully understood, it has been pointed out that any squid fishing developed off Brazil would have to consider a shared stock scenario with Argentina and Uruguay (Haimovici *et al.*, 2006c). The species is currently considered within the upper slope trawl fishery management plan as one of the target species (Table 7).

BYCATCH

The detailed recording of catch compositions by observers on board chartered vessels has provided opportunities to assess the impact of deep-water fishing on the slope ecosystems of Brazil. The most comprehensive study to date has focused on a qualitative and quantitative bycatch analysis of the chartered gillnet fishery for monkfish during 2001 (Perez & Wahrlich, 2005). Absolute catches in numbers of non-targeted species were estimated for the entire chartered gillnet fleet in 2001 through their observed mean catch rates (individuals per sampled net). These catches ranged from (a) 33 to 459,833 for invertebrate species, most notably the royal crab and spider crabs (family Majidae); (b) 41 to 23,954 in elasmobranchs, principally the angel shark and various skates (family Rajidae); (c) 41 to 110,665 in teleosts, namely the beardfish (*Polimixia lowei*), silvery John dory, Brazilian codling, Argentine hake, wreckfish; and (d) 8 to 711 turtle, cetacean, and bird species. Indirect mortality impacts tended to be higher in mobile bottom dwellers but bycatch abundances decreased and their basic composition changed southwards, where large teleosts, elasmobranchs, cetaceans, and birds were dominant over the small teleosts, crustaceans, and other invertebrates that characterized the bycatch composition in the northern area. Non-intentional mortality inflicted by bottom gillnets on large K-strategists (wreckfish, sharks, rays, turtles, cetaceans, birds) was regarded as critical, although highly correlated with operations in the southernmost areas of the Brazilian EEZ, where these groups tend to concentrate.

Assessments of the latter and other slope fisheries (including cephalopods and other invertebrates) have been mostly qualitative (Perez *et al.*, 2004, Bastos, 2004). A total of 185 macro and mega invertebrates as well as sponges, cnidarians, annelids, crustaceans, mollusks, and echinoderms were recorded in both studies. Contrary to previous expectations, static gears such as pots and gillnets were shown to catch a higher number of sessile (~54%) than mobile species (~46%). This pattern has been attributed to the intensive entangling of sessile fauna (mostly cnidarians) in these gears during their retrieval, as the equipment is dragged for a relatively long distance over the bottom before being lifted from the seafloor. Considering the length of the pot (9 km) and gillnet (20 km) lines used during each fishing set, it has been argued that their impact on benthic fauna may not be as unimportant as previously thought. Closer attention has been paid the impact of the trawling fishery directed at aristeid shrimps on the lower slope because (a) this fishery produces diverse bycatch of truly deep-water benthopelagic fishes (families Synaphobranchidae, Macrouridae, Trachichthyidae, Berycidae, Astronestidae, Oreosomatidae, Ipnopidae, Alepocephalidae, Ophidiidae, and others) (unpub. data) and (b) removes deep-sea corals, particularly where they form slope and seamount reef formations (Pires, 2007).

All the above assessments have been regarded as empirical evidence necessitating the inclusion of ecosystem-based measures in deep-water fishery management plans, mostly through reduced efforts, bycatch restrictions, and marine protected areas (Table 7) (Perez *et al.*, 2002b, 2007b).

ECONOMICS

The chartering of foreign fishing vessels was a political instrument to develop deep-water fisheries off Brazil and contribute to increased of foreign currency, since most deep-water resources available in the Brazilian EEZ attained high prices in their main international markets. Soares (2007, 2008) analyzed the efficiency of this instrument by examining official records of revenues obtained by deep-water products exported between 2001 and 2006.

In this period, a total of US$ 8.3 million were negotiated from exports of 1,838.2 ton of frozen monkfish products, 78.39% of which was destined to EU markets (mostly Spain) (Soares, 2008). As for deep-sea crabs (*Chaceon* spp.), exports of 7,315.3 ton of frozen products in the same period rendered US$ 12.4 million. From 2004 onwards, deep-sea crab exports decreased as a direct consequence of the reduced effort by the chartered pot fleet (Soares, 2007).

Aristeid deep-sea shrimps have not been distinguished in Brazilian exports, which aggregate all shrimp species exploited in the country. However, considering the estimated prices of scarlet and giant red shrimps in the European market (around US$ 20 per kg), the revenues accumulated between 2002 and March 2006 can be estimated to have reached US$ 8.8 million (Soares, 2007).

Official figures such as those presented above, however, have raised considerable uncertainties about the economic importance of all deep-water fishing in Brazil, particularly because prices of several species negotiated by Brazil, as estimated from the total annual revenue – total annual catch ratio (*i.e.* monkfish US$ 4.54 kg^{-1}; deep-sea crabs US$ 1.70 kg^{-1}), have frequently remained significantly below known international prices (*i.e.* monkfish US$ 13.00 kg^{-1}; deep-sea crabs US$ 9.70 kg^{-1} [1]). The reasons behind such inconsistencies are not clear, but they seem to be most likely related to incorrect official records, either as a result of inadequate product definitions in Brazilian export customs or misreporting. In any case, a realistic figure of total revenues obtained by the export of deep-water resources is currently unavailable (Soares, 2007). According to chartering contracts signed by both national and foreign partners, it is known, however, that only 5 to 10% of the total revenues obtained by fish products generated by deep-water operations were retained by Brazilian companies.

[1]Average values obtained in several Spanish markets www.bim.ie

INSTITUTIONAL FRAMEWORK, DEVELOPMENT, MANAGEMENT, AND CONTROL

In the 1960s, Brazilian fishing activity changed radically as the so-called "industrial" fleet was structured and unprecedented large-scale fishing regimes were established on the continental shelf. Nearly forty years later, deep-water fishing development passed another turning point in the country's fishing history, largely provoked by the combination of increasingly uneconomic shelf resources and clear government incentives to promote the occupation of the Brazilian EEZ. This process involved new paradigms, not only of fishing practices, areas, resources, and markets, as described above, but also regarding the institutional framework, development, management, and control.

Institutional framework

Until 1998, fishing management and control were responsibilities of the Ministry of the Environment (MMA), which was strongly rooted in an almost 40-year-old coastal fishing-oriented management model. Fishing administration was placed under this ministry nearly 10 years before, as fishing resources were recognized in the Federal Constitution of 1988 as pertaining to the *environmental resources*, whose protection and preservation were explicitly assured by the Law. The Constitution was promulgated after the end of more than two decades of dictatorial political regime and strongly reflected the new democratic atmosphere prevailing in the country. In fact, Article 225 stated explicitly that not only the Public Power but also the collectivity were both obligated to protect and preserve the environment for present and future generations. Such a political and institutional scenario opened the opportunity for participatory management practices to be attempted and reinforced in the following years (Marrul Filho, 2003). Mostly developed through punctual and "open" multiparty meetings (*i.e.* not organized under a formal structure in terms of composition and functioning), forums promoted by the MMA since the 1990s have focused mainly on overexploited coastal stocks demanding urgent management decisions.

In 1999, through political pressure from the fishing industry interested in a more "development than environmentally-oriented philosophy", a second management authority was created under the Ministry of Agriculture and Livestock (DPA/MAPA) with a mandate to develop and manage aquaculture and the economic exploitation of those stocks defined as "sub-exploited, unexploited, and highly migratory"; overexploited stocks remained under the jurisdiction of the MMA. In essence, although no modifications of the national fishing legal concepts were set up at that point, this divided mandate allowed mostly oceanic and deep-water fishing policies to be promoted under a more social and economic scope of development. Both legal entities have co-existed ever since, not without strong and continuous inter-institutional conflicts (Dias-Neto, 2003). Nonetheless, in 2003, DPA/MAPA was transformed into a Special Secretariat directly linked to the Presidency of the Republic (SEAP/PR), and again, in 2009, into the Ministry of Fishery and Aquaculture (MPA).

Development

Incentives for the development of the deep-water fishery in Brazil were materialized mostly in a short-term chartering program launched by DPA/MAPA. This, in essence, allowed national and overseas fishing companies to associate and operate foreign deep-water vessels under temporary fishing authorizations. The explicit objectives of the chartering program were: (i) to enhance the fish supply in the domestic market and to generate foreign currency; (ii) to improve competence and promote employment in the national fishing industry; (iii) to occupy rationally and sustainably the Brazilian EEZ; (iv) to stimulate the formation of a national fleet capable of operating in deep-waters and utilizing equipment that incorporates modern technology; (v) to expand and consolidate fishing enterprises; (vi) to generate knowledge on living resources of the continental shelf and EEZ; and (vii) to sustainably exploit fishing resources on the high-seas. This government strategy led to the explosive development of foreign fleets targeting new, valuable, fragile deep-water resources (Perez *et al.*, 2002a, 2003, 2009a; Pezzuto *et al.* 2006a, 2006c), in some cases, paralleled by an expansion of coastal domestic fleets to the same areas and resources (*e.g.* Perez & Pezzuto, 2006). Not only did fishing efforts dramatically increase on virginal stocks for which the fishing potential was virtually unknown, but this process also stimulated conflicts between fleets and resulted in, within most of the national fishing industry, a disregard for fishing authorities (namely DPA/ MAPA, SEAP/PR) and established management plans (see below).

Management

Concerns about the sustainability of the target species as well as environmental, social, economic, and political impacts of such an uncontrolled scenario made indispensable the development of an institutional management framework that could provide investment dimensions, access limits, and controls. At the end of 2002, the Consultant Committee for the Management of Deep-water Resources (CPG) was created under the MAPA and was maintained by SEAP/PR after 2003. This committee inaugurated a new phase in the management of marine resources in Brazil, as participatory practices finally crystallized in a formal and organized multiparty forum. Delegates of the fishing sector (shipowners, fisherman, and fishing industry workers) and governmental agencies compose the CPG, along with an Executive Secretariat and members of Scientific and Compliance Subcommittees (SCC and SC, respectively). Through annual ordinary meetings, the SCC[2] produces the bulk of data and recommendations to be discussed and approved at the regular CPG meetings. Management plans and other recommendations from the CPG have consultant power only, as the final decision is under the jurisdiction of the Secretariat.

Despite representing significant progress towards a more rational management process in Brazil, the CPG experience has not yet been totally successful. Fishing development and its negative impacts have occurred more rapidly than the bureaucracy (challenged by political and institutional pressures) has been able to deal with. Weak representativeness, the limited dependence of the users on deep-water resources, strong intra- and intersectoral (government and industry) disputes, incredulity regarding the enforcement of the agreed measures, limited administrative structures available to support the CPG activities, and general inexperience with formal management forums are some of the main problems that have limited the effective commitment of fishermen, the industry, and the government to the sustainable development of deep-water fishing in Brazil.

Control

Managing deep-water fishing induced significant scientific, technological, and administrative advances. Programs of fishery observers and satellite VMS were developed for the first time in the country by 2001 in response to greater demands for control measures and data acquisition on deep-water fishing. Inserted within pragmatic, government-induced, scientific research programs that focused fully on deep-water-fishing, such tools allowed large data sets and assessments to be promptly generated, not only on fisheries and targeted stocks, but also on the deep-water environments of Brazil as a whole. Today, both tools are incorporated into national policies for marine resource conservation, regardless of the exploration area and fishing resource, and with a potential for broadening current management practices.

The monkfish fishery: a case study

The deep-water monkfish fishery was the first to be developed under the new institutional framework, management process, and control practices. As such, it is not only an example of their first practical implementation process but also illustrates the complexities involved in attaining a sustainable use of this deep-water resource. Following the explosive start of the fishery in the late 1990s, under the DPA/MAPA jurisdiction, biological, technological, and operational data were collected intensively during 2001. A complete stock assessment and management recommendations were first made available to government and industry in April 2002, even before reaching the CPG foundation (Perez *et al.*, 2002b).

Scientific results and recommendations were subsequently analyzed and improved during the first two SCC meetings of 2002. Three other meetings of a special working group formed by the SCC, government, and industry members produced the first version of the monkfish management plan. This plan was approved under the CPG in December 2002 but was not implemented until January 2003, when the recently elected President of the Republic created the Special Secretariat for Aquaculture and Fishing (SEAP/PR), which absorbed all responsibilities previously attributed to MAPA.

SEAP/PR then decided to reopen the debate on the monkfish fishery in 2003, considering not only the new institutional and political circumstances, but also the strong opposition by the part of the industry interested in a more free-access regime to the fishery. A new version of the management plan was discussed and approved in November but, again, it was not implemented. After more than four years of uncontrolled exploitation, in May 2004, the stock was declared to be overexploited. As a consequence, the jurisdiction on the species was shifted to the MMA, which also did not implement the plan, in spite of the negative situation of the stock. Therefore, in March 2005, scientists, members of the SCC, decided to adopt a strong political stance demanding legal intervention in the process in order to ensure the sustainability of the stock and respect for the Constitution. As a consequence, in May of the same year, MMA and SEAP/PR implemented, in cooperation, the monkfish management plan as previously approved under the last CPG sessions (Table 7). Even after that, enforcement of management rules has been poor and subsequent biomass assessments have not shown any signs of recovery.

The management of other deep-water resources such as geryonid crabs, aristeid shrimps, and demersal fishes has faced the same difficulties, with negative consequences for the sustainability of the respective stocks.

[2] All authors of this review have been permanent members of SCC CPG. The senior author has chaired the SCC since its creation in 2002.

FUTURE PROSPECTS

The recent deep-water fishing development off Brazil characterized what has been defined as a “gold-rush” fishing episode, both revealing valuable fishing opportunities on the slope areas of the EEZ and accumulating conflicts and environmental losses. Future prospects are highly uncertain and dependent on solving critical drawbacks that can be identified below as:

Developing a domestic deep-water fishing industry. On the upper slope, the Argentine hake, Brazilian codling, Argentine squid, and monkfish have been quickly incorporated as targets of the national trawl and gillnet fleet. Yet, on the lower slope, national fishing for deep-water crabs and shrimps is currently interrupted and may only be economically viable for foreign vessels that can cope with the elevated costs, lack of a domestic market, and uncertainties about long-term economic sustainability. Unlike national vessels, these originate from “distant-water” fleets and are prepared to supply fishing products to the international market and to move to different fishing areas of the world when opportunities for higher profits arise through bi-lateral political arrangements. This picture is not likely to change in the near future unless new government incentives oriented at the formation of a national truly deep-water fleet are made available to the fishing industry. These incentives do exist in the form of a vessel-financing plan (Program PROFROTA), but they have been highly unsuccessful since they fail to neutralize the referred limitations and risks associated with deep-water operations. Even if such difficulties are overcome, it must be acknowledged that previous expectations of a large-scale slope fishery now seem incompatible with the demonstrated biological productivity. Sustainable and profitable deep-water fishing off Brazil, if ever achievable, will be restricted to a few highly controlled fishing units.

Promoting social and economic benefits. Whereas environmental costs from the overexploitation of deep-water resources have been quantified through abundant and consistent data, benefits stemming from the economic earnings have been obscure and underestimated due to the failure of the national export recording systems or deliberate misreporting of values negotiated in the international market. It seems paradoxical that a public policy conceived to develop fishing would fail to promote an adequate dimensioning of the benefits obtained by it. Unless this scenario is reversed through strong actions from the fishing authorities, a more responsible political decision would be to promote full conservation of the deep areas within the Brazilian EEZ rather than the economic exploitation of its fragile renewable resources.

Improving management practices. The CPG constituted an innovative institutional framework, setting a direct path through which scientific assessments became subsidies to a participatory process of building deep-water fisheries management plans. Such a framework can be regarded as an important advance in the country’s management practices and is thought to promote (a) the required rupture with the obsolete management model and (b) balanced exploitation of valuable, fragile deep-water stocks. Both the fishing industry and government, however, have so far failed to explore the legitimacy of this forum and turn its management proposals into effective actions. In combination with the institutional instability that has characterized the history of fishing management in Brazil (see Paiva, 2004 for a review), these political difficulties have contributed to the overfishing of deep-water resources. These resources may take a long time (if ever) to recover to biologically safe levels. Hence, the maintenance of the CPG as a promising management mechanism may be at risk, as the expectations of the industry for the effectiveness of this forum to promote sustainable fishing earnings are frustrated in the long run.

Amongst these critical issues, however, are advances in monitoring and control systems, positive legacies that can radically contribute to public consciousness on the use of marine fishing resources in Brazil. It is now expected that these legacies and the lessons learned from this fishing episode may at least play a role in the education of scientists, fishers, and managers, allowing the definition of solutions that will help the country recover the sustainable potential of its valuable deep-water resources.

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