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Slipper lobster (Crustacea, Decapoda, Scyllaridae) fisheries off the southeastern coast of Brazil: I. Exploitation patterns between 23°00′ and 29°65′S

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A B S T R A C T

In southeastern Brazil, slipper lobsters (*Scyllarides deceptor* and *S. brasiliensis*) are caught by fleets trawling for pink shrimp (*Farfantepenaeus brasiliensis* and *F. paulensis*) and pots-and-traps fishing for octopuses (*Octopus vulgaris*). Eight hundred fifty-six landings of shrimp trawlers and 28 of the octopus fleet were monitored in the Santos region from May 2006 to April 2007. Additional analysis was performed using a database covering the period from 1999 onwards. This study seeks to identify the recent patterns of exploitation of these lobsters with the goal of improving the way towards fishery sustainability. *Scyllarides deceptor* was the dominant lobster species with 1032 specimens collected, while only three specimens of *S. brasiliensis* were identified. The area known as the 'Farol do Boi' (23°01′S, 45°00′W to 25°00′S, 45°40′W at 60–135 m deep) showed the highest Catch Per Unit Effort (CPUE). A General Linearized Model (GLM) was used to investigate the factors influencing variations in CPUE in trawl fleets and led to the conclusion that year, month and depth were the most important factors. We detected a significant decrease in the relative abundance of lobsters in the fishing zone despite relatively low fishing effort. Recommendations to protect the lobster resources include taking special precautions in the natural refuge area of the 'Farol do Boi', as an exclusion zone for trawl fleets, and controlling the use of traps longlines to catch octopuses. Concerns about depensatory processes due to the over-exploitation of lobster populations around the world are raised.

1. Introduction

Globally, there is limited knowledge about the biology and fishery potential of the 88 species of lobsters in the family Scyllaridae, commonly known as slipper lobsters (Williams, 1965; Holthuis, 1995; Burton and Davie, 2007). Spanier and Lavalli (2006, 2007) suggest that the lack of information about slipper lobsters is due to the low commercial value of this group in comparison to spiny lobsters (family Palinuridae) and clawed lobsters (family Nephropidae). However, as other species of lobster decline in numbers due to over-exploitation, focus on slipper lobsters for commercial production directly or as a by-product of other fisheries has occurred (Spanier and Lavalli, 2007; Lavalli and Spanier, 2007).

Consequently, slipper lobsters have become more popular as seafood in some parts of the world, resulting in an increase in their economic value since the 1990s (Spanier and Lavalli, 2006, 2007; FAO, 2009). However, in all cases where these species have been recorded as the target of a local fishery (i.e. Galápagos Islands, Hawaii, India, Australia, and the Mediterranean Sea), their abundances have declined rapidly with a subsequent collapse of such fishing activity (Spanier and Lavalli, 2007).

Moreover, over-exploitation does not require the removal of large quantities of specimens from the natural environment. Some vulnerable species or small local populations can experience significant declines in stock size even with relatively minimal fishing effort levels (FAO, 2009). This circumstance requires extensive research and monitoring of current exploitation patterns are necessary as a first step towards the maintenance of healthy and sustainable stocks.

In Brazil, there have already been some indications of a reduction in the yields of slipper lobsters even though they are not yet the target of fishery fleets and comprise only a small proportion of the total volume of fishery resources (Coelho et al., 1996; Santos and Freitas, 2002; Oliveira et al., 2008). Three genera of the family Scyllaridae are found in Brazil: *Scyllarus*, *Parribacus* and *Scyllarides* (*S. brasiliensis*, Rathbun, 1906; *S. deceptor*, Holthuis, 1963 and *S. delfosi*, Holthuis, 1963). Two species from these genera are recorded as fish-

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ery stocks in southern and southeastern Brazil: *S. brasiliensis*, which is found from Maranhão to São Paulo at depths of 20–40 m, and *S. deceptor*, which is found from Rio de Janeiro to Rio Grande do Sul at depths of 6–300 m (Holthuis, 1991; Melo, 1999; Oliveira et al., 2008; De Leo and Pires-Vanin, 2006).

The most important lobster fisheries of the Atlantic coast of South America are concentrated in northeastern Brazil, where the spiny lobster (*Panulirus* spp.) is the most important fishery resource (Paiva et al., 1971). However, Santos and Freitas (2002) reported relative increases of *S. brasiliensis* in spiny lobster landings in the states of Pernambuco and Alagoas.

In southern and southeastern Brazil, slipper lobsters are generally part of the bycatch of two fishery fleets: the pot-and-trap fleet fishing for octopuses (*Octopus vulgaris*) and the fleet of pink shrimp (*Farfantepenaeus brasiliensis* and *F. paulensis*) trawlers. The latter has increasingly shifted its focus to capture slipper lobsters, especially during the off closed season for shrimp (Severino-Rodrigues et al., 2007). In the regions of Santos and Guarujá (in the state of São Paulo), there are currently records for at least 33 trawlers and 9 pot-and-trap vessels that fish for these lobsters along the coast, and there is potential for further increases in these numbers (Instituto de Pesca, 2008).

Brazil currently has no fishery management legislation regulating the extraction of slipper lobsters. Further, there is limited basic knowledge of the fishery biology and exploitation patterns of these species on which to base any such eventual rules. Studies evaluating the fishing pressures to which these stocks are exposed and their impact on lobster populations are particularly important. Such analyses could be helpful in evaluating the degree of fragility of the populations of slipper lobsters based on data acquired for lobsters of the genus *Scyllarides* (Oliveira et al., 2008).

To assess the impacts of fishing on slipper lobster populations, it is necessary to understand how they are removed from their natural habitats by local fleets as well as the intensity, geographical and depth patterns of these practices. This may prove to be particularly useful in initiating management strategies for future lobster removals. Within this broad context, this study aims to detect the exploitation patterns of slipper lobsters as bycatch in the South Brazil Bight area by considering the different fishing strategies adopted by distinct fleets.

2. Materials and methods

Weekly visits to the major fishing landing points of the Santos region (São Paulo State, SE Brazil) were undertaken between May 2006 and April 2007. The presence of slipper lobsters as bycatches of both shrimp trawlers (medium-sized double trawlers) and “polveiros” (vessels for octopus pot-and-trap fishing) were monitored. Once all catch volumes were unloaded, all lobsters were taxonomically identified using Melo (1999) as a reference. At the same time, interviews were conducted with the skippers and vessel owners to obtain further details on each fishery. For trawlers, interview data included target species of the fishery, number of trawl hauls performed each day, time spent trawling each day, number of days spent fishing, fishing depths, substrate type, geographic location of the fishing area, total catch of the fishery and total catch of slipper lobsters. For the pot-and-trap fleet, data collected included target species of the fishery, number of pots and/or traps per parcel (line), immersion time (in days), bait type, total number of parcels collected, days spent fishing, fishing depths, substrate type, geographic location of the fishing area (latitude in °S), total catch and catch of slipper lobsters.

Fig. 1 illustrates the different types of fishing gear (double-trawl and trap-and-pot longlining) and the ways they are used in fishing. Pots are more selective and attract octopuses because they serve as shelters. The traps use bait to catch octopuses, fish and slipper lobsters (Tomás and Avila-Da-Silva, 2005; Tomás et al., 2006). Each of these vessels can include up to 10 lines with 2500 pots and 150 traps per line, resulting in a total of 25,000 pots and 1500 traps for an individual fishery.

Additional data from trawl fishing that captured *Scyllarides* spp. as bycatch from January 1999 to April 2007 were obtained from the Instituto de Pesca's fishery database (Propesq). These data included number of vessels and landings, catch of *Scyllarides* (kg), total catch of the fishery (kg), days spent fishing, number of trawls, duration of trawls, geographic positions of trawls (latitude in °S), depth of trawls and substrate type.

The data were added to the field data and analyzed on annual, monthly, and seasonal timescales. Analyses were also performed during the open and closure periods (currently from March to May) of the shrimp fishery, taking into account changes in legislation that occurred in 2001 (MMA, 2001).

For the pot-and-trap fleet, only data from May 2006 to April 2007 were analyzed, as the Propesq database does not include slipper lobsters from that fleet. The catch (of both *Scyllarides* and all species), latitude, depth, substrate type, effort, immersion days, numbers of vessels and landings were analyzed on monthly and seasonal scales.

Catch data for the industrial fishery of the state of Santa Catarina were provided by UNIVALI-GEP (www.univali.br/gep).

Both the trawl and pot-and-traps fleets that land in the Santos region cover the whole known area of distribution of slippers lobsters in the South Brazil Bight (Holthuis, 1991; Oliveira et al., 2008). They are further representative of the regional fisheries and have witnessed no major changes over the study period (Instituto de Pesca, 2009). Therefore, the Catch per Unit Effort (CPUE) was considered meaningful as an index of the relative abundance of slipper lobsters.

The CPUE of the trawl fleet was calculated using the ‘time of hauling’ (the duration of the trawling) per fishing trip as a measure of fishing effort. This variable was found to have the best fit in linear regressions between catch and effort. For the pot-and-trap fleet, the number of traps was selected as the best measure of fishing effort after being informed by skippers and fishermen that pots are not effective in the capture of the slipper lobsters. Calculations of CPUE follow Sparre and Venema (1998) where:

$$\textit{Medium-sized double trawl}: \mathrm{CPUE\,(kg/h)} = \mathrm{Total\ catch\,(kg)/Total\ fishing\ time\,(h)}$$

$$\textit{Traps}: \mathrm{CPUE\,(kg/trap)} = \mathrm{Total\ catch\,(kg)/Number\ of\ traps}$$

The CPUE of the trawl fleet was log-transformed and tested for normality using the Shapiro-Wilk test (Zar, 1996, 1999). A general linearized model (GLM) (Crawley, 2006) was used to determine the significance level of the different factors (year, station, month, latitude, depth and closure of fishery) that led to variations in the CPUE. The GLM applied the following equation:

$$\mathrm{CPUE} = \mu + \alpha_{\mathrm{year}} + \beta_{\mathrm{month}} + \gamma_{\mathrm{depth}} + \delta_{\mathrm{closure}} + \varepsilon_{\mathrm{season}} + \phi_{\mathrm{lat}} + \varepsilon$$

where that's a given, μ is the intercept, α_{year} is the factor associated with the year, β_{month} is the factor associated with the month, γ_{depth} is the factor associated with the depth class, $\delta_{\mathrm{closure}}$ is the factor associated with the off-season for shrimp fisheries, $\varepsilon_{\mathrm{season}}$ is the factor associated with the season, ϕ_{lat} is the factor associated with the latitude class and ε is the error relative to a normal distribution. The above model assumes a normal gamma distribution in the CPUE data based on the best fit of this distribution to the dataset.

Data analysis was performed using MS EXCEL, R 2.5.0 (Ihaka and Gentleman, 1996) for statistical analysis, and SURFER® 2002 for mapping.

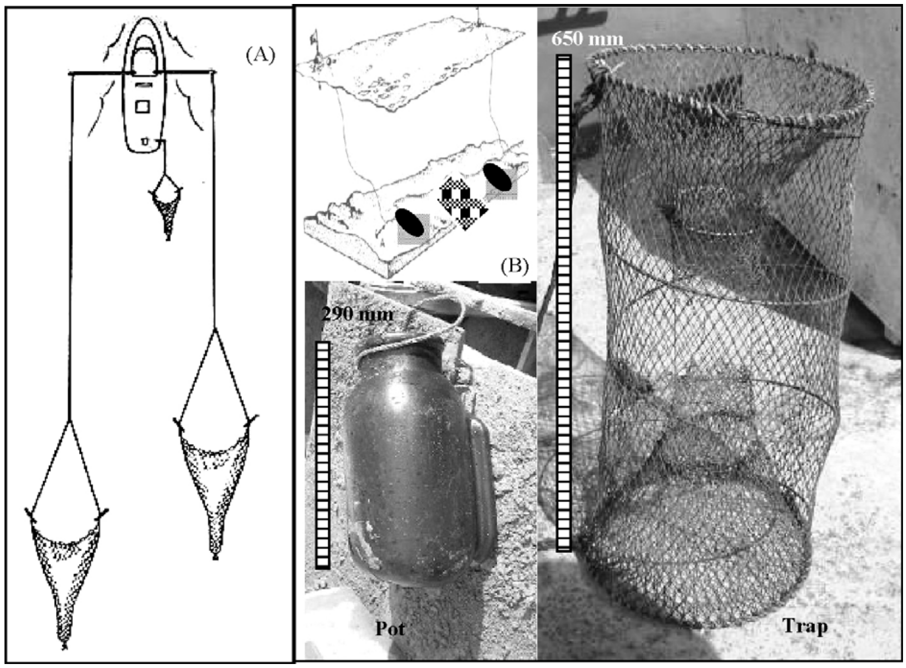

Fig. 1. Illustration of the fishing gear: double-trawl (A) and bottom longline (with pots-and-traps arranged interchangeably and deposited on the substrate) (B). Also shown are the sizes of these types of gear.

3. Results

A total of 1029 *S. deceptor* and three *S. brasiliensis* specimens were identified in fishery landings. *S. brasiliensis* were found in the autumn of 2006 in ships trawling at 45–130 m depths in the northernmost region of the study area (23°30′S, 43°00′W to 24°19′S, 45°09′W*)*. Comparing our results to the *Scyllarides* spp. distribution proposed by Melo (1999), it is likely that the data obtained by Propesq from the trawl fleet primarily refers to *S. deceptor*. However, doubts remain as to whether the specimens monitored by the database were identified and separated taxonomically; therefore, this study will simply refer to them as *Scyllarides* spp. Specimens of *S. deceptor* were detected in all months and were captured by both trawling and pot-and-traps fleets between 23°00′S, 41°60′W and 26°65′S, 47°70′W at 40–220 m depth.

Tables 1 and 2 summarize the annual and monthly fishery information for both fleets. Data were analyzed from 856 trawl cruises where slipper lobsters were part of the catch. These cruises operated between 23°00′S, 41°60′W and 29°65′S, 48°40′W and at depths of 15 and 350 m, and 206 of them were from the off-season for shrimp fisheries. A total of 25 cruises from the pot-and-trap fisheries were registered as operating between 23°30′S, 44°10′W and 27°00′S, 47°50′W at depths between 60 and 110 m.

Fig. 2 shows the spatial distribution of the trawl fleet in the period from January 1999 to April 2007. Both total fishing area and locations where no slipper lobsters were captured (for May 2006 to April 2007) are indicated. Fig. 3 presents the annual variations in fishing effort and catch for the trawl fleet. During the entire period analyzed, the fleet included 109 vessels with a total of 182,813 h of trawling. During the same period, the pot-and-trap fleet consisted of 9 vessels with a total of 22,801 traps set for fishing.

The proportion of slipper lobsters in monthly catches was low for both fleets. It varied from 0.20% (September) to 5.62% (July) for the pot-and-trap fishery and from 0.52% (September) to 1.17% (October) for the trawl fishery. The proportion of *Scyllarides* spp. in the annual catch by trawlers ranged from 0.07 (2007) to 1.96 (2001), with a slight decline from 2001 onwards (Fig. 3).

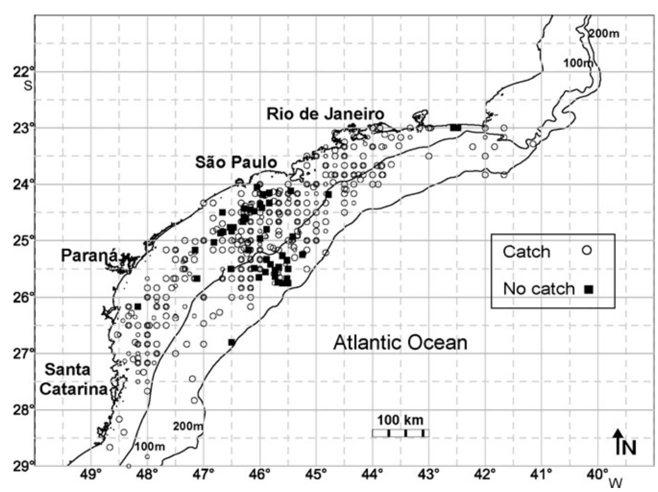

Fig. 2. Map of the spatial distribution of the trawl fisheries that caught slipper lobsters (*Scyllarides* spp.) during the period from January 1999 to April 2007 (Catch) and of the fisheries that did not capture slipper lobsters between May 2006 and April 2007 (no catch).

Approximately 1.3 tons of *S. deceptor* were obtained by the pot-and-trap fleet (Table 3) between January 1999 and April 2007, and 38.6 tons of *Scyllarides* spp. were caught by the trawl fleet during this period (Tables 1 and 2). In the state of Santa Catarina, these fleets landed approximately 252 tons of *S. deceptor* between January 2000 and December 2007 (Table 4). Calculated CPUE for both fleets shows a decrease in CPUE with increased fishing effort (Fig. 4).

Figs. 5 and 6 illustrate the spatial distributions of CPUE for slipper lobsters from each of the fleets. Of the 34 landings from the trawl fleet between May 2006 and April 2007, a total of 18 vessels did not catch slipper lobsters. They fished mainly between 24°00′S and 26°00′S at a mean depth of 72 m (SD ± 34.29), with only four vessels fishing above or below these limits. Note also that 27 of the landings occurred in the shrimp off-season at a mean depth of 57.6 (SD ± 23.66 m).

Table 1
Annual data for landings, vessels, fishing effort and catch of *Scyllarides* spp. landed, with standard deviation, by the trawl fleet of São Paulo State from January 1999 to May 2007 (data source: Propesq and this study).

Year	Landings	Vessels	Effort (hours fished)	Total catch (kg)	Minimum catch (kg)	Maximum catch (kg)	Mean catch (kg)	Std. dev. (kg)
1999	15	12	2,192	460	2	200	30.67	49.15
2000	16	11	2,908	1,423	10	300	88.94	106.54
2001	42	31	6,534	3,655	4	500	69.05	33.31
2002	14	14	2,894	1,573	4	400	112.36	129.23
2003	155	77	29,245	15,097	2	1.000	97.26	143.34
2004	270	76	60,059	7,709	2	300	28.82	25.02
2005	219	67	48,214	6,003	2	300	27.50	31.11
2006	112	42	27,467	2,667	2	100	23.60	21.26
2007	13	12	3,300	43	0.194	20	3.27	5.36
Total	856	109	182,813	38,630	0.194	1.000	45.00	78

Table 2
Monthly data for numbers of landings, vessels, fishing effort and catch of *Scyllarides* spp. landed, with standard deviation, by the medium-sized double trawl fleet in São Paulo State from January 1999 to May 2007 (data source: Propesq and this study).

Month	Landings	Vessels	Effort (hours fishing)	Total catch (kg)	Minimum catch (kg)	Maximum catch (kg)	Mean catch (kg)	Std. dev. (kg)
Jan	26	27	5,158	1,307	0.32	388	59.00	112.00
Feb	37	27	6,872	1,222	0.77	200	33.02	49.27
Mar	58	41	11,468	3,486	1	350	64.17	77.57
Apr	79	59	14,743	4,573	0.19	380	59.05	69.45
May	70	55	11,203	3,128	4	500	48.2	79.64
Jun	83	62	18,472	4,439	2	300	48.12	59.92
Jul	79	52	15,345	2,548	2	120	34.83	28.81
Aug	91	56	23,823	2,879	2	100	31.64	21.55
Sep	93	65	23,592	3,578	4	250	32.19	33.75
Oct	87	59	20,456	5,962	8	1.000	75.04	170.91
Nov	87	64	19,337	3,255	4	400	37.41	56.53
Dec	66	43	12,344	2,253	2	300	34.14	53.42
Total	856	109	182,813	38,630	0.19	1.000	45.00	78.00

Table 3
Numbers of landings, vessels, fishing effort, and landed catches of *Scyllarides deceptor*, with their respective standard deviations, by the pot and trap fleet of São Paulo State between May 2006 and April 2007 (data source: Propesq and this study).

Month	Landings	Vessels	Effort (No./trap)	Total catch (kg)	Minimum catch (kg)	Maximum catch (kg)	Mean catch (kg)	Std. dev. (kg)
Jan	2	1	1,920	23	5	18	11.50	9.19
Feb	2	2	805	40	4	36	20.00	22.62
Mar	3	3	3,720	67	7	40	22.33	16.62
Apr	1	1	3,900	88	88	88	88.00	–
May	2	2	1,740	408	8	400	204.00	277.18
Jun	2	2	846	7	2	5	3.40	2.25
Jul	4	3	3,600	554	1	523	138.50	6.36
Aug	3	3	1,354	62	10	32	20.66	11.01
Sep	1	1	750	4	4	4	4.00	–
Oct	1	1	1,200	8	8	8	8.00	–
Nov	3	2	2,840	18	4	10	6.00	3.46
Dec	1	1	126	19	19	19	19.00	–
Total	25	9	22,801	1,297	1	523	51.91	125.88

Table 4
Total catch of *S. deceptor* (kg) landed in Santa Catarina State from January 2000 to December 2007 by the medium-sized double trawl fleet (data source: UNIVALI-GEP).

Month	2000	2001	2002	2003	2004	2005	2006	2007	Total
Jan	425	1,560	7,404	148	923	103	327	1,060	11,950
Feb	3,647	4,199	6,747	1,079	893	1,922	1,558	4,799	24,844
Mar	4,871	8,851	8,226	2,003	165	3,934	4,721	1,840	34,611
Apr	2,640	12,071	19,053	2,228	1,993	5,211	1,879	1,269	46,344
May	1,664	9,629	11,441	1,517	2,342	1,968	4,105	3,111	35,777
Jun	608	9,080	1,261	852	374	1,324	1,360	1,877	16,736
Jul	1,254	5,134	5,105	535	1,669	2,328	756	4,140	20,921
Aug	584	7,049	2,276	625	3,198	1,129	690	2,695	18,246
Sep	342	4,067	2,866	190	2,569	173	279	928	11,414
Oct	178	1,154	4,915	221	1,562	1,192	190	53	9,465
Nov	1,660	281	1,380	386	166	930	36	299	5,138
Dec	2,571	7,759	1,383	1,110	425	540	599	1,014	15,401
Total	20,444	70,834	72,057	10,894	16,279	20,754	16,500	25,092	252,854

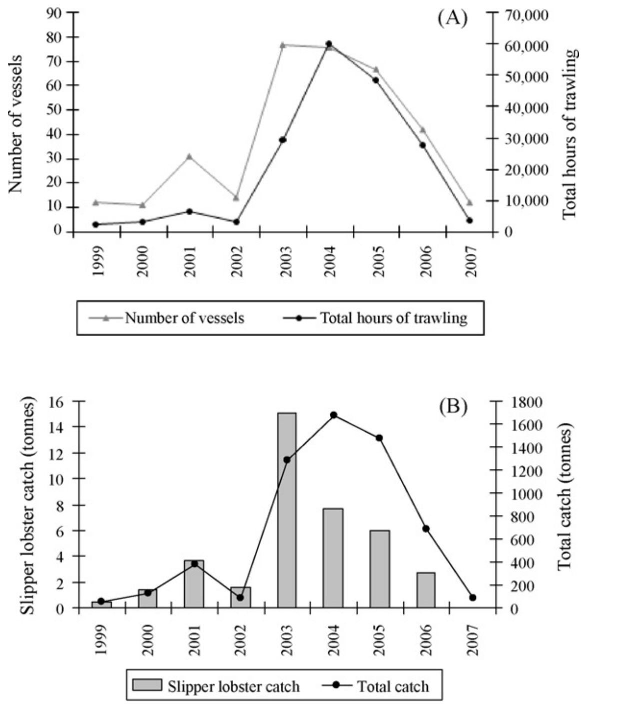

Fig. 3. Number of vessels and duration of trawling (total number of hours) of trawls that captured slipper lobsters (*Scyllarides* spp.) (A). Total annual catch of slipper lobsters and total catch of trawl fleet (January 1999 to April 2007) (B).

The CPUE of the pot-and-trap fleet varied mainly as a function of the area fished (Fig. 6). Figs. 6 and 7 illustrate that the areas with greatest CPUE values were similar for both fleets. The most productive area was the area known by local fishers as "Farol do Boi" (24°01′S, 45′00′W to 25′00′S, 45′40′W, between 60 and 135 m depth).

Fig. 7 presents the values of CPUE for the pot-and-trap fleet as a function of latitude, depth, season and duration of submergence of the traps. At "Farol do Boi", the CPUE values were greatest at depths of 90–100 m and around 24°50′S latitude (Fig. 7A and B). In the autumn, the season with highest observed CPUE, the fleet was also concentrated in this area (Fig. 7C). No clear relationship was observed between the number of days the traps were submerged and CPUE, although a period of 7–10 days appears to be most effective for capture in general (Fig. 7D).

To formulate a general linearized model (GLM) for the trawl fleet catches between January 1999 and April 2007, a logarithmic function was applied. The logarithm was necessary due to the asymmetric distribution of CPUE frequencies (Fig. 8). Diagnostic images of the dispersion of the deviance residuals and of the envelopes for the component of the deviance (Fig. 9) show a tendency for a homogeneous distribution. However, the normality test showed a non-normal distribution of the log-transformed CPUE data (SW: $p = 1.263\text{E}{-11}$). The overall correlation coefficient (r^2) of the model was 52%, which is interpreted as a good explicative value (Crawley, 2006).

Tables 5 and 6 demonstrate that the year, month and depth of fishing were the dominant factors that significantly influenced observed variations in CPUE for slipper lobster catches by the trawl fleet ($p < 0.05$). Figs. 10 and 11, along with Table 6, show details of CPUE and the associated explanatory factors.

The year was the principal source of variation in CPUE (Table 5, Fig. 11A). The model indicated that CPUE was significantly higher during the years from 2000 to 2003 than in 1999, with relative values of 161% (2000), 147% (2001), 122% (2002) and 138% (2003). There was a significant drop in CPUE for 2007, with a relative value of 95% (Fig. 10, Table 6).

The month was also significant in the model (Table 5). June was 97% more efficient than January. January was in turn 74% more efficient than May, though this result was not significant (Fig. 11B, Table 6). Also, depth proved to be an additional significant variable in the model (Table 5). Deeper waters (300 m class) were less efficient than shallower waters (50 m) (Table 6). The largest CPUE occurred between 50 and 100 m depth (Fig. 11C).

The off-season for shrimp fishing currently runs from March 1st to May 31st (MMA, 2001) and did not significantly influence the model (Table 5). From 1999 to 2001, the mean CPUE was slightly greater in the off-season, while from 2003 to April of 2007, there were no major differences in CPUE between the closed and open fishing seasons (Fig. 11D).

Neither season nor latitude was significant for the model. As shown in Table 5, these factors did not generate changes in the CPUE of slipper lobster fisheries. However, the CPUE was higher in spring (Fig. 11E) and at latitudes near 24.5°S, shaped by the relative abundance of *Scyllarides* in the "Farol do Boi" (Fig. 11F).

4. Discussion

The exploitation patterns of slipper lobsters in the South Brazil Bight by two different fleets show some vulnerability of such populations to fishing pressure rather than a sustainable by-product

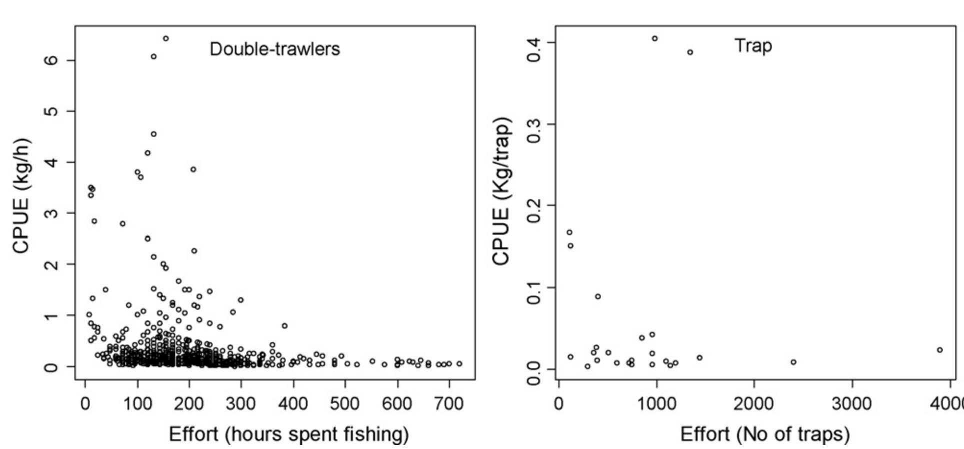

Fig. 4. Relationship between fishing effort and catch per unit effort (CPUE) of slipper lobsters captured by the double-trawler fleet from January 1999 to April 2007 and by the pot-and-trap fleet from May 2006 to April 2007.

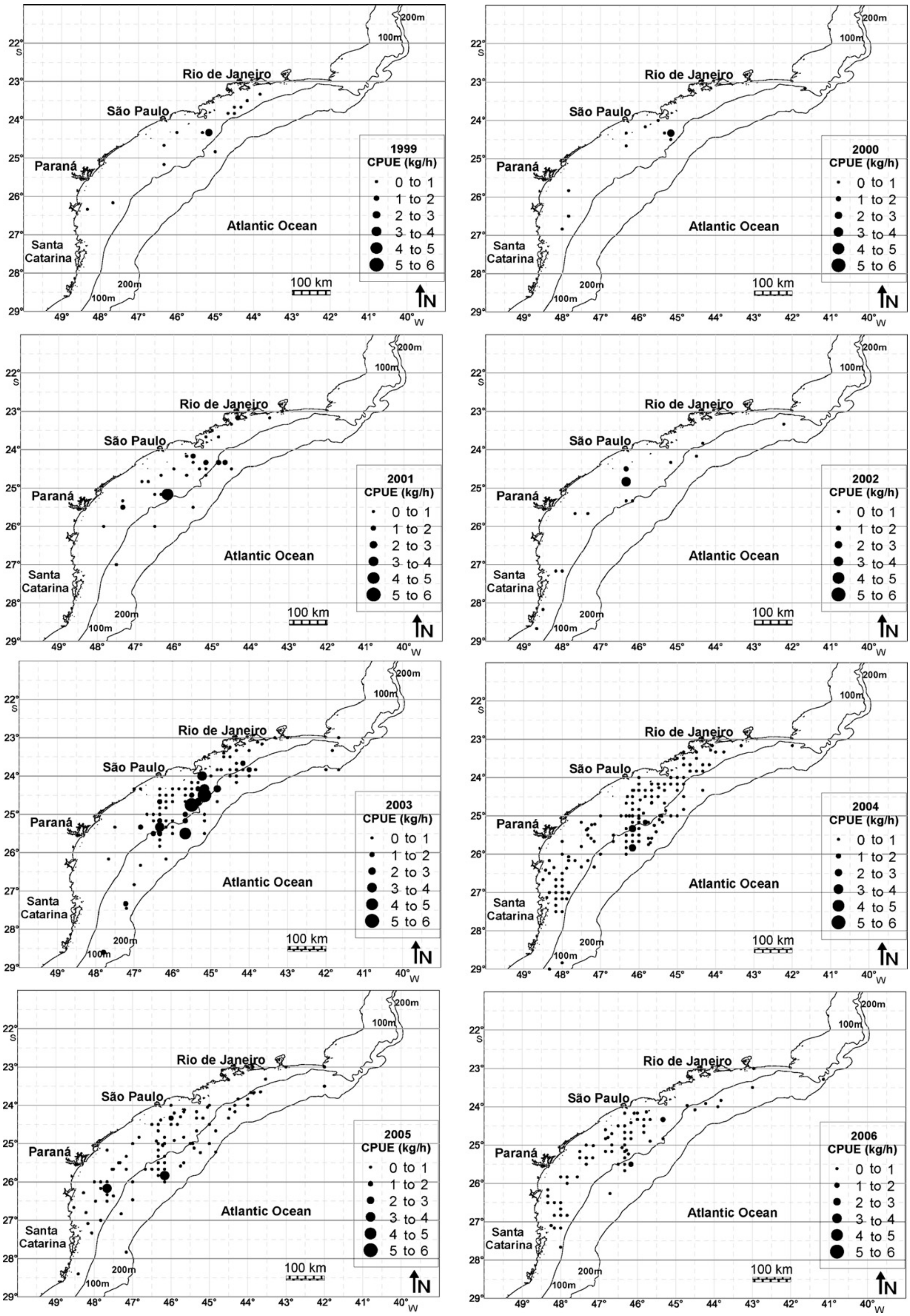

Fig. 5. Maps of spatial distributions and CPUE (catch per unit effort in kg/h), of the trawl fisheries that included slipper lobsters (*Scyllarides* spp.) in their landings in each of the years between January 1999 and April 2007.

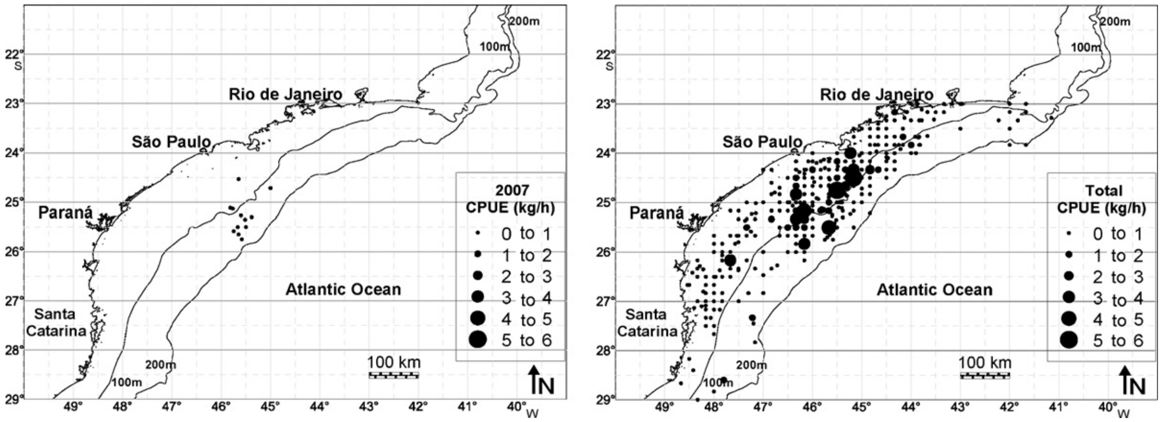

Fig. 5. (*Continued*).

optimization. Slipper lobster populations decline even with limited fishing effort, raising global concerns about their situation. The lack of fishery management measures aimed at bycatch has often been associated with information gaps in fisheries biology. Many species remain unreported in fishery statistics and are therefore unregulated. This failure has resulted in a decline in the abundance and distribution of numerous species of crustaceans due to over-exploitation to which they are exposed (Spanier and Lavalli, 2007).

A fundamental understanding of the distribution of slipper lobsters is a first issue. Previous records of *Scyllarides* sp. in Brazil reported a bathymetric distribution between 20 and 40 m deep for *S. brasiliensis* and from 45 to 300 m deep for *S. deceptor* (Melo, 1999; Holthuis, 1991). In this study, *S. deceptor* catches were more typically associated with depths between 270 and 320 m. Oliveira et al. (2008) recorded *S. deceptor* specimens up to depths of 420 m in the Brazilian state of Santa Catarina. The deeper extent of slipper lobsters in the South Brazil Bight could lead to the discovery of new fishing areas. The limited occurrence of *S. brasiliensis* and the distribution limits proposed by Melo (1999) suggest that this species is more prevalent to the north of our study area, while *S. deceptor* is more common in southern Brazil. The latter appears to have more a sub-tropical distribution and does not occur in the warmer regions of Brazil (Holthuis, 1991).

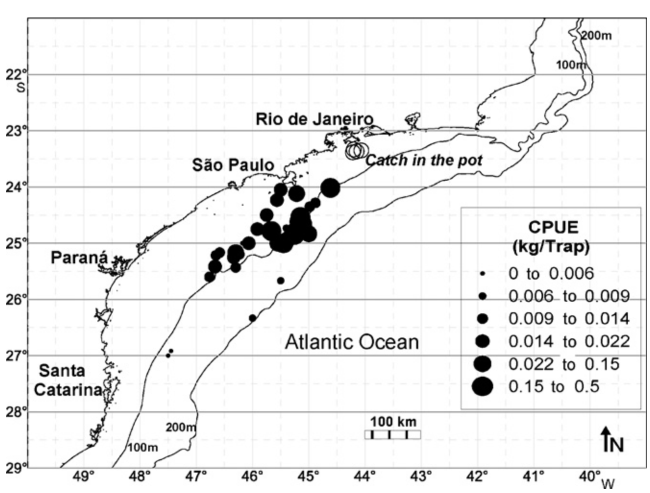

Fig. 6. Map of the spatial distribution and CPUE (kg/trap) of the pot-and-trap fisheries that caught the slipper lobster *Scyllarides deceptor* during the period from May 2006 to April 2007. Open circles represent locations where slipper lobsters were caught in octopus pots.

In fact, the state of Santa Catarina, which is further south than São Paulo, is the largest producer of slipper lobster in Brazil, mainly because the fishing effort there is much greater than in other States (Perez and Pezzuto, 2006; Gep, 2009; Oliveira et al., 2008). In São Paulo, the market for this lobster has become increasingly attractive due to both fluctuations in the landings of octopuses (Tomás and Avila-Da-Silva, 2005; Instituto de Pesca/SP, 2008) and the decline of shrimp stocks (D'Incao et al., 2002). Some ship owners and skippers of those fleets have demonstrated great interest in adapting their vessels to directly target slipper lobsters as a new commercial catch (Tomás et al., 2006; Oliveira et al., 2008).

Whether this species can withstand increased fishing effort is a central issue that needs to be addressed. In this study, the relative abundance of slipper lobsters decreased while fishing effort increased, indicating that a future increase in effort would not lead to an equivalent increase in catch and may even adversely affect overall stocks.

S. deceptor shows a late maturity (25 cm of total length), and a large proportion of the specimens caught by trawlers in Santa Catarina were females (92%) (Oliveira et al., 2008), suggesting that the impacts of fishing on the lobster population may be too severe to be sustainable (King, 1995; Sparre and Venema, 1998).

A very similar situation appears to occur in São Paulo. Our analysis of the trawl fishery throughout the area (between 23°00 and 29°65′S) shows that the relative abundance of slipper lobsters have declined following a high total catch in 2003 possibly limiting the recruitment (Fonteles-Filho, 1989; King, 1995; Sparre and Venema, 1998).

It is important to note that depensatory mechanisms are likely to occur in lobster species with reduced population densities due to the low mobility of adults (Liermann and Hilborn, 1997). Such an '*Allee effect*' (Allee, 1931) can reduce both fertilization (due to the difficulty of finding mates) and survival (due to predation exposure) and can prevent stocks from recovering even after fishing is terminated (Myers *et al*., 1995). Thus, maintaining spawning stock at sustainable levels is necessary to avoid the overfishing of lobster populations.

Natural shelters present a partial solution to this problem if properly protected. This study has shown that the area known as "Farol do Boi", which is not recommended for trawling (Figueiredo and Madureira, 2004) and shows low octopus yields (Tomás et al., 2006), showed a relatively large concentration of slipper lobsters. All interviewed skippers confirmed such patches. According to the professional fishers, the increased lobster population density in Farol do Boi is due to the characteristics of the local substrate, distinct of the sandy and silty adjacent areas. This area has a strong steep, with shells, and the presence of two spots of sand bottom and slabs of sandstone

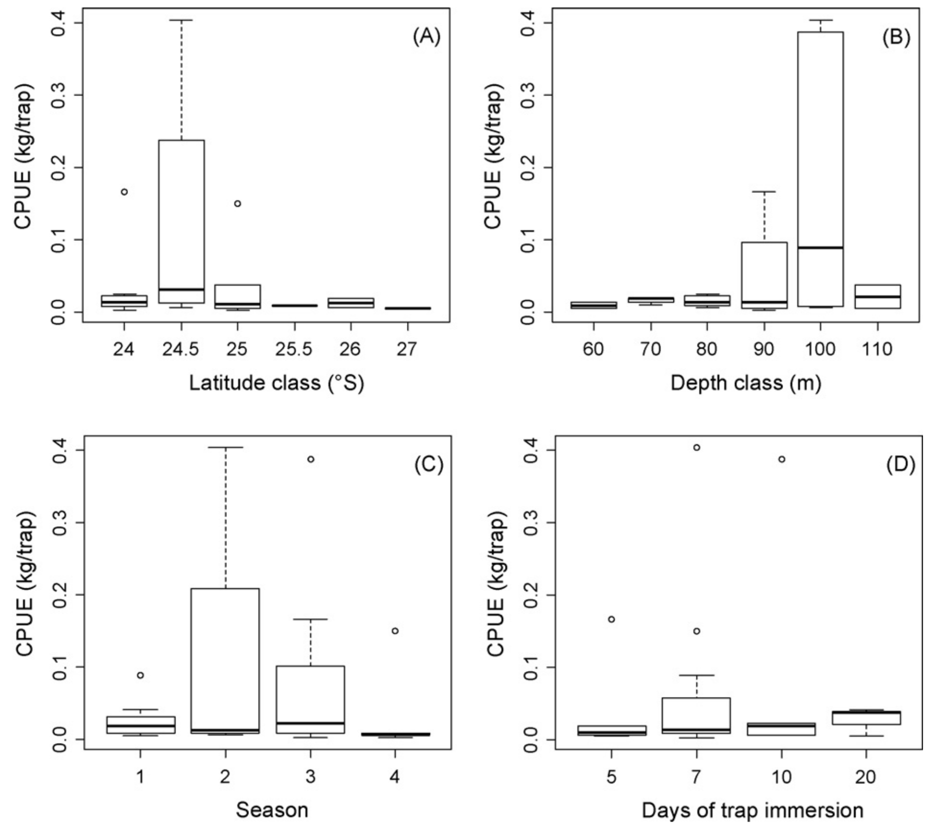

Fig. 7. Median, quartiles (Q1 = lower quartile, cuts off lowest 25% of data and Q3 = upper quartile, cuts off highest 75% of data) and amplitude of CPUE for slipper lobster catches by the pot-and-trap fleet between May 2006 and April 2007 analyzed by: latitude class (A); depth class (B); season (C; 1 = summer, 2 = autumn, 3 = winter, 4 = spring); and the number of days traps were immersed (D). Divide the sorted data set into four equal parts (25, 50, and 75%) so that each part represents one fourth of the sampled population.

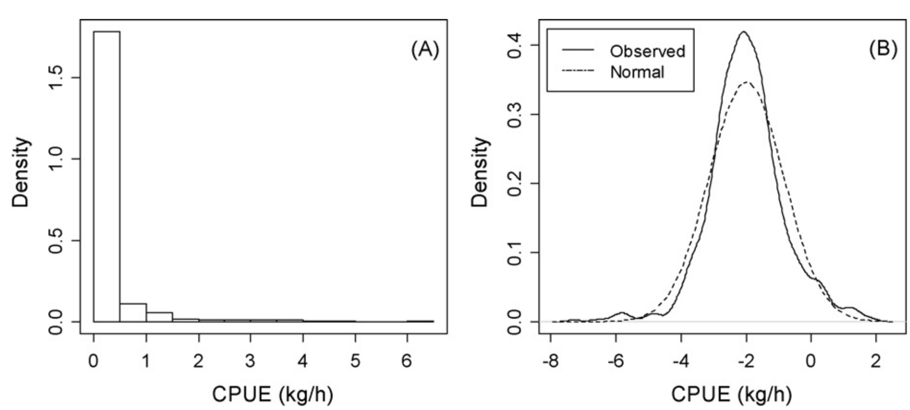

Fig. 8. Densities in the frequency distribution of CPUE data (kg/h), displayed linearly (A) and log-transformed (B), of the slipper lobster catch by the trawl fleet between January 1999 and April 2007. A normal distribution is also shown.

Table 5
Deviance analysis for the General Linear Model, based on a gamma distribution with logarithmic connection, adjusted for CPUE values of slipper lobsters captured by the trawl fleet from January 1999 to April 2007. The asterisks indicate the level of significance, where: "***" high; "**" intermediate, and "*" low.

Factors	Gl	Deviance	Gl. resid.	Dev. resid.	*F*	Pr (>*F*)	
Null			855	1135.92			
Year	8	334.48	847	801.45	454.664	$<2.2 \times 10^{-16}$	***
Month	11	29.26	836	772.18	28.930	0.0009553	***
Depth	4	9.68	832	762.5	26.320	0.0331671	*
Closure	1	2.81	831	759.69	30.551	0.0808611	
Latitude	13	9.26	815	749.45	0.7742	0.6881615	
Season	3	0.98	828	758.71	0.3569	0.7841321	

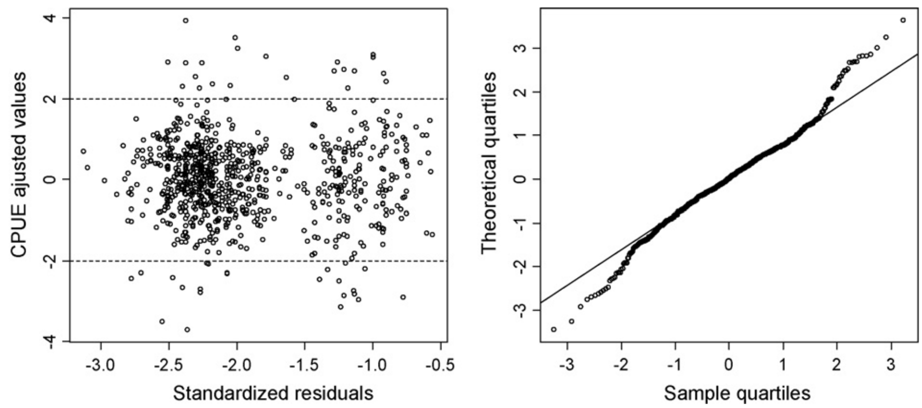

Fig. 9. Parameters describing the model of variation of the CPUE (kg/h) including: diagram of the dispersion of residuals (left) and normal graph of the probability of the residual component of the standard deviation (right). The figure also illustrates the quartiles sampled by the ANOVA method (points) and the theoretical quartiles (straight) for the slipper lobster catch of the trawl fleet between January 1999 and April 2007. The quartile is given as any of the three values that divide the sorted data set into four equal parts (25, 50 and 75%) so that each part represents one fourth of the sampled population.

(Figueiredo and Tessler, 2004). The latter seem to provide natural refuges and may be used diurnally as shelters for slipper lobsters of the genus *Scyllarides* (and potentially others) (Spanier and Lavalli, 2006). These features provide protection against diurnal predators (such as fish and perhaps octopuses) (Barshaw and Spanier, 1994). The distribution of this lobster likely depends on the availability of hard shelters with horizontal covers, sufficient size and an adequate number of openings. These factors appear to explain the increased abundance of slipper lobsters in “Farol do Boi” relative to open areas where the soft substrate supplies no shelter.

Previous studies have reported that similar rocky outcrops are preferred by *S. latus* in the Azores and Mediterranean Sea (Spanier et al., 1988; Martins, 1985; Spanier and e Almog-Shtayer, 1992; Barshaw and Spanier, 1994; Spanier and Lavalli, 1998; Lavalli and Spanier, 2001; Lau et al., 2009), *S. astori* in the Galapagos islands (Hearn, 2006), *S. aequinoctialis* and *S. nodifer* in Florida (Sharp et al., 2007) and *S. squammosus* and *S. haanii* in Hawaii (Dinardo and Moffitt, 2007).

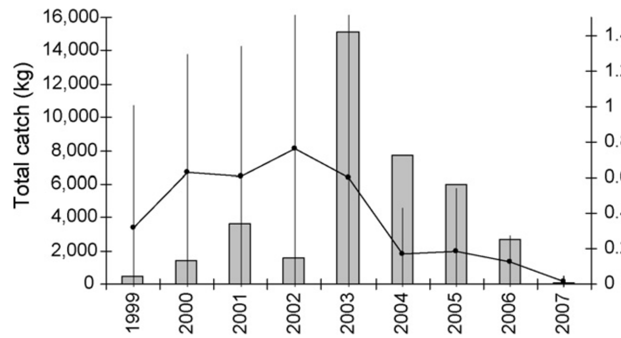

Fig. 10. Mean annual CPUE (continuous horizontal line) with variation in mean annual CPUE shown by standard deviations (continuous vertical line) and total catch (histogram) during each period for slipper lobsters caught by the trawl fleet between January 1999 and April 2007.

Table 6
Coefficients of the General Linear Model, based on a gamma distribution with logarithmic connection, adjusted for CPUE values of slipper lobsters caught by the medium-sized double trawl fleet from January 1999 to April 2007. The asterisks indicate the level of significance, where: “***” high; “**” intermediate, and “*” low.

Category	Value	Standard err.	Value *t*	*P* (>*t*)	%
Constant	−2.14391	0.37108	−5.777	1.08E−08***	
2000	0.96148	0.39631	2.426	0.01548*	161.56
2001	0.90704	0.29489	3.076	0.00217**	147.70
2002	0.79869	0.37701	2.118	0.03444*	122.26
2003	0.86720	0.26580	3.263	0.00115**	138.02
2004	−0.13652	0.26113	−0.523	0.60126	−12.76
2005	−0.22363	0.26334	−0.849	0.39601	−20.04
2006	−0.38899	0.27058	−1.438	0.15092	−32.23
2007	−3.18541	0.38919	−8.185	1.05E−15***	−95.86
February	0.19429	0.25488	0.762	0.44613	21.44
March	−0.94241	1.03147	−0.914	0.36116	−61.03
April	−0.92035	1.03858	−0.886	0.37579	−60.16
May	−1.38604	1.03070	−1.345	0.17908	−74.99
June	0.67989	0.29663	2.292	0.02216*	97.37
July	0.37566	0.32086	1.171	0.24203	45.60
August	0.47886	0.31874	1.502	0.13338	61.42
September	0.25065	0.30079	0.833	0.40493	28.49
October	0.46839	0.30548	1.533	0.12559	59.74
November	0.26676	0.30126	0.885	0.37616	30.57
December	0.29838	0.27633	1.080	0.28054	34.77
Depth 100 m	0.05874	0.08460	0.694	0.48766	6.05
Depth 150 m	0.02499	0.14778	0.169	0.86575	2.53
Depth 200 m	−0.24360	0.98658	−0.247	0.80504	−21.62
Depth 300 m	−1.45998	0.50058	−2.917	0.00364**	−76.78

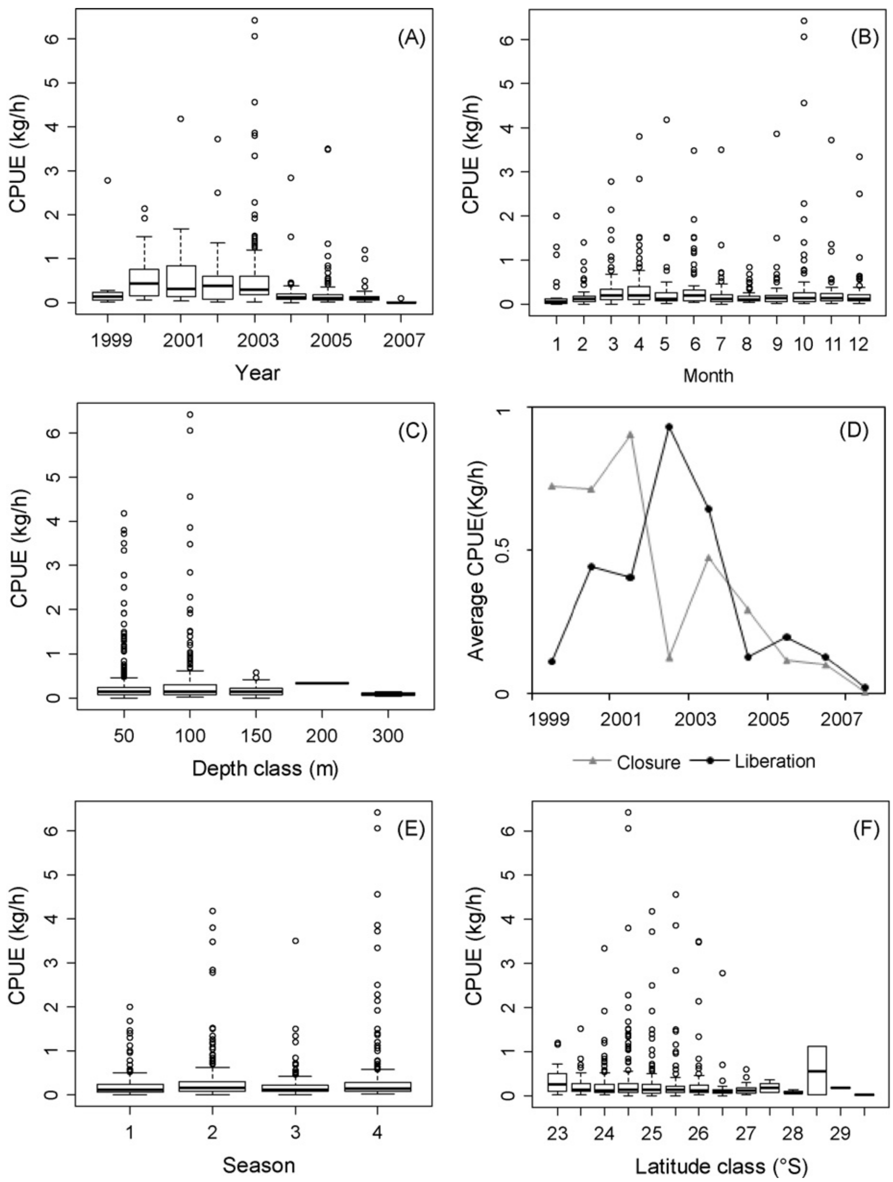

Fig. 11. Median, quartiles (Q1 = lower quartile, cuts off lowest 25% of data and Q3 = upper quartile, cuts off highest 75% of data) and amplitude of CPUE values for slipper lobster catches analyses by year (A); month (B); depth class (C); season (E; 1 = summer, 2 = autumn, 3 = winter, 4 = spring); and latitude class (F; °S). Mean annual CPUE in periods of closure and open of shrimp fishing by the trawl fleet from January 1999 to April 2007 (D). The quartile is given as any of the three values that divide the sorted data set into four equal parts (25, 50 and 75%), so that each part represents one fourth of the sampled population.

Our findings suggest that mitigating measures should be implemented to protect and recover the stock of slipper lobsters between 23°00 and 29°65′S. Initial measures should include:

- Limiting the use of traps by octopus fisheries since the majority of the octopus catches occurs in pots. Using only this more selective type of equipment would protect part of the slipper lobster population without negatively impacting octopus fishing; and
- The creation of a fishery trawling exclusion zone or protected area at "Farol do Boi". According to Sekiguchi et al. (2007), members of the *Scyllarides* genus are able to remain in the water column as phyllosoma larvae for many weeks or even months. Considering *S. deceptor* behaves similarly, even without knowing the particular larval development of the species, but the regional ocean dynamics (Castro et al., 2006), we suggest that this area could act as a rich source of this species, exporting larvae to areas where they can eventually be collected by fishers.

Further studies are clearly still necessary, especially those addressing the life cycle and current populations parameters of slipper lobsters in order to understand reproduction, mortality, growth, recruitment and stock identities and levels. Nonetheless, the two strategies recommended above might provide the first steps necessary for protecting the stocks.

It is also evident that a worldwide debate is needed concerning the proper management techniques for the sustainable removal of Scyllaridae from the marine environment. Given this context, the detection of slipper lobster fishing patterns and the evidence of a decrease in the relative abundance of *S. deceptor* presented here may contribute to further understanding of the vulnerability of these populations.

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