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ARTIGO

The horizontal migration of hammerhead sharks along the southern Brazilian coast, based on their exploitation pattern and considerations about the impact of anchored gillnets activities on these species.

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Abstract. Between 1995 and 2009 hammerhead sharks were sampled from the landings of the industrial fleets based in the harbours of Itajaí and Navegantes, Santa Catarina State, and Ubatuba, São Paulo State, Brazil. In this case, fishing boats which operated with gill-nets longlines and trawls along the southern Brazilian Economic Exclusive Zone and international adjacent waters were targeted. A total of 2483 and 353 *S. lewini* and *S. zygaena* carcasses respectively were sexed, measured and converted to total lengths (L_T). Additionally information about, year, season, latitude/longitude and local depth (m) from the catches, by fishing category, were obtained. During the considered period, intense fishing mortality over pups was caused by gillnets and trawls operating on shallow waters (≤ 20 m) and over juveniles along the continental shelf (> 20 m and ≤ 200 m). Additionally, adults were exploited by driftnets and longlines along the shelf border and slope (> 200 m). Therefore, both hammerhead species are exploited at all life-stages and throughout their migratory circuit. This includes during their inshore-offshore migration while they are growing from pups to juveniles and as the offshore-inshore migration of pregnant females to pupping areas in shallower waters. This apparently unsustainable exploitation pattern, over different size classes (newborns-juveniles-adults), and the economic pressure caused by the international fin market, is one of the reasons for population declining of these two species in southern Brazil. Non fishing zones for the hammerheads, protecting their migratory circuit, which is driven by their growth pattern and reproduction, are necessary. Additionally, fishing effort reduction and a control over the international fin market are recommended.

Key-words: Incidental catches; elasmobranchs; fishing mortality.

Resumo. A migração horizontal dos tubarões-martelo ao longo da costa sul-

brasileira, baseada no seu padrão exploratório. Entre 1995 e 2009 foram amostradas as carcaças de tubarões-martelo, desembarcadas pelas frotas pesqueiras industriais de emalhe, espinhel-de-superfície e de arrasto nos portos de Itajaí e Navegantes (SC) e de Ubatuba (SP). Essas frotas operaram ao longo da Zona Econômica Exclusiva do Sul do Brasil e em águas internacionais adjacentes. Um total de 2483 e 353 carcaças de *S. lewini* e de *S. zygaena* respectivamente foram sexadas, medidas e convertidas em comprimentos totais. Informações complementares sobre as capturas como ano, estação, latitude/longitude, profundidade local (m), foram também obtidas por modalidade pesqueira. Durante o supracitado período, as frotas de emalhe e de arrasto-de-fundo infligiram elevada mortalidade por pesca sobre os neonatos em águas rasas (≤ 20 m) e sobre os juvenis distribuídos ao longo da plataforma continental (> 20 m e ≤ 200 m). Adicionalmente os adultos eram capturados pelas frotas de emalhe e de espinhel-de-superfície ao longo da quebra de plataforma e talude (> 200 m). Portanto, ambas as espécies de tubarões-martelo são explotadas em todos os estágios do seu ciclo de vida e ao longo de todo o seu circuito migratório. Isto inclui os deslocamentos horizontais das regiões costeiras para o ambiente semi-oceânico, acompanhando o crescimento dos neonatos até a fase adulta e os deslocamentos horizontais das fêmeas grávidas no ambiente semi-oceânico, para as áreas de parto em águas rasas. Esse padrão insustentável de explotação sobre as diferentes classes etárias (neonatos, juvenis e adultos), aliado à pressão econômica do mercado internacional de barbatanas de tubarões é uma das principais causas do declinio populacional destas duas espécies de elasmobrânquios no sul do Brasil. Áreas de exclusão à pesca e que englobem o circuito migratório dos tubarões-martelo, função do seu padrão de crescimento e de seu comportamento reprodutivo, são necessárias. Adicionalmente, a redução no esforço de pesca e o controle sobre o mercado internacional de barbatanas são recomendados.

Palavras-chave: Capturas incidentais; elasmobrânquios; mortalidade por pesca.

Introduction

The scalloped hammerhead shark, *Sphyrna lewini* (Griffith & Smith, 1834), which occurs in tropical and warm-temperate waters, is considered a coastal and semi-oceanic species, being distributed over the continental shelf and oceanic adjacent waters, from the intertidal zone to deep water hypoxic zone at 980 m (Stevens, 1984; Chen et al., 1988; Stevens & Lyle, 1989; Jorgensen *et al.*, 2009). It is differentiated from its congener *S. zygaena*, by having a median indentation in the anterior margin of its head (*Cephalophoil*), whitish pattern and a transversal section over the precaudal pit is ellipsoidal (Castro, 1993).

The distribution of the life-stages of the scalloped hammerhead has been studied previously by many authors. Pups occur in turbid waters, near the bottom, in depths lower than 9 m (Holland *et al.*, 1993). Bigelow & Schroeder (1948), Klimley & Nelson (1981), Klimley (1987), Clarke (1971), Stevens & Lyle (1989) observed the juvenile's distribution of *S. lewini* near bays, estuaries and over the continental shelf, to a maximum depth of 275 m, i.e., over the superior slope. Conversely, the adults were found over the shelf border and slope, while pregnant females migrate to shallower coastal areas to give birth. Therefore, a horizontal migration from protected coastal areas to a pelagic habitat occurs simultaneously as juveniles grow. Juvenile's females have higher growth rates and mature at bigger sizes than males (Clarke, 1971; Schwartz, 1983; Klimley, 1987).

In addition to cross-shelf migration, long -shelf migration of hammerheads has been observed in South Africa and northern Australia. Great schools of juvenile hammerheads were observed to migrate to higher latitudes during summertime (Bass *et al*., 1973; Stevens & Lyle, 1989).

The scalloped hammerheads have geomagnetic orientation and navigational abilities, possibly enhanced by their laterally expanded head (Montgomery & Walker 2001, Kajiura & Holland 2002, Meyer *et al*. 2005). Klimley (1987), Galván-Magaña *et al*. (1989), Klimley (1993), Klimley *et al*. (2002) and Jorgensen *et al*. (2009) in the Gulf of California, Mexico, tracking adult scalloped hammerheads around seamounts, provided evidences of where *S. lewini* adults occur and their habitat preferences. Nocturnal movements, with distances ranging between 4 and 20 km from the seamounts to offshore for feeding purposes were observed. The seamounts would be used by the hammerheads as georeferencial points, and these sharks used to make deep dives between 25 and 980 m, during their migration course. The hypothesis about the vertical movements of *S.lewini* are that they would be associated to (1) pursuing preys such as deep-water squids, or (2) oscillatory swimming to sample chemical cues from different water strata, (3) to descend where the magnetic cues in the substratum may be more perceptible, or (4) an energy efficient locomotion *via* a fly-glide swimming strategy.

Sphyrna lewini is abundant along continental and islands shelves in tropical waters (Compagno 1988). It is not a truly oceanic species and it is unusual to capture a hammerhead in the open ocean (Duncan *et al*. 2006). Tagging data indicates that the species do not regularly roam across large distances (Kohler & Turner 2001). However, there is a record of an individual crossing 1600 km over deep water (Kohler & Turner 2001). Tagging and genetic data showed that individuals appear to disperse readily across continuous habitat, like continental shelves and rarely across open oceans.

Along the southern Brazilian coast, *S. lewini* juveniles are demersal and are distributed from the intertidal zone to 100 m (Vooren, 1997; Kotas, 2004). Their pupping grounds are in shallow waters, while the adults live offshore (Kotas *et al*., 1995; Lessa *et al*., 1998).

Kotas (2004) monitoring gillnetters based in Ubatuba, São Paulo State, detected *S. lewini* catches in an area between latitudes 26°S and 23°S . In this case, driftnets were used to catch adult scalloped hammerheads in summertime, over depths between 60 and 160 m. Additionally, anchored gillnets caught pups and juveniles of this species during wintertime over depths between 22 and 100 m.

Although the scalloped hammerhead sharks are widely distributed, they are also dependent on discrete coastal nursery areas, for part of their life history, a fact that promotes population structure (Keeney *et al*. 2003, 2005; Bowen *et al*. 2005). Along the Brazilian coast, there seems to be many regional populations of *S. lewini,* each of them with its own pupping area, and annual ontogenetic cycles of migration from these pupping grounds to offshore areas and vice-versa (Vooren, personal communication). More recent work on molecular biology showed that nursery populations of *S. lewini* linked by continuous coastline have high connectivity and that oceanic dispersal by females is rare. Relatively minor genetic structure along continental margins does not support philopatric behaviour of breeding females to natal nurseries, although the reproduction is strongly affiliated with coastal habitat. Oceanic barriers appear to have a much stronger influence on the genetic differentiation of *S. lewini (*Duncan *et al*., 2006).

Several difficulties exist to follow the migration patterns of these two species separately in southern Brazil: (1) lack of funds to do tagging and recapture experiments with the hammerheads, (2) The official statistics do not differentiate *Sphyrna lewini* from *Sphyrna zygaena,* putting them in a group sometimes called "hammerheads" or simply "sharks" (Arfelli & Amorim, 1994; Bonfil, 1994; Kotas, 2004), (3) A lack of an observers program to collect information from this two hammerhead sharks species aboard the different fleets.

It is also important to keep in mind that the hammerheads are transzonal and highly migratory species and to build a fisheries management model for this shark group in the Southwest Atlantic, the statistics from the neighbouring countries like Uruguay and Argentina should be considered (Kotas, 2004).

Although many authors observed the spatial distribution of the several life-stages of *S.lewini* in many parts of the world, like Sea of Cortés, Hawaii and Australia (Stevens & Lyle 1989, Holland *et al*. 1993, Klimley *et al*. 2002) nobody has described in detail the horizontal movements of the hammerhead sharks, *Sphyrna lewini* and *Sphyrna zygaena* based on their exploitation pattern along the southern Brazilian Economic Exclusive Zone and its international adjacent waters. This study will support the necessity to create non fishing zones, called "biodiversity corridors" along the southern Brazilian Economic Exclusive Zone. Prudent management for *S. lewini* must therefore include not only population-specific protection in the adult phase, but also access to regional nurseries (Bowen & Roman 2005).

During the XV CITES meeting (13-25 March 2010 in Doha in Qatar), it was proposed by Palau and the United States the inclusion of *S. lewini* and *S. zygaena* in Appendix II of the Convention, namely the regulation of international market of these species and their derivatives (e.g. fins). In the world scale, the greatest threats to these species has been the international fin trade and accidental catches, so generating historical declines from 15 to 20% in a period of approximately 10 years. These species are therefore threatened with extinction unless we take drastic measures to control the fishing industry and its trade (Anonymous, 2010).

Material and Methods

Between 1995 and 2009, the hammerhead shark carcasses landed by gillnetters, longliners, shrimp trawlers and pair trawlers based in Ubatuba (São Paulo State), Itajaí and Navegantes (Santa Catarina State) harbours, which operated along the southern Brazilian Economic Exclusive Zone and international adjacent waters, were sampled (Fig. 1). The hammerhead carcasses used to be landed without the first dorsal fin, pectorals, lower lobe of caudal and beheaded. 2483 hammerheads were identified as *S. lewini* and 353 as *S. zygaena*. During sampling the sex was also determined and from each carcass it was measured the distance from the insertion of first dorsal fin to the precaudal pit (D_C) (Fig. 2).

During sampling work, the crew members were also interviewed in order to collect information concerning the physical characteristics of the fishing boats, the fishing gear as additional information about the hammerhead catches like year, season, latitude, longitude, local depth and sea surface temperature (°C).

To study the horizontal movements of hammerhead sharks along the southern Brazilian Economic Exclusive Zone and international adjacent waters, the hammerhead length composition caught by different fishing fleets were distributed throughout different areas, according a stratified ocean floor criteria, i.e., (1) AREA 1 – shallow environment – 0 to 20 m deep; (2) AREA 2 – inner continental shelf – 21 to 100 m; (3) AREA 3 - outer continental shelf – 101 to 200 m; (4) AREA 4 – superior slope – 201 to 1000 m; (5) AREA 5 – inferior slope – 1001 to 4000 m; (6) AREA 6 - Abyssal – > 4000 m. Summary line graphs with the means and standard errors were used to show the length composition behaviour along the different areas.

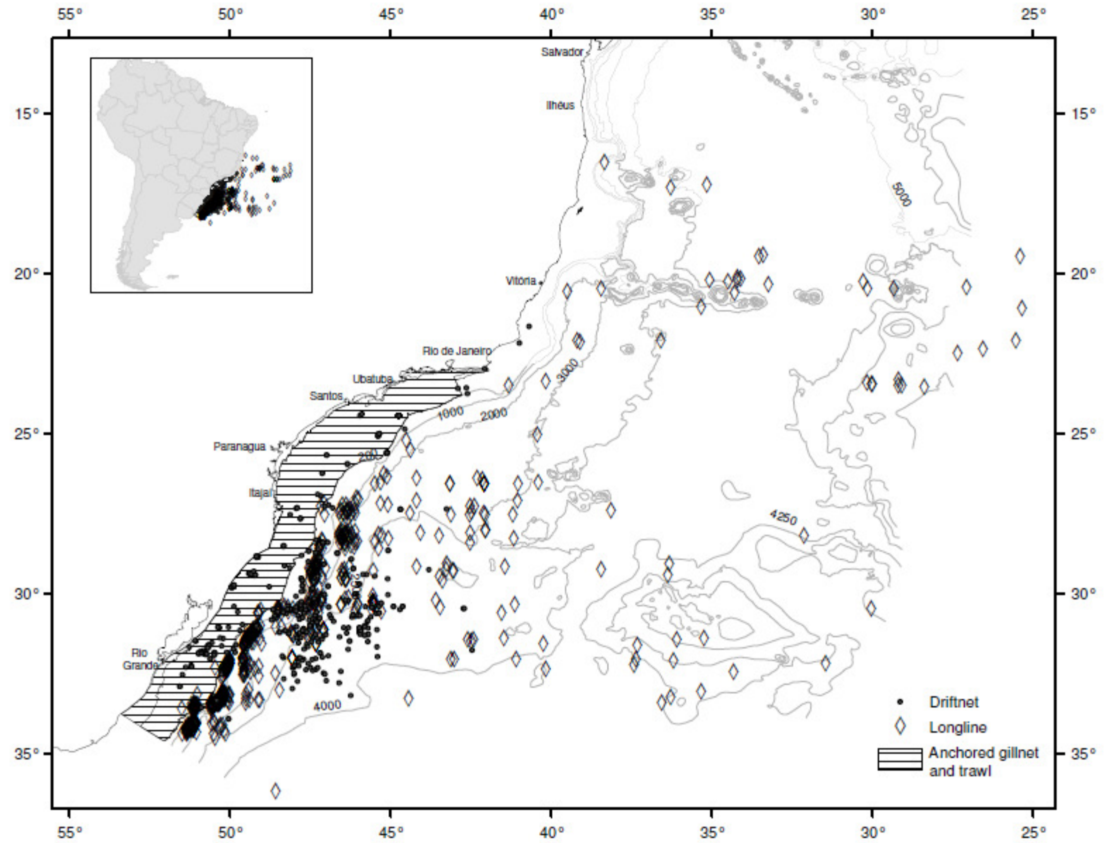


Figure 1. Fishing zones of the anchored gillnetters, trawlers, driftnetters and surface longliners based in Ubatuba (São Paulo State), Itajaí and Navegantes (Santa Catarina State) harbours, which operated along the southern Brazilian Economic Exclusive Zone and international adjacent waters. Period: 1995 to 2009. Numbers are depths (m).

Also the hammerheads exploitation pattern was followed, stratifying their length composition by different fishing fleet categories, i.e., (1) pair trawlers, (2) otter trawlers, (3) double riggers, (4) anchored gillnetters, (5) drifters, (6) surface longliners and (7) trammelers. Box-plots were used to identify this pattern.

Depth (m) variations in the yield *of S. lewini* and *S. zygaena* caught by the anchored gillnet landed in Itajaí and Navegantes (SC) between the fall of 2008 and the spring of 2009, were based in the CPUE index (individuals / (number of hauls) *(net area (m^2)) which was provided by the Statistical Section of the Research and Management Center of fishing resources from the Southeast and South Brazilian Coast ("Centro de Pesquisa e Gestão de Recursos Pesqueiros do Litoral Sudeste e Sul") - CEPSUL.

Analyses of sex ratios of the landed *S. zygaena* and *S. lewini* were carried out using the methodology suggested by Vazzoler (1996). Chi-square tests were applied in order to assess the significance of the differences in these proportions during the study period.

To estimate the age composition of *S. lewini*, grouped by sexes and caught by the anchored gillnetters based in Itajaí and Navegantes harbours between 2008 and 2009, the von Bertalanffy growth models built by Kotas *et al.* (2011) were used to convert total lengths (cm) to age (year).

Results

Convertion to total length

To convert the hammerheads carcass measurements to total length (L_T) the following

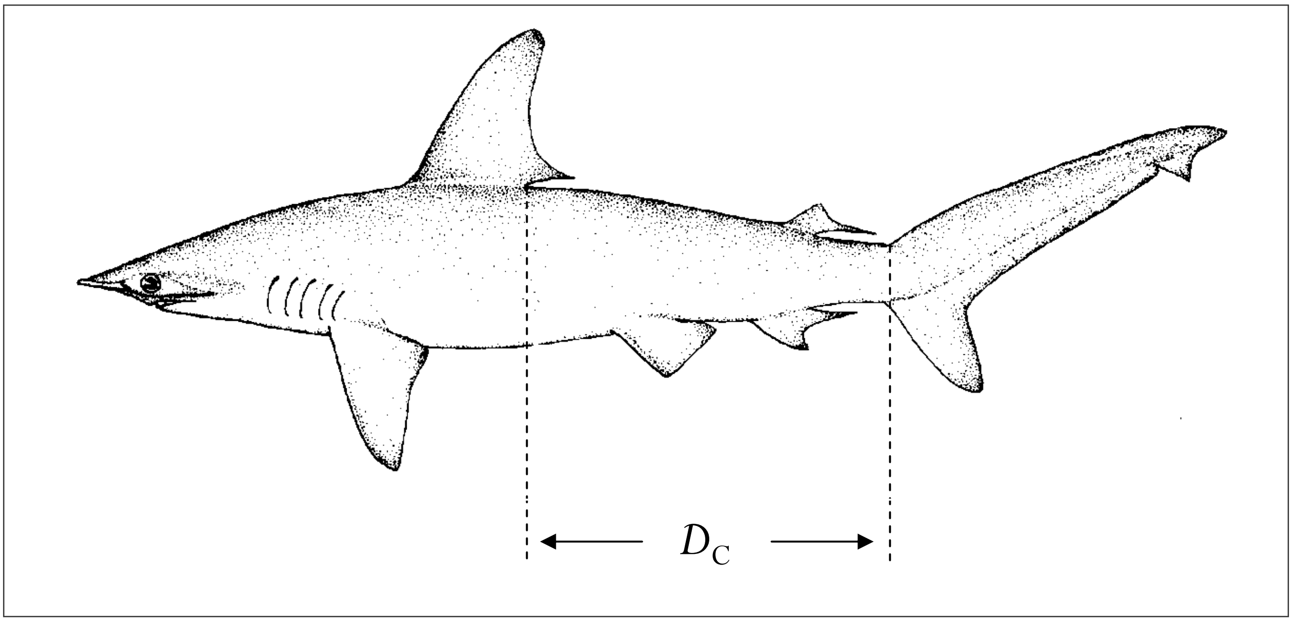


Figure 2. Hammerhead shark measurement used in this study (D_C = insertion distance of the first dorsal fin till the precaudal pit, cm) (Source: Compagno, 1984).

biometric relationships were obtained (Tables 1 and 2):

Sphyrna lewini: $L_T = 9.13 + 2.76*D_C$ ($r^2 = 0.99$; n = 92) (Kotas, 2004)

Sphyrna zygaena: $L_T = 30.52 + 2.10*D_C$ ($r^2 = 0.99$; n = 92).

Horizontal Movements and exploitation pattern

Between 1995 and 2009 a representative sample of *S. lewini* (n = 2481) and *S. zygaena* (n = 353) were obtained from the industrial fleets (anchored gillnetters, drifters, longliners, double riggers, pair trawlers and

Table 1. Morphometric relationships between the total length (L_T, cm) and the insertion distance of the first dorsal fin till the precaudal pit (D_C, cm) for *S. lewini*. Regression statistics, ANOVA and the significance of the coefficients are also shown.

Sphyrna lewini $L_T = 9.13 + 2.76*D_C$

Regression Statistics	
R-Squared	0.99
Standard error	5.81
n	92

ANOVA

	df	***SS***	***MS***	***F***	***P***
Regression	1	391756.48	391756.48	11626.35	0.00
Error	90	3032.60	33.70		
Total	91	394789.08			

	Coefficients	***Standard error***	***Stat t***	***P***	***95% inferior***	***95% superior***
a	9.13	1.25	7.26	0.00	6.64	11.61
b	2.76	0.03	107.83	0.00	2.71	2.81

Table 2. Morphometric relationships between the total length (L_T, cm) and the insertion distance of the first dorsal fin till the precaudal pit (D_C, cm) for *S. zygaena*. Regression statistics, ANOVA and the significance of the coefficients are also shown.

Sphyrna zygaena	$L_T = 30.52 + 2.10*D_C$

Regression Statistics	
R-Squared	0.80
Standard error	18.46
n	33

ANOVA

	df	*SS*	*MS*	*F*	*P*
Regression	1	42855.69	42855.69	125.75	0.00
Error	31	10565.08	340.81		
Total	32	53420.77			

	Coefficients	*Standard error*	*Stat t*	*P*	*95% inferior*	*95% superior*
a	30.52	13.76	2.22	0.03	2.45	58.60
b	2.10	0.19	11.21	0.00	1.72	2.48

otter trawlers) based in the harbours of Itajaí and Navegantes, Santa Catarina State and Ubatuba, São Paulo State (Table 3). In the case of *S. lewini* it could be noted that all its length composition was represented in the sample, i.e., from embryos of 16 to 39 cm, pups of 40 to 55 cm and adults of 192 to 331.08 cm total length (TL). The mean TL caught was 93.5 cm (SD = 53.30 cm). The scalloped hammerheads were exploited from inshore shallow waters (15 m) until offshore areas with local depths of 4400 m. However, most of the catches occurred in coastal areas, over the continental shelf, with a mean depth of 133 m (SD = 380.04 m).

For *S.zygaena* the sample was smaller (n = 353), due its lower proportion in the catches if compared to its congener *S. lewini*. In this case, also all its length composition was exploited by different fishing fleets, i.e., from embryos of 30.5 to 48 cm TL, pups of 49 to 55 cm and adults of 210 to 272 cm TL (mean = 109 cm; SD = 36.9 cm). *S. zygaena* was also caught throughout all its depth distribution, i.e., from inshore shallow waters of 33 m to offshore areas, with local depths of 3100 m (Table 3). In this case, most of the catches occurred over the shelf border with local depths

Table 3. Descriptive statistics of the two hammerhead shark species sampled from the industrial fleets (anchored gillnetters, drifters, longliners, double riggers, pair trawlers and otter trawlers) based in the harbours of Itajaí and Navegantes, Santa Catarina State, and Ubatuba, São Paulo State, between 1995 and 2009. TL – shark total length (cm); DEPTH – local depth (m).

Sphyrna lewini		
	TL (cm)	**Depth (m)**
N of cases	2481	2450
Minimum	16.04	14.75
Maximum	331.08	4400
Mean	93.50	132.59
Standard Dev	53.30	380.04
Sphyrna zygaena		
	TL (cm)	**Depth (m)**
N of cases	353	354
Minimum	30.52	33
Maximum	272.00	3100
Mean	109.03	226.18
Standard Dev	36.86	377.08

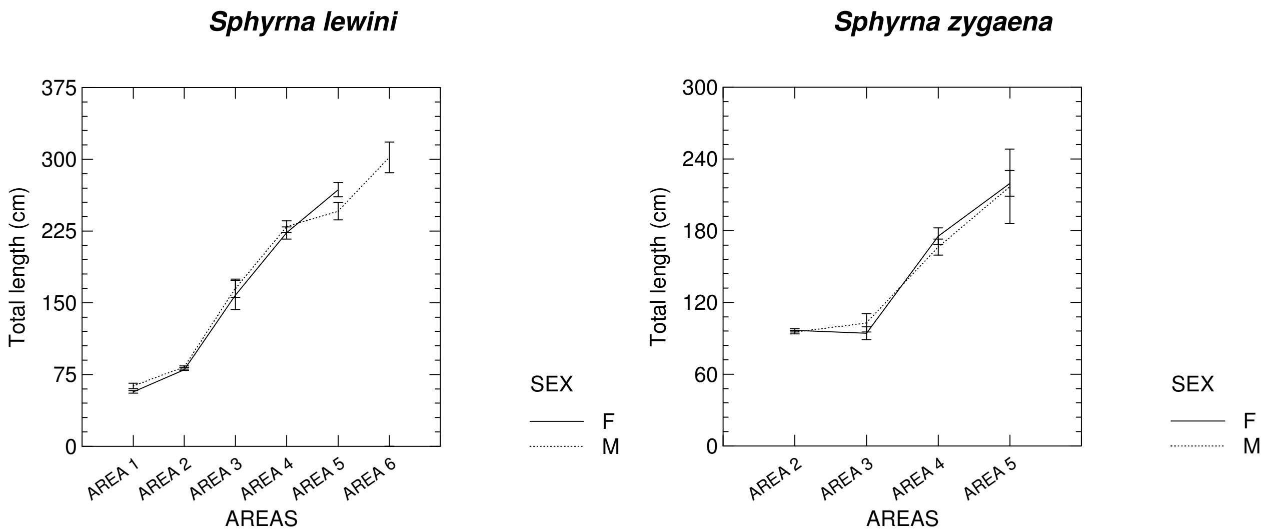


Figure 3. Spatial variation of the mean total length (cm) of *S.lewini* and *S.zygaena,* separated by sex. Vertical bars – Standard error. Horizontal axes are depth strata, i.e., Area 1 - 0 to 20 m; Area 2 - 21 to 100 m; Area 3 - 101 to 200 m; Area 4 - 201 to 1000 m; Area 5 - 1001 to 4000 m; Area 6 - > 4000 m.

226 m (SD = 377 m).

The model of horizontal movements of *S. lewini* and *S. zygaena* from inshore waters to offshore areas can be observed, following the variation in the mean TL (cm) of these hammerheads, caught by different fishing boats, throughout different depths (Fig. 3). In the case of *S. lewini* it is possible to observe that the pups are located in shallow waters (< 20 m), and juveniles spread over the continental shelf. On the other hand, the adults (> 192 cm TL) occur offshore, in areas with local depths higher than 200 m. This means that there is a horizontal migration of scalloped hammerheads as they grow, i.e., from their pupping grounds in shallow waters, passing through the continental shelf, where most of the juveniles are developing and ending in offshore areas over the slope, where most of the adults stay most of their time. Similar pattern is also observed with *S. zygaena,* although with a sample less representative than *S. lewini*.

Analysis of Variance test was applied to the mean TL (cm) of *S. lewini* distributed along different depth strata and the differences were significant ($p < 0.01$) (Table 4). After this procedure, the Tukey HSD Multiple Comparisons test was applied to the same pool of data and also there was a significant difference in the mean TL between different pair of areas (p <

Table 4. Analysis of Variance applied to the spatial variation of the mean TL (cm) of *S. lewini* There was a significant difference between areas ($p < 0.01$).

Dep Var: TL N: 2449 Multiple R: 0.80 Squared multiple R: 0.64

Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
AREA	4579798.57	5	915959.72	864.65	0.000
Error	2587969.52	2443	1059.34		

Durbin-Watson D Statistic 0.73

First Order Autocorrelation 0.64

0.01). The only exception was found between areas 5 and 6 where the differences between mean TL were not significant ($p > 0.01$) (Table 5).

Table 5. Tukey HSD Multiple Comparisons test applied to the spatial variation of the mean TL (cm) of *S.lewini*. There was a significant difference between different pair of areas ($p < 0.01$).

Tukey HSD Multiple Comparisons.

Matrix of pairwise comparison probabilities:

AREA	1	2	3	4	5	6
1	1.000					
2	0.000	1.000				
3	0.000	0.000	1.000			
4	0.000	0.000	0.000	1.000		
5	0.000	0.000	0.000	0.000	1.000	
6	0.000	0.000	0.000	0.000	0.087	1.000

The same procedure (ANOVA) was applied to mean TL (cm) of *S. zygaena* distributed along different depth strata and the differences were also significant ($p < 0.01$) (Table 6). Afterwards, the Tukey HSD Multiple Comparisons test also showed significant differences in the mean TL between different pair of areas ($p < 0.01$). The only exception was found between areas 1 and 2 where the differences between mean TL were not significant ($p > 0.01$) (Table 7).

Anchored gillnetter's activities and their impacts on the hammerheads.

The hammerheads (*S. lewini* and *S. zygaena*) are bycatches of the anchored gillnet fishery which targets the whitemouth croaker,

Table 7. Tukey HSD Multiple Comparisons test applied to the spatial variation of the mean TL (cm) of *S.zygaena*. There was a significant difference between different pair of areas ($p < 0.01$).

Tukey HSD Multiple Comparisons.

Matrix of pairwise comparison probabilities:

AREA	1	2	3	4
1	1.000			
2	0.914	1.000		
3	0.000	0.000	1.000	
4	0.000	0.000	0.000	1.000

M. furnieri. *Sphyrna lewini* was the most frequent, representing 80.4 % of the two landed sharks (Table 8) prevailing throughout the year with a ratio above 50 % in different seasons. The lowest values were reported in the winter of 2009 (55.4 %) and the highest proportion was reported in the summer of 2009 (94.2 %). In turn, its congener, *S. zygaena* occurred in abundances mostly below 30 %, with the exception of the winter of 2009, which peaked at 44.6%.

The anchored gillnetters operated on the shelf and in the upper slope, at maximum depth of 300 m between Cabo Frio (22 ° 52' S) and Chui (34 ° 45' S) (Fig. 1). However, the highest CPUE of the hammerhead sharks occurred below 120 m (Fig. 4).

For 2008, 2009 and 2010 there were records of 39, 56 and 28 anchored gillnet boats respectively targeting the whitemouth croaker, *Micropogonias furnieri*. These nets remained

Table 6. Analysis of Variance applied to the spatial variation of the mean TL (cm) of *S. zygaena* There was a significant difference between areas ($p < 0.01$).

Dep Var: TL N: 349 Multiple R: 0.819 Squared multiple R: 0.67

Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
AREA	316252.25	3	105417.42	233.44	0.000
Error	155794.09	345	451.58		

Durbin-Watson D Statistic 1,24

First Order Autocorrelation 0.37

Table 8. Occurence in number of individuals and its correspondent percentages of *S. lewini* and *S. zygaena* caught by the anchored gillnet industrial fishing fleet and landed in Itajaí and Navegantes harbours (Santa Catarina State, Brazil), from the autumn 2008 to the spring 2009. (a) total; (b) by year and season.

(a)

Specie	n	%
S. lewini	1126	80.4
S. zygaena	275	19.6
Total	1401	100

(b)

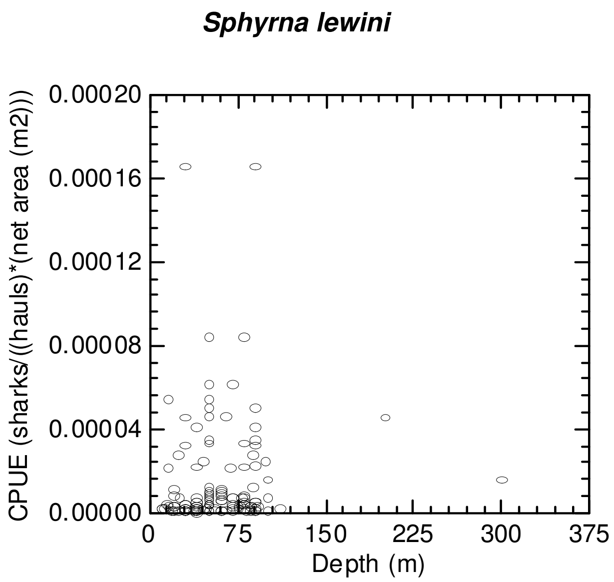
Year	Season	n	% *S. lewini*	% *S. zygaena*
2008	Autumn	280	88.9	11.1
2008	Winter	480	78.1	21.9
2008	Spring	98	79.6	20.4
2009	Summer	189	94.2	5.8
2009	Autumn	218	73.9	26.1
2009	Winter	101	55.4	44.6
2009	Spring	35	82.9	17.1

set between eight to 11 hours submerged and more than 90 % of the catches are the croaker. These anchored gillnets gradually increased during 2008, 2009 and 2010, i.e. 19.6 km, 21.2 km and 21.5 km, respectively and in this period of three years there were nets with a minimum of 7.2 km to a maximum of 31.5 km in total length (Table 9).

During the research period there were 48 vessels registered in the landing ports of Itajaí and Navegantes catching hammerhead sharks. The mean length of the wooden boats was 21 m (n = 47, SD = 2.3 m), engine power 299 HP (n = 48, SD = 59.3 HP), cargo capacity 49 t (n = 46, SD = 16.9 t), gross tonnage 69 (n = 35, SD = 24.1) and the mean crew number was seven men (n = 47, SD = 0.6 men) (Table 10).

The anchored gillnet fishing boats landing hammerheads in Itajaí and Navegantes, during the period 2008 - 2009, utilized total length nets averaging 19,978 m (n = 48, SD = 4,260.1 m). Each gillnet piece (panel) averaged 54 m length (n = 47, SD = 7.2 m). The average number of nets transported per trip was 367 (n = 47, SD = 61.8 panels). The mean height of the gillnets was 3 m (n = 47, SD = 0.9 m) and the mean mesh size (between opposite knots with stretched mesh) was 13 cm (n = 48, SD = 0.4 cm) (Table 10).

The size composition of *Sphyrna lewini*



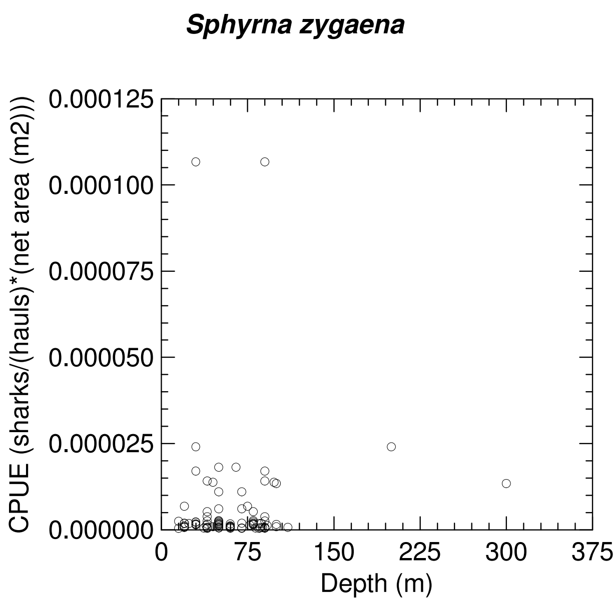


Figure 4. CPUE variations (individuals / (number of hauls) * (net area (m^2))) versus depth (m) for *S. lewini* and *S. zygaena* caught by the anchored gillnet industrial fishing fleet and landed in Itajaí and Navegantes harbours (Santa Catarina State, Brazil). Period: autumn 2008 to spring 2009.

Table 9. Anchored gillnet fishing targeting *M. furnieri*. Traits from interviews performed in Itajaí and Navegantes (Santa Catarina State, Brazil) between 2008 and 2010. Min – minimum; max – maximum.

Year	2008	2009	2010
Number of boats*	39	56	28
Number of trips	53	83	47
Number of hauls/ trip mean (min - max)	21 (7 - 32)	20 (5 - 29)	18 (2 - 28)
Depth (m) (min - max)	7 - 300	30 - 110	30 - 110
Boat lenght (m) mean (min -max)	21.4 (15.0 -25.7)	21.0 (15.0 -25.0)	20.8 (17.0 -24.7)
Gillnet height (m) mean (min -max)	3.4 (2.0 -7.4)	3.3 (2.3 -5.0)	3.3 (2.5 - 4.0)
Mean gillnet length (km) mean (min -max)	19.6 (10.5 - 27.2)	21.2 (7.2 - 28.8)	21.5 (14.0 - 31.5)
Fishing time (hour)	8 - 11	8 - 11	8 - 11
Catch (t) / trip mean (min—max)	21.1 (4.5 - 35.0)	17.8 (3.3 - 35.0)	16.7 (4.0 - 30.0)
% Croaker (in weight)	95,4%	93.0%	91.3%

landed consisted of neonates and juveniles, i.e., with total length (L_T) averaging 78.9 cm (n = 1,126, SD = 12.6 cm). According to Galina (2006) and Kotas (2004), the species in southern Brazil has L_T at birth between 40 and 55 cm and the length of first maturation averaging a L_T of 192 cm and 204 cm for males and females respectively. In the case of *S. zygaena*, landings were composed of juveniles, i.e., L_T averaging 94 cm (n = 274, SD = 13.1 cm). According to Vooren & Klippel (2005) in the State of Rio Grande do Sul, the L_T of *S. zygaena* at birth is between 49 and 55 cm. In the northwest Atlantic, the species matures with a L_T between 210 to 240 cm (Bigelow & Schroeder, 1948) (Table 11, Fig. 5 and Fig. 6).

Analysis of sex ratios of *S. lewini* caught by anchored gillnet, considering the whole period of autumn of 2008 to the spring of 2009, indicated a significant difference between sexes ($P < 0.05$) with favorable proportion for males (1.1:1). However, considering the sex ratio season separately, no significant difference between the sexes is detected. For *S. zygaena*, the sexual proportion showed no significant differences ($P > 0.05$), for the period from the two seasons above (Table 12).

It was also examined variation in sex ratio for *S. lewini* and *S. zygaena* according to

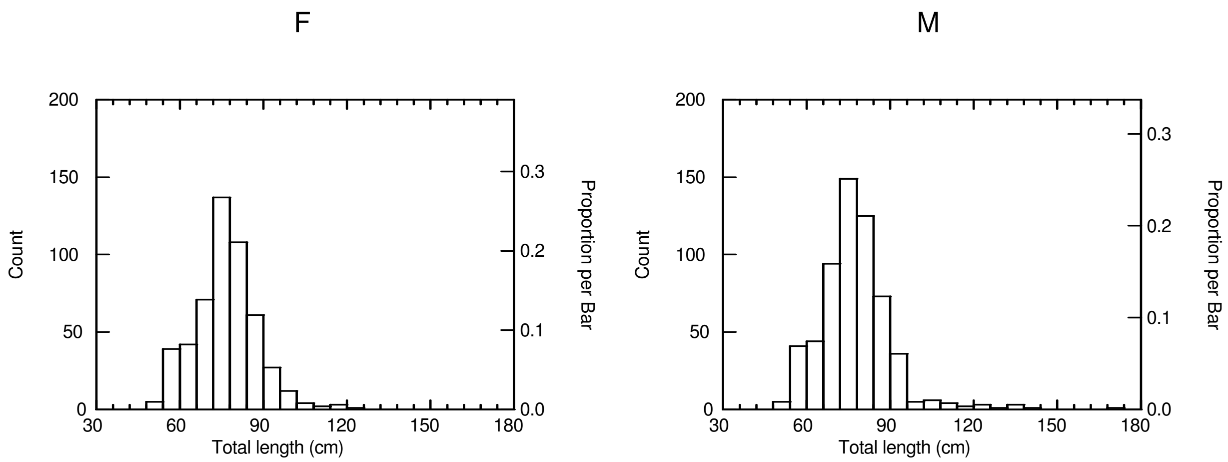


Figure 5. Size composition of *S. lewini* (n = 1105) by sex (left – females; right - males) caught by the anchored gillnet industrial fishing fleet landed in Itajaí and Navegantes harbours (Santa Catarina State, Brazil). Period: autumn 2008 to the spring 2009.

Table 10. Descriptive statistics of boats and nets from the industrial anchored gillnet fishing fleet which landed hammerheads in Itajaí and Navegantes harbours (Santa Catarina State, Brazil). Period: autumn 2008 to spring. BTL—boat total length (m).

Boat	BTL (m)	Engine Power (HP)	Cargo Capacity (t)	Gross Tonnage	Crew
Mean	21	299	49	69	7
Standard deviation	2.3	59.3	16.9	24.1	0.6
Upper 95% confidence interval	21.9	315.7	54.4	77.4	7.0
Lower 95% confidence interval	20.6	281.3	44.3	60.9	6.7
Minimum	16	115	18	30	5
Maximum	25	470	80	120	8
N	47	48	46	35	47

Anchored gillnet	Panel total length (m)	Panel number	Gillnet total length (m)	Gillnet height (m)	Gillnet area (m^2)	Mesh size (stretched opposite knots) (cm)
Mean	54	367	19978	3	68560	13
Standard deviation	7.2	61.8	4260.1	0.9	20295.8	0.4
Upper 95% confidence interval	56.5	385.2	21215.3	3.7	74453.3	13.1
Lower 95% confidence interval	52.3	348.8	18741.3	3.2	62666.7	12.8
Minimum	28	150	7500	2	18750	10
Maximum	70	500	28200	7	115600	14
N	47	47	48	47	48	48

the total length (cm). For *S. lewini* up to 100 cm the sex ratio was close to 1:1. Above this size the proportion of males are larger than females, suggesting the beginning of female's migration from demersal to pelagic habitat. Although small in numbers, from the class of L_T 130 cm onwards only males were caught (Table 13). Concerning *S. zygaena* till 110 cm

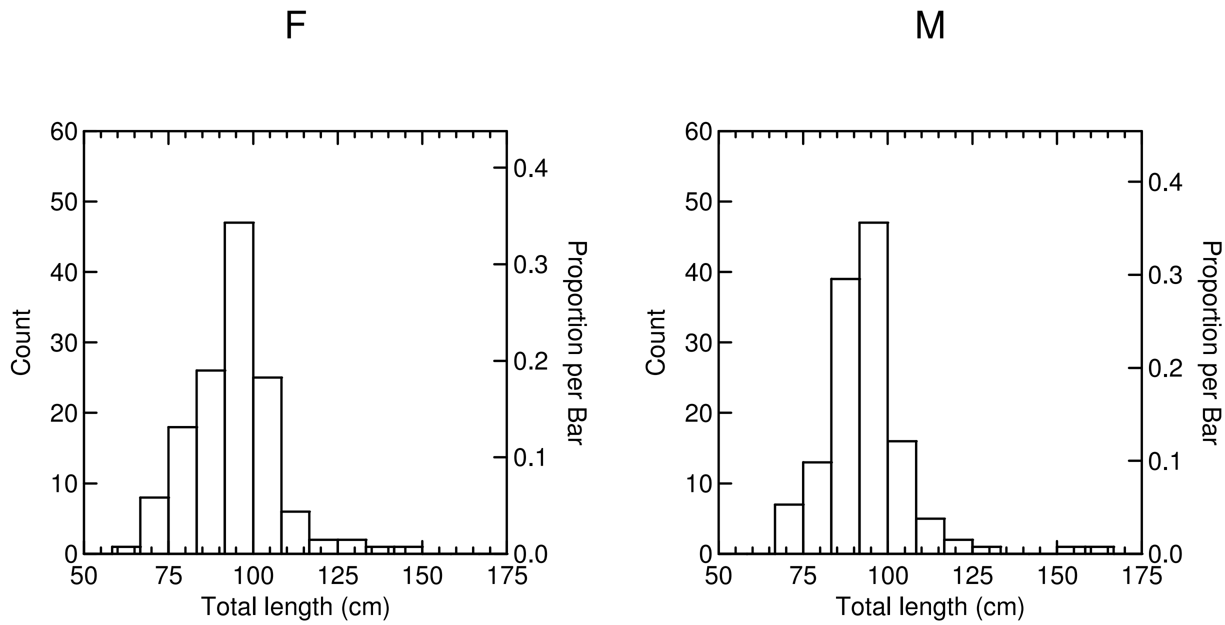


Figure 6. Size composition of *S. zygaena* (n = 269) by sex (left – females; right - males) caught by the anchored gillnet industrial fishing fleet landed in Itajaí and Navegantes harbours (Santa Catarina State, Brazil), from the autumn 2008 to the spring 2009.

the sex ratios were close to 1:1, with small fluctuations.

The age composition of *S. lewini* caught by anchored gillnets consisted of neonates and juveniles, i.e., with a mean age of 2.8 years (n = 1,108, SD = 1.4 years). According to Kotas *et al*. (2011) and Galina & Vooren (2005), *S. lewini* in southern Brazil present length at first maturation averaging 192 cm (22 years) and 204 cm (19 years) for males and females respectively (Table 14 and Fig. 7). The annual variation of total CPUE of hammerheads (kg/trip) caught by the anchored gillnetters, and registered to the statistics of Santa Catarina State (http://www.univali.br/gep), indicated a general declining trend (Fig. 8). There was a peak of 933 kg/trip in 2006 followed by a drop to only 185 kg/trip in 2010. Afterwards the

Table 11. Size composition descriptive statistics of *S. lewini* (n = 1126) and *S. zygaena* (n = 274) measured in the fishes landed by the anchored gillnet industrial fishing fleet in Itajaí and Navegantes harbours (Santa Catarina State, Brazil). Period: autumn 2008 to spring 2009. L_T – total length (cm).

Species	Sex	n	L_T (cm) minimum	L_T (cm) maximum	L_T (cm) mean	Standard deviation
S. lewini	Males	594	52.5	174.2	78.9	13.2
	Females	514	51.9	125.9	78.3	11.5
	Sexes combined	1126	51.9	174.2	78.9	12.6
S. zygaena	Males	133	66.9	166.2	93.8	13.1
	Females	137	63.7	143.9	94.1	12.8
	Sexes combined	274	63.7	166.2	94.0	13.1

Table 12. Chi-square test results applied to the number of individuals by sex per quarter of *S. lewini* and *S. zygaena* landed by the anchored gillnet industrial fishing fleet in Itajaí and Navegantes (SC), from the autumn 2008 to the spring 2009.

Sphyrna lewini					
Year	**Quarter**	**Number of females**	**Number of males**	χ^2	***P***
2008	2	86	102	1.36	0.243
2008	3	200	233	2.52	0.113
2008	4	33	42	1.08	0.299
2009	1	84	93	0.46	0.499
2009	2	73	62	0.90	0.344
2009	3	21	32	2.28	0.131
2009	4	9	16	1.96	0.162
	Total	506	580	5.04	0.025
Sphyrna zygaena					
Year	**Quarter**	**Number of females**	**Number of males**	χ^2	***P***
2008	2	18	12	1.20	0.273
2008	3	50	48	0.04	0.840
2008	4	10	7	0.53	0.467
2009	1	3	1	1.00	0.317
2009	2	20	28	1.33	0.248
2009	3	20	24	0.36	0.546
2009	4	2	4	0.67	0.414
	Total	123	124	0.00	0.949

Table 13. Sexual proportion of *S. lewini* and *S. zygaena* by total length class (cm) landed by the anchored gillnet industrial fishing fleet in Itajaí and Navegantes harbours (Santa Catarina State, Brazil). Period: autumn 2008 to spring 2009. L_T – total length (cm).

Sphyrna lewini					
L_T (cm)	**Female**	**Male**	**N total**	**% females**	**% *males***
50	36	33	69	52.2	47.8
60	67	97	164	40.9	59.1
70	200	210	410	48.8	51.2
80	142	173	315	45.1	54.9
90	54	58	112	48.2	51.8
100	8	7	15	53.3	46.7
110	4	6	10	40.0	60.0
120	3	5	8	37.5	62.5
130		3	3	0.0	100
140		1	1	0.0	100
170		1	1	0.0	100
Sphyrna zygaena					
L_T (cm)	**Female**	**Male**	**N total**	**% females**	**% *males***
60	1	1	2	50.0	50.0
70	17	12	29	58.6	41.4
80	31	35	66	47.0	53.0
90	51	59	110	46.4	53.6
100	28	17	45	62.2	37.8
110	5	4	9	55.6	44.4
120	1	3	4	25.0	75.0
130	2		2	100	0.0
140	1		1	100	0.0
150		1	1	0.0	100
160		1	1	0.0	100

CPUE remained reduced to only 219 kg/trip in 2012, and the CPUE never recover to the levels of the years 2000 and 2006. The same declining pattern was also found for the hammerheads caught by surface longliners. However, it is important to keep in mind that the use of CPUE as an index of abundance has to be used cautiously. It has many flaws and can be misinterpreted. Potential socio-economic and market-related factors can be affecting the general annual CPUE trend. The fishing strategy can be affecting these indexes. CPUE data use to be harmed due to differences in catchability and even due to environmental and behavioral patterns (Bigelow, Boggs and He, 1999; Abuabara e Petrere, 1997; Amorim *et*

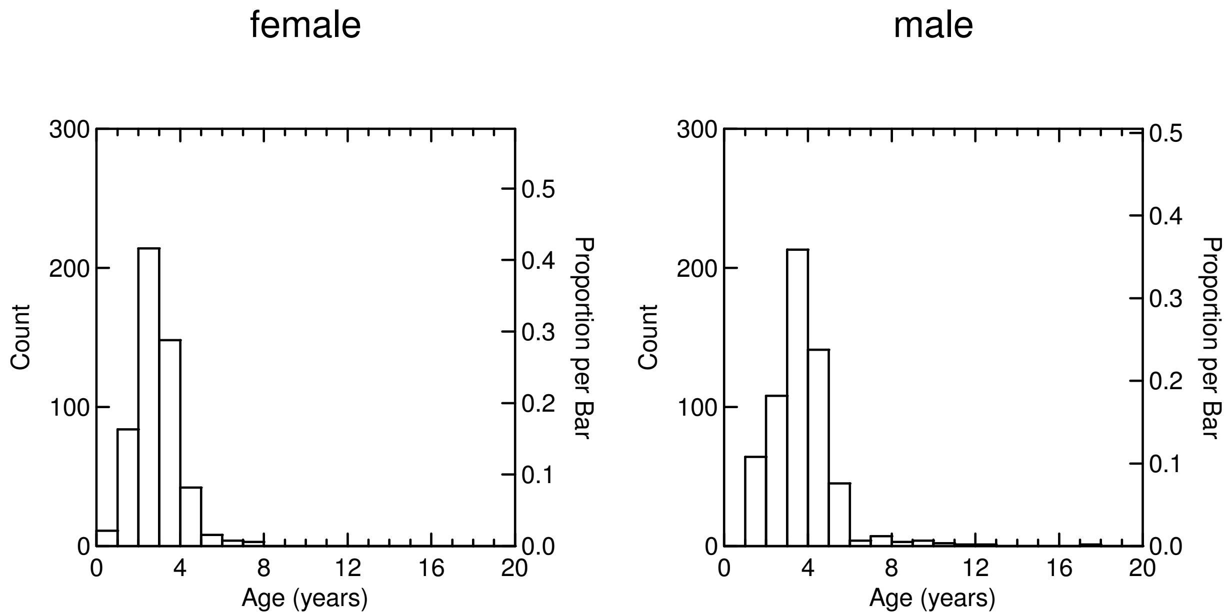


Figure 7. Age composition of *S. lewini* (n = 1108), grouped by sexes caught by the anchored gillnet industrial fishing fleet landed in Itajaí and Navegantes harbours (Santa Catarina State, Brazil). Period: autumn 2008 to spring 2009.

al., 1994; Kotas, 2004).

Box-plots of seasonal variations in the hammerhead shark's CPUE (individuals / n° of hauls*net area (m^2)) caught by the anchored gillnetters, indicated higher values for *S. lewini* in summer-autumn and for *S. zygaena* during wintertime (Fig. 9).

Discussion

The high fishing effort exceeding the stock reproductive capacity is the main cause of the abundance declining of several shark species (Cortés *et al.*, 2002; Simpfendorfer & Burgess, 2002). In the Northwestern Atlantic *S. lewini* abundance declined 89 % between 1986 and 2000, and it is considered one of the most vulnerable shark species to overexploitation (Baum *et al.*, 2003).

Mortality rates between 71.5 and 100% were found for members of the family Sphyrnidae in gillnet catches (Manire *et al.*, 2001; Thorpe *et al.*, 2004; Thorpe & Frierson, 2009). Due to the particular hammerhead sharks *cephalophoil* it appears that most of them are wrapped up irrespective of mesh size or gear modifications (Thorpe & Frierson, 2009).

The hammerheads landings in southern Brazil are mainly composed of 2 species, i.e. *S. lewini* and *S. zygaena* (Kotas, 2004). However, the national fisheries statistics doesn't

Table 14. Age composition descriptive statistics of *S. lewini* recorded in the landings by the anchored gillnet industrial fishing fleet in Itajaí and Navegantes harbours (Santa Catarina State, Brazil). Period: autumn 2008 to spring 2009.

Species	Sex	n	Age (years) minimum	Age (years) maximum	Age (years) mean	Standard deviation
	Males	594	0.5	17.4	3.2	1.5
S. lewini	Females	514	0.1	7.0	2.3	1.1
	Sexes combined	1108	0.1	17.4	2.8	1.4

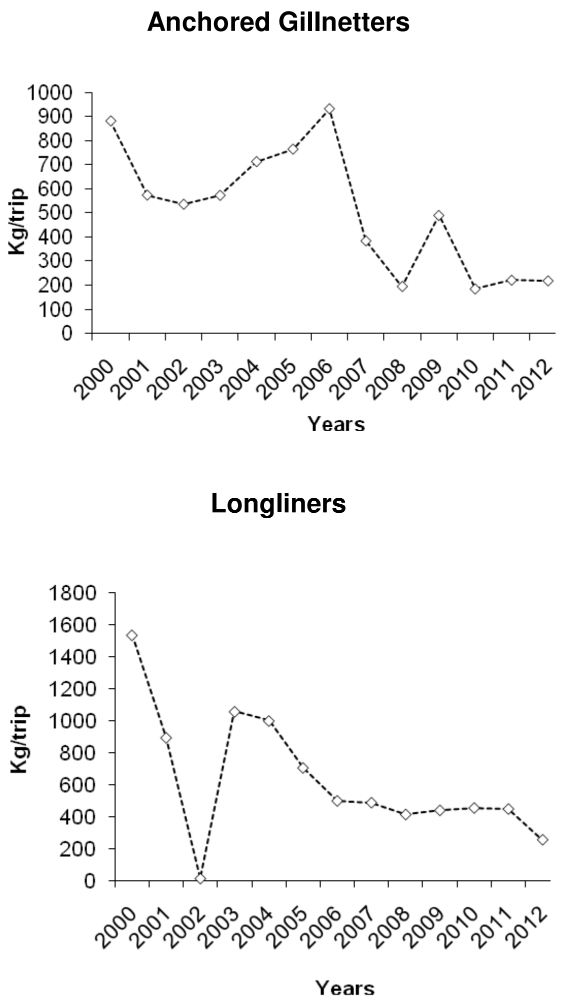


Figure 8. Total CPUE annual variation of hammerheads caught by the anchored gillnetters (upward) and surface longliners (kg/trip) from 2000 to 2012 in the State of Santa Catarina.

separate both species, including them in a "hammerhead shark group" or "shark group" (Bonfil, 1994). This condition hampers stock assessments for each species.

The present work indicated that along the southern Brazilian coast *Sphyrna lewini* has an exploitation pattern that encompasses all its different life-cycle phases (Figures 10 and 11. Considering that neonates ranged between 40 and 55 cm TL (Kotas, 2004) and that sizes at first sexual maturity are 192 and 204 cm for males and females respectively (Vooren *et al.*, 2005), it is observed that pair trawlers, otter trawlers, double riggers, anchored gillnetters, and drifters operating in coastal areas (≤ 200 m depth), essentially catch neonates and juveniles as bycatch. On the other hand, drifters and surface longliners, catch mainly adults in offshore areas (≥ 200 m). This exploitation pattern spans all the horizontal distribution of *S. lewini*, without hideouts for this species and endangering its conservation.

With respect *Sphyrna zygaena*, similar exploitation pattern was also found. In this case, considering that neonates observed in southern Brazil and Uruguay have TL ranging from 49 to 55 cm (Vooren *et al.*, 2005; Doño, 2008) and that the first reproduction TL in the NW Atlantic was found between 210 and 240 cm (Bigelow & Schroeder, 1948), it was possible to observe that anchored gillnetters, operating mainly along the continental shelf use to catch neonates and juveniles. On the other hand, considering drifters operating from the continental shelf to offshore areas over the slope, and surface longliners only over the slope, the catches are composed mainly by juveniles and adults of *S. zygaena* (Figures 10 and 11).

Stevens & Lyle (1989) in northern Australia, observed juveniles of *S. lewini* being caught from coastal zones until 275 m by gillnets, trawlers, longlines and finally hook and line. Similar pattern occurs in southern Brazil with *S. lewini* and *S. zygaena.*

Andrade & Mazzoleni (1999) detected catches of juveniles and pre-adults of *S. lewini* by pair and shrimp trawlers over the southern continental shelf of Brazil. Also sampling anchored gillnetters, they found mean TL of 134.2 +/- 51.5 cm and 134 +/- 56.9 cm for females and males respectively. Comparing their results with what was found in the present work with the same gear (mean TL of 78.9 cm and 78.3 cm for males and females respectively, caught during the period 2008-2009), it seems that a reduction in the mean size occurred, which is a sign of overfishing.

Kotas (2004) studying the length composition of *S. lewini* caught by gillnetters based in Ubatuba, São Paulo State, observed that the distribution was polimodal, ranging from newborns of 45 cm, to adults of 330 cm TL. Anchored gillnets used to catch high quantities of immature sharks (i.e., mean TL of 85.3 and 88 cm for males and females respectively). Meanwhile, driftnets caught mainly adults (mean TL

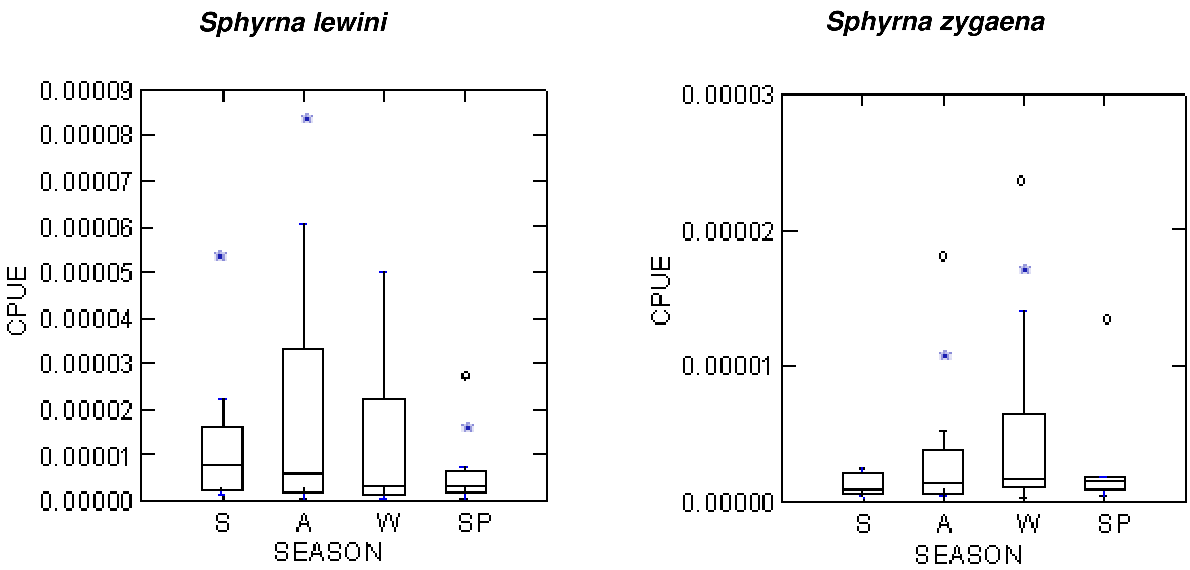


Figure 9. Box plots of the seasonal CPUE (individuals / (number of hauls) *(net area (m^2)) for *S. lewini* and *S. zygaena* caught by the anchored gillnet industrial fishing fleet landed in Itajaí and Navegantes (SC), from the autumn 2008 to the spring 2009. S – summer; A – autumn; W – winter; SP – spring.

of 190.1 and 196.2 cm for males and females respectively).

The monitoring carried out for the gillnet fishing fleet (anchored and driftnets) and surface longliners based in Itajai (SC) and Ubatuba (SP), which operated along the southern coast of Brazil between 1995 and 2008, showed that the hammerhead shark, *S. lewini* has been subjected to high levels of fishing mortality throughoutthe continental shelf where most juveniles and subadults its life cycle, i.e. (1) from the coastal nurseries (hammerhead sharks 40 to 55 cm L_T), (2) on are found (60 to 192 cm L_T), and (3) in areas further offshore, already on the continental slope, where adults feed and mate (> 192 cm L_T). This fishing mortality was mainly exerted by anchored gillnets on the continental shelf and by surface longlines and driftnets in the slope area (Kotas *et al.*, 2005; Kotas *et al.*, 2008).

Along the southern Brazilian coast, newborns and juveniles of *S. lewini* used to occur in shallower waters, between 2 and 10 m, over sandy bottoms, areas usually explored by coastal gillnetters and trawlers (Vooren & Lamónaca, 2003; Kotas, 2004). On the other hand, adults are intensively caught by surface longliners and driftnets, which operate over the continental shelf border and slope, without any kind of control (Kotas, 2004).

Vooren & Lamónaca (2003) compared the CPUE levels of *S. lewini* caught by gillnet during spring and observed a decline of 90 % between 1993 and 2001. This phenomenon was related with the reduction of pregnant females.

Musick (1999) observed that the main threats over longevous marine species are the multispecies fisheries, catching them mainly as by-catch.

The Industrial landings of hammerheads in the State of Santa Catarina showed a substantial increment from 6.7 t in 1989 to a peak of 570 t in 1994 due to the quick development of a gillnet fleet targeting the hammerheads to the international market for shark fins. In the spring-summer season of 1995, it was estimated that 72216 km of driftnets were used by the Itajaí and Navegantes fleet to target hammerheads (Kotas *et al.*, 1995). Afterwards the trend was a steep decline, reaching to only 79 t in 1997. There was a recovery to a peak of 381 t in 2005, due the development of a national longline fishery, but again was followed by a steep decline to only 43 t in 2012. The hammerhead's industrial landings never recovered to the levels of 1994 (Kotas, 2004; Kotas, personal communication; http://www.univali.br/gep; IBAMA) (Fig. 12). High annual declines in CPUE (kg / fishing trip) were also observed for

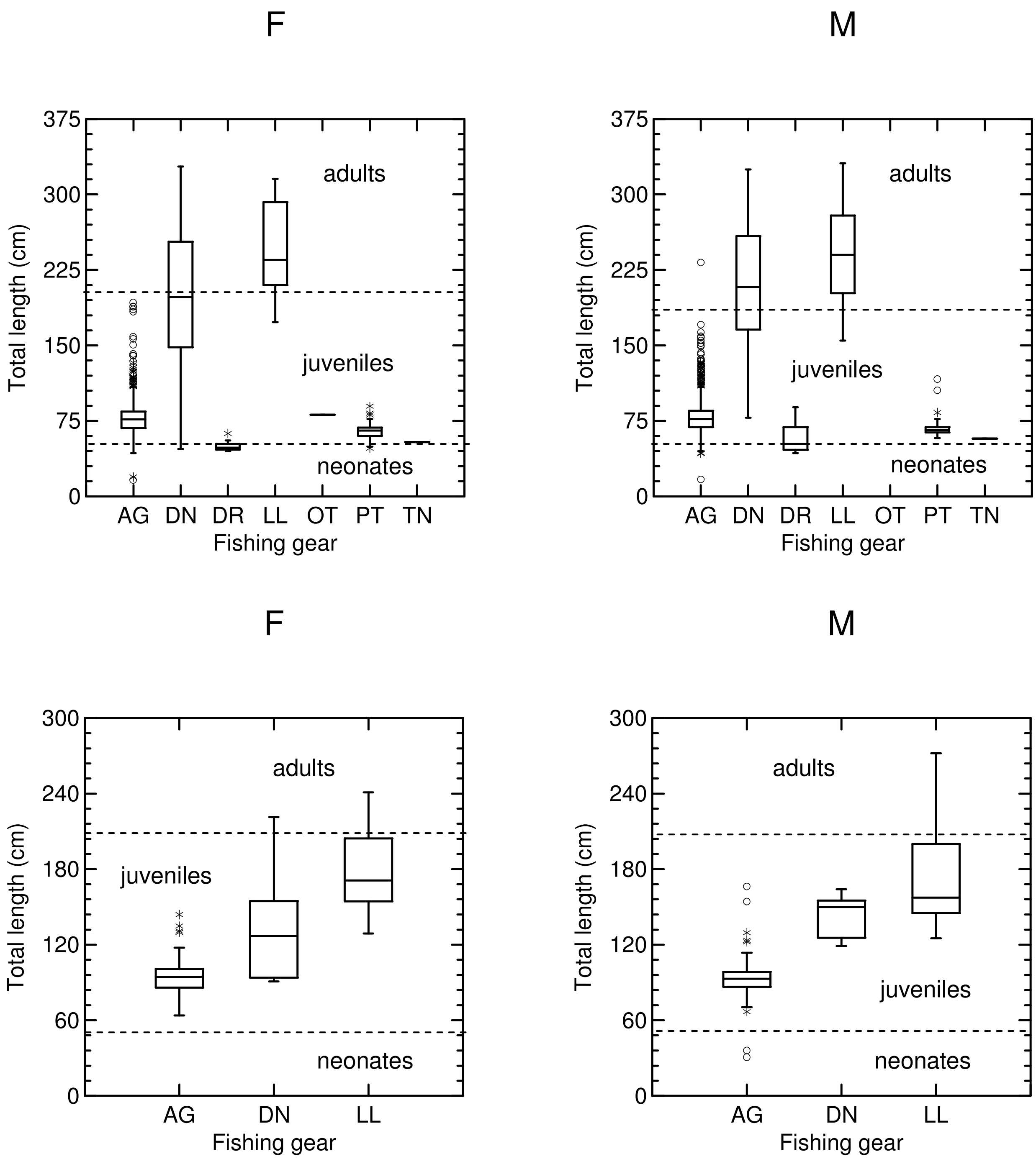


Figure 10. Box-plots representing the exploitation pattern of *Sphyrna lewini* (up) and *Sphyrna zygaena* (down) by the industrial fleet. Vertical axes represents shark total length (cm). Horizontal axes are the fishing modalities. F – female; M – male. AG – anchored gillnet; DN – driftnet; LL – longline;

the hammerhead sharks caught by surface longline fleets and anchored gillnet fleet based in the state of Santa Catarina for the period 2000 to 2012 (Kotas, 2004; Kotas *et al.*, 2008; http://www.univali.br/gep) (Fig. 8).

The industrial fishing gillnets are a serious threat to the hammerheads existence along the southern Brazilian coast. Due to the relative smaller abundance of *S. zygaena* than *S. lewini* this implies a greater risk of extinction for *S. zygaena* (Kotas personal communica-

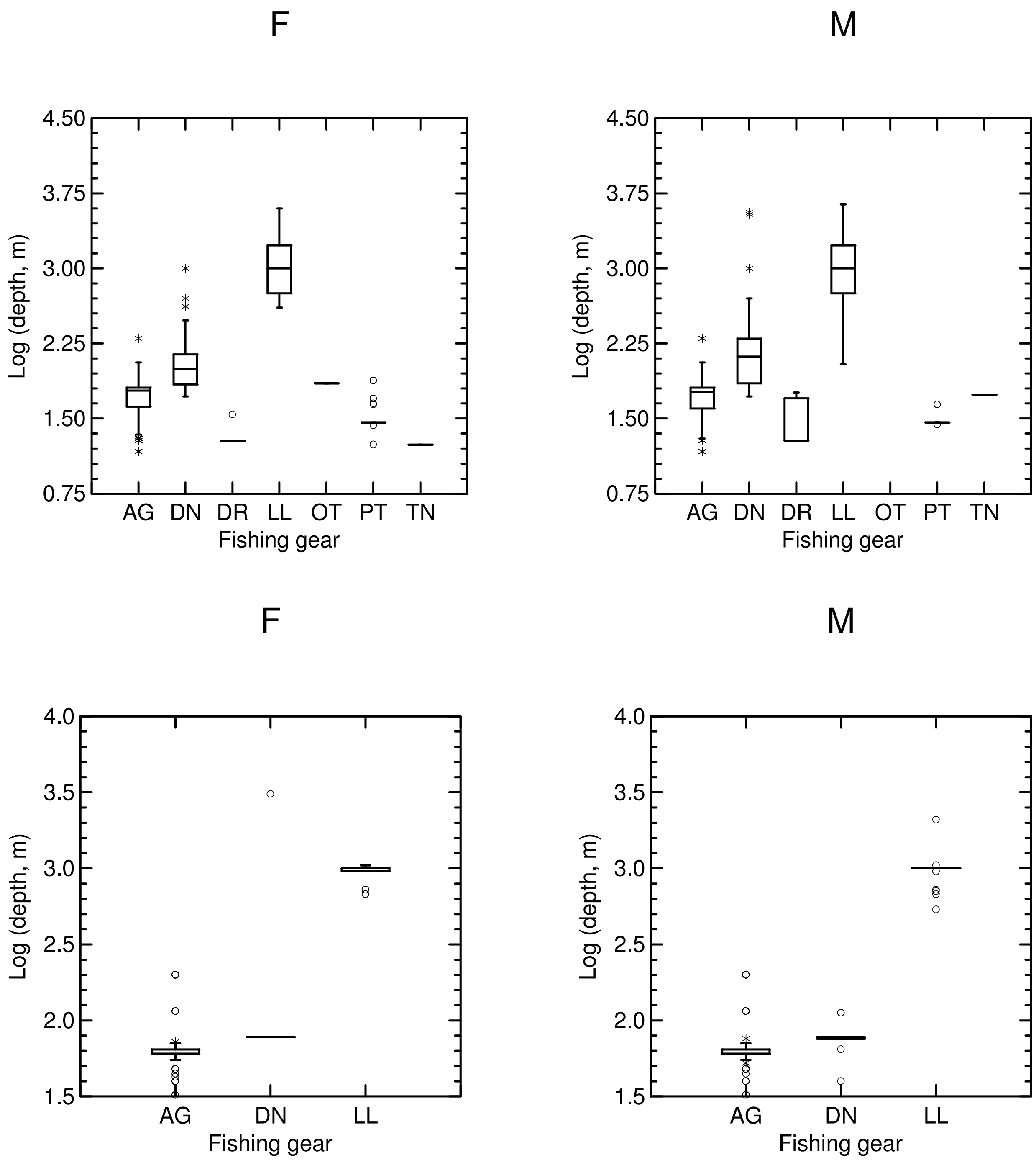


Figure 11. Box-plots representing the exploitation pattern of *Sphyrna lewini* (up) and *Sphyrna zygaena* (down) by fishing gear. Vertical axes represents logarithm (base 10) of depth (m). Horizontal axes are the fishing gears. F – female; M – male. AG – anchored gillnet; DN – driftnet; LL – longline; DR – double rig; PT – pair trawler; OT – otter trawler; TN – trammel net.

tion).

In coastal Southern and Southeastern Brazil the industrial fleet of anchored gillnet targeting the whitemouth croaker *Micropogonias furnieri* (Desmarest, 1823) accidentally catch scalloped *Sphyrna lewini* (Griffith & Smith, 1834) and smooth hammerhead sharks *Sphyrna zygaena* (L., 1758). In this case, the target species continues to sustain the fishery while several species of elasmobranchs, due to intrinsic characteristics of their life cycles,

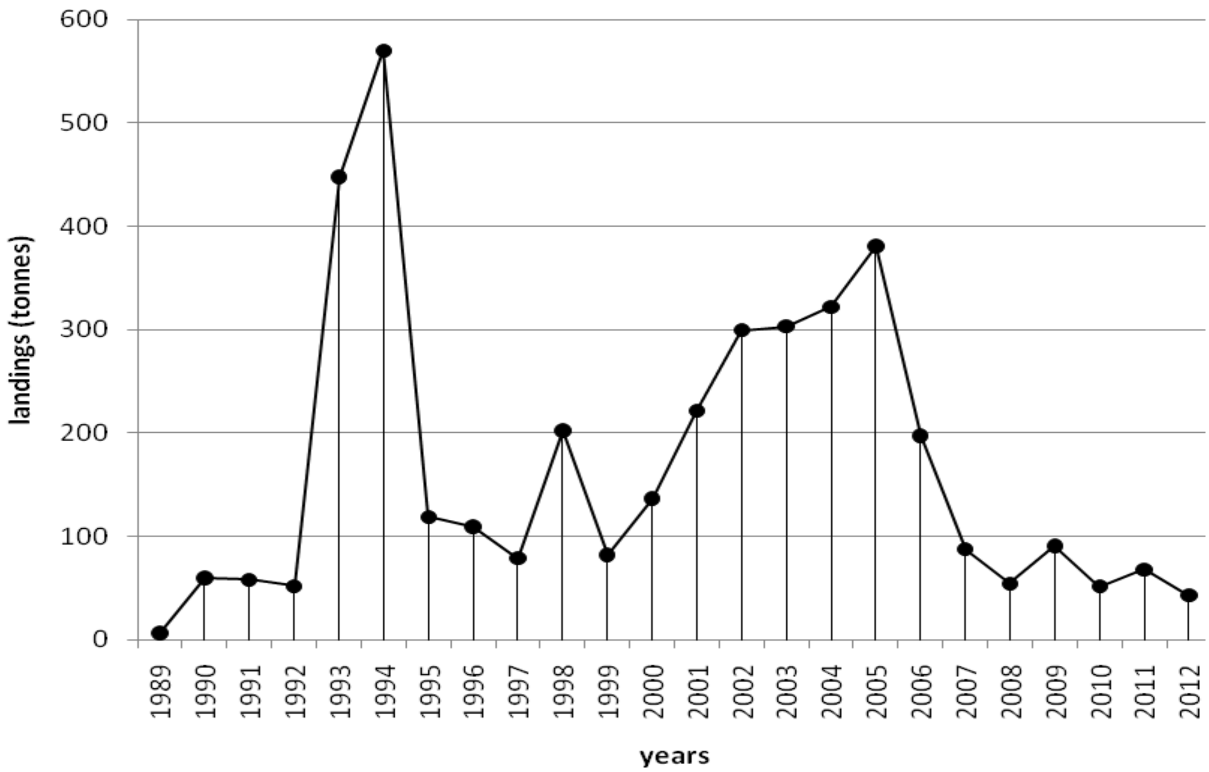


Fig. 12. Annual variation of the hammerheads total industrial landings (t) in the State of Santa Catarina, Brazil. Period: 2000 to 2012 (Source: GEP / Univali; IBAMA).

become more vulnerable to intensive fishing and less able to recover, therefore staying near to the brink of extinction (Musick *et al*., 2000).

Gillnets can be highly selective for given size classes of target species, but might be somewhat less selective in the case of hammerheads. Species morphology, fish behaviour, net design and manufacturing affect catch rates (Gray *et al*., 2005*a*; Gray *et al*., 2005*b;* Kelleher, 2005).

Tests done with anchored gillnets showed for the bonnethead shark, *Sphyrna tiburo* L. 1758, uniform selectivity, not a normal distribution, due the morphology of its cephalophoil. *S. tiburo* was enmeshed by the head, regardless of mesh size or the net structural modifications. Hammerheads are wrapping caught, and the increased gillnet tension due the installation of larger buoys and more weight near the bottom would be alternative ways to reduce their incidental catches (Trent *et al*., 1997; Thorpe & Frierson, 2009). This modification has also the advantage to reduce gillnet repairing costs (Carlson, personal communication to Kotas, 2008).

According to Gallucci *et al*., (2006) juveniles removal of any shark species (whether or not long-lived) leads to a higher stock depletion risk than those fisheries which just remove the adult stock biomass. Unfortunately the Itajaí and Navegantes (SC) anchored gillnet fleets rightly focus more intensely on juvenile hammerhead sharks, reflecting in seasonal landings nearing to critical levels. Several authors suggest that stocks of sharks are more resilient to fishing when a small number of age classes are the target of the fishery and the age group chosen is the key to sustainability (Prince, 2005; McAuley *et al*., 2007).

The study of the horizontal movements of *Sphyrna lewini* and *Sphyrna zygaena* and their exploitation pattern by different fisheries (trawls, gillnets, longliners) along southern Brazilian coast, showed the necessity for the hammerheads to have non-fishing zones for the protection of their pupping grounds, juveniles and adults. This protected areas need to embrace different depth strata, i.e., from the shallow areas where the neonates occur (< 20 m depth), passing through juveniles zone over the continental shelf (< 200 m), and finally reaching the slope where the adults use to stay for mating and feeding purposes (< 1000 m). This protected areas called “Biodiversity Corridors”, would also allow the pregnant hammerhead females to migrate from the upper slope to the shallower waters over the continental shelf (< 20 m) which are the parturition zones (Vooren & Klippel, 2005; MMA, 2002).

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