Species diversity, relative abundance and length structure of oceanic sharks caught by the Venezuelan longline fishery in the Caribbean Sea and western-central Atlantic

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ABSTRACT

This study examines the species diversity, relative abundance, and length structure of oceanic sharks caught by the Venezuelan longline fishery targeting swordfish and tuna. Shark catch data was collected by scientific observers during the period 1994 to 2003. The total shark catch was comprised of 25 species, in which the most frequently caught were *Prionace glauca* (34.8%) and *Carcharhinus signatus* (20.2%). Other common species in the catch composition were *C. falciformis* (8.5%), *Sphyrna mokarran* (6.8%), and *Isuru oxyrinchus* (6.2%). The inter-annual variation of the Shannon-Wiener index was characterized by an apparent loss of the shark diversity throughout the time series. Kriging map showed that areas with relative high diversity values were located in the southeastern Caribbean Sea, primarily in areas close to the islands and coast of Venezuela. Other areas with significant diversity values corresponded to the inner arc of the Lesser Antilles and the Suriname shelf. The analysis of catch per unit effort trends for the five most common species revealed that all series had a negative slopes, but only one (*C. falciformis*) was statistically significant. Shark catches for the most important species comprised a large proportion of juveniles. Major efforts will be needed to generate steady scientific information required for stock assessment.

Keywords: blue shark, CPUE, diversity, elasmobranchs, fishery, variogram

Diversidad de especies, abundancia relativa y estructura de tallas de tiburones oceánicos capturados por la flota palangrera venezolana en el Mar Caribe y Atlántico centro-occidental

RESUMEN

En este estudio se analiza la diversidad de especies, abundancia relativa y estructura de tallas de tiburones oceánicos capturados en la pesquería palangrera industrial venezolana que dirige su esfuerzo al pez espada y atunes. Los datos fueron obtenidos del monitoreo de embarcaciones por observadores científicos durante el periodo 1994 a 2003. La captura estuvo conformada por 25 especies de tiburones, siendo las más frecuentemente capturadas, *Prionace glauca* (34,8%) y *Carcharhinus signatus* (20,2%). Otras especies comúnmente observadas fueron *C. falciformis* (8.5%), *Sphyrna mokarran* (6.8%) e *Isuru oxyrinchus* (6.2%). La variación interanual del índice de Shannon-Wiener está caracterizada por una aparente perdida de los niveles de diversidad de tiburones a largo de la serie de tiempo. El análisis espacial de la diversidad, utilizando el método de interpolación Kriging muestra que las áreas geográficas con niveles de diversidad de tiburones relativamente elevados están localizadas en el sudeste del Mar Caribe, principalmente alrededor de las islas y costa venezolanas. Otras áreas con niveles importantes

de diversidad corresponden al arco interior de Las Antillas Menores y plataforma de Surinam. El análisis de las tendencias interanuales en la abundancia relativa para las cinco especies más comunes arrojaron pendientes negativas, pero únicamente la serie de *C. falciformis* fue estadísticamente significativa. Los resultados revelaron que la pesquería realizada por la flota palangrera industrial selecciona porcentajes importantes de individuos juveniles. Un mayor esfuerzo será necesario para generar de manera sostenida la información requerida para la evaluación de estos recursos.

Palabras clave: CPUE, diversidad, elasmobranquios, pesquería, tiburón azul, variograma.

INTRODUCTION

Sharks constitute an important predator group in marine ecosystems and consequently play an essential role on energy exchange within the highest trophic levels (Wetherbee and Cortés, 2004). For centuries, humans have conducted fishing for sharks in a sustainable manner by the use of artisanal fishing methods (FAO, 1999). Recently, modern technology in combination with an increase demand for sharks products have resulted in increasing effort and yield of shark catches, as well the expansion of fishing areas (Bonfil, 1994). One fishery practice that has dramatically increased since the 1980s is the targeting of swordfish, *Xiphias gladius*, and tuna, *Thunnus* spp., using pelagic longline gear (Castro *et al*., 1999). This fishery catches large numbers of oceanic sharks as bycatch. In general, sharks have a combination of biological characteristics, such as slow growth, late maturation and low fecundity that make them extremely susceptible to overfishing (Stevens *et al*., 2000). Recent studies have revealed a significant reduction in abundance of large predatory fishes, including sharks, in the Atlantic Ocean (Baum *et al*., 2003; Myers and Worm, 2003; Hutchings and Baum, 2005). Fishing pressure can affect shark stock structure, diversity, and biological parameters, and in the worst of cases, could cause a species to become extinct (Jennings and Kaiser, 1998; Stevens *et al*., 2000).

In the Caribbean Sea and adjacent waters, information related with the biology, fishery and landings of sharks is scarce or non-existent. About of 60 species of sharks have been reported to occur off Venezuelan Caribbean, of which species within the family Carcharhinidae are the most common (Cervigón and Alcalá, 1999; Carpenter, 2002; Tavares, 2005). However, the stock status of the most common shark species inhabiting in the Caribbean region is unknown. Preliminary oceanic shark by-catch analyses from the Venezuelan pelagic longline fishery (Gonzalez and Gaertner, 1992; Alió *et al*., 1994; Yegres *et al*., 1996) have only provided general information on fishing effort and catch data, and preliminary species composition with a considerable degree of uncertainty in accurate taxonomic identification of most species. The species-specific composition of the catches constitutes the basic information required for fisheries stock assessment. The purpose of this study was to examine the catch composition, species diversity, relative abundance and length structure of oceanic sharks caught as bycatch by the Venezuelan longline fleet in the Caribbean Sea and western-central Atlantic during the period 1994 a 2003.

MATERIALS AND METHODS

The data analyzed in the present study came from Venezuelan's Enhanced Research Program for Billfish (ERPB) data base, sponsored by the International Commission for the Conservation of Atlantic Tuna (ICCAT) and corresponds to the period 1994 to 2003. Shark by-catch data were collected by scientific observers on board industrial longline fishing vessels targeting swordfish and tuna. The study area comprises the southeastern Caribbean Sea and the western-central Atlantic Ocean in an area bounded by 22°N 68°W and 4°N 44°W (Figure 1). Detailed information of the Venezuelan longline fishery (size fleet, effort data, fishing gear, target species, etc.) are given by Arocha and Marcano (2001) and Marcano *et al*. (2004).

Once captured, sharks were identified to the lowest taxonomic level possible by scientific observers of the Venezuelan Pelagic Longline Observer Program (VPLOP). Observer personnel were the same individuals throughout the study. During the last two years of the study, observers collected digital images and tooth of the shark species caught by the fishery to validate identification of the species. The total
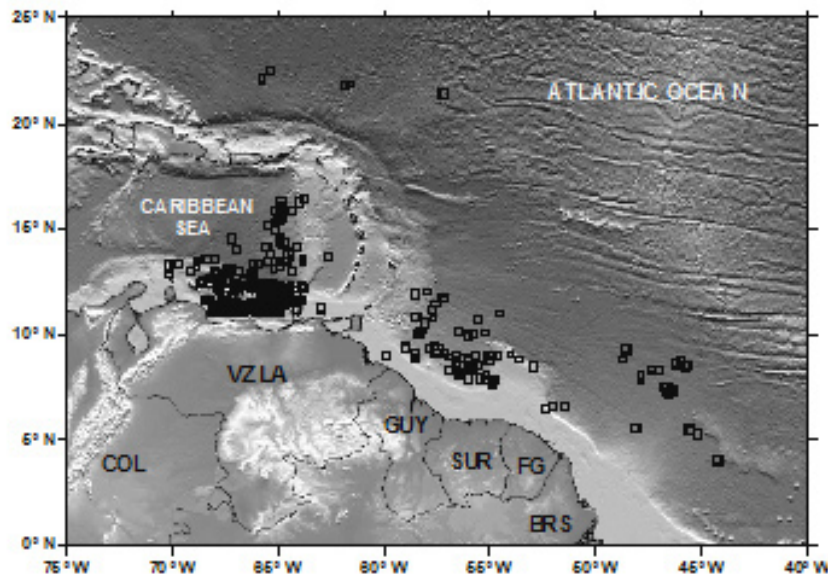
Figure 1. Study area showing the distribution of sets with positive shark catches from the Venezuelan pelagic longline fishery targeting swordfish and tuna during 1994 to 2003.

length (TL, cm) of sharks was measured according Compagno (1984) and sex was recorded for each specimen. Pregnant females were identified as those carrying uterine eggs or embryos within the uterus. The size at maturity of the females was estimated from the mean total length of all pregnant females. Also, sizes at maturity reported in the literature for the five studied species and for both sexes were considered in order to classify juvenile and adult sharks.

Based on the geographical region explored by the Venezuelan longline fleet the study area was divided in two smaller areas, the Caribbean and the Atlantic, for the purpose of data analysis. The shark catch composition was expressed in percentage of numbers (n, %) by species and geographic areas. The Shannon-Wiener index was used to evaluate the levels of shark diversity within the study region:

$$H = -\sum_{i=1}^{s} \rho_i \log_2 \rho_i$$

where S is the number of species in the sample, ρ_i is the proportion that the ith species contributes to

the total abundance of the sample ($\rho_i = N_i/N$), N_i the number of individuals of the ith species, and N the number of individuals in the sample. Nonparametric permutation and bootstrap statistical methods (Manly, 1997) were applied with the purpose of estimating the annual mean and variance of the diversity index estimates.

The spatial distribution of shark diversity in the study areas was also examined through the use of the Kriging interpolation method, assisted by variogram analysis (Petitgas, 1996). In this approach, the diversity index was calculated by $3^\circ \times 3^\circ$ quadrants and combining the data for all years. The primary purpose of the variogram modeling is to describe the spatial structure of the data set when gridding with the kriging algorithm. The variogram is a three-dimensional function containing two independent variables, the direction and separation distance, and one dependent variable that is the variogram value. The experimental variogram equation (Petitgas, 1996) is written as:

$$\gamma(\theta,h) = 1/2n(\theta,h)\sum_i (f(x_i) - f(x_i+h))^2$$

Table 1. Shark species caught by Venezuelan pelagic longline fishery targeting swordfish and tuna during 1994 to 2003.

Family/species	English name	Spanish name
Carcharhinidae		
Carcharhinus falciformis	Silky shark	Tiburon jaquetón
Carcharhinus leucas	Bull shark	Tiburón toro
Carcharhinus limbatus	Blacktip shark	Tiburón macuira
Carcharhinus longimanus	Oceanic whitetip shark	Tiburón oceánico
Carcharhinus obscurus	Dusky shark	Tiburón arenero
Carcharhinus perezi	Caribbean reef shark	Tiburón coralino
Carcharhinus plumbeus	Sandbar shark	Tiburón trozo
Carcharhinus porosus	Smalltail shark	Tiburón poroso
Carcharhinus signatus	Nigth shark	Tiburón nocturno
Galeocerdo cuvier	Tiger shark	Tiburón tigre
Prionace glauca	Blue shark	Tiburón azul
Sphyrnidae		
Sphyrna lewini	Scalloped hammerhead	Cornúa común
Sphyrna media	Scoop hammerhead	Cornúa cuchara
Sphyrna mokarran	Great hammerhead	Cornúa gigante
Sphyrna tudes	Smalleye hammerhead	Cornúa ojichica
Sphyrna zygaena	Smooth hammerhead	Cornúa cruz
Lamnidae		
Isurus oxyrinchus	Shortfin mako	Marrajo dientuso
Isurus paucus	Longfin mako	Marrajo carite
Alopidae		
Alopias superciliosus	Bigeye thresher	Zorro ojón
Alopias vulpinus	Thresher shark	Zorro
Squalidae		
Centroscymnus owstoni	Roughskin dogfish	Sapata lija
Squalus cubensis	Cuban dogfish	Galludo cubano
Hexanchidae		
Hexanchus griseus	Bluntnose sixgill	Tiburon ojo de vaca
Triakidae		
Mustelus norrisi	Narrowfin smooth-hound	Viuda
Pseudocarchariidae		
Pseudocarcharias kamoharai	Crocodile shark	Tiburón cocodrilo

where $\gamma(\theta,h)$ is the variogram value, $f(x_i)$ denotes the data value measured at point x_i, $n(\theta,h)$ denotes the number of data pairs for direction θ and distance h, and i is the index of the data. Therefore, the variogram measures the level of dissimilarity between points as a function of the distance between them and the units being equivalent to the variance. Parameters estimated by fitting non-linear models are: A, distance at which the samples are no longer autocorrelated; C_0, unresolved small-scale variability, and C, maximum variability due to the spatial structure.

The measure of relative abundance was the catch per unit effort (nominal CPUE) estimated as the number of sharks per 1000 hooks in positive fishing sets. The inter-annual variability of mean CPUE was examined for the five most common shark species in the study area. Trends in relative abundance were analyzed by fitting linear regressions between years and log-transformed CPUE values (95% level of significance). For this approach, CPUE values correspond to the initial year (1994) of the study period were excluded from regression analysis. Additionally, it was assumed that years with no captures between 1995 and 2003 correspond to cero CPUE. The size structure of the five selected species was described using length-frequency histograms and grouped by 10 cm TL classes. A chi-square (χ^2) test was performed to test for differences in the expected sex ratio of 1:1.

RESULTS

During the study period a total of 25 species (n = 2,601) of sharks from 8 families (Table 1) were recorded. The most common species in the catch composition were *Prionace glauca* (34.8%) and *Carcharhinus signatus* (20.2%) (Figure 2). Other species with relatively high occurrence were *C. falciformis* (8.5%), *Sphyrna mokarran* (6.8%), and *Isurus oxyrinchus* (6.2%). The remaining species accounted for 23.6%, in which hammerhead sharks were the most significant group. The shark catch composition from the Caribbean area was very similar with that observed in the overall study area. Caribbean shark catches also consisted of 25 species (n = 2,151) and were dominated by *P. glauca* (29.9%), and *C. signatus* (23.7%). In the Atlantic area, the shark catch consisted of 16 species (n = 450), with the most common species being *P. glauca* (57.6%), followed by *I. oxyrinchus* (6.7%), *C. longimanus* (5.3%), *Alopias superciliosus* (4.0%), and *S. zygaena* (4.0%).

The annual mean diversity indices by geographic area ranged between 1.17 (± 0.09 s.d.) and 2.10 (± 1.09 s.d.) and between 0.38 (± 0.17 s.d.) and 1.90 (± 0.13 s.d.) for the Caribbean and the Atlantic, respectively (Table 2; Figure 3). The shark diversity levels in both geographic areas were higher at the beginning of the time series, from approximately 1995 to 1998. Subsequent years were characterized by a downward trend in species diversity, with an apparent recovery in 2003. The spatial diversity analysis showed that the structure data was better described by an exponential variogram function (Figure 4), which is characterized to have an autocorrelation level within nearby areas that decreases with the increase of spatial distance. No spatial autocorrelation was observed for diversity data at distances larger than 380 km. The map of diversity distribution reveled that areas with relatively highest values (1.6 to 2.4) are located in the southeastern Caribbean; mainly in zones close to the islands and coast of Venezuela (Figure 5). Other areas with significant diversity values (1.2 to 1.6) corresponded to the inner arc of the Lesser Antilles and Suriname shelf.

Prionace glauca

This species had a general mean CPUE of 3.13 (± 2.89 s.d.) sharks/1000 hooks, with values ranging between 0.19 and 25.46 sharks/1000 hooks. The inter-annual variation of mean CPUE was characterized by fluctuations through the time series (Figure 6). Highest mean CPUEs were observed in 1998 and 1999, and the lowest corresponded to the last year of the study period. Regression analysis between years and log-transformed CPUEs showed a not significant negative slope (slope = -0.030; r^2 = 0.049; P = 0.567). Of the 904 specimens caught, which ranged in size from 93 to 387 cm TL, 45.8% were females. Significant difference in sex ratios was not found for this species ($\chi^2_{(0.05;1)}$ = 0.71; P = 0.401). Pregnant females ranged in size from 152 to 387 cm and comprised 23.9% of the female catches of this species. Mean size at maturity estimated for females was 213.4 (± 50.77 s.d.) cm. A length frequencies histogram showed that *P. glauca* catches in the study area were primarily represented by individuals with sizes ranging between 160 and 280 cm TL (Figure 7).
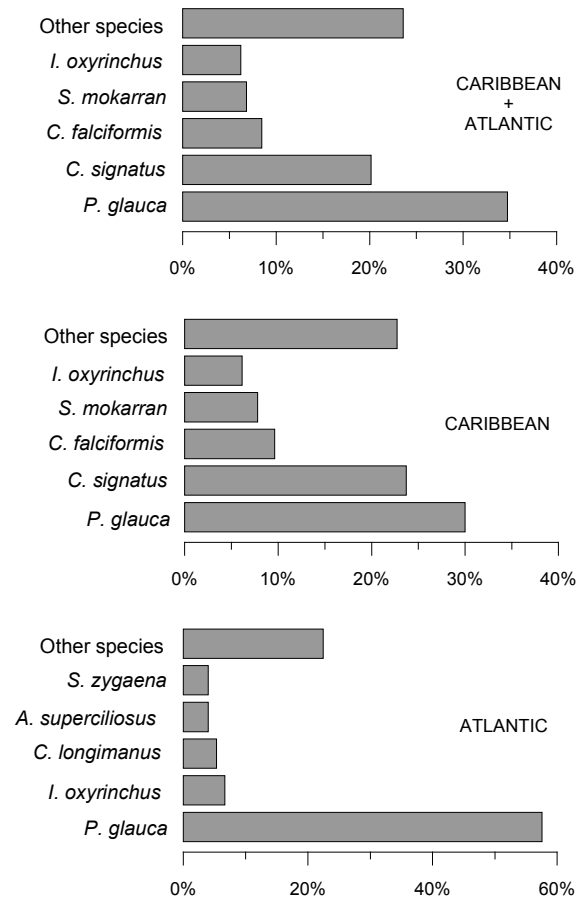
Figure 2. Shark by-catch composition by geographical areas from the Venezuelan pelagic longline fishery targeting swordfish and tuna during 1994 to 2003.

Carcharhinus signatus

The overall CPUE average estimated for this species was 4.0 (± 3.58 s.d.) sharks/1000 hooks, and the values varied between 1.25 and 45.45 sharks/1000 hooks. The inter-annual variation of CPUE showed an oscillatory pattern, with a highest mean CPUE observed in 1995 and a markedly decreasing trend from 2000 to 2003 (Figure 6). No capture of this species was reported during the last year of the time series. Statistically not significant negative slope was obtained from linear regression among years and log-transformed CPUE (slope = -0.121; r^2 = 0.304; P = 0.124). A total of 524 specimens ranging in size from 64 to 280 cm TL were examined, with females accounting for 32.8% of the catch. For this species, a highly significant difference in sex ratios was found ($\chi^2_{(0.05;1)}$ = 11.80; P = 0.001). Of these females, 77.2% were gravid and measured between 158 and 280 cm TL. Mean size at maturity estimated for females was 166.1 (± 24.54 s.d.) cm LT. The catch length structure

was mainly composed of individuals measuring between 130 and 180 cm TL (Figure 7).

Carcharhinus falciformis

The mean CPUE was 4.31 (± 5.87 s.d.) sharks/1000 hooks, with values fluctuating between 0.35 and 37.04 sharks/1000 hooks. The highest mean CPUE was recorded in 1994, after which a constant decline was observed throughout the study with a lowest point in 2003 (Figure 6). The analysis of CPUE series indicated a significant negative slope (slope = -0.141; r^2 = 0.714; P = 0.004), suggesting a decreasing trend in abundance for this species. In total, 220 sharks (70-312 cm TL) of this species were caught during the study period. Males and females comprised 37.7 and 34.6%, respectively, and the remaining 27.7% corresponded to specimens with unidentified sex. Differences between sex proportions were not significant ($\chi^2_{(0.05;1)}$ = 0.13; P = 0.701). Only 18.1% of the females were pregnant and measured from 188 to 280 cm TL. Mean size at

Table 2. Bootstrap mean values, standard deviation (SD), and confident limits (C.L., 95%) by geographical areas and by years of the Shannon-Wiener index estimated for oceanic sharks caught by the Venezuelan pelagic longline fishery targeting swordfish and tuna during 1994 to 2003.

Areas/years	Shannon-Wiener Index			
	Mean	SD	C.L. 95%	
Caribbean				
1994	1.56	0.20	1.17	1.94
1995	2.04	0.08	1.89	2.18
1996	2.10	0.09	1.92	2.26
1997	2.03	0.06	1.91	2.14
1998	1.67	0.13	1.41	1.92
1999	1.44	0.09	1.27	1.61
2000	1.39	0.07	1.19	1.51
2001	1.47	0.11	1.25	1.68
2002	1.17	0.09	0.98	1.32
2003	1.60	0.10	1.40	1.92
Atlantic				
1994	0.82	0.21	0.37	1.19
1995	0.94	0.19	0.55	1.30
1996	1.73	0.14	1.42	1.96
1997	1.57	0.17	1.21	1.86
1998	1.90	0.13	1.62	2.13
1999	0.43	0.18	0.15	0.79
2000	0.38	0.17	0.11	0.68
2001	---	---	---	---
2002	1.12	0.34	0.56	1.46
2003	1.42	0.20	0.96	1.71

maturity estimated for females of this species was 216.0 (± 25.70 s.d.). The length frequency histogram showed that catches were dominated by individuals measuring between 100 and 190 cm TL (Figure 7).

Sphyrna mokarran

CPUE for this species varied between 1.33 and 8.70 sharks/1000 hooks, with an estimated mean of 2.9 (± 1.58 s.d.) sharks/1000 hooks. The inter-annual CPUE appeared to remain stable from 1994 to 2002, although no captures were recorded for this species during the last year of the time series (Figure 6). The absence of *S. mokarran* catches in the initial year (1993) of the monitoring program for sharks was probably a consequence of species misidentification by scientific observers. Regression results revealed

a non significant negative slope for CPUE series of this species (slope = -0.069; r^2 = 0.146; P = 0.310). Of the 177 specimens captured, which ranged in size from 86 to 213 cm TL, 67.6% were females. A highly significant difference in sex ratios was found for this species ($\chi^2_{(0.05;1)}$ = 12.67; P = 0.0001). No pregnant females were observed during the study period. Based on the length frequencies, catches of this species were primarily represented by individuals ranging between 130 and 190 cm TL (Figure 7).

Isurus oxyrinchus

Overall mean CPUE obtained for this species was 1.81 (± 1.68 s.d.) sharks/1000 hooks, with values ranging from 0.19 to 10.32 sharks/1000 hooks. The annual CPUE trend from 1996 to 2000 showed
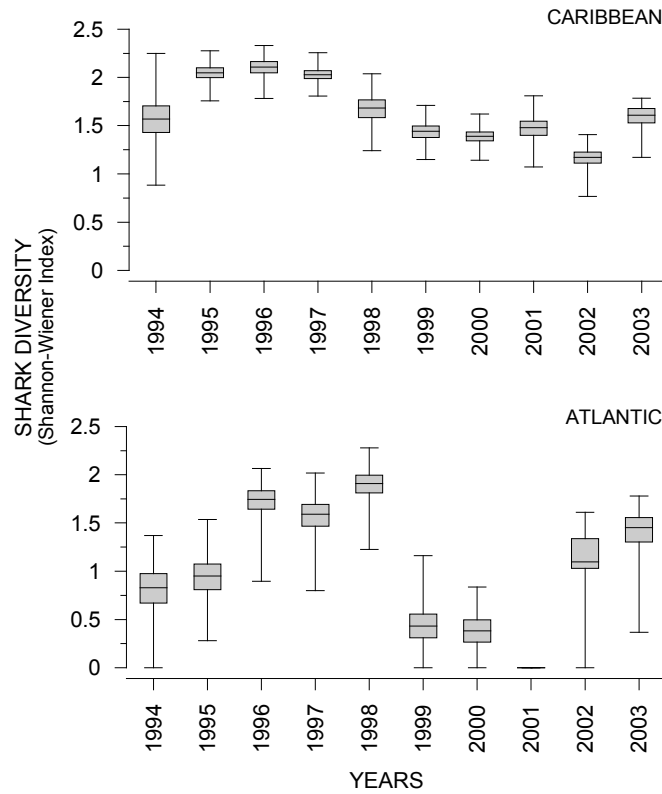
Figure 3. Inter-annual trend by geographical areas of the Shannon-Wiener index estimated for sharks caught by the Venezuelan pelagic longline fishery targeting swordfish and tuna during 1994 to 2003. Horizontal lines indicate bootstrap mean, boxes indicate lower and upper quartiles and whiskers indicate minimum and maximum values.
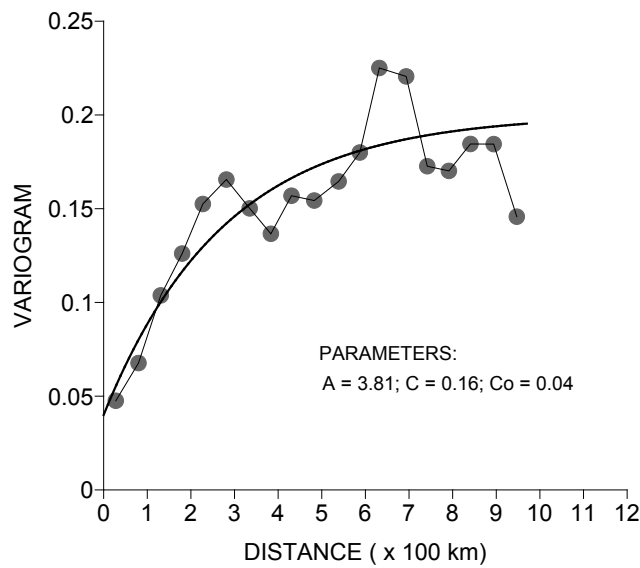

Figure 4. Variogram computed for shark diversity data (Shannon-Wiener index) in the study area (years combined). Diversity data was fitted with an exponential model.
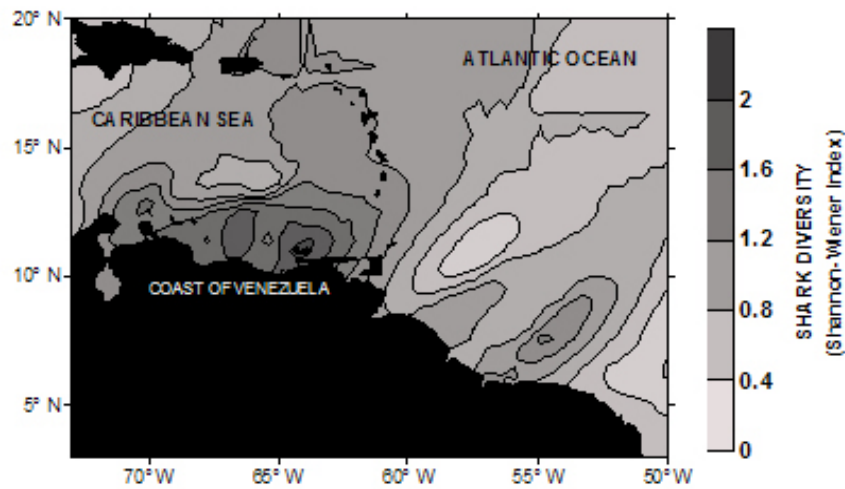
Figure 5. Spatial distribution map of shark diversity (Shannon-Wiener index) estimates in the study area (years combined).

little variation, whereas subsequent years showed a sustained decline (Figure 6). Highest mean CPUE was recorded in the year 1996 and the lowest during 2003. CPUE series for this species also show a non significant negative slope (slope = -0.055; r^2 = 0.251; P = 0.169). A total of 162 specimens ranging in size from 93 to 370 cm TL were captured, of which females constituted 33.6% of the catches. Differences between sexes were statistically significant ($\chi^2_{(0.05;1)}$ = 11.11; P = 0.001). Only two pregnant females were detected, measuring 162 and 370 cm TL. Mean size at maturity estimated for females of this species was 210.0 (± 70.71 s.d.). Most individuals were between 160 and 260 cm TL in catches of this species (Figure 7).

DISCUSSION

The oceanic shark catch by the observed Venezuelan longline fleet throughout the study period was comprised of 25 species, a significant number in longline fisheries targeting swordfish and tunas. Results showed that P. glauca was the most abundant shark species caught both, in the Caribbean and Atlantic areas. This finding was consistent with a previous study on blue shark caught as by-catch in the same general region (Arocha et al., 2005). Large numbers of this species are commonly captured as by-catch in longline fisheries targeting swordfish and tuna

throughout different regions of the Atlantic Ocean and adjacent seas (Hazin et al., 1994; Marín et al., 1998; Buencuerpo et al., 1998; Simpfendorfer et al., 2002; Megalofonou et al., 2005). These results indicate that P. glauca is perhaps the most abundant oceanic species in the Atlantic Ocean, including both the Caribbean and Mediterranean seas. Carcharhinus signatus was the second most abundant species and was caught mainly in the Caribbean area. This species is also commonly caught by other pelagic longline fisheries operating along the coast of Brazil (Hazin et al., 1994; Amorim et al., 2002) and southeastern United States, Gulf of Mexico and Caribbean Sea (Beerkircher et al., 2002; Cortés et al., 2007). However, the absence of capture reports in the North Atlantic might be attributed to differences in the geographical distribution of C. signatus. Compagno (1984) describes this species as a semi-oceanic carcharhinid occurring on tropical and warm-temperate waters of the Atlantic. Carcharhinus falciformis, S. mokarran, and I. oxyrinchus comprised a relatively large percentage values of the shark catch in the study area. The catch and abundance of these species in the pelagic longline fisheries activities carried out throughout the Atlantic region also vary depending on geographical areas.
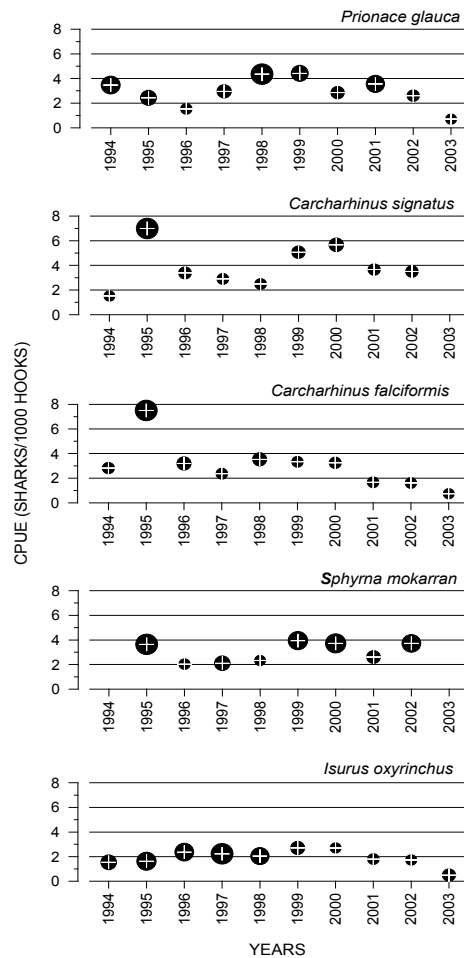
Figure 6. Inter-annual variation of the relative abundance (CPUE) estimates for the five most common shark species caught by Venezuelan pelagic longline fishery targeting swordfish and tuna during 1994-2003. The size of the bubbles is proportional to the variability (*s.d.*) of CPUE data corresponding to each year. The cross symbols within the bubbles indicate centroids

The annual mean variation in the Shannon-Wiener diversity index corresponding to oceanic shark occurrence in the Caribbean and Atlantic areas suggested a loss of shark diversity throughout the study period. Estimates of diversity levels in fishery studies can be useful as changes can be detected in the structure of commercially exploited populations. The application of diversity indices in fisheries biology is relatively recent, and few studies using this technique have been reported. Worm *et al.* (2003) analyzed the diversity of oceanic predatory fishes, including sharks, in the western Atlantic and found a diminishing trend in diversity with respect to time. These authors state that maintaining high diversity in oceanic areas could be an important objective in the future. In the present study, the highest diversity levels observed off the coast of Venezuela in the Caribbean are likely related to the oceanographic factors associated with high marine productivity. Among these factors, the most important are the seasonal upwelling along the Venezuelan coast (Castellanos *et al.*, 2002) and the influx of the Orinoco River water into the Caribbean Sea (Muller-Karger and Varela, 1990).

The annual CPUE levels of *P. glauca* obtained in this study were quite similar to those reported by Beerkircher (2005) and Cortés *et al.* (2007) for the Caribbean Sea, Gulf of Mexico and midwestern Atlantic. Although *P. glauca* exhibited a constant declining trend in abundance during the last three years of the study period, the analysis of CPUE series did not show a significant negative slope. However, other studies in the northwestern Atlantic have shown a considerable decrease in population
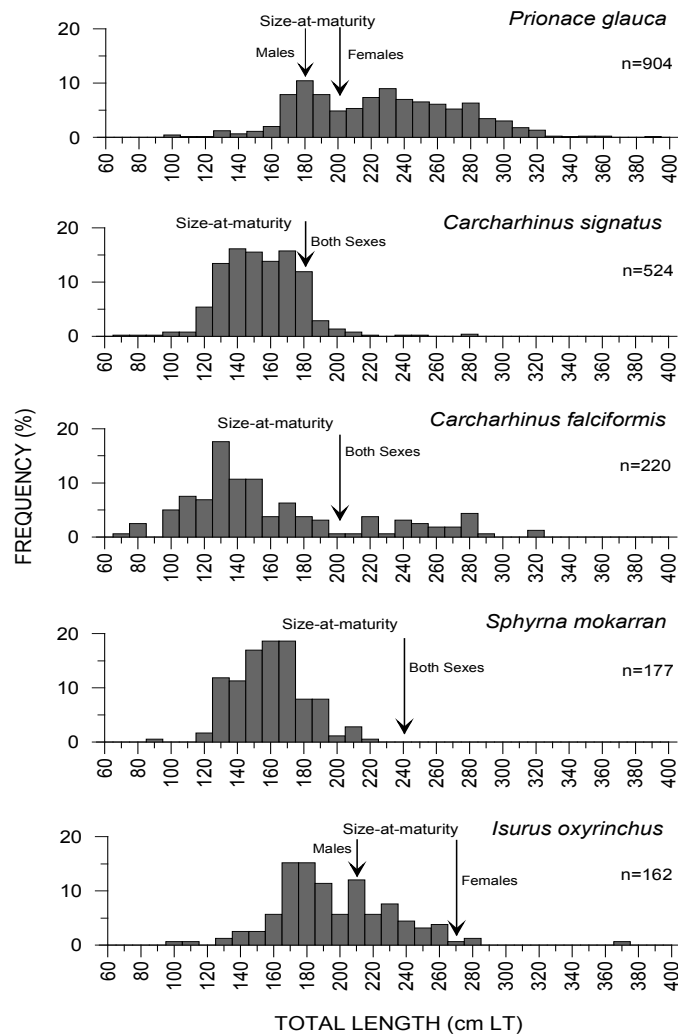
Figure 7. Length frequency histograms for the five most common shark species caught by Venezuelan pelagic longline fishery targeting swordfish and tuna during 1994 to 2003. The mean sizes at maturity are indicated by arrows

densities of this species. Cortés (2002) found that *P. glauca* CPUE series, covering the period 1978-2000, had a highly significant negative slope. Baum *et al.* (2003) analyzed CPUE series from logbook-data to found that the population of this species in the northwestern Atlantic had declined by 60% over the period 1986-2000. More recently, Cortés *et al.* (2007) examined CPUE trends on the basis of logbook- data corresponding to the combined areas of the Gulf of Mexico and Caribbean Sea during the period 1992-2005, and found a decline in relative abundance of 91%. Considering the highly migratory behavior of *P. glauca*, it is possible that the significant decrease in abundance of this species from the North Atlantic might be reflected in the Caribbean Sea as well. According to Pratt (1979), female blue sharks do not

mature until after 200 cm TL, and males until they reach 180 cm TL. Female size at maturity estimated in this study was 213 cm TL, a similar length to the one reported in the literature for this species. Based on these sizes at maturity, a considerable proportion of juveniles was captured by the fishery.

The annual CPUE estimates for *C. signatus* were slightly higher to those reported by Beerkircher *et al.* (2002) and Cortés *et al.* (2007) off the northwestern Atlantic. CPUE series for this species had a non significant negative slope, but a continuous declining trend in abundance was observed throughout the last 4 years of the study period. The analysis of *C. signatus* CPUE series (period: 1992-2000) conducted by Beerkircher *et al.* (2002) in the southeastern United States showed a significant negative slope. Cortés *et al.*

(2007) reported a decrease in abundance of 90% since 1992. *Carcharhinus signatus* has been poorly studied; therefore, information on its biology and abundance is almost unknown. Results showed that *C. signatus* is a common oceanic shark in the Caribbean region. The female size at sexual maturity estimated for this species was 166 cm TL, slightly lower than the 180 cm TL (both sexes) reported by Hazin *et al.* (2000). Therefore, the catch of this species in the study area was mostly composed by juveniles.

The inter-annual CPUE values corresponding to *C. falciformis* is comparable from those reported by Beerkircher *et al.* (2002). Our results showed a significant decline in abundance of this species throughout the study period. Decrease in abundance of 48% was recently reported by Cortés *et al.* (2007). *Carcharhinus falciformis* was commonly caught by several fisheries in the Gulf of Mexico; consequently, their populations were heavily impacted in this region (Bonfil *et al.*, 1993). This species is one of the most common carcharhinid sharks caught by the artisanal line-hook fishery conducted around Venezuelan oceanic islands (Tavares, 2005). However, the status of its population is unknown in waters of Venezuela and adjacent areas. The size at maturity reported for this species by Branstetter (1987) is around of 200 cm LT in both sexes, which is very close to the female size estimated (216 cm LT) in the present study. Taking into account these sizes at maturity, catches of *C. falciformis* in the study area were also comprised by a large numbers of juveniles.

Analysis of inter-annual CPUE trend for *S. mokarran* showed an apparent steady pattern with a non significant decrease in abundance, however, captures of this species were not recorded during the last year of the study. Information related with the distribution, biology and fishery data is scarce for this species. Our results showed that *S. mokarran* also appeared to be a common species in the Caribbean region. This species is the most frequently caught hammerhead in the artisanal shark fishery around the insular shelf of the Los Roques Archipelago (Tavares, 2005). In pelagic longline fisheries in the Gulf of Mexico and southern coast of the United States, *S. lewini* is the most common hammerhead species captured (Branstetter, 1987; Beerkircher *et al.*, 2002). In fishing monitoring programs, sphyrnid sharks have been usually grouped into a single complex, due to morphological similarities among species.

This practice has complicated the understanding of catch and abundance trends of hammerhead species. Nonetheless, Baum *et al.* (2003) found that the abundance of hammerhead sharks in the northwest Atlantic has declined by 89% since 1986. The size at maturity for *S. mokarran* is between 230 and 280 cm TL in both sexes (Compagno, 1984); therefore, catches from the study area were entirely composed by juvenile sharks.

Annual CPUE levels obtained for *I. oxyrinchus* were relatively higher than estimates reported for the Caribbean and midwestern Atlantic by Beerkircher (2005). However, in the North Atlantic this species showed a considerable occurrence as by-catch in the swordfish and tuna longline fishery (Buencuerpo *et al.*, 1998). The inter-annual CPUE trend for *I. oxyrinchus* showed a continuous decrease during the last three years of the study; however, regression analysis of CPUE series indicated a non significant declining trend in abundance. In the study of Cortés (2002), a highly significant negative slope was found in CPUE series of this species. For the Gulf of Mexico and Caribbean areas, Cortés *et al.* (2007) reported a decline in relative abundance of 57%. In the Venezuelan Caribbean, *I. oxyrinchus* appear to be a species exclusively caught by pelagic longline fisheries targeting swordfish and tuna. Individuals of this species are infrequently observed in catch composition from artisanal shark fisheries operating in Venezuelan waters (R. Tavares, personal observation). Mollet *et al.* (2000) reported that *I. oxyrinchus* females maturing at about of 280 cm TL and males at about of 210 cm TL. Based on this information, our results show that fishing activities carried out by the Venezuelan longline fleet also include large number of juvenile individuals of this species.

CONCLUSIONS

The present research provided information that was previously lacking in the study area. Results showed the importance of the Caribbean Sea and adjacent areas as habitat for several species of oceanic sharks. Trends in relative abundance reported in this study might not be considered as definitive. Moreover, differences in abundance patterns between studies might be consequence of several factors such as sample size, data source (logbooks, observer programs, and research surveys), fishing characteristics (effort, areas, and target species), and distinct approaches

for data analysis. Our results also revealed that the Venezuelan longline fishery captured a large numbers of juvenile sharks, and in some cases, considerable percentages of pregnant females. Among the reasons that have led to the reduction of shark populations worldwide, the most important are the degradation of nursery areas and the excessive capture of juveniles by commercial fisheries. Both features interfere directly with recruitment which is normally subject to high fishing mortalities. Major efforts will be needed to generate steady scientific information required for stock assessment. Therefore, considering the highly migratory behavior of oceanic sharks that are harvested by several nations in the Atlantic Ocean, international cooperation is essential to create the mechanisms to ensure shark research and fishery monitoring programs between regions.

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