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Characteristics of Shark Bycatch Observed on Pelagic Longlines off the Southeastern United States, 1992–2000

LAWRENCE R. BEERKIRCHER, ENRIC CORTÉS, and MAHMOOD SHIVJI

Introduction

In some commercial fishing operations, elasmobranchs represent a significant amount of discarded bycatch. Due to the slow growth rate, late maturity, and low fecundity of sharks in general, shark populations are particularly vulnerable to fishing pressure (Pratt and Casey, 1990). The history of directed shark fisheries in North American waters contains many examples of the deleterious effects overfishing can have on shark populations, including the rise and collapse of the porbeagle, *Lamna nasus* (Casey et al., 1978); soupfin shark, *Galeorhinus zyopterus* (Ripley, 1946); and spiny dogfish, *Squalus acanthias* (Rago et al., 1998) fisheries. Even in the case of species not subject to directed fisheries, such as many pelagic sharks, there is concern that bycatch mortality may still be high enough to harm shark populations (Musick et al., 2000). This concern has led to an urgent call for population assessments of elasmobranch species that often appear as bycatch in pelagic commercial fishing operations.[1]

To help increase the amount of management-relevant information available on pelagic sharks, we have examined nine years of fishery observer data to quantify and describe the patterns of shark bycatch in a major U.S. pelagic fishery, the swordfish, *Xiphias gladius*, and tuna, *Thunnus* spp., pelagic longline fleet, off the southeastern United States. These results may provide a clearer perspective of the magnitude of shark bycatch, and the distribution, relative abundance, and characteristics of shark populations that utilize the pelagic habitat in this region than has previously been available from fishery-independent scientific cruises alone. The data sources we used for this study, albeit fishery-dependent, offer the advantage of providing a much greater number of observations spread out over various times of the year from which to assess the status of Atlantic pelagic shark populations, and provide information relevant for their management.

Materials and Methods

Description of the Fishery

The major fishery targeting large pelagic species off the southeastern United States is the pelagic longline fishery. Descriptions of this fishery can be found in Berkeley et al. (1981), Berkeley and

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ABSTRACT — *Data collected by fisheries observers aboard U.S. pelagic longline vessels were examined to quantify and describe elasmobranch bycatch off the southeastern U.S. coast (lat. 22°–35°N, long. 71°–82°W). From 1992 to 2000, 961 individual longline hauls were observed, during which 4,612 elasmobranchs (15% of the total catch) were documented. Of the 22 elasmobranch species observed, silky sharks,* Carcharhinus falciformis, *were numerically dominant (31.4% of the elasmobranch catch). The catch status of the animals (alive or dead) when the gear was retrieved varied widely depending on the species, with high mortalities seen for the commonly caught silky and night,* C. signatus, *sharks and low mortalities for rays (Dasyatidae and Mobulidae), blue,* Prionace glauca*; and tiger,* Galeocerdo cuvier*; sharks. Discard percentages also varied, ranging from low discards (27.6%) for shortfin mako,* Isurus oxyrinchus, *to high discards for blue (99.8%), tiger (98.5%), and rays (100%). Mean fork lengths indicated the majority of the observed bycatch — regardless of species — was immature, and significant quarterly variation in fork length was found for several species including silky; dusky,* C. obscurus*; night; scalloped hammerhead,* Sphyrna lewini*; oceanic whitetip,* C. longimanus*; and sandbar,* C. plumbeus*; sharks. While sex ratios overall were relatively even, blue, tiger, and scalloped hammerhead shark catches were heavily dominated by females. Bootstrap methods were used to generate yearly mean catch rates (catch per unit effort) and 95% confidence limits; catch rates were generally variable for most species, although regression analysis indicated significant trends for night, oceanic whitetip, and sandbar sharks. Analysis of variance indicated significant catch rate differences among quarters for silky, dusky, night, blue, oceanic whitetip, sandbar, and shortfin mako sharks.*

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[1] NMFS. 2000. United States national plan of action for the conservation and management of sharks. U.S. Dep. Commer., NOAA, NMFS, Silver Spring, MD 20910, 86 p.

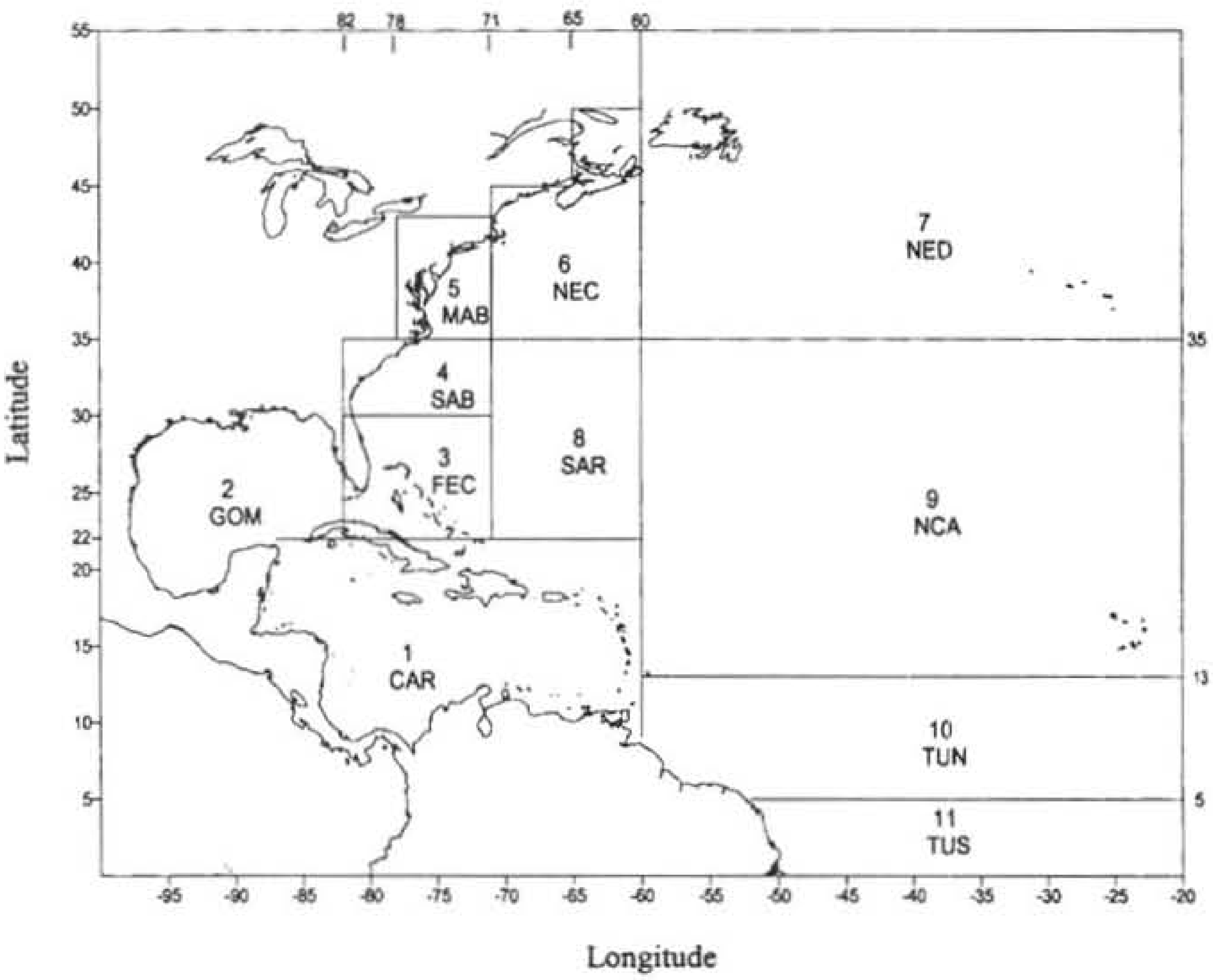

Figure 1. — NMFS geographical classification of fishing areas (Cramer and Adams, 1999). The study area combines NMFS areas 3 (FEC) and 4 (SAB).

Campos (1988), and Beerkircher et al. (2002): the pelagic longline gear used in this area consists of a heavy monofilament mainline (7–65 km long), which is suspended at various depths below the surface and from which are suspended numerous lengths of lighter monofilament line with a single large (size 7/0–11/0) hook at the end. Hooks are placed along the line at a ratio of 11–19 hooks/km, resulting in a total of 80–1,200 hooks. The average number of hooks is 400–500 per longline. The gear free-floats on the surface of the ocean, with the hook depths varying from 35 to 60 m (Beerkircher et al., 2002).

Vessels targeting swordfish generally set gear around sunset and haulback around dawn, use chemical light sticks attached near the hooks, and use mackerel or squid for bait. Fishery-dependent data indicate an average of 4,028 longline sets were deployed per year in this area between 1994 and 1999 (Cramer, 1995; Cramer and Adams, 1999; Cramer, 2002). The primary species targeted by these fishermen is swordfish, although tunas, mahi-mahi, *Coryphaena* spp., and certain shark species are also commercially important portions of the catch.[2]

Bycatch in this fishery includes teleosts, elasmobranchs, and on rare occasions marine mammal and sea turtle species. The greatest percentage of bycatch in this fishery is composed of sharks (Anderson, 1985). Shark species commonly caught in the pelagic longline fishery include the dusky, *Carcharhinus obscurus*, night, *C. signatus*; silky, *C. falciformis*; oceanic whitetip, *C. longimanus*; tiger, *Galeocerdo cuvier*; blue, *Prionace glauca*; shortfin mako, *Isurus oxyrinchus*; and scalloped hammerhead, *Sphyrna lewini* (Anderson, 1985; Beerkircher et al., 2002).

Several of these species are neither generally described as "pelagic" in the literature nor defined as pelagic by the National Marine Fisheries Service (NMFS) Shark Fishery Management Plan (FMP).[2] Since several shark species encountered in the pelagic fishery occupy more than one habitat, this paper ignores subjective distribution classifications and describes bycatch of sharks of any species by the pelagic longline fishery off the southeastern United States.

Study Area and Data Set

The primary data we examined were compiled and maintained by the NMFS Southeast Fisheries Science Center (SEFSC) as part of the pelagic observer program and include data collected since the observer program's inception in June 1992 through December 2000. Observer coverage is mandatory for Federal swordfish permit holders, and selection of a vessel for coverage is based on a random draw. The percentage of longline sets observed in any given area and calendar quarter (quarter 1: January–March, quarter 2: April–June, quarter 3: July–September, quarter 4: October–December) was targeted to be 5% of the total reported number of sets for that area and calendar quarter in the previous year.

The northwest Atlantic (including the Gulf of Mexico and Caribbean) is divided into eleven areas thought to represent regions of similar types of fishing effort (Fig. 1). Two areas, the "Florida East Coast" (FEC, NMFS area 3) and the "South Atlantic Bight" (SAB, NMFS area 4) were combined into the study area examined herein. This area is bounded on the north and south by lat. 35° and 22°N and on the east and west by long. 71° and 82°W, respectively. This area was selected as the spatial limits of the study because the pelagic longline fishery in it has been classified as one of the five distinct U.S. Atlantic pelagic longline fisheries based on the nature of the target species, temporal distribution of effort, and other fishing practices.[2] The rough similarity of fishing effort throughout this area allows some standardization of catch per unit of effort (CPUE) data, which would be more difficult if a larger study area encompassing variable fishing practices were used. One observed shark-directed set that occurred in shallow water during 1996 was not included in the analysis to preserve

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[2] NMFS. 1999. Final fishery management plan for Atlantic tunas, swordfish, and sharks. U.S. Dep. Commer., NOAA, NMFS, Silver Spring, MD 20910, 854 p.

Table 1.—Observed and reported effort in the pelagic longline fishery off the southeastern U.S., 1992–2000.

	Year									
Effort	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
Observed effort										
Hauls	72	129	119	67	126	95	116	111	126	961
Hooks	19,315	47,846	38,126	25,184	61,943	48,778	49,214	54,338	69,129	413,873
Reported effort[1]										
Hooks	1,094,082	1,281,618	1,516,723	1,496,686	2,249,194	1,677,461	1,357,197	1,474,411	1,484,554	13,631,926
Percent of hooks observed	1.8	3.7	2.5	1.7	2.8	2.9	3.6	3.7	4.7	3.0

[1] Data from Cramer, 1995; Cramer and Adams, 1999; and Cramer, 2002.

Table 2.—Cumulative monthy effort and elasmobranch catch by species observed in the pelagic longline fishery off the southeastern U.S., 1992–2000.

Species	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	%
Silky	55	159	184	163	255	120	81	63	81	137	81	67	1,446	31.4
Dusky	5	15	107	39	125	186	28	49	58	34	27	6	679	14.7
Night	1	39	128	153	160	52	7	15	0	11	4	2	572	12.4
Blue	4	63	67	102	115	52	2	2	0	6	8	13	434	9.4
Unidentified sharks	9	11	21	39	29	83	9	35	7	19	11	34	307	6.7
Tiger	5	25	4	42	46	20	22	22	17	26	16	18	263	5.7
Scalloped hammerhead	5	22	10	4	29	46	10	13	16	13	7	25	200	4.3
Oceanic whitetip	1	8	3	8	12	5	7	11	12	24	25	15	131	2.8
Rays	0	12	12	9	4	1	5	16	13	9	18	14	113	2.5
Sandbar	1	6	7	7	20	48	16	3	0	0	2	2	112	2.4
Bigeye thresher	1	2	10	10	13	12	11	4	3	3	2	11	82	1.8
Shortfin mako	3	13	11	3	15	11	2	8	1	3	2	8	80	1.7
Other[1]	14	11	22	19	26	49	9	2	4	21	7	9	193	4.2
Totals	104	386	586	598	849	685	209	243	212	306	210	224	4,612	
Hooks	7,796	38,128	37,275	57,835	62,247	71,395	22,136	27,221	15,793	27,491	21,897	24,659	413,873	

[1] Other includes (in numerical order) great hammerhead, *Sphyrna mokarran*; bignose, *Carcharhinus altimus*; blacktip, *C. limbatus*; longfin mako, *Isurus paucus*; bull, *C. leucas*; common thresher, *Alopias vulpinus*; spinner, *C. brevipinna*; Caribbean reef, *C. perezi*; smooth hammerhead, *S. zygaena*; and nurse, *Ginglymostoma cirratum*, sharks.

CPUE standardization and the intent of the study to examine shark bycatch in the tuna-swordfish fishery.

Quantitative Methods Used for Data Analysis

Bootstrap procedures with 1,000 bootstrap replications (Efron and Tibshirani, 1993) were used to estimate the mean yearly CPUE (expressed as number of sharks caught per 1,000 hooks) for eleven commonly observed elasmobranch species and for unidentified sharks as a group. Upper and lower 95% confidence limits were taken from the 97.5 and 2.5 percentiles of the ranked replicant means, respectively.

For each shark species, mean CPUE was analyzed to test for differences among seasons using analysis of variance (ANOVA); post-hoc identification of seasonal differences were determined by Tukey-Kramer testing (Sokal and Rohlf, 1995). Yearly time series of bootstrapped mean CPUE were charted; yearly mean CPUE values were weighted by the inverse of the yearly bootstrapped variance and both weighted and non-weighted CPUE series were analyzed for significant trends through linear regression.

Live sharks that are not retained (due to quota closures, small size, or low commercial value) are normally cut off the line in the water, and precise length measurements are therefore not possible. In such cases, the observer estimates the total length of the shark to the nearest foot. Because exclusion of estimated length data would preclude length analyses for species such as the blue; tiger; scalloped hammerhead; oceanic whitetip; sandbar, *C. plumbeus*; bigeye thresher, *Alopias superciliosus*; and shortfin mako, we included estimated lengths for these species in our analyses. Fork length was chosen for analysis because this is the most consistently reported measurement by observers. Fork length data were log-transformed and analyzed using one-way ANOVA and Tukey-Kramer testing to determine if and where length differences existed among seasons. Length-frequency distributions were constructed for the four most-common species observed; mean fork lengths were calculated for the ten most-common shark species observed.

Sex ratios over the entire study period were determined for most species (rarely encountered species or species for which sex data were lacking, were omitted). To detect any seasonal changes in sex ratios, quarterly sex ratios were examined for ten of the most common species. Chi-square testing was used to analyze the sex ratio data for heterogeneity among quarters.

Results and Discussion

General

During June 1992 through December 2000, NMFS personnel observed 961 individual hauls of longline fishing gear in the study area (Table 1). Mean yearly observed effort was 107 hauls and 45,986 hooks. The greatest amount of yearly effort was observed in 2000 (69,129 hooks), and the minimum in a 7-month period in 1992 (19,315 hooks). Monthly fishing effort ranged from a high of 71,395 hooks observed in June to a low of 7,796 hooks in January (Table 2). Observations of the fishing effort were distributed uniformly throughout the time period of the study, occurring in all seasons of all years, except for 1992. This was the year when the observer program began at the SEFSC, and field operations did not start until June. The locations of individual hauls of the gear (by quarter) are shown in Figure 2.

Spatially, the fishing effort was generally confined to the Gulf Stream or its edges, in water depths greater than 200 m. Thus, although the defined study area includes the Bahamas, very little effort was observed in the immediate vicinity of the Bahamas due to a restriction on U.S. longliners operating in the Bahamian Exclusive Economic Zone (EEZ). An exception was the Florida Straits, where the close proximity of the Bahamian islands to the continental United States results in a narrower EEZ for both countries.

Elasmobranchs comprised 15% and the target species (swordfish and tuna) comprised 53% of the total catch (Fig. 3). A total of 4,612 individual elasmobranchs were observed during the study period, with silky, dusky, night, blue, unidentified, tiger, and scalloped hammerhead sharks making up the majority (84.6%); 15 other species made up the remainder of the elasmobranchs observed (Table 2). Rays were not identified to species, but observer notes indicate the majority were pelagic stingrays, *Dasyatis violacea*; and some manta rays (Mobulidae) were also reported. The wide variety of species observed in the study was consistent with the temporal and spatial distribution of fishing effort and a previous study on pelagic zone sharks in the same general region (Berkeley and Campos, 1988).

The intent of our study was to identify the characteristics of that portion of the shark populations that use the pelagic zone (>200 m), although due to the free-floating nature of pelagic longline gear some of the effort observed might have come from water as shallow as 100 m. A review of the gear haul location data indicated that few sets of gear drifted into shallower water. Therefore, it seems reasonable to assume the species diversity observed is fairly representative (within the constraints of the nature of the fishing gear) of elasmobranchs that use the pelagic zone in this region, and particularly those species that frequent the Gulf Stream and its edges.

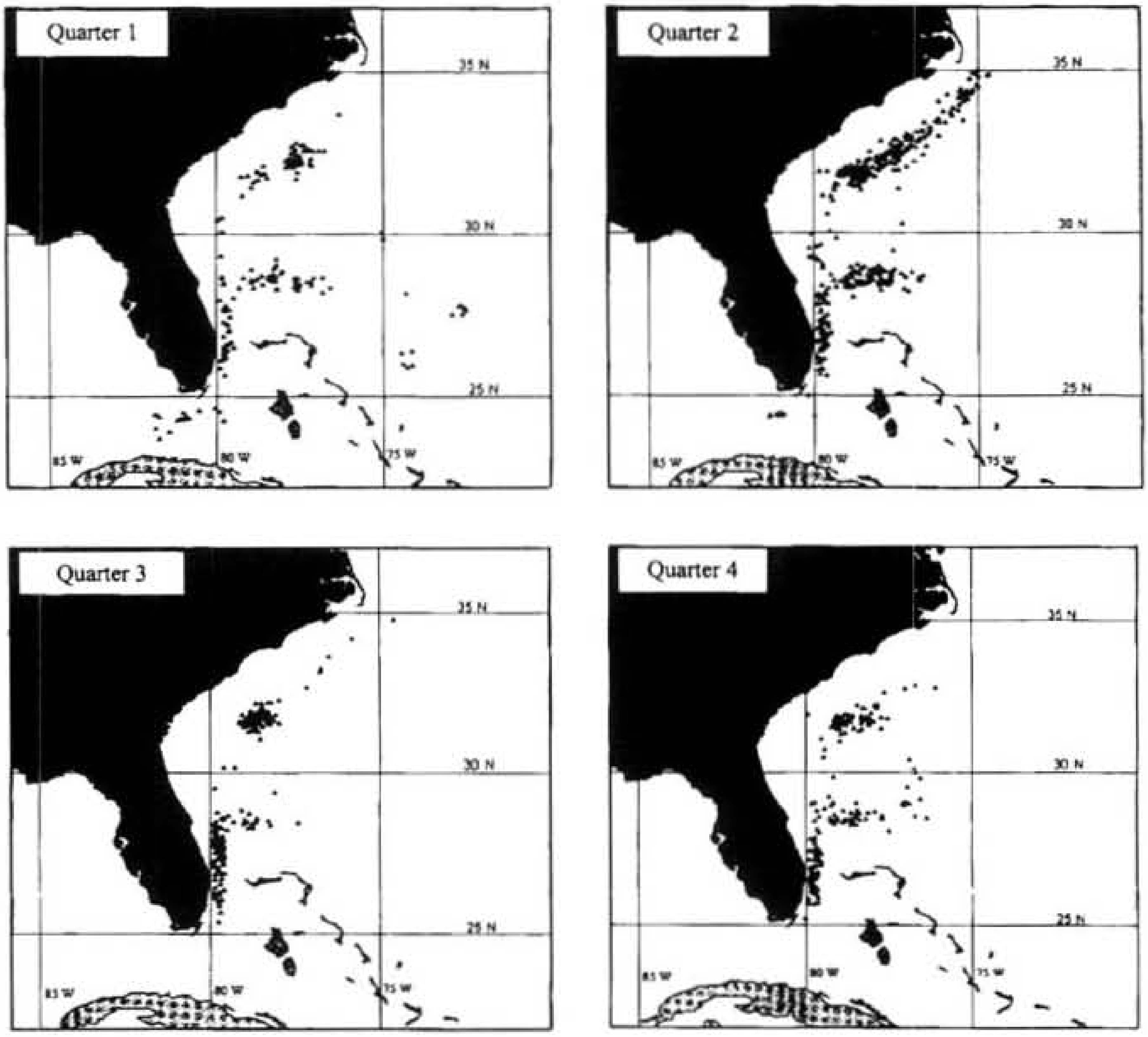

Figure 2. — Locations of observed hauls in the pelagic longline fishery off the southeastern U.S. coast, 1992–2000, by quarter.

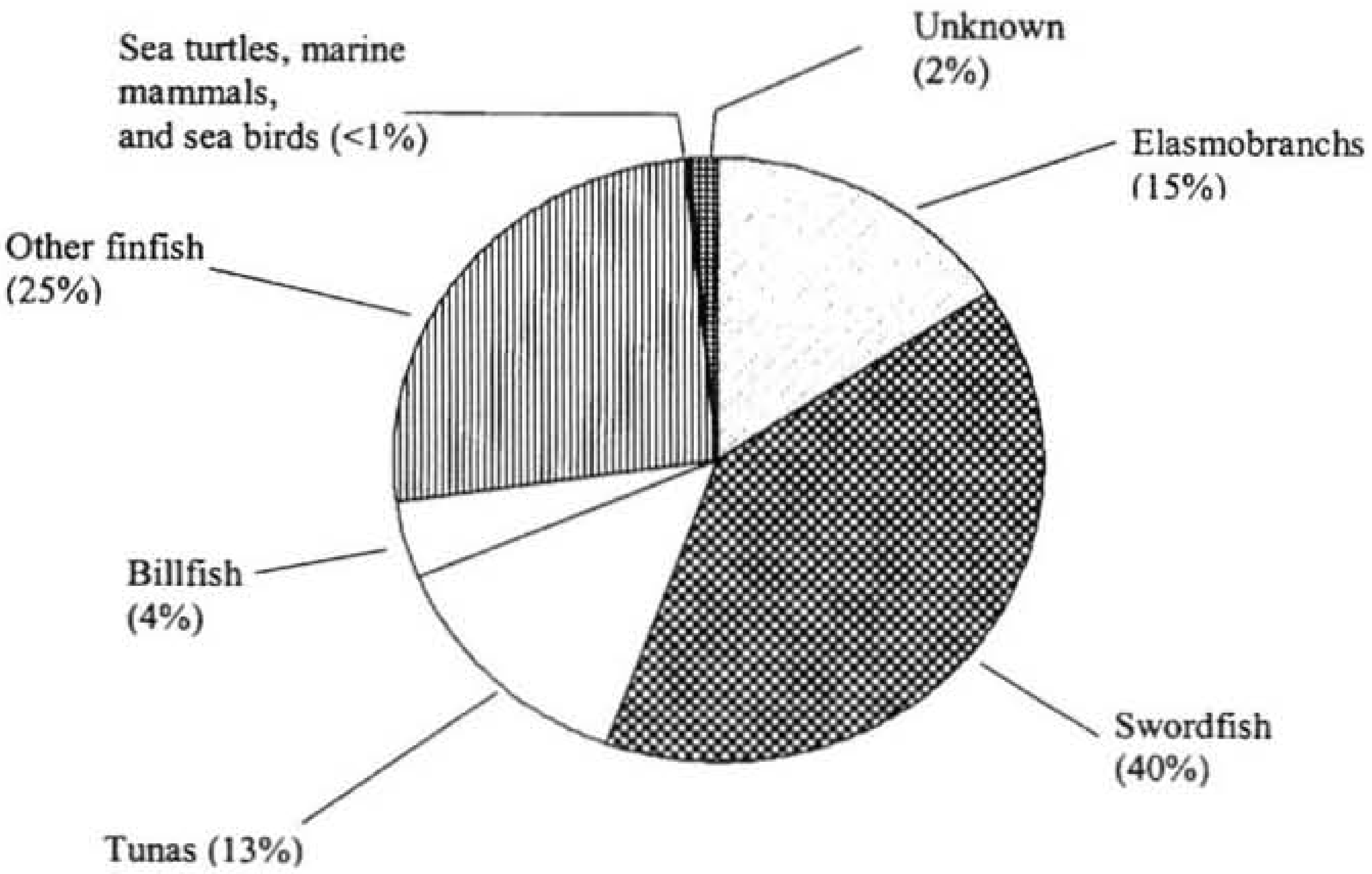

Figure 3. — Percentage of observed catch by category from the pelagic longline fishery off the southeastern U.S. coast, 1992–2000.

Table 3.—Catch status of elasmobranchs observed in the pelagic longline fishery off the southeastern U.S., 1992–2000.

Species	Alive	Dead	Unknown	Damaged	% Dead
Silky	487	949	0	10	66.3
Dusky	348	325	0	6	48.7
Night	110	451	0	11	80.8
Blue	381	49	0	4	12.2
Tiger	255	8	0	0	3.0
Scalloped hammerhead	77	117	1	5	61.0
Oceanic whitetip	95	36	0	0	27.5
Rays	113	0	0	0	0.0
Sandbar	82	29	0	1	26.8
Bigeye thresher	38	43	0	1	53.7
Shortfin mako	52	28	0	0	35.0

The numerical dominance of the silky shark in elasmobranch bycatch observed in this study agrees with similar studies that document this species as making up a large portion of the longline shark bycatch off the southeastern U.S. coast (Guitart-Manday, 1975; Hoey, 1983a; Berkeley and Campos, 1988). However, the relatively high percentage of shark bycatch comprising dusky sharks (14.7%) is not typical of previous findings. Hoey (1983a) found this species to comprise only 5.8% of the total shark catch off the southeastern U.S. coast, although this data set was hampered by species identification problems, and many of the unidentified sharks reported in Hoey's study may have been dusky sharks. Further, Hoey's (1983a) data were dominated by shark-directed effort, which presumably occurred in more shallow water.

Two NMFS bottom longline, fishery-independent shark surveys captured only three dusky sharks in water depths less than 80 m along the coast from Cape Cod, Mass., to Texas (Grace and Henwood, 1997). Springer (1963) reported the dusky shark as being common off the coast of Florida in relatively deeper waters (60–300 m); however, other researchers who have examined catch data from the southern portion of the study area have not found the dusky shark to be as common offshore as we report here (Guitart-Manday, 1975; Berkeley and Campos, 1988).

The night shark, the third-most common elasmobranch observed in our study (12.4%), has also been reported as common in the study area by previous authors, particularly in the Florida Straits (Guitart-Manday, 1975; Castro, 1983; Berkeley and Campos, 1988). The amount of night sharks we observed in the study area is inconsistent with information presented in Castro et al. (1999), who reported night sharks as being rare off the southeastern United States.

In our study, NMFS observers reported very few night sharks in the first 4 years (1992–95), but many more from 1996 to 2000. Unless there was some change in fishing effort after 1996, or a major change in the population's size or migratory patterns in those years — both of which seem doubtful — NMFS observers either misidentified night sharks or reported them as "unidentified sharks" during the early years of the SEFSC pelagic longline observer program.

It seems likely that more night sharks were caught during 1992–95 but were reported mostly as "unidentified sharks" by NMFS observers. Unfortunately, it is also probable that some night sharks were misidentified as other species in the genus *Carcharhinus*. Despite the uncertainty of accurate species identification, our data suggest that the night shark is still a relatively common species in the study area, although a decline in abundance from historical levels is possible.

Catch Status and Disposition

The catch status (condition of the animal, defined as dead or alive, when brought alongside the boat) varied widely depending on species (Table 3). Rays, tiger sharks, and blue sharks were observed to survive best (0%, 3.0%, and 12.2% mortality, respectively), but the three most common shark species in the study — silky, dusky, and night — had much higher mortalities (66.3%, 48.7%, and 80.8%, respectively).

These mortality data suggest that catch status should be taken into account when considering species-specific management measures, as prohibitions on possession of species with generally low survival rates may not substantially reduce bycatch mortality, but might have the effect of reducing economic benefits to the fishermen. Detailed and more extensive examination of fishery-dependent data with concomitant research on gear modification will be necessary for development of regulations aimed at increasing the number of sharks that survive capture.

Table 4.—Catch disposition of elasmobranchs observed in the pelagic longline fishery off the southeastern U.S., 1992–2000.

Species	Retained (%)	Discarded dead (%)	Released alive (%)
Silky	30.0	44.1	25.9
Dusky	24.6	38.7	36.7
Night	26.0	61.9	12.1
Blue	0.2	12.4	87.3
Tiger	1.5	4.6	93.9
Scalloped hammerhead	14.1	51.8	34.2
Oceanic whitetip	24.4	14.5	61.1
Rays	0.0	4.4	95.6
Sandbar	23.2	19.6	57.1
Bigeye thresher	15.9	43.9	40.2
Shortfin mako	72.4	0.0	27.6

The percentage distribution of catch disposition (i.e. whether the elasmobranch was kept, released alive, or released dead) was also highly variable, ranging from 72.4% kept for shortfin mako to less than 2% kept for blue sharks, tiger sharks, and rays (Table 4). The catch disposition percentages we report are likely the result of a combination of factors such as marketability of the species and compliance with fishery regulations. Several of the most common species observed in this study are subject to quota closures, and thus a significant portion of the discard figures for these species might be regulatory.

Length Characteristics

Mean fork lengths by gender (Table 5) were calculated from both actual measurements and combined actual and estimated measurements, with the exception of blue, tiger, and bigeye thresher sharks, for which virtually all lengths were estimated. Because large sharks that fishermen do not intend to keep are rarely

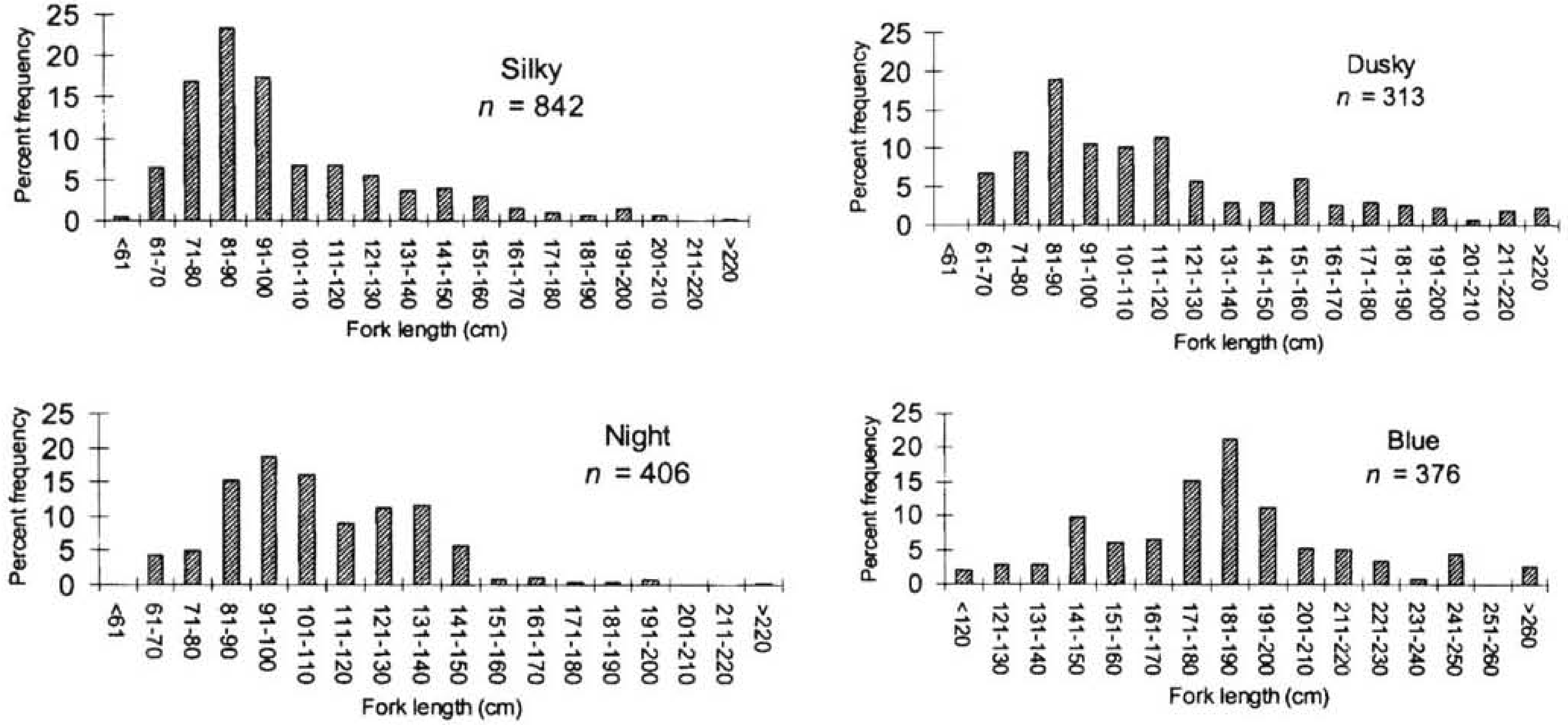

Figure 4. — Percent length-frequency distributions observed for silky, dusky, night, and blue sharks off the southeastern U.S. coast, 1992–2000. All length data were from actual measurements except for blue sharks, where 97% of the length data were estimations.

Table 5.—Mean fork lengths (FL) of sharks observed in the pelagic longline fishery off the southeastern U.S., 1992–2000. Length-at-maturity estimates are taken from the literature cited here; estimates are given as length at first maturity or a range according to the the original study. Where sources reported total length, conversions to fork length were made using relationships given in Kohler et al. (1995).

		Actual measurements (cm)		All measurements (cm)			
Species	Sex	*n*	FL	*n*	FL	Length at maturity (cm)	Citation
Silky	M[1]	375	103	440	107	186	Bonfil et al., 1993
	F[1]	461	101	591	107	192–203	
Dusky	M[1]	163	117	224	119	231	Natanson et al., 1995
	F[1]	148	116	220	125	235	
Night	M[1]	222	109	243	111	156–160	Hazin et al., 2000
	F[1]	181	109	212	113	168–173	
Blue	M	N/A[2]	N/A	22	198	183	Pratt, 1979
	F	N/A	N/A	58	189	185	
Tiger	M[1]	N/A	N/A	21	211	258	Branstetter et al., 1987
	F[1]	N/A	N/A	47	198	263–267	
Scalloped hammerhead	M	24	150	43	156	139	Branstetter et al., 1987
	F[1]	34	146	71	173	194	
Oceanic whitetip	M[1]	24	105	34	100	145–153	Lessa et al., 1999
	F[1]	27	105	44	100	145–153	
Sandbar	M[1]	26	142	36	149	150	Sminkey and Musick, 1995
	F	10	145	19	156	150	
Bigeye thresher	M	N/A	N/A	21	192	172	Moreno and Moròn, 1992
	F[1]	N/A	N/A	16	190	208	
Shortfin mako	M	38	186	39	186	179	Stevens, 1983
	F[1]	21	177	22	175	258	

[1] Indicates species/gender whose mean lengths were below reported maturity size.

[2] N/A = not available.

brought aboard for actual measurement by observers, using only actual measurements to determine mean fork lengths might result in smaller mean sizes being estimated than those actually occurring in the fishery.

For most of the species, mean fork lengths estimated from the combined data were greater than those obtained from actual measurements only. Even then, mean lengths were still clearly below the reported size at maturity (for both males and females) in silky, dusky, night, tiger, and oceanic whitetip sharks. For the three most common species (silky, dusky, and night sharks) greater than 95% of the observed catch consisted of immature individuals (Fig. 4).

Gear selectivity should be considered when examining length data derived from longline observation. The gear type used by U.S. pelagic longline fishermen consists largely of monofilament. Although many authors have reported length information from sharks taken by monofilament longline gear, few have discussed the possibility that the mean lengths and length frequencies constructed from catch data may not be representative of the actual length characteristics of the population.

Table 6.—Regression results of mean yearly CPUE series for sharks observed in the pelagic longline fishery off the southeastern U.S., 1992–2000. Only species with statistically significant results ($P < 0.05$) are shown. SE=standard error.

Species	Series type	R^2	Slope	SE of slope	P
Night	Variance-weighted	0.592	–3.782	1.188	0.015
	Non-weighted	0.747	0.309	0.068	0.003
Oceanic whitetip	Variance-weighted	0.611	3.684	1.112	0.013
	Non-weighted	0.805	–0.051	0.009	0.001
Sandbar	Variance-weighted	0.461	3.688	1.508	0.044
	Non-weighted	0.075	–0.033	0.044	0.475

Hoey (1983b) believed that most "lost hooks" or "bite offs" (a gangion that is retrieved without the hook, the monofilament having been broken or cut in some way) were a result of sharks taking the bait, and all such incidences were recorded in his data as "unidentified sharks." Because it seems reasonable to assume that larger and stronger sharks would stand a greater chance of severing the monofilament gangion, the observed catch data could be biased in favor of smaller sharks.

Berkeley and Campos (1988) provided the only evidence available that the size and characteristics of sharks are not influenced by the use of monofilament gangions. These authors used steel gangions for 20–25% of the hooks set during the first 13 sets of their 111-set study and found no significant differences in either the species composition or the mean size of the shark catch between the two gangion types.

We suggest, however, that given the common occurrence of gangion "bite offs", it is likely that size selectivity is occurring in the fishery. Such selectivity should be detected by analysis of catches from gangions of various strengths. Preliminary comparisons of the observed size of silky sharks captured on gangions of two different breaking strengths, 135 kg (300-lb) test and 180 kg (400-lb) test, have shown that significantly larger silky sharks were observed on gear utilizing the stronger gangions (Beerkircher[3]). The relationship between catch lengths and gangion size should be explored further as it may have important implications when examining long-term changes in catch size distributions.

ANOVA results indicate significant fork length differences among quarters for silky (F=6.51; df=3, 839; P<0.0001), dusky (F=7.55; df=3, 309; P<0.0001), night, (F=8.34; df=3, 402; P<0.0001), oceanic whitetip (F=9.00; df=3, 111; P<0.0001), and sandbar (F=4.61; df=3, 93; P<0.0047) sharks. Post-hoc tests on silky, dusky, and sandbar sharks indicated that significantly smaller individuals were observed during the fourth quarter (October–December) compared to the rest of the year.

For the silky shark, these data, coupled with the length-frequency results (Fig. 4) indicating that few silky sharks at or below the reported size of neonates (60 cm or less; Bonfil et al., 1993) were observed in the study area, are consistent with Springer's (1967) hypothesis that silky shark neonates may stay near reefs on the outer shelf until they have grown large enough to move to pelagic habitats. This movement probably occurs by the first winter after a late spring–early summer pupping season (Branstetter, 1987). The quarterly ANOVA result of a smaller mean size observed in quarter 4 could reflect the yearly movement of small young-of-the-year silky sharks into the pelagic habitat.

Yearly and Quarterly CPUE

For elasmobranchs as a group, yearly mean nominal CPUE was 12.04 elasmobranchs per 1,000 hooks, ranging from 8.67 (1996) to 14.99 (1998). For individual species, bootstrapped estimates of yearly mean CPUE were highly variable (Fig. 5), yet variance-weighted regression analysis indicated a significant decrease for night sharks (P<0.015), and a significant increase for oceanic whitetip (P<0.013) and sandbar sharks (P<0.044). However, regression analysis of non-weighted data for these three species produced slopes contrary to the weighted results (results not significant for sandbar) (Table 6).

For night sharks, we suggest the analyses are confounded by species identification problems. The weighting procedure used the inverse of the variance as a weight; thus, CPUE from years when observations were very rare and consequently had a low variance (such as 1992, 1993, and 1994 when only 1, 2, and 13 night sharks were observed, respectively) were weighted more heavily than CPUE from years when greater numbers were observed.

The weighting procedure we used assumes yearly variance is an estimate of precision, an assumption that is incorrect if species identification problems resulted in the low numbers of night sharks observed in the first few years. Sharks in the genus *Carcharhinus* are difficult to identify; we believe that these difficulties were likely more pronounced during the early years of the observer program before both observers and observer trainers gained experience with the variety of shark species encountered by this fishery. No such problem is suspected for the oceanic whitetip, where the large, rounded white-tipped fins present even an inexperienced observer with little identification difficulty. If the yearly variance in this case is a reasonable estimate of precision, the analysis suggests an increasing trend in the relative abundance of oceanic whitetips sharks.

These results serve to illustrate the substantial effect that weighting can have on the analysis of CPUE time series data. This is a common problem in stock assessment, where the choice of weights is an area of intense debate. The contradictory results of the nonweighted and weighted yearly CPUE regressions also need to be considered in view of the speculative nature of the relationship between CPUE and actual abundance.

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[3] Beerkircher, L. Unpubl. data on file at Southeast Fisheries Science Center, NMFS, NOAA, Miami, FL 33149.

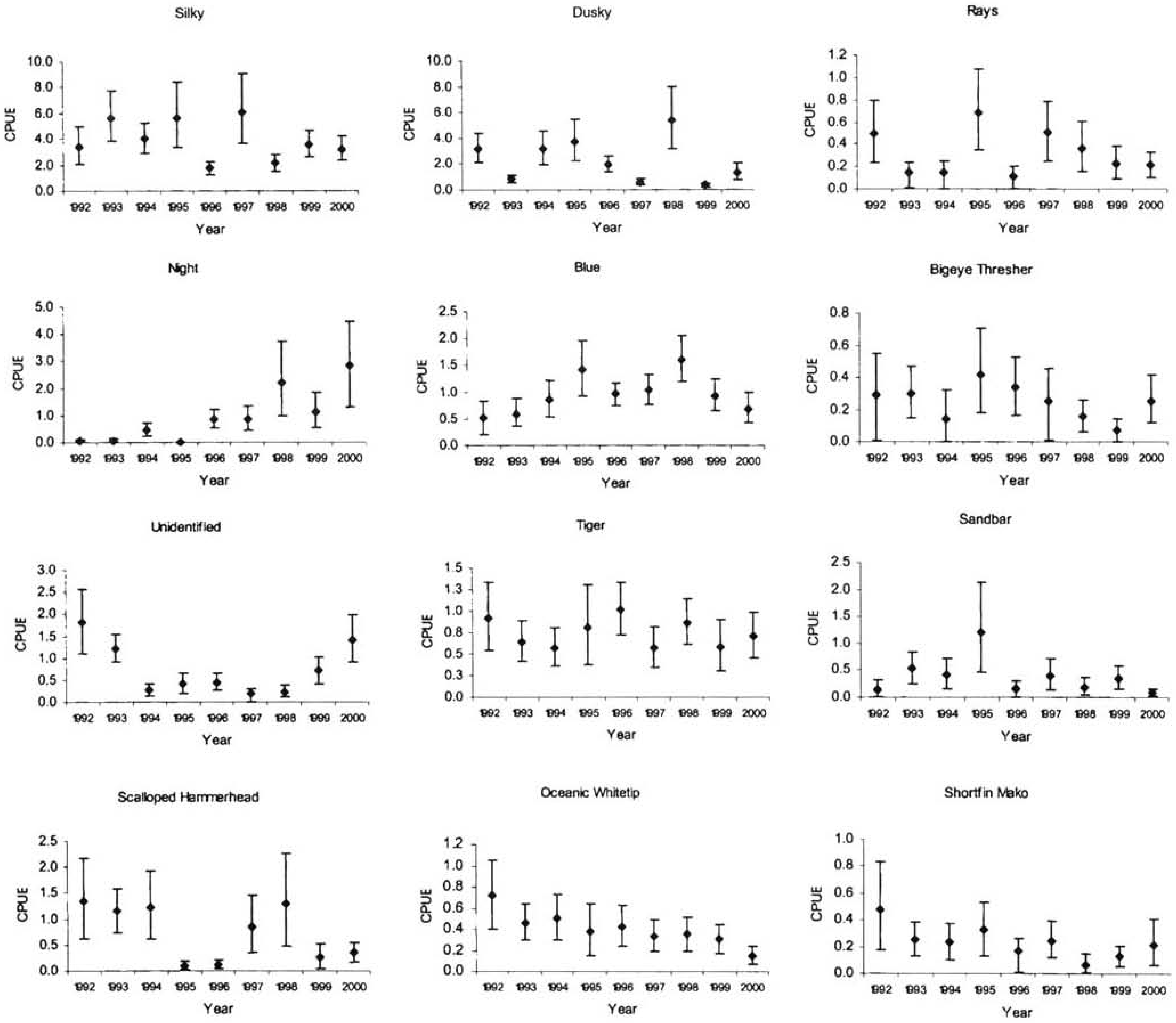

Figure 5. — Bootstrapped estimates by species of yearly mean catch per unit effort (CPUE) expressed as number caught per 1,000 hooks, 1992–2000. Vertical bars represent bootstrap 95% confidence limits.

Yearly CPUE trends, even highly significant ones, might not be indicative of real population change, but merely a result of spatial or gear changes in observed fishing effort. Additional years of data may help clarify any significant changes in CPUE; however, a more rigorous analytical approach, such as application of Generalized Linear Modeling, may also serve to account for factors not related to abundance but affecting CPUE.

To detect possible seasonal trends in CPUE, we analyzed the observer data by quarter. Quarterly overall elasmobranch CPUE varied from a high of 13.79 during quarter 2 (April–June) to a low of 9.73 in quarter 3 (July–Sept.), but the only significant ($P<0.004$) relationship was that elasmobranch CPUE in quarter 2 was greater than that in quarters 3 and 4 (Oct.–Dec.). For individual species, significant quarterly variation in CPUE was found for silky, night, blue, oceanic whitetip, rays, sandbar, and shortfin mako sharks (Table 7).

The higher relative abundance of blue sharks seen in quarters 1 and 2 reflects the occurrence of this species in the northern part of the study area (SAB) during the winter and spring. During these seasons the ocean temperature in the area (outside the Gulf Stream) is closer to the preferred temperature range of 10–20°C for blue sharks (Castro, 1983). In contrast to the blue shark, relative abundance of oceanic

Table 7.—Quarterly CPUE (numbers per 1,000 hooks) and significant relationships observed in the pelagic longline fishery off the southeastern U.S., 1992–2000.

	CPUE					
Species	Qtr. 1	Qtr. 2	Qtr. 3	Qtr. 4	Quarterly relationship(s)	*P*
Silky	5.38	3.22	3.16	4.28	4>2	0.001
Dusky	1.50	3.09	1.94	1.10		
Night	1.48	1.62	0.30	0.28	1,2>3,4	0.0001
Blue	1.29	1.51	0.09	0.41	1,2>3,4	0.0001
Unidentified	0.58	1.04	0.63	0.62		
Tiger	0.57	0.64	0.93	0.87		
Scalloped hammerhead	0.63	0.83	0.78	0.62		
Oceanic whitetip	0.16	0.16	0.51	0.90	4>3>1,2	0.0001
Rays	0.28	0.09	0.45	0.49	4,3,1>2	0.0001
Sandbar	0.21	0.59	0.30	0.07	2>1,4	0.0002
Bigeye thresher	0.23	0.26	0.26	0.16		
Shortfin mako	0.41	0.19	0.18	0.16	1>2,3,4	0.01

Table 8.—Overall nominal CPUE (numbers caught per 1,000 hooks) off the southeastern U.S. Data for 1981–83 are from Berkeley and Campos (1988); 1992–2000 data are from this present study.

	CPUE	
Species	1981–83	1992–2000
Silky	11.22	3.49
Dusky	0.47	1.64
Night	10.75	1.36
Blue	0.60	1.05
Unidentified	0.87	0.66
Tiger	0.60	0.64
Scalloped hammerhead	13.37	0.48
Oceanic whitetip	0.87	0.32
Sandbar	0.07	0.28
Bigeye thresher	0.67	0.20
Shortfin mako	0.00	0.19

Table 9.—Sex ratios of elasmobranchs observed in the pelagic longline fishery off the southeastern U.S., 1992–2000.

	Sample size		Ratio		
Species	Male	Female	Male	Female	Total no.
Silky	453	627	1.0	1.4	1,080
Dusky	236	231	1.0	1.0	467
Night	243	212	1.0	0.9	455
Blue	22	61	1.0	2.8	83
Tiger	25	49	1.0	2.0	74
Scalloped hammerhead	44	76	1.0	1.7	120
Oceanic whitetip	34	46	1.0	1.4	80
Rays	26	15	1.0	0.6	41
Sandbar	38	20	1.0	0.5	58
Bigeye thresher	24	19	1.0	0.8	43
Shortfin mako	41	23	1.0	0.6	64

whitetips was greater in quarter 3, and particularly quarter 4, which may reflect this species' preference for warmer waters.

Relative abundance of night sharks was higher in quarters 1 and 2. This increase in night shark abundance from January through June was also described by Guitart-Manday (1975) for a fishery off the northwestern coast of Cuba. Relatively little is known about this species, and no published information is available that might help to explain the decrease in night shark abundance during July–December. Night sharks may remain in the study area but feed at greater depths than fishing occurs, or possibly migrate outside of the study area.

A paucity of comparable historical CPUE data for the study area makes comparisons with recent catch rates difficult. Berkeley and Campos (1988) provided the only fishery-dependent, but limited, observations of shark catch on similar gear during the early 1980's. Comparisons of overall nominal CPUE for sharks between the two sets of data are shown in Table 8. Large declines in relative abundance are seen for silky, night, and scalloped hammerhead sharks, and moderate increases are seen in dusky and blue sharks.

It should be noted, however, that several sampling differences exist between the two studies. Berkeley and Campos (1988) observed trips on vessels only in the Florida Straits (about lat. 25°N to 28°N), and there were at least some sets made in the Bahamian EEZ. The majority of the 111 sets made in the 1988 study were from a single vessel. Such significant spatial and vessel differences reduce direct comparability with the present data set, which is drawn from a much larger area and sampling effort from 65 different vessels.

An obvious spatial effect is the greater relative abundance of blue sharks noted in the present study. Blue sharks may be found in high numbers at certain times of the year in the South Atlantic Bight, but they are rarely seen in the warm waters between Florida and the Bahamas. It is possible that these or other biases also explain the other notable differences between the 1980's and 1990's data, but they may, in some cases, be indicative of real population declines.

Sex Ratio

Females dominated the catch for silky, blue, tiger, scalloped hammerhead, and oceanic whitetip sharks (Table 9). The gender dominance of female silky, scalloped hammerhead, and tiger sharks was observed previously in this area (Berkeley and Campos, 1988). Springer (1963), however, in data from an inshore bottom longline fishery, observed a more mixed (1:1) sex ratio for tiger sharks. These gender ratio differences for tiger sharks in different habitats may indicate the occurrence of some degree of gender segregation based on habitat type. The observation that female blue sharks were caught almost three times as often as males is consistent with reports of gender-biased segregation in this species (Pratt, 1979; Nakano and Nagasawa, 1996).

Analysis of the sex ratio by quarters indicated that although female silky sharks dominated in all quarters, there were significantly more males observed during the third quarter ($\chi^2 = 9.71$, df=3, $P > 0.05$). Significant differences in sex ratios among quarters were also found for the blue shark, but the very low numbers of individuals observed during quarters 3 and 4 preclude any meaningful conclusions regarding seasonal distributions of the sexes.

Conclusions

Analysis of 9 years of observer bycatch data indicates that the characteristics of sharks using the pelagic habitat off the southeastern United States vary greatly depending on the species, year, and season. The various degrees of seasonal abundance seen in these data are probably a reflection of the seasonal north-south or inshore-offshore migrations displayed by many species. Of concern is the indication that relative abundance of several shark species that utilize the pelagic habitat off the southeastern United States may have declined in the last 2 decades, and that the bulk of bycatch mortality was borne by individuals below size-at-maturity. For several of the observed species, examination of catch status suggests that bycatch mortality is not prevented by retention prohibitions.

While longline gear selectivity and a paucity of long-term, standardized catch and effort data may affect the robustness of inferences that can be drawn regarding population trends, these data serve as an important baseline for future shark surveys. Large portions of the study area have recently been closed to pelagic longline fishing to protect undersized swordfish, and the shark populations in this area may also benefit from these closures. However, area closures may not be effective when large portions of the populations they are designed to protect migrate into other areas where they are subject to fishing mortality. Since most of the sharks observed in this study are highly migratory in nature, close monitoring of this and surrounding areas will be needed for evidence that relatively small closures may benefit these populations.

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Literature Cited

Anderson, E. D. 1985. Analysis of various sources of pelagic shark catches in the northwest atlantic and western central Atlantic Ocean and Gulf of Mexico with comments on catches of other large pelagics. *In* E. D. Anderson, J. G. Casey, J. J. Hoey, and W. N. Witzell (Editors), Shark catches from selected fisheries off the U.S. east coast, p. 1–14. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 31.

Beerkircher, L. R., C. J. Brown, and D. W. Lee. 2002. SEFSC pelagic observer program data summary for 1992–2000. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SEFSC-486, 26 p.

Berkeley, S. A., E. W. Irby, Jr., and J. W. Jolley, Jr. 1981. Florida's commercial swordfish fishery: longline gear and methods. Univ. Miami Sea Grant Prog. Mar. Advis. Bull. MAP-14, 23 p.

________ and W. L. Campos. 1988. Relative abundance and fishery potential of pelagic sharks along Florida's East Coast. Mar. Fish. Rev. 50(1):9–16.

Bonfil, R., R. Mena, and D. deAnda. 1993. Biological parameters of commercially exploited silky sharks, *Carcharhinus falciformis*, from the Campeche Bank, Mexico. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 115:73–86.

Branstetter, S. 1987. Age, growth, and reproductive biology of the silky shark, *Carcharhinus falciformis*, and the scalloped hammerhead, *Sphyrna lewini*, from the northwestern Gulf of Mexico. Environ. Biol. Fishes 19(3):161–173.

________, J. A. Musick, and J. A. Colvocoresses. 1987. A comparison of the age and growth of the tiger shark, *Galeocerdo cuvier*, from off Virginia and from the northwestern Gulf of Mexico. Fish. Bull. 85:269–279.

Casey, J. G., F. J. Mather, J. M. Mason, and J. Hoenig. 1978. Offshore fisheries of the Middle Atlantic Bight. Mar. Rec. Fish. 3:107–129.

Castro, J. I. 1983. The sharks of North American waters. Texas A&M Univ. Press, Coll. Sta., 180 p.

________, C. M. Woodley, and R. L. Brudeck. 1999. A preliminary evaluation of the status of shark species. Food Agric. Organ., U.N., FAO Fish. Tech. Pap. 380, 72 p.

Cramer, J. 1995. Large pelagic logbook newsletter-1994. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SEFSC-378, 33 p.

________. 2002. Large pelagic logbook newsletter-2000. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SEFSC-471, 26 p.

________ and H.M. Adams. 1999. Large pelagic logbook newsletter-1997. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SEFSC-420, 26 p.

Efron, B., and R. Tibshirani. 1993. An introduction to the bootstrap. Chapman and Hall, N.Y., 436 p.

Grace, M., and T. Henwood. 1997. The distribution and abundance of coastal sharks in the U.S. Gulf of Mexico and eastern seaboard, 1995 and 1996. Mar. Fish. Rev. 59(4):23–32.

Guitart-Manday, D. 1975. Las pesquerías pelágico-oceánicas de corto radio de acciòn en la regiòn noroccidental de Cuba. Ser. Ocean. 31:1–26.

Hazin, F. H. V., F. M. Lucena, T. S. A. L. Souza, C. E. Boeckman, M. K. Broadhurst, and R. C. Menni. 2000. Maturation of the night shark, *Carcharhinus signatus*, in the southwestern equatorial Atlantic Ocean. Bull. Mar. Sci. 66(1):173–185.

Hoey, J. J. 1983a. Distribution and relative abundance of sharks in the western North Atlantic as indicated by longline catch data. Ph.D. Dissert. Univ. R.I., Kingston. Manuscr. 2, p. 137–243.

________. 1983b. The magnitude and species composition of the incidental by-catch of pelagic longline fisheries in the western North Atlantic. Ph.D. Dissert. Univ. R.I., Kingston. Manuscr. 1, p. 1–136.

Kohler, N. E, J. G. Casey, and P. A. Turner. 1995. Length-weight relationships for 13 species of sharks from the western North Atlantic. Fish. Bull. 93:412–418.

Lessa, R., F. M. Santana, and R. Peglerani. 1999. Age, growth, and stock structure of the oceanic whitetip shark, *Carcharhinus longimanus*, from the soutwestern equatorial Atlantic. Fish. Res. 42:21–30.

Moreno, J. A., and J. Moròn. 1992. Reproductive biology of the bigeye thresher shark, *Alopias superciliosus* (Lowe, 1839). Aust. J. Mar. Freshwater Res. 43:77–86.

Musick, J. A., G. Burgess, G. Cailliet, M. Camhi, and S. Fordham. 2000. Management of sharks and their relatives (Elasmobranchii). Fisheries 25(3):9–13.

Nakano, H., and K. Nagasawa. 1996. Distribution of pelagic elasmobranchs caught by salmon research gillnets in the North Pacific. Fish. Sci. (Tokyo) 62(5):860–865.

Natanson, L. J., J. G. Casey, and N. E. Kohler. 1995. Age and growth estimates for the dusky shark, *Carcharhinus obscurus*, in the western North Atlantic Ocean. Fish. Bull. 93:116–126.

Pratt, H. L. 1979. Reproduction in the blue shark, *Prionace glauca*. Fish. Bull. 77:445–469.

________ and J. G. Casey. 1990. Shark reproductive strategies as a limiting factor in directed fisheries, with a review of Holden's method of estimating growth parameters. *In* H. L. Pratt, Jr., S. H. Gruber, and T. Taniuchi, (Editors), Elasmobranchs as living resources: advances in the biology, ecology, and systematics, and the status of the fisheries, p. 97–109. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 90.

Rago, P. J., K. A. Sosebee, J. K. T. Brodziak, S. A. Murawski, and E. D. Anderson. 1998. Implications of recent increases in catches on the dynamics of northeast Atlantic spiny dogfish (*Squalus acanthias*). Fish. Res. 39(2): 165–181.

Ripley, W. E. 1946. The soupfin shark and the fishery. Calif. Dep. Fish Game Fish. Bull. 64:7–37.

Sminkey, T. R., and J. A. Musick. 1995. Age and growth of the sandbar shark, *Carcharhinus plumbeus*, before and after population depletion. Copeia 1995(4):871–883.

Sokal, R. R., and F. J. Rohlf. 1995. Biometry: the principles amd practice of statistics in biological research. W. H. Freeman and Co., N.Y., 887 p.

Springer, S. 1963. Field observations of large sharks of the Florida–Caribbean region. *In* P. W. Gilbert (Editor), Sharks and survival, p. 95–113. D.C. Heath and Co., Boston, Mass.

________. 1967. Social organizations of shark populations. *In* P. W. Gilbert, R. F. Mathewson, and D. P. Rall (Editors), Sharks, skates, and rays, p. 149–176. Johns Hopkins Press, Baltimore, Md.

Stevens, J. D. 1983. Observations on reproduction in the shortfin mako *Isurus oxyrinchus*. Copeia 1983(1):126–130