Assessment of the Distribution and Abundance of Coastal Sharks in the U.S. Gulf of Mexico and Eastern Seaboard, 1995 and 1996

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Introduction

The 1993 FMP for sharks stressed the need for monitoring and assessment of shark populations to determine the efficacy of FMP measures. Prior to 1995, little fishery independent monitoring of small and large coastal shark populations had occurred in the Gulf of Mexico, and only sporadic or localized surveys had been conducted in the western North Atlantic. Developing a program and survey design to address this need has been difficult due to factors that include species diversity, geographic distributions, seasonality, and gear selectivity. Since all of these factors and many others contribute to high

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ABSTRACT—During 1995 and 1996, the National Marine Fisheries Service (NMFS), conducted pilot studies to develop survey methodology and a sampling strategy for assessment of coastal shark populations in the Gulf of Mexico and western North Atlantic. Longline gear similar to that used in the commercial shark fishery was deployed at randomly selected stations within three depth strata per 60 nautical mile grid from Brownsville, Tex. to Cape Ann, Mass. The survey methodology and gear design used in these surveys proved effective for capturing many of the small and large coastal sharks regulated under the auspices of the 1993 Fisheries Management Plan (FMP) for Sharks of the Atlantic Ocean. Shark catch rates, species composition, and relative abundance documented in these pilot surveys were similar to those reported from observer programs monitoring commercial activities. During 78 survey days, 269 bottom longline sets were completed with 879 sharks captured.

variability in catch rates for each of the species of interest, effective survey design with contemporary gear was considered vital for a meaningful project.

This report summarizes the result of a 2-year pilot study to develop survey methodology and a sampling strategy for assessment of coastal shark populations in the U.S. waters of the Gulf of Mexico coast and the eastern seaboard (Fig. 1). Analysis of data collected over the course of this study demonstrates the feasibility of a fishery independent approach to monitoring coastal shark populations.

Materials and Methods

Survey Design

Due to lack of prior shark assessment information over much of the study area, survey design for the pilot study incorporated random station selection stratified by depth (3 depth strata were sampled; 10–19.9 fm, 20–29.9 fm, and 30–40 fm). To ensure relatively uniform coverage over the geographic range of the survey, 60 n.mi. latitudinal or longitudinal grids (parallel to the coastline) were selected with a minimum of 3 samples per grid (1 in each depth stratum). For the 1995 U.S. eastern seaboard study (Thompson[1]), some survey sites were selected to replicate previous NMFS, Narragansett Laboratory project site locations (Casey[2], Casey[3], Casey[4]). During the 1995 Gulf of Mexico sur vey (Grace[5]) and the 1996 U.S. eas coast and Gulf of Mexico survey (Grace[6]), all sites were selected base on random stratified sampling design Additional random stratified sampling sites were selected during the pilot stud ies between extreme distances or to full utilize sea days. Effort during 4 longlin sets was in waters shallower than 10 fm catch results for these survey sites ar grouped with data for the 10–19.9 fm strata. With the exception of experimen tal pelagic longline sets, catch results fron all survey sites occupied during the pilo studies are included in data analyses.

Selection of the July through Septem ber time frame to conduct these survey was dictated by availability of the ves sel. It is known that shark catch rates b species may vary seasonally (NOAA 1993), but no adjustment for seasona variations was possible. This is no problematic as long as future survey are conducted during this time frame However, if surveys are conducted dur ing different seasons, the resultant in dices may not be comparable.

Longline Gear

Monofilament longline gear was se lected for these studies because it is th preferred gear of the commercial sec tor, and because comparison of longlin gear versus "Yankee gear" (Branstette

[1] Cruise results for RELENTLESS 95-03 (2), coastal shark longline assessment survey. Perry Thompson, NMFS Mississippi Laboratories cruise report, 8 p.

[2] Cruise results for WIECZNO (86-01), longline survey of apex predators. Jack Casey, NMFS Narragansett Laboratory cruise report, 37 p.

[3] Cruise results for DELAWARE II (89-03), survey of apex predators - sharks. Jack Casey, NMFS Narragansett Laboratory cruise report, 9 p.

[4] Cruise results for DELAWARE II (91-06), su vey of apex predators - sharks. Jack Casey, NMF Narragansett Laboratory cruise report, 12 p.

[5] Cruise results for OREGON II 95-04 (218 coastal shark assessment. Mark Grace, NMF Mississippi Laboratories cruise report, 19 p.

[6] Cruise results for OREGON II 96-04 (222 coastal shark assessment. Mark Grace, NMF Mississippi Laboratories cruise report, 12 p.

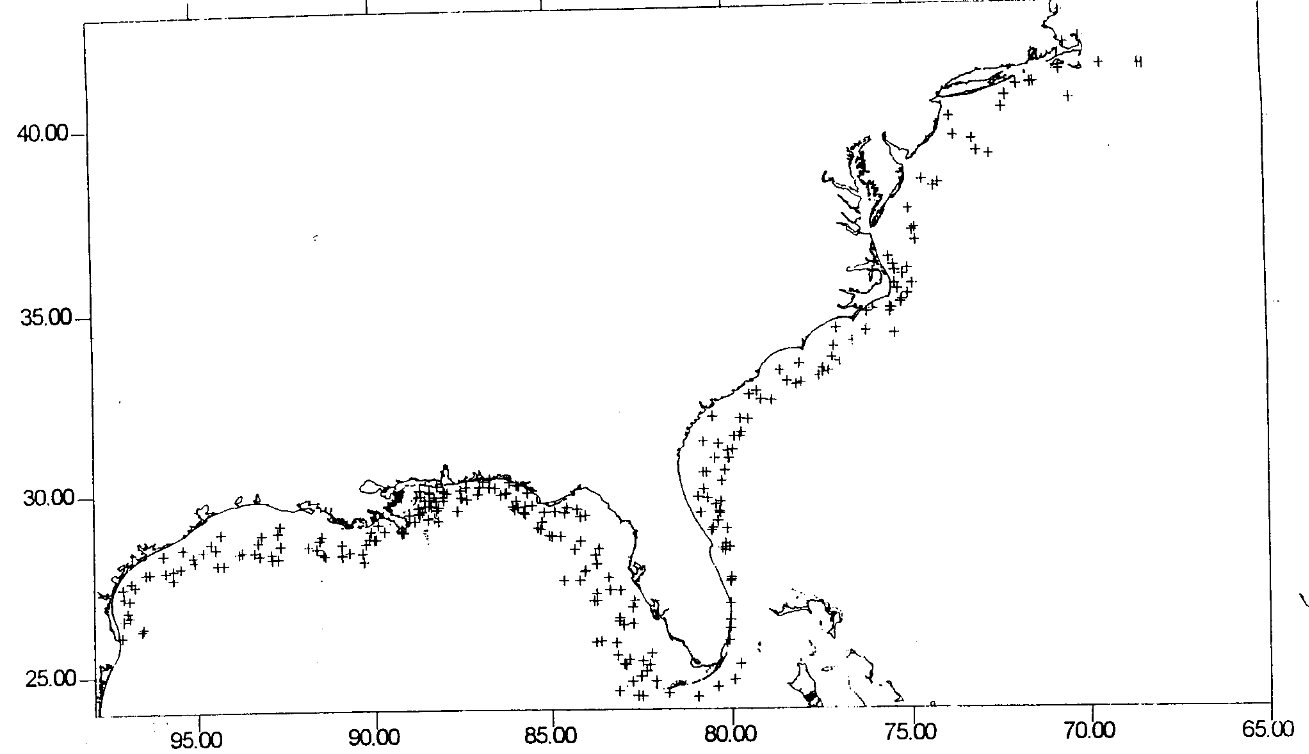

Figure 1. — Longline station locations for NMFS shark longline pilot studies, 1995–1996.

and Musick, 1994) indicated that monofilament gear is significantly more efficient. The longline consisted of 1.0 n.mi. of 940-lb (426 kg) test monofilament mainline, 100 baited (*Scomber scomber*) #3/0 shark hooks with 12-ft (3.66 m) gangions of 730-lb (332 kg) test monofilament (3.66 m). A hydraulic longline reel was used for setting and retrieving the mainline. Radar high-flyers with strobes and bullet buoys were used to mark longline locations. The mainline was weighted at the start buoy, midset, and end buoy; additional weights were added (between start and midset, between midset, and end) for sites in areas of strong currents.

Effort was primarily bottom longline, but nine experimental pelagic longline sets were included in the 1996 project. Unfortunately, the pelagic sets failed to capture sharks and effort for these experimental stations were excluded from all subsequent analyses.

During the Gulf of Mexico 1995 survey, approximately 750 hooks were baited with other bait (shark pieces and finfish pieces) since the bait supply was not adequate to complete the survey. Differences in shark catches as related to bait type during the Gulf of Mexico 1995 survey were not statistically evaluated due to the small sample size and our inability to address the effects of other variables such as location, depth, and time of day. Effort and catch for hooks with other bait were included in data analyses.

All sharks captured during the surveys were identified and most were tagged and released. Selected shark species were brought aboard for collection of biological data. Specimens collected were for scientific uses that included DNA analysis, ecto- and endoparasites, tooth morphology, reproductive biology, and vertebrae for age and growth. The volume of specimens landed depended upon the objectives of cruise participants, and landing of sharks for scientific purposes was less than 10% of all live specimens captured; sharks landed dead were generally sampled. Sharks landed for biological sampling were primarily U.S. shark management plan species (Table 1).

Biological data for all sharks captured included identifications (genus and species), length (mm), weight (kg) sex, and mortality. Length measurements were fork length and total length and were either actual or estimated (sharks not landed or measurement no recorded). Some lengths or weights were derived with conversion factors using a known variable (length o weight). Exceptions were for those sharks too large to land or for those tha escaped; estimating both length and weight was then necessary. During th 1996 project, a section of the ship's rul rail 1.5 m above waterline was marke in 0.25 m, 0.50 m, and 1.0 m increment (up to 4.0 m) to facilitate length esti mates for sharks brought alongside ship Estimated lengths and weights wer identified in survey data and were in cluded with summary information pre sented for each species.

Research Platforms

Two research vessels were used du ing the 1995 and 1996 surveys. The re search platform for the Gulf of Mexic

Table 1. — Management units for sharks of the Atlantic and Gulf of Mexico (NOAA, 1993).

Species and management unit	
Large Coastal Sharks	
Sandbar	*Carcharhinus plumbeus*
Blacktip	*Carcharhinus limbatus*
Dusky	*Carcharhinus obscurus*
Spinner	*Carcharhinus brevipinna*
Silky	*Carcharhinus falciformis*
Bull	*Carcharhinus leucas*
Bignose	*Carcharhinus altimus*
Narrowtooth	*Carcharhinus brachyurus*
Galapagos	*Carcharhinus galapagensis*
Night	*Carcharhinus signatus*
Caribbean reef	*Carcharhinus perezi*
Tiger	*Galeocerdo cuvieri*
Lemon	*Negaprion brevirostris*
Sand tiger	*Odontaspis taurus*
Bigeye sand tiger	*Odontaspis noronhai*
Nurse	*Ginglymostoma cirratum*
Scalloped hammerhead	*Sphyrna lewini*
Great hammerhead	*Sphyrna mokarran*
Smooth hammerhead	*Sphyrna zygaena*
Whale	*Rhincodon typus*
Basking	*Cetorhinus maximus*
White	*Carcharodon carcharias*
Small Coastal Sharks	
Atlantic sharpnose	*Rhizoprionodon terraenovae*
Caribbean sharpnose	*Rhizoprionodon porosus*
Finetooth	*Carcharhinus isodon*
Blacknose	*Carcharhinus acronotus*
Smalltail	*Carcharhinus porosus*
Bonnethead	*Sphyrna tiburo*
Atlantic angel	*Squatina dumerili*
Pelagic Sharks	
Shortfin mako	*Isurus oxyrinchus*
Longfin mako	*Isurus paucus*
Porbeagle	*Lamna nasus*
Thresher	*Alopias vulpinus*
Bigeye thresher	*Alopias superciliousus*
Blue	*Prionace glauca*
Whitetip	*Carcharhinus longimanus*
Sevengill	*Heptranchias perlo*
Sixgill	*Hexanchus griseus*
Bigeye sixgill	*Hexanchus vitulus*

Table 2. — Total number of captures, catch per unit effort (CPUE, captures/100 hook hours), standard deviation of the mean (STD), standard error of the mean (STDERR), and coefficient of variation of the mean (VC) for sharks encountered during NMFS 1995 and 1996 shark pilot studies.

Shark species	Captures	CPUE	STD	STDERR	CV
1995 NMFS Shark Pilot Study (n = 127)					
Blacknose	18	0.142	0.545	0.048	0.341
Spinner	7	0.055	0.341	0.030	0.548
Silky	6	0.047	0.278	0.025	0.521
Finetooth	4	0.032	0.355	0.032	1.000
Bull	6	0.047	0.305	0.027	0.573
Blacktip	26	0.205	0.749	0.066	0.325
Dusky	1	0.008	0.089	0.008	1.000
Sandbar	30	0.236	0.684	0.061	0.257
Tiger	65	0.512	1.119	0.099	0.194
Nurse	6	0.047	0.213	0.019	0.400
Smooth dogfish	8	0.063	0.484	0.043	0.682
Sand tiger	1	0.008	0.089	0.008	1.000
Atlantic sharpnose	258	2.032	3.593	0.319	0.157
Scalloped hammerhead	10	0.079	0.298	0.026	0.336
Great hammerhead	9	0.071	0.338	0.030	0.422
1996 NMFS Shark Pilot Study (n = 142)					
Bignose	1	0.007	0.084	0.007	1.000
Blacknose	40	0.282	1.020	0.086	0.304
Spinner	5	0.035	0.220	0.018	0.524
Silky	2	0.014	0.118	0.010	0.705
Bull	2	0.014	0.118	0.010	0.705
Blacktip	17	0.120	0.469	0.039	0.328
Dusky	2	0.014	0.118	0.010	0.705
Sandbar	18	0.127	0.410	0.034	0.271
Tiger	10	0.070	0.283	0.024	0.337
Nurse	3	0.021	0.144	0.012	0.573
Smooth dogfish	5	0.035	0.220	0.018	0.524
Sand tiger	2	0.014	0.118	0.010	0.705
Atlantic sharpnose	288	2.028	5.338	0.448	0.221
Scalloped hammerhead	7	0.049	0.217	0.018	0.370
Great hammerhead	6	0.042	0.234	0.020	0.466
Spiny dogfish	16	0.113	0.745	0.062	0.555

1995 and the entire 1996 survey was the NOAA Ship *Oregon II* (R332). Vessel specifications are: 170 ft (51.8 m) length, 34 ft (10.4 m) width, 14 ft (4.3 m) draft when fully fueled, displacement of 952 tons, accommodates 31 (13 scientists).

The research platform for the U.S. east coast 1995 survey was the NOAA Ship *Relentless* (R335). Vessel specifications are: 224 ft (68.3 m) length, 43 ft (13.1 m) width, 15 ft (4.6 m) draft when fully fueled, displacement of 2,300 tons, accommodates 42 (20 scientists).

Oceanographic and Meteorological Data

Oceanographic data were collected with a CTD unit deployed at depth. The CTD was hardwired to a ship's computer for data archival. Data elements included water temperature (Celsius), dissolved oxygen (mg/l), salinity (ppt), fluorometer (chlorophyll, mg/l), transmissivity (turbidity), and depth (m). Dissolved oxygen, salinity, and temperature recorded by the CTD were verified daily by comparison with measurements from an oxygen meter, refractometer, and thermometer. During the Atlantic 1995 survey, only temperature and salinity data were collected due to a CTD malfunction.

Meteorological data were collected hourly and recorded in the ship's weather log and on survey station sheets. Observations included air temperature, barometric pressure, wind speed and direction, and sea state.

Results and Discussion

During 78 survey days, 269 bottom longline and 9 pelagic longline sets were completed. A total of 879 sharks representing 17 species (Table 2) were captured in coastal waters from Brownsville, Tex., to Cape Ann, Mass. (Fig. 2) during the NMFS 1995 and 1996 pilot studies. Twelve of the 22 species classified in the fishery management plan (NOAA, 1993) as large coastal sharks were encountered. Also captured were 3 of 7 species classified as small coastal sharks and 2 other small sharks not classified as small coastals (*Mustelus canis* and *Squalus acanthias*). Of the sharks captured, 66% (330 small coastal sharks and 246 large coastal sharks) were tagged and released.

The Atlantic sharpnose shark, *Rhizoprionodon terraenovae*, was the most commonly encountered species over the geographic range of this study with 546 captures. This species occurred throughout the Gulf of Mexico and eastern seaboard except north of Chesapeake Bay where the spiny dogfish, *Squalus acanthias*, replaced it as the dominant small coastal shark species. The second most abundant species encountered was the tiger shark, *Galeocerdo cuvieri*, with 75 captures from as far west as Texas in the Gulf of Mexico to as far north as the Chesapeake Bay in the western North Atlantic. The blacknose shark, *Carcharhinus acronotus*, another small coastal species, was the third most abundant shark with 58 captures, all from the Gulf of Mexico. The fourth and fifth most abundant species, the sandbar shark, *C. plumbeus*, and the blacktip

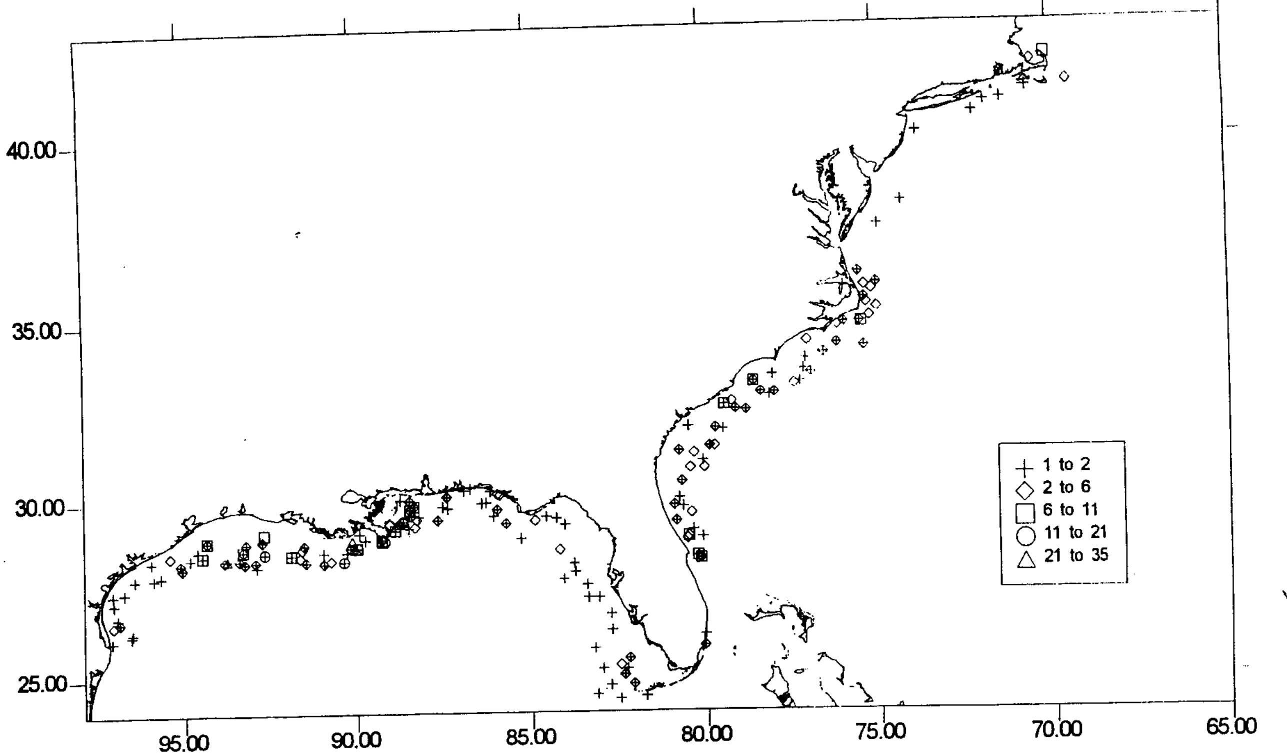

Figure 2. — Locations of shark captures for NMFS shark longline pilot studies, 1995–1996.

shark, *C. limbatus*, are the primary target species of directed shark fisheries. Sandbars were captured throughout the geographic range of this study from just north of Brownsville, Tex. to just south of Cape Ann, Mass. Blacktips were captured in the north-central Gulf of Mexico and in tropical waters of southern Florida, but were not encountered throughout most of their known range along the eastern seaboard.

Most species of sharks were captured during both day and night (Table 3) suggesting that the commercial practice of fishing only at night is not a requirement for catching sharks. It is possible that some species are more vulnerable to capture at night, but significant differences in catch rates are not evident from the relatively small samples. Provided this survey is continued, differences in catch rates with time of day will be detected if such differences exist.

During the pilot studies, 24 incidental non-shark species were captured (Table 4). Banded eels, *Ophichthus rex*, were the most frequently caught incidental species with 44 captures, followed by great barracuda, *Sphyraena barracuda* — 36 captures, roughtail stingray, *Dasyatis centroura* — 25 captures, and red grouper, *Epinephelus morio* — 17 captures. During the 1996 project, one swordfish, *Xiphias gladius*, was captured during an experimental pelagic longline set. Incidental captures comprised 17% of the total captures (1,065) for all surveys combined and incidental captures occurred in most survey areas.

Species Profiles

Small Coastal Sharks

Small coastal sharks comprised 72% of all shark captures. Of 7 small coastal shark species managed under the 1993 shark FMP, 3 species were captured during the 1995 and 1996 surveys.

Blacknose shark, *Carcharhinus acronotus*

Blacknose sharks were captured only in the Gulf of Mexico (58 captures).

Table 3. — Mean shark catch rates by 6-hour time periods during NMFS 1995 and 1996 shark pilot studies.

Species	Day[1] $n = 66$	Dusk $n = 77$	Night $n = 61$	Morning $n = 65$
Blacknose	0.152	0.117	0.262	0.354
Finetooth	0.0	0.0	0.0	0.062
Atlantic sharpnose	1.182	1.675	2.525	2.846
Bignose	0.0	0.013	0.0	0.0
Spinner	0.030	0.039	0.066	0.046
Silky	0.030	0.052	0.0	0.031
Bull	0.045	0.013	0.049	0.015
Blacktip	0.212	0.065	0.131	0.246
Dusky	0.030	0.013	0.0	0.0
Sandbar	0.106	0.130	0.295	0.200
Tiger	0.348	0.195	0.213	0.369
Nurse	0.015	0.039	0.049	0.031
Sand tiger	0.0	0.0	0.033	0.015
Scalloped hammerhead	0.045	0.078	0.033	0.092
Great hammerhead	0.015	0.052	0.098	0.062
Smooth dogfish	0.0	0.0	0.164	0.464
Spiny dogfish	0.030	0.104	0.016	0.077

[1] Day 10am–4pm, Dusk 4pm–10pm, Night 10pm–4am, Morning 4am–10am.

Blacknose sharks were distributed from south of Galveston Bay, Tex., to the Dry Tortugas, Fla., with most captures from the vicinity of the eastern slope of the Mississippi River Delta. Captures occurred in all depth strata but only 2 of the 58 captures were in depths >25 fm. Total lengths ranged from 795 to 1270 mm.

Finetooth shark, *C. isodon*

Finetooth sharks were captured only during the 1995 Gulf of Mexico survey (4 captures), and all captures occurred in the vicinity of the southwest pass of the Mississippi River in the 20–30 fm depth strata. Total lengths ranged from 1,117 to 1,440 mm.

Atlantic sharpnose shark, *Rhizoprinodon terranovae*

Atlantic sharpnose sharks were captured during all surveys (546 captures). Distribution in the Atlantic was from Cape Canaveral, Fla., to Chesapeake Bay, Va. In the Gulf of Mexico, distribution was fairly uniform except from Cape San Blas, Fla., to west of Tampa Bay, Fla., where no captures were recorded. Captures occurred in all depth strata. Total lengths ranged from 439 to 1,200 mm.

Large Coastal Sharks

Large coastal sharks comprised 28% of all sharks captured during the pilot studies. Twelve of the 22 large coastal shark species managed under the 1993 shark FMP were captured.

Bignose shark, *C. altimus*

One bignose shark, a female, was captured during the 1996 Atlantic survey off the New Jersey coast in a depth of 25 fm. The total length was 1,293 mm and weight was 28 kg. This capture is considerably north of the known range (Compagno, 1984). Confirmation of this capture was by subsequent examination of tooth morphology and counts (Hubbell[7]).

Spinner shark, *C. brevipinna*

Spinner sharks were captured only in the Gulf of Mexico (12 captures), and were distributed primarily in the vicinity of the Mississippi River Delta with additional captures south of Destin, Fla. (1) and just north of the Dry Tortugas, Fla. (1). Captures occurred in all depth strata. Total lengths ranged from 850 to 1,720 mm.

Silky shark, *C. falciformis*

Silky sharks were captured only in the Gulf of Mexico (8 captures). They were distributed in two areas: from the U.S.–Mexico border to Galveston Bay, Tex., and additional captures just north of the Dry Tortugas, Fla. Captures occurred in all depth strata. Total lengths ranged from 770 to 2,120 mm.

[7] Hubbel, Gordon. Key Biscayne, Fla. Personal commun.

Table 4. — Incidental catch mean catch rates for NMFS 1995 and 1996 shark pilot studies.

Species	Atlantic 1995 *n* = 45	Atlantic 1996 *n* = 56	Gulf 1995 *n* = 82	Gulf 1996 *n* = 86	Combined (# captured) *n* = 269
Roughtail stingray *Dasyatis centroura*	.133	.196		.093	.093 (25)
Gafftop catfish *Bagre marinus*	.022				.004 (1)
Great barracuda *Sphyraena barracuda*	.200	.018	.134	.174	.134 (36)
Jewfish *Epinephelus itajara*	.022				.004 (1)
Scamp *Mycteroperca phenax*	.022				.004 (1)
Cobia *Rachycentron canadum*	.044	.018	.024		.015 (4)
Clearnose skate *Raja eglanteria*		.054		.058	.030 (8)
Rosette skate *Raja garmani*		.180			.037 (10)
Atlantic cod *Gadus morhua*		.018			.004 (1)
Red Grouper *Epinephelus morio*		.018	.122	.070	.063 (17)
Gag grouper *Mycteroperca microlepis*		.018			.004 (1)
Bluefish *Pomatomus saltatrix*		.125			.026 (7)
Remora *Echeneis naucrates*		.018			.011 (3)
Amberjack *Seriola dumerili*		.018		.012	.007 (2)
Wrymouth *Crytacanthodes maculatus*		.036			.007 (2)
Devil ray *Mobula hypostoma*			.024		.007 (2)
Cownose ray *Rhinoptera bonasus*			.085		.026 (7)
Banded eel *Ophichthus rex*			.280	.244	.164 (44)
Red snapper *Lutjanus campechanus*			.073	.023	.030 (8)
Atlantic bonito *Sarda sarda*			.012		.004 (1)
Cusk eel *Lepophidium* sp.			.024		.007 (2)
Southern stingray *Dasyatis americana*				.012	.004 (1)
Wahoo *Acanthocybium solandri*				.012	.004 (1)
Swordfish *Xiphias gladius*				.012	.044 (1)

Bull shark, *C. leucas*

Bull sharks were captured only in the Gulf of Mexico (8 captures). They were encountered in all depth strata and were captured from south of Galveston Bay, Tex., to south of Mobile Bay, Ala. Total lengths ranged from 1,830 to 2,987 mm.

Blacktip shark, *C. limbatus*

Blacktip sharks were captured in both the Gulf of Mexico and western North Atlantic (43 captures). They were distributed in the Gulf of Mexico from south of Galveston Bay, Tex., to south of Mobile Bay, Ala., and along the western Florida shelf from Naples, Fla., to the Dry Tortugas. In the Atlantic, distribution was along the east Florida shelf from Miami to West Palm Beach. Captures occurred in all depth strata. Total lengths ranged from 880 to 2,000 mm, but specimens with fork lengths less than 1,266 mm occurred only in depths less than 15 fm.

Dusky shark, *C. obscurus*

Dusky sharks were captured off the eastern seaboard and in the Gulf of Mexico (3 captures). The areas of dusky shark captures were east of Corpus Christi, Tex., southwest of the Dry Tortugas, Fla., and east of Charleston, S.C. Captures occurred in the 30–40 fm depth strata. Total lengths ranged from 2,200 mm to 2,980 mm.

Sandbar shark, *C. plumbeus*

Sandbar sharks, captured during all Atlantic and Gulf of Mexico surveys (48 captures), were distributed in the Atlantic east of Miami to Cape Canaveral, Fla., from the Georgia–South Carolina area to Cape Hatteras, east of the Delmarva peninsula and south of the eastern end of Long Island, N.Y. In the Gulf of Mexico, distribution was fairly uniform, and captures occurred in all depth strata. Total lengths ranged from 1,060 to 2,437 mm. In the Atlantic, all specimens with total lengths <1,649 mm (converted by FL = (0.8175)TL + 2.5675 (Kohler et al., 1996)) were captured in depths <15 fm.

Tiger shark, *Galeocerdo cuvieri*

Tiger sharks were captured during all Atlantic and Gulf of Mexico surveys (75 captures), with total lengths ranging from 760 to 3,356 mm and captures occurring in all depth strata. In the Atlantic, tiger sharks were distributed from north Florida to Cape Hatteras with an additional capture close to Miami, Fla. In the Gulf of Mexico, distribution was from the eastern slope of the Mississippi River Delta to west of Tampa Bay, Fla., with additional captures between Galveston Bay, Tex., to south of western Louisiana.

Nurse shark, *Ginglymostoma cirratum*

Nurse sharks were captured during the Atlantic 1995 and Gulf of Mexico 1995 and 1996 surveys (9 captures). Distribution in the Atlantic was from east of New Smyrna Beach, Fla., to Charleston, S.C., and in the Gulf of Mexico from south of Pensacola, Fla., and west of Clearwater, Fla., to the Dry Tortugas, Fla. Captures in the Atlantic occurred in the 10–20 fm depth strata; in the Gulf of Mexico captures occurred in all depth strata. Total lengths ranged from 1,820 to 3,040 mm.

Sand tiger shark, *Odontapspis taurus*

Sand tiger sharks were captured during the Atlantic 1995 and 1996 and the Gulf of Mexico 1996 surveys (3 captures). Distribution in the Atlantic was between Cape Hatteras, N.C., and Chesapeake Bay, Va., and the Gulf of Mexico capture was from south of Destin, Fla. Captures occurred in the 10–20 fm and 30–40 fm depth strata. Total lengths ranged from 1,800 to 2,199 mm.

Scalloped hammerhead shark, *Sphyrna lewini*

Scalloped hammerhead sharks were captured during all surveys (17 captures). Distribution in the Atlantic was off Cape Canaveral, Fla., and Cape Fear, N.C., and in the Gulf of Mexico distribution was from south of Galveston Bay, Tex., to south of Mobile Bay, Ala., off Cape San Blas, Fla., and south of the lower Florida Keys. Captures occurred in all depth strata, and total lengths ranged from 1,010 to 2,882 mm.

Great hammerhead shark, *S. mokarran*

Great hammerhead sharks were captured during all surveys (15 captures). Distribution in the Atlantic was from Cape Canaveral, Fla., to Cape Hatteras, N.C., and in the Gulf of Mexico from south of Galveston Bay, Tex., to south of western Louisiana, south of Pensacola, Fla., to south of Panama City, Fla., and just north of the Dry Tortugas, Fla. Captures occurred in depth strata less than 30 fm, and total lengths ranged from 1,974 to 3,048 mm.

Other Sharks

Smooth dogfish, *Mustelus canis*

Smooth dogfish were captured during the Atlantic 1996 and Gulf of Mexico 1995 and 1996 surveys (13 captures). Distribution in the Atlantic was east of New Jersey and south of Martha's Vineyard, Mass., and in the Gulf of Mexico from south of western Louisiana to south of Cape San Blas, Fla. Captures in the Atlantic occurred in the 10–20 fm depth strata, and in the Gulf of Mexico in the 30–40 fm depth strata. Total lengths ranged from 560 to 1,280 mm.

Spiny dogfish, *Squalus acanthias*

Spiny dogfish were only captured during the Atlantic 1996 survey (16 captures). They were distributed from the east tip of Long Island, N.Y., southeast and north of Cape Cod, Mass., and within Cape Cod Bay, Mass. Captures occurred in all depth strata, and total lengths ranged from 600 to 970 mm.

Species Profiles for Sharks Not Captured

The lack of captures for some species can be explained by considering the habitats and distributions of each species and by comparing the NMFS pilot study longline data with data summarized by Branstetter[8] and NMFS SEAMAP bottom trawling survey data (1972 to 1996). The Branstetter[8] commercial shark longline fishery catch summaries reports 7,836 large coastal shark captures and 3,037 small coastal shark captures from specific areas in the eastern Gulf of Mexico and the U.S. Atlantic coast from Florida north to Cape Hatteras, N.C. (1994 and 1995). The NMFS SEAMAP surveys (Table 5) represent Gulf of Mexico effort from 3,712 bottom trawling tows (Texas-Mexico border to Alabama).

Small Coastal Sharks

Smalltail shark, *C. porosus*

Smalltail sharks were not captured but are distributed from inshore estuaries and coastal areas to 18 fm (Compagno, 1984). NMFS SEAMAP trawl data reports 2 smalltail shark captures, which verifies their presence in the survey area. Branstetter[8] reported no captures of this species from commercial shark vessels, which leads to speculation that either the species is relatively rare, longline gear may not efficiently sample this species, or that survey sampling depths which were deeper than 10 fm may be outside of the primary range for smalltail sharks.

Caribbean sharpnose, *R. porosus*

The Caribbean sharpnose is the only small coastal shark that occurs primarily outside of the survey area (Com-

[8] Branstetter, S. 1996. Characterization and comparisons of the directed commercial shark fishery in the eastern Gulf of Mexico and off North Carolina through an observer program. Gulf and South Atlantic Fisheries Development Foundation, Inc. Marfin award NA57FF0286, Final rep. 41 p.

pagno, 1984). Based on the known Caribbean distribution of this species, captures were not expected during the pilot studies. Branstetter[8] and NMFS SEAMAP trawl surveys did not report any Caribbean sharpnose captures.

Bonnethead shark, *S. tiburo*

Bonnethead sharks were not captured but are distributed from inshore estuaries and coastal areas to 44 fm (Compagno, 1984). Based on NMFS SEAMAP trawl data, bonnetheads are the second most commonly caught sharks with 830 captures; Branstetter[8] reports 16 bonnethead captures. The lack of bonnethead captures may be due to the low number of nearshore sampling sites occupied during these pilot surveys or inefficiency of longline gear for capturing this species.

Angel shark, *Squatina dumerili*

Angel sharks are coastal residents to depths of 760 fm (Compagno, 1984). They were lacking from the longline catches, and apparently are rare in commercial catches as well (Branstetter,[8] 0 captures), although their distribution is known to be within survey depths. A total of 59 angel sharks were captured during NMFS SEAMAP trawl surveys, so the species is present within the survey area. Fisheries for angel shark species in various parts of the world exist, but these fisheries generally employ gill nets or bottom trawls (Bonfil, 1994). Gear selectivity is probably responsible for the lack of angel shark captures in these longline surveys.

Large Coastal Sharks

For the large coastal shark species not captured, the narrowtooth, *C. brachyurus*; bigeye sand tiger, *Odontaspsis noronhai*; reef, *C. perezi*; and galapagos sharks, *C. galapagensis*, are generally distributed outside of the survey areas or are rare. Whale sharks, *Rhincodon typus*; and basking sharks, *Cetorhinus maximus*, are filter feeders and, except for accidental entanglement, would not be a component of longline catches.

White shark, *Carcharodon carcharias*

White sharks are distributed within the survey area (Compagno, 1984), but none were captured. Branstetter[8] reports 2 white shark captures; there were no white shark captures reported during NMFS SEAMAP trawl surveys. The lack of white shark captures may be due to low sampling densities, or the species may be uncommon in the depths and temperatures (Compagno, 1984) of survey sites.

Table 5. — NMFS/SEAMAP trawl catch summary for sharks captured during Gulf of Mexico suveys, 1972–96; catches adjusted to a 60-minute tow.

Species	Captures	Weight (kg)	Frequency of occurence	% frequency of occurence
Atlantic sharpnose	4,197	5,199	732	12.3
Bonnethead	830	1,519	201	3.4
Smooth dogfish, *Mustelus canis*	134	344	59	1.0
Florida smoothhound, *Mustelus norrisi*	121	291	36	0.6
Carcharhinidae	85	99	12	0.2
Blacknose	81	226	29	0.5
Angel shark	59	159	23	0.4
Carcharhinus sp.	56	109	13	0.2
Silky	44	68	8	0.1
Blacktip	35	137	11	0.2
Scalloped hammerhead	13	20	5	0.1
Great hammerhead	9	219	4	0.1
Mustelus sp.	8	21	4	0.1
Sphyrna sp.	7	2	3	0.1
Bull	4	182	2	0.0
Chain dogfish, *Scyliorhinus retifer*	3	0.1	2	0.0
Nurse	3	3	2	0.0
Spinner	2	69	1	0.0
Dusky	2	4	1	0.0
Smalltail	2	8	1	0.0
Sphyrnidae	2	9	1	0.0

Night shark, *Carcharhinus signatus*

No night sharks were encountered during these surveys although their distribution can be from 14 fm (Bigelow and Schroeder, 1948) to 328 fm (Raschi et al., 1982). Raschi et al. (1982) summarized the general distribution as between 109 fm to 328 fm. Survey depths sampled may be outside of the primary depth range for night sharks, and the species may be relatively rare in shallower waters. Branstetter[8] reports 2 night shark captures; there were no night shark captures reported during NMFS SEAMAP trawl surveys.

Lemon shark, *Negaprion brevirostris*

Lemon sharks were not captured even though they are distributed within depths less than 50 fm (Compagno, 1984). Castro (1983) refers to them as a "common coastal shark" and Compagno (1984) indicates these sharks occur in a variety of inshore and coastal habitats. The lack of survey sites inside of 10 fm may be the primary reason for no catch of this species. Branstetter[8] reports 78 lemon shark captures with 91% of those captures from the west Florida shelf. The shelf in this area of the Gulf of Mexico is very broad and NMFS survey sites were generally well offshore. No lemon shark captures were reported by NMFS SEAMAP trawl surveys.

Smooth hammerhead shark, *Sphyrna zygaena*

Distribution of the smooth hammerhead shark is coastal to offshore (Compagno, 1984). Branstetter[8] reported 5 smooth hammerhead captures; there were no smooth hammerhead captures reported during NMFS SEAMAP trawl surveys. Lack of smooth hammerhead captures may be due to low sampling densities or the species may simply be uncommon in the depths sampled.

Environmental Data

Dissolved oxygen levels at survey sites ranged from 0.0 to 8.5 mg/l; the CTD dissolved oxygen meter is accurate to within 0.5 mg/l dissolved oxygen and levels were compared daily with a YSI oxygen meter. Dissolved oxygen levels associated with shark captures ranged from 0.0 to 7.8 mg/l (Table 6). The lowest oxygen levels were generally from maximum sampling depths near sea bottom. Recent laboratory experiments by Parsons and Carlson[9] indicate oxygen levels below

[9] Parsons, G., and J. Carlson. Behavioral and physiological responses to hypoxia in the bonnethead shark, *Sphyrna tiburo*. Dep. Biol., Univ. Miss., Oxford. Unpul. manuscr., 30 p.

Table 6.— Dissolved oxygen, temperature and salinity values associated with shark captures during NMFS 1995–96 shark longline pilot studies.

Species	Dissolved oxygen (mg/l)	Temperature (°C)	Salinity (‰)
Blacknose	3.0–6.7	20.0–30.0	32.8–36.8
Finetooth	3.9	25.8	34.9
Atlantic sharpnose	0.2–7.5	18.0–30.0	32.4–36.4
Bignose	7.5	8.0	32.3
Spinner	3.0–7.3	20.0–26.0	34.9–35.1
Silky	4.3–6.6	18.8–26.2	35.9–36.4
Bull	3.1–5.9	22.5–30.0	33.6–36.0
Blacktip	0.0–7.0	17.5–30.0	27.0–36.0
Dusky	4.9–5.5	21.0–25.0	36.3–36.4
Sandbar	3.4–6.8	10.5–28.5	31.6–36.4
Tiger	3.6–6.4	17.0–29.0	32.4–36.6
Nurse	5.3–7.4	22.5–28.5	35.4–36.4
Sand tiger	3.9–6.2	18.0–24.0	32.0–36.0
Scalloped hammerhead	2.5–7.4	7.5–27.5	32.4–36.4
Great hammerhead	3.2–6.7	13.5–28.5	34.3–36.3
Smooth dogfish	3.5–6.5	15.0–22.5	31.5–36.0
Spiny dogfish	6.5–7.8	9.6–12.0	31.5–32.1

3.5 mg/l create physiological stress for bonnethead sharks (increased mouth gape and swimming speed). Renaud (1986) considered hypoxia (<2.0 mg/l) to be a barrier affecting distribution of finfish and crustaceans off southern Louisiana. There were 22 longline sites in hypoxic areas with oxygen concentrations ≤3.5 mg/l. The mean shark catch rate from these sites was 4.9 shark captures/100 hook hours (4.0/100 hook hours for small coastals and 0.9/100 hook hours for large coastals) with eight shark species captured: Atlantic sharpnose, blacknose, smooth dogfish, spinner, blacktip, bull scalloped hammerhead, and great hammerhead. Shark captures in hypoxic areas may be attributable to gear fishing above near-bottom hypoxic zones or from attraction to the baited longline.

Bottom temperatures ranged from 6.8°C to 31°C with sharks captured at most temperatures within this range (Table 6). Bottom temperatures in the Gulf of Mexico and along the eastern seaboard south of Cape Hatteras, N.C., were generally between 18 and 31°C; bottom temperatures north of Cape Hatteras ranged from 6.8 to 18°C. Atlantic sharpnose, blacknose, blacktip, and bull sharks were the only sharks captured from longline sets with bottom temperatures above 30°C; a bignose shark, scalloped hammerheads, and spiny dogfish were the only sharks captured from longline sets with bottom temperatures below 10°C.

Station salinities ranged from 26.7 to 36.8‰ and sharks were captured throughout this range (Table 6). Blacktips, sandbars, smooth dogfish, and spiny dogfish were the only sharks captured from longline sets with bottom salinities less than 32 ‰; blacktip sharks were the only sharks captured from longline sets with salinities less than 30‰.

Precision of Estimates

These surveys demonstrated that populations of many shark species can be sampled using longline gear and random sampling design, but the fundamental question in terms of fishery management is whether these surveys can be used for stock assessments. From a management perspective, the primary objective was to develop a method for tracking year-to-year variations in abundance for as many species as practical, therefore, the surveys were designed to satisfy the following five principles: stockwide survey, synopticity, well defined sampling universe, controlling biases, and useful precision.

The stockwide survey principle can be difficult to achieve with large and active species; for multispecies complexes it is usually not feasible to cover the complete range of all species. If the survey area is too small compared to the full range of a stock, year-to-year variation may be dominated by local immigrations and emigrations, and thus of little use for assessment. The surveys were designed to cover the 10–40 fm depth range over as large a geographical area as possible given a general distributional knowledge of most of the species encountered. A survey along the Mexico coast of the Gulf of Mexico was planned for 1997 to extend stockwide coverage for Gulf of Mexico species and those species that possibly migrate between the Gulf of Mexico and western North Atlantic.

Synopticity, the idea of a survey as a snapshot in time, is probably not a restrictive issue in the current survey development. Populations and distributions of adult sharks are probably not changing rapidly over the course of these surveys. This could be a problem if surveys were conducted during spring and fall when distributions are likely to change considerably.

Defining the sampling universe will not be complex once decisions regarding species range distributions have been made. Controlling bias is related to options for survey operations and bias for this study can be defined as anything that might produce a catch per unit effort (CPUE) not proportional to abundance.

Probably the most useful measure of precision is the coefficient of variation of the mean (CV), defined as the standard error of the mean over the mean. The CV of the mean expresses uncertainty as a potential percentage change of a population. For each shark species encountered, the total number of captures, the mean CPUE (catch/100 hook hours), standard deviation of the mean, the standard error of the mean, and the CV of the mean are presented by survey year in Table 2.

For species that have been subjected to heavy fishing pressure for at least 2 decades and that must be considered depleted over parts, if not all, of their range, CV's of less than 0.40 may fall within reasonable expectations. If that is an acceptable criterion, these surveys are providing estimates with adequate precision for Atlantic sharpnose, tiger, sandbar, blacktip, blacknose, and scalloped hammerhead sharks. Of these species, the sandbar and blacktip sharks are of particular management concern because they are the primary targets of the U.S. commercial shark fishery.

Conclusions

After 2 years of this pilot study, it is possible to draw some conclusions regarding the efficacy of this approach for determining distribution and abundance of coastal shark species. The pilot study shark catches, summarized across years from offshore Brownsville, Tex. to Cape Ann, Mass., were very close to those reported by Branstetter[8] for commercial activities on major fishing grounds in the eastern Gulf of Mexico and western North Atlantic. This suggests that a 1-mile, 100-hook bottom longline fished for 1 hour at randomly selected locations produces similar catch rates to what might be expected in a commercial fishing operation.

Sharks encountered during this study were of similar size to those reported from commercial landings (Branstetter[8]). This implies that the surveys were sampling the same age and size groups of sharks targeted by commercial operations. This is an important consideration when attempting to compare this survey information with observer data from commercial vessels. It is also of importance when evaluating shark distributions and abundance since the range of commercially important species often extends well beyond geographic boundaries of primary fishing grounds. By determining catch rates and landings in heavily fished areas, it may be possible to develop minimum estimates for areas outside the fishing grounds where fishing mortality rates are lower. Continuation of observer programs in conjunction with fishery independent surveys should provide a good means of monitoring the status of populations over their entire ranges, and not just mortalities for primary fishing grounds.

Size ranges for each shark species encountered during the pilot studies included minimum sizes at maturity for males or females (Table 7). This indicates that a portion of the potential spawning stock of most shark species was sampled. Continued development of time series will be useful for monitoring changes in spawning stock complexity (number, sex ratios, and distribution).

Due to small sample sizes for most of the shark species encountered, any differences in species composition and CPUE by depth are not detectable. However, of the commonly encountered shark species (>10 captures), there was little change for species composition and CPUE values over the 3 sampling depth strata. This is probably because the depth distribution range of most coastal species is more extensive than the 10–40 fm depth range of the surveys.

Examination of the CV of the mean by species suggests the survey provides reasonably precise estimates for 6 species of sharks. For the remainder of shark species encountered, CV's indicated very imprecise estimates. In addition, CV's for any species of interest can be improved by altering the sampling design to increase sampling in areas or depths where target species are most abundant.

Table 7. — Genus and species, number of captures (No.) and total length (mm) size ranges for sharks encountered during NMFS 1995 and 1996 pilot studies and minimum sizes for males and females.

Species	No.	Total length size range (mm)	Minimum total length maturity for males and females
Blacknose	58	795–1270	Males 970 mm, Females 1030 mm Compagno (1984)
Finetooth	4	1117–1440	Males 1300 mm, Females 1350 mm Castro (1993)
Atlantic sharpnose	546	439–1200	Males 800 mm, Females 850 mm Parsons (1985)
Bignose	1	1293	Males 2160 mm, Females 2260 mm Compagno (1984)
Spinner	12	850–1720	Males 1700 mm, Females 1800 mm Branstetter (1987a)
Silky	4	700–2120	Males 2100 mm, Females 2200 mm Branstetter (1987b)
Bull	8	1830–2987	Males 2100 mm, Females 2250 mm Branstetter (1987)
Blacktip	43	880–2000	Males 1300 mm, Females 1550 mm Branstetter (1987a)
Dusky	3	2200–2980	Males 2759 mm, Females 2798 mm Natanson (1995)[1]
Sandbar	48	1060–2437	Males 1800 mm, Females 1803 mm Springer (1960)[2]
Tiger	75	760–3356	Males 2900 mm, Females 2970 mm Clark and von Schmidt (1965)
Nurse	9	1820–3040	Males 2250 mm, Females 2300 mm Compagno (1984)
Sand tiger	3	1800–2199	Males 2200 mm, Females 2200 mm Compagno (1984)
Scalloped hammerhead	17	1010–2882	Males 1800 mm, Females 2500 mm Branstetter (1987b)
Great hammerhead	15	1974–3048	Males 2340 mm, Females 2500 mm Compagno (1984)
Smooth dogfish	13	560–1280	Males 820 mm, Females 900 mm Compagno (1984)
Spiny dogfish	16	600–970	Males 590 mm, Females 700 mm Compagno (1984)

[1] Measurements converted from fork length to total length, TL = FL/0.8396–0.9947 (Kohler et al., 1996).
[2] Measurements converted from inches to mm.

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