An Index of Abundance for Coastal Species of Juvenile Sharks from the Northeast Gulf of Mexico

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Introduction

In 1993, a Fishery Management Plan For Sharks (FMP) (NMFS, 1993) reported the abundance of many species of sharks, particularly large coastal species, could have declined by up to 75% from the 1970's to mid 1980's. To improve management and recovery of shark stocks, the FMP stressed the need for better estimates on the assessment and monitoring of shark populations. Prior to 1993, most estimators of shark stocks were derived using fishery-dependent indices which generally lacked a standardized statistical sampling design. The validity of an abundance estimator (i.e. indices of abundance) depends on its accuracy and precision, and its robustness (the strength of its relationship with recruitment or stock size). Indices of shark abundance are currently used in production model analysis integrated using Bayesian statistical techniques (NMFS[1]).

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ABSTRACT—A fishery-independent assessment of juvenile coastal shark populations in U.S. waters of the northeast Gulf of Mexico was conducted using two methods: gillnets and longlines. Surveys were conducted monthly during April–October in two fixed sampling areas from 1996 to 1998. The Atlantic sharpnose shark, Rhizoprionodon terraenovae, *and the blacktip shark,* Carcharhinus limbatus, *were the most common species captured with either longlines or gillnets. An additional 14 shark species were captured, and juvenile indices of abundance were developed for 8 species with gillnets and 6 species of sharks with longlines. Trends in catch-per- unit-effort were found to vary depending on species. Length-frequency information revealed that the majority of sharks captured were juveniles. Given the direct relationship between stock and recruitment for sharks, continued monitoring of juvenile abundance will aid in determining the strength of the parental stock size and for predicting future population strength.*

Fishery-independent estimates of relative abundance are presently limited but can be the best estimator of shark stocks (NMFS[1,2,3]). Currently, only three surveys exist for monitoring shark relative abundance:

1) Musick et al. (1993) reported on a 17-year time series of abundance for sandbar, *Carcharhinus plumbeus,* and dusky, *C. obscurus*, shark from areas adjacent to the middle U.S. Atlantic coast.
2) Grace and Henwood (1997) performed pilot studies and have been conducting an assessment of the distribution and abundance of coastal sharks in the Gulf of Mexico and western North Atlantic since 1995.
3) National Marine Fisheries Service (NMFS), Narragansett Laboratory has executed shark longline surveys between Miami, Fla. and southern New England for 1986, 1989, 1991, and 1998 (Casey[4,5,6]; Natanson[7]). However, most of these surveys are generally conducted in deeper waters (>10 m) where adult sharks mostly congregate. Neonate and juvenile sharks are commonly found in coastal nursery areas (<10 m deep) where they feed and avoid predation (Branstetter, 1990) during summer months.

With the exception of Musick et al.[8] and Merson and Pratt's[9] work on juvenile sandbar sharks along the U.S. east coast, little data exists on juvenile shark stock size and recruitment to the adult portion of the population. Unlike most teleost species, the relationship between stock size and recruitment is direct, owing to the reproductive strategy of low fecundity combined with few, fully formed offspring (Holden,

[1] NMFS. 1998. Report on the 1998 shark evaluation annual workshop. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southeast Fish. Sci. Cent., 3500 Delwood Beach Rd., Panama City, Fla., 109 p.

[2] NMFS. 1996. Report on the 1996 shark evaluation workshop. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southeast Fish. Sci. Cent., 75 Virginia Beach Dr., Miami, FL 33149, 47 p.

[3] NMFS. 1994. Report on the 1994 shark evaluation annual workshop. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southeast Fish. Sci. Cent., 75 Virginia Beach Dr., Miami, FL 33149, 23 p.

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

[5] Casey, J. Cruise results for FRV Delaware II (89-03), survey of apex predators-sharks. NMFS Narragansett Laboratory cruise report, 9 p.

[6] Casey, J. Cruise results for FRV Delaware II (91-06), survey of apex predators-sharks. NMFS Narragansett Laboratory cruise report, 12 p.

[7] Natanson, L. Cruise results for NOAA FRV Delaware II, Cruise 98-06 (I-II), survey of apex predators-sharks. NMFS Narragansett Laboratory cruise report, 12 p.

[8] Musick, J. A., J. Gelsleichter, R. D. Grubbs, and K. Goldman. 1998. A delineation of shark nursery grounds in Chesapeake Bay and assessment of abundance of shark stocks. 1998 Shark Evaluation Workshop Document SB-IV-13. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southeast Fish. Sci. Cent., 3500 Delwood Beach Rd., Panama City, Fla., 56 p.

[9] Merson , R. R., and H. L. Pratt. 1998. Nursery and pupping grounds of the sandbar shark, Carcharhinus plumbeus, in Delaware Bay. 1998 Shark Evaluation Workshop Document SB-IV- 24. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southeast Fish. Sci. Cent., 3500 Delwood Beach Rd., Panama City, Fla., 18 p.

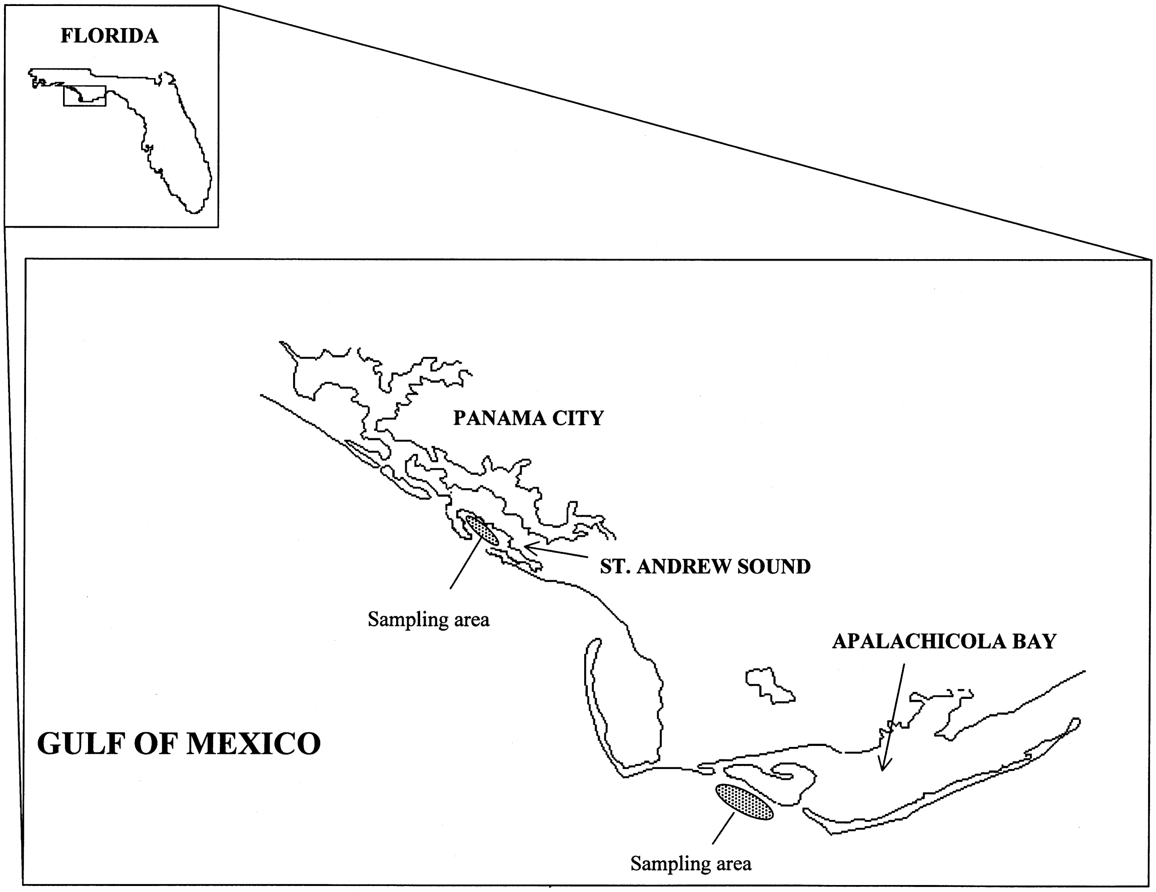

Figure 1.—Location of study site near lat. 30°00'N and long. 85°35'W. Sampling areas are represented by scattered dots.

1977). Quantitative estimates of juvenile abundance can provide promising alternatives to traditional hindcasting models and could improve the ability to assess current and future shark stock size and strength. Herein, we report on a 3-year fishery independent assessment of juvenile coastal shark populations in U.S. waters of the northeastern Gulf of Mexico derived using two methods.

Materials and Methods

Study area

Two regions were established as fixed sampling areas in the northeastern Gulf of Mexico (Fig. 1). The criteria for establishing these areas were based on a priori shark abundance survey information (Trent et al.[10]) and depth strata. The depth strata were between 1–5 m and 5–10 m.

The first area (shallow stratum) is located in St. Andrew Sound. This area is a small semi-enclosed marine lagoon with expanses of submerged vegetation, *Thalassia* spp. and *Halodule* spp. It is about 14.5 km long and 0.2–2.0 km wide and has mean water depths of 3–5 m. Salinity ranges from 25–36 ‰ and tidal amplitude averages 0.42 m. The sound exchanges water with the Gulf of Mexico through passes about 0.5–2.0 km wide.

The second area (deep stratum) is located off St. Vincent Island at the southwest end of the Apalachicola Bay system. This area is about 1–3 km south of St. Vincent Island in the Gulf of Mexico where water depths average 5–10 m. The bay system surrounding this area is largely a line of barrier islands fronting the intersection of the Apalachicola delta and is the only bay system in Florida in which a large river system drains. As a result of river discharge, there is little submerged vegetation due to high turbidity. Salinity fluctuates from 15 to 35 ‰ and tidal fluctuation averages 0.66 m.

[10] Trent, L., S. Gunter, J. K. Carlson, and B. Heinisch. 1998. Relative abundance and size of juvenile and small adult sharks in St. Andrew Sound in northwest Florida. 1998 Shark Evaluation Workshop Document SB-IV-15. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southeast Fish. Sci. Cent., 3500 Delwood Beach Rd., Panama City, Fla., 56 p.

Sampling Gear and Survey Design

Gillnets

A 186 m long gill net consisting of panels of six different mesh sizes was utilized for sampling. Stretched mesh sizes (SM) ranged from 8.9 cm (3.5") to 14.0 cm (5.5") in steps of 1.27 cm (0.5"), with an additional size of 20.3 cm (8.0"). Panel depths when fishing were 3.1 m. Webbing for all panels, except for 20.3 cm, was of clear monofilament, double-knotted and double-selvaged. The 20.3 cm SM webbing was made of #28 multifilament nylon, single-knotted, and double-selvaged. When set, the nets were anchored at both ends.

Longlines

The longline was constructed of a mainline made of two 152 m lengths of 425.8 kg test monofilament line. A 15.2 m length of 0.79 cm diameter braided polypropylene line connected each 152 m length, and the entire line when fished was 319.2 m long. Polyethylene floats made of 1.5 m lengths of 136 kg test monofilament line with a snap were attached to the mainline every 30.4 m. A standard longline consisted of 10–20 gangions placed at 15.2 m intervals along the mainline. Gangions were 0.9 m long and composed of snaps, aluminum sleeves, hooks (Mustad[11] #12/0, no 2888), and monofilament lines (136-kg test). Bait was either menhaden, *Brevoortia* spp., or Atlantic mackerel, *Scomber scombrus*. The mainline, when set, was tethered to an anchor on each end with a 30.4 m, 0.79 cm polypropylene rope between the anchor and the end of the mainline. A buoy (3.6 m aluminum pole with 1.8-kg weight and 50.8 cm poly float), with a strobe light and flag extended 2.4 m above the float, was attached at each end of the mainline.

Survey Design

In both areas, surveys were conducted monthly from April through October. For each survey period, the sampling gear was randomly set within each area in a station designated on Loran C coordinates. Gillnets were checked and cleared of catch, or pulled and reset every 1.0–2.0 h. Longline soak times ranged from 1.0–1.5 h. Following each soak period, the longline was checked and all gangions that had caught sharks, been broken or damaged, or had damaged or lost baits, were removed from the mainline and a fresh-baited gangion attached. Sharks captured using either method were measured to the nearest cm for body lengths (precaudal, fork, total, and stretch total length) and data for sex and life history stage (neonate, young-of-the-year, juvenile, adult) were recorded. Sharks in poor condition were sacrificed for life history studies and those in good condition were tagged with a nylon-head dart tag and released.

Environmental data were collected prior to sampling. Mid-water temperature (°C), and dissolved oxygen (mg l^{-1}) was measured with a YSI Model 55 oxygen meter, and light transmission (cm) was determined using a secci disk. Surface salinity (‰) was measured with a refractometer.

Catch Per Unit of Effort

The shark abundance index (CPUE yr^{-1}) is calculated as the arithmetic mean catch per unit of effort of combined samples within all months and areas sampled for each year. Adult sharks were removed from the analysis based on size at maturity information (Table 1) and maturity state assessed in the field. For gillnets, a CPUE value was defined as the mean number of sharks caught per 186 m long gillnet per hour. For longlines, CPUE was standardized to 10 hooks and defined as the mean number of sharks per 10 hook-hours.

Table 1.—Mean sizes of sharks captured using gillnets and longlines.

Species	Total length (cm) Mean size captured[1]	Size range captured	Size at maturity[2]	Reference
Atlantic sharpnose	70.3 (±17.4)	32–111	80 (M) 85 (F)	Parsons (1983)
Blacknose	79.5 (±21.7)	46–132	103 (M) 110 (F)	Clark and von Schmidt (1965) Carlson et al. (1999)
Blacktip	96.1 (±19.6)	50–150	120–145 (M) 155 (F)	Killam and Parsons (1989) Castro (1996)
Bonnethead	73.7 (±15.8)	44–121	80 (M) 80–90 (F)	Parsons (1993) Carlson and Parsons (1997)
Finetooth	98.0 (±19.3)	54–140	130 (M) 135 (F)	Castro (1993)
Sandbar	91.0 (±20.3)	58–160	170 (M) 180 (F)	Sminkey and Musick (1995)
Scalloped hammerhead	61.7 (±15.9)	38–153	180 (M) 250 (F)	Branstetter (1987b)
Spinner	83.8 (±17.8)	53–134	170 (M) 180 (F)	Branstetter (1987a)

[1] Numbers in parentheses are ± 1 standard deviation.
[2] M=male and F=female. Size at maturity was taken from the most recent information in the literature.

Results and Discussion

A total of 14 species of sharks were collected with gillnets and longlines of which eight and six species, respectively, were captured consistently. Data from species consistently caught were used to generate abundance indices. Within each respective management group, the Atlantic sharpnose shark, *Rhizoprionodon terraenovae*, a member of the small coastal management group, was most often captured, and the blacktip shark, *Carcharhinus limbatus*, was the species captured most often in the large coastal management group, using either longlines or gillnets (Table 2). The bonnethead shark, *Sphyrna tiburo*, was the species captured second most often in the small coastal group and overall was the third most encountered species. The remaining species captured in decreasing abundance were the finetooth shark, *C. isodon*; spinner shark, *C. brevipinna*; scalloped hammerhead shark, *S. lewini*; blacknose shark, *C. acronotus;* and sandbar shark, *C. plumbeus*. Other species caught but not consistently captured were Florida smoothhound, *Mustelus norrisi*; bull shark, *C. leucas*; nurse shark, *Ginglymostoma cirratum*; lemon shark, *Negaprion brevirostris*; tiger shark, *Galeocerdo cuvieri;* and great hammerhead shark, *S. mokarran*.

CPUE trends varied by species. Declines in CPUE were noted for Atlantic sharpnose, blacknose, and bonnethead using gillnets (Fig. 2) and for Atlantic sharpnose, finetooth, and spinner sharks for longlines (Fig. 3).

[11] Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

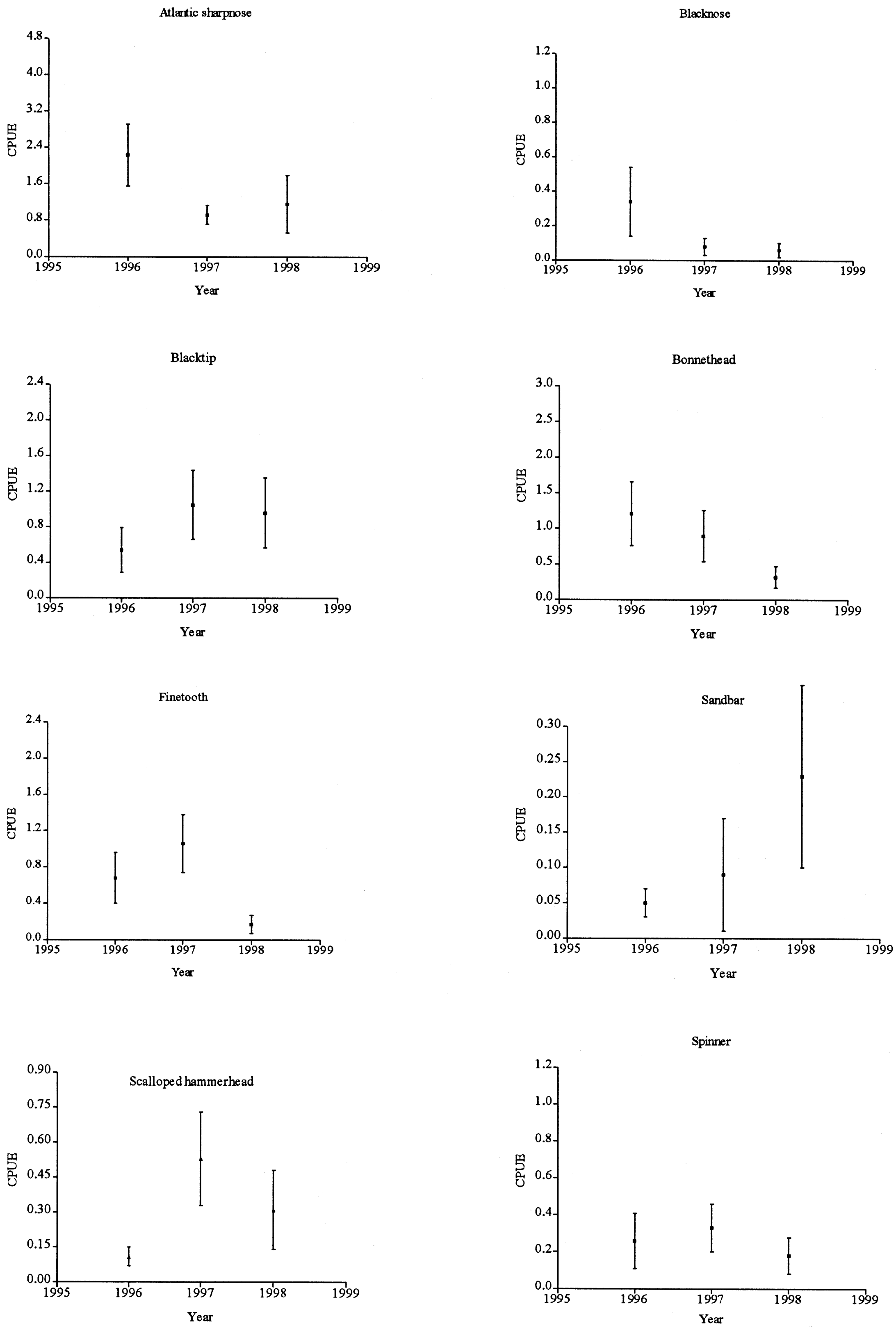

Figure 2.—(Caption on facing page).

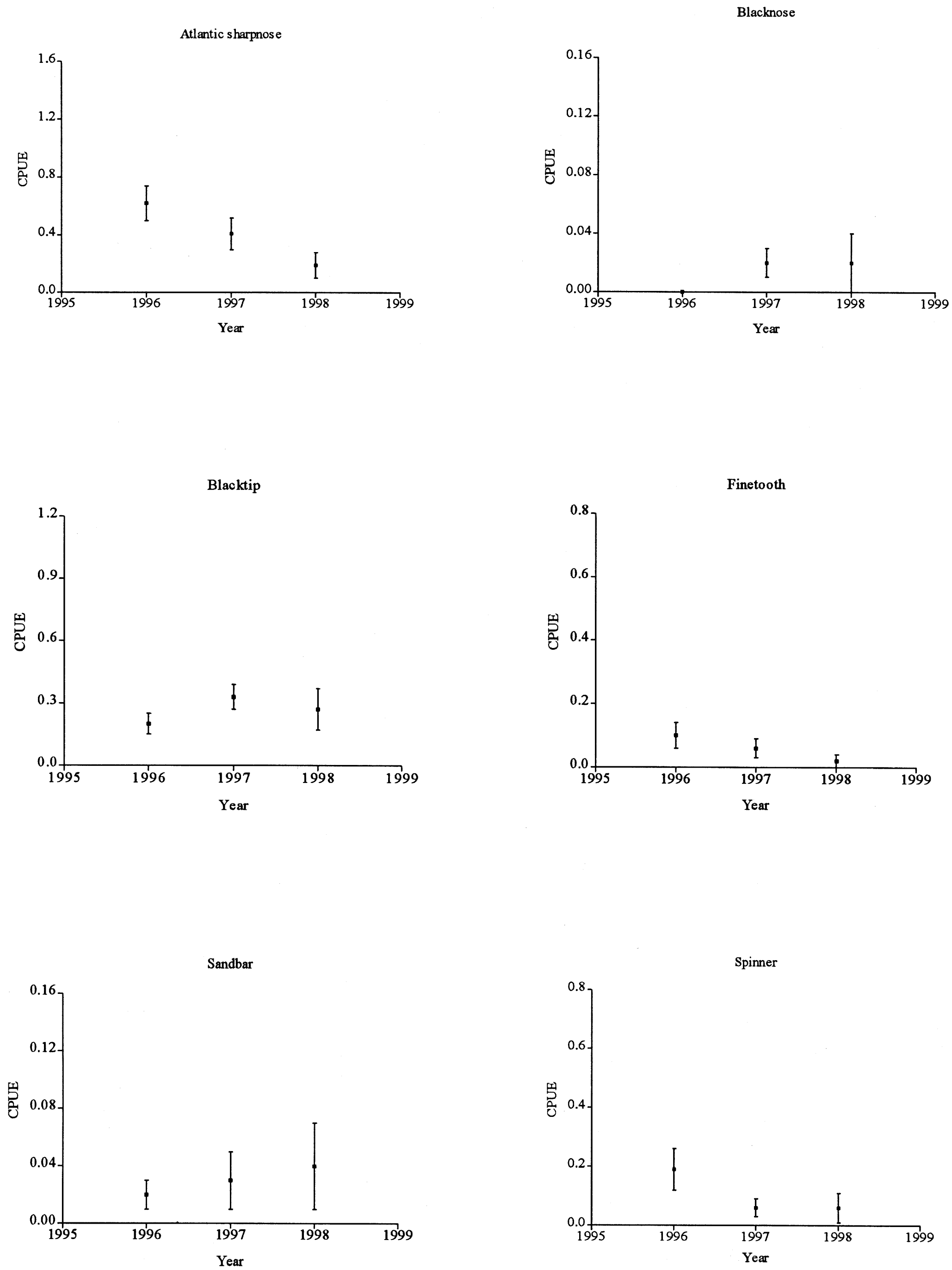

Figure 3.—Catch-per-unit-effort by species for juvenile sharks caught on longline, 1996–98. Vertical bars indicate standard errors of the mean. Adult sharks were removed from overall catch for generation of juvenile indices of abundance.

Figure 2.—On facing page: Catch-per-unit-effort by species for juvenile sharks caught in gillnets, 1996–98. Vertical bars indicate standard errors of the mean. Adult sharks were removed from overall catch for generation of juvenile indices of abundance.

Increases in CPUE were found for sandbar sharks for gillnets. Species with a relatively stable or no clear trend in CPUE include blacktip shark for both methods, blacknose shark using longlines, and finetooth shark and spinner sharks caught using gillnets. Because this survey is relatively new, the small number of values for the independent variable (i.e. 3 years) precluded fitting regression models to each species time series.

The overall objective of this study was to develop a species-specific index of abundance (i.e. time series) for a variety of juvenile sharks that can be ultimately used for stock assessment. Juvenile sizes vary by species and, due to the high selectivity of gillnets, captures of different species are likely for particular mesh sizes. To accommodate the wide range in size of juvenile sharks, we used multi-panel gillnets with variable mesh sizes that have been shown to be effective for capturing juveniles of many economically important species (Trent[12]). For all species, the mean size and range of sharks captured during the survey included mostly neonates and juveniles (Fig. 4). Although the commercial shark industry commonly uses large J hooks on bottom longlines, we utilized smaller J hooks fished in mid water over larger J hooks fished on the bottom because the former are more efficient at capturing juvenile coastal sharks (Trent and Carlson[13]). This method permitted capture of six species of sharks in significant numbers for which indices could be generated, with at least 85% of each species being juveniles (Fig. 5).

The best index of fish abundance is one by which extraneous influences on CPUE can be controlled. Although certain environmental factors (e.g. weather patterns, water temperature, salinity) could not be controlled, we have attempted to minimize bias associated with factors such as spatio-temporal distributions by sampling throughout all months when sharks are beginning to or have recruited to their summer nursery areas. To control gear selectivity bias, the same gear and methodology were used for all years sampled.

The validity of an index of abundance depends on its precision, especially if changes in CPUE are regarded as real. The use of fixed areas or stations for developing indices of abundance as opposed to a simple random or stratified random statistical design has recently come under discussion (National Research Council, 1998). Although relying on fixed areas assumes no change over time in recruitment patterns, emigration or immigration, arguments have been made that the mean from a fixed survey design can be more precise than the mean from a simple random sample (Cochran, 1977) or a stratified random design (Simmonds and Fryer, 1996). Our sampling design attempts to embrace both a random and fixed statistical design by utilizing random samples within fixed areas. By comparing coefficients of variation, as a measure of relative precision, from this study with those provided in Grace and Henwood (1997), most CPUE values derived in this study were similar or more precise than those calculated for similar shark species captured by Grace and Henwood (1997) (Table 3). Moreover, it should be noted that the index of abundance for striped bass, *Morone saxatilis*, developed from a 20-yr fixed station sampling design, was found to predict subsequent commercial landings of striped bass (Goodyear, 1985).

[12] Trent, L. Unpubl. data on file at National Marine Fisheries Service, NOAA, Panama City Facility, Panama City, FL 32408.

[13] Trent, L., and J. K. Carlson. 1998. Comparisons of longline methods to estimate juvenile shark abundance indices in shallow coastal areas of northwest Florida. 1998 Shark Evaluation Workshop Document SB-IV-16. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southeast Fish. Sci. Cent., 3500 Delwood Beach Rd., Panama City, Fla., 41 p.

Table 2.—Management groups and associated sharks captured in the northeast Gulf of Mexico during 1996–98. Management group reports sharks in overall decreasing abundance.

Management group	Common name	Scientific Name
Large coastal sharks	Blacktip	*Carcharhinus limbatus*
	Spinner	*Carcharhinus brevipinna*
	Scalloped hammerhead	*Sphyrna lewini*
	Sandbar	*Carcharhinus plumbeus*
	Bull	*Carcharhinus leucas*
	Nurse	*Ginglymostoma cirratum*
	Lemon	*Negaprion brevirostris*
	Great hammerhead	*Sphyrna mokarran*
	Tiger	*Galeocerdo cuvier*
Small coastal sharks	Atlantic sharpnose	*Rhizoprionodon terraenovae*
	Bonnethead	*Sphyrna tiburo*
	Finetooth	*Carcharhinus isodon*
	Blacknose	*Carcharhinus acronotus*
Nonmanagement group	Florida smoothhound	*Mustelus norrisi*

Table 3.—A comparison of CPUE and coefficient of variation (CV is defined as the standard error divided by the mean following Grace and Henwood (1997)) for similar shark species captured in this study and from data provided in Grace and Henwood (1997). For gillnets, CPUE is defined as the mean number of sharks caught/186 m long gillnet/h. For longlines, CPUE is defined as number of sharks/10 hook h for this study and defined as number of sharks/100 hook h for Grace and Henwood (1997).

	This study (gillnet)		This study (longline)		Grace and Henwood (1997)	
Species	CPUE (1996)	CV	CPUE (1996)	CV	CPUE (1996)	CV
Atlantic sharpnose	2.23	0.31	0.62	0.12	2.03	0.22
Blacknose	0.34	0.57	0.00		0.28	0.30
Blacktip	0.54	0.46	0.20	0.26	0.12	0.33
Finetooth	0.68	0.40	0.10	0.34	0.00	
Sandbar	0.05	0.48	0.02	0.71	0.13	0.27
Scalloped hammerhead	0.11	0.39	0.00		0.05	0.37
Spinner	0.26	0.56	0.19	0.36	0.04	0.52
	CPUE (1997)	CV	CPUE (1997)	CV	CPUE (1997)[1]	CV
Atlantic sharpnose	0.92	0.23	0.41	0.26	2.33	0.12
Blacknose	0.08	0.60	0.02	0.71	0.30	0.20
Blacktip	1.05	0.37	0.33	0.19	0.22	0.27
Finetooth	1.06	0.30	0.06	0.59	0.004	1.00
Sandbar	0.09	0.83	0.03	0.57	0.23	0.31
Scalloped hammerhead	0.53	0.37	0.00		0.06	0.31
Spinner	0.33	0.38	0.06	0.53	0.07	0.53

[1] Grace, M., and T. Henwood. 1998. Summary of NMFS Shark Surveys/Southeastern Region 1995, 1996, 1997. 1998 Shark Evaluation Workshop Document SB-IV-29. U.S. Dep. Commer., NOAA, NMFS, Southeast Fisheries Science Center, Panama City, Fla., 34 p.

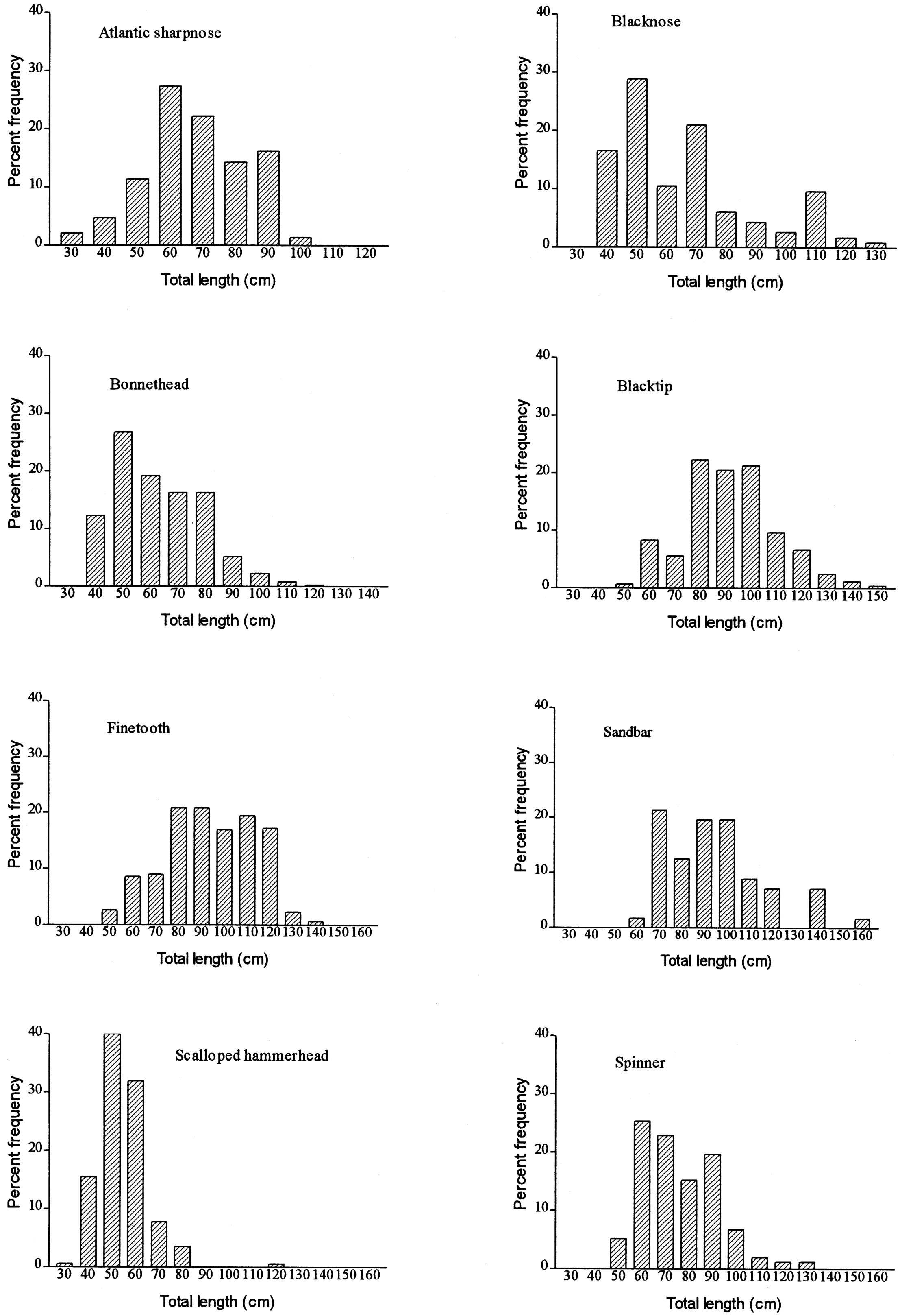

Figure 4.—Percent length-frequency distributions by species for all sharks caught in gillnets, 1996–98.

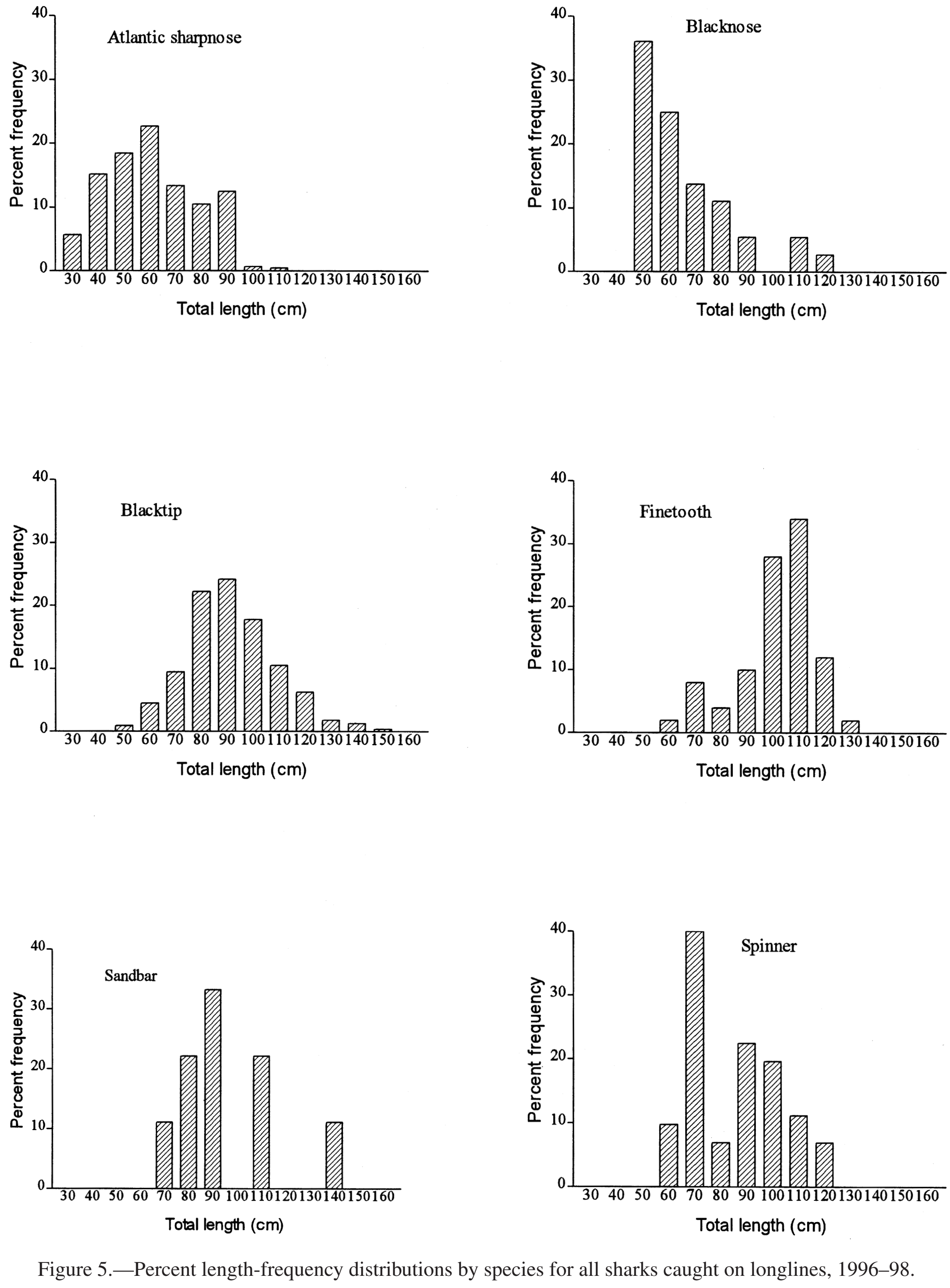

Figure 5.—Percent length-frequency distributions by species for all sharks caught on longlines, 1996–98.

Because shark summer nursery and pupping grounds are generally found in inshore areas, they are particularly susceptible to anthropogenic disturbances such as shoreline development, additions of wastewater, and recreational activities. Although loss of these habitats has not been quantitatively assessed in terms of shark production, preliminary evidence suggests that estuaries with more coastal development have less diversity and abundance of shark species (Carlson[14]). Moreover, the revised Magnuson-Stevens Fishery Conservation and Management Act of 1996 requires the description and identification of essential fish habitat (EFH) for all Federally managed species and further requires identification of threats to EFH.

It is still unclear whether the abundance estimates presented herein represent stockwide estimates or represent populations only for the northeastern Gulf of Mexico. Although adults of many species, particularly sandbar, blacktip, scalloped hammerhead, and spinner shark are highly migratory, whether sharks from the eastern Gulf of Mexico mix with stocks from the western Gulf of Mexico, Atlantic Ocean, or Mexican waters is yet to be determined. There is growing evidence that the abundance and distribution of juvenile sharks in nursery areas is not the same throughout the northern Gulf of Mexico (Parsons[15]; deSylva[16]). The paucity of tag and recapture information in the Gulf of Mexico further complicates understanding of the geographical and seasonal distribution of sharks.

Given the direct relationship between stock and recruitment for sharks (Holden, 1974, 1977; Hoenig and Gruber, 1990), monitoring of juvenile abundance will aid in assessing current parental stock. This information, combined with current efforts by Grace and Henwood (1997) to monitor adult stock size, will also benefit current management regulations and forecasting of future stock size.

[14] Carlson. J. K. 1999. Unpubl. data on file at National Marine Fisheries Service, NOAA, Panama City Facility, Panama City, FL 32408.

[15] Parsons, G. 1999. Biology Department, University of Mississippi, University, MS 38677. Personal commun.

[16] De Sylva, J. 1999. Coastal Fisheries Institute, Louisiana State University, Baton Rouge, LA 70803. Personal commun.

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