VIMS Books and Book Chapters

Virginia Institute of Marine Science

9-1993

Trends in Shark Abundance from 1974 to 1991 for the Chesapeake Bight Region of the U.S. Mid-Atlantic Coast

John A. Musick
Virginia Institute of Marine Science

Steven Branstetter
Virginia Institute of Marine Science

James A. Colvocoresses
Virginia Institute of Marine Science

Follow this and additional works at: https://scholarworks.wm.edu/vimsbooks

Part of the Aquaculture and Fisheries Commons, and the Marine Biology Commons

Recommended Citation

September 1993

Conservation Biology of Elasmobranchs

Steven Branstetter (editor)

NOAA Technical Reports NMFS

The major responsibilities of the National Marine Fisheries Service (NMFS) are to monitor and assess the abundance and geographic distribution of fishery resources, to understand and predict fluctuations in the quantity and distribution of these resources, and to establish levels for their optimum use. NMFS is also charged with the development and implementation of policies for managing national fishing grounds, with the development and enforcement of domestic fisheries regulations, with the surveillance of foreign fishing off U.S. coastal waters, and with the development and enforcement of international fishery agreements and policies. NMFS also assists the fishing industry through marketing services and economic analysis programs and through mortgage insurance and vessel construction subsidies. It collects, analyzes, and publishes statistics on various phases of the industry.

The NOAA Technical Report NMFS series was established in 1983 to replace two subcategories of the Technical Report series: "Special Scientific Report —Fisheries" and "Circular." The series contains the following types of reports: scientific investigations that document long-term continuing programs of NMFS; intensive scientific reports on studies of restricted scope; papers on applied fishery problems; technical reports of general interest intended to aid conservation and management; reports that review, in considerable detail and at a high technical level, certain broad areas of research; and technical papers originating in economics studies and in management investigations. Since this is a formal series, all submitted papers receive peer review and all papers, once accepted, receive professional editing before publication.

Copies of NOAA Technical Reports NMFS are available free in limited numbers to government agencies, both federal and state. They are also available in exchange for other scientific and technical publications in the marine sciences. Individual copies may be obtained from the U.S. Department of Commerce, National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

Recently Published NOAA Technical Reports NMFS

103. **Benthic macrofauna of the New York Bight, 1979–89,** by Robert N. Reid, David J. Radosh, Ann B. Frame, and Steven A. Fromm. December 1991, 50 p.

104. **Incidental catch of marine mammals by foreign and joint venture trawl vessels in the U.S. EEZ of the North Pacific, 1973–88,** by Michael A. Perez and Thomas R. Loughlin. December 1991, 57 p.

105. **Biology, oceanography, and fisheries of the North Pacific transition zone and subarctic frontal zone,** edited by Jerry A. Wetherall. December 1991, 92 p.

106. **Marine ranching: proceedings of the eighteenth U.S.-Japan meeting on aquaculture; Port Ludlow, Washington, 18–19 September 1989**, edited by Ralph S. Svrjcek. February 1992, 136 p.

107. **Field guide to the searobins (*Prionotus* and *Bellator*) in the western North Atlantic,** by Mike Russell, Mark Grace, and Elmer J. Gutherz. March 1992, 26 p.

108. **Marine debris survey manual,** by Christine A. Ribic, Trevor R. Dixon, and Ivan Vining. April 1992, 92 p.

109. **Seasonal climatologies and variability of eastern** tropical Pacific surface waters, by Paul C. Fiedler. April 1992, 65 p.

110. **The distribution of Kemp's ridley sea turtles (*Lepidochelys kempi*) along the Texas coast: an atlas,** by Sharon A. Manzella and Jo A. Williams. May 1992, 52 p.

111. **Control of disease in aquaculture: proceedings of the nineteenth U.S.-Japan meeting on aquaculture; Ise, Mie Prefecture, Japan, 29-30 October 1990,** edited by Ralph S. Svrjcek. October 1992, 143 p.

112. **Variability of temperature and salinity in the Middle Atlantic Bight and Gulf of Maine,** by Robert L. Benway, Jack W. Jossi, Kevin P. Thomas, and Julien R. Goulet. April 1993, 108 p.

113. **Maturation of nineteen species of finfish off the northeast coast of the United States, 1985-1990,** by Loretta O'Brien, Jay Burnett, and Ralph K. Mayo. June 1993, 66 p.

114. **Structure and historical changes in the groundfish complex of the eastern Bering Sea,** by Richard G. Bakkala. July 1993, 91 p.

NOAA Technical Report NMFS 115
A Technical Report of the *Fishery Bulletin*

Conservation Biology of Elasmobranchs

Steven Branstetter (editor)

September 1993

Contents

Introduction

Elasmobranchs are vital and valuable components of the marine biota. From an ecological perspective they occupy the role of top predators within marine food webs, providing a regulatory control that helps balance the ecosystem. From an evolutionary perspective, this group represents an early divergence along the vertebrate line that produced many unusual, but highly successful, adaptations in function and form.

From man's perspective, elasmobranchs have been considered both an unavoidable nuisance, and an exploitable fishery resource. A few of the large shark species have earned a dubious notoriety because of sporadic attacks on humans that occur in coastal areas each year worldwide; the hysteria surrounding an encounter with a shark can be costly to the tourist industry. More importantly, elasmobranchs are often considered a detriment to commercial fishing operations; they cause significant economic damage to catches and fishing gear. On the other hand, consumer attitudes have changed concerning many previously unpopular food fishes, including elasmobranchs, and this group of fishes has been increasingly used by both recreational and commercial fishing interests. Many elasmobranchs have become a popular target of recreational fishermen for food and sport because of their abundance, size, and availability in coastal waters. Similarly, commercial fisheries for elasmobranchs have developed or expanded from an increased demand for elasmobranch food products.

Unfortunately, elasmobranch stock-recruitment relationships are generally density-dependent, and their innate biological characteristics of slow growth, late maturation, and low fecundity do not support extensive exploitation. Today, many elasmobranch populations, and stocks, are jeopardized by overexploitation, and substantially reduced populations will have long-term negative impacts, not only for the elasmobranch stocks (and human user-groups), but to the marine community of which they are a part. There are numerous examples of imbalances that have occurred within communities after the primary apex predators were removed or reduced.

This was the third symposium convened in less than four years designed to elucidate the status of elasmobranch resources worldwide. Twenty-four authors contributed 16 formal and two informal presentations on a variety of topics concerning elasmobranch biology, use, management, and conservation. Nine of the 16 formal oral presentations translated into eight manuscripts for the proceedings of this symposium. Three presentations were slated for publication elsewhere, and four authors considered their results too preliminary to warrant publication at this time. In addition, this volume contains one paper by Sandra Zeiner that was a co-winner of the 1991 American Elasmobranch Society *Gruber Award* for the best student presentation.

The development of the symposium was possible only with the help of Sandra Zeiner and Jefferey Howe of the Symposium Committee. I would like to thank Michael Smith (Chair, Local Organizing Committee, the American Society of Ichthyologists and Herpetologists) and the host institution (The American Museum of Natural History, New York) for their support. I want to extend a special note of appreciation to Harold (Wes) Pratt Jr. (Chair, Local Organizing Committee, the American Elasmobranch Society) for his many hours of help in coordinating the symposium as part of the AES meeting. I congratulate the session chairs — John Morrissey, Robert Hueter, and Jefferey Howe — for keeping the ever-changing program on schedule. Each article was peer-reviewed by at least two anonymous referees consisting of symposium participants and 'outside' experts. Overall, 21 individuals contributed comments that improved the quality of these manuscripts; their expertise is greatly appreciated. Finally, I wish to thank the authors and symposium participants. These contributions will benefit man's efforts to understand and ultimately conserve this important marine resource.

Steven Branstetter, Editor
Gulf and South Atlantic Fisheries
Development Foundation
Tampa, Florida, 1993
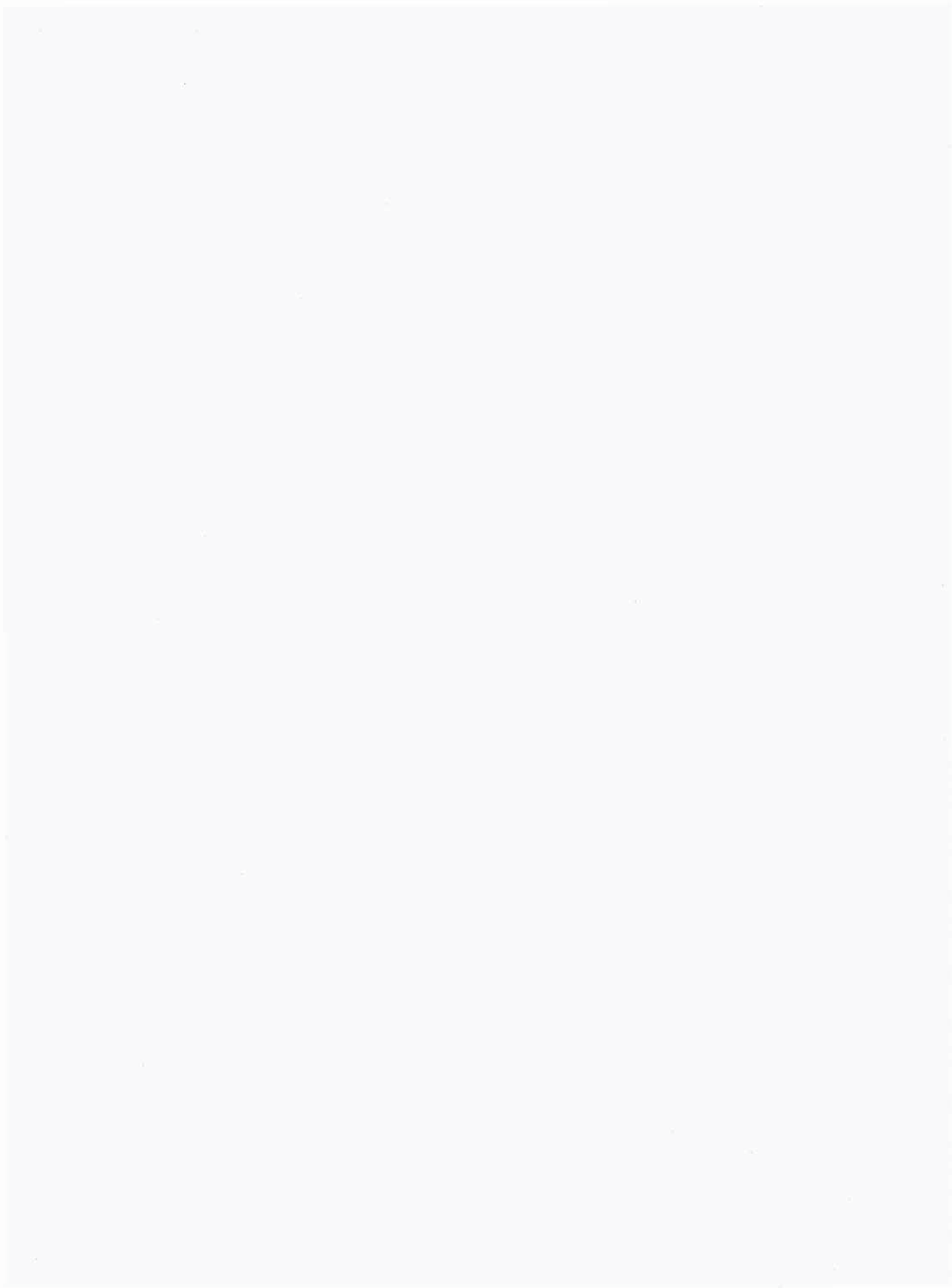
Trends in Shark Abundance from 1974 to 1991 for the Chesapeake Bight Region of the U.S. Mid-Atlantic Coast*

JOHN A. MUSICK, STEVEN BRANSTETTER, and JAMES A. COLVOCORESSES

Virginia Institute of Marine Science
College of William and Mary
School of Marine Science
Gloucester Point, Virginia 23062

ABSTRACT

Recent stock assessments indicate that the shark stock of the western North Atlantic is exploited at a rate twice the maximum sustainable yield. This finding is supported by data generated by the Virginia Institute of Marine Science longline program for sharks of the Chesapeake Bay and adjacent coastal waters. Trends in catch per unit of effort since 1974 indicate 60–80% reductions in population size for the common species — sandbar (*Carcharhinus plumbeus*), dusky (*C. obscurus*), sand tiger (*Odontaspis taurus*), and tiger (*Galeocerdo cuvier*) sharks. Declines include numbers of individuals for all species, size classes within species, and in one case a strong decline in relative abundance. Given the limited ability of sharks to increase their population size, these results suggest that stock recovery will probably require decades.

Introduction

The sharks of the northwest Atlantic have been increasingly exploited by recreational and commercial fisheries over the last 20 years. Because many of the species are highly migratory (Casey and Kohler, 1990), they are available to numerous regional fisheries on the U.S. east coast, and in some instances, to fisheries in Cuba, Mexico, and other Latin American countries (Springer, 1979; Anderson, 1990a; Bonfil et al., 1990). Thus there is wide-scale fishing pressure on the populations.

U.S. interest in recreational shark fishing rose in the mid-1970's following the release of the movie "Jaws"; shark fishing clubs and tournaments expanded throughout the region (Casey and Hoey, 1985; Hueter[1]). Additionally, apparent declines in abundance of traditional teleost target species like tuna, marlin, and snapper led many charter and head boat captains to fish for sharks to satisfy clients (NMFS[2]). Recreational catches are estimated at 2.5 million sharks annually, or 35,000 metric tons; annual mortality associated with this catch may exceed 10,000 t (Hoff and Musick, 1990).

Commercial use of sharks has been sporadic and based on economic parameters of supply and demand. Based on the success of a 1940's Florida-based fishery for shark liver oils (Springer and French, 1944; Springer, 1949, 1951), shark fishing was later promoted as a control measure against the economic damages sharks caused to other fishing operations and to the tourist service industry (Springer and Gilbert, 1963; Beaumariage, 1968). However, although sharks were a major bycatch in various fisheries (Cody et al., 1981; Anderson, 1985, 1990a, 1990b; Berkeley and Campos, 1988), the catch was usually discarded because of its

---

[1] Hueter. R. E. 1991.—Survey of the Florida recreational shark fishery utilizing shark tournament data and selected longline data. Final Report to Fla. Dept. Natl. Resources, Grant #6627, 74 p.

[2] National Marine Fisheries Service (NMFS). 1991. Draft (19 April 1991) Secretarial Shark fishery management plan for the Atlantic Ocean. U.S. Dep. Commer. NOAA, Nat. Mar. Fish. Serv., Southeast Regional Center, St. Petersburg, FL, 127 p.

low ex-vessel value and because of limited onboard storage capability. Only easily stored shark products with market value, such as jaws and fins, were sold by vessel crews as supplemental income.

This shark discard was identified as an underutilized resource with a potential for fishery expansion (Ronsivalli, 1978; Springer, 1979; Colvocoresses and Musick, 1980; Branstetter, 1981a; Cody et al., 1981; Stevens et al., 1982; Cook, 1982; Cook (ed.), 1987; Berkeley and Campos, 1988). Shark meat was recognized as a high-protein, low-fat food source (Gordievskaya, 1971) containing high quantities of lysine, an amino acid important in fish meal (Kreuzer and Ahmed, 1978). Driven by an increasing price for fins, shark landings increased from fisheries that took a large shark bycatch (Graham, 1987; Berkeley and Campos, 1988). As more shark was landed, a supportive market developed on both a domestic and international level, and more vessels shifted their directed efforts toward shark. Shark landings rose exponentially after 1985, totalling > 7100 t in 1989 (NMFS[2]).

In addition to rising U.S. landings, established commercial fisheries for sharks have expanded throughout the Caribbean and southern Gulf of Mexico (Kleign 1974; Springer, 1979; Bonfil et al., 1990). In recent years, foreign squid and tuna fleets have also taken a substantial bycatch of sharks from their efforts in the region (Anderson, 1985, 1990a; Witzell, 1985).

Shark mortality within FAO Area 31 (the U.S. mid-Atlantic and Caribbean region) has been estimated to exceed 42,000 t whole weight; 22,000 t of which was from U.S. waters (Anderson, 1990a). This mortality level exceeds the 9,800–16,500 t whole weight maximum sustainable yield (MSY) estimated for U.S. waters (Anderson, 1990b; Parrack, 1990); thus the stock is apparently overexploited. Sharks are particularly vulnerable to overfishing because of their slow growth, late maturation, and low fecundity (Holden, 1974, 1977). Historically, shark fisheries have succumbed, owing in part, to overfishing (Byers, 1940; Ripley, 1946; Olsen, 1959, 1984; Springer, 1951; Aasen, 1963; Grant et al., 1979; Thorson, 1982; Cailliet and Bedford, 1983; Florida Sea Grant, 1985; Holts, 1988; Smith and Abramson, 1990).

Hoff and Musick (1990) noted that strict management was needed for conservation and rational long-term utilization of the shark stocks in the northwest Atlantic because of the limited ability of the stocks to withstand heavy fishing pressure. A federal shark fishery management plan for the U.S. east coast is in preparation (NMFS[2]); in the interim, several states have enacted laws to regulate shark fisheries within their respective waters (14% of commercial and 64% of recreational catches occur in state controlled waters [NMFS[2]]). Hoff and Musick (1990) also noted the

dearth of appropriate data available for stock assessments, and Parrack (1990) indicated that the lack of these data hindered his assessment for the management plan. This information included

- biological data (delineation of nursery grounds, age structure, reproduction, stock delineation),
- species-specific fisheries data (catch/effort, size and weight data), and
- fishery-independent assessment.

Such data are crucial to adequately derive projections of maximum sustainable yield on a species-by-species basis.

To that end, the Virginia Institute of Marine Science (VIMS) has conducted a longline sampling program since 1974 examining the distribution, abundance, and biology of sharks and large pelagic teleosts off Virginia. This long-term program provides information on the three data needs listed above. This report analyzes trends in catch, effort, and species composition from 1974 through 1991 for the Chesapeake Bight region, and highlights pertinent biological features associated with these data.

Methods and Materials

Sharks were collected by longlines fished from May through October 1974–1991. The majority of longlines were fished at specific stations from the lower Chesapeake Bay to the edge of the continental shelf (200-m contour). For analysis, these stations were stratified by depth: 1) lower Chesapeake Bay; 2) coastal (<10 m depth); 3) nearshore (10–20 m depth); 4) mid-shelf (20–100 m depth); and 5) offshore (>100 m depth). Supplemental localities within these strata were fished on occasion to provide additional data on species distributions within strata.

A longline consisted of a 6.4-mm (1/4") hard-laid and tarred nylon mainline anchored at both ends with 3–5 m gangions spaced about 20 m apart and set with buoys at 20-gangion intervals. Gangions were composed of a heavy-duty quick-snap with 8/0 swivel, 2–3 m of 3 mm (1/8") hard-laid and tarred nylon line, an 8/0 swivel connecting 1–2 m of 1.6 mm (1/16") 1X7 or 7X7 stainless steel wire, and a 9/0 hook. Based on sonar scans of longlines set in deep water, the catenary of the mainline reached depths exceeding 80 m; thus, for most coastal stations the majority of hooks were on or near the bottom specifically targeting semi-demersal species. Soak time varied from 2 to 17 hr, but most sets were of 3–4 hr duration. Bait varied with local availability but consisted primarily of coastal teleost fishes such as croaker, spot, menhaden, bluefish, and mackerel. Bait pieces were 0.10–0.25 kg each in order not to

exclude the capture of small fish. A standard 100 hook longline covered about 2 km (1.25 miles).

Complete records were kept for each set. Data included 1) location; 2) start and finish times for set and haul operations; 3) water depth; 4) water temperatures at the surface and bottom (to a maximum of 30 m); 5) number of hooks; and 6) bait type. Each shark caught was identified to species; measured for pre-caudal length (PCL), fork length (FL), and total length (TL) to the nearest cm; weighed (lbs.); and sexed. Pertinent biological data and samples were collected. Healthy sharks not needed for biological sampling were tagged with M-type dart tags supplied by the National Marine Fisheries Service and released after species, length, and sex were determined; lengths were estimated for those large sharks that could not be safely boarded. Sharks that broke the gangion or dislodged the hook after being brought alongside were counted as a catch, and noted as a "lost" shark. Broken gangions, or 'bite-offs,' retrieved during haul-back, were not recorded as a lost shark.

Yearly fishing efforts varied with programmatic support and immediate research goals (Table 1). During 1980 and 1981, stations were surveyed on a monthly basis from May through October; 1990 and 1991 efforts replicated the 1980–81 effort, in addition to sampling ancillary localities. However, some years were represented by as little as 200–500 hooks of effort. Sampling within a depth stratum was sometimes confined to a single month which provided limited information on the spatial and temporal distributions of species over an entire year (Table 2). Sampling months varied among years, and some depth strata were sampled disproportionately. Additionally, shifting prioritites during the 1980's led to efforts over a wider geographic range, from Washington Canyon in the north to Cape Hatteras in the south. Ancillary localities of similar habitat were sometimes fished in lieu of established stations, and offshore (>100 m) sampling was greater than 1/3 of the total effort during this period (Fig. 1).

Sampling was directed at biological and ecological objectives; fishery analysis was not an a priori objective of the sampling program. Even when effort is evenly distributed, longlining as a sampling method is notorious for its variable catch rates (Branstetter, 1981a; Berkeley and Campos, 1988). Combined with changing programmatic goals and sampling effort, these variations precluded the use of standard statistical procedures. Large sample sizes that would reduce such variability were not always available in this data base (Table 1; Table 2); thus, graphically-apparent trends between consecutive years were not always significantly different. Yoccoz (1991) emphasized that statistical significance, or lack thereof, does not equate with biological significance, and that biological significance levels should be set before sampling begins. For this reason, this presentation is restricted to analysis of trends over the 18-yr period. For illustrative purposes, low-effort years were combined into multi-year categories by grouping 1974–79 and 1982–89. Although combining data from consecutive years reduced the information available for a given year, it provided a more equitable basis of effort to illustrate the long-term continúum in catch and effort trends around the comprehensive high-effort survey periods 1980–1981 and 1990–1991.

Catch per unit of effort (CPUE) was defined as the total number of sharks caught for the total number of hooks fished, multiplied by 100 within each sampling category, although the number of hooks per set increased over time (Table 1). CPUE was analyzed for total catch and by individual species in designated year categories. Because sharks segregate by sex and size, disjunctly distributed by depth on a seasonal basis, CPUE was analyzed for each time-series by depth strata and by month. The majority of species considered were coastal sharks; thus, because of the relatively higher percentage of hooks fished in offshore (>100 m) waters during the 1980's and in 1990 (Fig. 1, D–E), species-specific CPUE analyses were restricted to efforts from the Bay to the 100-m depth contour to avoid negatively biasing results for these species. Efforts in the >100-m depth category were included only for total CPUE and CPUE for the more widely distributed dusky and scalloped hammerhead sharks. Additionally, after 1981, new sampling areas — offshore (>100 m) areas away from the standard station at Norfolk Canyon, and a lagoon within the Virginia eastern shore peninsula — were fished for very specific purposes. These efforts (Fig. 1, D–F) were not directly comparable with previous data, and were excluded from analyses.

Results

A total of 383 sets, comprising of 33,115 hooks, caught 2,736 sharks of 20 species. Based on categorization of data and exclusion of extraneous efforts, this report (Table 1) includes 329 sets, totalling 28,329 hooks, that caught 2346 sharks of 20 species (Table 3). Analyses are provided for six species taken consistently throughout the survey period. Other species, some of which were taken in good numbers, occurred only sporadically over time; thus they were excluded from further analyses.

Relative Abundance

Species composition remained relatively stable throughout the survey (Fig. 2); however, the numbers of individuals collected declined strongly over the survey period even though effort generally increased. The sandbar shark (*Carcharhinus plumbeus*) was the dominant

Table 1

Catch and effort data of VIMS longline program for 1974-1991 used for analysis. Sampling localities were categorized by depth strata. Numbers in parentheses in the ">100 m" category are additional sets not included in analyses, but indicate the inshore-to-offshore shift in research priority of the VIMS longline program over time. To provide more equitable amounts of effort for comparison, the years 1974–1979 and 1982–1989 were combined. An intermediate grouping of year categories — 1974–76, 1977–1979, 1982–85, 1986–89 - is provided for comparative purposes. Catch per unit of effort (CPUE) equals sharks per 100 hooks.

	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
BAY																		
Sharks	23	44	15	36		4	102	57	1							12	122	112
Hooks	162	198	38	228		120	1200	500	50							200	1476	740
No. sets	4	5	1	3		2	12	5	1							2	16	8
<10 m																		
Sharks	34	47	25	68	29	5	277	243	5	7	7		1	33	11	1	51	41
Hooks	181	286	106	595	180	60	1900	1700	96	259	208		75	184	72	97	1347	1045
No. sets	4	7	3	9	3	1	19	17	1	3	3		1	3	1	1	16	11
10–20 m																		
Sharks	15	29		6	9		136	145		23	7	2	3	7	9	12	75	59
Hooks	142	119		62	56		700	1100		261	79	70	172	96	105	187	1200	1095
No. sets	3	3		1	1		7	11		3	1	1	2	1	1	2	12	11
20-100 m																		
Sharks	10	26	16	6		2	55	65	43	13	2		2	13	5	6	41	49
Hooks	74	136	68	215		41	500	500	190	272	81		86	200	190	180	1043	2170
No. sets	2	4	2	3		1	5	5	2	3	1		1	2	2	2	10	22
>100 m																		
Sharks			6			17	10	22	4	3	18	4	1	3	1	0	3	3
Hooks			36			200	350	350	192	91	219	150	241	194	200	102	770	550
No. sets			1(1)			2	4	4	2	1(2)	3(1)	2(3)	3(1)	2(1)	2(3)	1	7(9)	6(2)
TOTAL																		
Sharks	82	146	62	116	38	28	580	480	53	46	34	6	7	56	26	31	293	264
Hooks	559	739	248	1100	236	421	4650	4150	528	883	587	220	574	674	567	766	5827	5600
No. sets	13	19	7	16	4	6	47	42	6	10	8	3	7	8	6	8	61	58
Mean hooks/set	43	39	35	69	59	70	99	99	88	73	73	82	84	95	96	96	95	97
CPUE	14.7	19.8	25.0	10.5	16.1	6.7			10.0	5.2	5.8	2.7	1.2	8.3	4.6	4.1		
		18.8			10.4						6.3				4.7			
			14.3				12.5	11.6						5.4			5.0	4.7

Table 2

Monthly (May through October) distribution of effort by depth strata over the time period 1974— 1991. A plus (+) indicates a month surveyed, a dash (—) indicates no survey.

Region	1974 M J J A S O	1975 M J J A S O	1976 M J J A S O	1977 M J J A S O	1978 M J J A S O	1979 M J J A S O	1980 M J J A S O	1981 M J J A S O	1982 M J J A S O
Bay	− + − + + −	− − + − + −	− + − − − −	+ + + − − −	− − − − − −	+ + − − − −	+ + + + + +	− + + + + +	+ − − − − −
<10 m	+ − + + + −	+ + + + + +	− + + − + −	− − + + + +	− + − − − −	− − + − − −	+ + + + + +	+ + + + + +	− − − + − −
10–20 m	− + + − − +	+ − − − + +	− − − − − −	+ − − − − −	− + − − − −	− − − − − −	+ + + + + +	+ + + + + +	− − − − − −
20–100 m	− − − + + −	+ + + + − −	− + + − − −	+ + − + − −	− − − − − −	− − − − + −	+ + + + + −	− + + + + +	+ − − − − −
>100 m	− − − − − −	− − − − − −	− − + − − −	− − − − − −	− − − − − −	− − − − + −	+ − + + − −	− + + − + +	− − − + − −

Region	1983 M J J A S O	1984 M J J A S O	1985 M J J A S O	1986 M J J A S O	1987 M J J A S O	1988 M J J A S O	1989 M J J A S O	1990 M J J A S O	1991 M J J A S O
Bay	− − − − − −	− − − − − −	− − − − − −	− − − − − −	− − − − − −	− − − − − −	− − − − + −	+ + + + + +	− + + + + −
<10 m	− − + + + −	− − + − + −	− − − − − −	− − − + − −	− + + − − −	− − + − − −	− − − − + −	+ + + + + +	+ + + + + −
10–20 m	− − − − + −	− + − − − −	− − + − − −	− − + + − −	− − − − + −	− − − − + −	− − − − + −	− + + + + +	+ + + + + −
20–100 m	− + + − − −	− − − + − −	− − − − − −	− − + − − −	− − + − + −	− − − − + −	− − − − + −	− + + + + +	+ + + + + −
>100 m	− − + − − −	− − + + + −	− − + − − −	− − + − − −	− − − + − −	− − − − + −	− − − − + −	− + + + + −	− − + + + −

species collected in the lower Chesapeake Bay and adjacent coastal regions, and constituted over 55% of the total catch. In contrast, relative abundance declined for the dusky shark (*Carcharhinus obscurus*). From 1974 through 1981 this species composed 10–20% of the total catch, and declined to approximately 5% of the total during 1982–1989. In 1990 only three individuals

(1%) were collected; in 1991 only six (2%). This was in stark contrast to the 1980 catch of 117 dusky sharks.

Catch per Unit of Effort (CPUE)

CPUE for individual years (Fig. 3A) indicated an overall decline in shark abundance; however, fluctuations between consecutive years were often explainable as sampling biases associated with the months, location, and number of hooks fished during a given year. For example, the extremely low CPUE's for 1985 and 1986 were biased because of the large percentage of hooks fished in relatively unproductive offshore waters (Table 1). Reductions in variability were possible by combining three or four consecutive low-effort years into a single category (Fig. 3B); however, this eight-category method offered only slightly greater resolution of long-term trends than a six-category time-series (Fig. 3C). The six-category method is used here.

CPUE by Species

Total CPUE (Fig. 3C) was strongly affected by the dominance of the sandbar shark catch (Fig. 4A). Total CPUE and sandbar shark CPUE declined approximately two-thirds over the sampling period. For sandbar sharks, catches included neonates and large adults.

CPUE over time declined at varying rates for the other species. The strongest decline in CPUE was that of the dusky shark (Fig. 4B). This one-time common species in the Virginia region has only rarely been caught on longlines in recent years. The majority of individuals collected were juveniles. The sand tiger (*Odontaspis taurus*) and the tiger shark (*Galeocerdo cuvier*), were caught regularly, but in low numbers, on longlines. Catch rates for the sand tiger declined about 75% over

Table 3

Numbers of individuals of 20 species of sharks collected on VIMS longlines from 1974 through 1991. Species are listed by order of abundance.

Species analyzed

sandbar shark	*Carcharhinus plumbeus*	1293
Atlantic sharpnose shark	*Rhizoprionodon terraenovae*	352
dusky shark	*Carcharhinus obscurus*	243
sand tiger	*Odontaspis taurus*	113
tiger shark	*Galeocerdo cuvier*	53
scalloped hammerhead	*Sphyrna lewini*	38

Miscellaneous coastal species

smooth dogfish	*Mustelus canis*	94
blacktip shark	*Carcharhinus limbatus*	56
spinner shark	*Carcharhinus brevipinna*	6
bull shark	*Carcharhinus leucas*	5
lemon shark	*Negaprion brevirostris*	5
spiny dogfish	*Squalus acanthias*	5
blacknose shark	*Carcharhinus acronotus*	1
Atlantic angel shark	*Squatina dumeril*	1

Miscellaneous oceanic species

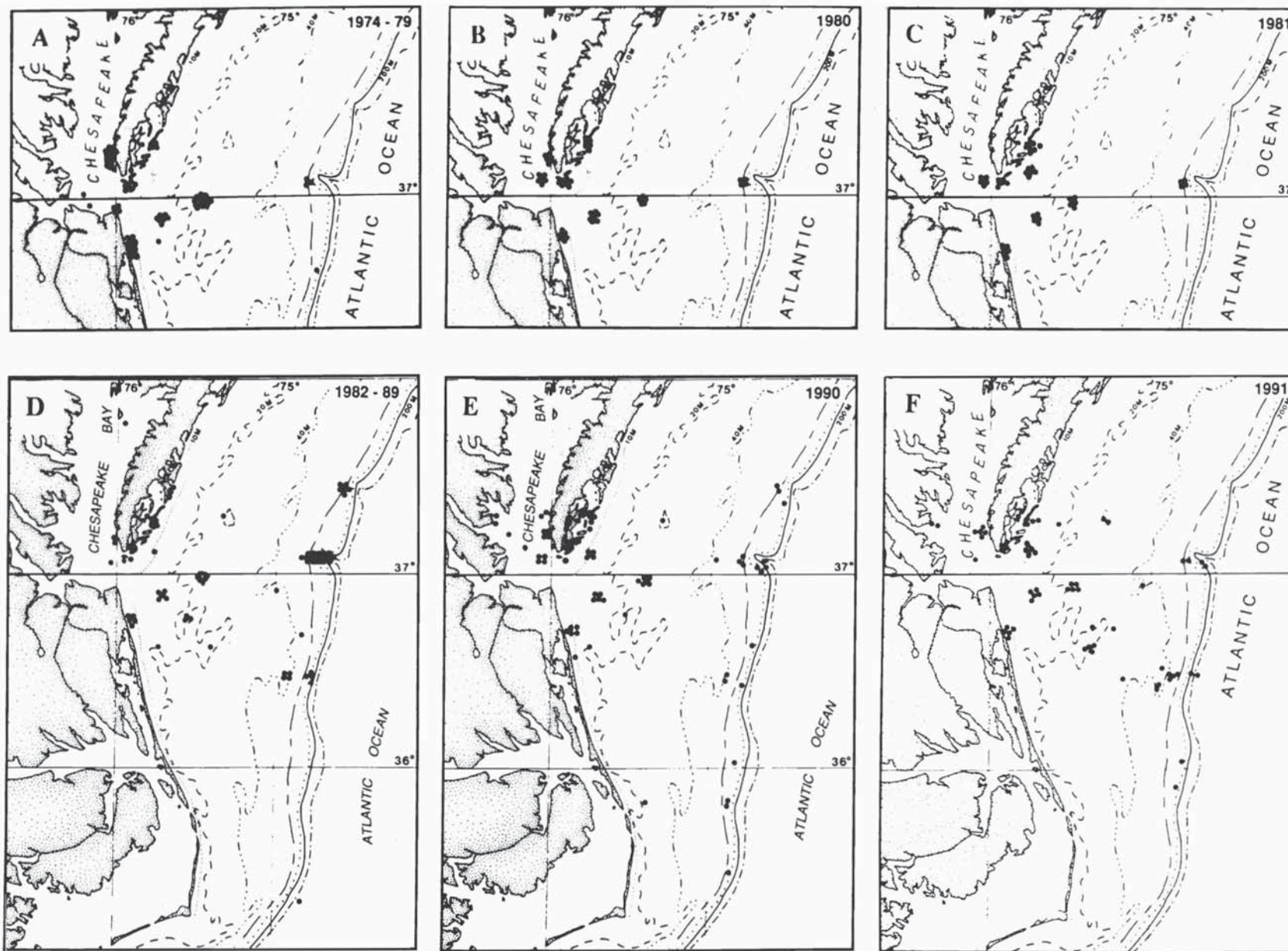|		
bignose shark	*Carcharhinus altimus*	37
silky shark	*Carcharhinus falciformis*	18
shortfin mako	*Isurus oxyrinchus*	15
blue shark	*Prionace glauca*	9
bigeye thresher	*Alopias superciliosus*	1
night shark	*Carcharhinus signatus*	1

Figure 1
Location and number of all VIMS longline sets by year or year-group in the Chesapeake Bight of the mid-Atlantic coast of the United States.
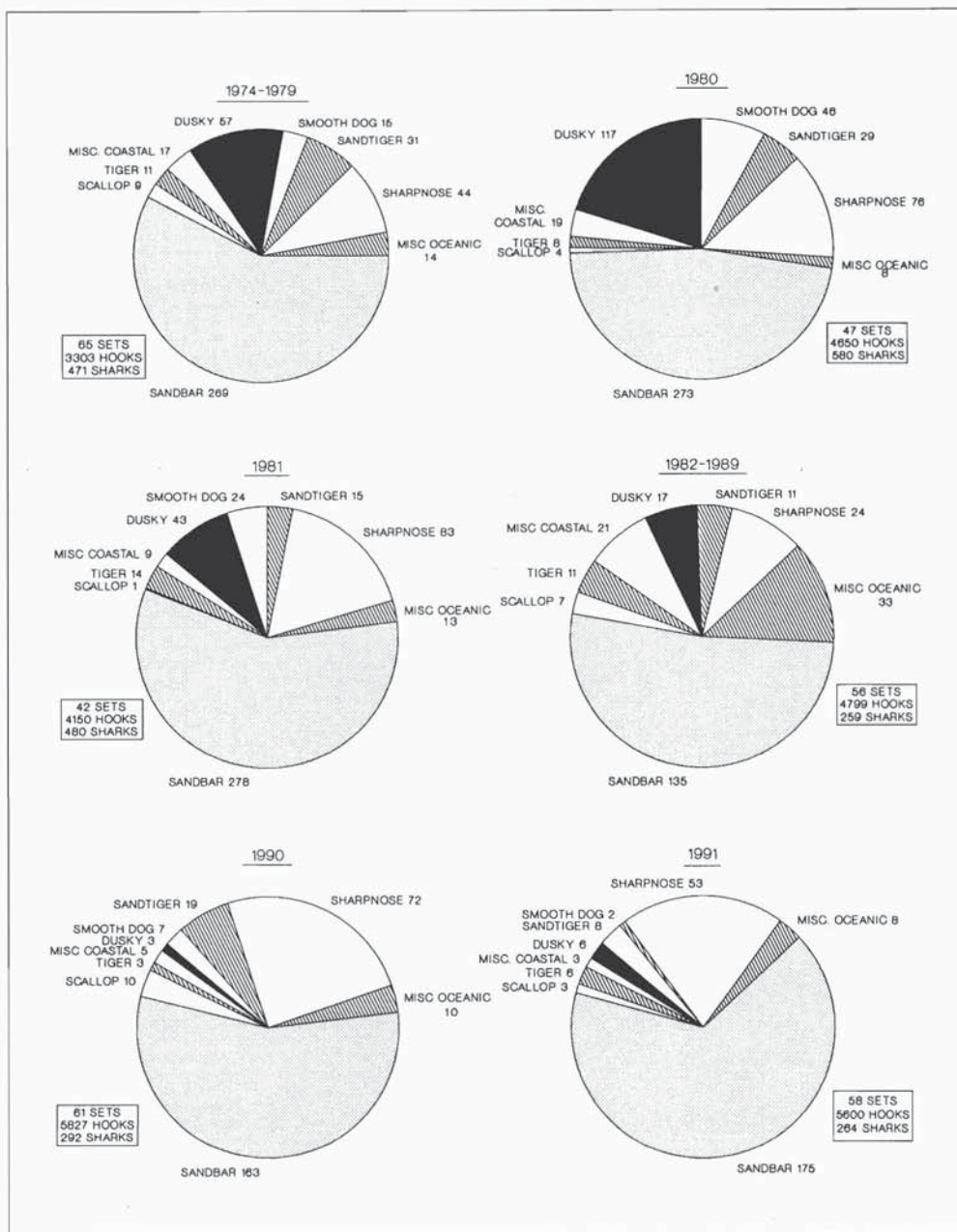
Figure 2
Relative abundance of shark species collected by VIMS longlines by year-group or year from 1974 through 1991.

the survey period (Fig. 4C). The tiger shark generally was caught at depths >10 m; catch rates in the mid-continental shelf region (10–100 m) declined almost 80% (Fig. 4E).

CPUE for two species, the Atlantic sharpnose shark (*Rhizoprionodon terraenovae*) and the scalloped hammerhead (*Sphyrna lewini*), did not show the same distinct trend in this analysis. Atlantic sharpnose sharks were taken in substantial numbers during mid-summer, but catches were sporadic and clustered, reflecting the school-

ing behavior of this species. Although a slight decline is suggested in Figure 4D, it is not of the magnitude shown by the other species, and normal variation in occurrence could explain this effect; however, more detailed CPUE analyses in the following sections suggested possible declines in abundance. The number of scalloped hammerheads collected was similar to that of tiger sharks, but there was not such a distinct downward trend in CPUE, although a decline is suggested by the data (Fig. 4F).
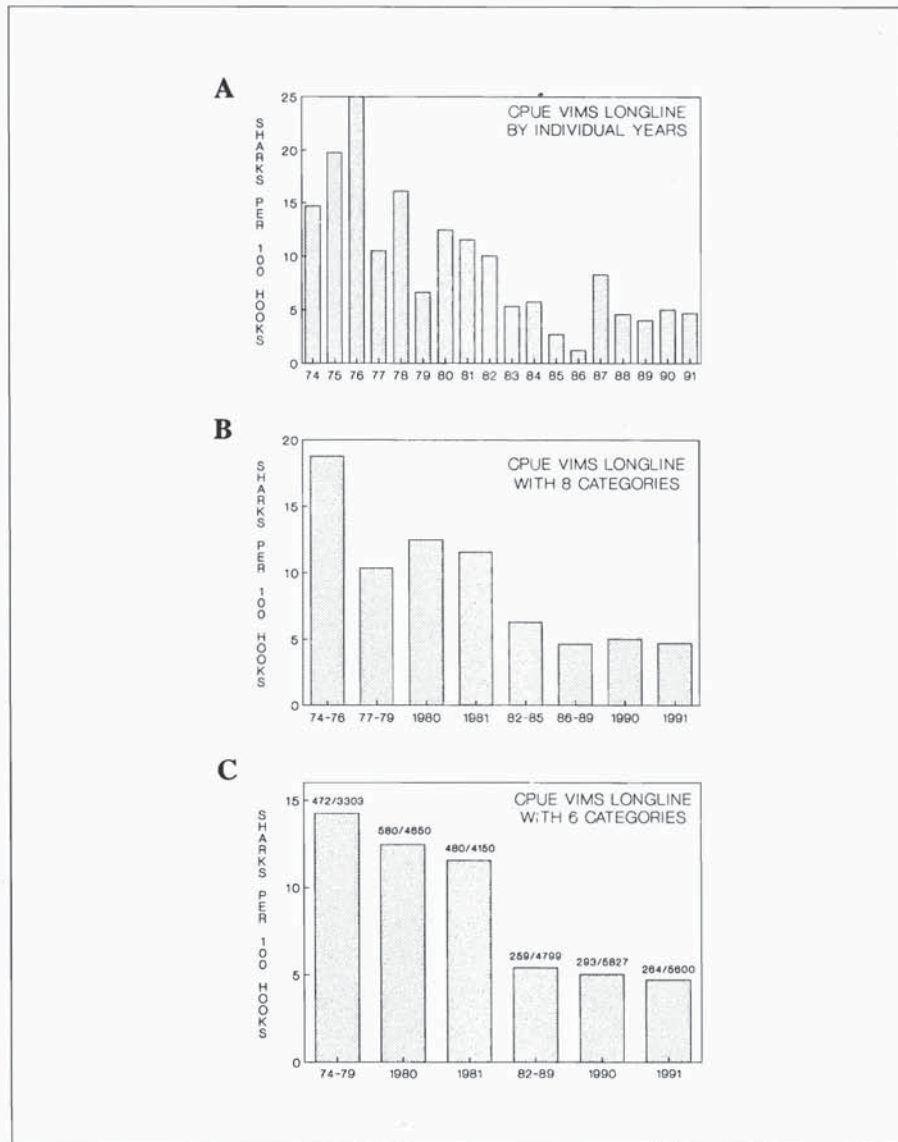
Figure 3
Three categorical analyses of catch per unit effort (CPUE) of the VIMS longline program 1974–1991. Annual catch rates (**A**) were subject to fluctuations in numbers of hooks fished, and the area and time of the effort. To offset these fluctuations, the data were categorized by varying year groups (see Table 1 for values). There was little loss of resolution between an eight category analysis (**B**) combining data over three or four year periods, and a six category analysis (**C**) which combined data for years 1974–79 and 1982–89. Thus, all analyses were performed by using the combination shown in (C). Numbers above the bars in (C) represent sharks/hooks for each category.

Catch per Unit of Effort by Depth Strata over Time

Declines in CPUE were also apparent for the various species within the various depth strata (Fig. 5). For all species combined, CPUE for each depth category (Fig. 5A) reflected the CPUE of sandbar sharks (Fig. 5B) over the same regions. Total catch rates declined in all depth categories except within Chesapeake Bay. Catches within the Bay consisted primarily of juvenile sandbar sharks.

Distinct declines across depth over time were also apparent for the dusky, sand tiger, and Atlantic sharpnose sharks (Fig. 5, C–E). The majority of dusky sharks were juveniles taken in coastal (<20 m) waters outside the Bay, although a few sub-adults and adults were taken at various continental shelf stations. Two of the three standard coastal (<10 m) stations produced

99 of the 106 juvenile (<150 cm) dusky sharks taken in that depth zone. Approximately equal numbers of dusky sharks were taken at each station, but one station was discontinued after 1983, thereby possibly biasing the apparent decline. However, CPUE for the other continuously fished coastal station also showed a similar strong decline; from 1974–81 CPUE was 43/1733 {2.48}, but from 1982–91 CPUE was 1/1486 {0.067}. The sand

tiger was caught most frequently on sets made in the Bay and coastal (<10 m) waters, and CPUE declined about 75% over the survey period. (Fig. 4C) In the case of the Atlantic sharpnose shark, a distinct decline was not apparent when looking at total CPUE over time; however, in the <10 m depth range, there was a marked decline in CPUE. In the 10–20 m depth range, where the species appeared to be most common, catch rates appeared rather stable.
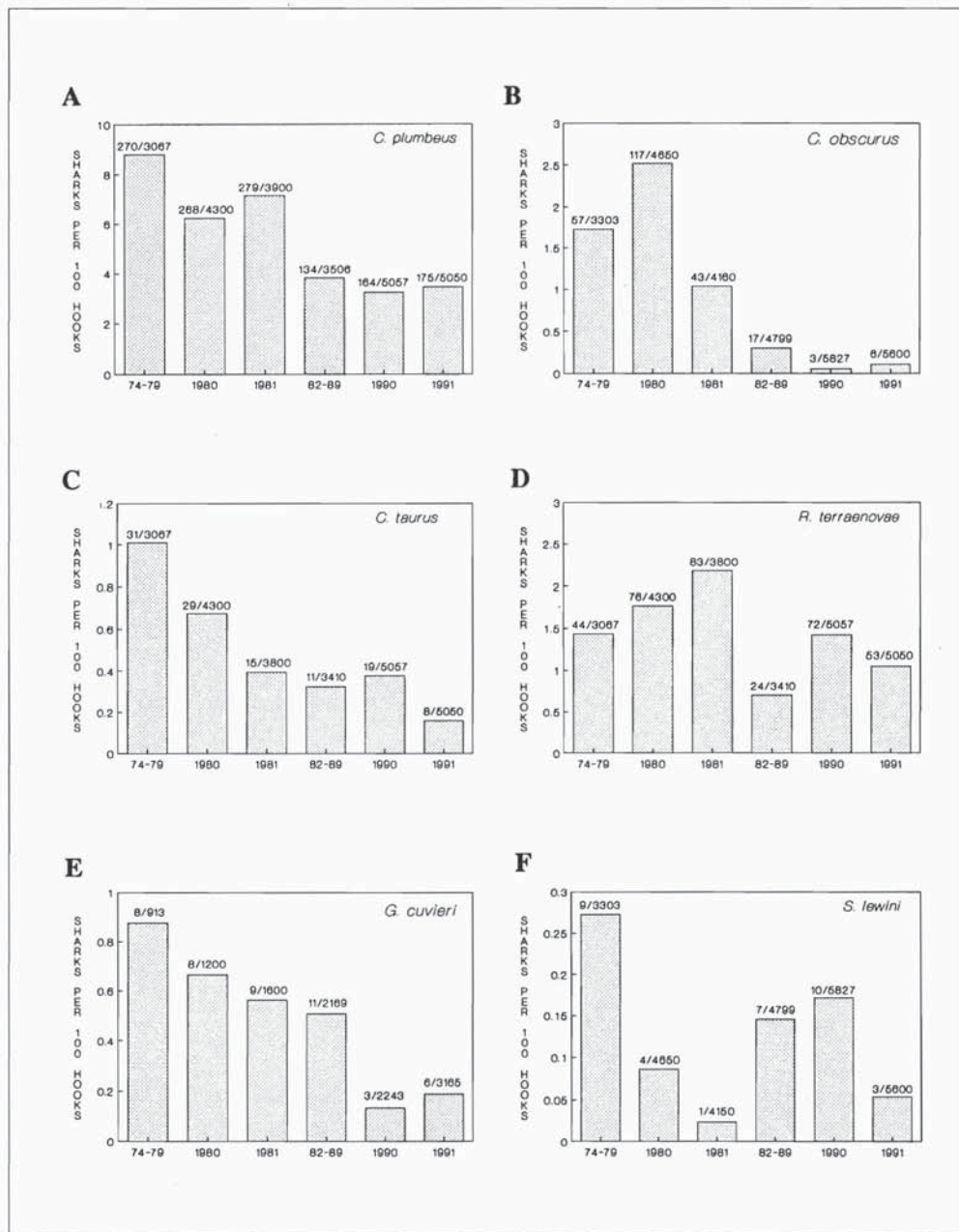

Figure 4
Catch per unit of effort for six species taken commonly on VIMS longlines, 1974–1991. (**A**) sandbar (Bay to 100 m), (**B**) dusky (Bay to >100 m), (**C**) sand tiger (Bay to 100 m), (**D**) Atlantic sharpnose (Bay to 100 m), (**E**) tiger (10-100 m), and (**F**) scalloped hammerhead sharks (Bay to >100 m). Numbers above the bars represent sharks/hooks.
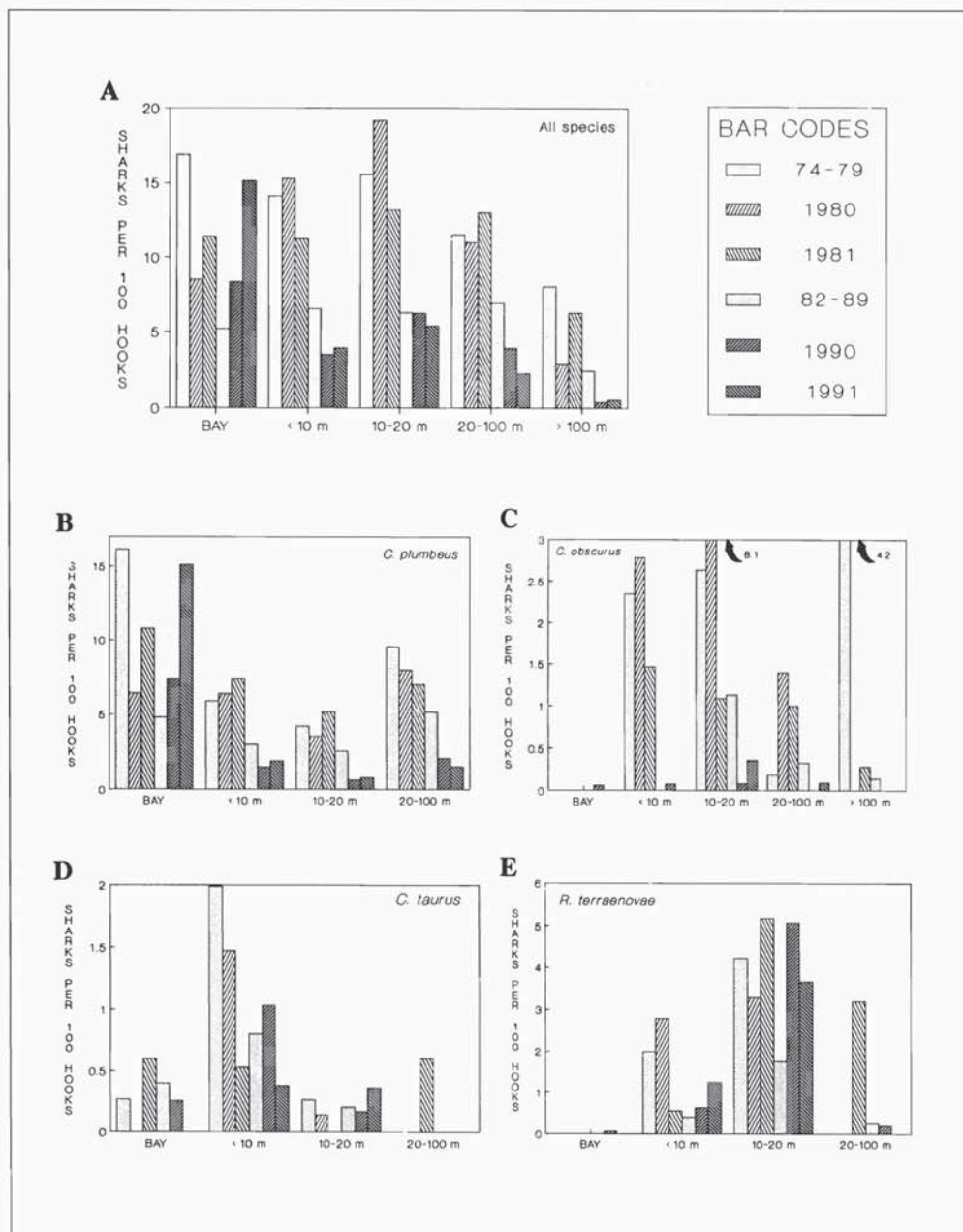
Figure 5
Shark catch per unit of effort for longlines fished in various depth strata by year category, 1974–1991. (**A**) all species combined, (**B**) sandbar, (**C**) dusky, (**D**) sand tiger, and (**E**) Atlantic sharpnose sharks.

Catch per Unit of Effort by Month over Time

Shark availability varied seasonally; thus, the declines seen over time and depth could have been affected by the months of the sampling effort in low-effort years. CPUE for all species combined showed a distinct decline by month of collection over time (Fig. 6A).

Two species — sandbar and dusky sharks — were taken in sufficient quantities over an extended period of the sampling season to permit examination of catch rates by month of capture. For the dusky shark, a graphic representation was unnecessary considering the near-total failure to capture this species in recent years. Total catch by month distinctly reflected the decline of the most common species, the sandbar shark (Fig. 6B). Sandbar sharks migrated into the Chesapeake region in May, were common throughout the summer, and began migrating south out of the area by mid-October. Catch rates have declined for all months since the early 1980's.
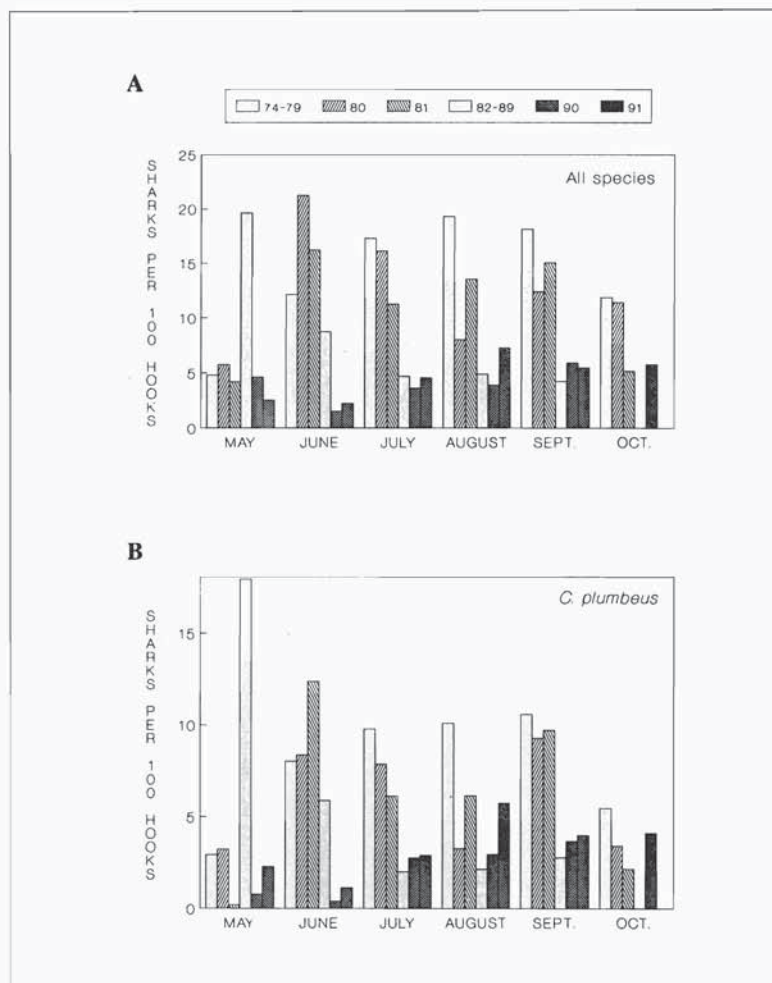
Figure 6
Shark catch per unit of effort on longlines by month by year category for
(**A**) all species, and (**B**) sandbar sharks.

Catch per Unit of Effort for Size Categories of Common Species

Two species, sandbar and dusky sharks, were collected in sufficient quantities to examine CPUE by size groups. Juvenile sandbar sharks were more abundant in the lower Chesapeake Bay, whereas juvenile dusky sharks were more abundant in shallow coastal habitats outside the Bay (Musick and Colvocoresses, 1988).

The majority of sandbar sharks collected were juveniles and adolescents, 50–150 cm TL, taken in bay and coastal (<10 m) waters, whereas sub-adults and adults were more common in waters >10 m (Fig. 7A). The sandbar shark catch was categorized into four 50 cm size groups, and analyzed for CPUE by depth.

Group 1 — juveniles (50–100 cm TL)
Group 2 — adolescents (100–150 cm TL)
Group 3 — sub-adults and young adults (150–200 cm TL)
Group 4 — large adults (>200 cm TL)

These categories had some general biological significance; the majority of small sandbar sharks collected in the nursery are <100 cm TL, but adolescents use nursery grounds until they are approximately 130–150 cm TL (Casey et al., 1985; Branstetter, 1990), and the majority of sub-adults and adults taken are less than 200 cm TL (Dodrill, 1977; Branstetter, 1981b; Casey et al., 1985) (Table 4).

Catch rates differed for juvenile and adolescent fish taken in their primary habitat - Bay and coastal (<10 m) waters (Figure 7B). For juveniles 50-100 cm, CPUE declined continually until 1990. During 1990 and 1991, catch rates showed a marked increase; and reasons for this apparent increase are discussed later. In contrast, catch rates continually declined for the 100–150 cm adolescents.

Because of the overall lower number of sub-adult and adult sharks collected, data from all depths (Bay to 100 m) were used for CPUE analysis of larger fish. Again, both size groups exhibited marked declines over the survey period (Fig. 7C). This was especially true for fish
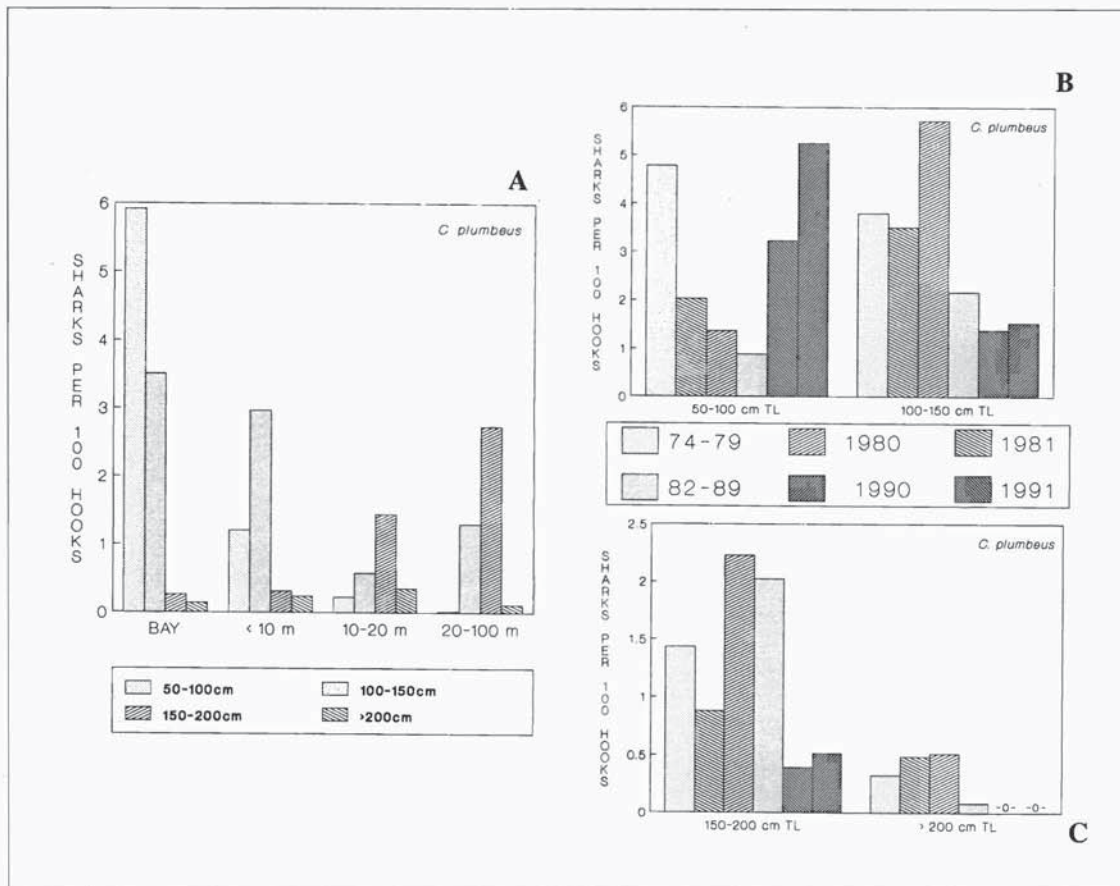
Figure 7
(A) Catch per unit of effort of four size classes of sandbar sharks in four depth strata illustrating the depth segregation by size class; juveniles are more common in bay and coastal waters, whereas sub-adults and adults are more common in continental shelf waters; (B) catch per unit of effort for two juvenile size classes of sandbar sharks taken on longlines in lower Chesapeake Bay and coastal (<10 m) waters; (C) catch per unit of effort for adolescent and young adults and large adults of the sandbar shark taken on longlines from the lower Chesapeake Bay to the 100-m depth contour.

>200 cm TL; since 1981, only three fish >200 cm were collected at survey sites; in 1990 and 1991, no fish were collected in this size category.

The vast majority of dusky sharks taken in the survey were juveniles (Table 5). Dusky sharks were divided into three size groups:

Group 1 — juveniles (<150 cm TL)
Group 2 — adolescents and sub-adults (150-275 cm TL)
Group 3 — adults (>275 cm).

As with the sandbar shark, these categories had a general biological significance; juveniles <150 cm TL are usually found in a nursery (Musick and Colvocoresses, 1988; Branstetter, 1990), and the species matures at approximately 275 cm TL (Compagno, 1984; Natanson, 1990). All three size classes showed a marked decline over time (Fig. 8a), especially juveniles. The drastic decline in CPUE of juveniles was further apparent in the CPUE analysis of this group by depth

strata (Fig. 8b). Dusky pups rarely entered the Bay proper; only one individual has ever been taken there during the survey. Coastal (<10 m) CPUE may have been biased in that a station which produced numerous individuals was dropped from the survey after 1983. However, 1981 data for both coastal and nearshore depth categories (<10 m and 10–20 m) showed a marked decline in number of juveniles compared with the period 1974 through 1980; this reduction has continued to the present. Additionally, catches declined at stations fished continuously throughout the survey period.

Larger dusky sharks were not common in the survey (Table 5). Adolescents (150–275 cm) were taken consistently, but in low numbers each year. However, prior to a single capture in 1991, none had been taken since 1987. Mature dusky sharks (>275 cm TL) have been rare in VIMS longline collections (9 since 1974); however, the most recent captures were in 1982.

Table 4
Percent distributions of sandbar shark size classes (cm TL) collected in each depth stratum from Chesapeake Bay to the 100-m depth contour for each time-series. Some time series may not total 100% because of rounding.

Years	Size class (%) <100	100–150	150-200	>200	Size class (%) <100	100–150	150–200	>200
Bay					**<10m**			
74–79	55	38	4	3	34	50	11	5
1980	4	83	4	9	34	59	3	3
1981	17	64	10	9	17	76	7	1
82–89	33	33	22	11	11	86	4	0
1990	69	30	1	0	63	32	5	0
1991	85	15	0	0	20	60	20	0
Mean %	44	44	7	5	30	61	7	2
10–20 m					**20–100 m**			
74–79	47	47	7	0	0	33	63	4
1980	12	24	32	32	3	30	60	8
1981	0	16	67	18	0	17	81	2
82–89	4	8	84	4	0	28	70	2
1990	13	38	50	0	0	36	64	0
1991	0	44	56	0	0	50	50	0
Mean %	13	30	49	9	1	32	65	3

Discussion

The VIMS longline catch was dominated by the sandbar shark. Large sandbar sharks use the mid- Atlantic region seasonally as a feeding ground; more importantly, the bays, inlets, and barrier island areas from Chesapeake Bay to New Jersey are a major nursery ground for this species (Milstein, 1978; Medved and Marshall, 1981, 1983; Casey et al., 1985; Musick and Colvocoresses, 1988). Juveniles occupy these areas during the summer for the first several years of life until

they are 130–150 cm TL, moving offshore and south in winter, and returning in the spring (Casey et al., 1985; Musick and Colvocoresses, 1988). Use of nursery grounds may reduce juvenile mortality associated with predation by larger sharks (Branstetter, 1990).

CPUE increased markedly within the Bay for 1990 and 1991 (Fig. 5A), primarily from catches of juvenile (50–100 cm TL) sandbar sharks in their nursery ground (Table 4; Fig. 7B). Although this phenomenon is similar to a documented proliferation of juvenile dusky sharks off South Africa (van der Elst, 1979) which was associated with a drastic decline in large predatory sharks. The apparent increase in relative abundance of small sandbar sharks that we observed in Chesapeake Bay may also be due to increased survivorship of young of the year, because of a large decline (60–80%) in large coastal sharks that are their principal predators. Regardless, this compensatory mechanism can be only temporary at best as the remaining mature females are captured by the fishery.

This abundance of small, juvenile sandbar sharks within Chesapeake Bay artifically inflated the overall catch rates during this time period; overall catch rates appeared to be relatively stable since the early 1980's (Fig. 3). Exclusion of all Bay efforts removed this bias and indicated a continued decline in CPUE, even between 1990 and 1991 (Fig. 9). By excluding efforts in the sandbar shark nursery ground, where individuals are concentrated in specific areas, this analysis provides a more realistic trend in shark population abundance for the region over time.

Table 5
Catch by year category of dusky shark individuals in three size classes taken on VIMS longines, 1974-1991, from Chesapeake Bay to the 100 m depth contour.

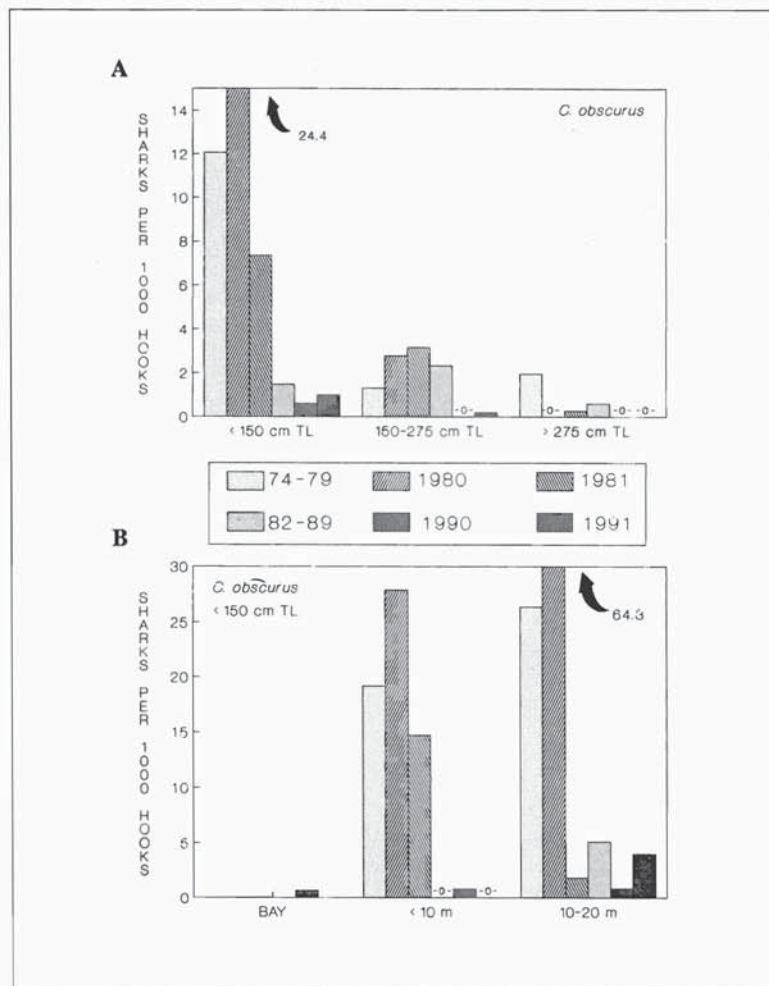| Group	Hooks	Size class (cm TL) <150	150–275	>275
74–79	3067	37	4	6
1980	4300	105	12	0
1981	3800	28	12	1
82–89	3410	5	8	2
1990	5057	3	0	0
1991	5050	5	1	0
Total	24684	183	37	9

Figure 8
(A) Catch per unit of effort (sharks/1000 hooks) on longlines for three size classes of dusky sharks taken from Chesapeake Bay to the 100-m depth contour. (B) Catch per unit of effort (sharks/1000 hooks) by depth for juvenile dusky sharks (<150 cm TL) taken on longlines in lower Chesapeake Bay to the 20-m depth contour.

The biology of sharks limits their potential for exploitation (Branstetter, 1990; Pratt and Casey, 1990). This is apparently true for the sandbar shark, considering the declining CPUE's exhibited here. The species is slow-growing ($K = 0.04$–0.06), and does not reach maturity (>180 cm TL) until it is 13–15 years of age (Casey et al., 1985). Fecundity is low; females produce 6–10 young after a one-year gestation period, and have, at least, a one-year resting stage in the reproductive cycle. Only 25–50% of females collected are pregnant (Springer, 1960; Clark and von Schmidt, 1965; Dodrill, 1977; Cliff et al., 1989). Hypothetical maximum ages from von Bertalanffy growth models reach as high as 50 years of age (Casey et al., 1985), but this may be an artifact of the exponential nature of the model. The oldest individuals aged by analysis of vertebral ring structure have

been <25 years old (Lawler, 1976; Casey et al., 1985). However, tagged juvenile sandbar sharks have been recaptured after 25 years at liberty (Casey et al., 1990, 1991); a maximum age of at least 30 years may be more realistic. Given an age at maturity of 15 years, a life span of 35 years (Hoff, 1990), and a two year reproductive cycle, each female may reproduce about ten times.

Although the biology of the dusky shark is more poorly understood, there are components of their life history that may explain the drastic decline noted here. The dusky shark is a slow-growing species ($K = 0.05$–0.06: Lawler, 1976; Schwartz, 1983; Natanson, 1990) that does not mature (>275 cm TL) until it is about 17 years of age (Natanson, 1990). The reproductive cycle is not well understood. Clark and von Schmidt (1965) suggested a 16-month gestation period with two dis-
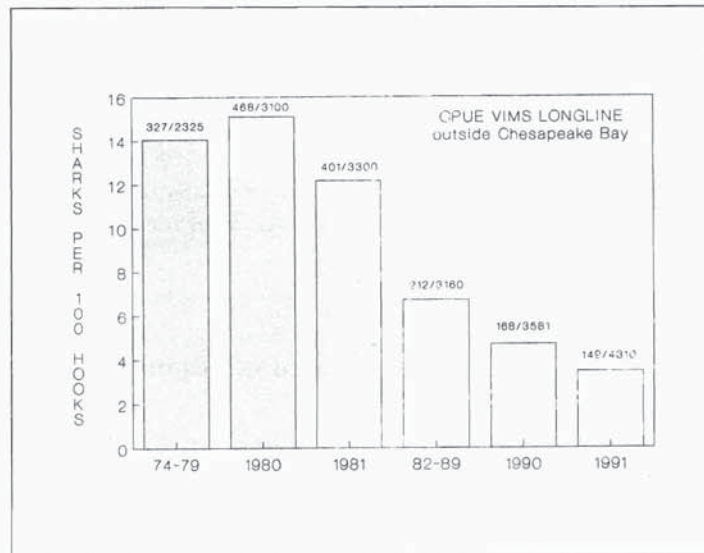
Figure 9
Catch per unit of effort on longlines fished in the Chesapeake
Bight, excluding efforts in the sandbar shark nursery ground within
Chesapeake Bay.

tinct reproductive groups of females: one that pupped
in late June–early July, and the other in December–
January. However, their data, in combination with addi-
tional literature records (Dodrill, 1977; Branstetter,
1981b), can also be used to illustrate a single-phased
gestation period of about 22 months. With a one-year
resting stage for post-partum females, the entire repro-
ductive cycle would require at least three years. Dodrill
(1977) noted that only about 20% of the mature fe-
males he examined were gravid. The number of young
is 6–12, and most litters comprise about 10 pups
(Natanson, 1990) that are correspondingly large (90–
100 cm TL) in relation to the extended gestation pe-
riod. The oldest specimens aged (Natanson, 1990) were
30–35 years old; thus, with a three-year reproductive
cycle, the species may reproduce only about seven times.

Given the direct relationship between stock and re-
cruitment for sharks (Holden, 1974, 1977), the de-
clines in juvenile abundance strongly suggests a re-
duced parental stock size (Musick and Colvocoresses,
1988). Large dusky sharks have become a rarity in
recreational fishing tournaments and commercial land-
ings (Hueter;[1] Burgess[3]). A longer reproductive cycle,
and corresponding lowered annual production, coupled
with increased fishing mortality, may be important in
the apparent reductions in the population size of this
species over the last 10 years.

Based on their biology, estimates of the intrinsic rate
of increase (*r*) for slow-growing species such as the

sandbar and dusky sharks are between 0.015 and 0.020
(Hoenig and Gruber, 1990; Hoff, 1990). In other words,
with a stable age structure, the population can increase
only about 2% per year; thus there is little flexibility in
the population's ability to withstand additional mortal-
ity associated with fishing (Hoff, 1990). It is probable
that some of the declines of sandbar and dusky sharks
are associated with the recent exponential rise in com-
mercial efforts; both species are preferred targets of
this fishery. However, the decline in the CPUE for both
species in the VIMS survey began in the early 1980's,
prior to the escalation of the U.S.-directed commercial
fishery about 1985 (NMFS[2]). These early declines may
have been associated with the combined heavy fishing
pressure from 1) the recreational shark fishery that
expanded rapidly along the U.S. Atlantic coast in the
1970's (Casey and Hoey, 1985), 2) the bycatch associ-
ated with an expanding swordfish and tuna longline
fishery in the late 1970's and early 1980's (Berkeley and
Campos, 1988), and 3) increasing foreign efforts such
as the expanding Mexican shark fishery in Yucatan
(Bonfil et al. 1990) that probably harvests the same
stock (Hoff and Musick, 1990). Thus, the directed U.S.
commercial fishery may simply have been the "straw
that broke the camel's back."

In contrast to these slow-growing species, the Atlan-
tic sharpnose shark grows rapidly, matures quickly, and
reproduces often. Females mature in 3–4 years (85 cm
TL), and give birth to 4–6 relatively large young (30 cm
TL) after an 11–12 month gestation period (Branstetter,
1981b, 1987; Parsons, 1983 a and b, 1985). The repro-

---

[3]G. Burgess. Univ. Fla., Gainesville, FL, pers. commun. 1991)

ductive cycle does not include a resting stage; females mate and ovulate approximately one month after parturition (Branstetter, 1981b; Parsons, 1983b). Maximum age is estimated to be about 10 years (Branstetter, 1987). Because of its small size, this species is not targeted by commercial fishermen, however, it is a frequent bycatch on longlines targeting larger sharks (Branstetter, 1981b; Cody et al., 1981). It is also a major species taken in the recreational fishery of the southeast U.S. Atlantic coast and the Gulf of Mexico (NMFS[2]; Parrack, 1990).

The relatively rapid recruitment for this species suggests that it would be more resilient to fishing pressure than other carcharhinids. Parrack (1990) estimated that present production approximates the catch rate. However, our data indicate that CPUE may be declining for this small coastal shark. Parrack may have underestimated mortality for this species in that he did not include the significant commercial bycatch of this species in his mortality estimates; however, he did note that this species has the potential for quick recovery with a reduction of fishing effort.

Conclusions

In the recent past sharks were underutilized; 58% of the estimated recreational and commercial catch was discarded (Hoff and Musick, 1990). Apparently, however, they were not underexploited. Since 1980, the combined recreational and commercial fishing mortality has averaged 22,000 t/year (NMFS[2]); however, MSY for U.S. waters was estimated at 9,800–16,250 t (Anderson, 1985; Parrack, 1990), therefore mortality was 1.5–2.0 times MSY.

This over-exploitation is reflected in the declining CPUE for both juveniles and adults of the primary species taken in the Chesapeake Bight region of the mid-Atlantic coast. General declines in shark CPUE have been documented in both the U.S. Atlantic recreational and commercial fisheries (Parrack, 1990). Similar declines in stock abundance and size of landed fish, reflecting over-exploitation, have been noted for various shark species targeted in expanding California fisheries (Holts, 1988; Smith and Abramson, 1990), and in past elasmobranch fisheries worldwide (Aasen, 1963; Holden, 1977; Grant et al., 1979; Anderson, 1990b).

The intrinsic biological characteristics of this group of fishes makes direct exploitation of limited scope on a sustainable basis, and elasmobranch fisheries must be closely managed from the outset to avoid over- exploitation. Our data suggest that a lack of timely management contributed to a 60–80% decline in the population size of the common shark species that seasonally inhabit the mid-Atlantic region. Because these species migrate seasonally into this region from more south-

erly latitudes, the declines for this region are most likely representative of the stock condition throughout the majority of southeastern U.S. waters. Given the limited ability of many shark species to increase their population sizes (Hoff, 1990), this multi-species stock will take many years to recover, even after stringent management measures are implemented.

Acknowledgments

Literature Cited

Aasen, O.
    1963.   Length and growth of the porbeagle (*Lamna nasus* Bonnaterre) in the northwest Atlantic. Fiskeridir. Skr. Ber. Havunder. 13:20–37.
Anderson, E.D.
    1985.   Analysis of various sources of pelagic shark catches in the northeast and western central Atlantic Ocean and Gulf of Mexico. *In* Shark catches from selected fisheries off the U.S. East Coast, p. 1–14. NOAA Tech. Rep. NMFS 31.
    1990a.   Estimates of large shark catches in the Western Atlantic and Gulf of Mexico, 1960-1986. *In* Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries (H.L. Pratt Jr., S.H. Gruber, and T. Taniuchi, eds.), p. 443–454. NOAA Tech. Rep. NMFS 90.
    1990b.   Fisheries models as applied to elasmobranch fisheries. *In* Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries (H.L. Pratt Jr., S.H. Gruber, and T. Taniuchi, eds.), p. 473–484. NOAA Tech. Rep. NMFS 90.
Beaumariage, D.S.
    1968.   Commercial shark fishing and processing in Florida. Fla. Board Conserv., Mar. Res. Lab, Educational Series No. 16, 21 p.
Berkeley, S.A., 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., D. de Anda, and R. Mena.
    1990. Shark fisheries in Mexico: the case of Yucatan as an example. *In* Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries (H.L. Pratt Jr., S.H. Gruber, T. Taniuchi, eds.), p. 427–441. NOAA Tech. Rep. NMFS 90.

Branstetter, S.
    1981a. Shark fishery potential for the north-central Gulf of Mexico. Dauphin Island Sea Lab (Ala.) Tech. Rep. 81-001, 21 p.
    1981b. Biological notes on the sharks of the north-central Gulf of Mexico. Contrib. Mar. Sci. 24:13–34.
    1987. Age and growth validation of newborn sharks held in laboratory aquaria, with comments on the life history of the Atlantic sharpnose shark, *Rhizoprionodon terraenovae.* Copeia 1987:291–300.
    1990. Early life-history implications of selected carcharhinoid and lamnoid sharks of the Northwest Atlantic. *In* Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries (H.L. Pratt Jr., S.H. Gruber, and T. Taniuchi, eds.), p. 17–28. NOAA Tech. Rep. NMFS 90.

Branstetter, S., and J.A. Musick.
    In press. A comparison of shark catch rates on longlines using rope/steel (Yankee) and monofilament gangions. Mar. Fish. Rev.

Byers, R.D.
    1940. The California shark fishery. Calif. Fish and Game 26(1):23–28.

Cailliet, G.M., and D.W. Bedford.
    1983. The biology of three pelagic sharks from California waters, and their emerging fisheries. Calif. Coop. Fish. Invest. Rep. 24:57-69.

Casey, J.G., and J.J. Hoey.
    1985. Estimated catches of large sharks by U.S. recreational fishermen in the Atlantic and Gulf of Mexico. *In* Shark catches from selected fisheries off the U.S. East Coast, p. 5–19. NOAA Tech. Rep. NMFS 31.

Casey, J.G., and N.E. Kohler.
    1990. Long distance movements of Atlantic sharks from the NMFS cooperative shark tagging program. *In* Discovering sharks (S.H. Gruber, ed.), p. 87–91. American Littoral Society, New Jersey.

Casey, J.G. H.L. Pratt Jr., N. Kohler, and C.E. Stillwell.
    1990. The shark tagger: 1990 summary. Newsletter, coop. shark tagging program. U.S. Dep. Commer., NOAA, NMFS, Narragansett, RI, 12 p.
    1991. The shark tagger: spring 1991. Newsletter, coop. shark tagging program. U.S. Dep. Commer., NOAA, NMFS, Narragansett, RI, 2 p.

Casey, J.G., H.L. Pratt, Jr., and C.E. Stillwell.
    1985. Age and growth of the sandbar shark (*Carcharhinus plumbeus*) from the western North Alantic. Can. J. Fish. Aquat. Sci. 42(5):963–975.

Clark, E., and K. von Schmidt.
    1965. Sharks of the central Gulf coast of Florida. Bull. Mar. Sci. 15:13–83.

Cliff, G., S.F.J. Dudley, and B. Davis.
    1989. Sharks caught in the protective gill nets off Natal, South Africa. 1. The sandbar shark, *Carcharhinus plumbeus* (Nardo). South Afr. J. Mar. Sci. 7:255–265.

Cody, T.J., B.E. Fuls, G.C. Matlock, and C.E. Bryan.
    1981. Assessment of bottom longline fishing off the Central Texas coast; a completion report. Texas Parks and Wildl. Dep., Coastal Fish. Branch, Mgmt. Data Ser. 22, 51 p.

Colvocoresses, J.A., and J.A. Musick.
    1980. A preliminary evaluation of the potential for a shark fishery in Virginia. Va. Inst. Mar. Sci., Special Sci. Rep., No. 234, 39 p.

Cook, D.
    1982. Virginia's winter shark fishery a promising alternative. Mar. Res. Bull., Va. Sea Grant 12(4), 12 p.

Cook, S. (editor)
    1987. Sharks; an inquiry into biology, behavior, fisheries, and use. proceedings of a conference; Portland, OR, 13-15 October 1985. Oregon State Univ. Ext. Service, 237 p.

Dodrill, J.W.
    1977. A hook and line survey of the sharks found within five hundred meters of shore along Melbourne Beach, Brevard County, Florida. M.S. thesis, Florida Inst. Technol., Melbourne, FL, 304 p.

Florida Sea Grant.
    1985. Manual on shark fishing. Florida Sea Grant College, Sea Grant Rep. No. 73, 44 p.

Graham, G.
    1987. The development of Gulf coast shark fisheries; synopsis. *In* Sharks: an inquiry into biology, behavior, fisheries, and use (S. Cook, ed.), p. 179–181. Oregon State Univ. Ext. Service.

Grant, C.J., R.L. Sandland, and A.M. Olsen.
    1979. Estimation of growth, mortality and yield per recruit of the Australian school shark, *Galeorhinus australis* (Macleay), from tag recoveries. Austr. J. Mar. Freshwater Res. 30:625–637.

Gordievskaya, V.S.
    1971. (1973). Shark flesh in the food industry. Israel program for scientific translation for NOAA/NMFS. IPST catalog No. 60080 2, Springfield, VA, 26 p.

Hoenig, J.M., and S.H. Gruber.
    1990. Life-history patterns in the elasmobranchs: implications for fisheries management. *In* Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries (H.L. Pratt Jr, S.H. Gruber, and T. Taniuchi, eds.), p. 1–16. NOAA Tech. Rep. NMFS 90.

Hoff, T.B.
    1990. Conservation and management of the Western North Atlantic shark resource based on the life history strategy limitations of sandbar sharks. Ph.D. diss., Univ. Delaware, 282 p.

Hoff, T.B., and J.A. Musick.
    1990. Western North Atlantic shark fishery management problems and informational requirements. *In* Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries (H.L. Pratt Jr., S.H. Gruber, and T. Taniuchi, eds.), p. 455-472. NOAA Tech. Rep. NMFS 90.

Holden, M.J.
    1974. Problems in the rational exploitation of elasmobranch populations and some suggested solutions. *In* Sea fisheries research (F.R. Hardin-Jones, ed.), p. 117–137. John Wiley and Sons, N.Y.
    1977. Elasmobranchs. *In* Fish population dynamics (J.A. Gulland, ed.), p. 187–214. John Wiley and Sons, New York.

Holts, D.B.
    1988. Review of U.S. west coast commercial shark fisheries. Mar. Fish. Rev. 50(1):1–8.

Kleign, L.J.K.
    1974. Results of experimental and exploratory shark fishing off northeastern South America. Mar. Fish. Rev. 36(9):67–78.

Kreuzer, R., and R. Ahmed.
    1978. Shark utilization and marketing. Food and Agricultural Organization of the United Nations, Rome, Italy; FAO/UNCTAD/GATT, 180 p.

Lawler, E.F.
    1976. The biology of the sandbar shark, *Carcharhinus plumbeus* (Nardo, 1827), in the lower Chesapeake Bay and adjacent waters. M.A. thesis, Va. Inst. Mar. Sci., College of William and Mary, 49 p.

Medved, R.J., and J.A. Marshall.
    1981. Feeding behavior and biology of young sandbar sharks, *Carcharhinus plumbeus* (Pisces, Carcharhinidae), in Chincoteague Bay, Virginia. Fish. Bull. 79(3):441–448.
    1983. Short-term movements of young sandbar sharks, *Carcharhinus plumbeus* (Pisces, Carcharhinidae). Bull. Mar. Sci. 33(1):87–93.

Milstein, C.B.
    1978. Sharks taken by longline in inshore New Jersey waters during 1973 and 1974. Bull. New Jersey Acad. Sci. 23(1):34–38.

Musick, J.A., and J.A. Colvocoresses.
    1988. Seasonal recruitment of subtropical sharks in Chesapeake Bight, U.S.A. *In* Workshop on recruitment in tropical coastal demersal communities (A. Yanez, Y Arancibia, and D. Pauly, eds.); Campeche, Mexico, 21–25 April 1986. FAO/UNESCO, I.O.C. workshop report No. 44.

Natanson, L.
    1990. Relationship of vertebral band deposition to age and growth in the dusky shark, *Carcharhinus obscurus*, and the little skate, *Raja erinacea*. Ph.D. diss., Univ. Rhode Island, 153 p.

Olsen, A.M.
    1959. The status of the school shark fishery in southeastern Australian waters. Austr. J. Mar. Freshwater Res. 10:150–177.
    1984. Synopsis of biological data on the school shark, *Galeorhinus australis* (Macleay 1881). FAO Fish. Synopsis No. 139, 42 p.

Parrack, M.L.
    1990. A study of shark exploitation in U.S. Atlantic coastal waters during 1986–1989. NOAA/NMFS SEFC contrib. MIA-90/91-03, 14 p.

Parsons, G.R.
    1983a. The reproductive biology of the Atlantic sharpnose shark, *Rhizoprionodon terraenovae* (Richardson). Fish. Bull. 81:61–73.
    1983b. An examination of the vertebral rings in the Atlantic sharpnose shark, *Rhizoprionodon terraenovae*. Northeast Gulf Sci. 6:63–66.
    1985. Growth and age estimation of the Atlantic sharpnose shark, *Rhizoprionodon terraenovae:* a comparison of techniques. Copeia 1985:80–85.

Pratt, H.L. Jr., 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* Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of

the fisheries (H.L. Pratt Jr., S.H. Gruber, and T. Taniuchi, eds.), p. 97–109. NOAA Tech. Rep. NMFS 90.

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

Ronsivalli, L.J.
    1978. Sharks and their utilization. NOAA/NMFS Mar. Fish. Rev. paper 1281, 13 p.

Schwartz, F.J.
    1983. Shark ageing methods and age estimation of scalloped hammerhead, *Sphyrna lewini*, and dusky, *Carcharhinus obscurus*, sharks based on vertebral rings. *In* Proceedings of the international workshop on age determination of oceanic pelagic fishes: tunas, billfishes, and sharks (E.D. Prince and L.M. Pulos, eds.), p. 167–174. NOAA Tech. Rep. NMFS 8.

Smith, S.E., and N.J. Abramson.
    1990. Leopard shark, *Triakis semifasciata*, distribution, mortality rate, yield, and stock replenishment estimates based on a tagging study in San Francisco Bay. Fish. Bull. 88:371–382.

Springer, S.
    1949. An outline for a Trinidad shark fishery. Proc. Gulf and Caribb. Fish. Inst. 2nd ann. session, Miami Beach, p. 1–10.
    1951. The effect of fluctuations on the availability of sharks on a shark fishery. Proc. Gulf and Caribb. Fish. Inst. 4th ann. session:140–145.
    1960. Natural history of the sandbar shark, *Eulamia milberti*. Fish. Bull., 61(178), 38 pp.
    1979. Report on shark fishing in the Western Central Atlantic. FAO/WECAF (Panama) report No. 3, 37 p.

Springer, S., and P.M. French.
    1944. Vitamin A in shark liver oils. Industr. Engin. Chem. 36:190–191.

Springer, S., and P.W. Gilbert.
    1963. Anti-shark measures. *In* Sharks and survival (P.W. Gilbert, ed.), Section VI, Chap. 18, p. 465–476. Heath and Co., Boston.

Stevens, J.D., T.L.O. Davis, and A.G. Church.
    1982. NT shark gillnetting survey shows potential for Australian fishermen. Austr. Fish. (April) 1982:39–43.

Thorson, T.B.
    1982. The impact of commercial exploitation on sawfish and shark populations in Lake Nicaragua. Fisheries 7(2): 2–10.

Van der Elst, R.P.
    1979. A proliferation of small sharks in the shore-based Natal sport fishery. Environ. Biol. Fishes 4(4):349–362.

Witzell, W.N.
    1985. The incidental capture of sharks in the Atlantic United States Fishery Conservation Zone reported by the Japanese tuna longline fleet. *In* Shark catches from selected fisheries off the U.S. East Coast, p. 21–22. NOAA Tech. Rep. NMFS 31.

Yoccoz, N.G.
    1991. Use, overuse, and misuse of significance tests in evolutionary biology and ecology. Bull. Ecol. Soc. America 72(2):106–111.