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Evaluation of Bycatch in the North Carolina Spanish and King Mackerel Sinknet Fishery with Emphasis on Sharks During October and November 1998 and 2000 Including Historical Data from 1996 -1997

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ABSTRACT

Shark bycatch with an emphasis on sandbar, *Carcharhinus plumbeus*, and dusky, *C. obscurus*, sharks was evaluated from October-November 1996-1998 and 2000 during Spanish mackerel, *Scomberomerus maculatus*, and king mackerel, *S. cavalla*, sinknet fishing at Cape Hatteras, North Carolina. Twelve species of sharks representing six families were documented. The percentage of species abundance was: Smooth dogfish, *Mustelus canis*, 45.3%, sandbar shark 41.9%, Atlantic sharpnose shark, *Rhizoprionodon terraenovae* 9.3%, dusky 0.9%, spinner, *C. brevipinna* 0.8%, Atlantic angel shark, *Squatina dumerili* 0.7%, common thresher, *Alopias vulpinus* 0.6%, and other species 0.4% (spiny dogfish, *Squalus acanthias*, sandtiger, *Odantaspis taurus*, blacktip, *C. limbatus*, scalloped hammerhead, *Sphyrna lewini*, and smooth hammerhead, *S. zygaena*). Data suggest that the region off Cape Hatteras is an important overwintering nursery ground for neonatal (young of the year) and juvenile sandbar sharks, supporting the findings of other studies. Evidence suggests that dusky sharks use the region as primary, secondary, and overwintering nursery grounds. Acute mortality was 10% for sandbar sharks and 11% for dusky sharks over the period. Both sandbar and dusky sharks were dominated by neonate and small juveniles of 50-60 cm and 80-90 cm fork length (FL) respectively. Data are provided for soak times, mortality rates, CPUE, length frequency, mesh size and sex ratios for sandbar and dusky sharks. Length frequency and mesh size data are provided for the smooth dogfish and Atlantic sharpnose sharks. Overall acute mortality rates and sex ratios are provided for all shark species. Length frequencies are provided for the Atlantic angel shark, common thresher, and spinner sharks.

Evidence suggests that the Cape Hatteras region is used as a primary and secondary nursery ground for the sandtiger, common thresher, smooth dogfish, spinner, and Atlantic sharpnose sharks and a secondary nursery for the smooth hammerhead. Corroboration with other studies suggests the region is used as primary and secondary nursery grounds for the sandbar shark.

The smooth dogfish was the only shark species that demonstrated selectivity based on length frequency by mesh size. Further selectivity studies are needed to evaluate mesh size for shark species examined in this fishery.

Spanish mackerel are dominated by age 1-3, (30-50 cm FL) and enter the fishery at age 1 or less, while king mackerel are dominated by age 5-7, (80-95 cm FL) and enter the fishery at age 2. Data are presented for sex ratios, length frequency and mesh size, acute mortality, and length/weight relationships for Spanish and king mackerel.

Data are provided for cobia, *Rachycentron canadum*, and little tunny, *Euthynnus alletteratus*, as well as the status of other elasmobranchs and teleost fishes.

INTRODUCTION

Background of the Fishery

The region of Cape Hatteras, North Carolina supports a substantial gillnet day fishery in state waters for Spanish (*Scomberomerus maculatus*) and king mackerel (*Scomberomerus cavalla*). Spanish mackerel are present in commercial catches from May to October from Core Banks, NC to Buxton at Cape Hatteras, decreasing in abundance by mid October with only scattered numbers into late November. King mackerel appear in commercial catches during mid October, and remain in the fishery until about the third week of November. Water temperature in conjunction with strong weather systems during October and November are the limiting factors in the abundance of these mackerel species from year to year. The fishing gear used to target both species is sinking gillnets, referred to in the commercial industry as sinknets or dropnets. Sinknets extend from the bottom and fish part of the water column or in some cases the entire water column depending on individual preference. The fishing techniques described in this study are consistent among the Spanish and king mackerel fleet fishing the Cape Hatteras region.

Bycatch in the fishery consists of a variety of elasmobranchs and teleosts. Many of these species either have been or are currently landed as an addition to the days catch. These species include the common thresher shark, *Alopias vulpinus*, cobia, *Rachycentron canadum*, little tunny, *Euthynus alletteratus*, and members of the family Scaenidae. Shark bycatch from mid October to the third week of November is dominated by members of the family Carcharhinidae most notably the smooth dogfish, *Mustelus canis*, sandbar shark, *Carcharhinus plumbeus*, and Atlantic sharpnose shark, *Rhizoprionodon terraenovae*. Due to the abundance of sharks in this fishery, shark damage to marketable species is of constant concern. Also, large numbers of sharks create a tremendous burden in clearing the nets, particularly if they must be discarded, as well as net damage. These factors create a fast paced fishery in which nets are routinely checked for the presence of sharks; retrieved or reset thus inadvertently creating a better opportunity of survival for discarded sharks.

Historical data and nursery grounds

Shark data were obtained in this fishery during October 1996 and November 1997 aboard the fishing vessel (F/V) Water Sport. The data indicated that this region and adjacent areas in the vicinity of Cape Hatteras is an important overwintering and secondary nursery ground for neonate (young of the year, age 0) and small juvenile sandbar sharks (≥ age 1+). Since the sandbar shark is one of the most important species in the directed commercial longline shark fishery in the Southeast US, additional life history information will be useful for fishery management purposes (Pratt and Casey, 1990; Branstetter and Burgess, 1997; NMFS, 1993; 1999a). Moreover, recommendations for future elasmobranch research include habitat requirements, fate of the young, and delineation of pupping areas (Pratt and Otake, 1990).

Primary nursery grounds are defined as habitat in which parturition and neonatal sharks occur, while secondary nursery grounds are areas that are used by juveniles (age 1+). Juveniles also inhabit primary nursery grounds (Merson, 1998; Pratt, et. al 1998). Castro (1993) stated that nursery grounds are characterized by both the occurrences of gravid females and neonates (YOY). Neonate and juvenile (age 1+) sandbar sharks tagged during summer months in the Chesapeake and Delaware Bays (major sandbar shark pupping and primary nursery grounds) were recaptured during the fall in the Cape Hatteras region (Pratt, et. al, 1998; VIMS; Kohler, pers comm). Conversely, neonate sandbar sharks tagged in the fall off Cape Hatteras were recaptured during summer months in and around Chesapeake and Delaware Bays (Kohler, pers comm). These data suggest a fairly low mortality rate for sandbar sharks. Additionally, neonate and juvenile dusky sharks, *Carcharhinus obscurus*, (now a prohibited species, NMFS, 1999a) were observed in the area.

SYNOPSIS

The abundance of sharks in this region provided a unique opportunity to document several variables: 1) data would be useful for shark management in North Carolina state waters, 2) data would supplement the on-going Cooperative Atlantic States Shark Pupping and Nursery Survey (COASTSPAN) conducted by individual states for the National Marine fisheries Service (NMFS), Apex Predators Program (APP) on critical habitat for shark management, 3) tag large numbers of sharks in a relatively short time for ongoing migration and age and growth studies conducted by the APP, 4) records of soak times with survival rates of sharks, particularly the sandbar and dusky sharks, 5) basic knowledge of mesh size selectivity on sharks to supplement other studies, and 6) information on Spanish and king mackerel as well as the disposition of other elasmobranchs and teleosts would be useful for fishery managers with the NCDMF.

MATERIALS AND METHODS

Historical data, region, and time 1996-1997

Shark bycatch data were collected during Spanish and king mackerel sinknet operations between Cape Hatteras and Ocracoke Island, North Carolina between 19 - 31 October (9 days) and 4 - 5 November 1997 (2 days). The shark data were included with the present study data. However, these data were not included with the 1998 and 2000 net mesh size. The area, gear, and fishing techniques were identical to the present study.

Current data, region, and time 1998 and 2000

Spanish and king mackerel sinknet operations were conducted between 14 October - 12 November 1998 (ten days) and 25 October - 21 November 2000 (twelve days) aboard the 14.6 meter (m) (48 foot) fishing vessel (F/V) Water Sport. The mackerel fishery was not pursued during the 1999 fall season. The fishing area was in North Carolina state waters (<3 nautical miles from shore) between Cape Hatteras (35°14'N 75°31'W) and Portsmouth Island (35°00'N 76°06'W) (Figure 1). The Spanish mackerel season in this region runs through the first two weeks of October. A transition from Spanish to king mackerel occurs during mid-October (± 1 week). Both Spanish and king mackerel are caught at this time, however past the third week of October, the catch is dominated by king mackerel. King mackerel disappear from the fishery in state waters after the third week of November as the water temperature drops below 16.7 - 17.8° C (62-64° F). Therefore, a wide range of stretch mesh size [8.26 - 15.24 cm (3.25 - 6")] are used during this time as both species may be encountered. All small mesh nets were used to target Scaeanids during poor mackerel conditions on 7 November 1998.

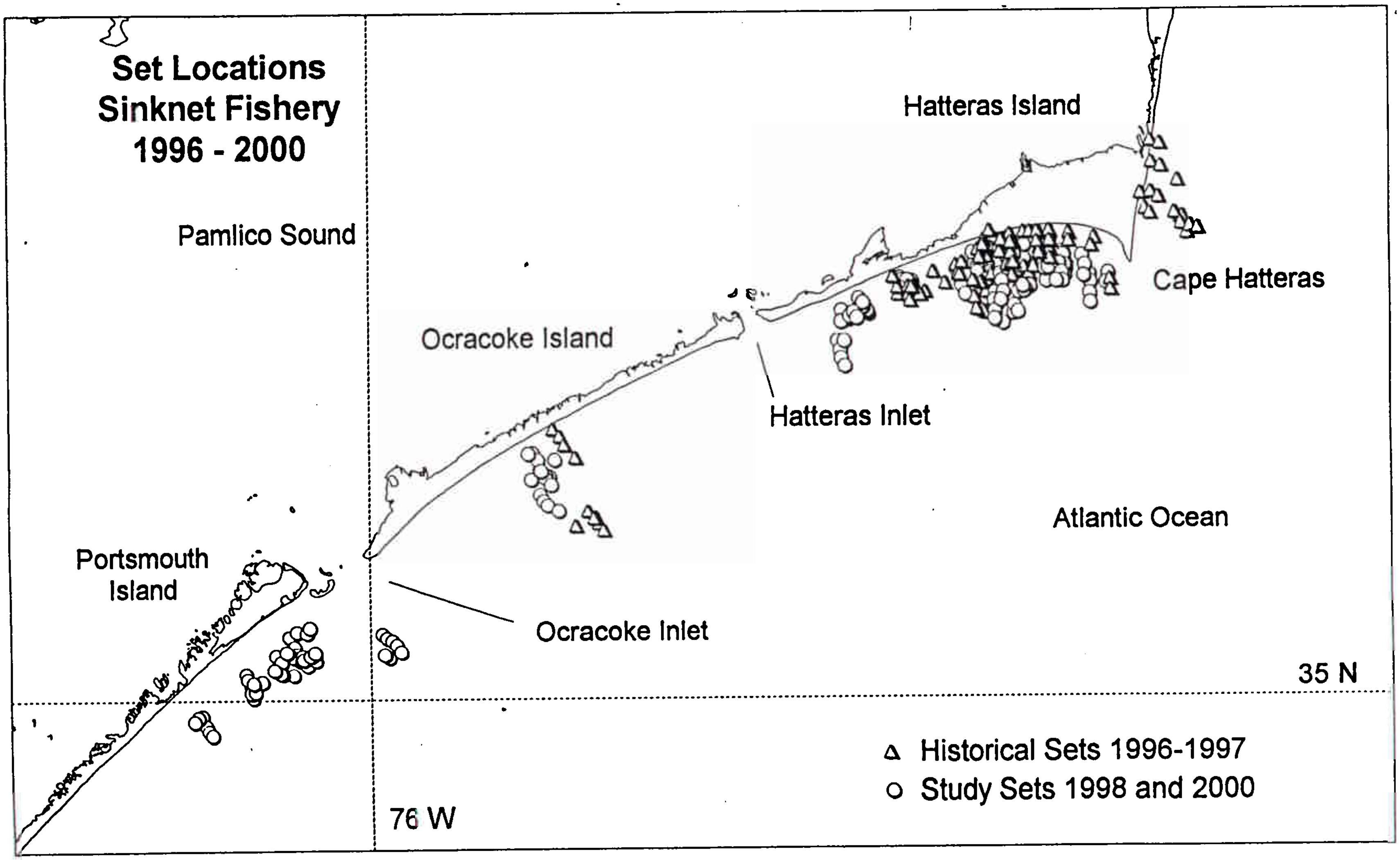


Figure 1: Spanish and king mackerel sinknet sample locations during the years 1996 to 1998 and 2000 at Cape Hatteras, NC.

This day was included in the data set as part of the study since sharks were captured. Otherwise, normal fishing operations were conducted throughout the study.

No special treatment was given to location and soak times. Gear was set to avoid shark concentrations, i.e., normal mackerel fishing practices[1].

Gear Description and Deployment 1998 and 2000

All nets used during the study were non-anchored monofilament sinking gillnets (sinknets) 182.9 - 457.2 m (200 - 500 yards) total length comprised of 30.5 m (100 yd) sections. Nets were attached at each end to 3.81 m (12.5 ft) bridles connected to 18.3 m (60 ft) float lines and marked with a single plastic poly form float. Nets were suspended in the water column using plastic football shaped floats at intervals on the float line while a lead core lead line kept the nets on the bottom.

Net specifications and stretch mesh size targeting mainly Spanish mackerel during the study were: 8.26 cm (3.25") [62 mm twine and 45 meshes deep, 274 - 365.8 m (300 - 400 yd)], 9.53 cm (3.75") [70 mm twine and 45 meshes deep, 457.2 m (500 yd)], and 10.2 cm (4") [70 mm twine and 35 meshes deep, 182.9 - 365.8 m (200 - 400 yd)].

Net specifications and stretch mesh size targeting mainly king mackerel during the study were: 13.97 cm (5.5") [90 mm twine and 35 meshes deep, 457.2 m (500 yd)], 14.61 cm (5.75") 90 mm twine and 35 meshes deep, 365.8 m (400 yd), and 15.24 cm (6") [90 mm twine and 35 and 50 (deep) meshes deep, 365.8 m (400 yd)].

Additionally, one bait net of ~68.6 m (75 yd) with 8.26 cm (3.25") stretch mesh was used several times to catch menhaden, *Brevoortia tyrrannis*, for hook and line king mackerel fishing. This net was also recorded for the presence of sharks.

A 365.8 m (400 yd) study net was deployed randomly each fishing day with no special treatment. This net consisted of four 30.5 m (100 yd) panels consisting of two 13.97 cm (5.5"), one 14.61 cm (5.75") and one 15.24 cm (6") stretch mesh. Construction was the same as the other nets in length, mesh depth, twine size, float, and lead lines.

[1] The exception being one day in October 1996 when gear was set to catch king mackerel in an area reported to contain concentrations of neonate and juvenile sandbar sharks for tagging and documentation for a news crew. These data are included in the analysis and is representative of shark/mackerel catches.

Originally, one panel of 12.7 cm (5") stretch mesh was to be included in the test net for four individual mesh sizes. However, at the time of manufacture, this mesh size was not available in the specification. This net was not treated separately but was combined with the other mesh size for characterization.

Nets were stored, deployed, and retrieved from a stern mounted, hydraulically operated net reel. Nets were deployed from the stern of the vessel with the net reel in neutral while idling forward. Generally, nets were set in series perpendicular to the shoreline beginning nearshore and working offshore to water generally no deeper than about 15.2 m (50 ft). Occasionally, some nets were set parallel to the beach while a few were set perpendicular to the offshore end of a net or series of nets to form a "T" or "L". The first sets of the day were generally in the water before or at dawn for the first morning run of mackerel. Nets were retrieved by backing down the net usually against the wind to prevent entanglement of the net with the propeller when the vessel or net reel was stopped to remove fish from the net. All nets were retrieved by late afternoon.

Data collection

During the study (1998 and 2000), poly-form floats were marked with a number to keep track of each set and mesh size. Data recorded at the beginning and end of each set included time, depth, location (latitude/longitude), water temperature, mesh size, length of net, and general gear strategy. During gear retrieval data included beginning time, location, depth, water temperature, and direction of haul relative to set, i.e., start to end, or end to start. Usually, at the end of haul back only time was noted, because many times fish were still being recorded. Location of the sets for chart plotting was start of the set. Most set locations are plotted on Figure 1.

Water temperature and depth were converted to degrees centigrade and meters, and Loran coordinates were converted to latitude and longitude. Water temperature frequently changed over the set, therefore mean water temperature was calculated from 2-4 readings taken during each set.

Soak time was calculated as the time between the end of the set to the beginning of haul back in tenths of hours. Occasionally, an individual set will be given a test haul in which a portion of the gear is hauled [~7.6 - 30.5 m (25 - 100 yd)] then immediately reset.

This was done to either check for the presence of sharks or the presence of live mackerel. Live mackerel, particularly king mackerel is an indication that a run is in progress, so the net is quickly let back out to soak for a longer period. Although the entire net was not hauled, the soak time was used for evaluating mortality rates if sharks were encountered.

BIOLOGICAL DATA

Elasmobranchs

Sharks were measured on a flat surface to the nearest 0.1 - 0.5 centimeter. Lengths included pre-caudal (pre caudal pit), fork length (FL), total length with the upper lobe of the caudal fin in a natural position (TL), and stretch total length with the upper lobe at maximum extension in a strait line (TL str). FL was used as the basic measurement for length analysis for most species. TL was used for the Atlantic angel shark, *Squatina dummerili*. During several sets, some smooth dogfish were only measured in TL str. Smooth dogfish TL str was converted to FL using the regression formula: FL cm = 0.8834(TL str) -2.0552, $r^2 = 0.9979$, N=562. Lengths were estimated for sharks that either fell out of the net or were too large to bring aboard without damaging the net (includes sandtiger and scalloped hammerhead). Estimated lengths were not included in length frequency histograms.

Sex was recorded for each shark. Males were classified as juvenile or adult based on clasper condition. Soft or uncalcified to nearly calcified (plastic) claspers were juvenile, while rigid or fully calcified claspers were considered adult. Females were classified as juveniles or not classified at all in the field. Unless the size of a species is obviously juvenile, females must be examined internally for indicators of maturity. Complete dissection of all dead sharks was not practical. Therefore, both sexes were observed or estimated either juvenile or adult to reduce confusion (Castro, 1993b; Jensen, et. al, in prep (a)). Final maturity estimates during analysis were established by using extrapolated lengths of known maturity using other studies, while some specimens were not used to reduce bias.

Neonate sharks for this report are defined as young of the year or age 0, which were born during the year in which they were captured. Neonate sharks were determined using a combination of FL and the degree of healing of the umbilical scar present on sharks of the families Carcharhinidae and Sphrynidae, which nourish their young via placental connection through an umbilical cord (viviparity) (Castro, 1983; Compagno, 1984b).

Umbilical scar conditions were classified as: UR – umbilical remains, FR – fresh, PH – partially healed, MH – mostly healed, and WH – well healed (Pratt, et. al, 1998). A FL of 68 cm with observed umbilical scar condition was used as a cutoff for estimating neonate vs. juvenile (age 1+) sandbar sharks during fall sampling for consistency with North Carolina COASTSPAN results of 1998 (Jensen, 1998). A FL of 54 cm was used as a cutoff for neonate smooth dogfish based on extrapolated growth estimates based on the largest neonates aged for September combined with umbilical condition (Conrath, pers comm.). A TL of 53 cm (~43.5 cm FL) was used as a cutoff between neonate and juvenile Atlantic sharpnose sharks based on observed umbilical scar condition and extrapolated growth rates (Branstetter 1987a). This allowed for growth after parturition. In general, most shark species observed during the study, mainly the families Carcharhinidae and Sphrynidae, drop their young off North Carolina in late spring to mid summer (Jensen, 1998; Thorpe et al., in review; pers. obs). Therefore, with a few exceptions, very few partially healed umbilical scars were present during the study. However, neonatal sharks may remain in primary nursery areas well after parturition (Castro, 1993a; Jensen, 1998; Merson, 1998; Pratt et al., 1998; Thorpe et al., in review).

Known size at birth and growth rates were used to estimate between neonate and juveniles (age 1+) in shark species that have no placental connection with umbilical cords (ovoviviparity) (Castro, 1983). These sharks are from the families Squalidae, Squatinidae, Odontaspididae, and Alopiidae (Compagno, 1984a).

Tagging

Sharks (except spiny dogfish, *Squalus acanthias*, smooth dogfish, and Atlantic sharpnose sharks) were tagged using a blue NMFS rototag in the dorsal fin if ≤70 cm FL, while larger sharks were tagged with a NMFS M-type dart tag (a few larger sharks were tagged with rototags when M tags were exhausted). Most tagged sharks were injected with tetracycline hydrochloride for age and growth studies. NMFS Hallprint (HP) tags were used on sharks ≤70 cm FL during 1996 and 1997. Recaptured sharks were measured, umbilical scar condition noted, recorded, and released if alive or discarded. Release conditions were classified as excellent, good, fair, poor, and moribund, and lost from net before being measured. All tag recapture data were reported to the Apex Predators Program (APP) (NMFS) Narragansett, RI.

All sandbar and dusky sharks were assigned alive or dead for mortality rates. Most other species were recorded as alive or dead, but in some cases this was not practical because the focus was recording and releasing alive as many sandbar and dusky sharks as possible. As Atlantic sharpnose and smooth dogfish are landed, they were often piled up and recorded after haul back when the original condition was not evident. However, most sharks were examined for condition.

Survival and mortality

Mortality rates were calculated as the percentage of sandbar and dusky sharks dead in each set regardless of mesh size and condition. This mortality is based on "acute" or "at-the-boat" mortality described by Hueter and Manire (1994). This did not take in to account possible delayed mortality after release as a result of an interaction with the gear (Hueter and Manire, 1994). Tag/recapture data provide more accurate fishing mortality estimates. The mortality rates were plotted against individual soak times to determine the relationship between soak time and mortality.

CPUE

CPUE for sandbar and dusky sharks was expressed as number of sharks/400 yards/ hour. Data were analyzed for 1998 and 2000 only. The unit of effort was four hundred yards because most nets fished were of this length. Three hundred and five hundred yard nets were adjusted proportionately to estimate sharks per 400 yards/hour. CPUE was calculated for each net set by the formula: #sharks÷soak time in decimal hours = sharks/400yds/hour.

Weight

Whole weight in kilograms (kg) was taken when practical.

Mesh selectivity

The speed at which the fishery occurred prevented accurate method of capture observations of each fish encountered during haul back. Therefore, shark length frequency histograms were constructed for each mesh size to determine trends in size selection. These can be applied to future detailed mesh selectivity studies.

Skates and Rays

Most skates and rays were recorded to species. The sex, weights (when practical), condition, and disc width, the widest point between the pectoral fins on a flat surface to the nearest 0.1-0.5 cm, were recorded for most skates and rays. These data were not analyzed, but a list of species is provided (Appendix 1).

Spanish mackerel

Commercial numbers of Spanish mackerel were encountered on three days in October 1998. Measurements were taken to the nearest 0.1 -0.5 cm FL over a flat surface. Individual weights (kg) were taken when practical. In most cases, all were measured during each set. However, in a few sets containing large numbers of specimens, as many representatives were measured as practical, and the remainder counted. Length frequencies were plotted for individual mesh size, and overall length frequency was fitted with age and growth data (NCDMF, 1992). After about age 3, Spanish mackerel age at length become wide spread so that age/length data on the length frequency plot is general (R. Gregory, pers comm). Length/weight scatter plots were constructed. Sex was not examined as Spanish mackerel are not eviscerated at sea.

King mackerel

King mackerel were measured to the nearest 0.1 cm FL on a flat surface. Sex was recorded on most fish. Weights (kg) were taken when practical over the full size range encountered. Length frequency histograms were constructed for each mesh size, while an overall length frequency was fitted to age and growth data (NCDMF, 1994). After about age 3, king mackerel age at length become wide spread so that age/length data on the length frequency plot is general (R. Gregory, pers comm). Sex ratios and length/weight scatter plots by sex and combined sex were constructed.

Other teleosts

Additional data were collected on cobia and little tunny. FL to the nearest 0.1 - 0.5 cm was taken on a flat surface for both species. Weight (kg) was taken when practical. Sex was determined for cobia. Length frequency histograms were constructed for both species. Sex ratios and length/weight scatter plots were constructed (Appendix 2).

A list of other teleosts and their disposition was compiled during the study (Appendix 1).

Fishing effort

Eleven fishing days were observed during 1996 and 1997. This included 9 days in October 1996 and 2 days in November 1997. Twenty two fishing days were observed in 1998 and 2000. This included 4 days in October and 6 days in November 1998 and 4 days in October and 8 days in November 2000. During 1996 and 1997 120 sinknet sets were observed for the presence of sharks and a total of 193 sinknet sets and 2 bait net sets were examined for sharks and mackerel in 1998 and 2000 for a total of 315 sets. Number of sets by month and year were: October 1996 - N=92, November 1997 - N=28, October 1998 - N=56, November 1998 - N=45, October 2000 - N=36 and 1 bait net, and November 2000 - N=53 and one bait net. Range of sets per day was 4 to 17 with a mean of 10 sets per day. Mean water temperature ranged from 16.8 - 23.8°C (62.2 - 74.8°F). Depth ranged from 2.4 - 16.5 m (8 - 54 ft), while mean depth per set ranged from 4.6 - 16 m (15 - 52.5 ft). Soak time including seven partial haul backs ranged from 0.32 - 7.87 hours[2].

RESULTS

Sharks were encountered in 209 of 313 total sets and 2 bait nets for the period 1996-1998 and 2000 (1996-1997 N=88, 1998 and 2000 N=121). A total of twelve species representing six families were recorded for the region during the four year period. Table I presents a breakdown of shark species by month and year during 1996 - 1998 and 2000. Figure 2 illustrates the overall shark species composition from 1996-1998 and 2000 at Cape Hatteras, North Carolina.

[2] Water temperature, depth and soak times only for sets with sharks 1996-1997, most sets 1998 and 2000

Table I: Shark species composition by month and year during directed Spanish and king mackerel sinknet fishing from Ocracoke Island to Cape Hatteras, North Carolina during 1996 - 1998 and 2000

Species	Family Species	Oct 1996	Oct 1998	Oct 2000	Nov 1997	Nov 1998	Nov 2000	N
Spiny dogfish	Squalidae *Squalus acanthias*	0	0	0	0	0	3	3
Atlantic angel shark	Squatinidae *Squatina dumerili*	0	0	0	5	2	18	25
Sandtiger	Odontaspididae *Odontaspis taurus*	1	1	2	0	1	0	5
Common thresher	Alopiidae *Alopias vulpinus*	2	0	0	6	5	9	22
Smooth dogfish	Carcharhinidae *Mustelus canis*	111	2	334	33	904	336	1720
Blacktip	Carcharhinidae *Carcharhinus limbatus*	0	0	0	1	0	0	1
Spinner	Carcharhinida *C. brevipinna*	3	0	7	2	0	17	29
Dusky	Carcharhinidae *C. obscurus*	4	0	4	4	0	24	36
Sandbar	Carcharhinidae *C. plumbeus*	673	0	145	17	181	575	1591*
Atlantic sharpnose	Carcharhinidae *Rhizoprionodon terraenovae*	11	146	56	0	7	134	354
Scalloped hammerhead	Sphrynidae *Sphyrna lewini*	0	0	0	3	0	0	3
Smooth hammerhead	Sphrynidae *Sphyrna zygaena*	0	0	1	0	1	3	5
Unknown	Unknown	0	1	0	0	0	0	1

* one sandbar shark was tagged and released from another boat during the study, gear data not known

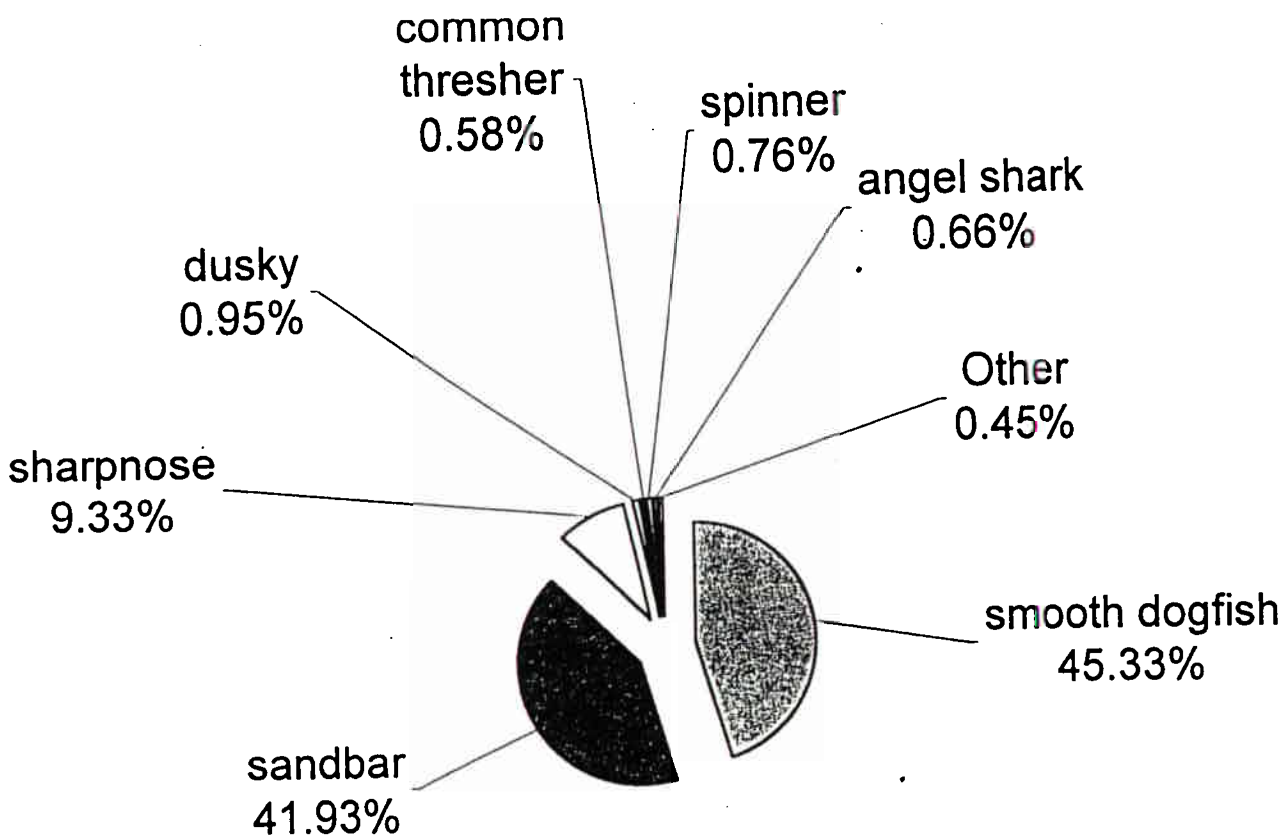


Figure 2: Shark species composition during Spanish and king mackerel sinknet operations in October-November 1996-1998 and 2000 at Cape Hatteras, North Carolina (other spp: spiny dogfish, sandtiger, blacktip, scalloped and smooth hammerhead).

Tagging effort and maturity

A total of 1264 sharks representing ten species were tagged during the four year period. Sandbar sharks were the only species recaptured on the F/V Water Sport during the study. Seventy seven were recaptured, of which seventy three tagged during the study were recaptured in either the same net, the same day, or within the sampling period. Four sandbar sharks were recaptured that were tagged by other studies and were considered long term recaptures. Three were tagged by NMFS biologists in Delaware Bay and one was tagged by Virginia Institute of Marine Science (VIMS) biologists in Chesapeake Bay (Conrath, pers comm; Kohler, pers comm). Other sinknets or hook and line fishing in the general vicinity of Cape Hatteras during the study period recaptured twenty four sandbar sharks and one spinner shark tagged during the study in 1998 and 2000. Two long term recaptured sandbar sharks tagged by NMFS biologists in Delaware Bay were reported to us during the study and turned in to the APP, Narragansett, RI. One sandbar shark tagged in Chesapeake Bay in August, 2000 by VIMS was turned in to us by a nearby sinknet vessel during the study in 2000 (Caldwell, pers. obs; Conrath, pers. comm). Five neonate sandbar sharks tagged during the study were recaptured during the summer months in and around Chesapeake Bay, Virginia (Kohler, pers comm). Neonate sandbar sharks tagged during the study were also recaptured at the following locations: 1 near Cape Lookout, NC; 1 in Core Sound inside Drum Inlet, NC; and 3 recaptured near the original tag site by other fisherman off Hatteras Inlet, NC (Kohler, pers comm).

Neonate sharks were identified in seven species based on umbilical scar condition, known lengths at birth, extrapolation of growth rates from other studies, and direct observation from other studies. These were the sandtiger, common thresher, smooth dogfish, spinner, dusky, sandbar, and Atlantic sharpnose sharks. Adult sharks were seen in seven species based on clasper condition and extrapolated lengths from other sources documenting sexual maturity. These were the spiny dogfish, sandtiger, smooth dogfish, blacktip, Atlantic sharpnose, and scalloped hammerhead (Table II). Most mature female smooth dogfish and Atlantic sharpnose sharks were gravid in 2000. Due to the numbers encountered during the study, only a few were specifically identified for presence of embryos. However, direct observation during field dressing indicated that most were gravid.

Table II: Size range, maturity, and tagging effort for sharks encountered during directed Spanish and king mackerel sinknet operations during October-November 1996-1998 and 2000 at Cape Hatteras, North Carolina, N=total sharks including lost and unknown status

Species	Size range cm	Neonate YOY	Juvenile	Adult	N	Tagged	Recapture
Spiny dogfish	FL 72-82.5	0	0	3	3	0	0
Atlantic angel shark	TL 92.5-124	0	4	6	25	18	0
Sandtiger	TL 100-244	2	1	2	5	3	0
Common thresher	FL 73-128	10	12	0	22	2	0
Smooth dogfish	FL 45-115	195	577	916	1720	6	0
Spinner	FL 64.5-141	3	26	0	29	13	0
Blacktip	FL 130	0	0	1	1	1	0
Dusky	FL 74.5-144.5	33	3	0	36	28	0
Sandbar	FL 47-145	1117	444	———	1591	1184	77
Atlantic sharpnose	FL 35.2-87	5	7	341	354	4	0
Scalloped hammerhead	TL 260-275	0	0	3	3	2	0
Smooth hammerhead	FL 62.5-92.5	0	5	0	5	3	0

Environmental data

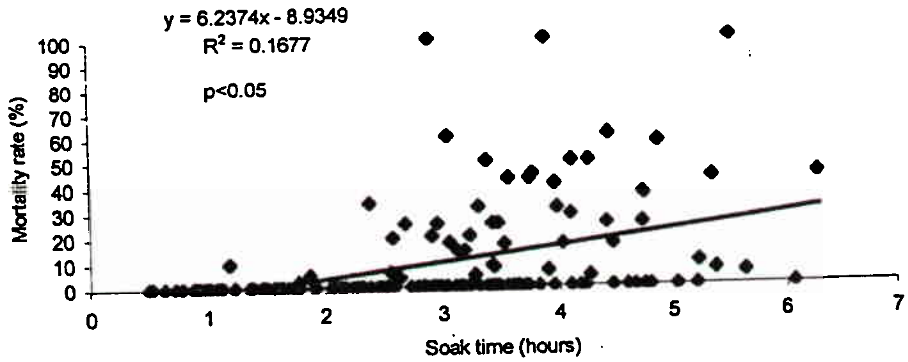
Table III: Mean water temperature range (°C), depth range (m), and mean depth range (m) for sharks encountered during directed Spanish and king mackerel sinknet operations at Cape Hatteras, North Carolina in 1996-1998 and 2000.

Species	Mean water temperature range (°C)	Depth range (m) of sets	Mean depth range (m) of sets
Spiny dogfish	19.0 - 20.9	8.5 - 12.2	10.2 - 11.4
Atlantic angel shark	16.8 - 21.4	7.3 - 13.7	8.7 - 13.4
Sandtiger	19.1 - 20.2	10.7 - 14.6	12.5 - 14.2
Common thresher	18.2 - 20.9	4.6 - 13.7	6.9 - 13.6
Smooth dogfish	16.8 - 22.9	3.0 - 16.5	5.5 - 16.0
Spinner	18.1 - 20.8	7.6 - 16.5	8.7 - 16.0
Blacktip	20.7	9.1 - 12.8	11.0
Dusky	18.1 - 20.8	4.3 - 15.5	6.1 - 15.4
Sandbar	16.8 - 23.8	3.0 - 15.8	5.5 - 15.5
Atlantic sharpnose	18.1 - 23.3	4.3 - 16.5	6.1 - 16.0
Scalloped hammerhead	20.9 - 21.2	10.1 - 11.3	10.5 - 11.0
Smooth hammerhead	17.8 - 20.2	7.6 - 15.5	9.4 - 15.4

Sandbar shark survival and mortality

Sandbar sharks were the main focus of this study. No acute mortality in sandbar sharks was observed up to 1.18 hours of soak time. Between 1.18 and 2.38 hours four sets ranged from 2.5 - 33.3% mortality, while the remaining sets within this range demonstrated no mortality. Sets beyond 2.38 hours began showing a marked increase in observed acute mortality, although sets with no acute mortality were observed up to 6.07 hours of soak time (Figure 3). There was a significant relationship between acute mortality rate and soak time ($p<0.05$) although the correlation was very low ($r^2=0.1677$). There was no significant relationship between acute mortality and mean water temperature ($p>0.05$, $r^2=0.0013$)(Figure 3). Overall sandbar acute mortality rate for 1996-1998 and 2000 was 10% (N=1591) (Figure 5).

Sandbar shark (N=1509) mortality rate (%) with soak time (hours) 1996-1998 and 2000 at Cape Hatteras, North Carolina (N=164 full and partial haul backs) each data point represents mortality for individual sets



Sandbar shark mortality rate (%) with mean water temperature (C) by set 1996-1998 and 2000 at Cape Hatteras, North Carolina N=164 sets

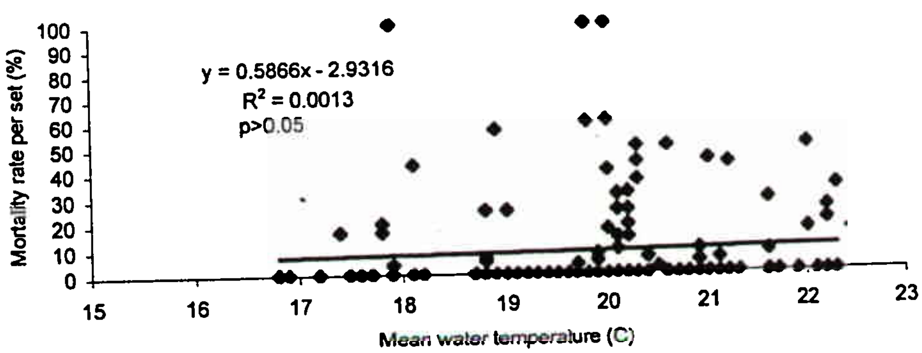


Figure 3: Relationship between mortality rate (%) with soak time (hrs) and mean water temperature (C) for sandbar sharks 1996-1998 and 2000 at Cape Hatteras, North Carolina.

Dusky shark survival and mortality rate

Dusky sharks are generally found interspersed with sandbar sharks in much smaller numbers (44:1 in this study). Dusky shark (N=36) mortality rates were included as they are an important component of the commercial shark fishery in North Carolina. However, dusky sharks are restricted from landing within NC state waters (maximum size 213 cm FL can be landed, 1/vessel/day) while it is a prohibited species in federal waters (Branstetter and Burgess, 1997, 1998; NMFS, 1999a; NCDMF, 2000). All observed sets up to 3.75 hour soak time containing dusky sharks had zero acute mortality. One set of 4.45 hours had 100% acute mortality while one set at 5.37 hours zero acute mortality. One set at 6.3 hours had 33.3% acute mortality (Figure 4). There was no significant relationship between acute mortality rate and soak time ($p>0.05$, $r^2=0.1882$) or mean water temperature ($p>0.05$, $r^2=0.0075$)(Figure 4). Overall dusky shark acute mortality for 1996-1998 and 2000 was 11% (Figure 5). Figure 5 summarizes survival/mortality rates of the remaining shark species encountered during the study.

Shark sex ratio

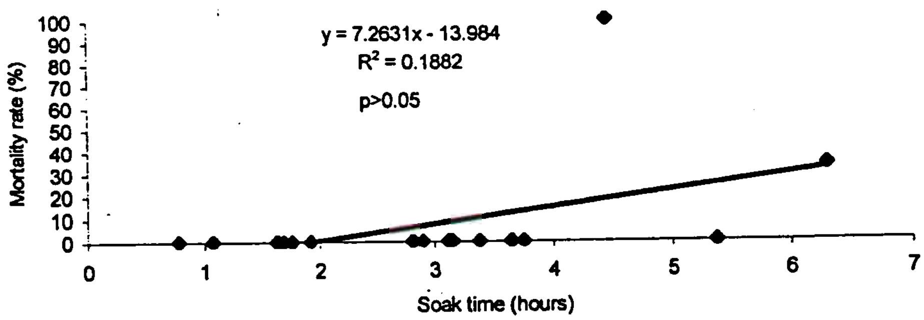
Figure 5 summarizes observed sex ratios for all shark species encountered during the study.

Sandbar and dusky shark length frequency

All observed sandbar and dusky sharks were neonate or juvenile (age 1+). Sandbar sharks were dominated by neonates 50 - 60 cm FL. Few sandbars were captured in 3.25" (N=2) and 3.75" (N=3) mesh. This is most likely due to temporal relative abundance. Sandbar sharks of 50 -60 cm FL dominate the 5.5", 5.75", and 6" mesh. A second much lower peak at 70 - 75 cm FL, probably representing large neonates and/or juvenile (age 1+) fish, was clearly evident in 5.75" and 6" mesh (Figure 6).

Dusky sharks were dominated by neonates 80 - 90 cm FL (Natanson, et al., 1995) (Figure 7). Dusky sharks of 80 - 90 cm FL dominated 5.75" and 6" mesh, while only two dusky sharks were encountered in 5.5" mesh (Figure 7).

Dusky shark (N=36) mortality rate % with soak times (hours) 1996-1998 and 2000 at Cape Hatteras, North Carolina (N=18 full and partial haul backs) each point represents mortality rate for individual sets



Dusky shark mortality rate (%) with mean water temperature (C) by set 1996-1998 and 2000 at Cape Hatteras, North Carolina N=18 sets and partial haulbacks

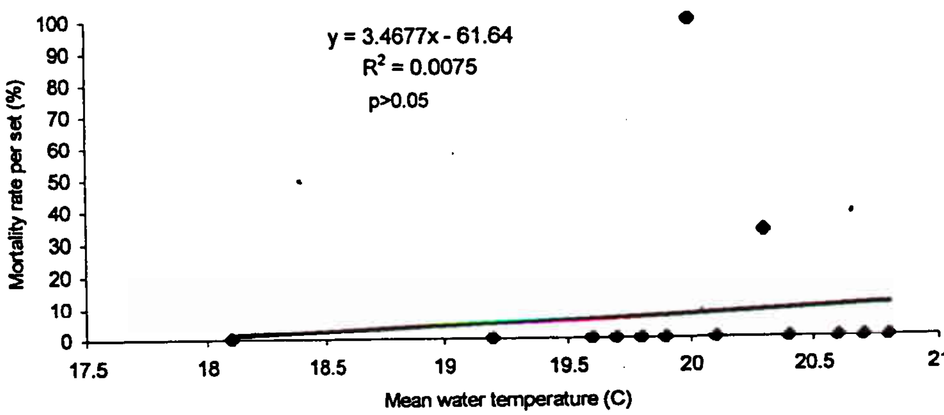


Figure 4: Relationship between mortality rate (%) with soak time (hrs) and mean water temperature (C) for dusky sharks 1996-1998 and 2000 at Cape Hatteras, North Carolina.

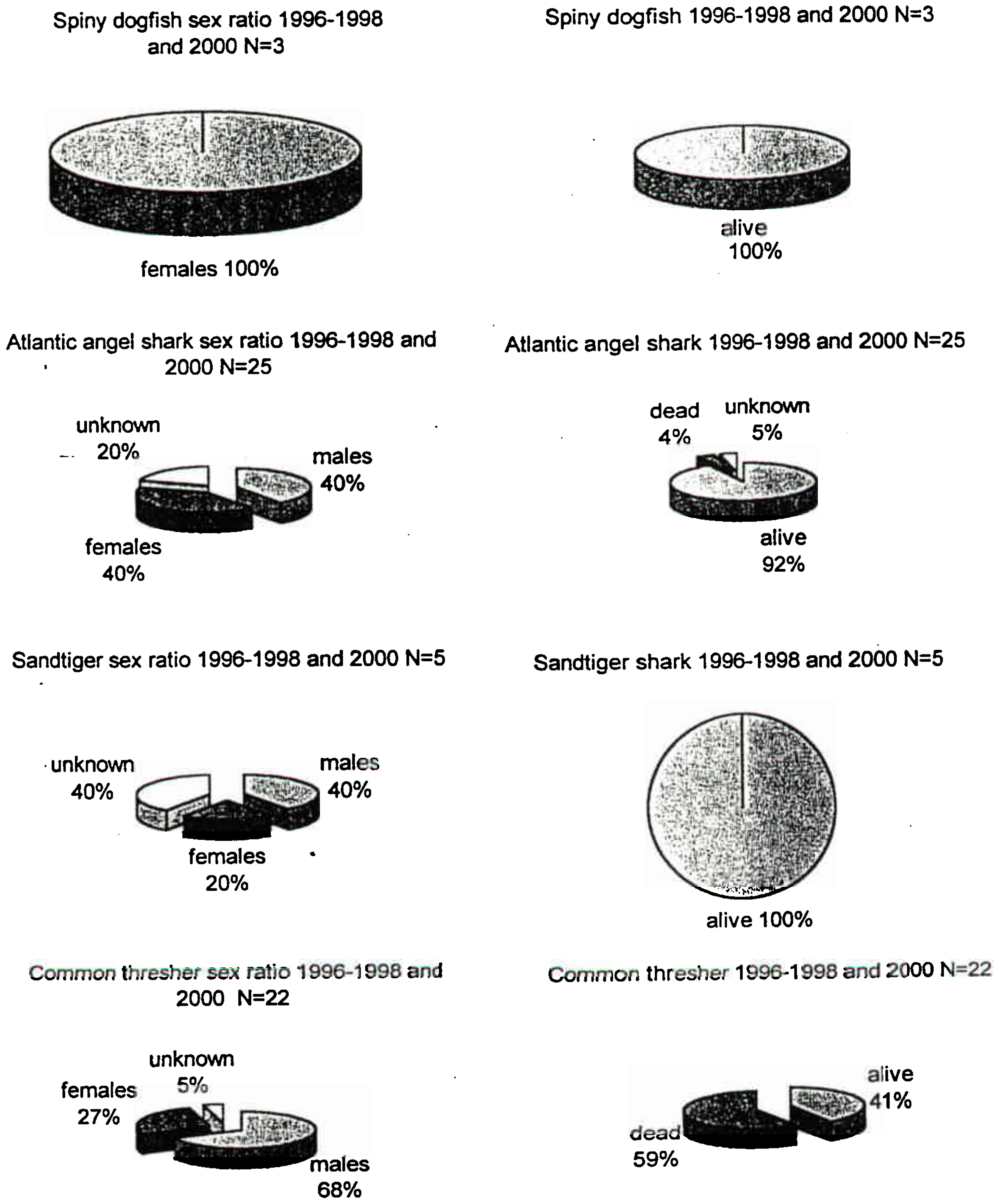


Figure 5: Sex ratios and survival rates for sharks encountered during 1996-1998 and 2000 at Cape Hatteras, North Carolina.

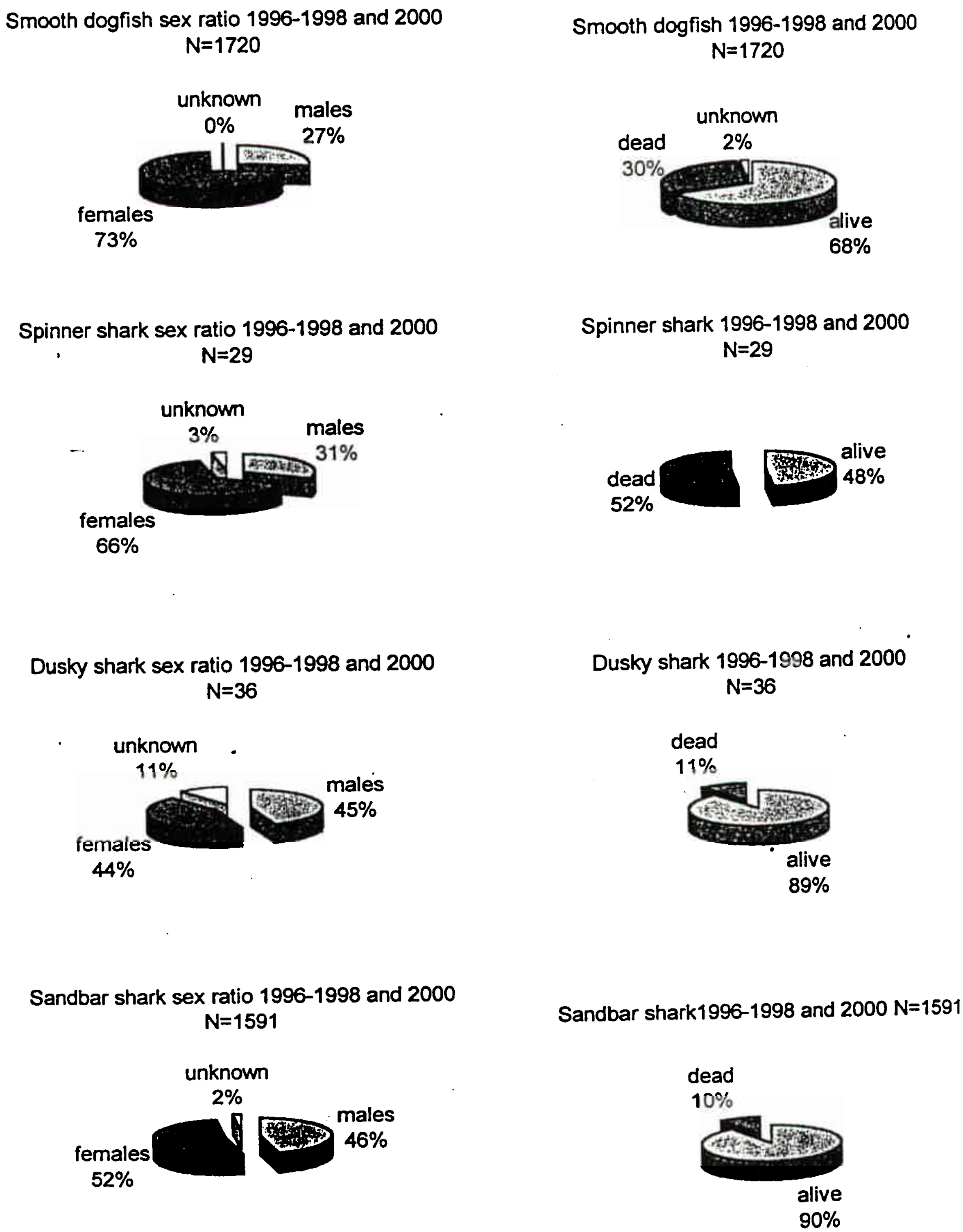
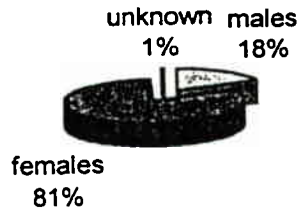
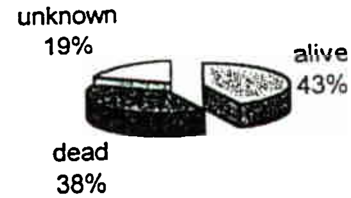


Figure 5: Continued

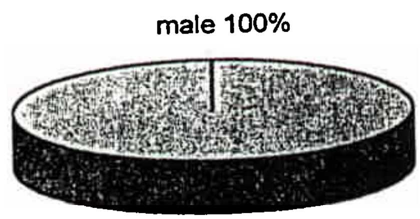
Atlantic sharpnose shark sex ratio 1996-1998 and 2000 N=354



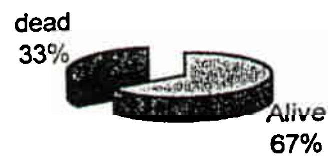
Atlantic sharpnose shark 1996-1998 and 2000 N=354



Scalloped hammerhead sex ratio 1996-1998 and 2000 N=3



Scalloped hammerhead 1996-1998 and 2000 N=3

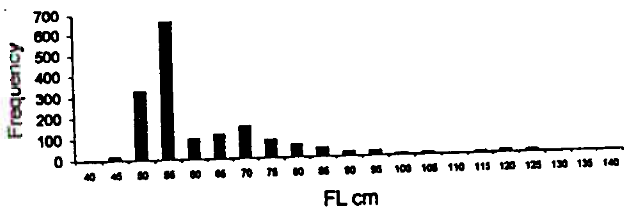


Smooth hammerhead sex ratio 1996-1998 and 2000 N=5

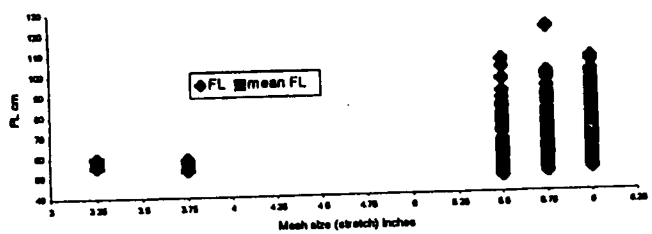
Smooth hammerhead 1996-1998 and 2000 N=5

Figure 5: Continued

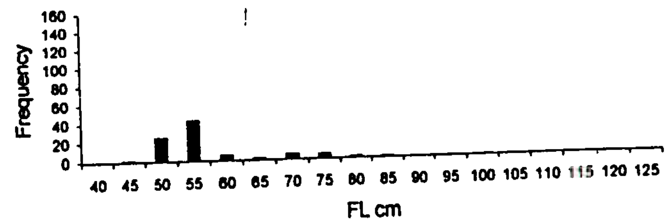
Sandbar shark length frequency 1996-1998 and 2000 sex combined N=1570



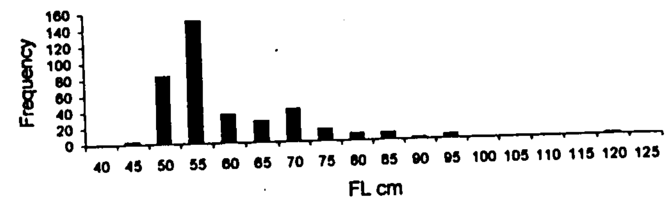
Sandbar shark length frequency and mean length by mesh size 1998 and 2000 N=891 sex combined



Sandbar shark length frequency 5.5" stretch mesh sinknet 1998 and 2000 sex combined N=103



Sandbar shark length frequency 5.75" stretch mesh sinknet 1998 and 2000 sex combined N=371



Sandbar shark length frequency 6" stretch mesh sinknet 1998 and 2000 sex combined N=410

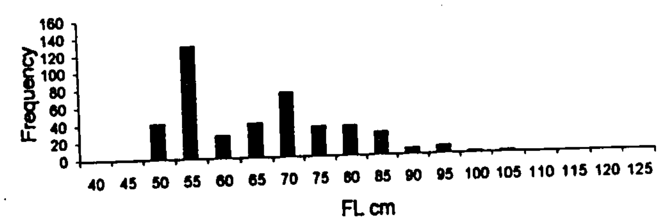


Figure 6: Sandbar shark length frequency FL (cm) 1996-1998 and 2000, and length frequency by mesh size 1998 and 2000 at Cape Hatteras, North Carolina.

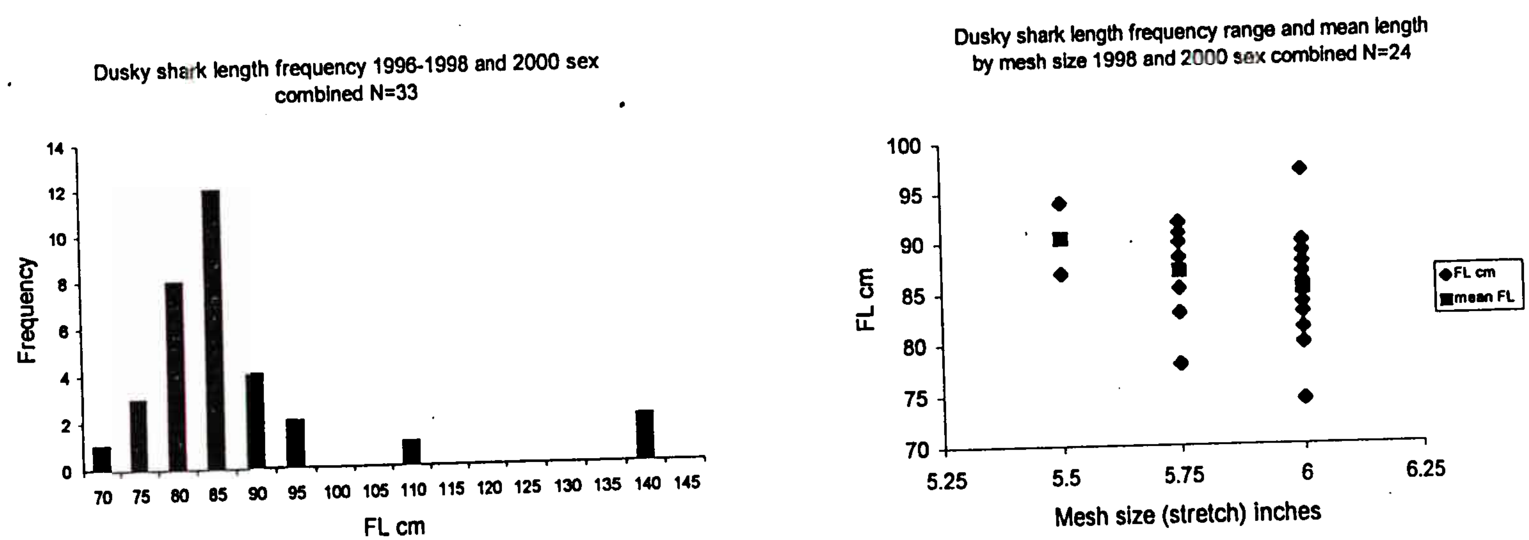


Figure 7: Dusky shark length frequency FL (cm) 1996-1998 and 2000 and length frequency by mesh size 1998 and 2000 at Cape Hatteras, North Carolina.

Sandbar and dusky shark CPUE

Ninety eight sets were analyzed for CPUE during 1998 and 2000 (Figure 8). The highest CPUE observed for the 2 year period was 205.13 sandbar sharks/400 yds/hour (N=160 sandbar sharks in the set). This observation was not used for trends in CPUE because it was an extreme outlier of the observed samples and severely skewed the data. CPUE excluding the outlier set ranged from 0.16 - 23.08 sandbar sharks/400yds/hr in 97 sets, with a mean of 2.95 sharks/400yds/hr. CPUE showed a significant relationship with mean water temperature ($p<0.05$), although the correlation was low ($r^2=0.0441$). There was no significant relationship between CPUE and mean depth per set ($p>0.05$, $r^2=0.0517$) (Figure 8).

Thirteen sets were examined for CPUE of dusky sharks during October and November 2000 (Figure 9). The highest CPUE for dusky sharks during 1998 and 2000 was 7.7 sharks/400yds/hour in the same set containing the highest CPUE of sandbars (205.13 sharks/400yds/hour). This set was not included in the analysis since it was an outlier and would distort the data. CPUE excluding the outlier set ranged from 0.27 - 2.8 dusky sharks/400yds/hr with a mean of 0.78 sharks/400yds/hr. There was no significant relationship between CPUE and mean water temperature ($p>0.05$, $r^2=0.0261$) or mean depth per set ($p>0.05$, $r^2=0.2328$) (Figure 9).

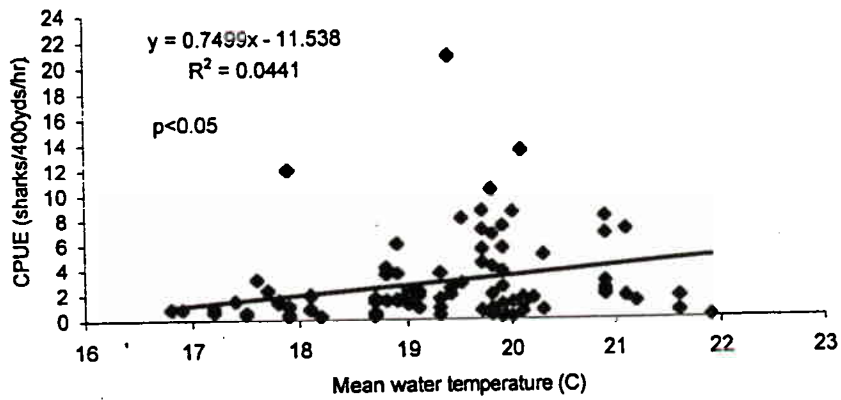
Spanish mackerel

Spanish mackerel catches were dominated by ~ age 1-3 fish ~ 30-50 cm FL in the overall length frequency. Age 1 fish dominated catches in 3.25" mesh, while age 2-3 fish dominated 3.75" - 4" stretch mesh (Figure 10). Spanish mackerel enter the fishery at about age 1 or less (Figure 10).

King mackerel

King mackerel were dominated by ages 5 - 7, ~80 - 95 cm FL in the overall length frequency (Figure 11). King mackerel enter the fishery at age 2 (Figure 11). Few fish were captured in 3.25", 3.75", and 4" mesh nets. A peak of 90 - 95 cm FL ~ age class 7 - 9 dominated 5.5" mesh (Figure 12). The 5.75" mesh demonstrated two peaks in length frequency, 85 - 90 cm FL age 5 - 7, and 95 - 100 cm FL age 8 - 10.

Sandbar shark CPUE (sharks/400yds/hour) as a function of mean water temperature (C) 1998 and 2000 at Cape Hatteras, North Carolina N=98 sets



Sandbar shark CPUE (sharks/400yds/hr) as a function of depth (m) 1998 and 2000 at Cape Hatteras, North Carolina N=97 sets

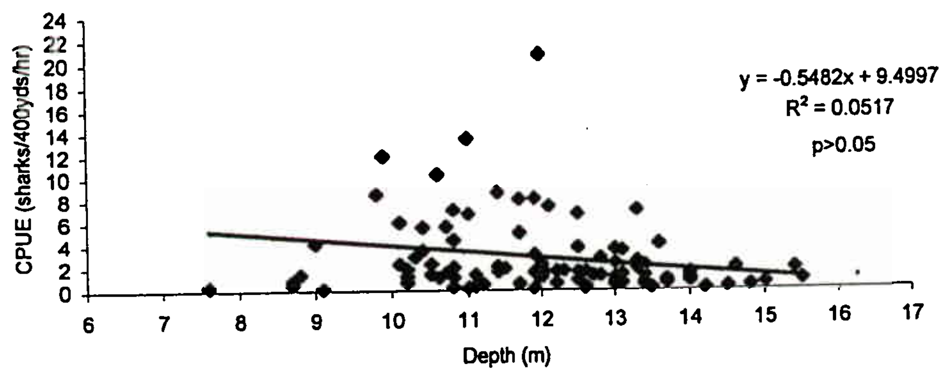
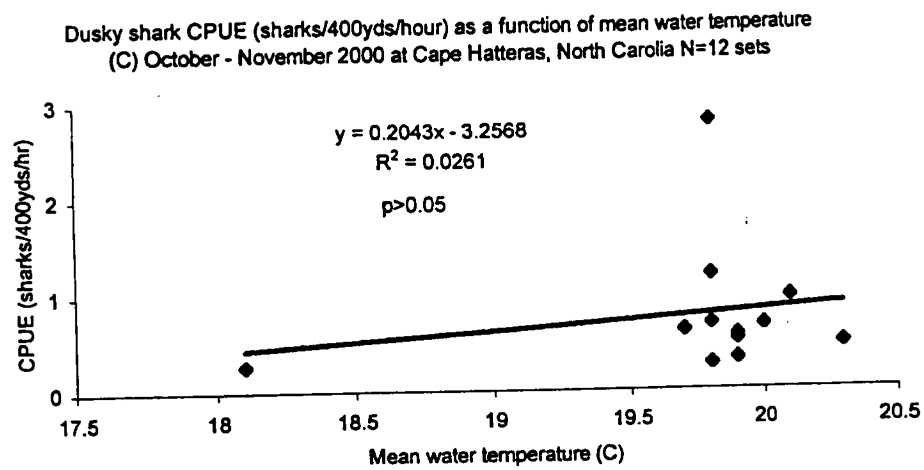


Figure 8 : Sandbar shark CPUE (sharks/400yds/hour) as a function of mean water temperature (C) and mean water depth (m) 1998 and 2000 at Cape Hatteras, North Carolina N=97 sets. One set with 205.13 sandbar sharks/400yds/hour is not shown on the chart because it severely skews the data set, although catch rates of amount are reported in the Cape Hatteras area and not considered unusual.



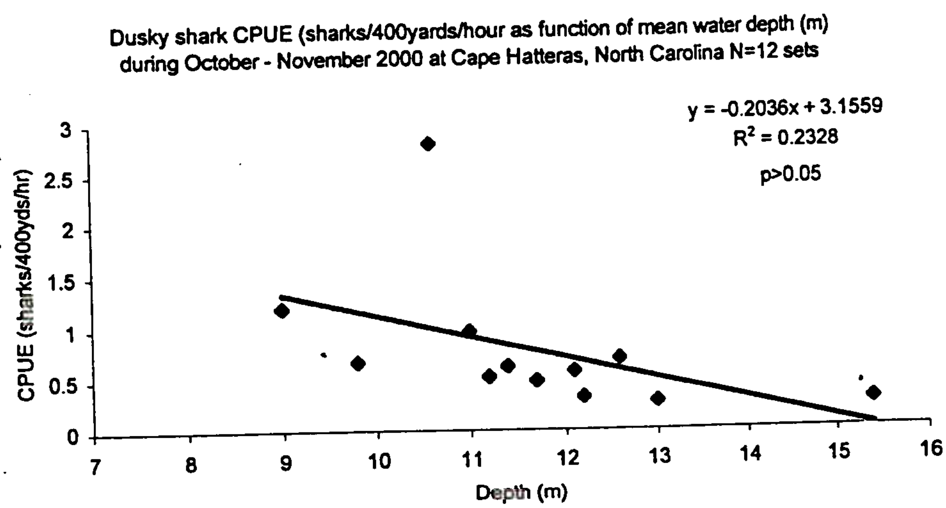
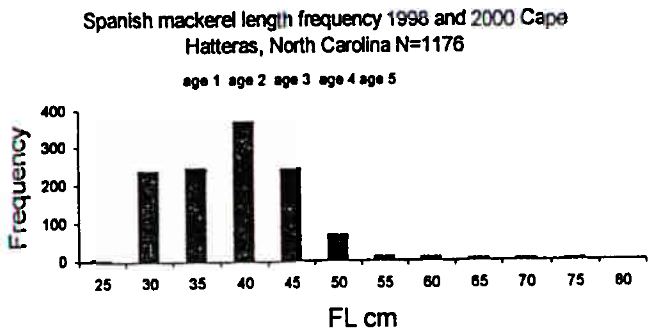
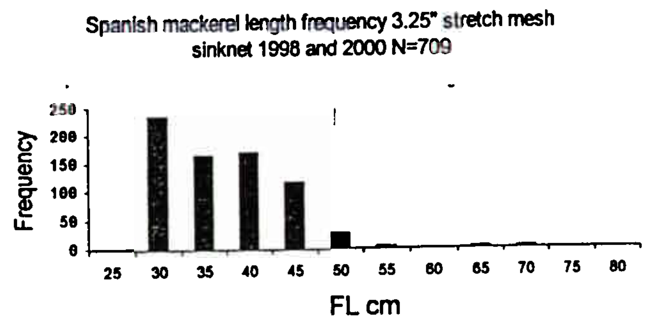
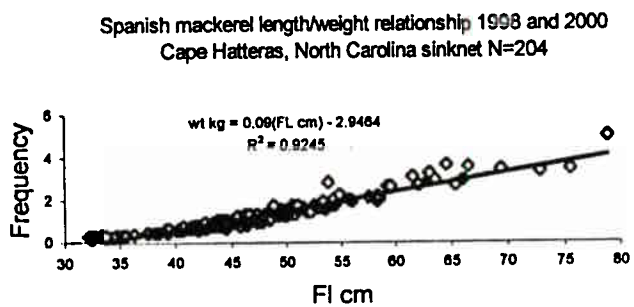
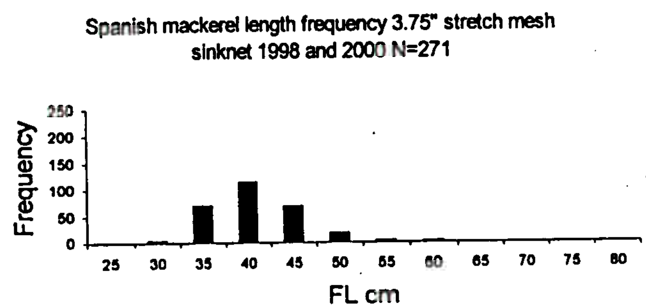


Figure 9: Dusky shark CPUE (sharks/400yds/hour) as a function of mean water temperature (C) and mean water depth (m) during November 2000 at Cape Hatteras, North Carolina N=12 sets. One set with 7.7 dusky sharks/400yds/hour is not shown on the chart because it severely skews the data set, although catch rates of this amount are reported in the Cape Hatteras area and are not considered unusual.









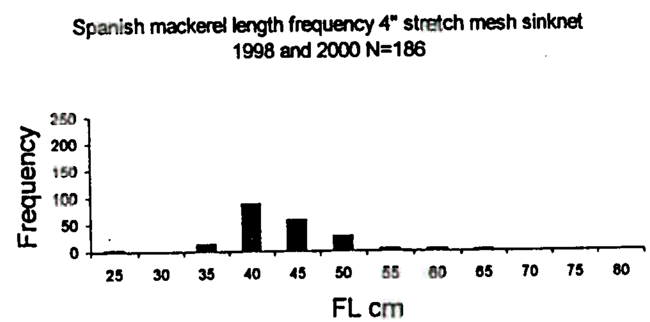


Figure 10: Spanish mackerel, *Scomberomerous maculatus*, length frequency (FL cm) by stretch mesh size (inches) and length/weight relationship 1998 and 2000 at Cape Hatteras, North Carolina.

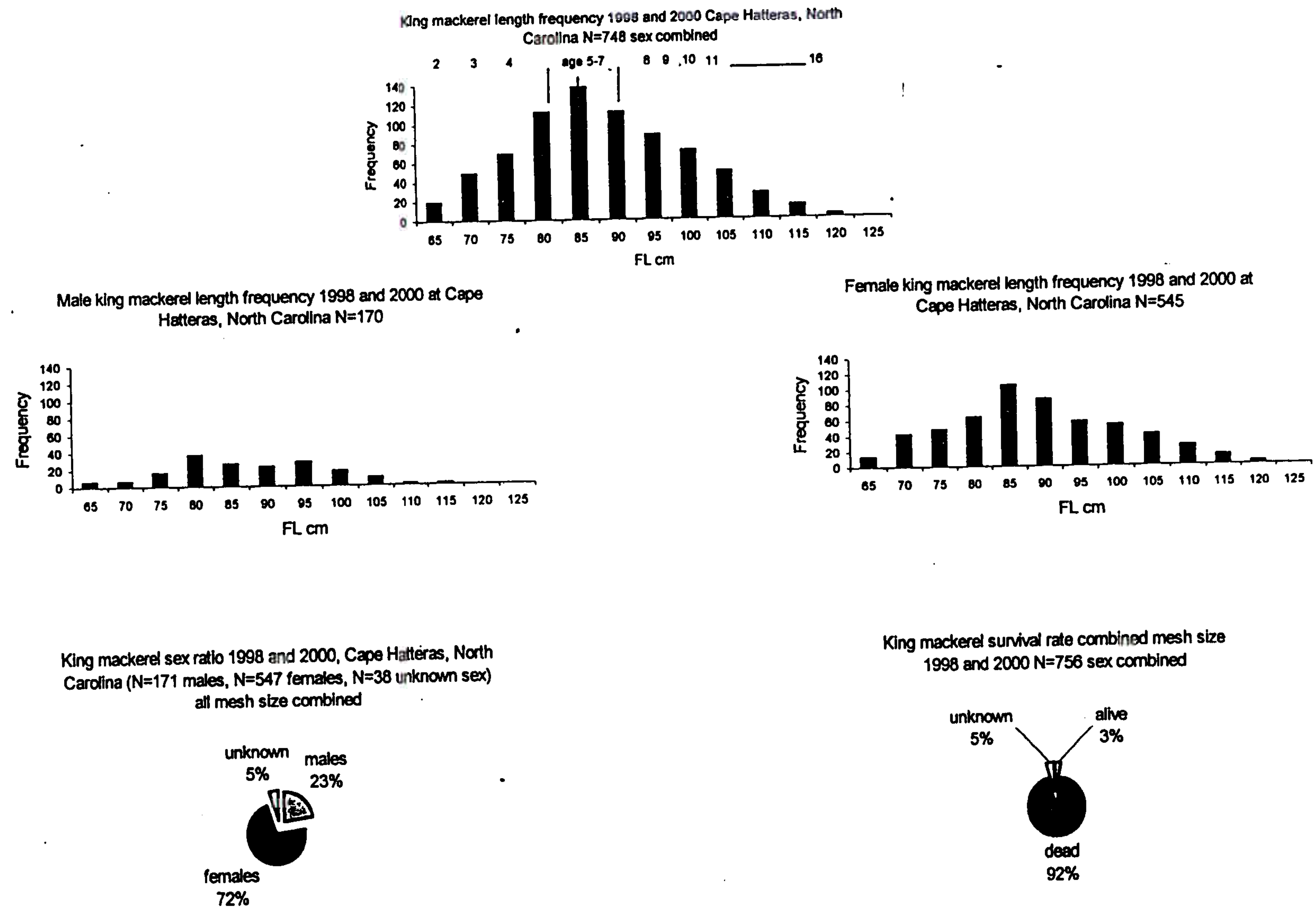


Figure 11: King mackerel length frequency FL (cm), sex ratio, and mortality rate 1998 and 2000 at Cape Hatteras, North Carolina.

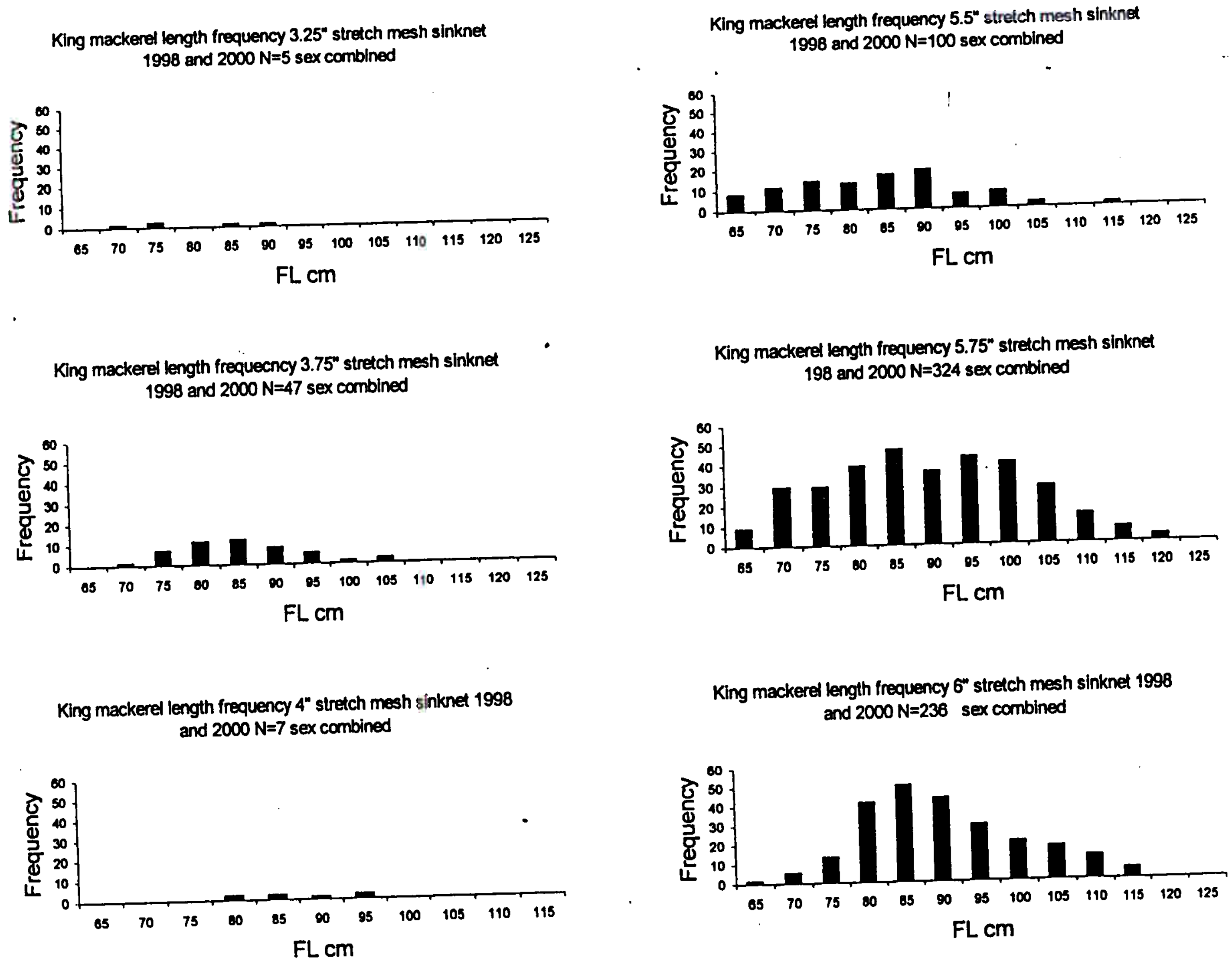


Figure 12: King mackerel length frequency FL (cm) by stretch mesh (inches) 1998 and 2000 at Cape Hatteras, North Carolina.

A single peak dominated the 6" mesh at 85 - 90 cm FL age 5 - 7 (Figure 12). Females dominated the overall catch and 92% of king mackerel were brought aboard dead (Figure 11). Females dominated the catch over 110 cm FL (Figure 11). Length/weight relationships were constructed by sex and combined (Figure 13).

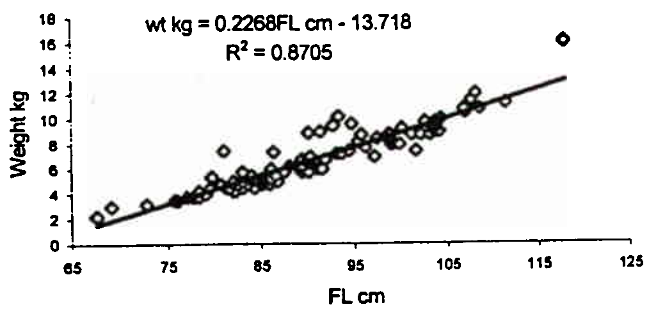
DISCUSSION

Sandbar shark

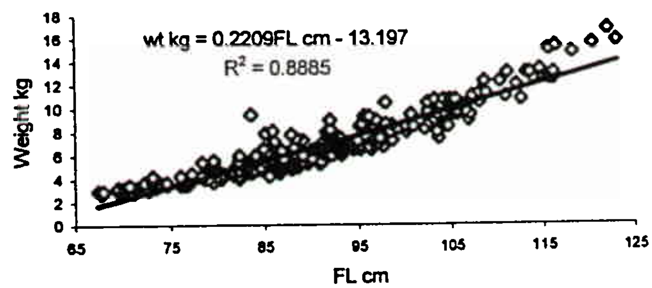
The sandbar shark currently uses inshore regions and embayments between South Carolina and New Jersey, the current northern boundary, for primary nursery grounds on the U. S. East coast (Musick and Colvocoresses, 1988; Castro, 1993; Musick et al., 1993; Pratt and Merson, 1996b; Merson, 1998; Pratt et al., 1998; Jensen et al., in prep). Historical data indicates that traditional sandbar primary nursery grounds extended as far north as Cape Cod, Massachusetts (Springer, 1960). The sandbar shark makes seasonal north/south migrations along the US Atlantic coast. During the spring, they begin migrating north of Cape Hatteras and by summer extend as far north as Cape Cod, Massachusetts, with some juveniles returning to the same primary/secondary nursery grounds the following year (Kohler, et. al, 1998; Merson, 1998). During the summer months north of Cape Hatteras, gravid females give birth in the large primary nursery grounds of Chesapeake and Delaware bays and other smaller embayments as far north as Great Bay, New Jersey between May and early September (Musick and Colvocoresses, 1988; Musick et al. 1993; Pratt and Merson, 1996b; Merson, 1998; Pratt et al., 1998). During the fall, sandbar sharks begin a southerly migration to the overwintering grounds off Cape Hatteras and to the south (Springer, 1960; Musick, et.al, 1993; Kohler, pers comm).

Neonate and juvenile (age 1+) sandbar sharks begin arriving in the Cape Hatteras region during the last two weeks of October. The immigration of sandbar sharks into North Carolina waters was documented in 1998. No sandbar sharks were captured near Oregon Inlet during COASTSPAN sampling on 4 October (Jensen, 1998). On 11 October, a commercial gill-netter reported small sandbars were showing up in the nets off Oregon Inlet. Intense fishing operations at Cape Hatteras 14-16 October 1998 (N=49 sets) produced no sandbar sharks. By the last two weeks of October 1998, neonate and juveniles began showing up in the catches at Cape Hatteras.

Male king mackerel length/weight relationship 1998 and 2000
Cape Hatteras, North Carolina N=96



Female king mackerel length/weight relationship 1998 and
2000 Cape Hatteras, North Carolina N=248



King mackerel length/weight relationship for Cape Hatteras,
North Carolina 1998 and 2000 sex combined N=352

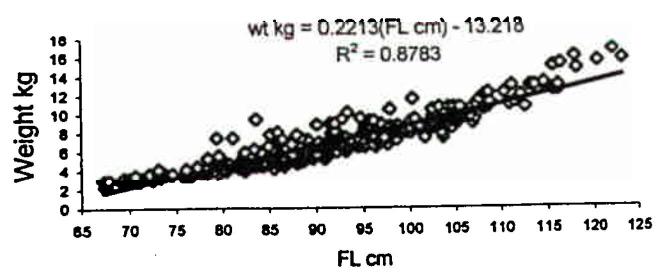


Figure 13: King mackerel length/weight (FL cm/kg) relationships by sex and combined sex 1998 and 2000 at Cape Hatteras, North Carolina.

The southerly migration between the primary and secondary nursery grounds north of Cape Hatteras to overwintering nursery grounds off Cape Hatteras and to the south have been confirmed through tag and recapture data (Pratt, et, al, 1998; Conrath, pers comm; Kohler, pers comm). Sandbar sharks tagged in both Chesapeake and Delaware bays in the summer months were recaptured during this study in the fall off Cape Hatteras. Neonates and juveniles (age 1+) are captured during the remainder of the inshore king mackerel fishery through about the third week in November when the fishery ceases. Commercial shark longline, trawl, and COASTSPAN sampling, along with tag and recapture data demonstrates that neonate and small juveniles remain in the region from Cape Hatteras to Cape Lookout in numbers through at least early May (Springer, 1960; Branstetter and Burgess, 1997; Branstetter and Burgess, 1998; Jensen, 1998; Kohler, pers comm).

By June the frequency of neonate and juveniles decreases in state waters around Cape Hatteras. Evidently they migrate north or possibly further offshore. Sandbar sharks tagged during this study have been recaptured in and around Chesapeake Bay, while COASTSPAN tagged sandbars from this same region, coinciding with the time of this fishery, have been recaptured in Delaware Bay during the summer months (Conrath, pers comm; Kohler, pers comm). Overall length frequency of sandbars caught during the study was dominated by 50 - 60 cm FL size range, categorizing neonates at age 0. A much smaller length frequency peak at 70 - 75 cm FL may represent large neonates and/or age 1 or 2 (Casey et al, 1985; Casey and Natanson, 1992; Sminkey and Musick, 1995). Merson (1998) found sandbar sharks were born in Delaware Bay between 40 - 60 cm FL, with 2- 3 cm growth between July and September. A recaptured sandbar originally tagged as a neonate in Delaware Bay grew 10 cm over a one year period (Merson, 1998; Kohler, pers comm). Overall, 68 cm FL was used as a cutoff for neonatal sandbars to remain consistent with 1998 COASTSPAN analysis. Several sandbars >68 cm FL had mostly healed (MH) umbilical scars characterized by a thin gray line (Figure 14). These could have been very large neonates, or in some cases the gray color characteristic of an MH condition may have persisted past the first year, as these fish would probably fall into the age 1 or 2 size range.

Evidence supporting the use of the Cape Hatteras region as both a primary and secondary nursery ground for sandbar sharks was obtained during the first week of June 2000 during COASTSPAN sampling (Jensen, et al., in prep (b)).

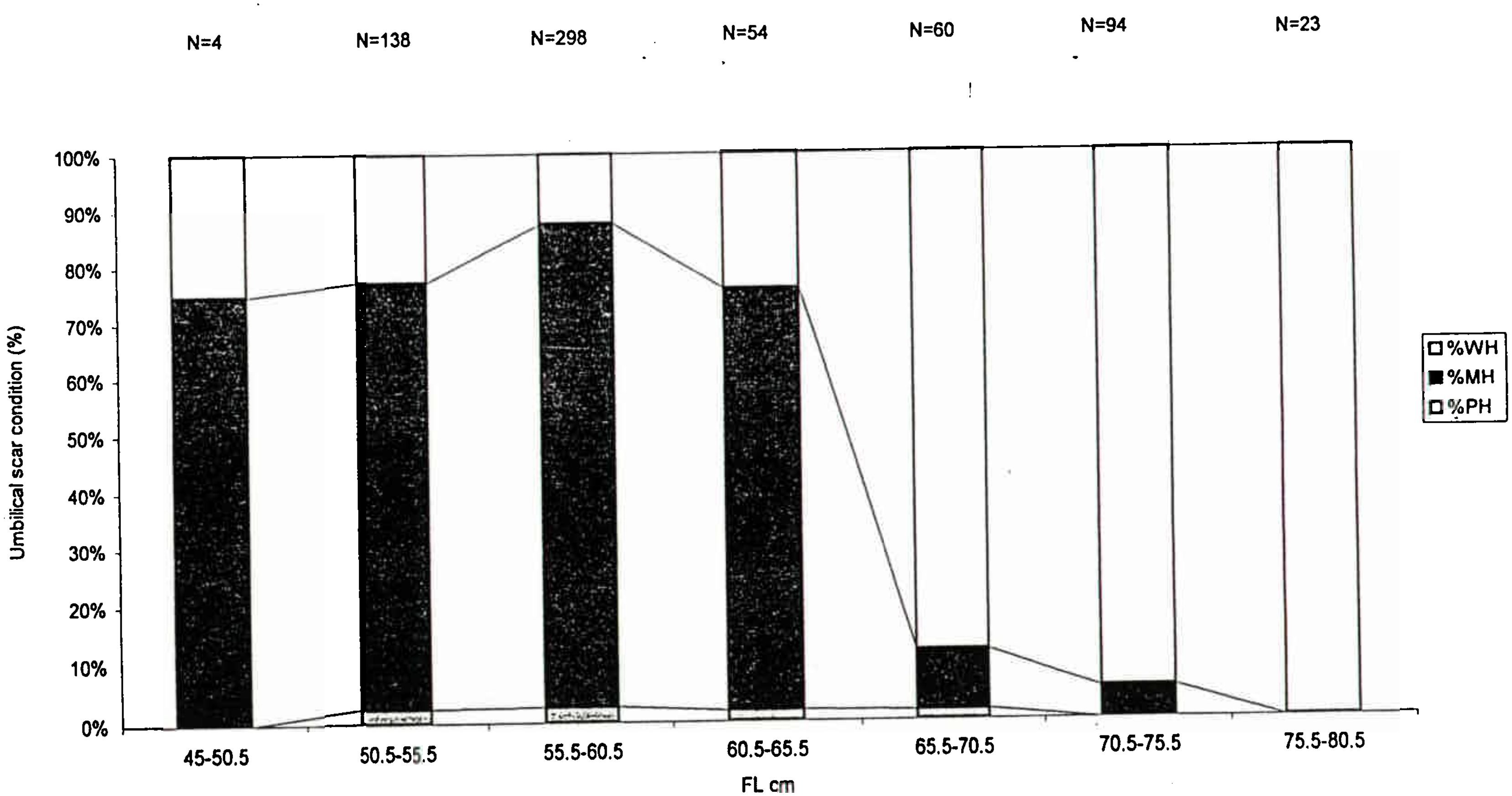


Figure 14: Sandbar shark umbilical scar condition (%) with length frequency (FL cm) at Cape Hatteras, North Carolina 1998 and 2000 N=671 (umbilical scars on specimens larger than 75.5 cm FL are WH and/or retain umbilical scar which resemble well healed).

On 2 June 2000 a neonate (46 cm FL) with umbilical remains was caught near Frisco, NC near Cape Hatteras (COASTSPAN), and another was reported nearby the same day with a long piece of umbilical cord still attached (Caldwell, pers comm). This indicates that parturition was very recent, during late May-early June. On 3 June 2000 a larger juvenile (88 cm FL) was caught off Ocracoke Island. The extent with which this region is used as a primary nursery ground, and whether sandbar sharks born at Cape Hatteras remain here or move further south needs further investigation. Additionally, parturition appears to be in unprotected nearshore areas (beach front) which is in sharp contrast to large bays and embayments used at Bulls Bay, SC (Castro, 1993) and north of Cape Hatteras (Musick and Colvocoresses, 1988; Merson, 1998). The presence of a few near term gravid females during July and August in the commercial shark fishery off North Carolina suggests that parturition in the area is protracted (Branstetter and Burgess, 1997; pers obs). This needs further investigation. Although small sandbar sharks have been reported and recaptured in both adjacent Pamlico and Core Sounds (two tagged in this study) they are considered infrequent in these areas (Barrington, pers comm; Caldwell, pers comm; Francesconi, pers comm; Kohler, pers comm). Schwartz (1995) reports only seven occurrences of sandbar sharks inside protected waters from Pamlico Sound to Shallote Inlet, while Barrington (pers comm) reports the regular occurrence of small juveniles in the lower Cape Fear river estuary during July and August.

The Cape Hatteras region is highly productive and provides a variety of prey items to support large populations of neonate and juvenile (age 1+) sandbar sharks. Sandbar sharks have a wide prey spectrum from crustaceans to teleosts (Springer, 1960; Stillwell and Kohler, 1992; Pratt, et al., 1998). Branstetter (1990) categorized shark reproductive strategies and nursery grounds on litter size and birth length, and concluded that predation may be the most important source of mortality on juvenile sharks. Such a concentration of small sharks in this region indicates favorable survival from predation by larger sharks. Springer (1960) suggested that interspecies competition between large bull sharks, *Carcharhinus leucas,* and small sandbar sharks may be a contributing factor for the general absence of a significant sandbar nursery in the Gulf of Mexico. Further detailed investigation of predator/prey relationships as well as habitat comparisons and requirements are needed to understand the complexities of the Cape Hatteras region.

Therefore, the Cape Hatteras region is an important overwintering nursery ground for the sandbar shark, as well as a primary and secondary nursery ground.

In general, immature sandbar sharks generally school by size, while mature sharks tend to segregate by sex and size (Kohler, pers comm). Springer (1940; 1960), found about equal numbers of males and females in embryonic and neonatal sandbar sharks. This study supports those findings (Figure 5).

The observed acute mortality rates of sandbar sharks throughout the four year period was 10%, indicating that the sandbar shark is a resilient species. Moreover, sandbar sharks tagged in very poor condition have been recaptured (Kohler, pers comm). Zero mortality was observed in sandbar sharks up to 1.18 hours of soak time, while in 4 sets, low mortality was seen up to 2.38 hours. Past 2.38 hours, acute mortality increased substantially (Figure 3). Some sets out to 6.07 hours had no acute mortality. The mortality data are widely scattered after 2.38 hours of soak time. Although there was a significant relationship between increased soak time and mortality, the correlation was low (Figure 3). A possible explanation for low mortality rates after long soak times is sharks may not encounter the net until late in the set. Also, currents could keep a shark alive in the net if the mouth could remain open into the current providing some ventilation (McCandless, pers comm). Conversely, the degree in which they are either meshed or entangled may affect their ability to respire normally. The sandbar shark was observed in the widest range of mean water temperatures during the study (Table III). However, there was no direct correlation with acute mortality and water temperature (Figure 3).

Sandbar shark CPUE

Sandbar sharks demonstrated a patchy distribution probably related to schooling behavior. Several nets would contain sandbar sharks while others nearby would have none. One set containing 160 sandbar sharks during a 0.78 hour soak (205.13/400yds/hr) is not considered unusual within the mackerel sinknet fleet at Cape Hatteras. Although there was a significant relationship between CPUE and an increase in mean water temperature, the correlation was low (Figure 8). The clumped distribution of CPUE with certain water temperature and depth may reflect the mackerel fishing effort, temporal and spatial differences due to immigration, or following prey items rather than a preference for a certain water temperature or depth (Figure 8). Sandbar sharks may be associated with, or following prey in the area and either encounters the net, or are attracted to the net by struggling fish. In many cases, one or several sandbar sharks would often be entangled next to a struggling or dead fish. Moreover, fish were retrieved from the nets with small bite marks. Sandbar sharks in general are captured in a wide variety of water temperatures and depths off North Carolina throughout the year.

As only a few sandbar sharks were captured in 3.25" and 3.75" mesh, few conclusions can be drawn on selectivity (Figure 6). Most sandbar shark size ranges observed during the study were seen in 5.5", 5.75", and 6.0" mesh with 50 - 60 cm FL dominating all three sizes (Figure 6). Sandbar shark mesh selectivity needs further evaluation, most notably method of capture (gilled, wedged, or entangled) and differences in twine size, elasticity, and hanging coefficient (Hamley, 1975; Simpfendorfer and Unsworth, 1998).

Dusky shark

Dusky sharks are a year round resident of North Carolina, ranging from shallow coastal waters to off the edge of the continental shelf. Dusky sharks were regularly encountered during the large coastal commercial shark season off North Carolina (Schwartz, 1984a; Branstetter and Burgess, 1997, 1998).

During the four year period, neonate (74 - 103 cm FL) and juvenile (113 -144.5 cm FL) dusky sharks were captured during October and November (Table I, II; Figure 7). Most were neonates based on length and umbilical scar (PH-MH) condition (Figure 7; 15). Observations of the smallest neonate and largest near term embryos indicate a birth size range of about 74 - 92 cm FL (pers obs; Natanson, et al., 1995; Branstetter and Burgess, 1997, 1998). Natanson et al. (1995), found that males and females grew to about 100.5 - 104.3 cm FL respectively by 6 months of age. Castro (1993a), reported gravid females and neonates with both open (81 cm FL) and healing (83-85 cm FL) umbilical scars during April and May at Bulls Bay, South Carolina. A near term embryo of 76.5 cm FL tagged 20 NM SE of Ocracoke on January 1997, was recaptured in May 1997 at South Hatteras Beach, Cape Hatteras. Based on umbilical scar condition, dusky sharks may exhibit a protracted pupping season. Therefore, evidence supports the use of the Cape Hatteras region as both primary and secondary nursery grounds for the dusky shark, as well as an overwintering nursery ground.

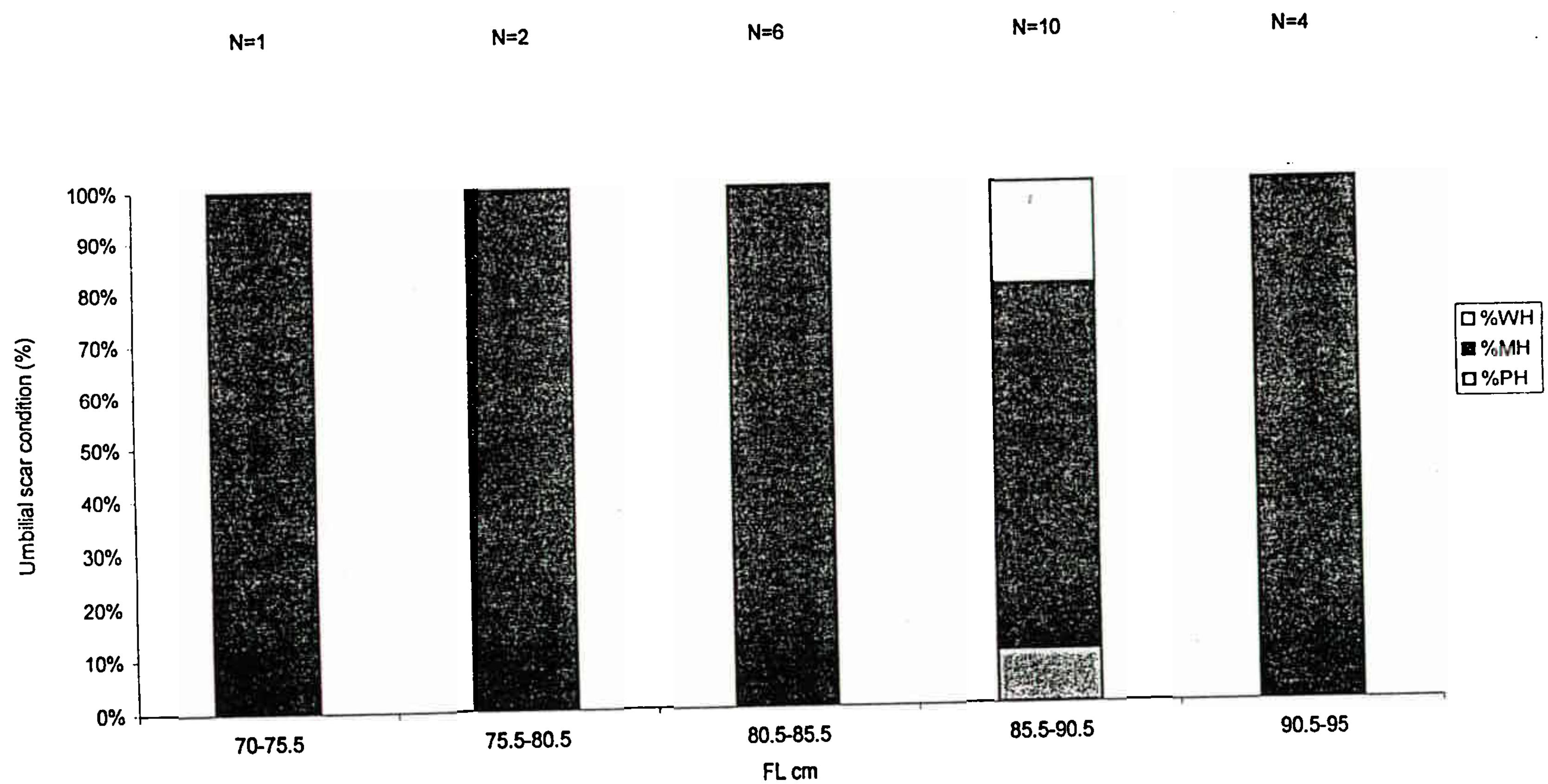


Figure 15 Dusky shark umbilical scar condition (%) with length frequency (FL cm) at Cape Hatteras, North Carolina 1998 and 2000 N=23.

Sex ratios for neonate and juvenile dusky shark were similar to the sandbar shark, roughly equal (Figure 5). This is similar to that found by Springer (1940) for dusky shark embryos.

Overall acute mortality rate for the dusky shark was 11% (Figures 4 and 5). This was similar to the sandbar shark acute mortality rate. Soak times less than 3.75 hours would significantly increase dusky shark survival, but caution should be exercised due to a small sample number. There was no pattern in mortality. The degree of acute mortality may be similar to the sandbar either in encountering the net later in the set, or degree in which they were meshed or entangled. However, this study reports relatively good survival rates for dusky sharks compared to longline catches that reported a much higher mortality rate (Branstetter and Burgess 1997, 1998).

The low CPUE of dusky sharks compared with sandbar sharks is not unusual. Although much less frequent, neonate and juvenile dusky sharks appear to have a similar habitat preference to neonate and juvenile sandbar shark in this region.
This proportional relationship (including sex/size segregation) was similar to that found during the directed shark longline fishery off North Carolina (Branstetter and Burgess, 1997; 1998). Neonates and juveniles (age 1+) of both sandbar and dusky sharks were captured together in this region during the study. One set with 6 dusky sharks in a 0.78 hour soak with a CPUE of 7.7 sharks/400yds/hr, was not considered unusual by the mackerel fleet for this region. CPUE did not appear to correlate with either mean water temperature or depth (Figure 9). Dusky sharks are caught in a wide variety of depths and water temperatures in North Carolina, similar to the sandbar shark.

Earlier evidence supporting the use of state waters as primary nursery grounds was based on neonates with fresh and partially healed umbilical scars caught instate waters both south of Cape Fear and at Bogue Banks during April-May and November respectively (Jensen, 1998; Thorpe, et al., in review). Schwartz (pers comm) has observed neonate dusky sharks off Cape Lookout from March - May during shark longline surveys. Evidence indicates that dusky sharks use federal waters between Cape Hatteras and Cape Fear as primary nursery grounds based on near term gravid, post-partum, and neonates with fresh umbilical scars in the same area from February - April (Branstetter and Burgess, 1997, 1998; pers obs). This study supports those findings.

Net mesh selectivity was difficult to interpret with a low sample size. However, as in the sandbar shark, similar length dusky sharks were encountered in 5.5", 5.75", and 6.0" mesh (Figure 7). This aspect needs further investigation.

Spiny dogfish

Three female spiny dogfish were observed during the study. These were all considered mature based on extrapolated growth rates (Compagno, 1984a) (Table 1, 2; Figure 5). These were most likely individuals migrating into the area to overwinter. Spiny dogfish overwinter off the Carolinas and have contributed to an important commercial fishery.

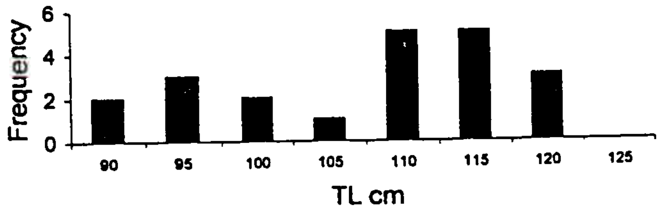
Atlantic angel shark

Both juveniles and adults were observed during the study (Table 1, 2; Figure 16). Assignment of juveniles and adults was based on clasper condition of the males, while no females were examined internally. Quite possibly at least some of the females may have been mature based on size, but they were all released or lost. No evidence of neonatal Atlantic angel sharks were observed during the study. This region provides at least a secondary nursery for this species.

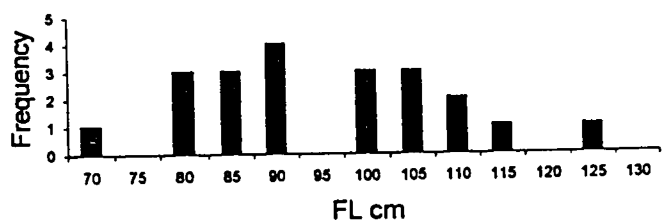
Sandtiger

No sandtigers encountered during the study were brought aboard for examination. However, based on estimated total length, two were judged as neonate (Gilmore, et al., 1983; Compagno, 1984a). One male was assigned as late juvenile, although it was probably approaching maturity (Gilmore et. al, 1983). One male and one female were judged mature based on length at maturity (Gilmore et al., 1983; Compagno, 1984a) (Table 1, 2). This evidence suggests the use of this region during the study as both a primary and secondary nursery for the sandtiger.

Atlantic angel shark length frequency 1996-1998 and 2000 sex combined N=21



Common thresher shark length frequency 1996-1998 and 2000 sex combined N=21



Spinner shark length frequency 1996-1998 and 2000 sex combined N=28

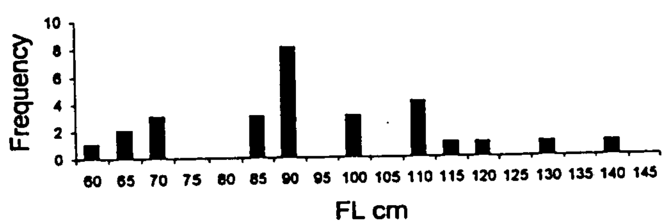


Figure 16: Length frequency (FL and TL cm) of Atlantic angel, common thresher, and spinner sharks 1996-1998 and 2000 at Cape Hatteras, North Carolina (sex and mesh size combined).

Common thresher shark

Common thresher sharks are a regular occurrence in the Cape Hatteras region during the fall mackerel season. All specimens examined were judged as neonate or juvenile (≥1+) based on size as compared to extrapolated growth rates from other studies (Cailliet, et al., 1983; Compagno, 1984a). No adults were observed during sampling (Table 1, 2; Figure 16). This species is rare in the directed shark longline fishery off North Carolina (Branstetter and Burgess, 1997; 1998). They may be spatially or temporally excluded from the gear or avoid it. Small juvenile thresher sharks have been observed off Holden Beach and Wrightsville Beach, North Carolina, primarily from late winter to early spring (pers obs; Thorpe, et al., in review). Preliminary evidence from this study indicates use of this region as both a primary and secondary nursery as well as possibly an overwintering nursery. They are not reported during net fishing in the summer months. The dynamics of this species warrant further investigation in this area.

Smooth dogfish

The smooth dogfish contributes to the fall coastal fishery and coincides with the king mackerel fishery at Cape Hatteras. This species is the dominant shark bycatch during October and November and is landed along with king mackerel as part of the catch. Based on growth rates (Conrath, 2000) and umbilical scar condition, neonates (age 0) through adults were seen during the study (Table 1, 2; Figure 17). Most mature females observed during 1996 and 2000 were gravid. Smooth dogfish begin showing up in the catches at Cape Hatteras generally during October, probably migrating from the north or possibly from deeper offshore water (Castro, 1993a; Rountree and Able, 1996). Smooth dogfish were generally scarce to absent from June - November in other shark surveys in North Carolina (Jensen, 1998; Thorpe et al., in review). The presence of both neonate and juvenile (age 1+) smooth dogfish suggests that this region and other areas of North Carolina are used as a primary and secondary as well as an overwintering nursery ground for the smooth dogfish (Jensen, 1998; this study). Some neonates had partially healed to mostly healed umbilical scars. Whether these sharks were born nearby or migrated south is not known. However, it is likely that some pupping occurs in the region, as a neonate was observed near Oregon Inlet during July 2000 (Jensen, et al., in prep (b)).

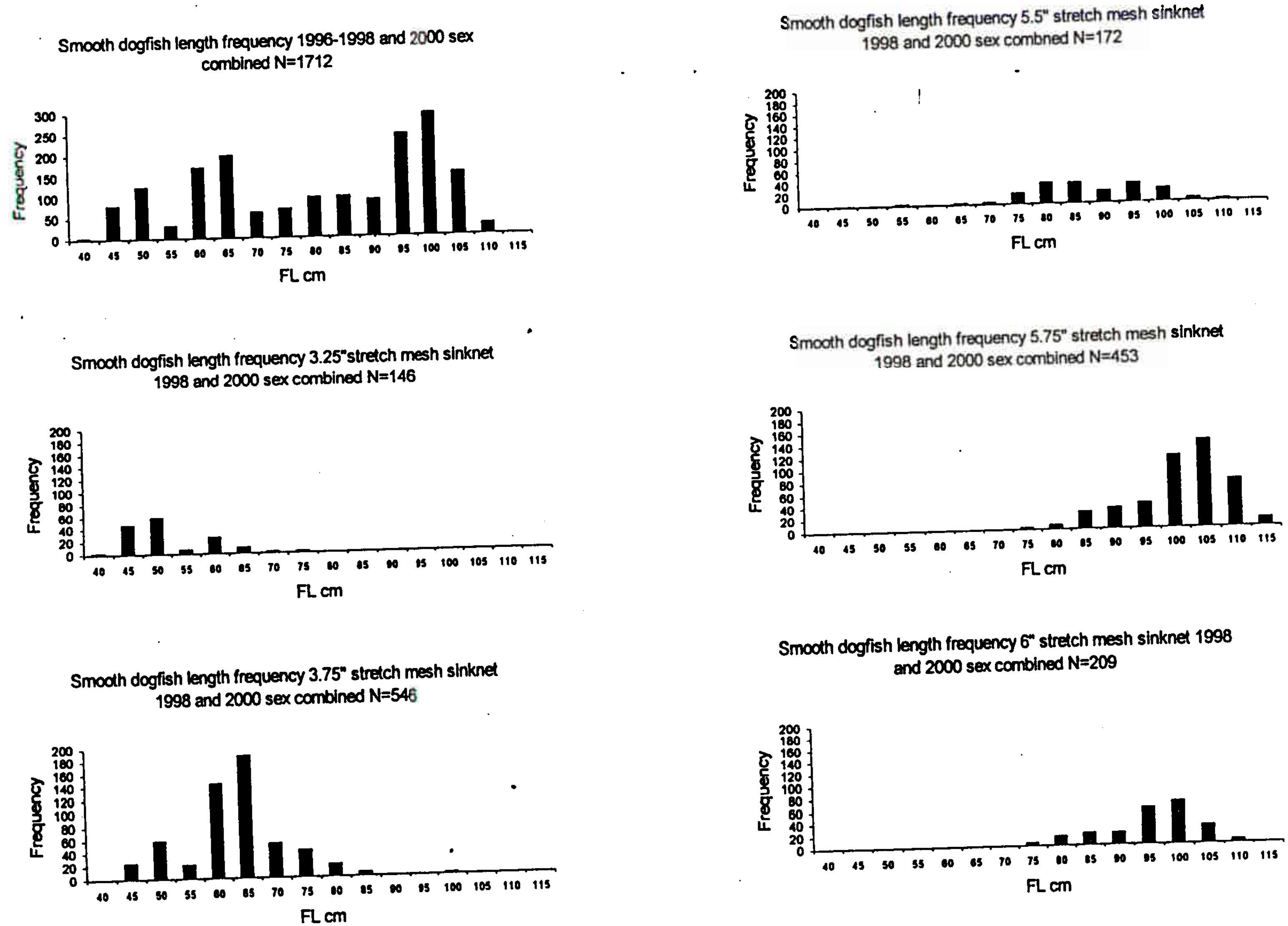


Figure 17: Smooth dogfish overall length frequency 1996-1998 and 2000 and by stretch mesh size 1998 and 2000 at Cape Hatteras, North Carolina.

Schwartz (1984a; pers comm), reports observing neonate and juvenile (age 1+) smooth dogfish near Cape Lookout from April to as late as September in some years. Castro (1993a), reports neonate smooth dogfish at Bulls Bay, South Carolina during April and May, prior to the northward migration of adults. General size selectivity by mesh size is apparent (Figure 17). Mesh 3.25" - 3.75" favor shark's ≤75 cm FL while 5.5"- 6.0" mesh favor sharks ≥75 cm FL (Figure 17).

Spinner shark

Neonate and juvenile (age 1+) spinner sharks were observed during the study based on umbilical scar condition and size comparison with other studies (Table 1, 2; Figure 16). No adults were observed, although one nearly mature male was seen. Evidence suggests that this region is used as both a primary and secondary nursery ground for the spinner shark. Neonate and juvenile (age 1+) spinner sharks were documented along the North Carolina coast during two other surveys in the state (Jensen, 1998; Pratt, et al., 1998; Thorpe et al., in review). Gravid spinner sharks have been observed in the commercial shark fishery off North Carolina during January (Branstetter and Burgess, 1997; pers obs). The extent that this region contributes to an overwintering nursery ground needs further investigation.

Blacktip shark

Only one adult male blacktip shark was observed during the study in November 1997 (Table 1, 2). Normally, blacktip sharks have migrated south or further offshore during this period, so this would be considered as a stray. Large juvenile and mature blacktip sharks are commonly encountered during the summer months in the commercial shark fishery south of Cape Hatteras (Branstetter and Burgess, 1997).

Atlantic sharpnose shark

Mature fish, mostly females, dominated the catch of Atlantic sharpnose sharks. Only five neonate and seven small juveniles were identified based on umbilical scar condition and extrapolated growth rates (Branstetter, 1987a) (Table 1, 2; Figure 18).

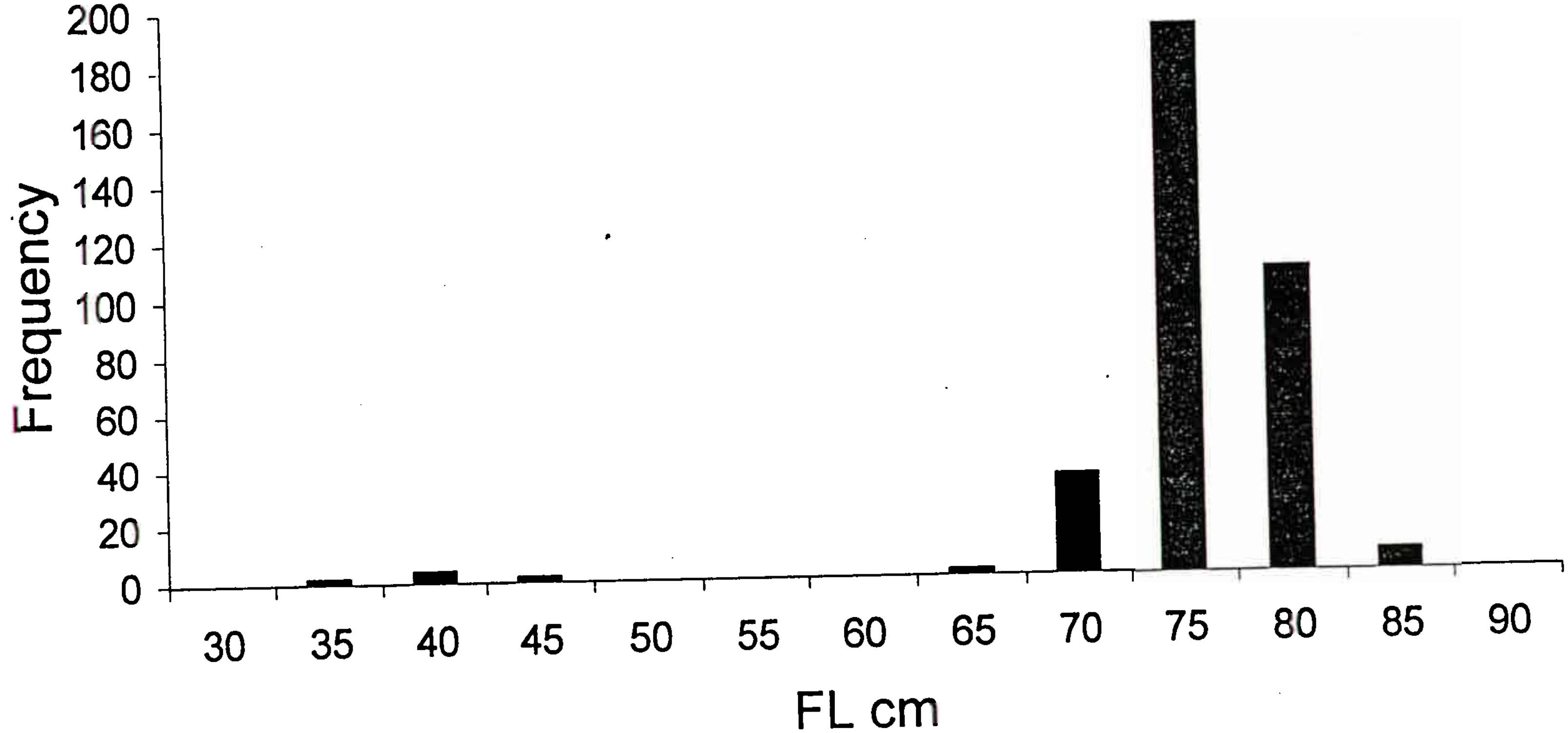


Figure 18: Atlantic sharpnose shark length frequency 1996-1998 and 2000 at Cape Hatteras, North Carolina, sex and mesh size combined N=351.

Most observed mature females in 2000 were gravid. Atlantic sharpnose sharks occur year round off North Carolina. Evidence from this study suggests Atlantic sharpnose use this region for primary and secondary nursery grounds. Jensen (1998) and Thorpe et al., (in review) provided evidence that Atlantic sharpnose sharks use the region from Cape Hatteras to Southeast North Carolina as primary and secondary nursery grounds. This study supports those findings.

The dominant length frequency for most mesh was about 75 - 85 cm FL (Figure 19). Few neonate and small juveniles (age 1+) were captured during the study (Table II). Few conclusions can be drawn from the length frequency by mesh size other than the obvious susceptibility of this species to a variety of mesh sizes. Selectivity for this species needs further examination.

Scalloped hammerhead

Three scalloped hammerheads were observed during the four year period (Table 1, 2; Figure 5). Based on direct observation and estimated size, all three were mature males (Compagno, 1984b; Branstetter, 1987b). A neonate scalloped hammerhead was observed during July 2000 off Hatteras Village and a juvenile was seen in June 2000 near Hatteras Inlet while sampling for COASTSPAN (Jensen et. al, in prep). This suggests that scalloped hammerhead use this region as a primary and secondary nursery ground. However, no such evidence was found during this time of year, suggesting either migration out of the area, or pupping is infrequent in this area.

Smooth hammerhead

Five juvenile smooth hammerhead sharks were observed during the study (Table 1, 2; Figure 5). This species has not been commonly encountered during studies in North Carolina (Branstetter and Burgess, 1997, 1998; Jensen, 1998; Thorpe et al., in review; pers. obs). However, data from this study suggests this region provides habitat to support a secondary nursery ground for the smooth hammerhead.

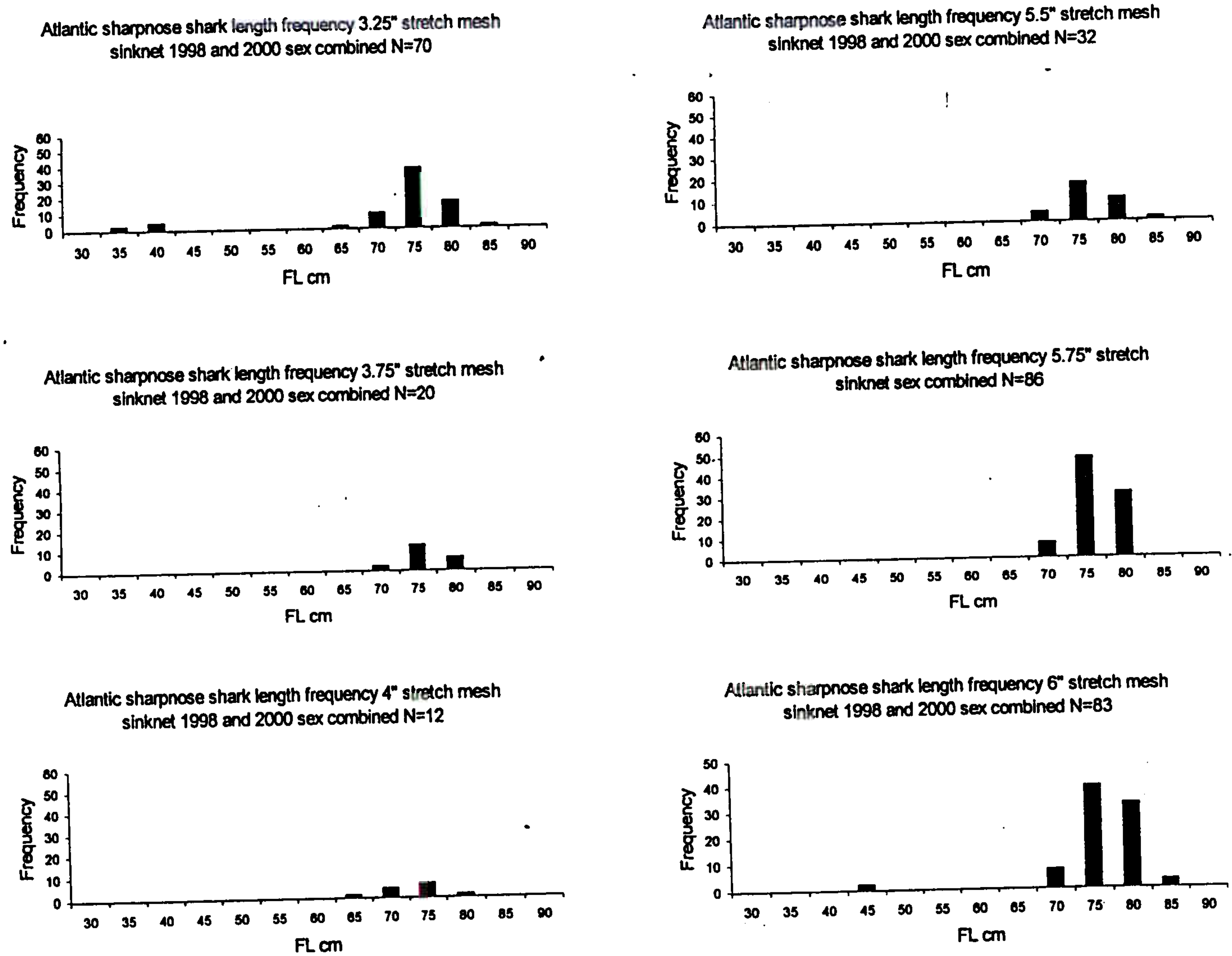


Figure 19: Atlantic sharpnose shark length frequency FL (cm) by mesh size 1998 and 2000 at Cape Hatteras, North Carolina.

Spanish mackerel

Directed Spanish mackerel fishing occurred during only three sample days in the study. Generally, Spanish mackerel catches decline about mid-October, with only large, sporadic individuals encountered during the transition to king mackerel and during directed king mackerel fishing. Ages 1-3 were most prevalent, with age 1 dominating the 3.25" stretch mesh. A shift in length frequency indicates there is size selection for 3.75 - 4" stretch mesh, as the age 1 (~30-40 cm FL) class is much reduced compared to 3.25" stretch mesh. Spanish mackerel enter the fishery at age 1 or less (Figure 10). Few sharks were encountered during the Spanish mackerel sets, most likely due to a transition in species composition with water temperature as sharks and teleosts begin migrations.

King mackerel

Few king mackerel were observed in small mesh net (3.25-4" stretch). This was probably due to a combination of size selectivity, and low numbers encountered during a transition period. Overall catches were dominated by age class 5-7 (~80-95 cm FL) (Figure 11). Most king mackerel were caught in 5.75-6" stretch mesh (Figure 12). Based on length frequency, the 5.75" stretch mesh was the most efficient at catching most lengths of king mackerel. King mackerel enter this fishery at about 65 cm FL or about age 2. Females outnumbered males and were larger in size, representing most observations greater than about 110 cm FL (Figure 11, 13). Most king mackerel were dead in the net at haul back (Figure 11).

CONCLUSIONS

Shark bycatch was dominated by the smooth dogfish 45.3%, sandbar shark 41.9%, and Atlantic sharpnose shark 9.3%. These were followed by the dusky shark 0.9%, spinner 0.8%, Atlantic angel shark 0.7%, common thresher 0.6%, and 0.4% consisting of the spiny dogfish, sandtiger, blacktip, scalloped and smooth hammerheads.

Sandbar shark neonates and juveniles (age 1+) use the region of Cape Hatteras as an overwintering nursery ground. This project supports the findings of other studies. Sandbar sharks begin arriving at Cape Hatteras about the second to third week in October. Tag and recapture data indicate that they remain in the region over winter, and migrate to and from the Chesapeake and Delaware Bays. Corroborating evidence supports the use of this region as a primary and secondary nursery ground, although this needs further refinement. Overall acute mortality for the sandbar shark over the four year period was low (10%), with mortality beginning after 1.18 hours of soak time. Mortality was related to soak time, although the data is widely scattered. Mortality was not related to water temperature. CPUE was significant in relation to an increase in water temperature, but the correlation was low. CPUE was not significantly related to depth. Sandbar shark overall length frequency was dominated by neonate and juveniles (age 1+) 50-60 cm FL.

Dusky sharks use the region of Cape Hatteras as a primary and secondary nursery ground, and possibly an overwintering nursery ground. Overall acute mortality for the dusky shark over the four year period was low (11%). Mortality was not significantly related to soak time or water temperature. CPUE was not significant in relation to water temperature or depth. Dusky shark length frequency was dominated by neonate and juveniles 80-90 cm FL.

Data suggests that the region at Cape Hatteras is used as a primary and secondary nursery ground for the sandtiger, common thresher, smooth dogfish, spinner, and Atlantic sharpnose sharks. The smooth hammerhead uses this region as a secondary nursery ground. Although evidence from other studies suggests that scalloped hammerhead use this area as a primary and secondary nursery ground during at least June and July, there was no evidence during this study.

The smooth dogfish was the only shark species that demonstrated mesh selectivity based on length frequency by mesh size. Other shark species in the study need more detailed mesh selectivity studies for conclusions on mesh size and net characteristics for management of shark bycatch.

Spanish mackerel were dominated by age classes 1-3 (30-50 cm FL) and enter the fishery at age 1 or less. Size selection is evident between 3.25" and 3.75-4" stretch mesh. King mackerel were dominated by age classes 5-7 (80-95 cm FL) and enter this fishery at about age 2. The 5.75" stretch mesh appears to be the most efficient mesh size for capturing most size ranges. Females outnumber males and account for most fish over about 110 cm FL.

In summary, the continuance of detailed sampling is needed to further understand the relationships and dynamics of this important region as shark nursery grounds. Further studies are needed to evaluate mesh selectivity.

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Appendix I

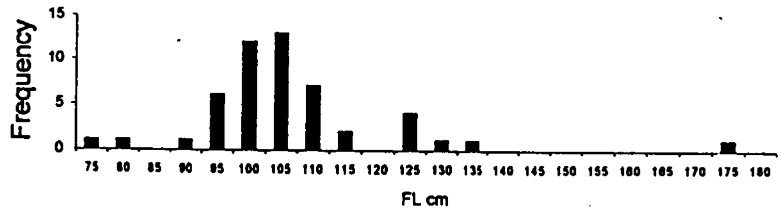
ADDITIONAL ELASMOBRANCH AND TELEOST BYCATCH AND DISPOSITION

	Disposition
Skates - Family Rajidae	
Clearnose skate - *Raja eglanteria*	release
Stingrays - Family Dasyatidae	
Roughtail stingray - *Dasyatis centraura*	released
Ray spp - Dasyatis spp	released
Spiny butterfly ray - *Gymnura altavela*	released
Smooth butterfly ray - *Gymnura micrura*	released
Eagle rays - Family Myliobatidae	
Bullnose ray - *Myliobatis freminvillei*	released
Myliobatis spp	released
Cownose ray - *Rhinoptera bonasus*	released
Sturgeons - Family Acipenseridae	
Atlantic sturgeon - *Acipenser oxyrinchus*	released
Tarpons - Family Elopidae	
Ladyfish - *Elops saurus*	landed
Herring - Family Clupeidae	
Atlantic menhaden - *Brevoortia tyrannus*	landed
Atlantic thread herring - *Opisthonema oglinum*	released
Bluefishes - Family Pomatomidae	
Bluefish - *Pomatomus saltatrix*	landed
Jacks - Family Carrangidae	
Florida pompano - *Trachinotus carolinus*	landed
Grunts - Family Haemulidae	
Pigfish - *Orthopristis chrysoptera*	landed
Porgies - Family Sparidae	
Sheepshead - *Archosargus probatocephalus*	landed

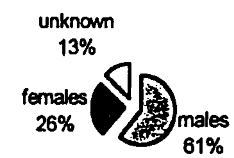
Appendix I, cont'd

Pinfish - *Lagodon rhomboides*	released
Drums - Family Sciaenidae	
Banded drum - *Larimus fasciatus*	released
Southern kingfish - *Menticirrhus littoralis*	landed
Northern kingfish - *Menticirrhus saxatilis*	landed
Kingfish species - *Menticirrhus spp*	landed
Atlantic croaker - *Micropogonias undulatus*	landed
Black drum - *Pogonias cromis*	landed
Spot - *Leistomus xanthurus*	landed
Red drum - *Sciaenops ocellatus*	landed
Spotted seatrout - *Cynoscion nebulosus*	landed
Weakfish - *Cynoscion regalis*	landed
Snake mackerels - Family Trichiuridae	
Atlantic cutlassfish - *Trichiurus lepturus*	released
Mackerels and tunas - Family Scombridae	
Chub mackerel - *Scomber japonicus*	released
Atlantic bonito - *Sarda sarda*	landed
Butterfishes - Family Stromateidae	
Butterfish - *Peprilus triacanthus*	landed
Harvestfish - *Peprilus alepidotus*	landed
Lefteye flounders - Family Bothidae	
Summer flounder - *Paralichthys dentatus*	landed
Southern flounder - *Paralichthys lethostigma*	landed
Windowpane - *Scophthalmus aquosus*	released
Triggerfish - Family Balistidae	
Gray triggerfish - *Balistes capriscus*	landed

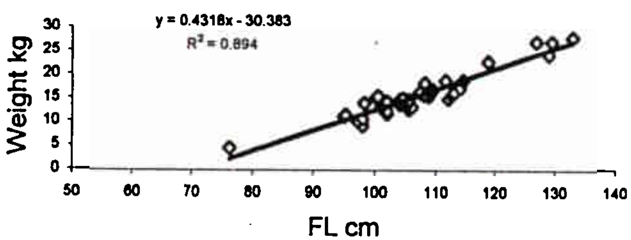
Cobia length frequency all mesh combined 1998 and 2000 N=50 sex combined



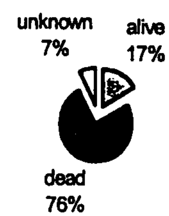
Cobia sex ratio 1998 and 2000
(33 males, 14, females, 7 unknown) N=54
all mesh combined



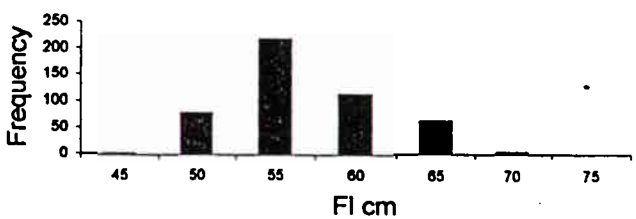
Cobia length/weight relationship combined mesh
1998 and 2000 N=41



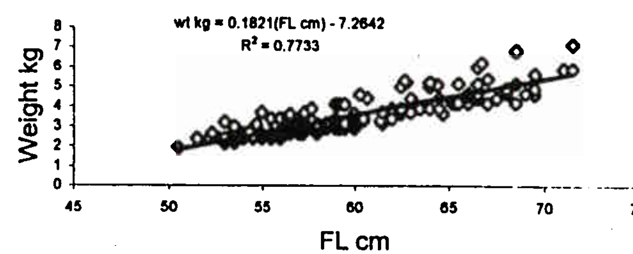
Cobia survival rate combined mesh size 1998 and 2000 N=54



Little Tunny length frequency combined mesh 1998 and 2000
N=474



Little tunny length/weight relationship 1998 and 2000 N=171



Appendix II: Status of coba, *Rachycentron canadum,* and little tunny, *Euthynus alletteratus,* 1998 and 2000 at Cape Hatteras, North Carolina.