Life history of cobia, *Rachycentron canadum* (Osteichthyes: Rachycentridae), in North Carolina waters

Smith, Joseph

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Life History of Cobia, *Rachycentron canadum* (Osteichthyes: Rachycentridae), in North Carolina Waters

JOSEPH W. SMITH
National Marine Fisheries Service
Southeast Fisheries Science Center
Beaufort Laboratory
101 Pivers Island Road
Beaufort, North Carolina 28516-9722

ABSTRACT.—Cobia (n = 416) were collected primarily along the central North Carolina Atlantic coast from recreational anglers between 1983 and 1994. Males (n = 174) ranged up to 136-cm fork length (FL) and 32.0 kg, and females (n = 182) up to 142-cm FL and 32.2 kg. Most cobia greater than 100-cm FL were females. Ages of cobia (to age 14) were estimated by counting opaque zones on cross-sectioned sagittal otoliths. Von Bertalanffy growth parameter (k) estimates were 0.37 for males and 0.24 for females. Adult cobia occurred in major sounds and coastal Atlantic waters of North Carolina from May through July, and in nearshore oceanic waters through fall. Cobia may overwinter between Cape Fear and Cape Canaveral at depths of 30–75 m. Cobia fed chiefly on demersal crustaceans and fishes in the study area. Cobia may be one of the few teleosts that regularly consumed small elasmobranchs. Male cobia were sexually mature at 60–65-cm FL (age 2), and females at 80-cm FL (age 2). Cobia spawned May through July along the North Carolina coast, and ocean waters adjacent major coastal inlets were probable sites for cobia spawning activity.

Cobia, *Rachycentron canadum*, a large, coastal fish of the monotypic family Rachycentridae, has a cosmopolitan distribution in tropical to warm temperate seas, except for the eastern Pacific Ocean (Briggs 1960, Shaffer and Nakamura 1989). Cobia occur during summer in the United States coastal waters of the northern Gulf of Mexico and along the Eastern Seaboard from the Florida Keys north to Cape Cod (McClane 1965), although they are uncommon north of Chesapeake Bay (personal observations). Cobia migrate north along the Atlantic coast from northern Florida to the Carolinas, and then into Chesapeake Bay (McClane 1965, Shaffer and Nakamura 1989) during spring and summer. By late spring and early summer cobia enter polyhaline to mesohaline areas of major coastal bays, sounds and river systems in the Carolinas and Virginia (Musick 1972, Moore et al. 1980, Schwartz et al. 1981). Lone fish or "pods" of several cobia often hover in the shadow of near-surface objects, such as buoys, boats, sharks, and rays (Joseph et al. 1964, McClane 1965, Shaffer and Nakamura 1989). Their size, commonly exceeding 23 kg (McClane 1965), and nearshore residence during spring through summer, make them a favorite of coastal recreational fishermen. Recent estimates (1991) place recreational cobia landings along the United States south Atlantic coast (292,600 kg) at five times that of commercial landings (58,000 kg)(Isley 1992).

To date, Richards (1967) conducted the most comprehensive life history study of cobia on the Atlantic coast of the United States, collecting specimens during the mid-1960s in lower Chesapeake Bay. Various facets of cobia biology have been examined, including feeding habits (Knapp 1951, Darracott 1977), reproduction (Biesiot et al. 1994), spawning areas and season (Joseph et al. 1964), movements and growth (Richards 1977, Franks 1995), rearing eggs and larvae (Hassler and Rainville 1975), and egg and larval distributions (Ditty and Shaw 1992). Recent mitochondrial DNA analyses (Hrincevich and Biesiot 1994) suggested that cobia from the northern Gulf of Mexico and the south Atlantic coast of the United States should be considered a unit stock. Shaffer and Nakamura (1989) compiled a biological synopsis of the species.

My interest in cobia stems from (1) a perceived increase in fishing effort for the species along the North Carolina coast during the 1980s, including a directed charter boat fishery for cobia at Ocracoke Inlet and the establishment of a cobia fishing tournament in Carteret County, and (2) the lack of contemporary fishery statistics on which to base cobia stock assessments (Gulf of Mexico and South Atlantic Fishery Management Councils 1985, Isley 1989). Objectives were to elucidate various aspects of cobia life history in North Carolina waters, in particular, age and size composition of the recreational catch, distribution, feeding habits, and reproduction.

MATERIALS AND METHODS

Recreational fishermen in the Morehead City-Beaufort area (Carteret County) of the central North Carolina coast (Fig. 1) were the major sources of specimens from 1983 to 1994. Beginning in June 1987 and each spring thereafter, fish were processed at a local cobia tournament. Additionally, during 1989–92 charter boat captains and tackle shop proprietors at Ocracoke Island and Hatteras, North Carolina, provided frozen cobia carcasses, individually labeled with date, location of capture, and whole (round) mass; for most of these specimens the head, axial skeleton and viscera were intact. Carcasses were returned to the laboratory biweekly for processing. Additional specimens came from pound nets and haul seines in Pamlico Sound near Cape Hatteras, ocean research

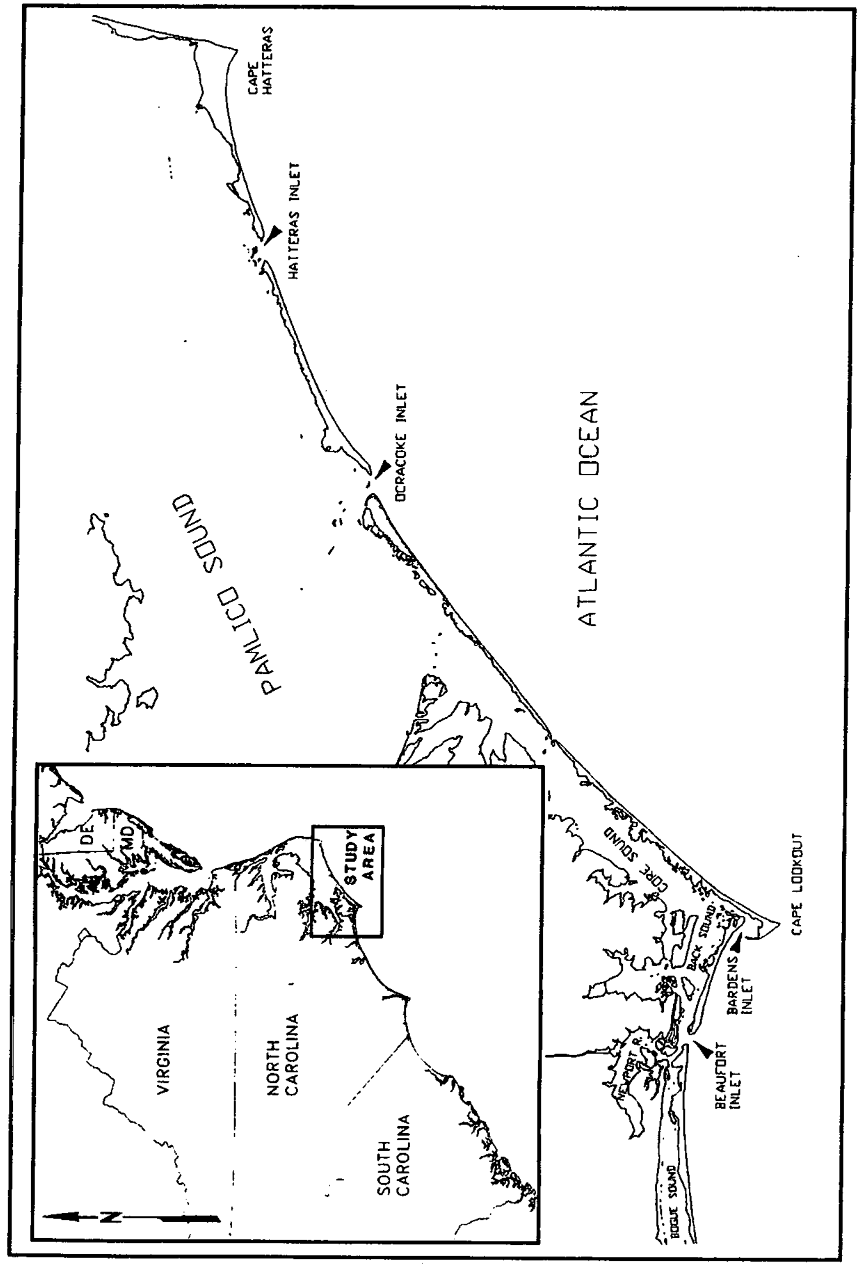

Fig. 1. Major sampling sites (arrows) for cobia along the North Carolina coast, 1983–94.

cruises between Cape Lookout, North Carolina, and northern Florida, research trawls in lower Chesapeake Bay, and port agents in South Carolina and northeast Florida.

Whole cobia were weighed to the nearest 0.1 kg. Carcasses and whole cobia were measured for total (TL) and fork length (FL) in centimeters and sexed. Gonads were staged for maturity based on criteria in Waltz et al. (1979), then excised and weighed to the nearest gram. Subsamples of fresh gonadal tissue from 99 cobia were preserved in 10% buffered formalin, and later sectioned by standard histological techniques (Humason 1972) to verify maturity staging in the field. A gonadosomatic index (*gsi*) was computed for sexually mature specimens, whereby *gsi* = (gonad mass/body mass) x 100. Axial skeletons were missing from some frozen specimens, as catches were "steaked" versus filleted. Fork lengths for fish lacking an axial skeleton were estimated by calculating a regression of FL on intraorbital distance (measured with a caliper in mm) from whole fish (Table 1). Fork length was then assigned to carcasses based on this regression.

Table 1. Mass-length (ln) and length-length regression equations for cobia from North Carolina and adjacent waters, 1983-94.

Variables[a]	Sex[b]	*n*	Equation	R^2	Range
W-FL	♂	86	log W=3.4 log FL -13.3	0.972	0.5–32.0 kg
	♀	94	log W=3.2 log FL -12.3	0.949	0.7–32.2 kg
	♂+♀+I	194	log W=3.4 log FL -13.0	0.987	0.5–32.2 kg
TL-FL	♂	105	TL=1.1 FL -1.1	0.989	39–136 cm FL
	♀	97	TL=1.1 FL +0.7	0.993	44–142 cm FL
	♂+♀+I	217	TL=1.1 FL -0.9	0.995	39–142 cm FL
FL-IO	♂	75	FL=0.8 IO + 17.3	0.929	39–136 cm FL
	♀	65	FL=0.8 IO + 18.5	0.956	44–142 cm FL

[a] W = fish mass in kg, IO = intraorbital distance in mm, FL and TL in cm.
[b] I = undifferentiated specimens.

Stomachs were examined and the contents were preserved in 10% formalin and later transferred to 50% isopropanol. Bait or chum (fish that had obviously been sliced or cut by anglers, mostly Atlantic menhaden, *Brevoortia tyrannus*, pinfish, *Lagodon rhomboides*, and various sciaenids) occurred in 37 stomachs; these items were eliminated from any analyses, as were 15 stomachs where bait or chum was the only food item present. Represented food items were drained, identified, counted, and weighed to the nearest gram.

Importance of each prey item to the cobia diet was based on an index of relative importance (*iri*; Pinkas et al. 1971). Percent frequency of occurrence for each item in non-empty stomachs (*f*), percent total number of prey items (*n*), and percent total mass of prey items (*w*) were calculated. The original *iri* formula was modified to use the mass of a prey item instead of volume, (*iri* = *f*(*n*+*w*)). The results were examined for areal differences in diet (Beaufort Inlet and vicinity, Ocracoke and Hatteras inlets and vicinity, and offshore oceanic waters). To determine changes in cobia food habits with growth, specimens with food items were partitioned into arbitrary size classes (<4.5, 4.5–9.0, and >9.0 kg), and prey items were grouped into four categories, that is, shrimps, crabs, teleost fishes, and elasmobranch fishes. Percent *iri*'s were calculated as a percent of total *iri* within each cobia size class.

Acetate impressions of cobia scales were difficult to interpret, therefore, sagittal otoliths of cobia were used to estimate specimen age. Sagittae of cobia were removed, washed in distilled water, and stored dry in individually labeled envelopes. Sagittae were embedded in 14x6x3-mm epoxy molds. Casts were affixed to a microscope slide with a drop of cyanoacrylate glue, then clamped to the arm of a circular low-speed saw. A 0.5-mm transverse section was made through the sagittal focus using a diamond-edge circular blade. The resulting wafer was permanently mounted to a microscope slide with a fixative.

Sagittal sections were viewed on a dissecting microscope (16x) with transmitted, polarized light. Cross-sectioned sagittae had an opaque central core, followed by alternating translucent and opaque zones (Fig. 2). Although marginal increment analyses were precluded because specimens were unavailable throughout the year, most sagittae had an opaque edge, or an opaque zone in close proximity to the sagittal edge. Moreover, research in the northern Gulf of Mexico (Franks et al. 1991, Thompson et al. 1991) confirmed the validity of the formation of one translucent and one opaque zone on cobia sagittae each year. Thus, I assumed that one translucent and one opaque zone was deposited each year, and that opaque zones could be used to estimate cobia ages.

Opaque zones along the ventral medial axis were counted as apparent annuli; estimated fish ages were based on opaque zone counts. I used the SAS NLIN procedure with the Marquardt option (SAS Institute, Inc. 1987) to estimate von Bertalanffy growth parameters based on individual fork lengths. Lengths referred to in the text are fork lengths.

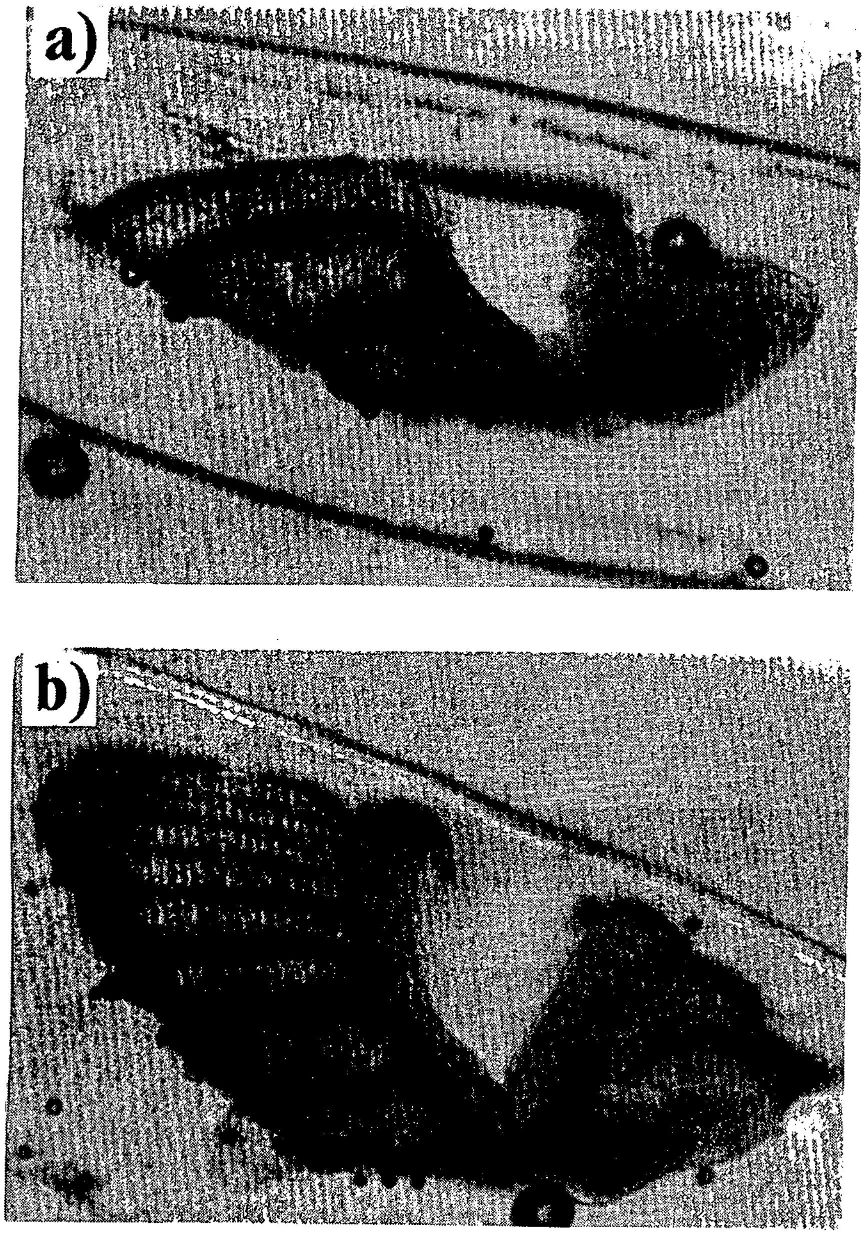

Fig. 2. Cross-sections (0.5 mm thick) of cobia sagittae: a) sagitta from age 3 fish (89 cm FL male, 18x magnification), b) sagitta from age 8 fish (125 cm FL female, 18x magnification). Note that spheres are artifacts of fixative.

RESULTS

Size and Age Composition

Four hundred sixteen cobia were collected. Most (n = 366) were acquired from recreational hook-and-line fishermen, while others came from trawls (n = 34), gill nets (n = 7), pound nets (n = 4), stop nets (n = 2), long hauls (n = 2), and purse seine (n = 1). A majority (n = 356) of the specimens came from North Carolina waters, mostly from inlet areas. A few specimens were from the Virginia portion of Chesapeake Bay (n = 17), and others were collected by port agents in South Carolina (n = 11), and northeast Florida (n = 15). Research trawls (75-ft high-rise mongoose net) from Daytona Beach, Florida, to Cape Lookout, North Carolina captured 17 specimens at ocean stations in depths 7–17 m.

Using pooled data from all gear types, 174 male cobia ranged from 39 to 136 cm and 0.47 to 32.0 kg, and 182 females ranged from 44 to 142 cm and 0.66 to 32.2 kg (Fig. 3). Only 27 of 152 (17.8%) males, taken by hook-and-line, measured greater than 100 cm; conversely 91 of 174 (52.3%) of the females caught by the same gear were greater than 100 cm (Fig. 3).

North Carolina enacted bag (2 fish/angler/day) and minimum size limits (33 inches [84 cm] FL) for cobia in 1991, thus bringing the state in line with corresponding cobia regulations in other south Atlantic states and the Federal Fisheries Conservation Zone (3–200 miles from shore). Between 1983 and 1990, 261 cobia caught by hook-and-line were examined, and 65 (24.9%) were less than 84 cm. Between 1991 and 1994, only five (5.3%) of 93 fish caught by hook-and-line were less than 84 cm, and four of these were 82–83 cm.

Sectioned sagittae from 326 specimens were examined for opaque zone counts (Fig. 2). Mean observed fork length of cobia increased with opaque zone count (Table 2). Otoliths with no opaque zones distal to the sagittal core presumably came from young-of-the-year cobia that averaged 31-cm (n = 17, range = 21-46-cm). Age 1 cobia, or those with one opaque zone distal to the core, averaged 51 cm (n = 9, range = 39-64-cm). Mean length of females was larger than mean length for males at a given estimated age (Table 2). Maximum estimated age was 14 for males, and 13 for females. The von Bertalanffy growth coefficient, k, was greater for males than females, although mean asymptotic size was larger for females (Table 3).

Seasonality and Distribution

Initial catches of cobia by North Carolina anglers usually occurred in March or April 50–65 km offshore over rocky outcroppings and

Table 2. Sample size (n), fork length range, mean observed fork lengths (±1 SE), mean observed mass, and von Bertalanffy estimates of fork lengths (VB FL) for each sex of cobia from North Carolina and adjacent waters, 1983-94, by estimated age. Results of Richards' (1967 and 1977) studies are presented for comparison. All lengths are in cm.

		Present Study							Richards (1967)[1]		Richards (1977)
Sex	Estimated Age	n	FL range	$\bar{x}$ observed FL	±1SE	$\bar{x}$ mass kg	n	VB[2] FL	$\bar{x}$ observed FL	$\bar{x}$ kg	mass VB FL
Males	1	6	39– 64	50	4	1.3	6	56	54	1.5	31
	2	22	63– 93	74	2	3.9	13	71	71	3.8	53
	3	41	68–102	82	1	6.7	23	82	84	7.6	69
	4	32	82– 97	88	1	8.3	14	89	94	9.6	82
	5	20	78– 99	92	1	9.4	12	94	101	11.9	91
	6	7	90–103	95	2	10.6	7	97	104	13.7	99
	7	6	94–108	100	2	11.5	5	100	105	14.5	104
	8	8	89–107	99	2	13.6	5	101			108
	9	6	99–136	107	6	18.3	4	103	109	17.7	
	10	5	101–109	105	1	12.2	1	103	119	19.0	
	11	3	102–109	105	2			104			
	12	0						104			
	13	1		113		19.3	1	104			
	14	1		106		20.0	1	105			
Females	1	3	49– 63	55	4	1.0	1	61	58	1.8	36
	2	18	57–106	81	3	6.1	16	77	78	4.6	61
	3	50	79– 99	89	1	8.4	36	89	95	11.1	82
	4	23	88–132	102	2	12.5	12	99	104	13.2	99
	5	13	98–113	106	1	14.9	10	107	116	19.7	112
	6	20	99–126	111	2	17.8	14	113	120	21.8	122
	7	11	110–126	117	2	21.0	10	117	126	25.1	131
	8	8	114–128	123	2	23.9	6	121	130	28.4	137
	9	7	114–134	125	2	24.6	5	124	133	30.5	
	10	3	117–133	127	5	29.7	2	126			
	11	1		121		18.1	1	128			
	12	3	125–130	127	2	28.6	1	130			
	13	2	134–142	138	4	32.0	2	131			

[1] Values converted to metric units from published English units.
[2] Values are von Bertalanffy estimates of FL based on individual FLs at estimated age.

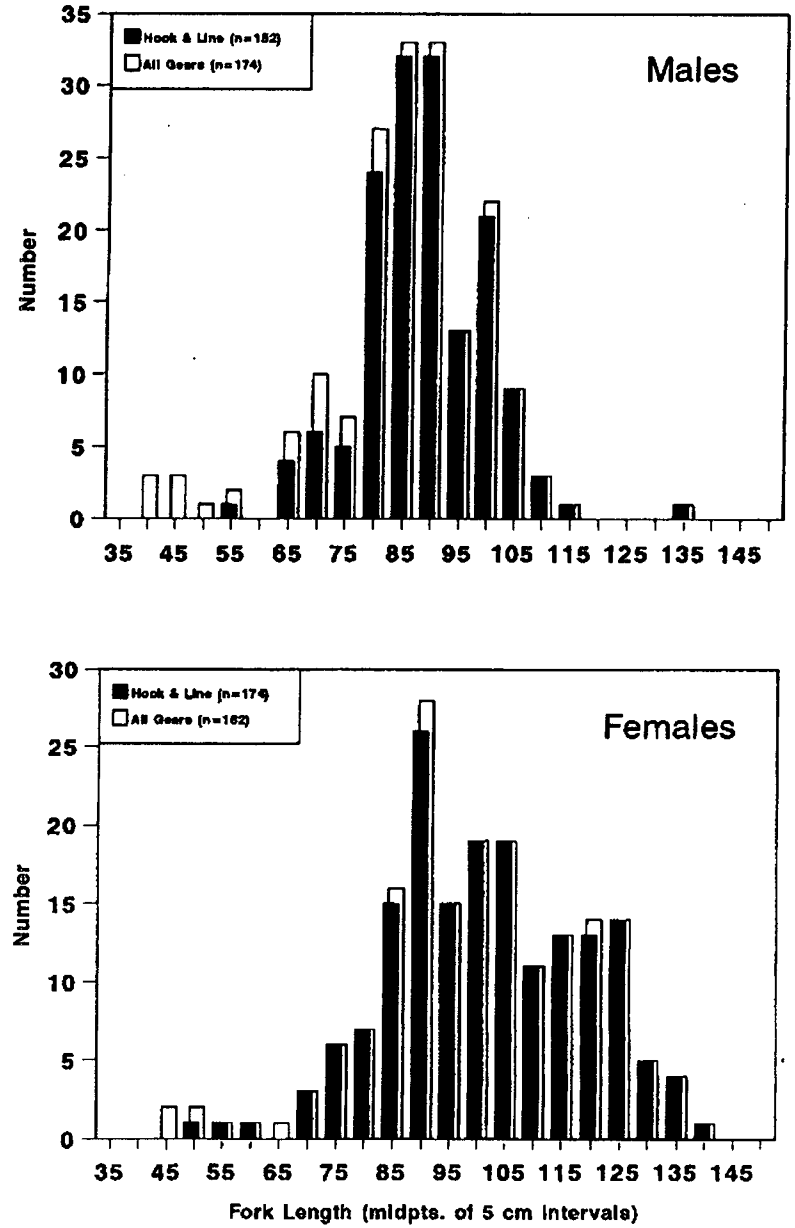

Fig. 3. Fork length frequency distributions (all gears and hook-and-line) by 5-cm increments for male and female cobia from North Carolina and adjacent waters, 1983–94.

Table 3. Von Bertalanffy parameter estimates by sex describing the growth of cobia from North Carolina and adjacent waters, 1983-94; CL = 95% confidence limits. Richards' (1977) estimates shown for comparison.

Sex	Parameter	Estimate	Asymptotic SE	Asymptotic CL lower	Asymptotic CL upper	Richards' (1977) estimates
Males	l_∞	105	1.85	101	108	121
	k	0.37	0.04	0.29	0.45	0.28
	t_0	-1.08	0.29	-1.65	-0.51	-0.06
Females	l_∞	135	3.82	127	142	164
	k	0.24	0.03	0.18	0.31	0.23
	t_0	-1.53	0.39	-2.30	-0.77	-0.08

coral patches of low relief (Huntsman 1976). By early May, cobia were found on nearshore artificial reefs and under navigation buoys in the vicinity of Beaufort, Ocracoke, and Hatteras inlets (Manooch et al. 1981). The earliest record for cobia caught by hook-and-line in North Carolina estuarine waters during the study was 8 May 1990. Initial spring catches in the sounds coincided with inshore water temperatures reaching 20 C and higher. Most "inshore" angling activity for cobia was concentrated in Bogue and Back sounds adjacent to Beaufort and Bardens inlets near Cape Lookout, and Pamlico Sound adjacent to Ocracoke and Hatteras inlets near Cape Hatteras (Fig. 1). Traditional fishing locations for cobia in North Carolina's inlets, sounds, and coastal rivers were poly- to mesohaline waters >5–6 m deep. These sites were characterized by long, straight troughs or embayments (up to several kilometers long and/or wide), often with adjacent feeder creeks or channels, e.g., Bogue Sound, Newport River, and Wallace and Blair channels of Ocracoke Inlet.

Peak catches of cobia in the North Carolina sounds occurred during June, and declined thereafter (Table 4). The latest record for an adult cobia taken by hook-and-line in the Carolina sounds during this study was 18 August 1988. Cobia were captured during summer in the nearshore ocean adjacent to buoys and fishing piers, and over artificial reefs and live bottom areas. Catches were often incidental to bottom fishing or live-bait fishing for other species. During May 1988 and June 1991, catches were poor in the sounds following the passage of unseasonable cold fronts that quickly chilled estuarine water temperatures from 26 C to 19 C and 28 C to 22 C, respectively.

Juvenile cobia also occurred in North Carolina sounds during summer. Young-of-the-year (based on length frequency distributions

Table 4. Number of cobia processed that were and caught by hook-and-line in North Carolina by month and date, 1983-90 (date intervals arbitrarily chosen).

Dates	May	June	July	August	September
1–7	1	45	8	0	0
8–15	5	100	5	0	1
16–22	27	6	3	1	0
23–31	20	33	5	0	0
Totals	53	184	21	1	1

and otolith analyses) were collected in pound nets and long haul nets from Pamlico Sound in August and September (Fig. 3). Age 1 fish occurred in the sounds from late May through mid-September, and most specimens were taken by hook-and-line.

Food Habits

During 1989–1990, 140 cobia stomachs were examined, of which 72.1% (n = 101) contained representative food items. *Iri*'s were computed from these samples and nine additional stomachs with food items from 1987 to 1988. Twenty-four species groups of crustaceans, 16 species groups of fishes, and one cephalopod were identified from 110 stomachs (Table 5).

After pooling data from all three sampling areas, the blue crab, *Callinectes sapidus*, had the highest *iri*, followed by the blackcheek tonguefish, *Symphurus plagiusa*, and unidentified fish remains. Other identifiable fishes in the diet with high *iri*'s were pipefishes, *Syngnathus* sp., and the smooth dogfish, *Mustelus canis*. Items apparently incidentally ingested included eelgrass (*Zostera marina*) blades, small fragments of oyster shell (*Crassostrea virginica*), and small gastropods.

In the Beaufort area, the blue crab (Table 6) had the highest *iri*, followed by the smooth dogfish, pipefishes, and dasyatid sting rays. Abundant crustaceans included the iridescent swimming crab, *Portunus gibbesii*, the brown shrimp, *Penaeus aztecus*, and the mantis shrimp, *Squilla empusa*. High-ranking food items from the Hatteras-Ocracoke area (Table 6) were the blackcheek tonguefish and the blue crab. Important food items from offshore waters (Table 6) included the coarsehand lady crab, *Ovalipes stephensoni*, unidentifiable fishes, the blotched swimming crab, *Portunus spinimanus*, and rock shrimps, *Sicyonia* sp.

Among individual prey taxa, elasmobranchs were the largest prey

Table 5. Percent frequency of occurrence (*f*), percent number (*n*), percent mass (*w*), and index of relative importance (*iri*) of food items in cobia stomachs from North Carolina and adjacent waters, 1987-90.

Prey Taxa	*f*	*n*	*w*	*iri*
Mollusca				
Cephalopoda				
Loligo plei	0.9	0.2	<0.1	<1
Arthropoda				
Crustacea				
Stomatopoda				
Squilla sp.	2.7	0.7	0.4	3
S. empusa	3.6	1.3	2.5	14
S. neglecta	1.8	4.2	2.5	12
Decapoda				
Penaeidae				
Penaeus sp.	3.6	0.9	0.2	4
P. aztecus	6.4	2.9	3.7	42
P. setiferus	0.9	0.2	0.2	<1
Trachypenaeus constrictus	0.9	1.5	<0.1	<1
Sicyoniidae				
Sicyonia sp.	3.6	7.9	2.7	38
Palaemonidae				
Palaemonetes vulgaris	0.9	0.4	<0.1	<1
Crangonidae				
Crangon septemspinosa	4.5	2.6	0.2	13
Upogebiidae				
Upogebia sp.	0.9	0.2	<0.1	<1
Albuneidae				
Albunea gibbesii	0.9	0.2	0.1	<1
Portunidae				
Ovalipes sp.	6.4	3.7	2.0	36
O. ocellatus	2.7	0.9	1.1	5
O. stephensoni	6.4	4.6	4.0	55
Callinectes sp.	7.3	3.3	1.8	37
C. sapidus	30.0	15.4	19.2	1,038
C. similis	3.6	0.9	0.8	6
Portunus sp.	3.6	1.1	0.5	6
P. gibbesii	5.5	2.2	1.8	22
P. spinimanus	2.7	0.7	1.4	6
Unidentified portunid remains	4.5	2.2	0.3	11
Xanthidae				
Menippe mercenaria	0.9	0.4	0.1	<1
Unidentified decapod remains	0.9	0.2	<0.1	<1
Chondrichthyes				
Carcharhinidae				
Mustelus canis	6.4	6.1	21.2	175

Table 5. Continued.

Prey Taxa	*f*	*n*	*w*	*iri*
Dasyatidae				
Dasyatis sp.	3.6	0.9	12.7	49
Osteichthyes				
Clupeidae				
Opisthonema oglinum	0.9	0.4	0.4	1
Engraulidae				
Anchoa sp.	0.9	1.3	0.1	1
Synodontidae				
Synodus foetens	0.9	0.2	0.3	<1
Batrachoididae				
Opsanus sp.	3.6	1.1	2.7	14
Syngnathidae				
Hippocampus sp.	0.9	0.2	<0.1	<1
Syngnathus sp.	19.1	7.0	2.2	176
Sparidae				
Lagodon rhomboides	0.9	0.2	0.2	<1
Uranoscopidae				
unidentified remains	0.9	0.2	<0.1	<1
Soleidae				
Trinectes maculatus	0.9	0.7	0.4	1
Cynoglossidae				
Symphurus plagiusa	17.3	13.2	6.8	346
Balistidae				
unidentified remains	2.7	1.3	0.1	4
Tetradontidae				
Sphoeroides maculatus	0.9	0.7	1.9	2
Diodontidae				
Chilomycterus schoepfi	0.9	0.2	1.2	1
unidentified fish remains	21.8	7.5	4.5	262

ingested. Smooth dogfish pups (n = 28) averaged 42 g; dasyatid sting rays (n = 4) averaged 173 g. The largest teleosts consumed were the striped burrfish, *Chilomycterus schoepfi* (n = 1, 65 g), the northern puffer, *Sphoeroides maculatus* (n = 3, $\bar{x}$ = 34 g), and toadfishes, *Opsanus* sp. (n = 5, $\bar{x}$ = 29 g). Most portunid crabs were less than 7 cm in carapace width (CW) and were ingested whole; commercial-sized blue crabs (ca. 12.5-cm CW) were rarely consumed. Ovalipid crabs were often macerated. Small balistid fishes occurred in the stomachs of juvenile cobia from offshore trawl catches and were among the smallest teleosts consumed (n = 6, $\bar{x}$ = 1 g).

As cobia increased in size, penaeid shrimps and teleost fishes became relatively less important in the diet, while decapod crabs increased

Table 6. The ten highest ranked prey items in cobia stomachs by sampling area in North Carolina[1], 1987–90.

Beaufort Inlet (n = 40)		Ocracoke-Hatteras Inlets (n = 56)		Offshore Areas (n = 14)	
Prey	*iri*	Prey	*iri*	Prey	*iri*
Callinectes sapidus	1,609	*Symphurus plagiusa*	1,311	*Ovalipes stephensoni*	870
Mustelus canis	802	*Callinectes sapidus*	1,111	Unidentified fish	654
Syngnathus sp.	236	Unidentified fish	355	*Portunus spinimanus*	561
Dasyatis sp.	208	*Ovalipes* sp.	164	*Sicyonia* sp.	516
Unidentified fish	133	*Syngnathus* sp.	130	Unident. *Balistidae*	277
Portunus gibbesii	89	*Sicyonia* sp.	69	*Syngnathus* sp.	182
Penaeus aztecus	73	*Opsanus* sp.	56	*Trachypenaeus constrictus*	95
Squilla empusa	69	*Penaeus aztecus*	42	*Anchoa* sp.	90
Callinectes sp.	55	*Crangon septemspinosa*	32	*Synodus foetens*	41
Symphurus plagiusa	38	*Callinectes* sp.	31	*Symphurus plagiusa*	35

[1] n = number of stomachs examined by locality.

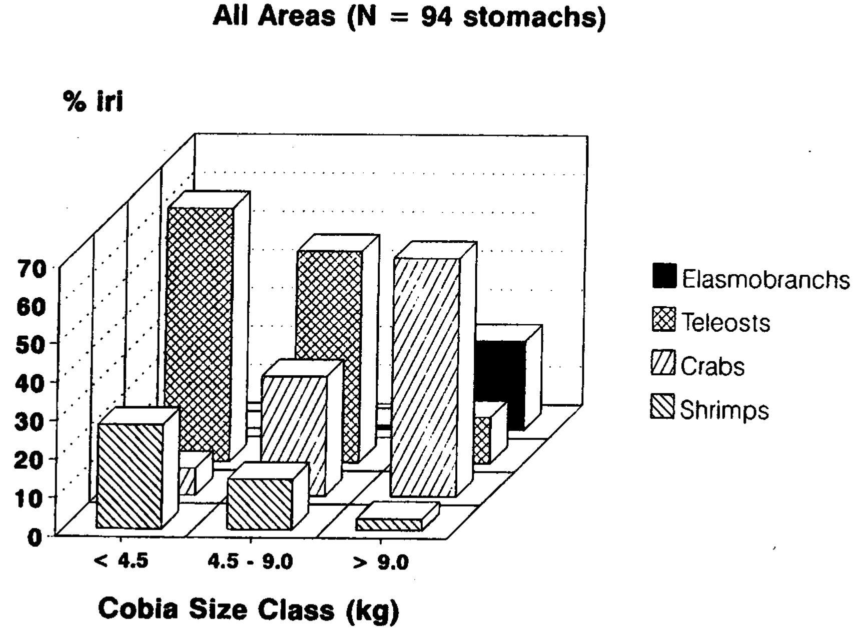

Fig. 4. Percent *iri*'s for various prey groups by cobia mass interval (intervals arbitrarily chosen).

in importance (Fig. 4). Elasmobranchs, that is, the smooth dogfish and dasyatid sting rays, were consumed almost exclusively by cobia greater than 9 kg. Seventy-five percent (50 of 67) of female cobia from North Carolina sounds and inlet areas had food in their stomach at capture, suggesting that these areas may be foraging grounds before and after spawning.

Reproduction

One hundred and twenty-seven male and 113 female cobia were sexed and staged for maturity in the field. Most male cobia were developing or ripe (Table 7). The latter state was characterized by active spermatogenesis and copious amounts of sperm within testicular ducts (Fig. 5a). Mean *gsi*'s for males increased from 3.0 (SD = 1.2, n = 14) in May, to 4.7 (SD = 1.5, n = 44) in June, then declined slightly to 4.4 (SD = 1.6, n = 7) in July. Most male cobia were sexually mature by 60–65 cm FL (Table 7), or age 2.

Most female cobia examined were staged as developing (Table 7), and most were sexually mature by 80 cm FL, or age 2. Histological sections revealed that the ovaries of early developing females had

Table 7. Cobia from North Carolina and adjacent waters, 1983–94, in various stages of sexual development by 5-cm-FL intervals.

Midpoint	Males		Females		
5-cm-FL	Immature	Developing and Ripe	Immature	Developing	Ripe
≤ 50	5	0	4	0	0
55	1	0	1	0	0
60	1	3	1	0	0
65	0	6	1	0	0
70	0	5	1	2	0
75	0	22	5	0	0
80	0	23	0	6	0
85	0	25	0	11	0
90	0	11	0	19	1
95	0	17	0	8	0
100	0	7	0	9	0
105	0	0	0	11	0
110	0	1	0	9	0
115	0	0	0	5	0
120			0	6	0
125			0	8	0
130			0	2	0
135			0	2	0
140			0	1	0
Totals	7	120	13	99	1

many small basophilic oocytes with a few early vitellogenic oocytes (Fig. 5b), whereas the ovaries of late developing females had large (ca. 750 μm), yolk-filled oocyctes (Fig. 5c). Only one female had hydrated oocytes; it was uncertain if this fish was caught in estuarine or oceanic waters. A few females (collected in early June 1990) showed follicular atresia indicative of a recent spawn, yet also possessed numerous large oocytes, suggestive of an incipient spawn (Fig. 5d).

Mean *gsi*'s for female cobia were high in May at 5.5 (SD = 2.2, n = 8), peaked in June at 5.7 (SD = 2.1, n = 49), and declined slightly in July at 5.3 (SD = 2.2, n = 8). The largest ovaries excised weighed 2.49 kg (7 June) and were in a female weighing 25.4 kg. Peak spawning in June 1989 was confirmed by neuston net collections of cobia eggs from a channel in the lower Newport River estuary about 3 km from Beaufort Inlet (Fig. 1) (L. Settle, National Marine Fisheries Service, Beaufort, North Carolina, unpublished data). During 10 sampling dates between 14 June and 18 August, peak cobia egg

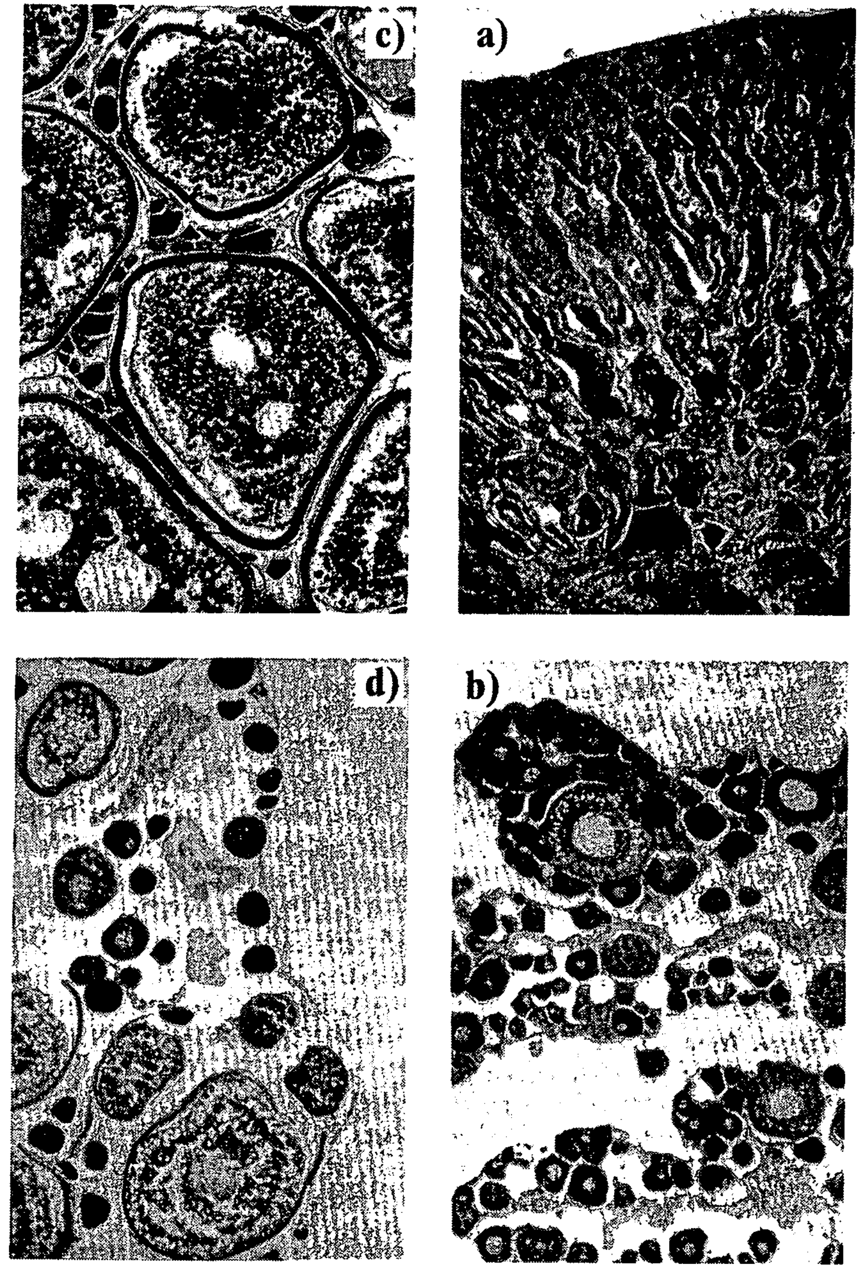

Fig. 5. Histologic preparations of cobia gonad sections: a) ripe male (70 cm FL), b) early developing female (80 cm FL), c) late developing female (104 cm FL), d) partially spent female (88 cm FL), but with numerous large oocytes.

concentrations occurred on 23 June (67 eggs/100 m^3), with minor peaks occurring on 11 July (44 eggs/100 m^3), and 4 August (28 eggs/100 m^3). Moreover, results of a concurrent ichthyoplankton survey (1989) near Ocracoke Inlet indicated that cobia eggs were one of the most common taxa encountered during May and June (W. Hettler, National Marine Fisheries Service, Beaufort, North Carolina, personal communications).

DISCUSSION

Cobia occurred in the sounds and ocean inlets of North Carolina from May to July, and as Richards (1967) observed in Chesapeake Bay, initial spring catches by sport fishermen were coincident with nearshore and estuarine water temperatures rising above 20 C. Cold fronts during May and June accompanied by strong northeast winds chilled inshore water temperatures and adversely affected spring catches of cobia in North Carolina. During August and into fall, cobia were found primarily in coastal oceanic waters. Cobia reside in other major estuaries along the United States Atlantic coast during spring and summer, e.g., Port Royal and St. Helena sounds in South Carolina (Moore et al. 1980) and Chesapeake Bay (Richards 1967). This contrasts with the northern Gulf of Mexico where most cobia occur along shallow coastal waters of the Gulf and offshore in association with oil and gas platforms and rafts of *Sargassum* (Ditty and Shaw 1992).

It is unclear where cobia from the south Atlantic coast of the United States overwinter. Winter trawl surveys by South Carolina's Marine Resources Monitoring, Assessment and Prediction Program (South Carolina Marine Resources Research Institute, Charleston, South Carolina, unpublished data) captured cobia (n = 22, range = 40-127 cm, $\bar{x}$ = 84 cm) during January and February between Cape Fear, North Carolina, and Cape Canaveral, Florida, in 31–75 m depths where water temperatures ranged from 15.9 to 20.8 C (also see Wenner et al. 1979). Cobia taken by various commercial gears (hand, troll, and long lines) have been processed by port agents in North Carolina during all quarters of the year, 1983–91 (L. Mercer, North Carolina Division of Marine Fisheries, Morehead City, North Carolina, personal communications). These findings suggested that off the south Atlantic coast of the United States cobia may overwinter on the outer half of the continental shelf.

Although Richards (1967) used scales to age cobia from Chesapeake Bay, I found that acetate impressions of cobia scales were difficult to interpret for annuli. Alternating translucent and opaque zones of cross-sectioned sagittae were distinct, although I was unable to validate their annual nature. Nevertheless, indirect evidence supported the validity

of opaque zones as annuli. First, mean size of cobia increased with opaque zone count. Second, young-of-the-year cobia (based on length frequency distributions) had no opaque zone distal to the sagittal core or focus, whereas age 1 fish had one opaque zone distal to the sagittal core. Moreover, recent research in the northern Gulf of Mexico (Franks et al. 1991, Thompson et al. 1991) confirmed the validity of the formation of one translucent and one opaque zone on cobia sagittae each year.

Assuming that opaque zones on cobia sagittae were valid annuli, my results indicated that cobia grew rapidly during the first few years of life, and by age 3 mean mass ranged from 6 to 8 kg. Results from public tagging programs report equally dramatic growth for recaptured specimens (Anonymous 1986, Richard 1989, Franks 1995). My study agreed closely with Richards (1967) on mean length for both sexes at age 1 and 2 (Table 2). For age 3 and older, Richards (1967) reported that mean sizes were larger. Eleven specimens were estimated as age 11 to 14, while Richards' (1967) maximum age for cobia was age 10. Perhaps, erosion on scale edges caused him to underestimate cobia ages, as has been shown in other fishes (Chilton and Stocker 1987).

Male cobia have a higher growth coefficient, k, than females, and the difference between sexes was greater for my study (0.37 to 0.24) than previous work (0.28 to 0.23; Richards 1977). Mean asymptotic FLs (Table 3) for both sexes were lower than Richards (1977) reported, possibly reflecting a greater availability of larger cobia in Chesapeake Bay during the 1960s. Age 3 females (n = 50) predominated in the present study, whereas Richards (1967) found age 5 females (n = 34) were most numerous. No doubt, estimates of mean asymptotic size in the present study were underestimates as the current North Carolina state record cobia (1988) weighed 46.7 kg.

Cobia were primarily demersal feeders along the North Carolina coast, and they preyed on portunid crabs, penaeid shrimps, stomatopods, numerous teleosts, and small elasmobranchs. Overall, the blue crab was the most important food item in the cobia diet, which reinforces the colloquial name of "crab-eater" used along the southeastern coast of the United States (Knapp 1951, Manooch 1984). Most portunids were ingested whole, except for *Ovalipes* which was usually macerated. Similar to the results of the present study, Knapp (1951) found demersal prey, such as portunids, stomatopods, penaeids, and eels in cobia stomachs from the northern Gulf of Mexico. Cobia from the western Indian Ocean consumed mostly portunids, cephalopods, and eels (Darracott 1977). In the sounds of North Carolina, cobia greater than 9 kg showed a predilection for smooth dogfish pups and small dasyatid sting rays, and these were among the largest prey items ingested. Cobia may be one of the few teleosts that regularly consumed small elasmobranchs.

Field inspections and histological sections of cobia gonads indicated that most adult cobia were developing and\or ripe as they entered North Carolina waters in spring. Males became sexually mature by 60–65 cm (age 2), and females by 80 cm (age 2). Richards (1967) stated that the smallest mature male in his collections measured 51.8 cm ("second....year of life") and that the smallest mature female measured 69.6 cm ("third year of life"), but he did not include maturity schedules.

Cobia spawned in North Carolina coastal waters from May through July, with peak spawning in June. In Virginia waters, cobia spawned mid-June through mid-August, as determined by ichthyoplankton surveys (Joseph et al. 1964). In the northern Gulf of Mexico, cobia arrived in coastal waters during April and May in prespawning condition and exhibiting peak *gsi* values (Biesiot et al. 1994). Some female cobia collected during June in North Carolina showed follicular atresia in the ovaries indicative of a recent spawn, yet also had numerous and adjacent, large oocytes, suggesting another potential spawning event. Data on ova diameters presented by Richards (1967) and work by Thompson et al. (1991) and Biesiot et al. (1994) in the northern Gulf of Mexico support the concept of batch spawning in cobia.

Precise location of cobia spawning areas along the North Carolina coast was uncertain, although my results suggested that cobia spawned adjacent the state's major ocean inlets. Likewise, Joseph et al. (1964) found that cobia spawned off the mouth of Chesapeake Bay in Virginia. Collections of cobia eggs in the Gulf Stream off Cape Hatteras, North Carolina, by Hassler and Rainville (1975) (almost 2,000 eggs in 10 collecting trips, May–June 1974) contrast an inlet spawning area hypothesis.

In summary, cobia inhabited coastal sounds and inlet areas of North Carolina from May through July. Specimens greater than 15 kg were common, hence the species' popularity with inshore recreational anglers. Cobia consumed a variety of demersal crustaceans and fishes; of the former, the blue crab was the most important. Spawning probably peaked during June in ocean waters adjacent major inlets. Management regulations adopted by North Carolina in 1991 prohibiting possession of cobia less than 84 cm were effective, and few fish below the minimum possession size were encountered between 1991 and 1994. Migratory routes and overwintering grounds of cobia along the south Atlantic coast of the United States are unclear. Comprehensive tagging of cobia along the south Atlantic coast of the United States and in Chesapeake Bay would help clarify (1) coast-wide migration patterns, (2) ingress and egress from estuaries to ocean, (3) fidelity to specific estuaries, and (4) movements into the northern Gulf of Mexico.

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