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Abstract.—We examined 1005 cobia, *Rachycentron canadum*, from recreational catches in the northeastern Gulf of Mexico from 1987 to 1995. Specimens ranged from 325 to 1651 mm fork length (FL); females had a mean FL of 1050 mm ($n=730$) and were significantly larger than males that had a mean FL of 952 mm ($n=275$). The overall male to female ratio was 1:2.7. Ages of 565 cobia were estimated from thin-sectioned otoliths (sagittae). Marginal-increment analysis of sagittal otoliths showed a single annual minimum during June. Male cobia ($n=170$; 525–1330 mm FL) ranged from age 0 to 9, and females ($n=395$; 493–1651 mm FL) ranged from age 0 to 11. The relationship of observed fork length and age was described by the von Bertalanffy growth equation for males $FL_t = 1171(1 - \exp[-0.432(t+1.150)])$ and for females $FL_t = 1555(1 - \exp[-0.272(t+1.254)])$. Growth in length for both sexes was relatively fast through age 2, after which growth slowed gradually. Estimates of the von Bertalanffy growth equation parameters L_∞ and K were significantly different for males and females, whereas estimates for t_0 were not significantly different. Sagittal otolith weight was a good predictor of age. The instantaneous rate of total mortality (Z) estimated by catch curve analysis for fully recruited ages 4–8 was 0.75.

Age and growth of cobia, *Rachycentron canadum*, from the northeastern Gulf of Mexico

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Cobia, *Rachycentron canadum*, are large, migratory, coastal pelagic fish of the monotypic family Rachycentridae and are distributed worldwide in tropical and subtropical seas, except for the eastern Pacific (Briggs, 1960; Shaffer and Nakamura, 1989). In the western Atlantic Ocean, cobia occur from Massachusetts and Bermuda to Argentina (Briggs, 1958) but are most common along the U.S. south Atlantic coast and in the northern Gulf of Mexico (Shaffer and Nakamura, 1989). In the Gulf of Mexico (Gulf), where they range from Key West, Florida, along the entire coast to Campeche, Mexico (Dawson, 1971), *R. canadum* is a highly-prized recreational species and is caught incidentally in several commercial fisheries (Shaffer and Nakamura, 1989). Cobia landings, recreational and commercial combined, from the Gulf and Atlantic averaged one million kilograms (kg) per year during a recent 12-year period (1984–95), of which 87% was recreational catch.¹

The majority of recreational landings of cobia in the United States are from the Gulf (Shaffer and Nakamura, 1989) and averaged 0.5 million kg for years 1984–95.¹ Recreational and commercial cobia regulations enacted in U.S. waters presently consist of a minimum size of 838 mm fork length (33 inches) and daily bag and possession limits of two fish per person.²

In the eastern Gulf, cobia typically migrate from their wintering grounds off south Florida into

¹ Gulf of Mexico and South Atlantic Fishery Management Councils. 1996. Report of the mackerel stock assessment panel meeting, April 15–18, 1996, Tampa, FL. Gulf Mex. Fish. Manage. Council., Tampa, FL, and South Atlan. Fish. Manage. Council., Charleston, SC.

² Gulf of Mexico and South Atlantic Fishery Management Councils. 1990. Amendment No. 5, fishery management plan for the coastal migratory pelagic resources (mackerels); environmental assessment and supplemental regulatory impact review. Gulf Mex. Fish. Manage. Council., Tampa, FL, and South Atlantic Fish. Manage. Council., Charleston, SC.

northeastern Gulf waters during early spring. They occur off northwest Florida, Alabama, Mississippi and southeast Louisiana from late-March through October, and return to their wintering grounds in the fall (Franks et al., 1991; Biesiot et al., 1994). Howse et al. (1992) reported that some cobia overwinter in the northern Gulf at depths of 100–125 m.

Information on the life history of cobia from the Gulf and U. S. Atlantic coast is limited. Most studies from the Gulf have addressed the occurrence and distribution of early life stages (Dawson, 1971; Ditty and Shaw, 1992), reproductive biology (Biesiot et al., 1994; Lotz et al., 1996; Thompson et al.³), and feeding (Knapp, 1949, 1951; Miles, 1949; Franks et al., 1996; Meyer and Franks, 1996). Hassler and Rainville (1975) collected cobia eggs from the Gulf Stream off North Carolina, successfully hatched most of them, and reared the larvae through juvenile stages. Mitochondrial DNA analyses of cobia from the northeastern Gulf and U.S. Atlantic coast suggest that cobia from those two areas are a unit stock (Hrincevich, 1993). Biesiot et al. (1994) induced spawning in ripe, wild-caught females from the northeastern Gulf, Howse et al. (1975, 1992) described diseased heart tissues and ubiquitous perivenous smooth muscle cords in viscera of cobia from northern Gulf waters, and Franks (1995) reported on an anomalous specimen collected off Mississippi. Only a limited amount of information is available on the age and growth of cobia from the Gulf (Thompson et al.³; Franks and McBee⁴) or the U.S. Atlantic coast (Joseph et al., 1964; Richards 1967, 1977; Smith, 1995). The objectives of our study

were to evaluate sectioned sagittal otoliths for ageing cobia from the northeastern Gulf, construct age-length keys, derive theoretical growth parameters, and obtain length-weight relationships.

Materials and methods

We sampled cobia caught by recreational hook-and-line gear in the northeastern Gulf during 1987–95. Cobia were sampled at the dock and at fishing tournaments. Fish were caught in an area located north of lat. 29°N and between long. 85°20'W and long. 89°W (Fig. 1) in waters that ranged from 2 to 200 m deep. Additional specimens from northwest Florida were provided by the National Marine Fisheries Service (NMFS), and marine enforcement personnel with the NMFS and the Mississippi Department of Marine Resources provided confiscated undersized specimens. Owing to the migratory nature of cobia, abundance varied seasonally. Most fish that we examined

³ Thompson, B. A., C. A. Wilson, J. H. Render, and M. Beasley. 1991. Age, growth and reproductive biology of greater amberjack and cobia from Louisiana waters. Year 1. Rep. to U. S. Dep. Commer., NOAA, NMFS, Coop. Agreement NA90AA-H-MF089, Marine Fisheries Initiative (MARFIN) Prog., Coastal Fish. Inst., Louisiana St. Univ., Baton Rouge, 55 p.

⁴ Franks, J. S., and T. M. McBee. 1991. Age and growth. In J. S. Franks, T. D. McIlwain, R. M. Overstreet, J. T. McBee, J. M. Lotz, and G. Meyer, Investigations of the cobia (*Rachycentron canadum*) in Mississippi marine waters and adjacent Gulf waters. Gulf Coast Res. Lab., Ocean Springs, MS 39564-7000. Final Rep. to Miss. Dep. Wildl., Fish. and Parks/Bur. Mar. Res. (Dep. Mar. Res.), 1141 Bayview Ave., Biloxi, MS 39531 and U. S. Fish Wildl. Serv., Atlanta, GA 30345, Proj. No. F-91, p. 1-1 to 1-60.

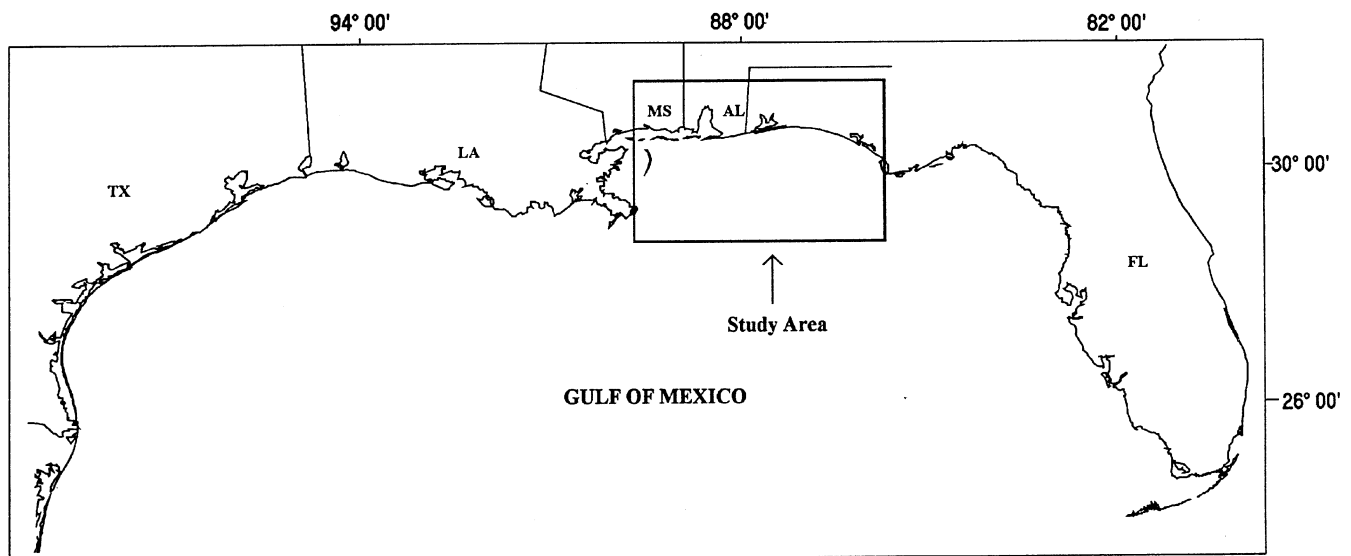


Figure 1

Map of the Gulf of Mexico showing the northeastern Gulf study area where cobia, *Rachycentron canadum*, were caught by hook-and-line gear, 1987–95.

were collected from April through July ($n=787$); peak samples were taken in May ($n=349$). Fewer fish were collected in August ($n=49$) and September through November ($n=157$). No samples were collected in December, and only 12 samples were collected from January through March.

For most fish, the date and location of catch were recorded along with fork length (FL, mm), total length (TL, mm), and total weight (TW, nearest 0.1 pound converted to kilograms), although some fish had been gutted. All lengths reported are FL. The sex of most fish was also recorded, including that of several young-of-the-year (YOY). Sex-specific length-weight regressions were calculated by linear regression of \log_{10} -transformed data, and the slopes and elevations of the regressions were compared by using analysis of covariance (Snedecor and Cochran, 1967). Relationships of fork length to total length were calculated by using the generalized linear regression model: $FL=a+bTL$.

Sagittal otoliths were removed from most specimens, then cleaned with distilled water, air dried, and stored dry in labeled vials. Cobia sagittae are small and fragile. They are elongate, laterally compressed structures, with a rounded posterior, a pointed rostrum, and a smaller, pointed antirostrum (Fig. 2). The distal surface is concave, and a wide, curved sulcus traverses the proximal surface longitudinally. Initially, we randomly selected ten sagittal otolith pairs (fish $FL=700\text{--}1613$ mm) to determine the number of opaque bands in each. Paired counts of opaque bands agreed in all cases. Therefore, the left sagittal otolith was used for age estimation unless missing, broken, or illegible, in which case the right sagitta, if available, was substituted for age analysis. Whole left sagittae were weighed on a microbalance to the nearest milligram to evaluate otolith weight as a predictor of age. Sex-specific linear regressions were fitted to otolith weight and age data and were compared by using analysis of covariance (Snedecor and Cochran, 1967); degree of significance set at $\alpha = 0.05$. Sagittae were embedded in Spurr (Secor et al., 1992) and sectioned through the core along a transverse, dorsoventral plane with a Buehler Isomet low-speed saw containing a diamond wafering blade. Two or three thin-sections (0.3 mm) were mounted on a microscope slide with CrystalBond 509 adhesive, sanded with wet 600- and 1500-grade sandpaper, polished on a felt wheel

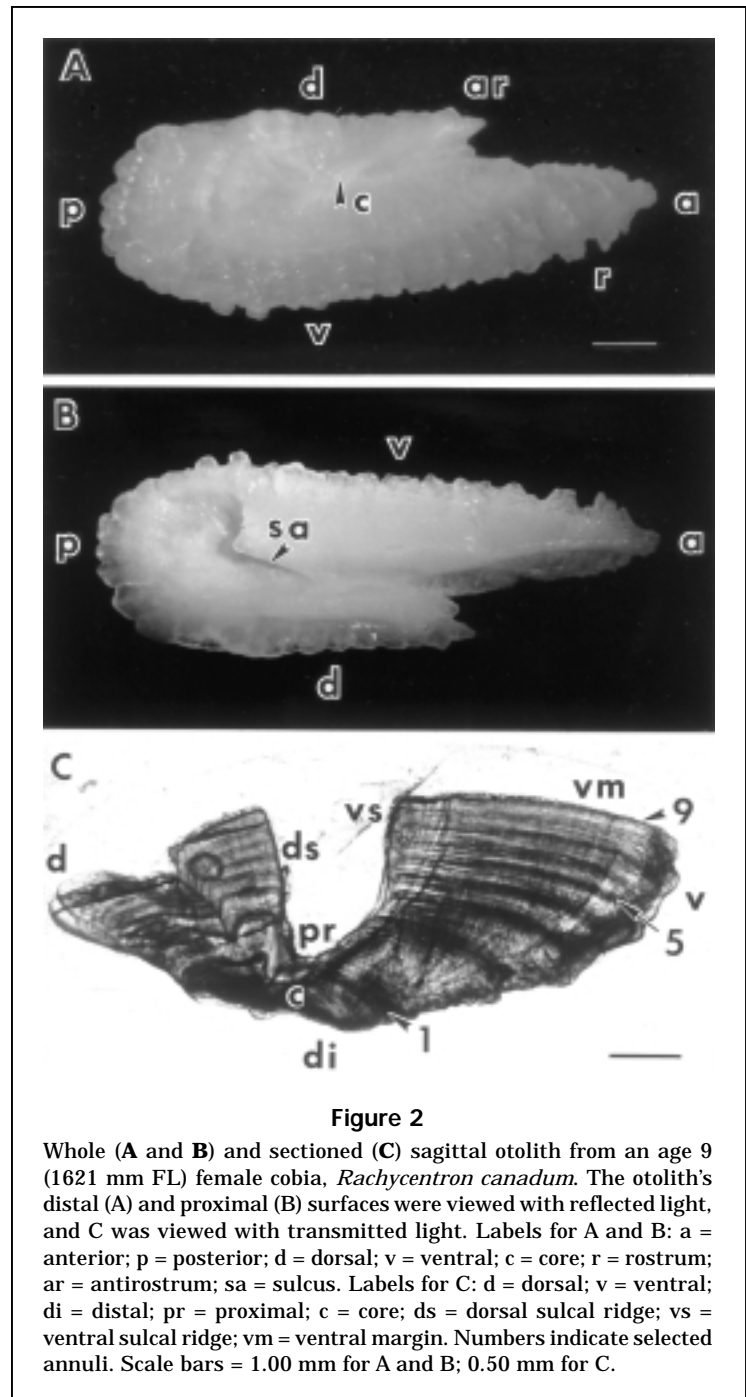


Figure 2

Whole (A and B) and sectioned (C) sagittal otolith from an age 9 (1621 mm FL) female cobia, *Rachycentron canadum*. The otolith's distal (A) and proximal (B) surfaces were viewed with reflected light, and C was viewed with transmitted light. Labels for A and B: a = anterior; p = posterior; d = dorsal; v = ventral; c = core; r = rostrum; ar = antirostrum; sa = sulcus. Labels for C: d = dorsal; v = ventral; di = distal; pr = proximal; c = core; ds = dorsal sulcal ridge; vs = ventral sulcal ridge; vm = ventral margin. Numbers indicate selected annuli. Scale bars = 1.00 mm for A and B; 0.50 mm for C.

with 0.3 μm alumina micropolish, then examined under a binocular dissecting microscope at 20–40 \times magnification with transmitted light.

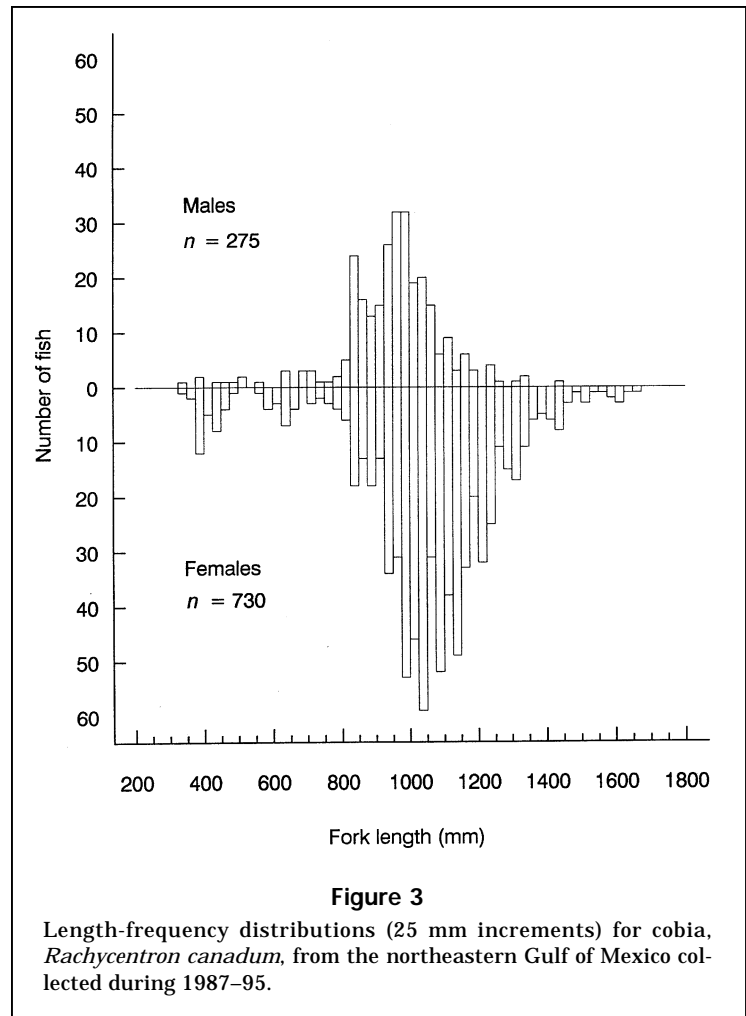
Three experienced readers independently counted opaque bands from the core to the outer otolith margin. Opaque bands were most distinct and easily counted in the midportion of the ventral lobe of a section, and our analyses were made in that region (Fig. 2). Opaque bands were often obscured at the

core or confluence with the sulcus acousticus. Opaque bands were initially counted as annuli until they could be properly validated. Annuli were counted without reference to fish length or date of capture. Where counts disagreed, otolith sections were re-examined jointly, and most disagreements were resolved. Unresolved counts and illegible otoliths were excluded from the analysis. Structural aberrations in otoliths judged unsuitable for age estimation included poorly defined annuli, unusual calcification, and erosion of the ventral lobe. Terminology for otolith readings followed definitions of Wilson et al. (1987).

We determined the periodicity of annulus formation and validated our ageing technique by marginal-increment analysis. As recommended by Beamish and MacFarlane (1983), all age classes were included in the analysis. Measurements for marginal-increment analysis were made in the ventral lobe of the magnified (30×) section by using a digital imaging system. Distances were measured ventrally from the sulcus along an axis passing through the center of the lobe and extending from the otolith's core to the outer margin of the section. The distance from the proximal edge of the ultimate annulus to the otolith's margin (marginal increment) was expressed as a percentage of the distance between the proximal edge of the last two annuli formed on the otolith. This procedure was adapted for age 1 fish by expressing the marginal increment as a percentage of the distance from the edge of the first annulus to a hypothetical second annulus (Crabtree et al., 1996). Mean percent marginal increments were plotted for all age groups and collection years combined by month of capture.

The von Bertalanffy (1957) theoretical growth equation, $FL_t = L_\infty(1 - \exp[-K(t - t_0)])$, was fitted to observed age-length data with the nonlinear regression procedure of Statgraphics (1994). Likelihood-ratio tests (Kimura, 1980; Cerrato, 1990) and approximate randomization tests (Helsler, 1996) were used to compare growth parameter estimates for males and females. Sexed YOY were included in the growth models.

Observed ages at lengths for all years combined were used to derive an age-length key for each sex (Ricker, 1975). Aged fish ($n=565$) were assigned to 50-mm length intervals, and age distribution (as percent) was then calculated for each size interval. Age-length keys were used to convert length frequen-



cies to age frequencies by assigning ages to unaged fish ≥ 838 mm FL from which a catch curve (Ricker, 1975) was constructed for 1987-92. We estimated instantaneous total mortality (Z) by catch curve analysis (Beverton and Holt, 1957; Everhart and Youngs, 1981) based on fully recruited fish.

Results

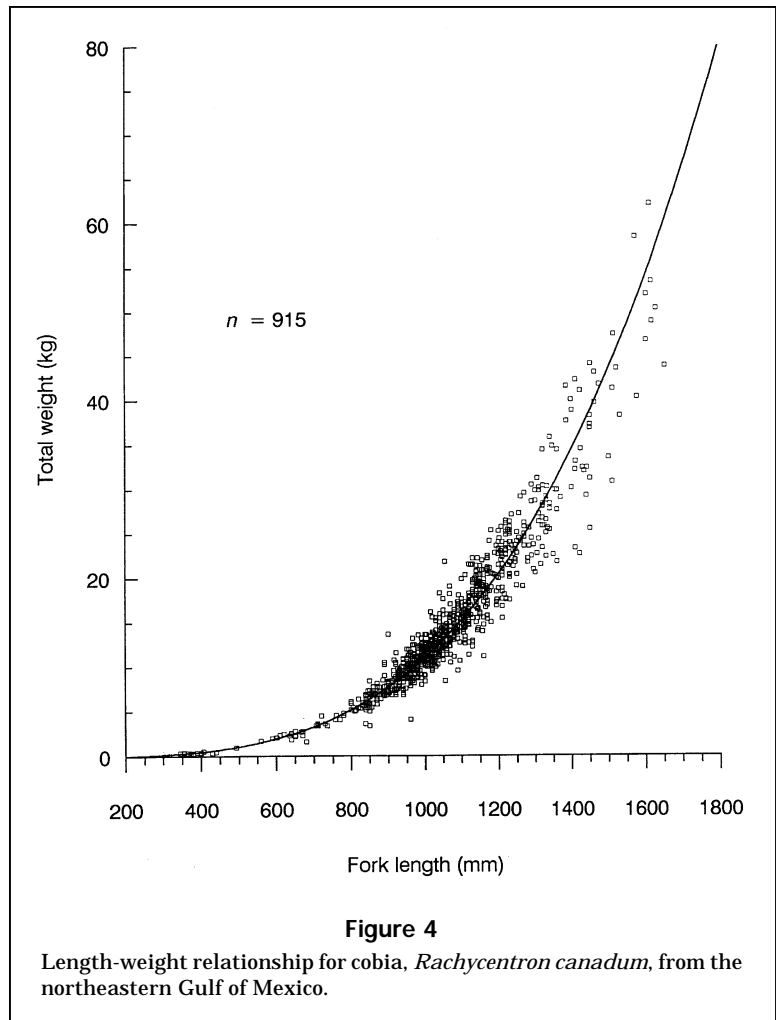
We examined 1005 cobia that ranged from 335 to 1651 mm FL, 33 of which were YOY (age 0) and ranged from 335 to 510 mm FL. External sexual dimorphism was not evident in *R. canadum*. Males ($n=275$) ranged from 345 to 1450 mm FL (mean=952 mm) and from 0.3-29.0 kg (mean=10.5 kg); females ($n=730$) ranged from 335 to 1651 mm FL (mean=1050 mm) and from 0.3 to 62.2 kg (mean=16.6 kg). The length-frequency distributions of males and females (Fig. 3) were significantly different (Kolmogorov-Smirnov two-sample test, $d=0.432$, $P<0.05$). Females

were significantly larger than males (Mann-Whitney U -test, $P < 0.001$), and 85% of fish ≥ 1000 mm were female. The sex ratio of 1:2.7 was significantly different from 1:1 ($\chi^2 = 205.8$, $df = 1$, $P < 0.0001$).

Neither slopes (ANCOVA, $df = 914$; $F = 2.156$, $P = 0.142$) nor elevations (ANCOVA, $df = 914$, $F = 2.334$, $P = 0.127$) of the length-weight regressions by sex were found to be significantly different; therefore, data were pooled and one relationship established (Table 1; Fig. 4). Weight was approximately a cubic function of length, implying nearly isometric growth. The relationships between FL and TL are presented in Table 1.

When viewed with transmitted light, thin-sectioned sagittae revealed a pattern of distinct, alternating narrow opaque and wide translucent bands (Fig 2). The distance between the first two opaque bands distally from the core typically was wider than the distance between subsequent opaque bands. Mean marginal increment analysis (Fig. 5) demonstrated that April through August was the time of annulus formation and suggested that opaque bands form once each year. All otoliths exhibited a zone of translucent material beyond the last annulus from September through February. Mean increment was minimal during June and increased to a maximum in February (no samples were collected during December). The sample size was too small to plot marginal increments for each year and age-group separately; however, a visual examination of the data indicated that marginal increments for individual years 1987–90 and age-classes 2–5 were similar, with a consistent seasonal minimum during summer. Timing of annulus formation was similar for each sex.

Of the 645 left sagittae processed for age estimates, 187 (29%) were judged illegible. Right sagittae from 168 of the latter group were available and processed, and 76% (128/168) were readable. Readers agreed on ages for 96% (565/586) of usable otoliths, 170 males (range 345–1330 mm FL) and 395 females (range 335–1651 mm FL). Only 21 (4%) of the usable otoliths were rejected because of disagreements among readings, owing primarily to disparities over the presence of an annulus adjacent to the core or at the otolith's margin. Of the sagittae found acceptable for age estimations, 33 were from YOY (335–510 mm) and 42 were from age 1 fish (493–910 mm). Ten age 1 fish were 838 mm (minimum legal size) or



larger. Most ($n = 463$, 82%) of the 565 fish that we aged were estimated to be ages 2–5 (27% age 2; 29% age 3; 17% age 4; and 9% age 5). Age 6 fish and older were conspicuously uncommon. There was a significant difference between the age-frequency distributions of males and females (Kolmogorov-Smirnov two-sample test, $dn = 0.308$, $P < 0.05$). An age 11 female (1568 mm) and age 9 males ($n = 2$, 1240 and 1260 mm) were the oldest cobia sampled (Table 2). Twenty five females (1170–1651 mm) were age 6 or older, but only six males (1035–1330 mm) were older than age 5 (Table 2).

Growth in length for both sexes was relatively fast through age 2, after which growth slowed gradually (Fig. 6). We found a wide range of lengths within most age groups for both sexes (Tables 3 and 4). For example, age 4 males and females ranged from 850 to 1250 mm and from 900 to 1250 mm, respectively. We also found a wide range of ages within some of the length groups. For example, the 1000 mm and 1200 mm groups of males ranged from ages 2 to 7 and from

ages 4 to 9, respectively (Table 3), whereas the 1350 mm group of females ranged from ages 5 to 9 (Table 4).

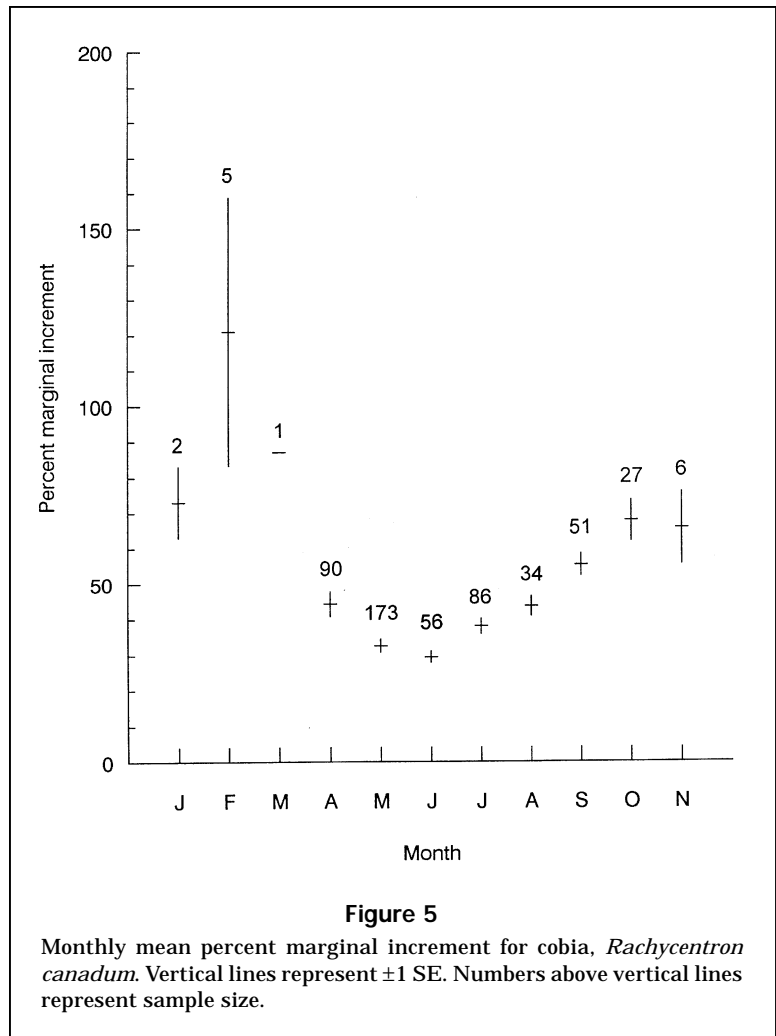
The results of likelihood-ratio tests showed a significant difference in the overall von Bertalanffy growth models for males and females ($\chi^2=175.06$, $df=1$, $P<0.0001$) (Table 5), a finding substantiated by approximate randomization testing of the growth models ($P<0.0001$). Likelihood-ratio tests showed that estimates of L_∞ ($\chi^2=24.60$, $df=1$, $P<0.0001$) and K ($\chi^2=7.02$, $df=1$, $P=0.008$) were significantly different between sexes, however, t_0 was not significantly different ($\chi^2=-0.11$, $df=1$, $P=0.752$). Growth parameters indicated that females achieved a greater theoretical asymptotic length and grew at a faster rate than males. Predicted lengths-at-age derived by the von Bertalanffy equations agreed with observed lengths, except for age 9 males ($n=2$) and age 8 and 10 females ($n=12$) (Table 2), where observed lengths were considerably larger than those predicted. Average observed lengths-at-age for females were greater than those of males for age 1 and older (Table 2), and predicted lengths of females were greater than those of males for all ages.

Otolith weight was significantly related to age (Fig. 7), and the slopes of the otolith weight-age regressions for males and females (Table 1) were significantly different (ANCOVA, $df=385$, $F=34.13$, $P<0.0001$).

Age-length keys were constructed to estimate the age structure of legal-sized cobia (≥ 838 mm FL) caught from 1987 to 92 (Fig. 8) which we believe was representative of the northeastern Gulf recreational fishery. Most (84%) of those fish were age 2–4, whereas age 3 represented 37% of the catch. Age at full recruitment to the fishery was age 4 (modal age plus one). Ages 1–3 represented 66% of the fishery, age 4 represented 19%, and ages 5–11 only 15%. The instantaneous rate of total mortality (Z) estimated by our catch curve analysis for ages 4–8 was 0.75 (Fig. 9).

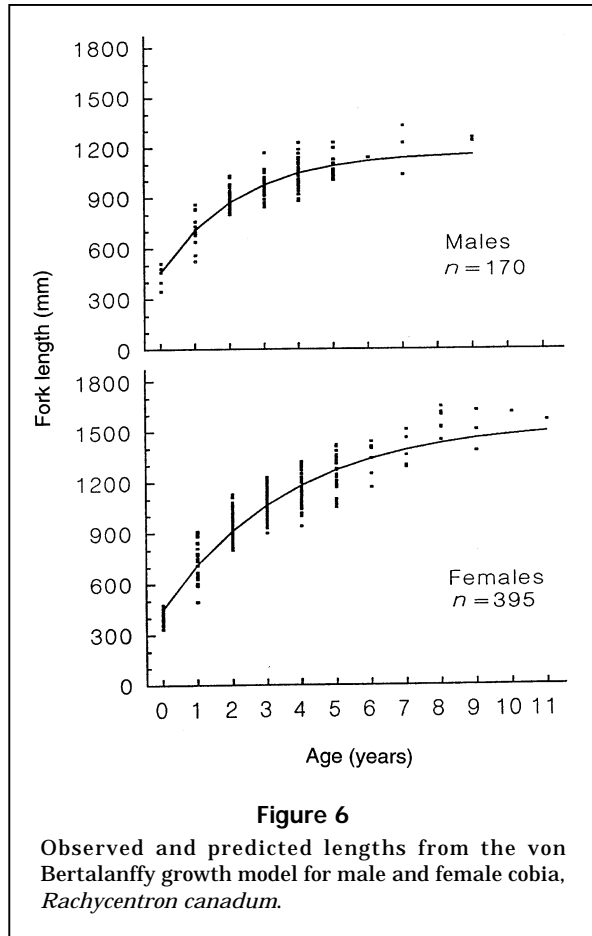
Discussion

Despite acquiring many of our cobia samples at fishing tournaments, we believe our overall collections reflect the recreational hook-and-line fishery for cobia in the northeastern Gulf during the late 1980s and early 1990s. Although anglers typically enter



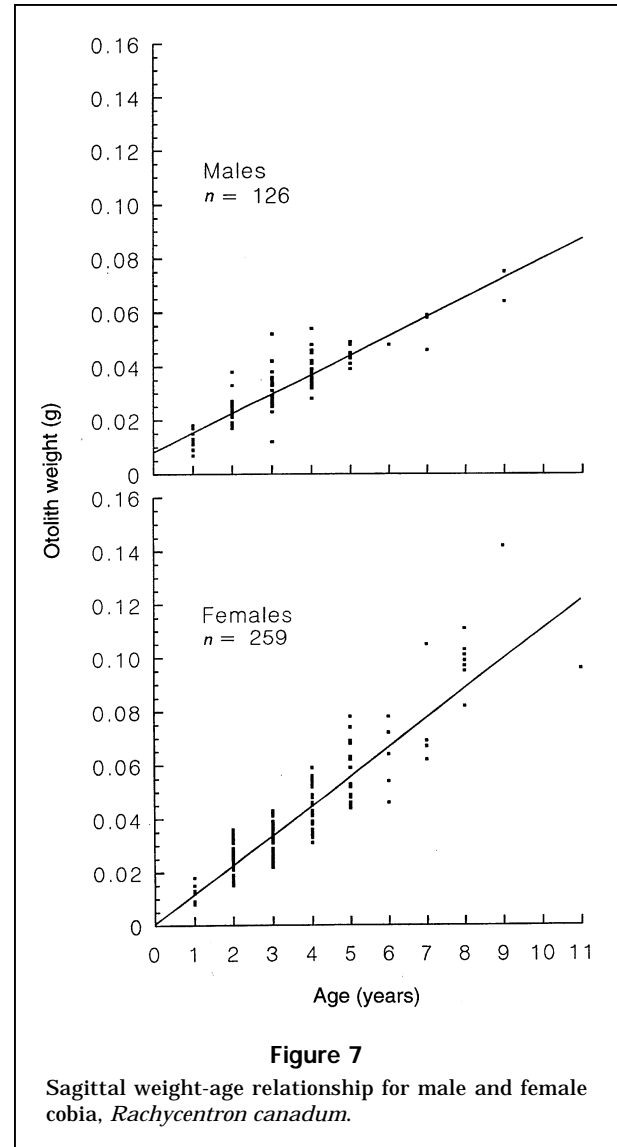
large fish in tournaments, substantial numbers of small fish were also entered during the competitions, particularly if aggregate weight awards were presented during multiday competitions. We frequently sampled anglers' entire catch which included small fish not entered in competition. Nontournament fish were also examined at docks and marinas, and these specimens ranged from less than minimum legal size to some of the largest fish that we encountered.

Although the length-weight relationships between the sexes did not differ significantly, females were typically larger than males. Thompson et al.³ reported similar results for cobia taken off western Louisiana. In our study, females predominated (2.7:1 overall sex ratio) during all study years. Females were dominant in all age groups, and the magnitude of that dominance varied with increasing age. During a five-year study (1987–91) of cobia from western Louisiana waters (west of the Mississippi River delta), Thompson et al.³ reported an overall sex ratio of 2.1:1 that was skewed towards males (464,



males; 218 females) for each year. Because our study and that by Thompson et al.³ were conducted concurrently, we are unable to explain this discrepancy, except to suggest differential segregation or a higher mortality for males east of the delta.

Sagittal otoliths were determined to be valid ageing structures for *R. canadum*, and alternating opaque and translucent bands were most conspicuous in the ventral lobe of otolith thin-sections. Annuli were not uniformly visible in thin-sections for some fish and were occasionally obscured along the ventral sulcal ridge, particularly for fish age 5 and older. Marginal-increment analysis indicated that annuli formed once per year during April–August. Therefore, age in years for cobia was presumed equal to the number of opaque bands observed in sectioned sagittae, findings that agree with those of Thompson et al.³ off Louisiana and Smith (1995) off North Carolina. Because cobia are infrequently caught in northeastern Gulf waters during the winter, the scarcity of otolith samples from November through March precluded us from making an unequivocal assertion on the annual nature of opaque band formation. However, thin-sectioned sagittae from seven cobia



caught in the Florida Keys during January 1991 and sampled dockside by us showed a substantial zone of translucent material extending from the distal edge of the last opaque band to the otolith margin. This finding suggests that winter annulus formation does not occur in the otoliths of cobia from south Florida waters (cobia that may migrate into northern Gulf waters in spring).

Although the timing of annulus formation coincides with the cobia's spawning season in the northern Gulf (Biesiot et al., 1994; Lotz et al., 1996), annulus deposition may be more related to cobia migration into the northern Gulf in spring. We found that sagittae of several sexually mature cobia sampled in April (early part of the spawning season) already showed opaque bands, as did sexually immature fish in spring. The relationship of annulus formation to

Table 4
Age-length key. Fork length (mm) composition, in percent, of female cobia by age group

Length group (50 mm)	Age in years											Number of fish	
	0	1	2	3	4	5	6	7	8	9	10		11
300	100.0												1
350	100.0												8
400	100.0												17
450	66.7	33.3											3
500													
550		100.0											1
600		100.0											7
650		100.0											5
700		100.0											3
750		100.0											3
800		25.0	75.0										12
850		19.0	81.0										21
900		3.3	66.7	26.7	3.3								30
950			52.2	47.8									46
1000			40.0	47.3	12.7								55
1050			12.2	53.1	28.6	6.1							49
1100			13.2	39.5	44.7	2.6							38
1150				46.4	28.6	21.4	3.6						28
1200				28.6	42.8	28.6							21
1250					40.0	40.0	10.0	10.0					10
1300					33.4	50.0	8.3	8.3					12
1350						60.0		20.0		20.0			5
1400						28.6	57.1		14.3				7
1450								50.0	50.0				2
1500								25.0	50.0	25.0			4
1550												100.0	1
1600									60.0	20.0	20.0		5
1650									100.0				1
Total													395

Table 5

Parameter estimates for the von Bertalanffy growth model for cobia, *Rachycentron canadum*, from U.S. waters. Values shown in parentheses are standard errors. — = not reported by author(s).

Area	Sex	<i>n</i>	L_{∞}	<i>K</i>	t_0	r^2	Structure	Authors
Virginia ¹	M	—	121	0.28	-0.06	—	scales	Richards, 1967
	F	—	164	0.23	-0.08			
North Carolina ¹	M	116	105 (1.85)	0.37 (0.04)	-1.08 (0.29)	—	otoliths	Smith, 1995
	F	92	135 (3.82)	0.24 (0.03)	-1.53 (0.39)			
Western Louisiana ²	M	—	1,132	0.49	-0.49	—	otoliths	Thompson et al. ³
	F	—	1,294	0.56	0.11			
Northeastern Gulf of Mexico ²	M	170	1,170.7 (28.08)	0.432 (0.046)	-1.150 (0.173)	0.78	otoliths	This study
	F	395	1,555.0 (35.14)	0.272 (0.017)	-1.254 (0.092)	0.87		

¹ L_{∞} estimates reported in centimeters.

² L_{∞} estimates reported in millimeters.

³ See Footnote 3 in text for this source.

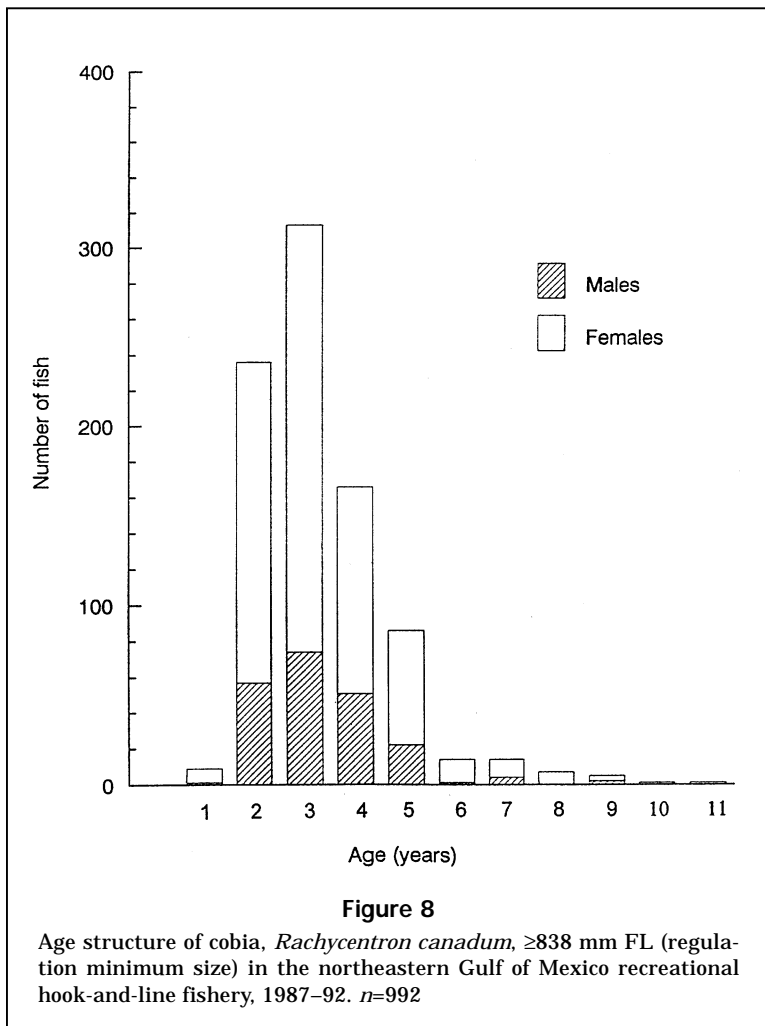
migration has been suggested for swordfish (Berkeley and Houde, 1983; Tserpes and Tsimenides, 1995) and Atlantic bluefin tuna (Compean-Jimenez and Bard, 1983). Other authors (Nelson and Manooch, 1982; Sturm et al., 1989; Beckman et al., 1990; Ferreira and Russ, 1994) also suggested that reproduction may not be the sole determining factor and commented on the physiological nature of annulus formation and the importance of environmental factors.

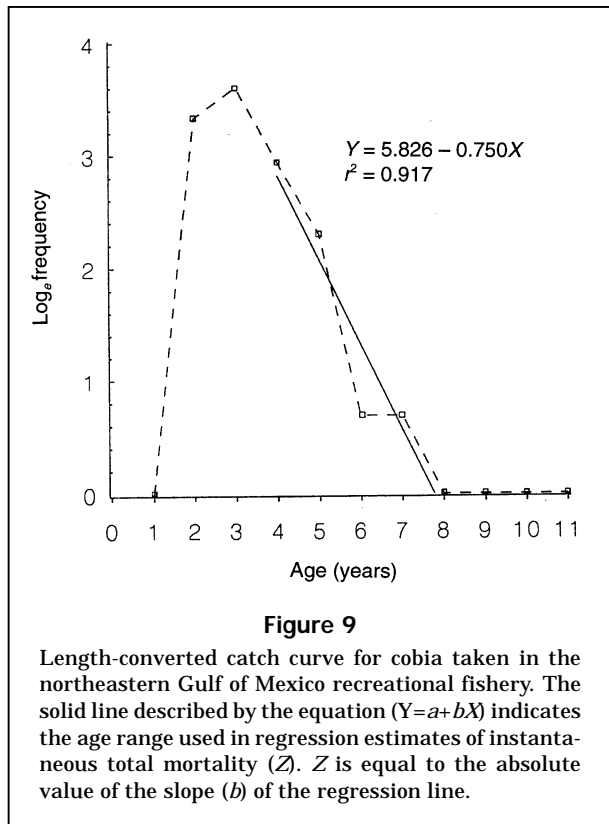
Longevity of male and female cobia differed considerably. Males older than age 7 were rare, and maximum age was 9. Females older than age 8 were rare, and maximum age was 11. Maximum ages of cobia from Louisiana (age 10, Thompson et al.³) and Virginia (age 10, Richards, 1967) were similar to our observations. However, Smith (1995) reported a maximum age of 14 for males and age 13 for females for cobia from North Carolina. We also found, as did Richards (1967) and Smith (1995), that mean observed lengths at age for females were larger than those for males for all age classes, except age 0 fish.

Considerable variation in size was observed within most age groups, including YOY, for both males and females, which, according to Goodwin and Johnson (1986), is not unusual for warm-water fishes. The variation in size makes it difficult to estimate precisely the age of cobia from length alone. For example, our largest cobia weighed 62.2 kg, which was slightly greater than the all-tackle world record weight for cobia (61.5 kg) reported by the International Game Fish Association (1997). At a fork length of 1610 mm and at age 8, this specimen was neither the longest fish in our sample nor the oldest. A prolonged spawning season and multiple spawnings characteristic of cobia (Lotz et al., 1996) probably account for the wide variation in size of YOY cobia and other age groups as well. Annual growth was most rapid through age 2 for both sexes, then gradually decreased thereafter, particularly for females.

Otolith weight was a good predictor of age, accounted for 78% and 84% of the variability in age of male and female cobia, respectively, and explained as much variation in age as fork length in the von Bertalanffy model for each sex.

Our estimates of growth parameters are the only estimates available for *R. canadum* in the northeastern Gulf. We found that the von Bertalanffy theoretical growth models for males and females were significantly different, as did Thompson et al.³ Lengths predicted from the theoretical growth curves agreed with the average observed lengths. Theoretical asymptotic lengths seemed realistic, even though few fish >1200 mm were sampled. Theoretical growth coefficients (L_{∞} and t_0) reported by Thompson et al.³ for cobia from Louisiana were smaller than our estimates (Table 5), although their estimates of K were larger, particularly for females. Asymptotic lengths for males and females taken off Virginia (Richards, 1977) were considerably larger than L_{∞} values reported by Smith (1995) for cobia from North Carolina, values reported by Thompson et al.³ for cobia from Louisiana and our study (Table 5), although our asymptotic length for males was similar to that in Richards' (1967) study. The differences in estimates of growth coefficients for cobia throughout their range in U.S. waters may be due to methodological differences, e.g. sectioned otoliths (this study) versus scales (Richards, 1967), or differences in geographical coverage. Nevertheless, we believe our growth parameter estimates are appropriate for





use in assessment studies of cobia from the northeastern Gulf.

Cobia were fully recruited to the recreational fishery in the northeastern Gulf at age 4. Catch curve analysis predicted a Z of 0.75. A fairly broad age structure and a low value for Z suggest that the northeastern Gulf population of cobia is reasonably healthy. We believe our estimate of Z is reliable, although several authors (Rounsefell and Everhart, 1953; Johnson, et al., 1983; and Manooch et al., 1987) caution against using catch curves to predict mortality for migratory pelagic species because, in part, such predictions are subject to a variety of assumptions, including a constant recruitment and mortality for each year and year class comprising a pooled data set. The popularity of cobia warrants continued monitoring of population age structure and growth parameters of this valuable gamefish in the northern Gulf.

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Literature cited

- Beamish, R. J., and G. A. MacFarlane**
1983. The forgotten requirement for age validation in fisheries biology. *Trans. Am. Fish. Soc.* 112:735-743.
- Beckman, D. W., A. L. Stanley, J. H. Render, and C. A. Wilson.**
1990. Age and growth of black drum in Louisiana waters of the Gulf of Mexico. *Trans. Am. Fish. Soc.* 119:537-544.
- Berkeley, S. A., and E. D. Houde.**
1983. Age determination of the broadbill swordfish, *Xiphias gladius*, from the Straits of Florida, using anal fin spine sections. *U. S. Dep. Commer., NOAA Tech. Rep. NMFS* 8:137-143.

- Beverton, F. J. H., and S. J. Holt.**
1957. On the dynamics of exploited fish populations. Fish. Invest. Minist. Agric., Fish. Food (G. B.), Ser. II, 19, 533 p.
- Biesiot, P. M., R. M. Caylor, and J. S. Franks.**
1994. Biochemical and histological changes during ovarian development of cobia, *Rachycentron canadum*, from the northern Gulf of Mexico. Fish. Bull. 92:686-696.
- Briggs, J. C.**
1958. A list of Florida fishes and their distribution. Bull. Fla. State Mus., Biol. Sci. 2:221-318.
1960. Fishes of worldwide (circumtropical) distribution. Copeia 1960(3):171-180.
- Cerrato, R. M.**
1990. Interpretable statistical tests for growth comparisons using parameters in the von Bertalanffy equation. Can. J. Fish. Aquat. Sci. 47:1,416-1,426.
- Compean-Jimenez, G., and F. X. Bard.**
1983. Growth increments on dorsal spines of eastern Atlantic bluefin tuna, *Thunnus thynnus*, and their possible relation to migration patterns. In E. D. Prince and L. M. Pulos (eds.), Proceedings of the international workshop on age determination of oceanic pelagic fishes: tunas, billfishes and sharks, p.111-115. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 8.
- Crabtree, R. E., C. W. Harnden, D. Snodgrass, and C. Stevens.**
1996. Age, growth and mortality of bonefish, *Albula vulpes*, from the waters of the Florida Keys. Fish. Bull. 94:442-451.
- Dawson, C. E.**
1971. Occurrence and description of prejuvenile and early juvenile Gulf of Mexico cobia, *Rachycentron canadum*. Copeia 1960(3):171-180.
- Ditty, J. G., and R. F. Shaw.**
1992. Larval development, distribution, and ecology of cobia, *Rachycentron canadum* (Family:Rachycentridae), in the northern Gulf of Mexico. Fish. Bull. 90:668-677.
- Everhart, H. W., and W. D. Youngs.**
1981. Principles of fishery science. Cornell Univ. Press, Ithaca, New York, NY, 349 p.
- Ferreira, B. P., and G. R. Russ.**
1994. Age validation and estimation of growth rate of the coral trout, *Plectropomus leopardus* (Lacepede 1802), from Lizard Island, Northern Great Barrier Reef. Fish. Bull. 92:46-57.
- Franks, J. S.**
1995. A pugheaded cobia (*Rachycentron canadum*) from the northcentral Gulf of Mexico. Gulf Res. Rep. 9(2):143-145.
- Franks, J. S., N. M. Garber, and J. R. Warren**
1996. Stomach contents of juvenile cobia, *Rachycentron canadum*, from the northern Gulf of Mexico. Fish. Bull. 94:374-380.
- Franks, J. S., M. H. Zuber, and T. D. McIlwain.**
1991. Trends in seasonal movements of cobia, *Rachycentron canadum*, tagged and released in the northern Gulf of Mexico. J. Miss. Acad. Sci. 36(1):55.
- Goodwin, J. M., and Johnson A. G.**
1986. Age, growth, and mortality of blue runner, *Caranx crysos*, from the northern Gulf of Mexico. Northeast Gulf Sci. 8(2):107-114.
- Hassler, W. W., and R. P. Rainville.**
1975. Techniques for hatching and rearing cobia, *Rachycentron canadum*, through larval and juvenile stages. Univ. N.C. Sea Grant Coll. Prog., UNC-SG-75-30, Raleigh, NC, 26 p.
- Helser, T. E.**
1996. Growth of silver hake within the U.S. continental shelf ecosystem of the northwest Atlantic Ocean. J. Fish. Biol. 48:1,059-1,073.
- Howse, H. D., J. S. Franks, and R. F. Welford.**
1975. Pericardial adhesions in the cobia (*Rachycentron canadum*) (Linnaeus). Gulf Res. Rep. 5(1):61-62.
- Howse, H. D., R. M. Overstreet, W. E. Hawkins, and J. S. Franks.**
1992. Ubiquitous perivenous smooth muscle cords in viscera of the teleost *Rachycentron canadum*, with special emphasis on liver. J. Morphol. 212:175-189.
- Hrinkevich, A. W.**
1993. Analysis of cobia *Rachycentron canadum* population structure in the northern Gulf of Mexico using mitochondrial DNA. M.S. thesis, Univ. Southern Miss., Hattiesburg, MS, 91 p.
- International Game Fish Association.**
1997. World record game fishes. International Game Fish Association, Pompano Beach, Florida, 352 p.
- Johnson, A. G., W. A. Fable, M. L. Williams, and L. E. Barger.**
1983. Age, growth, and mortality of king mackerel, *Scomberomorus cavalla*, from the southeastern United States. Fish. Bull. 81(1):97-106.
- Joseph, E. B., J. J. Norcross, and W. H. Massmann.**
1964. Spawning of the cobia, *Rachycentron canadum*, in the Chesapeake Bay area, with observations of juvenile specimens. Chesapeake Sci. 5:67-71.
- Kimura, D. K.**
1980. Likelihood methods for the von Bertalanffy growth curve. Fish. Bull. 77(4):765-776.
- Knapp, F. T.**
1949. Menhaden utilization in relation to the conservation of food and game fishes of the Texas Gulf Coast. Trans. Am. Fish. Soc. 79:137-144.
- Knapp, F. T.**
1951. Food habits of the sergeantfish, *Rachycentron canadus*. Copeia 1951:101-102.
- Lotz, J. M., R. M. Overstreet, and J. S. Franks.**
1996. Gonadal maturation in the cobia, *Rachycentron canadum*, from the northcentral Gulf of Mexico. Gulf Res. Rep. 9(3):147-159.
- Manooch, C. S., S. P. Naughton, C. B. Grimes, and L. Trent.**
1987. Age and growth of king mackerel, *Scomberomorus cavalla*, from the U. S. Gulf of Mexico. Mar. Fish. Rev. 49(2):102-108.
- Meyer, G. H., and J. S. Franks.**
1996. Food of cobia, *Rachycentron canadum*, from the northcentral Gulf of Mexico. Gulf Res. Rep. 9(3):161-167.
- Miles, D. W.**
1949. A study of the food habits of the fishes of the Aransas Bay area. M.S. thesis, Univ. Houston, TX, 70 p.
- Nelson, R. S., and C. S. Manooch.**
1982. Growth and mortality of red snappers in the west-central Atlantic Ocean and northern Gulf of Mexico. Trans. Am. Fish. Soc. 111:465-475.
- Richards, C. E.**
1967. Age, growth and fecundity of the cobia, *Rachycentron canadum*, from the Chesapeake Bay and adjacent Mid-Atlantic waters. Trans. Am. Fish. Soc. 96:343-350.
1977. Cobia (*Rachycentron canadum*) tagging within Chesapeake Bay and updating of growth equations. Chesapeake Sci. 18:310-311.
- Ricker, W. E.**
1975. Computations and interpretation of biological statistics of fish populations. Fish. Res. Board Can., Bull. 191, 382 p.

Rounsefell, G. A., and W. H. Everhart.

1953. Fishery science: its methods and applications. John Wiley and Sons, Inc., New York, NY, 444 p.

Secor, D. H., J. M. Dean, and E. H. Laban.

1992. Otolith removal and preparation for microstructural examination. In D. K. Stevenson and S. E. Campana (eds.), Otolith microstructure examination and analysis, p. 19–57. Can. Spec. Publ. Fish. Aquat. Sci. 117.

Shaffer, R. V., and E. L. Nakamura.

1989. Synopsis of biological data on the cobia *Rachycentron canadum* (Pisces: Rachycentridae). FAO Fisheries Synop. 153 (NMFS/S 153). U.S. Dep. Commer., NOAA Tech. Rep. NMFS 82, 21 p.

Smith, J. W.

1995. Life history of cobia, *Rachycentron canadum* (Osteichthyes: Rachycentridae), in North Carolina waters. Brimleyana 23:1–23.

Snedecor, G. W. and W. C. Cochran.

1967. Statistical methods, 6th ed. Iowa State Univ. Press, Ames, IA, 593 p.

Statgraphics

1994. Statistical graphics software, ver. 7.1. Manugistics, Inc., Rockville, MD.

Sturm, M. G. de L., and P. Salter.

1989. Age, growth and reproduction of the king mackerel *Scomberomorus cavalla* (Cuvier) in Trinidad waters. Fish. Bull. 88:361–370.

Tserpes, G., and N. Tsimenides

1995. Determination of age and growth of swordfish, *Xiphias gladius* L., 1758, in the eastern Mediterranean using anal-fin spines. Fish. Bull. 93:594–602.

von Bertalanffy, L.

1957. Quantitative laws in metabolism and growth. Quart. Rev. Biol. 32:217–231.

Wilson, C. A., R. J. Beamish, E. B. Brothers,

K. D. Carlander, J. M. Casselman, J. M. Dean,

A. Jerald, E. D. Prince, and A. Wild.

1987. Glossary. In R. C. Summerfelt and G. E. Hall (eds.), Age and growth of fish, p. 527–530. Iowa State Univ. Press, Ames, Iowa.