AGE, GROWTH, AND MORTALITY OF KING MACKEREL, *SCOMBEROMORUS CAVALLA*, FROM THE SOUTHEASTERN UNITED STATES[1]

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ABSTRACT

Age, growth, and mortality of king mackerel, *Scomberomorus cavalla*, from the southeastern United States were studied. Otoliths from 1,449 fish were used to estimate age composition, growth rates, and mortality rates of this species.

Age composition varied between locations (Texas, Louisiana, Florida, South Carolina, and North Carolina). The majority of older fish were found in Louisiana waters. The oldest females were 14+ years old and the oldest males were 9+ years old. Compensatory growth was found in both sexes. The von Bertalanffy growth equations were as follows: Males (all areas) $l_t = 965(1 - e^{-0.28(t+1.17)})$; females from Louisiana $l_t = 1,529(1 - e^{-0.14(t+2.08)})$; and females (excluding Louisiana) $l_t = 1,067(1 - e^{-0.29(t+0.97)})$ where l = fork length (mm) and t = years. The mean annual mortality rate determined by six methods of analysis ranged from 0.32 to 0.42. The length-weight relations of king mackerel were for males: $W = 0.8064 \times 10^{-5} L^{2.9928}$; for females: $W = 0.8801 \times 10^{-5} L^{2.9827}$, where W = weight in grams and L = fork length in millimeters.

King mackerel, *Scomberomorus cavalla*, is a major recreational and commercial fisheries resource in the southeastern United States (Manooch 1979). Age, growth, and mortality information has been based on small specimens collected from a limited geographical area (Beaumariage 1973). A need has existed to reexamine age, growth, and mortality from broader geographically based samples.

King mackerel of Brazil have been studied intensively, but the great distance separating these Brazilian fish from those in the United States makes application of their results to king mackerel in United States waters a questionable practice (see Manooch et al. 1978 for annotated bibliography on this species).

A geographically comprehensive sampling of king mackerel in U.S. waters was initiated by us in 1977. Recreational landings were sampled because the sport fishery is less localized than the commercial fishery. We utilized samples from Texas to North Carolina to meet our objectives of determining the age composition, growth rates, length-weight relationships, and mortality rates of king mackerel from U.S. waters.

METHODS AND MATERIALS

King mackerel (7,723 fish) were collected from Texas, Louisiana, Florida, South Carolina, and North Carolina from June 1977 through August 1979 (Fig. 1). They were caught by recreational hook and line, except for some small individuals, which were caught in shrimp trawls at Cape Canaveral, Fla., in December 1978. The trawl-caught fish were used in determining the relation between otolith radius and fish length. In 1979, 121 fish samples were taken only in northwest Florida and were used to supplement existing samples for the marginal increment analysis.

Processing the fish samples involved several steps. The fish were sexed when possible, measured to the nearest millimeter of fork length (FL), and weighed to the nearest gram. Otoliths were removed from the fish, cleaned, and stored either dry or in 100% glycerin.

The otoliths were examined under reflected light in a black-bottomed watch glass containing 100% glycerin with a binocular dissecting microscope at 28×. The otolith radius (OR) was measured on the posterior surface from the focus to the distal margin along the axis approximating the extension of the sulcus acousticus. All measurements were made in ocular micrometer units (1 omμ = 0.0363 mm). Marks were counted and measured along the radius to their distal edge. The marks were opaque (light) under re-

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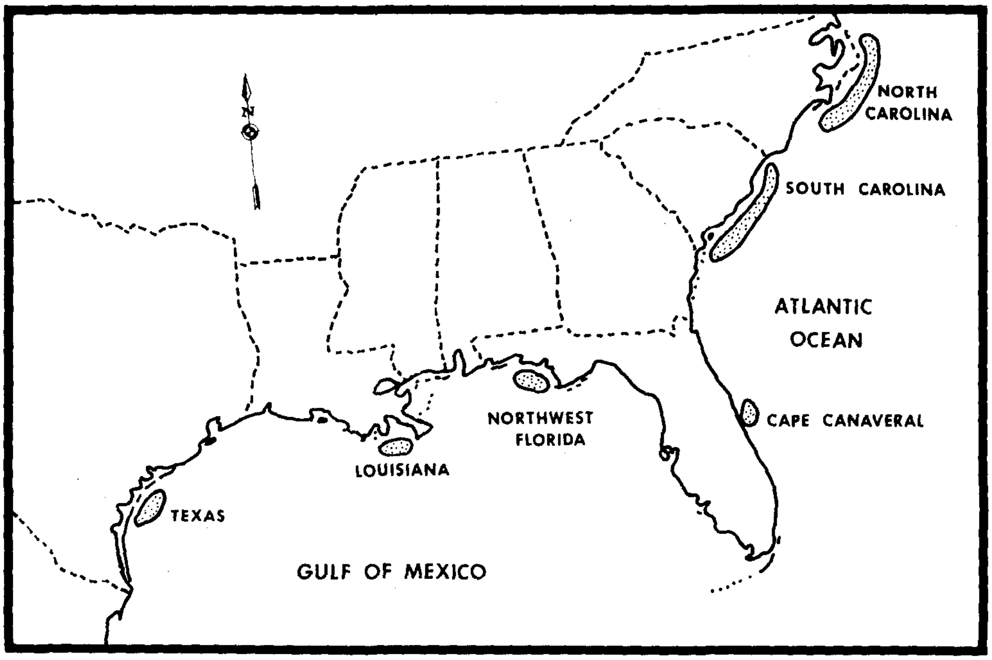

FIGURE 1.—Location of king mackerel, *Scomberomorus cavalla*, sampling sites.

flected light, while the interspaces were hyaline (dark).

Otoliths were classified into age groups according to the number of opaque nonmarginal marks (following the method of Beaumariage 1973). Each otolith was examined by two readers. If the readers did not agree on the age of a fish, data for that fish were not used.

We determined the time of mark formation by comparing frequency per month of otoliths with opaque margins. A high percentage of opaque margins indicated recent mark formation.

Comparison of age estimations was made, based on surface (whole) and internal (sectional) examination of 133 otoliths. Three to 10 otoliths from each age (0+ through 14+) were used for the comparison. Three to six sections, each 0.15 mm thick, were made through the focus of each otolith, using a Norton[3] diamond blade (SD519-N50m-1/8) rotating at about 285 rpm on an Isomet low-speed saw. The otolith was mounted in thermoplastic (quartz) cement (No. 70C Lakeside) and cooled with mineral spirits during sectioning. Later the cement was dissolved by soaking in 50% isopropanol. The free sections were then mounted on glass slides using Piccolyte cement and examined with a binocular dissecting microscope.

The relationship of the size of the aging structure (OR) to the size of the fish (FL) was determined by using least-square regressions with both linear and power curves. Once the relationship was established, fork lengths at earlier ages were back-calculated from surface otolith measurements, using methods adopted from Tesch (1971), Ricker (1975), and Everhart et al. (1975).

Otolith measurements were analyzed for implications of compensatory growth. A frequency distribution of otolith lengths from the focus to the proximal edge of the first opaque mark was developed. Both slow- and fast-growing fish were separated from those that grow at intermediate rates, and lengths at earlier ages were back-calculated for both the slow and fast growers.

A computer program by Abramson (1971) was used to fit von Bertalanffy theoretical growth curves. Each age was given equal weight, and mean back-calculated lengths were used in the computations.

Length-weight equations were developed for the entire king mackerel collection, and for males and females separately, by a computer program following Ricker's (1975) suggestions. Nonlogarithmic length intervals (50 mm) and

[3]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

weight intervals (computed by the program) were used. A maximum of 20 length-weight values was randomly selected for the analysis within each qualifying length and weight interval. If any length or weight interval contained fewer than 20 values, all were utilized.

Estimates of annual mortality rate A (after Ricker 1975) were developed by catch-curve analysis of south Florida length-frequency data. These data were used because they best represented the king mackerel in U.S. waters according to Trent et al. (1981). Since these data were not separated by sex, two age-length keys were developed, one combining males and females assuming a 1:1 sex ratio and the other assuming a 1 male:2 female ratio (the approximate ratio in our collection). The length-frequency data were converted to age-frequency distributions (N_i = number of fish caught in age-class i) by applying each of the combined age-length keys. Age classes I through X of the resultant catch curves were analyzed by

1. Heincke's (1913) method;
2. Jackson's (1939) method;
3. Rounsefell and Everhart's (1953) method;
4. Beverton and Holt's (1957) method, using the mean of values computed with their equation 13.4 between successive age groups;
5. Robson and Chapman's (1961) method, uncorrected for possible age-length key bias; and
6. finding the slope (m) of a regression line fitted to ln (N_i) and i and substituting in the equation $A = 1 - e^m$.

RESULTS AND DISCUSSION

Age

The validity of using otoliths for estimating the age and past growth history depends on these structures being directly correlated with the growth of the fish and on otolith mark formation being periodic. We found the otolith radii to be closely correlated to fork lengths, especially when the data were transformed to represent a "power" function. The "power curve" equation, $FL = 1.232\ OR^{1.331}$ with correlation coefficient $r = 0.987$, had a better fit than the linear equation, $FL = 5.559\ OR + 84.818$ with $r = 0.847$. This close correlation of OR and FL satisfied the first criterion for validation of otoliths as an age determination structure. The second criterion, mark formation of known periodicity, needed further investigation. Beaumariage (1973) found king mackerel with opaque margins during 8 mo of the year (February-September); the highest percentage of otoliths with opaque margins occurred in May. He concluded, "Most otolith margins become opaque (form annuli) during April, May, and June...." Fish in our collections exhibited opaque margins in 11 mo of the year with the peak during May (54%); however, few fish were collected during the winter months (November-February). No month had a high percentage (over 75%) of fish with opaque margins, and only one month (March) lacked fish whose otoliths had opaque margins (Table 1).

In recent years the use of whole otoliths for estimating the age of fish has been questioned. Beamish (1979) indicated that a fish's age may be underestimated using surface examination and that otolith sections are more reliable. However, we found 96.5% agreement between king mackerel age estimates (number of opaque marks) comparing surface and sectional readings. This indicates that our age estimations for whole otoliths are similar to those of sectioned ones.

The agreement between two readers about the number of marks on king mackerel otoliths was 98%. The number of otoliths found to be usable was 1,449.

Age and Size Composition

Age composition of king mackerel varied greatly among the areas (Table 2). Younger fish were taken in northwest Florida, while older fish were caught off Louisiana, particularly in 1978. Fish of intermediate age were landed primarily in Texas, South Carolina, and North Carolina. The oldest females in our sample were 14+ yr (over 1,400 mm FL) and the oldest males were 9+ yr (970 mm FL).

Much age variation occurred within a single length group in our data (Tables 3, 4) as it did in Beaumariage's (1973) data. For example, we found females 850-899 mm FL were 1-8 yr old (Table 3).

Back-Calculated Growth

The weighted means of the back-calculated fork lengths for male and female king mackerel from all areas and years sampled in this study are shown in Tables 5 and 6. Differences in mean

TABLE 1.—Percentages by month, area, and year of king mackerel otoliths having opaque margins. ( ) = total number of fish.

Area	Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Texas	1977	—	—	—	—	—	26.7 (15)	28.6	0.0 (5)	—	—	—	—
	1978	—	—	—	—	—	0.0 (5)	0.0 (17)	2.5 (40)	—	—	—	—
Louisiana	1977	—	—	—	—	—	0.0 (4)	—	—	0.0 (15)	0.0 (22)	0.0 (18)	—
	1978	0.0 (7)	16.7 (6)	0.0 (43)	40.6 (32)	0.0 (2)	15.4 (26)	6.5 (62)	13.5 (37)	0.0 (5)	0.0 (51)	5.0 (20)	14.3 (7)
NW Florida	1977	—	—	—	—	—	18.2 (11)	9.4 (64)	3.1 (65)	0.0 (73)	4.3 (46)	—	—
	1978	—	—	—	—	—	0.0 (15)	0.0 (160)	0.0 (97)	0.0 (107)	11.1 (135)	—	—
	1979	—	—	—	—	61.2 (62)	20.0 (20)	19.2 (27)	0.0 (12)	—	—	—	—
SE Florida	1978	—	—	—	—	—	—	—	—	—	—	—	50.0 (6)
	1979	83.3 (6)	—	—	—	—	—	—	—	—	—	—	—
South Carolina	1978	—	—	—	—	—	—	—	—	—	2.9 (104)	—	—
North Carolina	1978	—	—	—	—	0.0 (5)	63.6 (22)	38.5 (13)	26.7 (15)	3.8 (53)	8.9 (313)	—	—
Total		38.5 (13)	16.7 (6)	0.0 (43)	40.6 (32)	54.3 (70)	23.7 (118)	7.2 (364)	4.4 (271)	0.8 (253)	7.2 (671)	2.6 (38)	33.3 (13)

TABLE 2.—Percentages of king mackerel by area and year within each age group, developed from age-length keys and length-frequency distributions.

Area	Year	Age in years															No. fish
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Males																	
Texas	1977	—	—	6.9	24.1	24.1	27.6	3.5	6.9	6.9	—	—	—	—	—	—	29
	1978	—	2.6	1.9	13.5	16.5	20.6	32.5	3.6	3.3	5.8	—	—	—	—	—	533
Louisiana	1977	—	—	—	—	—	100.0	—	—	—	—	—	—	—	—	—	10
	1978	—	—	—	—	—	20.0	24.0	36.0	8.0	12.0	—	—	—	—	—	25
NW Florida	1977	—	26.9	31.3	16.7	20.5	2.0	2.6	—	—	—	—	—	—	—	—	498
	1978	1.8	93.1	2.7	1.2	0.4	0.8	—	—	—	—	—	—	—	—	—	1,107
South Carolina	1978	—	21.1	8.8	21.8	13.6	13.6	19.7	—	—	1.4	—	—	—	—	—	147
North Carolina	1978	—	5.2	5.2	18.3	35.7	20.0	8.6	3.5	3.5	—	—	—	—	—	—	115
Total males		*0.8*	*48.8*	*8.6*	*10.5*	*12.6*	*7.7*	*6.5*	*1.7*	*1.4*	*1.4*	—	—	—	—	—	*2,507*
Females																	
Texas	1977	—	—	27.9	48.8	7.0	9.3	4.7	2.3	—	—	—	—	—	—	—	43
	1978	—	4.1	8.5	5.8	37.3	23.6	9.9	10.8	—	—	—	—	—	—	—	780
Louisiana	1977	—	0.4	0.8	12.6	28.9	30.1	10.9	6.7	2.9	6.7	—	—	—	—	—	239
	1978	—	—	0.4	1.3	6.0	14.4	24.4	11.9	7.7	7.7	10.9	8.8	4.4	1.3	0.8	479
NW Florida	1977	—	39.6	30.4	12.5	10.0	5.8	0.6	0.6	0.4	—	0.1	—	—	—	—	1,393
	1978	2.0	85.0	5.9	2.5	2.1	1.6	0.8	—	—	—	0.1	—	—	—	—	1,463
South Carolina	1978	—	17.3	3.6	26.5	21.7	5.6	11.2	—	4.4	5.6	2.4	0.8	0.9	—	—	249
North Carolina	1978	—	4.5	3.7	19.7	20.4	19.2	16.4	8.5	4.0	3.2	—	—	0.4	—	—	402
Total females		0.6	37.9	10.9	9.9	11.1	8.6	0.3	4.0	2.2	1.7	1.7	1.1	0.7	0.2	0.1	5,216

length occurred from year to year and from area to area. Only data for Louisiana, however, where five or more individuals were used in computing a mean, showed the range of means within an age group to vary more than 100 mm.

In 2 yr of sampling in Louisiana, over 300 females were sampled, but too few males were collected to back-calculate size at previous ages. Generally, the Louisiana fish were also much larger than those taken elsewhere, and we concluded that this must be an anomalous group of fish. We separated Louisiana females from other females for growth computations, except those dealing with compensatory growth.

TABLE 3.—Length composition (%) of female king mackerel by age group (locations combined).

Length group (mm FL)	Age in years 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total no. fish
350-399	100.0															1
400-449	33.3	66.7														6
450-499	43.5	56.5														23
500-549		100.0														48
550-599		100.0														90
600-649		96.4	3.6													112
650-699		77.5	19.7	2.8												71
700-749		25.3	65.1	7.2	1.2	1.2										83
750-799		3.0	36.0	43.0	16.0	2.0										100
800-849		2.4	11.0	36.2	31.5	13.4	3.9	1.6								127
850-899		1.6	0.8	18.9	33.6	32.0	9.8	2.5	0.8							122
900-949			1.0	11.0	22.0	25.0	28.0	9.0	4.0							100
950-999				2.5	23.4	31.2	26.0	14.3	1.3		1.3					77
1,000-1,049					16.7	23.1	34.6	11.5	6.4	3.8	2.6		1.3			78
1,050-1,099					4.1	28.6	26.5	10.2	10.2	16.3	4.1					49
1,100-1,149					1.9	11.5	40.4	13.5	19.2	7.7	5.8					52
1,150-1,199						11.9	21.4	33.3	9.5	9.5	7.1	4.8	2.5			42
1,200-1,249						2.9	15.2	21.2	21.2	9.1	15.2	6.1	9.1			33
1,250-1,299							12.5	8.3	4.2	16.7	33.3	8.3	16.7			24
1,300-1,349							4.3	4.3	13.0	8.7	21.7	26.3	13.0	8.7		23
1,350-1,399									5.0	15.0	30.0	35.0	5.0	5.0	5.0	20
1,400-1,449										26.7	13.3	33.3	20.0		6.7	15
1,450-1,499											14.3		57.1	14.3	14.3	7
1,500-1,549																0
1,550-1,599												50.0	50.0			2

TABLE 4.—Length composition (%) of male king mackerel by age group (locations combined).

Length group (mm FL)	Age in years 0	1	2	3	4	5	6	7	8	9	10	11	12	Total no. fish
400-449		100.0												4
450-499	15.2	84.8												33
500-549		100.0												51
550-599		98.3		1.7										60
600-649		93.0	5.3		1.7									57
650-699		37.5	37.5	14.6	10.4									48
700-749		11.9	35.7	31.0	16.6	2.4	2.4							42
750-799			11.1	27.8	46.3	13.0	1.8							54
800-849			2.0	15.4	34.6	21.2	19.2	3.8	3.8					52
850-899				15.0	5.0	35.0	30.0	10.0	5.0					20
900-949					14.2	42.9	42.9							7
950-999							25.0	25.0	25.0	25.0				4
1,000-1,049								25.0		75.0				4
1,050-1,199														0
1,200-1,249									100.0					1

TABLE 5.—Weighted means of back-calculated fork lengths (mm) for female king mackerel from all areas, 1977-78.

Age class	Texas 1977	Texas 1978	Louisiana 1977	Louisiana 1978	NW Florida 1977	NW Florida 1978	South Carolina 1978	North Carolina 1978
I	487	457	504	502	463	443	415	393
II	688	673	718	714	670	687	638	627
III	777	748	824	824	755	764	750	738
IV	847	811	906	909	805	838	809	798
V	[1]805	853	970	983	866	895	864	844
VI	[1]849	937	990	1,045	[1]897	[1]934	916	891
VII	[1]932	[1]885	[1]1,097	1,096	[1]963		941	939
VIII			[1]1,203	1,148			996	992
IX			[1]1,361	1,202			1,033	[1]1,000
X				1,252			[1]1,034	
XI				1,311				
XII				1,332				
XIII				[1]1,350				
XIV				[1]1,399				

[1]Lengths based on less than 5 samples.

TABLE 6.—Weighted means of back-calculated fork lengths (mm) for male king mackerel from all areas, 1977-78.

Age class	Texas 1977	Texas 1978	Louisiana 1977	Louisiana 1978	NW Florida 1977	NW Florida 1978	South Carolina 1978	North Carolina 1978
I	414	413	—	—	473	407	373	385
II	588	574			635	665	607	614
III	659	658			686	[1]734	715	702
IV	703	720			736	[1]746	746	747
V	747	790			[1]798		[1]769	781
VI	[1]754	829			[1]850		[1]821	795
VII	[1]803	[1]896						[1]810
VIII	[1]789	[1]951						
IX		[1]943						

[1]Lengths based on less than 5 samples.

Back-calculations for male king mackerel from all areas combined are shown in Table 7. Growth is rapid until the third year of life, after which time the annular growth increment decreases and stabilizes at an average 42 mm FL.

Females from the combined areas (Table 8), excluding Louisiana, also showed rapid growth in the first 3 yr, after which the annual growth increment decreased to an average 40 mm FL. Females were larger than males for all ages.

Fish from Louisiana (all females) exhibited an impressive growth rate (Table 9). They averaged 69 mm longer than other females at age 1, and by age 10 were 218 mm longer than their counterparts. The yearly growth increment was over 60 mm to age 6, an increment not maintained by other females, or males, past age 3 in other locations.

Our combined back-calculated data were compared with those from Beaumariage (1973) (Table 10). His data were converted to fork lengths from standard lengths (SL) using his equation: FL = 1.096 SL − 17.143. Disregarding Louisiana females, both male and female mean

TABLE 7.—Average back-calculated fork lengths (mm) at age for male king mackerel from all areas, 1977-78.

Age class	Mean length at capture (mm FL)	N	Age in years: 1	2	3	4	5	6	7	8	9
I	570.3	206	425.0								
II	708.6	41	422.6	667.3							
III	767.0	41	408.5	618.7	737.6						
IV	772.5	44	403.3	594.6	677.5	747.9					
V	820.4	22	375.1	590.5	669.0	733.9	796.1				
VI	832.6	16	349.2	559.4	641.9	700.1	755.8	808.3			
VII	852.3	3	389.6	579.3	648.6	717.7	752.7	802.1	838.3		
VIII	920.0	2	415.2	578.8	649.2	714.5	773.1	817.3	862.5	896.0	
IX	970.0	1	476.6	560.3	623.3	754.1	796.2	830.2	864.7	899.4	943.4
Weighted mean		376	414.1	613.4	689.2	734.0	777.4	809.3	850.8	897.1	943.4
Annual increment				199.3	75.8	44.8	43.4	31.9	41.5	46.3	46.3

TABLE 8.—Average back-calculated fork lengths (mm) at age for female king mackerel from all areas except Louisiana, 1977-78.

Age class	Mean length at capture (mm FL)	N	Age in years: 1	2	3	4	5	6	7	8	9	10
I	604.8	315	456.4									
II	741.2	112	427.9	693.8								
III	809.6	105	435.8	645.4	774.4							
IV	858.7	100	426.2	648.9	753.5	830.2						
V	897.1	79	499.3	635.3	729.6	800.7	865.4					
VI	933.7	44	405.1	630.3	727.2	791.6	848.2	908.3				
VII	960.2	21	363.0	613.3	703.3	760.5	827.4	884.5	937.5			
VIII	1,028.0	8	392.4	635.0	732.5	796.6	852.2	910.0	955.3	1,020.9		
IX	1,056.0	6	337.4	609.2	732.0	790.9	847.3	893.9	938.1	987.7	1,034.6	
X	1,062.1	2	325.5	557.8	683.1	747.4	796.9	833.9	883.6	934.7	978.4	1,033.6
Weighted mean		792	433.9	652.0	747.1	806.5	853.5	899.4	936.5	997.7	1,020.6	1,033.6
Annual increment				218.1	95.1	59.4	47.0	45.9	39.1	59.2	22.9	13.0

TABLE 9.—Average back-calculated fork lengths (mm) at age for Louisiana female king mackerel, 1977-78.

Age class	Mean length at capture (mm FL)	N	Age in years: 1	2	3	4	5	6	7	8	9	10	11	12	13	14
I	635.0	1	571.5													
II	815.8	4	500.3	767.1												
III	890.3	16	523.0	745.3	852.0											
IV	955.9	30	525.9	725.9	829.4	927.8										
V	1,039.2	48	517.9	728.0	838.4	926.9	1,011.2									
VI	1,079.5	78	520.7	727.8	840.7	923.6	992.2	1,057.7								
VII	1,159.1	24	495.2	711.5	834.9	924.0	997.8		1,129.3							
VIII	1,204.5	16	443.0	668.9	793.7	878.3	960.9	1,033.7	1,100.2	1,170.2						
IX	1,261.7	16	462.8	689.0	800.2	885.8	959.9	1,032.6	1,099.8	1,168.0	1,234.5					
X	1,273.3	22	473.1	674.0	765.9	851.8	925.3	991.1	1,057.6	1,121.9	1,182.4	1,244.8				
XI	1,369.5	11	505.0	715.1	810.2	900.4	976.8	1,052.6	1,121.0	1,182.8	1,235.9	1,288.0	1,345.6			
XII	1,369.0	11	469.3	681.6	790.0	869.5	941.3	1,014.5	1,081.0	1,135.5	1,193.9	1,243.9	1,295.0	1,340.8		
XIII	1,404.1	2	380.4	656.5	764.9	843.1	931.4	988.8	1,055.3	1,117.5	1,172.5	1,227.7	1,278.4	1,327.0	1,357.0	
XIV	1,419.5	2	387.0	631.9	738.3	814.5	888.2	967.0	1,022.1	1,074.1	1,130.2	1,195.0	1,241.3	1,259.8	1,343.5	1,399.1
Weighted mean		281	502.6	714.5	823.7	908.8	981.3	1,041.4	1,095.6	1,149.7	1,204.7	1,251.7	1,311.0	1,332.3	1,350.2	1,399.1
Annual increment				211.9	109.2	85.1	72.5	60.1	54.2	54.1	55.0	47.0	59.3	21.3	17.9	48.9

TABLE 10.—Mean back-calculated fork length (mm) at ages, from Beaumariage (1973) and this study. Beaumariage's data were transformed from standard length by his formula FL = 1.096 SL – 17.143.

Age	Males: Beau-mariage	Males: Johnson et al.	Females (except La.): Beau-mariage	Females (except La.): Johnson et al.
1	457	414	491	434
2	643	613	703	652
3	705	689	793	747
4	752	734	857	807
5	795	777	928	854
6	822	809	986	899
7	839	851	1,033	939

fork lengths at age were smaller in our study than in his in all cases but one (7-yr-old males). Several explanations for the differences seem reasonable. First, our back-calculations employed a power curve, whereas his employed a linear equation. Secondly, our fish were sampled from a wide geographical range, which yielded fish with wide variation in age composition, whereas Beaumariage sampled from a more restricted area. Lastly, our sampling occurred almost 10 yr after his, and various changes may have occurred in the population owing to exploitation or other influences.

Compensatory Growth

Compensatory growth (Ricker 1975) appeared to occur in both male and female king mackerel. Length-frequency distributions of otolith measurements from the focus to the proximal edge of the first opaque mark in both sexes showed a normal distribution of values. After examination of the distributions, we defined slow-growing fish (both sexes) as those with an increment of 50 omμ or less, fast-growing males as those with an increment of 81 omμ or more, and fast-growing females as those with an increment of 86 omμ or more.

Back-calculated lengths for these fish are shown in Table 11. While fast-growing males grew 525 mm in year 1, they grew only 135 mm in year 2. The slow-growing males grew 303 mm in their first year, but made up some of their size difference by growing 285 mm in their second year. Females showed a similar trend, with fast-growing fish having a first-year increment of 559 mm and a second-year increment of 184 mm. The slow-growing females grew 282 mm in year 1 and 334 mm in year 2. Beyond age 2, yearly growth increments were similar within each sex.

Growth compensation in king mackerel is

TABLE 11.—Annual fork length increments (mm) computed from back-calculations on fast- and slow-growing male and female king mackerel (from all areas combined).

Age	Males Fast	Males Slow	Females Fast	Females Slow
1	525	303	559	282
2	135	285	184	334
3	87	85	101	99
4	53	72	89	67
5	104	63	75	63
6		49	64	66
7			46	75
8			52	65
9			53	47
10			44	47
11			51	67
12			34	10
13			67	35
14			11	100

probably the result of an extended spawning season. Long spawning seasons and multiple spawns are discussed by Beaumariage (1973) and would result in great size variation in young-of-the-year king mackerel. Some of that size variation would be decreased as the smaller fish continue to grow at a higher rate in their second year than do larger fish in their second year. Although the slow-growing fish make up some difference in size during year 2, they remain smaller than the fast growers throughout their lives.

Theoretical Growth

The von Bertalanffy theoretical growth parameters computed from back-calculated fork lengths are shown in Table 12, along with those reported by other authors. The von Bertalanffy (1938, 1957) growth equation is the following:

$$l_t = L_\infty \left(1 - e^{-k(t-t_0)}\right)$$

where l_t = length at age t,
L_∞ = asymptotic length,
k = growth coefficient, and
t_0 = time when length would theoretically be zero.

TABLE 12.—von Bertalanffy growth parameters for king mackerel.

Author	k value	L_∞ (mm FL)	t_0 (yr)
Males			
Johnson et al., all areas	0.28	965	−1.17
Beaumariage (1973)	0.35	903	−2.50
Nomura and Rodrigues (1967)	0.18	1,160	−0.22
Females			
Johnson et al., excl. La.	0.29	1,067	−0.97
Johnson et al., La.	0.14	1,529	−2.08
Beaumariage (1973)	0.21	1,243	−2.40
Nomura and Rodrigues (1967)	0.15	1,370	−0.13

Our theoretical growth parameters are between those calculated by Beaumariage (1973) and Nomura and Rodrigues (1967). Beaumariage's theoretical growth parameters were calculated by employing observed sizes of fish at each age, while Nomura and Rodrigues apparently combined both back-calculated lengths and empirical lengths in their calculations. We employed mean back-calculated lengths at age in our computations, which may account for some of the differences between our values and those of the other investigators.

Length-Weight Relationship

The length-weight values for king mackerel computed for the equation $W = a\ L^b$, where W is weight in grams and L is fork length in millimeters, are presented in Table 13. Male length-weight values from our study were within the confidence intervals set by Beaumariage (1973), but for both our female and combined sexes, length-weight values were below his lower confidence intervals.

Mortality

Mortality estimates are presented in Table 14. The mean annual mortality rate (A = 0.37) is lower than Beaumariage's (1973) estimate (A = 0.54). We feel that our results are more concordant with generally accepted techniques of catch-curve analysis, in that our catch-curves were developed from age-frequency data, as opposed to the length-frequency catch-curve used by Beaumariage. We also feel that our results are less influenced by the effects of gear selectivity than Beaumariage's results, since Trent et al. (1981) stated that commercial hook-and-line gear excludes small and large king mackerel to a greater extent than does recreational hook-and-line gear. Nevertheless, there are many difficulties in using catch-curve analysis in our study. Specific problems are related to the Beverton and Holt (1957) and Robson and Chapman (1961) techniques. The first technique involves using several consecutive years of data, which were unavailable in our study. With the second technique, we used age-length keys as the basis for our catch-curves but were unable to make corrections for the bias when such keys were used (Rob-

TABLE 13.—Summary of length-weight relations of U.S. king mackerel. W = weight in grams; L = fork length in millimeters.

Sex	No. fish	Range (mm FL)	$W = a L^b$		95% confidence interval		Correlation coefficient
			a	b	Lower	Upper	(r)
Male	701	428-1,355	0.8064×10^{-5}	2.9928	2.9572	3.0284	0.9909
Female	2,023	351-1,554	0.8801×10^{-5}	2.9827	2.9562	3.0092	0.9910
Sexes combined	2,821	351-1,554	0.8464×10^{-5}	2.9881	3.0153	3.0153	0.9899

TABLE 14.—Estimated annual mortality rate (A) by estimation technique, assuming 1:1 and 1:2 male:female ratios.

Male:Female ratio	Estimation technique						Mean A
	Heincke (1913)	Jackson (1939)	Rounsefell & Everhart (1953)	Beverton & Holt (1957)	Robson & Chapman (1961)	Regression analysis	
1:1	0.35	0.34	0.42	0.42	0.32	0.35	0.37
1:2	0.34	0.35	0.42	0.42	0.33	0.36	0.37

son and Chapman 1961). This was a result of the age-length keys being developed for a different fish sample than the one being analyzed for mortality rates. The difficulties in applying Robson and Chapman's technique resulted in an implication that king mackerel are not fully recruited into the south Florida recreational fishery until age 7, after which the annual mortality rate is 0.53. This mortality estimate is similar to Beaumariage's (A = 0.54), but the age at recruitment was found by Beaumariage to be 2-3. His estimate was based on a smaller age range (0-7) than was ours. This difference probably influenced the resulting mortality estimates.

Many difficulties are also involved in the basic concept of using catch-curve analysis to estimate mortality in king mackerel. Rounsefell and Everhart (1953) emphasized that catch-curve analysis is based on false assumptions when applied to most pelagic species, including mackerel. Robson and Chapman (1961) reiterated this warning, stating, "if year classes...vary in strength and survival rates vary from year class to year class and age to age, then the age-frequency distribution in the catch of a single season provides no identifiable information whatsoever regarding [mortality rates]...." These comments force us to state our mortality findings with some wariness.

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ADDENDUM

Fischer (1980) reported on the length-weight relationship of king mackerel off Louisiana. His length-weight values are similar to ours.

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