Age and Growth of Spanish Mackerel in the Northern Gulf of Mexico and Management Implications[1]

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Abstract: A total of 230 otoliths was used for age and growth analysis of Spanish mackerel (*Scomberomorus maculatus*) in the northern Gulf of Mexico. Male fish in the sample ranged from ages 0 to 6, whereas females were 0 to 4 years old. Females exhibited faster growth than did males. Von Bertalanffy growth equations were:

$$\text{males } L = 552(1 - e^{-0.29(t+1.66)}), \text{ and}$$
$$\text{females } L = 604(1 - e^{\;0.45(t+0.75)}).$$

Growth equations from this study showed that both sexes grew at significantly slower rates than did Spanish mackerel in south Florida waters. Age-frequency distributions showed a differential pattern of mortality between the sexes from ages 1 through 4. Females showed a 50% decline in numbers between ages 1 and 2, whereas males exhibited a decline of 80% between ages 2 and 3. The differential growth and age specific mortality patterns imply that males and females enter the fishery at different ages and that the fishery is contributing noticeably to total mortality. Fishery management alternatives are discussed.

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The Spanish mackerel, *Scomberomorus maculatus* (Mitchill), is a migratory pelagic species of fish which inhabits coastal Atlantic and Gulf of Mexico waters (Collette and Russo 1978). Commercial exploitation of Spanish mackerel began in 1882, and 86% of the total U.S. catch of this species was taken along the middle Atlantic coast at that time. Areas of major production shifted, and by 1945, 97% of the total production occurred in Florida and the Gulf Coast (Trent and Anthony

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1978). Presently, the Spanish mackerel stocks support important commercial and recreational fisheries in the Gulf of Mexico, and fishing pressure on the stocks has increased substantially over the years.

Because of the economic importance, early investigations on the general biology of *S. maculatus* were conducted by Earll (1883) and Ryder (1882) in the northeast Atlantic. Klima (1959) and Powell (1975), in south Florida waters, conducted studies on reproduction and age and growth. Other studies on migration (Southerland and Fable 1980), early life history, and larvae distribution (Wollam 1970, Dwinell and Futch 1973, and McEarhran et al. 1980) also exist in the literature. A summary of biological and fisheries data was compiled by Berrian and Finan (1977), and Manooch et al. (1978) published an annotated bibliography.

Recently, there has been concern over the condition of the Gulf's spawning stock of Spanish mackerel, and many fishery managers and biologists believe the stocks are stressed and on the verge of collapse, similar to the collapse of the Gulf's stock of king mackerel (*Scomberomorus cavalla*). Between 1978 and 1984, spawning stock biomass in the Gulf of Mexico decreased by roughly 50%, with a slight recovery in 1985 and 1986 (U.S. Dep. Commerce 1987). In 1985, the State of Alabama responded to the growing concern by implementing a marine recreational fishery survey and, in 1986, by placing a minimum length limit of 350 mm (14 inches) on Spanish mackerel harvested by anglers. The survey has provided a diverse data base for the estimation of effort, harvest, fishing success, and length frequencies of Spanish mackerel in the creel, as well as fishery statistics of other recreationally important fishes.

The purpose of this study was to determine growth characteristics of Spanish mackerel in the Northern Gulf of Mexico, to determine the age structure and age specific mortality of fish being exploited by the recreational fishery, and to identify alternatives for management of the Spanish mackerel stock in the Gulf of Mexico.

Methods

Spanish mackerel were sampled from recreational landings on the coast of Alabama between May and August 1986. During these months, Spanish mackerel are most abundant in the northern Gulf of Mexico which corresponds to the peak recreational fishing season in Alabama.

The fish sample for age and growth analysis was taken within the sampling scheme of the Alabama marine recreational fishery survey being conducted by the Marine Resources Division of the Alabama Department of Conservation and Natural Resources and the Department of Fisheries and Allied Aquacultures at Auburn University. The sample was supplemented by fish from charter boat landings and fishing rodeos. Individual fish were measured to the nearest mm (fork length), weighed to the nearest ounce, and sexed. Terms used in this paper concerning age and growth follow a glossary assembled at the Second International Symposium of Age and Growth of Fish (Prince and Pulos 1983).

Otolith Preparation and Reading

Otoliths (sagittae) were removed, cleaned, and stored in envelopes. Later, they were transferred to vials containing glycerin and allowed to clear for approximately 1 to 2 months before processing. Periodically, they were checked for signs of deterioration.

Otoliths were immersed in glycerin contained in a black-bottomed watch glass and examined for annular marks under a dissecting microscope using reflected light. Otoliths were measured using an ocular micrometer, in line with the sulcus acousticus (appears as a clear medial grove), posteriorly from the core to each annulus, and then to the otolith margin. This allowed the linear micrometer to be positioned perpendicular to each annular mark.

Annular marks appeared as dark translucent zones which were narrow in comparison to the opaque zones interspaced between them. The opaque zones became progressively narrower after the first annulus. The translucent and opaque zones corresponded to fall-winter (slow growth) and spring-summer (fast growth) periods, respectively (Powell 1975).

Prediction of Length at Age

The relationship between fish length (L) and otolith radius (R) was determined by regressing L on R using various models and choosing the best fit relation based on a maximum r^2 criterion. Regression models evaluated were: linear, power, exponential, and second- and third-degree polynomials. The sample of fish for this procedure was selected by dividing the entire length range of fish in the sample, 230–615 mm, into 50-mm length groups and choosing fish at random from each length range. This was done to avoid weighting the regression inordinately toward the most common lengths in the sample (300–400 mm). The final sample size for this analysis was 105 fish.

Back-calculated fish lengths at annulus formation were derived from the regression of fish length on otolith radius by substituting the micrometer distance of each annulus for (R) of the best model. For each fish, back-calculated lengths were multiplied by a correction factor to adjust for the discrepancy between the predicted value from the equation and the actual length at capture. The correction factor was computed by dividing the predicted length at capture into the observed length at capture (Carlander 1981). After back-calculation of fish length at annulus formation for each fish, mean back-calculated lengths at age were determined along with standard deviations and coefficients of variation (CV).

Estimating Growth Parameters

The Von Bertalanffy growth curve was fit to mean back-calculated lengths at age first by establishing a Ford-Walford plot, where length at age t + 1 was regressed against length at age t. The regression estimate of L_{max} was calculated as:

$$L_{max} = \text{intercept}/1\text{-slope}.$$

The value for L_{max} was then substituted into the linear form of the Von Bertalanffy model:

$$\ln(L_{max} - L) = \ln(L_{max}) + K(t_0 - t),$$

where L = length at age t, K = growth coefficient, and t_0 = the age at which individuals of the species would have had zero length had they always grown as described by the model (Ricker 1975).

The best linear fit of the above equation to the data was achieved by substituting different values of L_{max} into the equation and re-running the regression procedure to obtain the highest r^2 value. The slope of the best fit linear regression is the Von Bertalanffy growth coefficient (K) and t_0 was calculated as:

$$t_0 = \text{intercept} - \ln(L_{max})/K.$$

The Von Bertalanffy growth equation then was written:

$$L = L_{max}\,(1 - e^{-k(t-t_0)})\ \text{(Ricker 1975).}$$

Population Age Structure

The marine recreational fishery survey, which provided the sampling scheme for the age and growth study, was based on a roving creel survey employing non-uniform probability sampling (Malvestuto et al. 1978). The sampling design strives for unbiased estimates of effort, CPUE, and harvest. It was our contention that a representative fish (otolith) sample of the segment of the population fully vulnerable to the recreational fishery could be obtained via the sampling design employed by the recreational fishery survey so that an accurate age-frequency distribution could be generated directly from the otolith sample. The length frequencies of fish from the otolith sample were significantly ($P < 0.05$) correlated with the length frequencies of fish from the recreational creel. Maximum correlation ($r = 0.85$) was achieved by excluding the largest and smallest length classes of fish in the otolith sample to more accurately reflect the length range of fish taken in the recreational survey.

Results and Discussion

Of the 250 otoliths available for study, 22 were found not to have clearly discernable annual marks, leaving 228 otoliths for the age and growth analysis. Male fish in the sample ranged from age 0 to age 6, whereas females ranged from ages 0 to 4. Age I fish were most prevalent, comprising 50% of the total sample. Approximately 90% of the sample was composed of fish $\leq$3 years old.

Estimation of Length at Age

The regression of fork length on otolith radius was best fit ($R^2 = 0.84$) with the linear model:

$$L = 154.5(R) - 53.7,$$

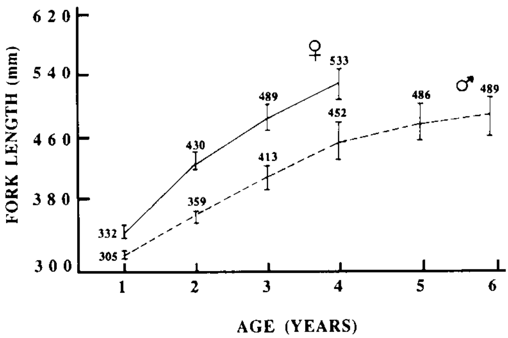

Figure 1. Von Bertalanffy growth curves for male and female Spanish mackerel showing predicted and mean back-calculated lengths at age. Vertical lines represent 95% confidence intervals around means. Mean fork lengths (mm) are given above vertical lines.

where L = fish length and R = otolith radius. This demonstrates proportional growth between body size and otolith radius.

Figure 1 shows mean back-calculated lengths at age for male and female Spanish mackerel. Females attained significantly ($P \leqslant 0.05$) greater size at age than males. Coefficients of variation suggest that growth is consistent across years and relatively few samples are needed to accurately back-calculate mean lengths (highest CV = 13%). Estimation of back-calculated lengths at age within ±5% at the 90% confidence level should require no more than 20 fish per age class according to Stein's formula (Steel and Torrie 1960).

Estimation of Growth Parameters

Estimates of L_{max} from the Ford-Walford regression were 552 and 604 mm for male and female Spanish mackerel, respectively. Iteration using other values of L_{max} to explore the best fit of the linearized Von Bertalanffy equation to the data, did not improve the initial estimates. The resulting Von Bertalanffy growth equations for male and female Spanish mackerel were:

$$\text{males: } L = 552(1 - e^{-0.29(t+1.66)}), \text{ and}$$
$$\text{females: } L = 604(1 - e^{-0.45(t+0.75)}).$$

Figure 1 shows that the Von Bertalanffy growth equations provide a good fit to the data over the ages under consideration. Growth curves for males and females fall within 95% confidence intervals around back-calculated means.

Growth of Spanish mackerel in the northern Gulf of Mexico described in this study was notably different from that determined by Powell (1975) in south Florida waters. In order to compare growth of Spanish mackerel in the northern Gulf of Mexico described in this study to that described by Powell (1975), it was necessary to use the Van Oosten direct proportion formula (Lagler 1956), as Powell did, to re-calculate lengths at age from our data. In addition, it was necessary to re-fit the Von Bertalanffy growth equation to Powell's (1975) data because his predicted lengths at age were consistently greater than his back-calculated lengths, which should not be the case.

Figure 2 shows the re-calculated Von Bertalanffy growth equations for both sexes from both studies. Placing 95% confidence intervals around back-calculated mean lengths from our data from northern Gulf waters (and treating Powell's values as constants) showed that both sexes in the north grew significantly slower than in the south. It should also be noted that the 2 data sets under comparison differ not only spatially, but also temporally, as Powell's (1975) data were collected in the early 1970s and ours in 1986.

Age Structure and Mortality

Figure 3 shows the frequencies at which various ages of males and females occurred in the recreational harvest of Spanish mackerel along the coast of Alabama. It is apparent from the age-frequency distributions that a differential pattern of mortality existed among the sexes from ages 1 through 4. Females exhibited a 50% decline in numbers between the ages of 1 and 2; males exhibited a decline of 80%, but between the ages of 2 and 3. The total reduction in the number of fish over the ages 1 to 4 represents an average annual mortality of approximately 70%

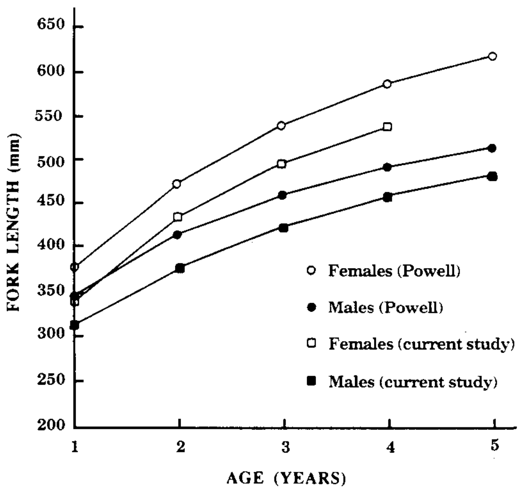

Figure 2. Von Bertalanffy growth curves for male and female Spanish mackerel from this study in the northern Gulf and from that of Powell (1975) in the southern Gulf.

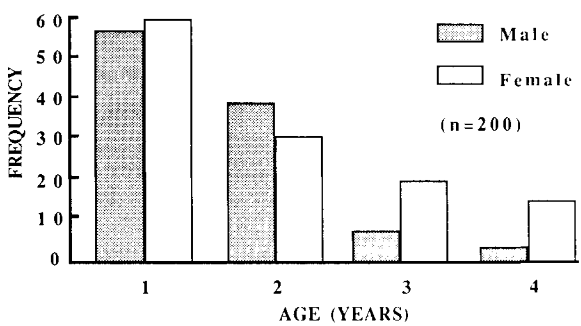

Figure 3. Age-frequency distribution of Spanish mackerel harvested by the marine recreational fishery in Alabama in 1986.

for males and 40% for females. The differential growth and the difference in reduction of numbers between the sexes over time may imply that males and females enter the fishery at different ages and are influenced strongly by fishing mortality when they do become vulnerable.

Management Implications

Sound management of the Spanish mackerel stock should consider the size at which fish in the population mature relative to the sizes being exploited by the fishery. Published data by Finucane and Collins (1986) showed that 70% of the female Spanish mackerel in the northern Gulf of Mexico were mature at 350 mm and all females >500 mm were fully mature. These authors also reported data from south Florida waters which concurred with Klima's (1959) findings that female Spanish mackerel should be fully mature by the time they obtain 350 mm in length. It should be noted, however, that mature fish were defined as having a gonadal development stage of 2 or higher (Finucane and Collins 1986). Maturity stage 2 was described as early maturing gonads and certainly does not imply that fish will actually spawn that season. Thus, it is likely that the fish making a spawning contribution to the stock are, in general, larger than 350 mm. Data from Powell (1975) indicated a potential for spawning at ages 1 and 2 (<500 mm), but suggest that female Spanish mackerel under the age of 3 probably do not make a significant spawning contribution to the stock.

Figure 4 shows the length-frequency distribution of Spanish mackerel from the recreational fishery. It appears that fish have fully recruited at about 345 mm or roughly during first maturation according to the information presented above. The steep decline in numbers of fish between 350 and 400 mm represents an overall mortality of 70% (Fig. 4). Based on the documented growth (Figs. 1, 2), females reside in this 50-mm length range for about 6 months and suffer 50% mortality; males reside in the range for about 1 year and suffer 80% mortality. Thus, during the time, or possibly before, adult Spanish mackerel can contribute strongly to stock replenishment, they are suffering heavy mortality. By the time fish of both sexes have reached 400 mm, females are only ≥1 years old, males are ≥2 years old, and 30% of the recruited stock remains. For a top carnivore such as the Spanish mackerel, the surviving spawning stock may be too small to accommodate current levels of fishing combined with natural mortality.

Under these conditions, protective management would strive to ameliorate the intensity of exploitation of young, maturing fish. Although the information presented here is not conclusive, it does suggest that the mortality that Spanish mackerel experience before reaching 400 mm is excessive and certainly may have exacerbated the decline in the abundance of spawning stock over the past 10 years as documented by the United States Department of Commerce (1987). This early mortality most likely is due to recreational fishing effort, though as Figure 5 indicates, the commercial fishery using 3.5-inch stretch mesh gill nets does capture fish in the length range vulnerable to sport gear. It is not possible with the data at hand to separate the effects of the recreational and commercial fisheries within this length

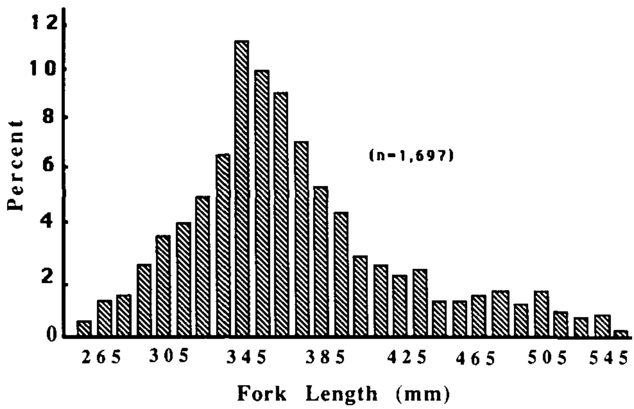

Figure 4. Length-frequency distribution of Spanish mackerel harvested by the marine recreational fishery in Alabama in 1986.

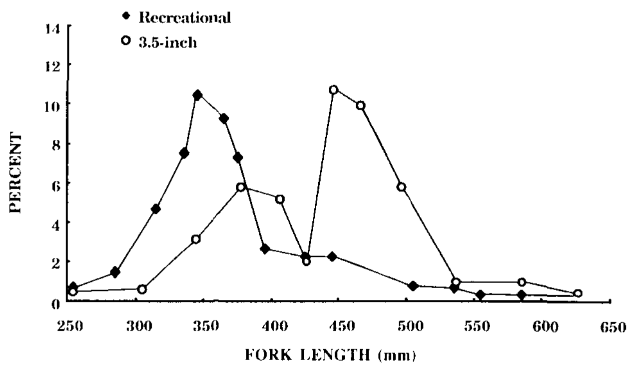

Figure 5. Catch curves for Spanish mackerel from sport and commercial fisheries. Commercial curve shows size selection for 3.5-inch stretch mesh gill nets.

range. It is apparent from Figure 5, however, that for the most part, the commercial gill net fishery captures Spanish mackerel >400 mm, after recreational fishing catches the smaller mackerel (<400 mm).

Amelioration of the high fishing mortality of Spanish mackerel <400 mm can be achieved only by regulation of the fisheries. The most expedient approach on the commercial side would be mesh size regulation of gill nets, though as pointed out above, the preponderance of fish caught by commercial gear in Alabama are >400 mm. The most expedient approach on the recreational side would be a length limit. Recently (August 1986), a 350-mm (14-inch) minimum length limit was placed on Spanish mackerel in Alabama. This limit should increase the number of fish recruited into the recreational fishery as a large portion (40%) of the fish harvested before the advent of the regulation were <350 mm in length (Fig. 4). Whether the additional recruits will affect the pattern of mortality between 350 and 400 mm remains to be seen. If not, an increase in the minimum length limit (possibly to 400 mm) would increase the age of first entry into the fishery and help to ensure that a larger proportion of those fish recruited have the opportunity to spawn at least once.

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