Aspects of King Mackerel Population Biology and Their Effect on Fishery Management strategies

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King mackerel (Scomberomorus cavalla) are an important fishery resource in the southeastern United States (Browder et al., 1981). They are exploited throughout the Gulf of Mexico and Caribbean as well. Recent assessment studies on king mackerel off the southeastern United States (Powers and Eldridge 1983a; b) have assimilated the available biological information relevant to assessing the status of these king mackerel stocks. In addition, fishery and management implications were derived from these results.

Assessing the status of a fishery resource requires an evaluation of how much of the resource is available for a fishery and in what form (for example, what fish sizes are available). This information is needed not just for management of a mature fishery, but for guiding the development of a new fishery, as well. In many instances, fishery data required to make these evaluations are lacking. However, a great deal of qualitative advice may be derived from knowledge of the biological characteristics of the resource. Knowing these characteristics, one can infer the effect that they will have on a fishery's development and the effect of various management strategies on the resource.

In this paper we examine the results of the recent assessment studies on king mackerel in the United States, as well as the associated biological information. In the context of this knowledge of the biological characteristics of king mackerel, we make inferences as to their likely effects on king mackerel fisheries and fishery management in the Gulf of Mexico and Caribbean region.

BIOLOGICAL CHARACTERISTICS

The biological characteristics of king mackerel stocks, indeed of any fish stock, determine the population dynamics of the resource being exploited. These characteristics are classified here as growth, mortality, movement (or migration) and recruitment.

Growth.--Several growth rates have been published for king mackerel with considerable differences in the resulting von Bertalanffy growth parameters. The best documented growth analyses were those of Beaumariage (1973), Nomura and Rodrigues (1967), Ximenes et al. (1978) and Johnson et al. (1983). The characteristics of these analyses are summarized below.

Beaumariage only used samples of smaller fish from Florida and cautioned readers about extrapolating results to older fish. Ximenes et al. used only Brazilian fish. Nomura and Rodrigues' study was also on Brazilian fish, but they estimated sizes for ages one to three from the relationship between otolith radius and fork length without taking measurements of otoliths in this age group to confirm the relationship. Also, it is unclear how the otolith annuli were read.

Johnson et al. (1983) had larger sample sizes distributed over the sizes of fish from the geographical area of the southeastern United States. In addition, their otolith-fork-length relationship was quite good, as was the relationship between sectioned and surface readings of otoliths (R^2 = 0.93, n = 123).

Powers and Eldridge (1983b) singled out the Johnson et al. (1983) growth rates for use in their assessment analyses. The choice was made using two criteria: (1) that the samples were more representative of the sizes and geographical areas of the king mackerel being assessed in that study and (2) on the demonstrated superiority of the Johnson et al. statistical fitting procedures. The choice did not imply agreement with any particular hypothesis of age at first annulus.

The Johnson et al. (1983) growth studies resulted in characteristic growth curves of male and female king mackerel. Specifically, the von Bertalanffy growth rate parameters were similar (K = 0.28 for males, K = 0.29 for females), indicating that these fish approach their average asymptotic length (L) at a relatively slow rate. However, females grow to a larger size (L = 1067 mm fork length for females, 965 for males). Additionally, the size at age zero is larger for males than females. Thus, king mackerel appear to be relatively slow-growing fish with sex differential growth curves; the larger fish being dominately females.

Mortality.--Estimates of the instantaneous natural mortality rate (M) of king mackerel were made using several methods (Powers and Eldridge, 1983b). The results indicated that values of M for males range from 0.3 to 0.6, whereas values for females range from 0.2 to 0.5. However, it is unlikely that M is above 0.45 or below 0.3.

Powers and Eldridge (1983a) also estimated the total mortality rate (Z) from 1975-79 tagging data from Williams and Godcharles (1982). These estimates were made using Heincke's method without including first year returns. This was done to adjust for differing availabilities. Information was not available to adjust for tag shedding, under-reporting or fishing effort; however, the data did provide some useful information relative to magnitudes and regional differences in the fishing mortality rates.

The estimates of Z varied considerably between the east and west coasts of Florida over the time period 1975-79. The total mortality rates for the west coast of Florida were higher than those of the east coast, which is consistent with the history of high catches on the Gulf of Mexico side of Florida. The summer fishery along the Florida east coast had a much lower mortality rate (Z=0.5); whereas, the winter Florida east coast and Florida

Keys-west coast fisheries were high (Z=1.1). This implies that the fishing mortality rates (F's) were F=0.1 and 0.7 for the respective areas (assuming M=0.4). Recent expansions of the fishery since 1979, especially in the Atlantic, would indicate the likelihood that the Atlantic F value may presently be higher.

These analyses indicate that king mackerel can be susceptible to relatively large fishing mortalities and total mortalities. In addition, the fishing mortality rates appear to differ between geographical areas. This implies that there may be differential impacts of fishing on king mackerel resources within the southeastern region of the United States.

Migration and Movement.--King mackerel fisheries are characteristically seasonal, indicating some migration pattern of the population. However, in recent years in the U.S., commercial catches have occurred throughout the year (Powers and Eldridge, 1983a). From a stock assessment and management perspective the migration studies are needed to determine: (1) where and when the fish move, (2) the extent of interbreeding within the range of the population and (3) the degree with which a fishery can distinguish the origin of the fish prior to their capture.

The source of data providing information on movement was the tagging of Williams and Godcharles (1982). They noted that 80% of the returns of fish tagged in southeastern Florida from December to March were recovered in the same winter fishery. Over half of these were recovered in the same time and after one full year of freedom. Similarly, about 72% of fish tagged in summer were recovered in the area where tagged. Of the tags returned in southeastern Florida, which did not originate in this area, approximately eight times as many originated in the Gulf of Mexico as compared to the southeast coast of the United States (Williams and Godcharles, 1982).

Williams and Godcharles (1982) also hypothesized the existence of two separate stocks: a Gulf stock and an Atlantic stock. They also suggest a zone of mixing in southeastern Florida. They did not rule out the possibility that this zone of mixing may include fish that are resident year-round.

Powers and Eldridge (1983a) examined this question quantitatively. Their results show that the probability of a surviving fish moving between the Gulf of Mexico to North Carolina is small. The probability is approximately 3% that a fish will either move from North Carolina to the Gulf or vice versa within 8 years. Given that mortality does occur, then the realized probability is much smaller. Similarly, the probability of a North Carolina fish moving to the southeastern Florida winter fishery in 8 years was approximately 5%. Thus, an individual fish is unlikely to move between North Carolina and the Gulf. This was also a conclusion of Williams and Godcharles (1982). Since annual mixing rates between areas (particularly the extremes of the range) appear to be low relative to the productivity of king mackerel, differential fishing mortality rates may locally reduce the resource. For these reasons, Powers and Eldridge (1983b) suggested that two migratory groups be considered for management: (1) Gulf Migratory Group - includes all fish landed in the Gulf of Mexico including Monroe County, Florida. This group also includes all fish landed on the east coast of Florida from November 1 to April 30. (2) Atlantic Migratory Group - includes all fish landed in North Carolina, South Carolina and Georgia. This group also includes fish landed on the east coast of Florida from May 1 to October 31.

Note that the boundary between the groups shifts with the season (Figure 1A and 1B). Note also that small variation in the exact time/area boundary has little biological impact.

Recruitment.--Available king mackerel catch-per-unit-effort (CPUE) information showed large annual variations (Powers and Eldridge, 1983b), which may be interpreted as large variations in the recruitment. These levels of fluctuation in recruitment are typical of scombrid fishes. These same CPUE data showed a rather large decline since 1980. Commercial size frequency data (Williams and Godcharles, 1982) were consistent with the CPUE decline in that the modal size seemed to get larger after 1980. This was particularly true of the Gulf Migratory Group. An increase in modal size indicates a reduction in small fish entering the fishery, i.e., a reduction in recruitment. However, there were not demonstrable increases in modal size from the Atlantic fish (Williams and Godcharles, 1982).

These data suggest that a large year class (relative to subsequent ones) entered the commercial fishery in 1979-80. The passage of this year class through time and area has supported the high catches on the west coast of Florida in 1980-81 and high catches on the east coast in 1981-82. The diminishing importance of this year class may have resulted in declining catches on the west coast in 1981-82. At this point it is unclear from these data if the year class entering the commercial fishery in 1979-80 was a normal year class relative to previous ones or if it was abnormally good. However, recreational size frequency data of Trent et al. (1983) support the hypothesis of an abnormally strong year class.

In either case these results suggest that king mackerel recruitment is likely to be dynamic with large variations. In addition, there does appear to be a possibility that recruitment rates may differ between geographical areas in respose to fishing pressure.

FISHERY CHARACTERISTICS

King mackerel fisheries in the United States have developed in response to the biological characteristics of the resource. Typically, the fisheries are seasonal, switching to other resources when king mackerel are not available. Additionally, the fisheries have increased in some geographic regions and declined in others, presumably due to a combination of economic and biological factors.

Commercial Fishery.--The commercial king mackerel fishery in the United States includes both hook and line and gill net gears.

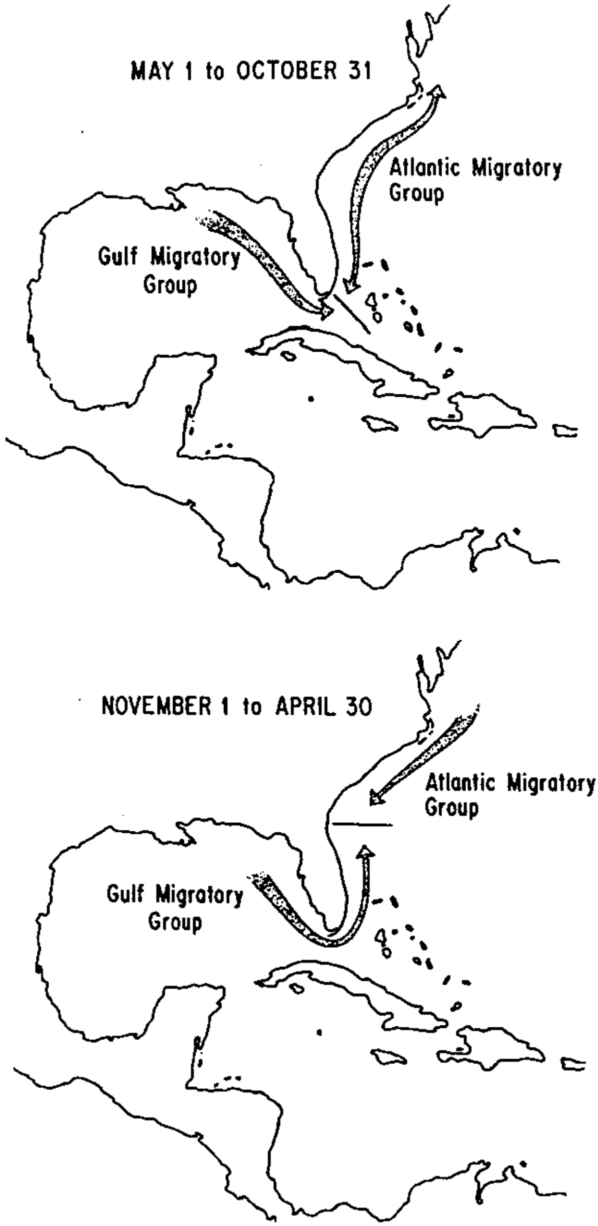

Figure 1. Range of Gulf and Atlantic Migratory Groups of king mackerel as determined from tagging data (Williams and Godcharles, 1982): A, Ranges during summer; B, Ranges during winter.

Additionally, there has been a small amount of experimentation with purse seines.

Traditionally, hook and line vessels have fished along the east coast of Florida and south in the Florida keys. Prior to approximately 1970, most fishing occurred during winter months in both the Keys and along the east coast. However, since the early 1970's, the hook and line fishery has become active year round on the east coast while remaining chiefly a winter fishery in the Keys.

The Florida king mackerel, large boat, gill-net fleet operated in the Florida Keys and along the Florida southwest during the 1960's and early 1970's. When catches declined substantially in southwest Florida in the mid-1970's, the large boat gill-net fleet expanded operations to include most of the Florida east coast.

The commercial fishery has expanded recently to North and South Carolina and to Louisiana. In 1982, approximately 1.5 million pounds of king mackerel were landed commercially in North and South Carolina. Of these, approximately one-third was taken by net and two-thirds by hook and line. Also, during the winter of 1982-83, over 1 million pounds of large king mackerel were taken commercially in Louisiana.

Recreational Fishery.--The king mackerel recreational fishery produces a very significant portion of the catch. Recent estimates (Powers and Eldridge, 1983b) indicate that the recreational catch is approximately three times the level of the commercial catch. This catch comes from a variety of sources including private boats, charter boats and party boats.

Recreational fisheries present many of the same fishery management problems as artisanal fisheries in developing regions. The U.S. recreational fishery for king mackerel is typical in this regard. Like artisanal fisheries, this recreational fishery is extremely diverse in the type of gears used, the size of fish at which fishing is being directed and the flexibility with which fish are being targeted. In addition, these fisheries exhibit imprecise catch estimates due to widely dispersed points of landing, and poorly defined indices of fishing effort due to the flexibility of the operation (e.g., part-time; full-time). The fishermen are diverse, so that establishing a sampling universe of fishermen is extremely difficult. Thus, the control of the fishery by management is severely hampered.

Both commercial and recreational king mackerel fisheries, then, tend to exhibit several general characteristics important to management. Typically, the fisheries will be seasonal and quite variable within a geographical region. Catches are expected to fluctuate from year to year in response to availability of the fish and to the dynamics of recruitment. Finally, the variety of gears being used in the fisheries contributes to real and perceived gear conflicts for the available resource.

YIELD AND STOCK ABUNDANCE

As mentioned previously, the dynamics of a fish stock and its fishery are defined by its biological and fishery characteristics. These characteristics, discussed above for king mackerel, were incorporated into the stock assessment analyses of Powers and Eldridge (1983a; b). These analyses allow us to make inferences about the likely dynamics of other king mackerel stocks in the Gulf of Mexico and Caribbean, the potential effects that they may impose on the fisheries and effective management strategies for control of those fisheries.

Yield-per-Recruit.--Yield-per-recruit analyses are used to determine if the average yield derived from each new recruit to the fishery may be improved by changing the size (age) at which they are susceptible to capture or by altering the rate oi fishing mortality. Thus, even without knowing what the level of recruitment is, an "optimal" strategy for taking the yield may be developed. The yield-per-recruit results using the Beverton-Holt equilibrium model are summarized in Figure 2. Note that these are based on the sex-differentiated growth models of Johnson et al. (1983), on estimates of the natural mortality rate (M) ranging from 0.3 to 0.4, and on an age of first capture of 1.5 years.

The yields-per-recruit for the Johnson et al. (1983) growth models were maximized at 1136 g and 1551 g for males and females, respectively (M=0.4) at F=1.2 and F=1.0 (Fig. 2) and an age of first capture of 1.5 years. However, these F and Z values, which produce maximum yield-per-recruit, are very high and would likely have an adverse effect on recruitment levels.

The king mackerel yield-per-recruit curves (Fig. 2) are characteristically "flat-topped" because of the relative values of the growth (K) and natural mortality rates (M). These curves will be similar to other king mackerel stocks if the K and M are not altered too much. It is unlikely that these parameters do differ greatly within the Gulf of Mexico and Caribbean region.

These analyses indicate that raising fishing mortality rates above moderate levels (F's greater than 0.3) will not increase yield-per-recruit very substantially. Therefore, the potential for obtaining increases in yield for a given level of recruitment tend to evaporate quickly as the fishery develops (F gets higher).

Surplus Production.--Using limited catch and effort data, Powers and Eldridge (1983b) developed surplus production models of the pooled Atlantic and Gulf Migratory Groups. These results are summarized in Figure 3. The surplus production analysis is designed to determine the equilibrium or average yield that may be expected to be extracted from the fishery for a given level of effort. However, for any given year the yield may vary considerably from this average. When there are large variations in recruitment as indicated previously for king mackerel, then the variation around the equilibrium curve will be large. This in turn adds to our uncertainty in the estimate of MSY (Fig. 3).

These data also indicated that the recent years have shown increases in effort (Powers and Eldridge, 1983b) with concurrent declines in yield, suggesting that yield and stock abundance could be increased by reducing the fishing mortality rate. In

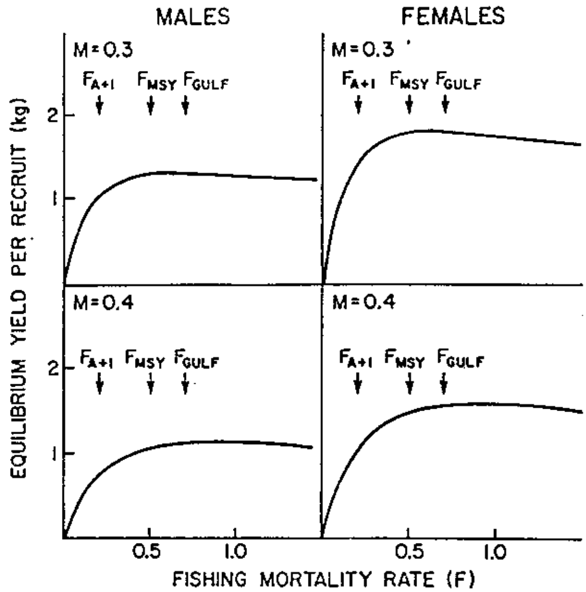

Figure 2. Equilibrium yield-per-recruit (kg) of king mackerel versus instantaneous rate of fishing mortality (F). Curves are given for two different alternative rates of natural mortality (M) and are differentiated by sex. Fatl and Fgulf are the present fishing mortality rates for the Atlantic and Gulf Migratory Groups, respectively. Fmsy is the estimated fishing mortality rate which produces maximum sustainable yield (MSY).

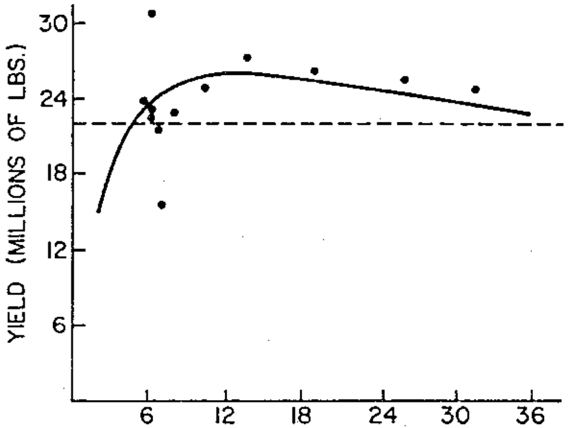

Figure 3. Equilibrium surplus production (yield in lb) of king mackerel on the Gulf of Mexico and Atlantic coasts of the U.S. versus standardized charter boat fishing effort. The maximum of this curve (MSY) occurs at approximately 26.2 million lb. The dashed lines represent the uncertainty in MSY, ranging from 22 to 32 million lb.

addition, these analyses show that the king mackerel have a low surplus production potential relative to shorter-lived organisms, such as anchovies and shrimp. Therefore, extraction of a large surplus yield will reduce the stock abundance disproportionately.

MANAGEMENT IMPLICATIONS

The above review indicates some key characteristics of king mackerel which are integral to any management or development strategy. A king mackerel resource will be migratory and, thus, the fishery will be seasonal. However, in a larger regional context (such as the Atlantic and Gulf of Mexico), the mixing between areas may be low. This may lead to differential fishing mortality rates and local depletion of the resource in a subarea.

Yield derived from a single recruit is not increased by raising the minimum age captures above 1 or 2 years. Gains in yield-per-recruit are quickly dissipated as the fishery develops, i.e., as fishing mortality rates reach moderate levels. Additionally, selection of larger fish in the catch may disproportionately impact females due to differential growth rates between males and females.

Variable year class strength in king mackerel stocks is expected. Thus, in a fishery with stable long-term average catches, annual catches may vary considerably. Therefore, if the fishery develops to the extent that the strong year classes are quickly removed by the fishery, then surplus yield may be depressed.

The fisheries on king mackerel will be quite diverse in the gear used and in the area and season fished. Yet, there likely will still be competition between gears. Because annual catch success will vary with year class strength, the fishermen will likely evolve some flexibility to target other fish if king mackerel are not available.

Management of king mackerel should allow for different regional strategies if the mixing rate between areas is low. The most biologically efficient strategy is to maintain an equal fishing mortality rate (or equal effective effort) between areas (Powers and Eldridge, 1983a). In the United States, if fishing mortality rate is to be equal to that at MSY, then this implies a reduction in fishing in the Gulf and an expansion in the Atlantic (Powers and Eldridge, 1983b).

Development or expansion of fishing should be done with the notion that subsequent controls may soon be needed because large increases in fishing mortality rate do not have much potential for increases in yield per recruit or surplus yield. An example would be to establish the mechanisms for control before the controls themselves are limiting to the fishery.

Reduction in fishing pressure (as has been suggested for Gulf of Mexico king mackerel) implies a reduction in catch. An obvious mechanism for this would be to allocate an annual quota. This has been done for the commercial king mackerel catches by gear in the United States (Powers and Eldridge, 1983a). Because of the temporal linkage between fisheries, it is likely that individual fisheries will be selectively impacted by an allocation plan unless the seasonality and migration data are encompassed in the plan. However, quota systems are only effective if the within-season catches can be monitored. This requires a limited number of landing sites and well-designed data collection procedures. Thus, it is expected that quota systems will only be effective for developed commercial fisheries.

Limiting the king mackerel catches of less structurally organized fisheries such as artisanal or recreatioal fisheries will likely require indirect control through bag limits and/or size limited. These mechanisms will still demand data collection and enforcement efforts. But the effectiveness of the management procedures does not have to be evaluated within the season. Therefore, the management costs should be less.

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