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# Yield-per-recruit analysis and management strategies for Atlantic croaker, *Micropogonias undulatus*, in the Middle Atlantic Bight*

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**Abstract.**–The effect of different fishing mortality ($F$) and natural mortality ($M$), and age at first capture ($t_c$) on yield-per-recruit of Atlantic croaker, *Micropogonias undulatus*, in the lower Chesapeake Bay and North Carolina were evaluated with the Beverton-Holt model. Independent of the level of $M$ (0.20–0.35) or $F$ (0.01–2.0) used in simulations, yield-per-recruit values for Chesapeake Bay were consistently higher at $t_c = 1$ and decreased continuously with increases in $t_c$ (2–5). Although maximum yield-per-recruit always occurred at the maximum level of $F$ ($F$=2.0), marginal increases in yield beyond $F$ = 0.50–0.75 were negligible. Current $F$ ($F_{CUR}$) is estimated to be below the level that produces maximum potential yield-per-recruit ($F_{MAX}$) and at or below the level of $F_{0.1}$ if $M \geq 0.25$. Although modeling results indicated yield-per-recruit could be maximized by reducing the current level of $t_c$ ($t_c$=2), the resultant gains were small and did not appear to justify such management measures. Instead, it is suggested that regulatory measures be directed at maintaining the current level of $t_c$ in the lower Chesapeake Bay. Simulation results for North Carolina showed a pattern opposite to that shown for Chesapeake Bay, with yield-per-recruit curves increasing consistently with increases in $t_c$. Estimates of $F_{CUR}$ for $t_c = 1$ were consistently higher than $F_{0.1}$ as well as $F_{MAX}$, indicating that during the period 1979–81 Atlantic croaker were being growth-overfished in North Carolina. However, differences between Chesapeake Bay and North Carolina seem to reflect temporal rather than spatial differences in Atlantic croaker population dynamics, because data for North Carolina came from a period coinciding with the occurrence of unusually large Atlantic croaker along the east coast of the United States.

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The Atlantic croaker, *Micropogonias undulatus* (Linnaeus), is one of the most important commercial and recreational fishery resources of the southeastern coast of the United States (Wilk, 1981; Schmied and Burgess, 1987; Mercer[1] ). Along the Atlantic coast, commercial fisheries for Atlantic croaker are centered in Chesapeake Bay and in North Carolina waters (Joseph, 1972; Rothschild et al., 1981; Ross, 1988; Mercer[1]); both inshore and offshore catches are distributed according to the seasonal migratory patterns of Atlantic croaker. From late spring to early fall Atlantic croaker are caught in estuarine areas, primarily by haul-seine, pound-net, and gill-net fisheries (Ross, 1988; Chittenden, 1991; Barbieri et al., 1994a). From late fall through winter, after adults have moved out of estuaries, they are caught in continental shelf waters by otter-trawl and gill-net fisheries (Wilk, 1981; Ross, 1988; Mercer[1]).

Commercial landings of Atlantic croaker have fluctuated widely over the past 50–60 years (Joseph, 1972; Rothschild et al., 1981; Wilk, 1981). Landings exceeded 20,000 metric tons (t) between 1937 and 1940, peaked at ca. 29,000 t in 1945 and dropped to less than 1,000 t between 1967 and 1971 (Wilk, 1981; McHugh and Conover, 1986). The most recent peak in landings occurred in 1977 and 1978 at just over 13,000 t annually (Mercer[1]). Recreational catches in the mid-Atlantic and South Atlantic regions during 1979–93 have also fluctuated, although they do not reflect fluctuations in commercial landings for the same period. Commercial landings from Virginia and North Carolina—the

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[1] Mercer, L. P. 1987. Fishery management plan for Atlantic croaker (*Micropogonias undulatus*). North Carolina Dep. Nat. Res. Comm. Dev., Div. Mar. Fish., Spec. Sci. Rep. 48, 90 p. [Available from North Carolina Department of Environment, Health, and Natural Resources, Div. Marine Fisheries, PO Box 769, Morehead City, NC 28557-0769.]

two states with 98% of the Atlantic catch—have declined since 1987, whereas recreational catches peaked in 1991 with an estimated 21 million fish (Newlin, 1992; Speir et al., 1994).

A lack of accurate catch and effort data from both the commercial and recreational fisheries makes it difficult to evaluate to what extent these long-term fluctuations represent natural changes in population abundance or reflect historic changes in Atlantic croaker exploitation. There has been a growing concern, however, that recent low landings may be related to the large numbers of young fish killed as bycatch in the southern shrimp fishery and as part of the scrap catch in pound-net, haul-seine, and trawl fisheries (Speir et al., 1994; Mercer[1]). In response to these concerns, the 1993 review of the Atlantic States Marine Fisheries Commission Fishery Management Plan for Atlantic croaker (Speir et al., 1994) has recommended the use of bycatch reduction devices and the establishment of a coast-wide minimum size limit that would maximize Atlantic croaker yield-per-recruit.

Yield-per-recruit models, widely used in fish population dynamics studies (Beverton and Holt, 1957; Ricker, 1975; Gulland, 1983), can be a useful tool in defining routine fisheries management measures such as minimum size limits, closed seasons, etc. (Gulland, 1983; Deriso, 1987). However, the only published application of yield-per-recruit models to Atlantic croaker is based on data from the northwestern Gulf of Mexico (Chittenden, 1977) and points out that results may or may not apply to other areas. In this paper we use stock assessment data from the Chesapeake Bay (years 1988–91; Barbieri et al., 1994a) and from North Carolina (years 1979–81; Ross, 1988) to evaluate the effect of different fishing (-induced) and natural mortality, and age-at-first-capture schedules on Atlantic croaker yield-per-recruit. Implications of this analysis for management of Atlantic croaker are discussed.

## Methods

### Yield-per-recruit analysis

Yield-per-recruit curves were calculated with the Beverton-Holt yield-per-recruit model (Beverton and Holt, 1957):

$$Y/R = Fe^{-M(t_c - t_r)} W_\infty \sum_{n=0}^{3} \frac{U_n e^{-nK(t_c - t_0)}}{F + M + nK}, \qquad (1)$$

where $Y/R$ = yield-per-recruit in weight (g);
$F$ = instantaneous fishing mortality coefficient;
$M$ = instantaneous natural mortality coefficient;
$W_\infty$ = asymptotic weight (von Bertalanffy growth parameter);
$U_n$ = summation parameter ($U_0$=1, $U_1$=–3, $U_2$=3, $U_3$=–1);
$t_c$ = mean age at first capture;
$t_r$ = mean age (years) at recruitment to the fishing area;
$t_0$ = hypothetical age at which fish would have been zero length (von Bertalanffy growth parameter); and
$K$ = the Brody growth coefficient (von Bertalanffy growth parameter).

Computations were performed with the computer program B-H3 available in the Basic Fisheries Science Programs package (Saila et al., 1988).

Parameter values used in simulations are summarized in Table 1. Estimates of growth parameters ($W_\infty$, $K$, and $t_0$) for Chesapeake Bay and North Carolina were obtained from Barbieri et al. (1994a) and Ross (1988), respectively. For both areas, $W_\infty$ was converted from $L_\infty$ by using an allometric length-weight relation ($b$=3.23; Ross, 1988; and $b$=3.30; Barbieri et al, 1994a). One of the assumptions of the Beverton-Holt yield-per-recruit model is that growth is isometric—i.e. the coefficient $b$ in the length-weight relation is equal to 3 (Beverton and Holt, 1957; Ricker, 1975). We, however, considered that departure from the assumption of isometric growth did not affect interpretation of our modeling results because the factor of interest in these simulations is the relative difference in yield resulting from varying $t_c$ and $F$ at different levels of $M$. The relative error in such differences, when using an incorrect $b$, tends to be much less than that in absolute levels (Ricker, 1975).

Estimates of $t_r$, the mean age at recruitment to the fishing area, were based on Atlantic croaker life history information (Chao and Musick, 1977; Ross, 1988). Estimates of current $t_c$, the mean age at first capture, was based on Atlantic croaker age compositions reported for the pound-net, haul-seine, and gill-net catches in the lower Chesapeake Bay for the period 1988–91 ($t_c$=age 2; Barbieri et al., 1994a) and from age compositions reported for the haul-seine fishery in North Carolina for the period 1979–81 ($t_c$=age 1; Ross, 1988). Because of the uncertainty associated with estimates of $M$ in fish populations (Vetter, 1988), simulations for both areas were conducted over a range of $M$ values (0.20–0.35; Table 1).

The instantaneous total annual mortality rate, $Z$, for fully recruited Atlantic croaker in North Carolina is 1.3 (Ross, 1988) and ranges from 0.55 to 0.63, with a mean value of 0.59 for the lower Chesapeake

**Table 1**

Parameter estimates or range of values used in yield-per-recruit simulations for Atlantic croaker, *Micropogonias undulatus*, in the lower Chesapeake Bay (period 1988–91) and North Carolina (period 1979–81). See Equation 1 for definitions of parameter variables.

| Parameter | Chesapeake Bay | North Carolina |
|---|---|---|
| $K$ | 0.36 | 0.20 |
| $W_\infty$ | 409.9 g | 3,814 g |
| $t_0$ | –3.26 yr | –0.60 yr |
| $t_r$ | 0 yr | 0 yr |
| $t_c$ | 1–5 yr | 1–5 yr |
| $F$ | 0.01–2.0 | 0.01–2.0 |
| $M$ | 0.20–0.35 | 0.20–0.35 |

Bay (Barbieri et al., 1994a). To estimate current levels of fishing mortality ($F_{CUR}$) for different values of $M$, we used $Z = 0.60$ for Chesapeake Bay and $Z = 1.3$ for North Carolina, as

$$F_{CUR} = Z - M_i \, , \tag{2}$$

where $i$ = 0.20, 0.25, 0.30, and 0.35.

The value of $F_{0.1}$ (the level of $F$ for which the marginal increase in yield-per-recruit due to a small increase in $F$ is 10% of the marginal yield-per-recruit in a lightly-exploited fishery [Gulland and Boerema, 1973; Anthony[2]]), was estimated for Chesapeake Bay with $F = 0.01$ and $t_c = 2$ (Barbieri et al., 1994a) and for North Carolina with $F = 0.01$ and $t_c = 1$ (Ross, 1988).

### Cohort biomass and harvesting time

In general, the maximum possible yield for a given year class occurs at the critical age $t_{CRITIC}$, the age where biomass of a cohort is maximum in the absence of fishing. For comparison with the Beverton-Holt yield-per-recruit modeling results, we estimated $t_{CRITIC}$ for Atlantic croaker following Alverson and Carney (1975) and Deriso (1987) as

$$t_{CRITIC} = t_0 + \frac{1}{K}\ln(3K/M + 1), \tag{3}$$

where $t_0$, $K$, and $M$ are defined as in Equation 1. Parameter estimates or the range of values used in calculations are listed in Table 1.

[2] Anthony, V. 1982. The calculation of $F_{0.1}$: a plea for standardization. Northwest Atlantic Fisheries Organization, SCR Doc. 82/VI/64 Ser. No. N557, 15 p. NAFO, PO Box 638, Dartmouth, Nova Scotia, Canada B2Y 3Y9.

To evaluate the proportion of the potential growth span ($P_g$) remaining when Atlantic croaker enter the exploited phase of life (Beverton and Holt, 1957), we used the quantity (Beverton, 1963):

$$P_g = (1 - l_c / L_\infty), \tag{4}$$

where $L_\infty$, the asymptotic length, was obtained from Barbieri et al. (1994a) and Ross (1988) and $l_c$, the average length at first capture, was obtained by converting $t_c$ to length with the von Bertalanffy growth curve reported for Atlantic croaker in Chesapeake Bay (Barbieri et al., 1994a) and North Carolina (Ross, 1988). Both parameters are based on total length (TL) in mm.

## Results

### Chesapeake Bay

Curves of yield-per-recruit on $F$ (Fig. 1) showed that the yield of Atlantic croaker in Chesapeake Bay could be maximized by decreasing the current level of $t_c = 2$ (265 mm TL) to $t_c = 1$ (245 mm TL). Independent of the level of $M$ or $F$ used in simulations, yield-per-recruit values were consistently higher at $t_c = 1$ and decreased continuously with increasing $t_c$. However, increases in yield from $t_c = 2$ to $t_c = 1$ were generally small and gradually increased with increases in $M$. For example, at the estimated current levels of fishing mortality for Atlantic croaker in the Chesapeake Bay ($F_{CUR}$), increases in yield between $t_c = 2$ and $t_c = 1$ would be 7.1% at $M = 2.0$, 12.6% at $M = 0.25$, 18.4% at $M = 0.30$, and 24.6% at $M = 0.35$.

The curves of yield-per-recruit for Atlantic croaker on $F$ for different levels of $M$ and $t_c$ showed no clearly defined peaks. Although the magnitude of yield curves was dependent on the level of $M$ used in simulations, relative changes in yield as a function of $F$ and $t_c$ were very similar, regardless of $M$ (Fig. 1). For all levels of $M$ and $t_c$, yield curves increased rapidly in the range of $F$ between 0 and 0.50–0.75, and remained relatively flat thereafter. Although yield values increased continuously with $F$, i.e. maximum yield-per-recruit always occurred at the maximum value of $F$ used in simulations ($F$=2.0), increases in yield beyond $F = 0.50$–$0.75$ were very small. For example, increases in yield from $F = 0.75$ to $F_{MAX}$ ranged from 5.3% to 22.7%, depending on the level of $M$ and $t_c$ used in the model (Table 2). However, this relatively small gain in yield corresponds to an increase in $F$ of 166.7%.

For the range of $M$ used in our study, estimates of $F_{CUR}$ are below the levels that give maximum potential yield-per-recruit ($F_{MAX}$) and, for $M \geq 0.3$, below

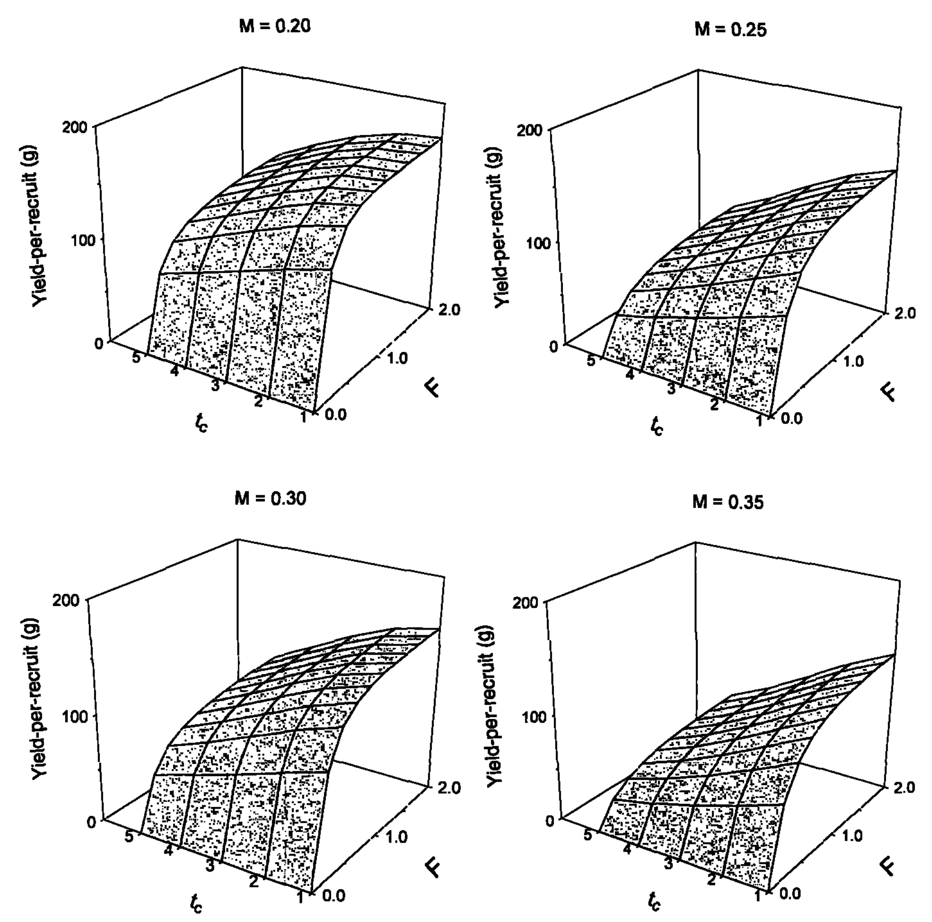


**Figure 1**

Curves of yield-per-recruit on fishing mortality (*F*) for Atlantic croaker, *Micropogonias undulatus*, in the lower Chesapeake Bay (period 1988–91) estimated for mean age-at-first-capture ($t_c$) = 1–5 and natural mortality (*M*) = 0.20–0.35.

**Table 2**

Percent increase in yield-per-recruit of Atlantic croaker, *Micropogonias undulatus*, from fishing mortality (*F*) = 0.75 to fishing mortality at the level that gives maximum potential yield-per-recruit ($F_{MAX}$) for mean age-at-first-capture ($t_c$) = 1–5 and natural mortality (*M*) = 0.20–0.35 for Chesapeake Bay.

| | | Yield-per-recruit (g) | | | | | Yield-per-recruit (g) | | |
|---|---|---|---|---|---|---|---|---|---|
| *M* | $t_c$ | *F* = 0.75 | $F_{MAX}$ | % increase | *M* | $t_c$ | *F* = 0.75 | $F_{MAX}$ | % increase |
| 0.20 | 1 | 160.4 | 168.9 | 5.3 | 0.30 | 1 | 129.2 | 142.5 | 10.3 |
| | 2 | 153.9 | 165.1 | 7.3 | | 2 | 112.8 | 128.9 | 14.3 |
| | 3 | 140.3 | 154.1 | 9.8 | | 3 | 93.4 | 109.0 | 16.7 |
| | 4 | 123.5 | 137.8 | 11.6 | | 4 | 74.6 | 88.2 | 18.2 |
| | 5 | 106.3 | 119.8 | 12.7 | | 5 | 58.2 | 69.4 | 19.2 |
| 0.25 | 1 | 143.7 | 153.5 | 6.8 | 0.35 | 1 | 116.5 | 132.4 | 13.6 |
| | 2 | 131.6 | 145.8 | 10.8 | | 2 | 97.0 | 114.0 | 17.5 |
| | 3 | 114.3 | 129.5 | 13.3 | | 3 | 76.5 | 91.7 | 19.9 |
| | 4 | 95.8 | 110.3 | 15.1 | | 4 | 58.1 | 70.7 | 21.7 |
| | 5 | 78.5 | 91.2 | 16.2 | | 5 | 43.1 | 52.9 | 22.7 |

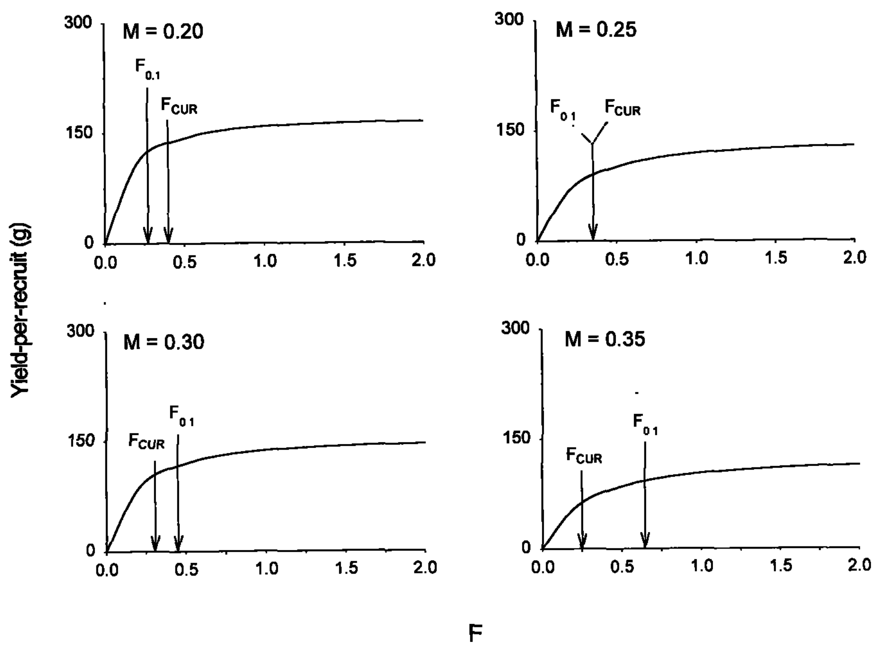


**Figure 2**

Curves of yield-per-recruit on fishing mortality (*F*) for Atlantic croaker, *Micropogonias undulatus*, in the lower Chesapeake Bay (period 1988–91) estimated for mean age-at-first-capture ($t_c$) = 2 and natural mortality ($M$) = 0.20–0.35. $F_{0.1}$ = the level of $F$ at which the marginal increase in yield-per-recruit due to a small increase in $F$ is 10% of the marginal yield-per-recruit in a lightly exploited fishery; $F_{CUR}$ = the estimated current levels of fishing mortality.

the level of $F_{0.1}$ (Fig. 2; Table 3). For $M$ = 0.20, $F_{CUR}$ is higher than $F_{0.1}$, indicating that, although it produces slightly higher yield values, current fishing mortality is not at its most economically efficient level. For example, for $t_c$ = 1 and $t_c$ = 2, over 90% of the yield obtained at $F_{CUR}$ can be achieved by lowering fishing mortality to the level of $F_{0.1}$. For $M$ = 0.25, both $F_{CUR}$ and $F_{0.1}$ equal 0.35, indicating that, although below the maximum potential yield-per-recruit, estimated current levels of harvest probably correspond to the most efficient level of $F$. In contrast, if $M$ ranges from 0.30 to 0.35, $F_{0.1}$ is higher than $F_{CUR}$ (Table 3), suggesting there would still be room to increase yield efficiently with increases in $F$. However, at these higher levels of $M$, increases in $F$ necessary to achieve the yields at $F_{0.1}$ may be unrealistically high (Table 3).

Values of $t_{CRITIC}$ estimated with different values of $M$ were relatively low for Atlantic croaker in Chesapeake Bay. For $M$ equal to 0.20, 0.25, 0.30, and 0.35, values of $t_{CRITIC}$ were 1.9, 1.4, 1.0, and 0.6 years, respectively. These values indicate that, for the range of $M$ considered herein, maximum theoretical cohort biomass in the absence of fishing would be achieved before Atlantic croaker reach age 2 (years).

**Table 3**

Estimated value of current levels of fishing mortality ($F_{CUR}$) and level of fishing mortality at which the marginal increase in yield-per-recruit due to a small increase in $F$ is 10% of the marginal yield-per-recruit in a lightly exploited fishery ($F_{0.1}$) for Atlantic croaker, *Micropogonias undulatus*, in the Chesapeake Bay region for a range of fishing mortality ($M$) = 0.20–0.35, and the percent increase or decrease in $F_{CUR}$ necessary to make it equal to $F_{0.1}$.

| $M$ | $F_{CUR}$ | $F_{0.1}$ | % Difference |
|---|---|---|---|
| 0.20 | 0.40 | 0.27 | –48 |
| 0.25 | 0.35 | 0.35 | 0 |
| 0.30 | 0.30 | 0.45 | +50 |
| 0.35 | 0.25 | 0.64 | +156 |

Estimated values of $P_g$ for Atlantic croaker in Chesapeake Bay were also relatively low. For $L_\infty$ = 312 mm, and the current estimated level of $l_c$ (265 mm, corresponding to $t_c$=2), $P_g$ = 0.15, i.e., on the average, only 15% of their potential growth still remains when Atlantic croaker in Chesapeake Bay enter the exploited phase at age 2. For alternative values of $t_c$

equal to 1, 3, 4 and 5 years, values of $P_g$ are 0.21, 0.10, 0.07, and 0.05, respectively.

## North Carolina

Curves of yield-per-recruit on $F$ for Atlantic croaker in North Carolina (Fig. 3) showed an opposite trend from that shown in Chesapeake Bay. For all levels of $F$ or $M$ used in simulations, yield values continuously increased from $t_c$ = 1 (177 mm TL) to $t_c$ = 5 (434 mm TL), indicating that yield could be maximized by increasing $t_c$. However, the shape of yield-per-recruit curves differed among different levels of $M$ and $t_c$ (Fig. 3). For $M$ = 0.20 and 0.25, curves for $t_c$ = 1–3 peaked at low to intermediate levels of $F$ ($F_{MAX}$ = 0.20–0.60) and gradually decreased after that, whereas for $t_c$ = 4–5 they increased rapidly in the range of $F$ between 0 and 0.35–0.60 and remained relatively flat thereafter. For $M$ = 0.30–0.35, the peaks in yield at low to intermediate levels of $F$ occurred only for $t_c$ = 1–2 and were a lot less pronounced than those at lower levels of $M$.

For the range of $M$ used in our simulations, estimates of $F_{CUR}$ (Fig. 4) indicated that during the period 1979–81 the level of fishing mortality for Atlantic croaker in North Carolina was well above the levels of $F_{0.1}$ and $F_{MAX}$. At $t_c$ = 1, estimated losses in potential yield-per-recruit from $F_{MAX}$ to $F_{CUR}$ were equal to 45%, 35%, 25%, and 4% for $M$ = 0.20, 0.25, 0.30, and 0.35, respectively. Estimated losses if fishing mortality were kept at the level of $F_{0.1}$ would be 44%, 22%, 20%, and 14%, respectively.

Estimated values of $t_{CRITIC}$ and $P_g$ for Atlantic croaker in North Carolina were much higher than those estimated for Chesapeake Bay. For $M$ equal to 0.20, 0.25, 0.30, and 0.35, values of $t_{CRITIC}$ were 7.5,

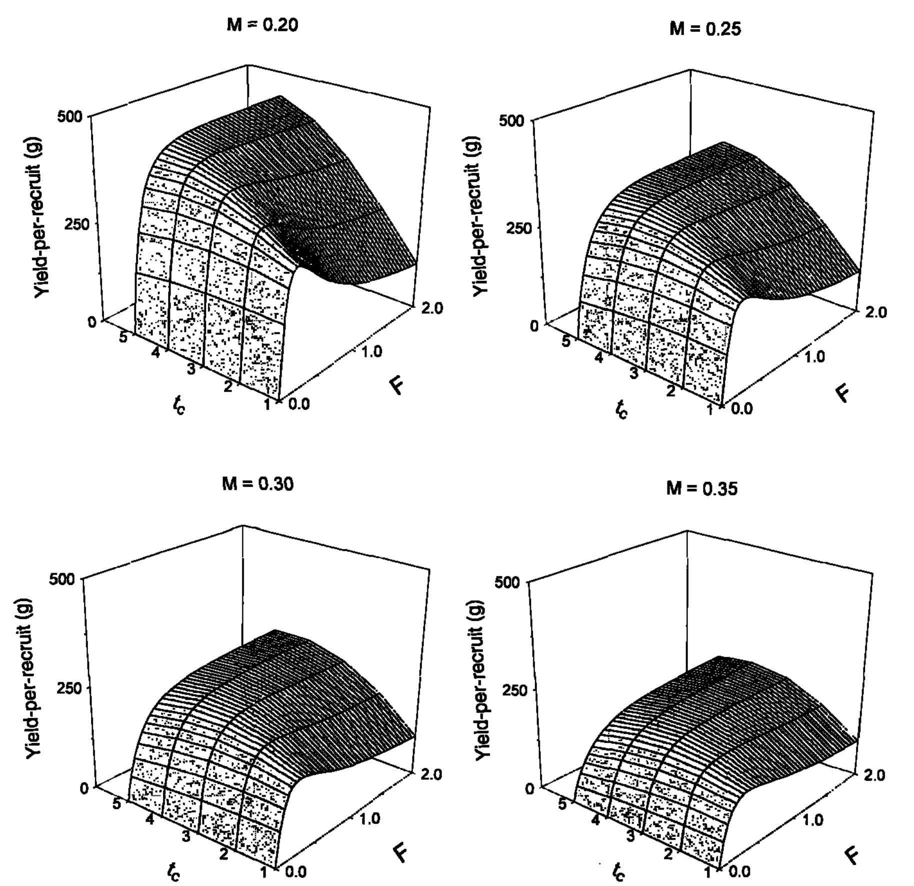


**Figure 3**

Curves of yield-per-recruit on fishing mortality ($F$) for Atlantic croaker, *Micropogonias undulatus*, in North Carolina (period 1979–81) estimated for mean age-at-first-capture ($t_c$) = 1–5 and natural mortality ($M$) = 0.20–0.35.

6.7, 6.1, and 5.6 years, respectively. For $L_\infty$ = 645 mm and the estimated level of $l_c$ for the period 1979–81 (177 mm, corresponding to $t_c$=1), $P_g$ = 0.72, i.e., on the average, 72% of their potential growth still remained when Atlantic croaker in North Carolina entered the exploited phase at age 1 during the period 1979–81. For alternative values of $t_c$ = 2–5 years, values of $P_g$ were 0.59, 0.49, 0.39, and 0.33, respectively.

## Discussion

Our modeling results indicate that, for the range of $M$ and $F$ used in simulations, yield-per-recruit of Atlantic croaker in the lower Chesapeake Bay could be maximized by a management strategy that incorporates early age at first capture ($t_c$=1) and high rates of fishing mortality ($F$=2.0). However, the analysis for Chesapeake Bay also showed this is probably not the most efficient management option for this species. Because of the essentially asymptotic relation between yield-per-recruit and $F$, harvesting Atlantic croaker at or near their maximum potential yield (i.e. at $F_{MAX}$) would require a disproportionate increase in fishing mortality making it an economically inefficient management option. In addition, given the multispecies nature of the main fisheries for Atlantic croaker in Chesapeake Bay (Austin, 1987; Chittenden, 1991), raising current levels of $F$ would greatly increase overall rates of exploitation and probably interfere with management of other species such as weakfish, *Cynoscion regalis*, and spot, *Leiostomus xanthurus*.

Decreasing the current level of $t_c$ for Atlantic croaker in Chesapeake Bay would not be recommended for two reasons. First, for the range of $M$ used in simulations, gains in yield-per-recruit from $t_c$ = 2 to $t_c$ = 1 were relatively small at $F_{CUR}$. Second, because of the magnitude of the scrap catch of Atlantic croaker in Chesapeake Bay (Mercer[1]), it is likely that this species is already entering the exploited phase at age 1 or younger. The current estimate of $t_c$ ($t_c$=2; Barbieri et al., 1994a) may be an overestimate because it was based on arbitrarily defined commercial market grades instead of overall catches—including the scrap. Because the market accepts only fish above a certain size, a reduction in mesh sizes to attempt to increase the proportion of age-1 Atlantic croaker in the catches would probably only increase the number of fish sold as scrap and have little or no effect on commercial market grades.

Nevertheless, the analysis showed no indication that fully recruited Atlantic croaker in Chesapeake Bay are being growth-overfished (i.e. that the fish were being caught before they had a chance to grow to their ideal size). Yield-per-recruit modeling results and estimated values of $F_{CUR}$ indicated that, over a likely range of $M$, current levels of harvest are below the levels at $F_{MAX}$ and, under most scenarios, at or below the levels at $F_{0.1}$. In addition, yield-per-recruit curves showed no signs of decrease at higher levels of $F$, even if $M$ is as low as 0.20. This pattern suggests that stocks of Atlantic croaker in the Chesapeake Bay region show the same great biologi-

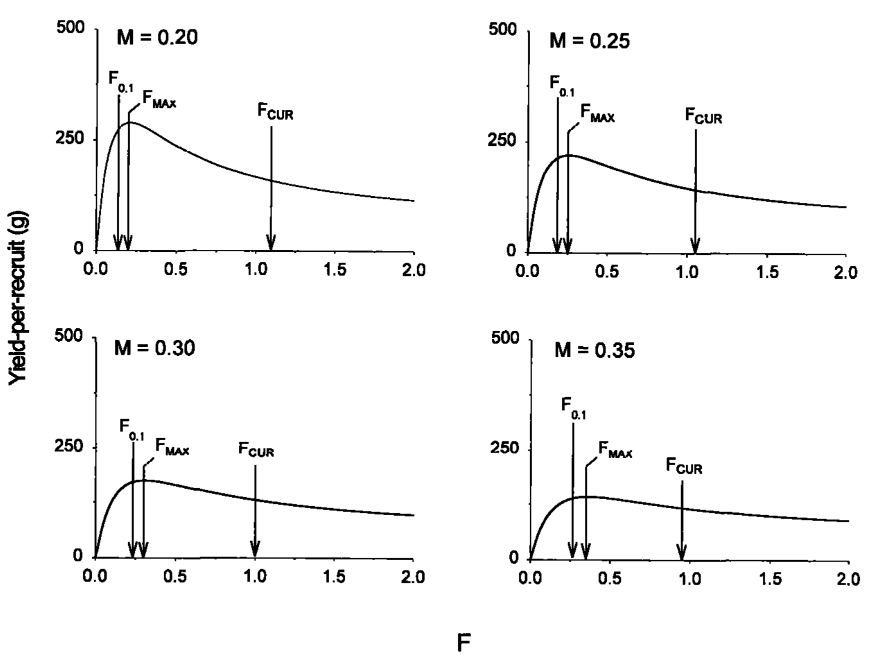


**Figure 4**

Curves of yield-per-recruit on fishing mortality ($F$) for Atlantic croaker, *Micropogonias undulatus*, in North Carolina (period 1979–81) estimated for mean age-at-first-capture ($t_c$) = 1 and natural mortality ($M$) = 0.20–0.35. $F_{0.1}$ = the level of $F$ at which the marginal increase in yield-per-recruit due to a small increase in $F$ is 10% of the marginal yield-per-recruit in a lightly exploited fishery; $F_{CUR}$ = the estimated current levels of fishing mortality.

cal capacity to resist growth overfishing as those stocks in the northwestern Gulf of Mexico (Chittenden, 1977). The low values of $t_{CRITIC}$ and $P_g$ agree with yield-per-recruit modeling results and indicate that 1) for a reported maximum longevity of 8 years in Chesapeake Bay (Barbieri et al., 1994a), maximum theoretical biomass is achieved very early in life, before fish reach age 2; and 2) very little potential for a growth span still remains when fish enter the exploited phase at age 2. As a precaution against future problems—especially considering that annual recruitment is reported to be highly variable and strongly density independent—we suggest that regulatory measures for Atlantic croaker in the lower Chesapeake Bay be directed at maintaining the apparent current level of $t_c$ (age 2; $l_c$=265 mm TL; Barbieri et al., 1994a). In addition, the magnitude and composition of the scrap catch for the main fisheries in this area need to be estimated, and their effect on estimates of $F_{CUR}$ and $t_c$ need to be assessed more precisely before any definite conclusion on Atlantic croaker yield-per-recruit can be reached.

In contrast to what we found for the lower Chesapeake Bay, results for North Carolina indicated that Atlantic croaker were being severely growth-overfished. First, independent of the level of $F$ or $M$ used in simulations, yield-per-recruit values were consistently higher at higher levels of $t_c$, indicating that age and size limits during the period 1979–81 ($t_c$=1, $l_c$=177 mm TL; Ross, 1988) were unrealistically low. Second, estimates of $F_{CUR}$ for $t_c$ = 1 were not just consistently higher than $F_{0.1}$ but were also well above $F_{MAX}$. The pattern of declining yield-per-recruit values with increasing $F$ at lower levels of $t_c$ agrees well with the high estimates of $t_{CRITIC}$ and $P_g$ and indicates that, contrary to the pattern shown in Chesapeake Bay, maximum cohort biomass is attained later in life (ages 5–7).

However, differences in yield-per-recruit modeling results between Chesapeake Bay and North Carolina seem to reflect temporal rather than spatial differences in Atlantic croaker population dynamics. Parameters used in simulations for North Carolina were obtained from a study (Ross, 1988) conducted during a period (1979–81) that coincides with the occurrence of unusually large Atlantic croaker (350–520 mm TL; Ross, 1988) along the east coast of the United States (Barbieri et al., 1994a). However, since 1982, Atlantic croaker catches in North Carolina have been dominated by smaller fish. Modal lengths of Atlantic croaker in the long haul-seine fishery during 1982-92 ranged from 215 to 245 mm TL; in the winter trawl fishery, they ranged from 215 to 240 mm TL. In both fisheries, less than 10% of the fish were older than age 3 (Wilson, 1993). Therefore, yield-per-recruit modeling results presented here for North Carolina should not reflect current conditions, but rather be considered representative of temporal changes in Atlantic croaker population dynamics.

The specific value of $M$ used in our simulations had no effect on the levels of $F$ or $t_c$ that produce maximum yield-per-recruit values and would not change conclusions for either Chesapeake Bay or North Carolina. However, these conclusions are still critically dependent on how realistic is the range of $M$ used in these simulations. Methods currently used to estimate $M$ have strong limitations and disadvantages (Vetter, 1988), and the method used here is no exception. However, we feel comfortable with the range of $M$ used in this study because it agrees with values of $M$ reported for other sciaenids with similar life spans, e.g. spotted seatrout, *Cynoscion nebulosus* (Rutherford et al., 1989).

Yield-per-recruit analysis is only part of a fishery management strategy (Beverton and Holt, 1957; Gulland, 1983; Deriso, 1987). It must be applied in conjunction with eggs-per-recruit (Prager et al., 1987) and spawning stock biomass per recruit models (Gabriel et al., 1989; Goodyear, 1993; Schirripa and Goodyear, 1994) to allow managers to examine the effects of different policies on both reproduction (i.e. egg production) and biomass yield. The pattern of early maturation, multiple spawning, long spawning season, and indeterminate fecundity in Atlantic croaker (Barbieri et al., 1994b) suggest that reproduction would be compromised only at extremely high levels of fishing. However, eggs-per-recruit and spawning stock biomass models must be applied before this issue can be properly evaluated.

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## Literature cited

**Alverson, D. L., and M. J. Carney.**
**1975.** A graphic review of the growth and decay of population cohorts. J. Cons. Cons. Int. Explor. Mer 36:133–143.

**Austin, H.**
**1987.** Chesapeake Bay fisheries: an overview. *In* S. K. Majumdar, L. W. Hall, and H. M. Austin (eds.), Contaminant problems and management of living Chesapeake Bay resources, p. 33–53. The Pennsylvania Academy of Science, Philadelphia, PA.
**Barbieri, L. R., M. E. Chittenden Jr., and C. M. Jones.**
**1994a.** Age, growth, and mortality of Atlantic croaker, *Micropogonias undulatus*, in the Chesapeake Bay region, with a discussion of apparent geographic changes in population dynamics. Fish. Bull. 92:1–12.
**Barbieri, L. R., M. E. Chittenden Jr., and S. K. Lowerre-Barbieri.**
**1994b.** Maturity, spawning, and ovarian cycle of Atlantic croaker, *Micropogonias undulatus*, in the Chesapeake Bay and adjacent coastal waters. Fish. Bull. 92:671–685.
**Beverton, R. J. H.**
**1963.** Maturation, growth, and mortality of clupeid and engraulid stocks in relation to fishing. Rapp. Reun. P.-V. Cons. Int. Explor. Mer 154:44–67.
**Beverton, R. J. H., and S. J. Holt.**
**1957.** On the dynamics of exploited fish populations. U.K. Min. Agric. Fish. Food., Fish. Invest. (ser. 2) 19:1–533.
**Chao, L. N., and J. A. Musick.**
**1977.** Life history, feeding habits, and functional morphology of juvenile sciaenid fishes in the York River estuary, Virginia. Fish. Bull. 75:675–702.
**Chittenden, M. E., Jr.**
**1977.** Simulations of the effects of fishing on the Atlantic croaker, *Micropogon undulatus*. Proc. Gulf Caribb. Fish. Inst. 29:68–86.
**1991.** Operational procedures and sampling in the Chesapeake Bay pound-net fishery. Fisheries (Bethesda) 16:22–27.
**Deriso, R. B.**
**1987.** Optimal $F_{0.1}$ criteria and their relationship to maximum sustainable yield. Can. J. Fish. Aquat. Sci. 44(suppl. 2):339–348.
**Gabriel, W. L., M. P. Sissenwine, and W. J. Overholtz.**
**1989.** Analysis of spawning stock biomass per recruit: an example for Georges Bank haddock. North Am. J. Fish. Manage. 9:383–391.
**Goodyear, C. P.**
**1993.** Spawning stock biomass per recruit in fisheries management: foundation and current use. *In* S. J. Smith, J. J. Hunt, and D. Rivard (eds.), Risk evaluation and biological reference points for fisheries management, p. 67–81. Can. Spec. Publ. Fish. Aquat. Sci. 120.
**Gulland, J. A.**
**1983.** Fish stock assessment. John Wiley & Sons, New York, NY, 223 p.
**Gulland, J. A., and L. K. Boerema.**
**1973.** Scientific advice on catch levels. Fish. Bull. 71:325–335.
**Joseph, E. B.**
**1972.** The status of the sciaenid stocks of the middle Atlantic coast. Chesapeake Sci. 13:87–100.
**McHugh, J. L., and D. Conover.**
**1986.** History and condition of food finfisheries in the Middle Atlantic region compared with other sections of the coast. Fisheries (Bethesda) 11:8–13.
**Newlin, K. (ed.)**
**1992.** Fishing trends and conditions in the southeast region 1991. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SEFSC-311, 84 p.
**Prager, M. H., J. F. O'Brien, and S. B. Saila.**
**1987.** Using lifetime fecundity to compare management strategies: a case history for striped bass. North Am. J. Fish. Manage. 7:403–409.
**Ricker, W. E.**
**1975.** Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191, 382 p.
**Ross, S. W.**
**1988.** Age, growth, and mortality of Atlantic croaker in North Carolina, with comments on population dynamics. Trans. Am. Fish. Soc. 117:461–473.
**Rothschild, B. J., P. W. Jones, and J. S. Wilson.**
**1981.** Trends in Chesapeake Bay fisheries. Trans. 46th N. Am. Wildl. Nat. Resour. Conf. 1981:284–298.
**Rutherford, E. S., J. T. Tilmant, E. B. Thue, and T. W. Schimidt.**
**1989.** Fishery harvest and population dynamics of spotted seatrout, *Cynoscion nebulosus*, in Florida Bay and adjacent waters. Bull. Mar. Sci. 44:108–125.
**Saila, S. B., C. W. Recksiek, and M. H. Prager.**
**1988.** Basic fisheries science programs. Elsevier, New York, NY, 230 p.
**Schirripa, M. J., and C. P. Goodyear.**
**1994.** Simulation modeling of conservation standards for spotted seatrout (*Cynoscion nebulosus*) in Everglades National Park. Bull. Mar. Sci. 54:1019–1035.
**Schmied, R. L., and E. E. Burgess.**
**1987.** Marine recreational fisheries in the southeastern United States: an overview. Mar. Fish. Rev. 49:2–7.
**Speir, H., H. Austin, and L. Mercer.**
**1994.** 1993 annual review of the Atlantic States Marine Fisheries Commission fishery management plan for Atlantic croaker (*Micropogonias undulatus*). *In* 1993 annual review of the Atlantic States Marine Fisheries Commission Interstate Fishery Management Plans, p. 11–16. Special Report 25 of the Atlantic States Marine Fisheries Commission, Washington, D.C.
**Vetter, E. F.**
**1988.** Estimation of natural mortality in fish stocks: a review. Fish. Bull. 86:25–43.
**Wilk, S. J.**
**1981.** The fisheries for Atlantic croaker, spot, and weakfish. *In* H. Clepper, (ed.), Proceedings of the 6th annual marine recreational fisheries symposium, p. 15–27. Sport Fish. Inst., Washington.
**Wilson, C.**
**1993.** North Carolina report for Atlantic croaker. *In* L. L. Kline and H. Speir (eds.), Proceedings of a workshop on spot (*Leiostomus xanthurus*) and Atlantic croaker (*Micropogonias undulatus*), p. 34–54. Atlantic States Marine Fisheries Commission Special Report 25.