**Abstract**–Black drum, *Pogonias cromis*, along the U.S. East Coast is subject to commercial and recreational harvest. However, prior to this study no modeling had been undertaken to examine the potential for overfishing in the Chesapeake Bay region. We present evidence from yield-per-recruit models that growth overfishing of black drum is unlikely under current fishing practices in this region. Particular attention was given to fishing practices in the Chesapeake Bay region where old, large fish predominate in the commercial and recreational catches (mean age=26 years; mean total length=108.4 cm; mean weight 22.1 kg). Yield-per-recruit model results showed that growth overfishing was unlikely in the Chesapeake Bay region under all but the lowest estimates of natural mortality (*M*=0.02–0.04). Such extreme low values of *M* predict potential life spans of 200 years and were dismissed as improbable—the oldest age recorded for this species is 59 years. Additionally, biomass-per-recruit model results indicated a 42–59% decrease to current biomass from the unfished stock. The apparent age-specific migration of this stock argues for protection of young fish that have dominated the catch in Northeast Florida. Modeling indicated that growth overfishing could result from heavy fishing on these young ages and would all but eliminate this resource of the northern fishery.

# Yield-per-recruit analysis for black drum, *Pogonias cromis,* along the East Coast of the United States and management strategies for Chesapeake Bay

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Black drum (*Pogonias cromis*; family Sciaenidae) range in U.S. waters primarily from Massachusetts to Florida along the East Coast and, in the Gulf of Mexico, from the west coast of Florida along the northern Gulf to Texas. They form at least three populations, at least two in the Gulf of Mexico (Gold et al., 1995) and one along the U.S. East Coast (Gold and Richardson, 1998; Gold[1]). This population structure is seen as "isolation by distance" (Gold and Richardson, 1998). East Coast black drum undertake long-range migrations with a general pattern of movement to the north and inshore in spring, and south and offshore in the fall (Richards, 1973; Murphy and Taylor, 1989; Jones and Wells, 1998). These seasonal migrations are age-specific and influence exploitation patterns differently along the coast. Although the East Coast stock shows a maximum age of 59 years, which indicates low total annual mortality of 8–11% (Jones and Wells, 1998), a greater proportion of old fish are found north of Cape Hatteras, and the potential exists for different age-specific mortalities along the range. Along the East Coast, fisheries for black drum predominantly target small, young fish in the south (Music and Pafford, 1984; Murphy and Muller[2] and Wenner[3]) and large, old fish in the north (Jones and Wells, 1998). Although small fish are targeted in the south, large fish are present and are caught occasionally in the recreational fisheries there. In contrast, small fish are rarely present north of Cape Hatteras besides young of the year fish that leave the bays after their first summer. Hence, little fishing

mortality occurs to young fish in the northern part of the range.

Compared with other exploited sciaenids, black drum do not support large recreational or commercial fisheries. Along the East Coast between 1979 and 1994, commercial catches averaged only 99,510 kg yearly (218,923 pounds)[2,4,5,6,7,8] Virginia and Florida have the greatest average annual land-

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[2] Murphy, M. D., and R. G. Muller. 1995. A stock assessment of black drum, *Pogonias cromis*, in Florida. Unpubl. manuscript, 20 p. Department of Environmental Protection, Florida Marine Research Institute, St. Petersburg, FL, 33701-5095.

[3] Wenner, C. 1995. Personal commun. South Carolina Department of Natural Resources, P.O. Box 12559, Charleston, SC 29422.

[4] Virginia Marine Resources Commission. 1993. Mimeo: Virginia black drum landings by gear type 1973–1993. Virginia Marine Resources Commission, 2600 Washington Ave, Newport News, VA, 23607.

[5] North Carolina Division of Marine Fisheries. 1980–94. Mimeos: North Carolina landings reports (1979–1993). North Carolina Division of Marine Fisheries, Morehead City, NC, 28557-0769.

[6] Werner, C. 1996. Personal written commun. Preliminary South Carolina landings reported to the Fisheries Statistics Program 1979–1995. South Carolina Department of Natural Resources, P.O. Box 12559, Fisheries Statistics Program, Charleston, SC, 29422-2559.

[7] Pafford, J. 1995. Fisheries Statistics Project: Georgia black drum landings 1972–94. Georgia Department of Natural Resources,

ings (averaging 37,000 and 26,000 kg respectively), whereas New Jersey, Delaware, Maryland, North Carolina, South Carolina, and Georgia have average landings of less than 18,000 kg. In contrast, between 1981 and 1994 recreational landings averaged 315,000 kg (693,000 pounds)[2,9] annually, 300% higher than the commercial catch. Recreational landings north of Cape Hatteras vary from 0.4% to 78% of the annual East Coast recreational catch, reflecting variations in abundance of older fish and in their seasonal migration patterns.

With its location at the northern end of the range, Chesapeake Bay fisheries target black drum that are primarily old (26 yr), and large (108.4 cm; 22.1 kg) during a short season; most of the catches occur from April to June (Jones and Wells, 1998). Large fish enter the Bay in April and are caught by the commercial fishery with 33-cm stretch mesh anchored and drifted gill nets. Historically, the commercial market is local, and fillets and roe are a spring treat for residents of the eastern shore of Virginia and Maryland during April and May (Jones et al., 1990). Because of this limited market that becomes saturated, the price drops in late spring and commercial fishermen turn from black drum to pursue more profitable fishes. The recreational fishery usually begins and ends a month later than the commercial fishery, from May to June, and anglers target large trophy fish with hook and line. Although the recreational season is short, it occurs before more popular fish enter the Bay, and the fishery supports local business at that time. Thus, the black drum fishery is important to the economies of two of the poorest counties in Virginia, which are located on the eastern shore (Jones et al., 1990).

In the mid-Atlantic region, the lack of accurate catch and effort data from the commercial and recreational black drum fisheries makes it difficult to evaluate whether the long-term fluctuations in population abundance and the current decline in abundance of citation-size fish result from natural patterns of dominant year classes or from excess exploitation and subsequent population decline. Reports of catch and effort in the commercial fishery have been based, generally, on voluntary reporting. Likewise, the difficulty in sampling this short-season and charter-based recreational fishery has led to estimates of catch and effort that are characterized by extremely broad confidence limits. Even so, in response to the concerns of Virginia's recreational anglers to supposed population decline, commercial harvest quotas were imposed on these fisheries in 1992 in the absence of any stock assessment (Commonwealth of Virginia, 1992, VMRC regulation 4 VAC 20-320-10 et seq.).

Yield-per-recruit models can provide the benchmarks for assessing growth overfishing (Gulland, 1983; King, 1995).

Specifically, yield-per-recruit modeling provides reference points to theoretically maximize yield from a cohort ($F_{MAX}$), or increase the number of trophy-size fish in the population. Because $F_{MAX}$ frequently results in unsustainable harvests, an *ad hoc* benchmark ($F_{0.1}$) is calculated to provide more conservative harvest recommendations. However as important as this modeling is to science-based management, no published application of yield-per-recuit models exists for black drum from the Chesapeake Bay region. In our study we used data from Chesapeake Bay (Jones and Wells, 1998) and Florida (Murphy and Taylor, 1989) to evaluate the effect of fishing mortality and age at first capture on yield-per-recruit models of these fish, especially for management in the Bay. Although more accurate stock assessments result when catch-age or age-structured models such as ADAPT are used, the absence of a time series of aged-catch data precludes their use for this fishery. Until such data become available, the results of yield-per-recruit models can be used now to determine whether regulations such as size limits, catch quotas, and effort limitations, which are already in effect, are necessary to manage this fishery.

## Materials and methods

### Yield-per-recruit analysis

The Beverton-Holt yield-per-recruit model (Beverton and Holt, 1957) was used to calculate yield-per-recruit curves following the formula

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

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

Computations were performed by using a modification of the computer program *B-H3* available in the Basic Fisheries Science Programs package (Saila et al., 1988). Parameters used in these simulations are summarized in Table 1. The first two parameters, $t_0$ and $K$, are derived from the von Bertalanffy growth equation for black drum (Jones and Wells, 1998):

$$l_t = 117.3\left(1 - e^{-0.105(t+2.3)}\right). \qquad (2)$$

Because fish aged 1–5 were not available in Chesapeake Bay, our estimate of $K$ (0.105) was smaller than that obtained by

[7] (*continued*) Coastal Resources Division, One Conservation Way, Brunswick, GA 31523-8600.

[8] Sutherland, D. 1995. 1979–94 Black drum commercial landings for Atlantic Coast states. Fisheries Statistics Division, National Marine Fisheries Service, 1315 East West Highway, Silver Spring, MD 20910.

[9] Fisheries Statistics Division and Economics Division. 1996. Personal commun. Fisheries Statistics Div. and Economics Div., National Marine Fisheries Service, 1315 East West Highway, Silver Spring, MD 20910.

Murphy and Taylor, *(K=*0.124; 1989) for black drum sampled from the northeast coast of Florida. Hence, we also used estimates of *K* from the northeast coast of Florida in our modeling to ensure that results would reflect the available scientific data from the U.S. East Coast. For both areas, asymptotic mean weight, $W_\infty$, was converted from an allometric weight-length relationship (*b*=3.11; Jones and Wells, 1998). This slight deviation from isometric growth (*b*=3.0) may result in a small overestimation of yield (less than 7%) which Ricker (1975) dismissed as inconsequential to further calculations. Because we focused on the relative yields that result from varying $t_0$ and *F* at different levels of *M*, differences in yield should be even less than this absolute level (Barbieri et al., 1997).

Age of recruitment to the fishing area, $t_r$, was unknown for this fishery and was set to age 1 for the Florida fishery and age 5 for the Chesapeake Bay fishery, a year less than the youngest adult black drum caught in the Bay during our three-year study. Fisheries-based data included *Z*, *F*, *M*, and $t_c$. Estimates of the instantaneous total mortality, *Z*, for fully recruited black drum were obtained from catch-curve analysis and maximum age procedures, and ranged from 0.08 to 0.12 (Murphy and Taylor, 1989; Jones and Wells, 1998). Although we had direct estimates of total mortality, *Z*, we lacked independent estimates of instantaneous fishing mortality, *F*, and instantaneous natural mortality, *M*. However, the estimate of *Z* allowed us to estimate current levels of fishing mortality, $F_{CUR(i)}$, for different values of *M*, as

$$F_{CUR(i)} = Z - M_i, \qquad (3)$$

where $M_i = 0.02\text{–}0.12$.

We estimated the most probable value of *M* by extrapolating to maximum age estimates realistic for an unfished fishery. This range of *M* was lower than that predicted with a multiple regression developed by Pauly (1980; *M*=0.16–0.30). Using our lower estimate of *M*, we made our modeling more sensitive to potential growth overfishing; therefore management strategies would be conservative.

### Ricker yield model

Ricker's yield model is used to simulate the potential for growth overfishing over the life of a cohort by measuring available biomass at age under various levels of *F* (King, 1995). Mortality and growth are opposing effects that result in a maximum biomass during the lifetime at the age of maximum biomass, $t_{CRITICAL}$. The model equation is from Saila et al. (1988):

$$\hat{Y}_e \sum_{i=t_c}^{t_L} \frac{F_i B_i \left[1 + e^{G_i - Z_i}\right]}{2}, \qquad (4)$$

**Table 1**

Parameter estimates or range of values used in yield-per-recruit and biomass simulations for black drum, *Pogonias cromis*, on the east coast of the U.S. Data taken from Jones and Wells (1998) for the Chesapeake Bay and Murphy and Taylor (1989).

| Parameter | Chesapeake Bay | NE Florida | Method |
|---|---|---|---|
| $t_c$ | 5–25 yr | | age composition of catches |
| $t_r$ | 5 yr | 1 yr | life history information |
| $t_0$ | –2.3 yr | –1.3 yr | growth curve |
| $K$ | 0.105 yr | 0.124 yr | growth curve |
| $L_\infty$ | 117.3 cm | 117.2 cm | growth curve |
| $W_\infty$ | 27.5 kg | 25.5 kg | converted from $L_\infty$ |
| $Z$ | 0.08–0.12 | | catch curves and longevity |
| $M$ | 0.00–0.12 | | longevity |
| $\beta$ | 3.11 | | length-weight regression |

where $\hat{Y}_e$ = estimated lifetime equilibrium yield referenced to an arbitrary recruitment biomass of 1000 g;
$B_i$ = biomass at age;
$F_i$ = instantaneous fishing mortality at age;
$Z_i$ = total mortality at age;
$G_i$ = growth in weight-at-age; and
$t_i$ = age where $t_i$ is calculated from the age of first capture, $t_c$, to the last fishable age, $t_L$.

When calculated at *F*=0, the model produces estimates of equilibrium yield for the unfished stock. Computations were performed by using the computer program *Ricker* modified from the Basic Fisheries Science Programs package (Saila et al., 1988).

Parameter values used in simulations are summarized in Table 1. Estimates of growth parameters $B_i$, and $G_i$ for Chesapeake Bay and Florida black drum were obtained from Jones and Wells (1998) and Murphy and Taylor (1989). Because of the long life of black drum, we grouped parameters into 5-year intervals to increase computation efficiency. Simulations used six values of *M* (0.02, 0.04, 0.06, 0.08, 0.10, and 0.12) and six levels of *F* (0.0, 0.02, 0.04, 0.06, 0.08, and 0.10). This model is not used to calculate optimum yield as is the Beverton-Holt yield-per-recruit model. By integrating the area under the curves, reduction in stock biomass at a given level of *F* can be compared with biomass of the unfished stock, thus demonstrating the loss of trophy-size fish that are prized in recreational fisheries.

Simulations were done to model two scenarios of fishing mortality and their effect on biomass: 1) uniform low *F* over the life span, and 2) very high *F* in the first 5-year interval and uniform low *F* over the remaining lifetime. In the first scenario the chosen level of *F* was partitioned equally over 12 age intervals. (Because we lacked age-specific estimates of *F*, the most straightforward approach was to equally partition *F* across age intervals.) In the second scenario fish in the first 5-year interval were given an *F*=2.0 and thereafter experienced the chosen level of *F*

partitioned equally over the remaining 11 age intervals. Hence, in the second scenario the lifetime $Z$ was greater than 2.0. The second scenario was chosen to model extremely severe $F$ on young fish that could be experienced from both directed fisheries and bycatch where young fish predominate.

## Cohort biomass and harvesting time

The maximum possible yield for a year class occurs at the age ($t_{CRITICAL}$) when the biomass of the cohort is at its maximum in the absence of fishing. For comparison with the Beverton-Holt and Ricker yield-per-recruit modeling results, we estimated $t_{CRITICAL}$ for black drum following Quinn and Deriso (1999) with the following equation:

$$t_{CRITICAL} = t_0 + \frac{1}{K}\ln\left(1 + \frac{\beta}{m}\right), \qquad (5)$$

where  $m = M/K$,
$\beta$ = the length-weight allometry coefficient, and
$t_0$, $K$, and $M$ are defined as in Equation 1.

Parameter estimates or the range of values used in calculations are listed in Table 1. Age at maximum biomass can be compared to mean age in the catch to indicate whether further juvenesence is possible.

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

$$P_g = (1 - l_c / L_\infty), \qquad (6)$$

where $L_\infty$, the asymptotic length, was obtained from Jones and Wells (1998); 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 black drum in Chesapeake Bay (Jones and Wells, 1998) and Florida (Murphy and Taylor, 1989). Both parameters are based on total length in cm.

## Results

### Modeling with parameters from Chesapeake Bay

Yield-per-recruit curves on $F$ showed that the yield of black drum in Chesapeake Bay could be maximized by decreasing $t_c$ to 10–15 yr over most of the range of $M$ (0.06–0.12) and $F$ used in our simulations (Fig. 1; Table 2). The gains in yield-per-recruit could be substantial. For example, at the estimated current levels of fishing mortality for black drum in Chesapeake Bay ($F_{CUR}$=0.04–0.06), yields could be increased 58% at $M$=0.06 and 89% at $M$=0.08 by decreasing current $t_c$ from 25 yr to 15 yr.

Yield-per-recruit curves showed marked peaks only at the lowest levels of $M$ (0.02; 0.04) when $t_c$≤10–15 or at higher levels of $M$ when $t_c$≤10 (Fig. 1). Otherwise, curves were asymptotic or rising, and $F_{MAX}$ was reached only at
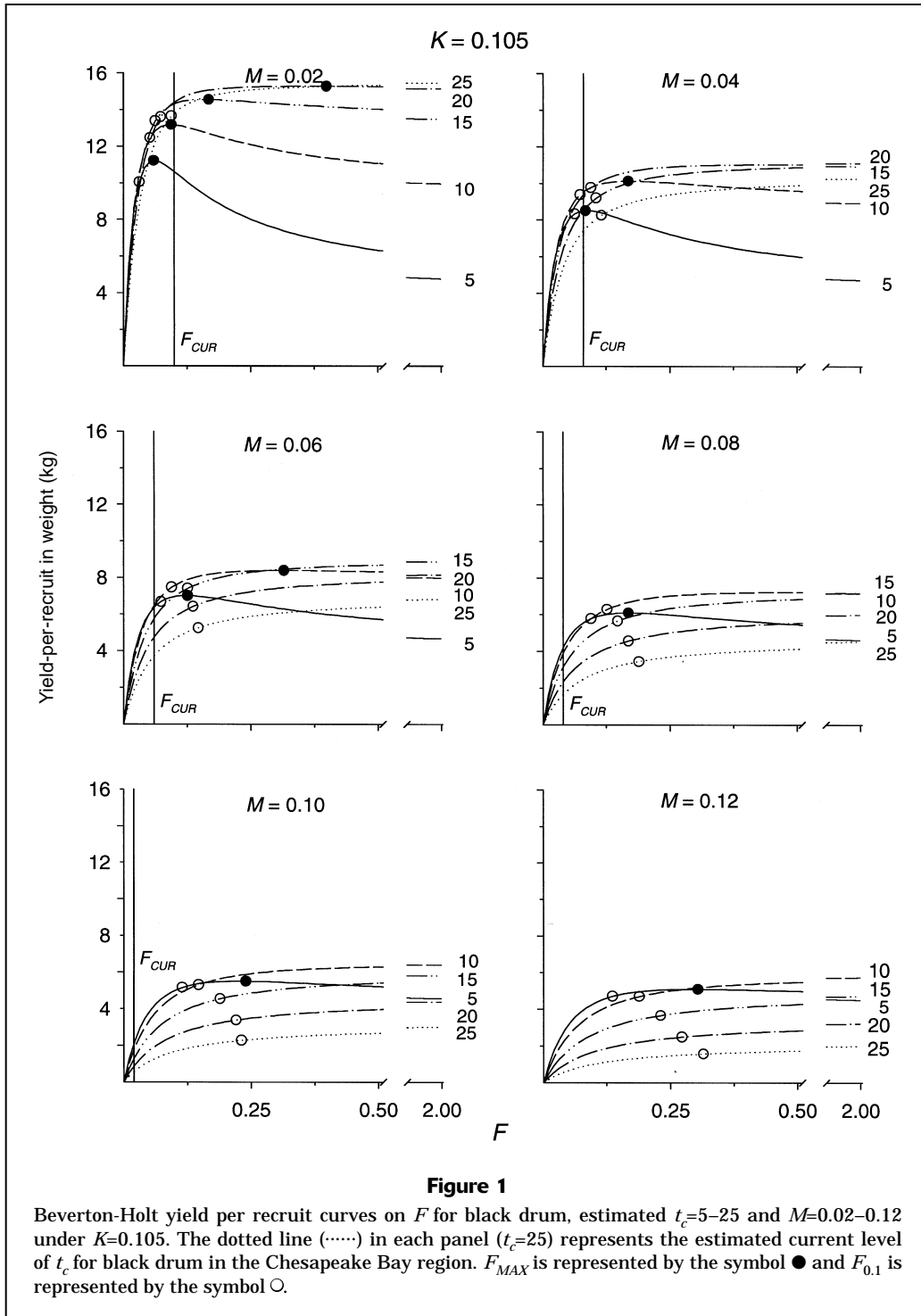
the highest fishing mortalities ($F_{MAX}$>2.0; Table 2). When $M$ was 0.02, curves peaked for $t_c$ up to 20 yr, resulting in $F_{MAX}$ <0.4. However, because an $M$ of 0.02 predicts a maximum age of over 200 yr in an unexploited stock and because there is no indication of such longevity in black drum, we rejected this scenario as improbable. When $M$ was 0.04, curves peaked for $t_c$≤15, for ages constituting less than five percent of the catch and well below the mean age (25 y) in the catch in the Chesapeake Bay fishery. At higher values of $M$ when $t_c$≥10, curves were asymptotic or rising and $F_{MAX}$ occurred only at the highest levels of $F$. Although yields increased continuously with $F$ for $M$>0.04, increases in yield beyond $F$=0.1–0.3 were very small.

For $M$≥0.06 and $t_c$≥5, estimates of $F_{CUR}$ were below the levels giving maximum potential yield-per-recruit ($F_{MAX}$) and $F_{0.1}$ (Fig. 1; Table 2). For $M$=0.06, $F_{CUR}$ equals 0.06 at most and $F_{0.1}$ equals 0.07, indicating that, although below the maximum potential yield-per-recruit, estimated current levels of harvest are only slightly below this more conservative benchmark of $F$. When $M$>0.06, $F_{0.1}$ is greater than 0.08 and always above $F_{CUR}$, indicating that current levels of harvest are below this conservative benchmark. In contrast, if $M$≤0.04 and $t_c$≤10, $F_{0.1}$ is higher than $F_{CUR}$ (Table 2) indicating that there is some justification for decreasing $F$. However, as mentioned previously, we believe these levels of $M$≤0.04 to be unrealistically low for this species.

Curves of biomass on age showed that biomass decreased with increases in $M$ or $F$ (Table 3). Lifetime cohort biomass of an unfished stock decreased by 85% from $M$=0.02 to $M$=0.12. Within a given $M$, increased $F$ resulted in decreased lifetime cohort biomass. For example, when the most credible combinations of $M$ and $F_{CUR}$ were modeled ($M$=0.06, $F_{CUR}$=0.06; $M$=0.08, $F_{CUR}$ = 0.04), biomass declined 59% and 42%, respectively, from that of the unfished stock (Fig. 2).

Similar patterns were shown when we modeled heavy fishing in the first 5 years ($F$=2.0), and uniform low mortality was evident thereafter. Curves of biomass on age showed a much larger decrease in biomass with increasing $M$ and $F$ (Fig. 3; Table 4). Maximum biomass at minimum fishing mortality ($F$=0.02; $M$=0.02–0.12) was 81–67% less than seen without heavy early mortality. For example, under the most likely combinations of $M$ and $F_{CUR}$ for the Chesapeake Bay fishery, biomass was reduced approximately 82–87% ($M$=0.06 $F_{CUR}$=0.06; $M$=0.08 $F_{CUR}$=0.04).

Values of $t_{CRITCAL}$ estimated by using different values of $M$ were relatively high for black drum in Chesapeake Bay. Increasing $M$ resulted in a decrease in $t_{CRITICAL}$ from 25 yr at $M$=0.02 to 10 yr at $M$=0.12. This finding indicates that, for the range of $M$ considered in our study, maximum theoretical cohort biomass, in the absence of fishing, is achieved before black drum reach age 25. This occurs at the lowest value of $M$, approximately the mean age of capture in Chesapeake Bay. For the most likely combinations of $M$ and $F$ ($M$=0.06 $F_{CUR}$=0.06; $M$=0.08 $F_{CUR}$=0.04), $t_{CRITICAL}$ declined from 13($M$=0.08)–15($M$=0.06) yr in the unfished stock to 10 yr in the fished stock. In this example, $t_{CRITICAL}$ is below the mean age of capture in the Bay, 26 yr, and potential yield is lost to natural mortality.

**Figure 1**

Beverton-Holt yield per recruit curves on $F$ for black drum, estimated $t_c$=5–25 and $M$=0.02–0.12 under $K$=0.105. The dotted line (·····) in each panel ($t_c$=25) represents the estimated current level of $t_c$ for black drum in the Chesapeake Bay region. $F_{MAX}$ is represented by the symbol ● and $F_{0.1}$ is represented by the symbol ○.

Estimated values of $P_g$ were also low for black drum caught in Chesapeake Bay. For $L_\infty$=117 cm, and the current estimated $l_c$ (110 cm, corresponding to $t_c$=25), $P_g$=0.06, i.e. on average, only 6% of their potential growth still remains when black drum in Chesapeake Bay enter the exploited phase at age 25. For alternative values of $t_c$ equal to 5, 10, 15, 20, and 30 years, values of $P_g$ are 0.46, 0.27, 0.16, 0.09, and 0.03, respectively.

### Modeling with $K$=0.124

Yield modeling was also done to encompass an alternative estimate of growth based on the Brody coefficient ($K$) determined from the northeast Florida fishery (Murphy and Taylor, 1989). Because Chesapeake Bay region catches did not include fish aged 1–5, the estimate of $K$ (0.105; Jones and Wells, 1998) differed slightly from that esti-

## Table 2

Estimates of $F_{0.1}$ and $F_{MAX}$ compared to $F_{CUR}$ from Beverton-Holt yield-per-recruit modeling for various levels of $K$, $M$, and $t_c$. The symbol *** indicates that $F_{MAX}$ occurs at the highest values of $F$. $F_{CUR(i)}$ was calculated from the upper-bound estimate of $Z$ (as $F_{CUR(i)}=Z-M_i$) and represents the upper-bound estimate of current $F$.

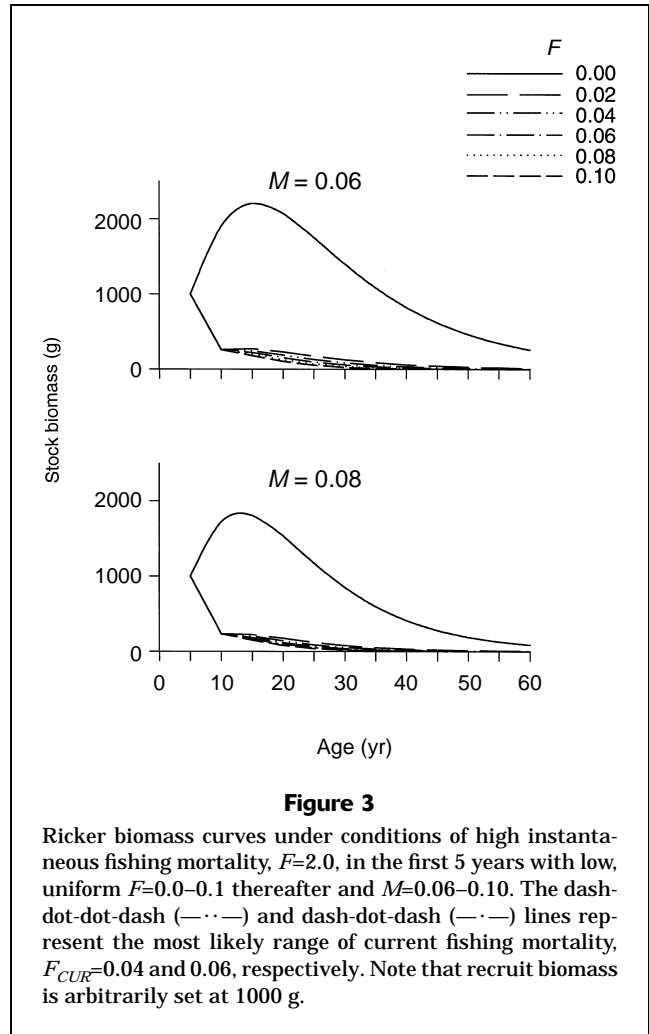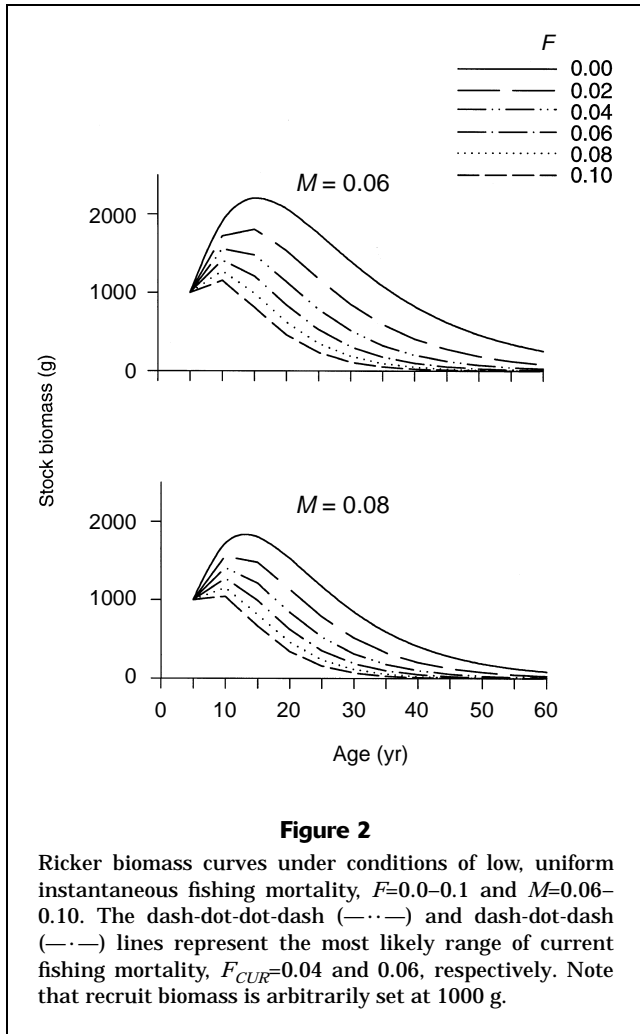| $K$ | $M$ | $t_c$ | $F_{0.1}$ | $F_{MAX}$ | $F_{CUR}$ | $K$ | $M$ | $t_c$ | $F_{0.1}$ | $F_{MAX}$ | $F_{CUR}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.105 | 0.02 | 5 | 0.03 | 0.06 | 0.10 | 0.124 | 0.02 | 5 | 0.05 | 0.07 | 0.10 |
| | | 10 | 0.05 | 0.09 | | | | 10 | 0.06 | 0.11 | |
| | | 15 | 0.06 | 0.17 | | | | 15 | 0.07 | 0.23 | |
| | | 20 | 0.07 | 0.40 | | | | 20 | 0.08 | *** | |
| | | 25 | 0.09 | *** | | | | 25 | 0.09 | *** | |
| | 0.04 | 5 | 0.06 | 0.08 | 0.08 | | 0.04 | 5 | 0.06 | 0.10 | 0.08 |
| | | 10 | 0.07 | 0.17 | | | | 10 | 0.07 | 0.24 | |
| | | 15 | 0.09 | 0.51 | | | | 15 | 0.09 | 1.38 | |
| | | 20 | 0.10 | *** | | | | 20 | 0.12 | *** | |
| | | 25 | 0.12 | *** | | | | 25 | 0.12 | *** | |
| | 0.06 | 5 | 0.07 | 0.13 | 0.06 | | 0.06 | 5 | 0.08 | 0.15 | 0.06 |
| | | 10 | 0.09 | 0.31 | | | | 10 | 0.10 | 0.47 | |
| | | 15 | 0.11 | *** | | | | 15 | 0.13 | *** | |
| | | 20 | 0.13 | *** | | | | 20 | 0.14 | *** | |
| | | 25 | 0.15 | *** | | | | 25 | 0.14 | *** | |
| | 0.08 | 5 | 0.09 | 0.17 | 0.04 | | 0.08 | 5 | 0.09 | 0.21 | 0.04 |
| | | 10 | 0.12 | 0.61 | | | | 10 | 0.14 | 1.11 | |
| | | 15 | 0.15 | *** | | | | 15 | 0.17 | *** | |
| | | 20 | 0.17 | *** | | | | 20 | 0.19 | *** | |
| | | 25 | 0.19 | *** | | | | 25 | 0.20 | *** | |
| | 0.10 | 5 | 0.11 | 0.23 | 0.02 | | 0.10 | 5 | 0.12 | 0.28 | 0.02 |
| | | 10 | 0.15 | 1.51 | | | | 10 | 0.18 | *** | |
| | | 15 | 0.19 | *** | | | | 15 | 0.20 | *** | |
| | | 20 | 0.22 | *** | | | | 20 | 0.23 | *** | |
| | | 25 | 0.25 | *** | | | | 25 | 0.27 | *** | |
| | 0.12 | 5 | 0.13 | 0.30 | 0.00 | | 0.12 | 5 | 0.14 | 0.39 | 0.00 |
| | | 10 | 0.19 | *** | | | | 10 | 0.20 | *** | |
| | | 15 | 0.23 | *** | | | | 15 | 0.25 | *** | |
| | | 20 | 0.27 | *** | | | | 20 | 0.29 | *** | |
| | | 25 | 0.311 | *** | | | | 25 | 0.30 | *** | |

## Table 3

Lifetime cohort biomass (g) from the Ricker biomass model (Saila et al. 1988) under $M$=0.02–0.12, and uniform $F$=0–0.12. Integration was by rectangular approximation. Simulations were based on an arbitrary starting biomass of 1000 g.

| | $F$ | | | | | | |
|---|---|---|---|---|---|---|---|
| $M$ | 0 | 0.02 | 0.04 | 0.06 | 0.08 | 0.1 | 0.12 |
| 0.02 | 180,730 | 107,915 | 70,195 | 49,170 | 36,595 | 28,595 | 23,210 |
| 0.04 | 107,915 | 70,195 | 49,170 | 36,595 | 28,595 | 23,210 | 19,420 |
| 0.06 | 70,195 | 49,170 | 36,595 | 28,595 | 23,210 | 19,420 | 16,675 |
| 0.08 | 49,170 | 36,595 | 28,595 | 23,210 | 19,420 | 16,675 | 14,600 |
| 0.10 | 36,595 | 28,595 | 23,210 | 19,420 | 16,675 | 14,600 | 13,040 |
| 0.12 | 28,595 | 23,210 | 19,420 | 16,675 | 14,600 | 13,040 | 11,750 |

mated for northeast Florida ($K$=0.124) which did include these ages. The values for $L_\infty$ were virtually identical from both studies. Model results based on this faster growth rate produced similarly shaped yield-per-recruit curves but with slightly higher yields and benchmark values (Fig. 4). At the most probable values of $M$ (0.06; 0.08), yield-per-recruit curves peaked only at $t_c \leq 10$ yr. Otherwise, curves were asymptotic or rising. $F_{MAX}$ at $t_c$=5 yr was 0.15 for

**Figure 2**

Ricker biomass curves under conditions of low, uniform instantaneous fishing mortality, $F$=0.0–0.1 and $M$=0.06–0.10. The dash-dot-dot-dash (—··—) and dash-dot-dash (—·—) lines represent the most likely range of current fishing mortality, $F_{CUR}$=0.04 and 0.06, respectively. Note that recruit biomass is arbitrarily set at 1000 g.



**Figure 3**

Ricker biomass curves under conditions of high instantaneous fishing mortality, $F$=2.0, in the first 5 years with low, uniform $F$=0.0–0.1 thereafter and $M$=0.06–0.10. The dash-dot-dot-dash (—··—) and dash-dot-dash (—·—) lines represent the most likely range of current fishing mortality, $F_{CUR}$=0.04 and 0.06, respectively. Note that recruit biomass is arbitrarily set at 1000 g.
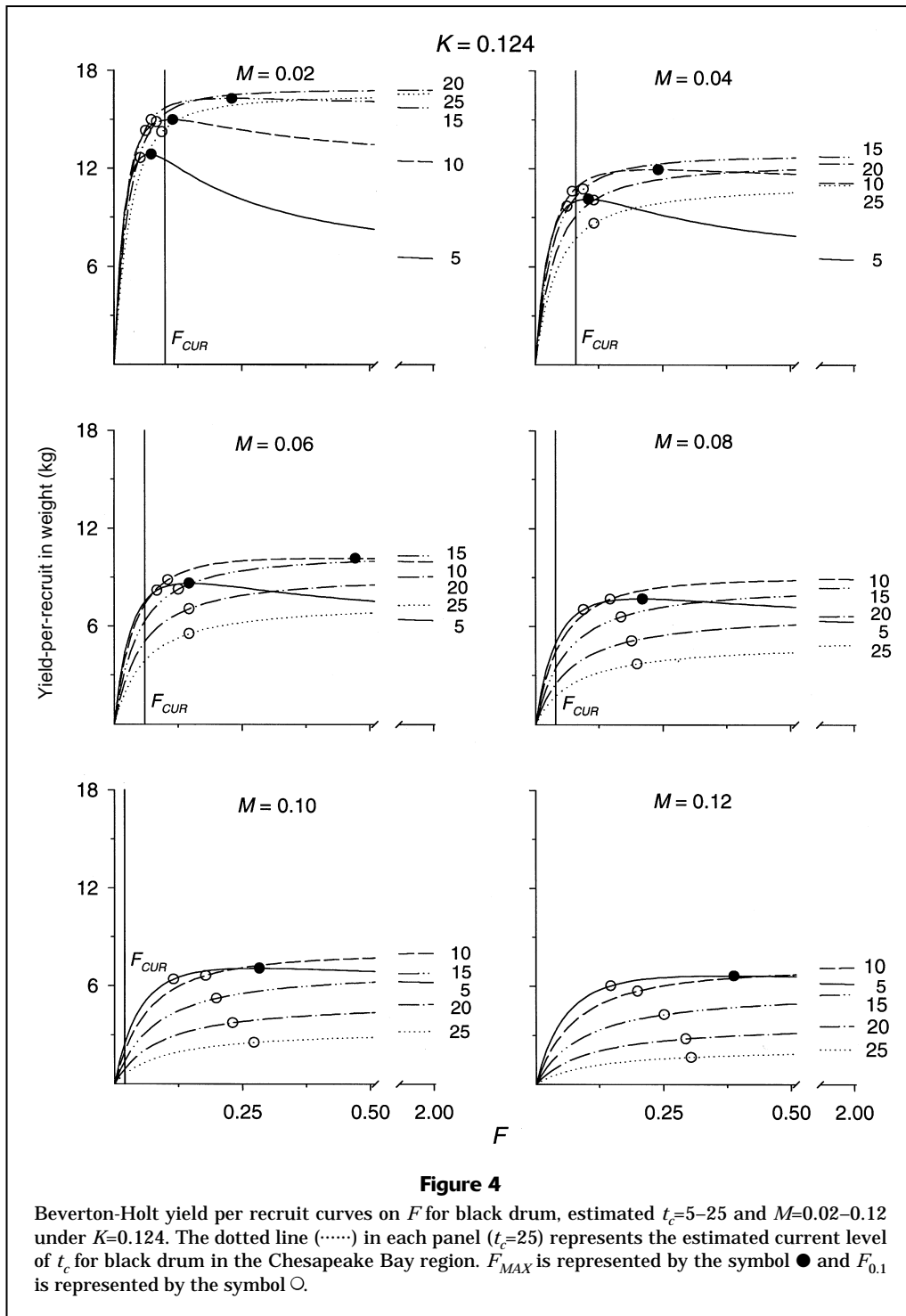
**Table 4**

Lifetime cohort biomass (g) from the Ricker biomass model (Saila et al. 1988) under $M$=0.02–0.12, and $F$=2.0 over the first 5 years and low uniform $F$=0–0.12 thereafter. Integration was by rectangular approximation. Simulations were based on an arbitrary starting biomass of 1000 g.

| | $F$ | | | | | | |
| $M$ | 0 | 0.02 | 0.04 | 0.06 | 0.08 | 0.1 | 0.12 |
|------|---------|--------|--------|--------|--------|--------|-------|
| 0.02 | 180,730 | 20,395 | 15,785 | 13,075 | 11,390 | 10,270 | 9495 |
| 0.04 | 107,915 | 14,750 | 12,305 | 10,775 | 9760   | 9055   | 8560 |
| 0.06 | 70,195  | 11,610 | 10,225 | 9315   | 8675   | 8225   | 7875 |
| 0.08 | 49,170  | 9730   | 8895   | 8325   | 7910   | 7600   | 7370 |
| 0.10 | 36,595  | 8525   | 8000   | 7630   | 7360   | 7145   | 6990 |
| 0.12 | 28,595  | 7730   | 7380   | 7130   | 6940   | 6785   | 6660 |

$M$=0.06 and 0.21 for $M$=0.08 (Table 2), greater than our estimate of $Z$ and $F_{CUR}$. At $t_c$>10, $F_{MAX}$ occurred at the highest levels of $F$. At the most probable levels of $M$, $F_{0.1}$ was greater than $F_{CUR}$ (Table 2). Hence under either $F_{MAX}$ or $F_{0.1}$ and larger $K$, $F_{CUR}$ was still below that needed to

obtain maximum yields from the fishery in Chesapeake Bay.

Similarly, model results from this faster growth ($K$=0.124) and broader levels of $M$ (0.02–0.12) showed that $F_{CUR}$ is below $F_{MAX}$ and $F_{0.1}$ for Bay region fisheries except

**Figure 4**

Beverton-Holt yield per recruit curves on $F$ for black drum, estimated $t_c$=5–25 and $M$=0.02–0.12 under $K$=0.124. The dotted line (·······) in each panel ($t_c$=25) represents the estimated current level of $t_c$ for black drum in the Chesapeake Bay region. $F_{MAX}$ is represented by the symbol ● and $F_{0.1}$ is represented by the symbol ○.

for $M$≤0.04. Yield values were slightly higher than for $K$=0.105 for all levels of $M$ (Fig. 4; Table 2), and the benchmarks, $F_{MAX}$ and $F_{0.1}$, fell at higher values of $F$. Hence, the reasoning that was used to discount growth overfishing previously can also be used here. When $M$=0.02–0.04, yield-per-recruit curves peaked at $t_c$ =5–15 yr and were asymptotic or rising at older ages. Both scenarios indicated that growth overfishing is possible but improbable

because of the unlikely maximum ages that such low values of $M$ imply and because curves peaked at values of $t_c$ lower than those experienced in this fishery. At higher levels of $M$ (0.10; 0.12), growth overfishing was even less likely than at slower growth levels. Yield-per-recruit curves peaked only at $t_c$=5 and for $F$>0.28. Likewise, this $t_c$ was too young for the fishery, and $Z$ and $F_{CUR}$ were considerably smaller than the lowest values of $F_{MAX}$ or $F_{0.1}$. Hence,

even when the full range of $M$ and faster growth were considered, growth overfishing was not likely for the Chesapeake Bay region fishery.

Overall, yield-per-recruit curves showed that a sixfold increase in $M$ resulted in a 50% decrease in yield for both growth rates (Figs. 1 and 4). As $M$ increased, yield-per-recruit decreased. For a given $M$, yield-per-recruit increased to a maximum at an intermediate level of $t_c$. Increases in yield slowed from 5–15 yr and decreased from maxima thereafter at older ages. In only one case ($M$=0.02 and $K$=0.105), yield-per-recruit increased with increased $t_c$ up to 20 yr. In all other cases, yield decreased for $t_c$>20 yr, indicating that, beyond 20 yr, biomass was lost to natural mortality.

## Discussion

Our results indicate that yield-per-recruit for black drum in the Chesapeake Bay region is below its maximum for all but the lowest values of $M$ used in our simulations. For $M$≥0.04, current fishing mortality was below $F_{MAX}$. Only when $M$=0.02 and $t_c$<15 does the upper bound of $F_{CUR}$ fall above $F_{MAX}$. We discounted this case of extreme low $M$ because of the unusually long lifetime that it predicts—some 200 years. Yield-per-recruit and economic efficiency could be maximized for black drum in Chesapeake Bay by decreasing $t_c$ to 5 years along with higher rates of fishing mortality. However, this may not be the most viable management option for this species for several reasons. First, because the relation between yield-per-recruit and $F$ is essentially asymptotic, harvesting black drum in the Bay at or near $F_{MAX}$ would require a huge increase in fishing effort, making harvest of this species economically inefficient, especially with the current low demand for these fish. Besides, benchmarks such as $F_{MAX}$ are no longer thought to provide a sustainable measure of long-term maximum yield from a fishery. Second, the current $t_c$ may reflect the mean age of migrating adults that are recruited to the fishery. If so, decreasing $t_c$ may not be possible because young fish may not undertake migration along the coast, and a decrease in mesh size may result in failure of the net to "gill" the larger fish, with the result that catches would be diminished.

Large reductions in biomass, especially of older fish, were shown in biomass modeling. Biomass decreases 42–59% under the most likely values of mortality ($M$=0.08, $F_{CUR}$=0.04; $M$=0.06, $F_{CUR}$=0.06, respectively) more than that of the unfished stock. Reductions in biomass (up to 87%) are exacerbated when heavy fishing mortality is concentrated on young fish. Concurrent with these reductions in biomass, is a rapid and dramatic loss of older fish from the stock. This juvenescence occurs quickly—$t_{CRITICAL}$ is reduced from 15 in the unexploited stock to 10 at $F$=0.02 for $M$=0.06, and from 13 to 10 at $M$=0.08. At greater $F$, the decrease in $t_{CRITICAL}$ is even greater and the abundance of older fish diminishes further.

Altogether these modeling results show no indication of growth overfishing in the Chesapeake Bay region where old fish are predominantly targeted. Moreover, it is diffi-

cult to growth overfish a stock when fishing concentrates on capturing primarily older, larger fish. For example, black drum have already obtained 58% of their lifetime growth in length, and 22% of their lifetime weight when they first recruit to the Chesapeake Bay region at age six (Jones and Wells, 1998). By their mean age of capture in this region, they have obtained 90% of their lifetime growth in length and 51% in weight. Exploited cohorts have already surpassed their maximum growth by the time they enter the Bay region, and thereafter, natural mortality predominates. Cohort biomass has already declined from its optimum by the age fish enter the exploited stock in the Bay region.

Although these modeling results show no indication of growth overfishing in Chesapeake Bay, they do indicate that black drum are vulnerable when heavy fishing is directed to young fish in the southern portion of their range along the U.S. East Coast. We chose a high level of $F$ in the first five years of life to dramatically illustrate the effect of targeted fishing on small fish and the potential effects of bycatch from other fisheries. These simulations clearly indicate the importance of limiting fishing mortality in regions where young fish occur. Prior to 1989, black drum landed in the Florida east coast commercial fisheries averaged 320 mm (Murphy and Muller[2]), and 80% of the catch was 4 yr or younger (Murphy and Taylor, 1989), raising the potential of growth overfishing at that time. Capture at this young age also raises concern for recruitment overfishing, which our modeling does not address, especially when fish are targeted before they can reach sexual maturity (age 5). The potential for recruitment overfishing is minimal in areas, such as Chesapeake Bay, where the fishery targets older fish that have reproduced for many years before capture. Moreover, recent bans on gillnetting in Florida and other regulations on black drum fishing since 1989 should preclude recruitment overfishing and help preserve the stock.

Models are typically used in management to regulate fishing mortality in order to obtain sustainable harvests from a stock. These regulations have historically resulted in harvests with large biomass that are valued in commercial fisheries. In contrast, recreational anglers are not as interested in obtaining maximum biomass as they are in catching fewer, but larger fish. Moreover, increased production of larger fish occurs when fishing mortality is below $F_{MAX}$ and when recruitment is high. Hence, in the black drum fishery, which is targeted by both commercial and recreational fishermen, management objectives are at cross purposes. The commercial fishery benefits when yields are maximized to the detriment of survival and growth for the trophy-size fish desired by recreational anglers. In the Chesapeake Bay region, fishing mortality is low and supports the objectives of managing the recreational fishery. However, the most influential fishing mortality is on young fish and is not under the control of the Bay region management agencies, but is controlled by states farther south.

The long-range migrations of the East Coast black drum stock argue for a coast-wide management strategy. Through our modeling, we have shown that fishing practices in the Bay region have little impact on the production

of harvestable biomass and that mortality on young fish drives eventual production available to the Chesapeake Bay region black drum fishery. The supply of fish to the Bay region depends on mortality during the first ten years of life, years when these fish are found off the coasts of the South Atlantic states. Hence, management practices by states south of Cape Hatteras will determine the supply of fish to this coast-wide stock.

## Acknowledgments

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