Black Sea Bass

by

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Executive Summary

The northern stock of black sea bass (*Centropristis striata*) was evaluated using length-based population models. Under the existing fishery management plan (FMP), black sea bass has been regulated based on annual changes in the Northeast Fisheries Science Center (NEFSC) spring bottom trawl survey index. Fishing mortality resulting in maximum sustainable yield was considered equal to F_{MAX} equal to 0.33. Overfishing status was evaluated only with an approximation of F, based on a relative exploitation rate. A new approach was presented to the Data Poor Workshop review panel (December 2008) which involved estimates of fishing mortality and population size determined from changes in the size composition of the population (SCALE model). In addition, a length based yield per recruit model was developed to determine the associated biological reference points. An array of natural mortality estimates was considered, ranging from 0.2 to 0.9, and they were modeled as either a constant value or in the form of a logistic function where M varied with body length. The panel adopted results using a constant M=0.4 as the preferred model. The resulting $F_{40\%}$, as a proxy for F_{MSY}, was equal to 0.42 with an associated SSB equal to 12,537 mt and MSY of 3,903 mt. Assuming a catch of 2,685 mt, F_{2007} was estimated to be 0.48 and SSB equal to 11,478 mt. Therefore the conclusions are that overfishing is occurring, but the stock is not overfished (assuming a biomass threshold equal to ½ B_{MSY}). These new reference points and stock status determinations should be used with caution due to the uncertainty in the natural mortality estimate, the model input parameters, residuals patterns in model fit, and significant uncertainty associated with managing a protogynous species (i.e., individuals change sex from female to male).

Terms of Reference

1. Recommend biological reference points (BRPs) and measurable BRP and maximum sustainable yield (MSY) proxies.
2. Provide advice about scientific uncertainty and risk for Scientific and Statistical Committees (SSCs) to consider when they develop fishing level recommendations for these stocks.
3. Comment on what can be done to improve the information, proxies or assessments for each species.

Life History

Black sea bass (*Centropristis striata*) are distributed from the Gulf of Maine to the Gulf of Mexico, however, fish north of Cape Hatteras, NC are considered part of a single fishery management unit. Sea bass are generally considered structure oriented, preferring live-bottom and reef habitats. Within the stock area, distribution changes on a seasonal basis and the extent of the seasonal change varies by location. In the northern end of the range (New York to Massachusetts), sea bass move offshore crossing the continental shelf, then south along the edge of the shelf. By late winter, northern fish may travel as far south as Virginia, however most return to the northern inshore areas by May. Sea bass originating inshore along the Mid-Atlantic coast (New Jersey to Maryland) head offshore to the shelf edge during late autumn, travelling in a southeasterly direction. They return inshore in spring to the general area from which they originated. Black sea bass in the southern end of the stock (Virginia and North Carolina) move offshore in late autumn/early winter. Given the proximity of the shelf edge, they transit a relatively short distance, due east, to reach over-wintering areas.

Fisheries also change seasonally with changes in distribution. Inshore commercial fisheries are prosecuted primarily with fish pots (baited and unbaited) and handlines. Recreational fisheries generally occur during the period that sea bass are inshore. Once fish move offshore in the winter, they are caught in a trawl fishery targeting summer flounder, scup and *Loligo* squid (Shepherd and Terceiro, 1994). Handline and pot fisheries in the southern areas may still operate during this offshore period. Additionally a small sector of the NJ charter fleet target sea bass offshore during the winter.

Black sea bass are protogynous hermaphrodites and can be categorized as temperate reef fishes (Steimle et al. 1999, Drohan et al. 2007). Transition from female to male generally occurs between the ages of two and five (Lavenda 1949, Mercer 1978). Based on sex ratio at length from NMFS surveys, males constitute approximately 30% of the population by 20 cm, with increasing proportions of males with size (Figure 1). Following transition from female to male, sea bass can follow one of two behavioral pathways; either becoming a dominant male, characterized by a larger size and a bright blue nuccal hump during spawning season, or subordinate males which have few distinguishing features. The initiation of sexual transition appears to be based on visual rather than chemical cues (Dr. David Berlinsky, UNH, Personal communication). In studies of protogny among several coral reef fish species, transition of the largest female to male may occur quickly if the dominate male is removed from the reef, however, similar studies have not been published for black sea bass.

Spawning in the Middle Atlantic peaks during spring (May and June) when the fish reside in coastal waters (Drohan et al. 2007). The social structure of the spawning aggregations is poorly known although some observations suggest that large dominant males gather a harem of females and aggressively defend territory during spawning season (Nelson et al. 2003). The bright coloration of males during spawning season suggests that visual cues may be important in structuring of the social hierarchy.

Black sea bass attain a maximum size around 60 cm and 4 kg. Although age information is limited for the northern stock of black sea bass, growth curves are available from one published study as well as several unpublished studies. Lavenda (1949) suggests a maximum age for females of 8 and age 12 for males. However he noted the presence of large males (>45 cm) in deeper water that may have been older. Available growth curves are listed in Table 1. The Von Bertalanffy parameters were averaged across studies for input to models used in this analysis. (The growth parameters from Caruso, MADMF, appeared to be unique, possibly due to geographic growth differences and were not included in the model average). Although growth information was available for use in models, annual age length keys were not, therefore sea bass modeling efforts are length based rather than age based.

Maturity data is routinely collected on Northeast Fisheries Science Center survey cruises. Proportion mature for all years and sexes combined (n=10,318) was fitted to a logistic model (Figure 2). The model estimate for length at 50% maturity was 20.4 cm with 95% maturity attained by 28 cm.

Fisheries

In the Northwest Atlantic, black sea bass support commercial and recreational fisheries. Prior to WWII in 1939 and 1940, 46-48% of the landings were in New England, primarily in

Massachusetts. After 1940 the center of the fishery shifted south to New York, New Jersey and Virginia. Landings increased to a peak in 1952 at 9,883 mt with the bulk of the landings from otter trawls, then declined steadily reaching a low point in 1971 of 566 mt (Table 2). Historically, trawl fisheries for sea bass have focused on the over-wintering areas near the shelf edge. Inshore pot fisheries, which were primarily in New Jersey, showed a similar downward trend in landings between the peak in 1952 and the late 60s. The large increase in landings during the 1950's appears to be the result of increased landings from otter trawlers, particularly from New York, New Jersey and Virginia (Figure 3). During the same period, a large increase in fish pot effort, and subsequent landings, occurred in New Jersey (Figure 4). In recent years, fish pots and otter trawls account for the majority of commercial landings with increasing contributions from handline fisheries. Landing since 1974 have remained relatively steady around 1400 mt. (Table 2). Recreational landings, available from MFRSS data since 1982, average about 1,600 mt annually (Table 2). Estimates for recreational sea bass landings in1982 and 1986 (4,485 mt and 5,618 mt, respectively) are unusually high, as they are for other species for those years. Similarly, recreational landings for 1998 and 1999 are lower than expected. Although the estimates have been confirmed by MRFSS, they remain suspect.

The species affinity for bottom structure during its seasonal period of inshore residency increases the availability to hook and line or trap fisheries compared to the decreasing susceptibility to bottom trawl gear commonly used for scientific surveys. In autumn when water temperatures decline, black sea bass migrate offshore to areas along the edge of the continental shelf (Moser and Shepherd 2009). During this offshore period, sea bass are vulnerable to otter trawls as part of a multispecies fishery (Shepherd and Terceiro 1994).

Stock assessment history summary

Black sea bass stock assessments have been reviewed in the SARC/SAW process (SAWs 1, 9, 11, 20, 25, 27, 39 and 43) beginning with an index based assessment in 1991. In 1995 a VPA model was approved and the results generally showed fishing mortalities exceeding 1.0 (estimated using an M=0.2). The VPA was reviewed again in 1997 and at this time was considered too uncertain to determine stock status but indicative of general trends. In 1998, another review was conducted and both VPA and production models were rejected as either too uncertain or inappropriate for use with an hermaphroditic species. A suggestion was made to use an alternative method such as a tag/recapture approach. The NEFSC survey remained the main source of information regarding relative abundance and stock status. A tagging program was initiated in 2002 and the first year results were presented for peer review in 2004. The review panel concluded that a simple tag model using the proportion recovered in the first year at large, as well as an analysis of survey indices, produced acceptable results to determine exploitation rate and stock status. The release of tags continued through 2004 and results of tag models as well as indices were presented for SARC review in 2006. Their findings were that the tag model did not meet the necessary assumptions and the variability in the survey indices created uncertainty which prevented determination of stock status. The panel did not recommend any alternative reference points, however they did recommend continued work on length based analytical models.

Existing Biological Reference Points

Based on revision through Framework 7 to the Summer Flounder, Scup and Black Sea Bass (SFSCBSB) FMP, the status determination criteria is defined for each of the species managed under the FMP. The maximum fishing mortality threshold for each of the species under the FMP is defined as F_{MSY} (or a reasonable proxy thereof) as a function of productive capacity, and based upon the best scientific information consistent with National Standards 1 and 2. Specifically, F_{MSY} is the fishing mortality rate associated with MSY. The maximum fishing mortality threshold (F_{MSY}) or a reasonable proxy may be defined as a function of (but not limited to): total stock biomass, spawning stock biomass, total egg production, and may include males, females, both, or combinations and ratios thereof which provide the best measure of productive capacity for each of the species managed under the FMP. Exceeding the established fishing mortality threshold constitutes overfishing as defined by the Magnuson-Stevens Act.

The minimum stock size threshold for each of the species under the FMP is defined as ½ B_{MSY} (or a reasonable proxy thereof) as a function of productive capacity, and based upon the best scientific information consistent with National Standards 1 and 2. The minimum stock size threshold (½ B_{MSY}) or a reasonable proxy may be defined as a function of (but not limited to): total stock biomass, spawning stock biomass, total egg production, and may include males, females, both, or combinations and ratios thereof which provide the best measure of productive capacity for each of the species managed under the FMP. The minimum stock size threshold is the level of productive capacity associated with the relevant ½ MSY level. Should the measure of productive capacity for the stock or stock complex fall below this minimum threshold, the stock or stock complex is considered overfished. The target for rebuilding is specified as B_{MSY} (or reasonable proxy thereof) at the level of productive capacity associated with the relevant MSY level, under the same definition of productive capacity as specified for the minimum stock size threshold.

The best scientific information consistent with National Standards 1 and 2, has not recommended revising the definitions for biological reference points set forward under Amendment 12 to the SFSCBSB FMP. Therefore, these reference points and values are defined as follows in Amendment 12: Overfishing for black sea bass is defined to occur when the fishing mortality rate exceeds the threshold fishing mortality rate of F_{MSY}. Because F_{MSY} cannot be reliably estimated, F_{MAX} (0.33) is used as a proxy for F_{MSY}.

The current biomass reference points are a function of the NEFSC spring bottom trawl survey. The current definitions were adopted as a way to measure stock status in the absence of an analytical age-based stock assessment. Commercial landings of black sea bass reached a peak in 1952 at nearly 9900 mt. From that peak through 1965, the landings averaged nearly 4600 mt whereas from 1966 through 1980 commercial landings averaged 1200 mt. The rationale behind the existing reference point was that the substantial landings prior to 1966 likely represented potential yield at B_{MSY}. The landings in the late 1960s-80s were likely more representative of ½ B_{MSY}. NEFSC spring survey indices began in 1968 and it was concluded that the maximum survey indices coinciding with landings in the 1970s were around ½ B_{MSY} and would therefore represent a biological threshold. To limit year to year variation, the spring offshore survey indices were calculated as a 3 point moving average. The 1977-1979 three year moving average of the spring survey value of exploitable stock biomass (index of black sea bass $\geq$ 22 cm = 0.98 kg/tow), would serve as a biomass threshold. B_{MSY} cannot be reliably estimated for black sea bass.

Without an analytical stock assessment, no current fishing mortality estimates are available to compare to the F_{MAX} proxy of F_{MSY} (0.33). A relative index of exploitation is calculated as total landings /spring survey index of exploitable biomass (defined as sea bass $\geq$ 22 cm). Changes in the relative exploitation index are evaluated for development of management advice. The current definition suffers from the inability to accurately measure fishing mortality relative to F_{MSY}. In addition, reviewers at SARC 43 concluded that the use of the spring offshore survey was not an appropriate measure of relative abundance and was not a valid basis of a biomass reference point. From the SARC 43 reviewer's summary:

"The perception of the status of the stock relative to biomass thresholds is very sensitive to the method used to calculate the survey indices. Not only are the confidence intervals very large, meaning the current biomass is probably indistinguishable from the BRP, but calculating both current biomass and the BRP on a consistent scale (i.e always arithmetic or always logged) can lead to a divergent perceptions of current stock size relative to the BRP. The definition of the biomass threshold was not considered satisfactory. One reviewer questioned whether it was consistent with F_{MAX}. The other pointed out that establishing the biomass threshold as the period of low biomass from which the stock recovered is as plausible as setting the BRP to the early period of high biomass. Given the uncertainty over growth, mortality and selectivity, the estimation of F_{MAX} is uncertain and there is no credible estimate of current fishing mortality with which to compare it. Hence the evaluation of status relative to fishing mortality reference points is not possible."

New analyses

Development of updated biological reference points for black sea bass is hampered not only by a lack of annual age data but also by limited understanding of how black sea bass productivity responds to exploitation. Traditional fisheries models, generally developed for gonochoristic species, may not apply to a protogynous hermaphrodite (Hamilton et al. 2007). Simulation studies of populations exhibiting protogny suggest that conservation of large terminal males is critical for sustainability (Alzono et al. 2008, Brooks et al. 2008, Hamilton et al. 2007, Heppell et al. 2006, Huntsman and Schaaf 1994). The implication is that removal of the terminal male will not only hamper male fertilization success but will induce transitioning of the larger females into males. The consequence is not only removal of male biomass but removal of potential egg production in the larger females. Reduction of dominant males in a population may, in effect, have a similar effect as increasing natural mortality on females.

Tag Release/Recapture model

To evaluate mortality rates, a tag release/recapture study was conducted with 13,794 tagged black sea bass (12,310 legal-size) released between Massachusetts and Cape Hatteras, NC from 2002 to 2004. Of these legal-size releases, 1,683 were recaptured during 2002 to 2007. An instantaneous rates configuration of a Brownie band recovery model was used to estimate both fishing and natural mortality. A seasonal model of fishing mortality, adjusted for non-mixing, and a constant natural mortality best explained the tag recoveries (Shepherd and Moser 2008, *Appendix I*). Fishing mortality estimates ranged between 0.3 and 0.4 whereas the natural mortality estimate was equal to 1.08 (Table 3). The estimate of natural mortality includes the effects of all unaccounted tag losses which could be influenced by an over-estimate of reporting rate (resulting from violation of the assumption that the return rate of high reward tags equaled 100%) or tag attrition (resulting from decreasing legibility of the tags, expulsion of the tags, etc.). An alternative model assuming only 75% reporting of $100 tags and a 9% attrition of tags per season over the recovery period resulted in a decreased estimate of natural mortality of 0.66. Despite uncertainty in the tag model, the results imply that natural mortality of the black sea bass population exceeds 0.2 as used in previous assessments.

Tag recovery data also indicates that extensive seasonal movements occur and are not homogeneous throughout the stock (Moser and Shepherd 2009). During summer months fish throughout the stock remain stationary in coastal areas with very little mixing among adjacent areas. In autumn, offshore migration toward the edge of the continental shelf begins in the north and progresses southward. During the offshore overwintering period on the continental shelf out to the shelf edge, intermixing of fish from various inshore areas is more frequent. Recaptures following spring inshore migrations demonstrate a high degree of site-fidelity with occasional straying to adjacent areas.

Length-based Analytical model

Since annual age information was unavailable, a length based model (SCALE developed by Paul Nitschke, NEFSC) was explored as a method for evaluating sea bass population dynamics. The model details are described in *Appendix II.* SCALE data input included catch time series (mt), NEFSC spring and winter survey recruit and adult indices, growth information, survey length frequencies and catch length frequencies. The model covered the period 1968 to 2007 based on the times series of NEFSC spring offshore surveys.

Commercial length frequencies were compiled beginning with samples in 1984. Sampling was done randomly by market categories and expanded as the ratio of sample weight to total landings, by calendar quarter. Black sea bass were culled as small, medium, large, jumbo or unclassified. In the rare cases where fish were categorized as extra small and extra large, they were combined with small and large, respectively. Total annual length measurements ranged from 300 to 7768 fish with an average of 2956 per year (Table 4).

Commercial discards were estimated since 1989 using a standard approach developed for national standardized by-catch reporting. (Wigley et al., 2008). Observer samples for sea bass were limited to otter trawl trips since 1989. Discard estimates were developed from the ratio of discarded black sea bass in mt to total landings (mt) of all fish species in the comparable statistical area, by half-year periods. Discards from pot and handline fisheries were estimated using the annual ratio of reported discards to landings in vessel trip reports, expanded to total annual landings. Since a component of the pot fishery is prosecuted solely in state waters without a requirement to submit VTR logs, they are not included in the total. A 50% discard survival rate was applied across all commercial gears. Total discards averaged 111 mt annually and represented 17% of reported commercial landings (Table 2). Discards in 1993 and 2004 were well above average at 35% and 62% of landings, respectively.

Complete recreational landings were available from the Marine Recreational Fisheries Statistics Survey (MRFSS) since 1981. Landings for 1968 to 1980 were hindcast based on the relationship between inshore commercial pot and handline landings and recreational landings between 1981 and 1997 (Table 2). In 1998 management regulations were imposed which controlled landings based on quota. The two abnormally large recreational landings in 1982 and 1986 were excluded. The ratio between average recreational landings and pot/handline landings was 2.63. This ratio applied to the commercial pot landings produced the 1968 to 1980 recreational landings. Length frequencies of sea bass were based on dockside sampling by MRFSS staff.

Recreational discard mortalities beginning in 1981 were calculated from MRFSS B2 estimates using a 25% discard mortality rate (Table 2). Discard number was converted to weight assuming comparable mean weight as landings. Between 1981 and 1998 the ratio of discards to landings was relatively constant with an average of 50%. Since 1999, the proportion discarded has increased dramatically averaging 179% of landed sea bass by weight. With a 25% mortality applied, the weight of discards was approximately 50% of landed weight. Length frequencies for recreational discards were not available for the time series.

Fishery Independent Indices

The NEFSC spring bottom trawl survey conducted since 1968 provided indices of relative abundance in number and weight. The review panel in SARC 43 questioned the use of NEFSC bottom trawl survey indices as an index of relative abundance. During autumn, sea bass are generally inshore on structured bottom that is not conducive to sampling with an otter trawl. Consequently those survey results are not considered indicative of sea bass abundance. However, since the 1930's commercial trawl fisheries have had significant landings of sea bass caught offshore during the winter and early spring on the continental shelf. The spring offshore bottom trawl survey takes place in the same areas suggesting that the use of trawl gear for sampling sea bass at this time of year is no less limited by habitat than commercial trawlers. Comparison of survey length frequencies and length frequencies of commercial landings suggest the selectivity at length is comparable (Figure 5). Additionally, the winter survey time series of relative abundance from 1992 to 2007, which uses a trawl with a chain sweep rather than roller gear, was highly correlated to the spring abundance. Although the catch per tow in the spring survey was low, the correlation to the winter survey as well as the comparable length frequency to the commercial fishery suggests that the survey adequately samples sea bass. Finally, the index of abundance from the spring survey also closely resembles the time series of recreational catch per angler trip estimated from MRFSS dockside sampling (Figure 6).

Concern has been raised in the past that environmental conditions significantly influence catchability of black sea bass in the survey. The relationship between catch and environmental anomalies (water temperature and salinity) was evaluated for the survey time series. There was no apparent pattern in deviations of annual survey catches around the time series mean and anomalous temperature or salinity conditions (Figure 7). Local conditions may alter distributions but the influence on the spring index time series appears to be minimal.

The use of $\log_e$ transformation of the survey indices was also criticized by the SARC 43 review panel. A plot of the mean number per tow by strata against the associated variance shows that the variance increases non-linearly (Figure 8). To reduce the influence of over-dispersion on the estimation of the stratified mean, $\log_e$-transform indices (followed by re-transformation) were used in the model. NEFSC spring survey indices with and without transformation are presented in figures 9a and 9b.

The index of exploitable biomass (defined as fish $\geq$ 22 cm presented as the $\log_e$ re-transformed stratified mean weight per tow) beginning in 1968 increased to a peak value in 1976, followed by a decline to the series low in 1982 (Figure 10). A slight rise in abundance was evident in the late 1980s but was followed by a decade of fluctuations around low levels of abundance. Between 1999 and 2002 the index increased again, peaking with the series high in 2002 (1.07 kg per tow), followed by a steady decline through 2008 when the index dropped to 0.18 kg per tow. The 2008 value of 0.19 is below the long-term average of 0.27 fish per tow. The NEFSC winter survey, initiated in 1992, follows a similar pattern with a peak in the $\log_e$ re-transformed index value for 2003 (1.83 kg/tow) followed by declining indices to 0.40 kg/tow in 2007 (Figure 10).

Juvenile indices of black sea bass from the winter and spring surveys provide some insight into cohort strength. The juveniles appear as clearly defined modes at sizes $\leq$ 14 cm in the autumn surveys (Figure 11). There appears to be little growth during the winter, as the same distinct size mode appears in the winter and spring survey length frequencies. In the spring, fish ≤ 14 cm would be considered one year old. Indices were calculated as the sum of $\log_e$ re-transformed mean #/tow at length for sea bass less than or equal to 14 cm. The indices in both the winter and spring surveys suggest large 1999 and 2001 cohorts (peaks in the 2000 and 2002 surveys) (Figure 12). Both of these modes in the length frequency appear the following year as increases in a mode above 20 cm, which is consistent with known growth rates. The winter and spring surveys show an above average 2002 year class and the spring survey shows a strong 1998 cohort that was below average in the winter survey. The 2007 juvenile index in the winter survey was above average.

SCALE Model input

A critical issue in development of new biological reference points is the choice of natural mortality. In the case of black sea bass this becomes particularly difficult due to the unique life history. Methods have been proposed for estimating M based on longevity (Hoenig 1983, Hewitt and Hoenig 2005). Maximum age has been reported by Lavenda (1949) as 12, although he suggests sea bass may survive for up to 20 years, while the oldest fish in a study by Mercer (1978) was age 9. NMFS spring survey age data collected in the 1980s found a sea bass at age 10. More recently, a trawl caught sea bass of 61 cm and 4 kg was taken in the winter of 2007 off the mouth of the Chesapeake Bay and aged as 9 years using otoliths (Chris Batsavage, pers. comm.). Additionally, a study at VIMS repeating the work of Mercer identified a fish as age 12 (R. Pemberton, pers. comm.) while Caruso (1995) found the oldest fish to be age 7. Applying the Hoenig regression method for maximum age suggests that M could possibly be between 0.37 (age 12) and 0.55 (age 8) (Figure 13). The results of the tag model previously noted suggest a much higher natural mortality of 1.08 for the period 2003-2007. If M were really greater than 1.0 at all sizes, it would be equivalent to a maximum age of 4 in the Hoenig model. However, if the tagging model assumptions of 100% reporting of high reward tags were relaxed to equal 75% and tag attrition of 9% applied, the estimate of M decreases to 0.66. It is clear from multiple approaches that natural mortality of the population is greater than 0.2. As an alternative to a constant natural mortality across sizes, M was also modeled as a logistic function of size (Figure 14). This was an attempt to include both a high natural mortality and a subgroup with a longer potential life expectancy. The point of inflexion corresponded to the approximate age when transition occurs.

Included as input to the SCALE model were spring and winter offshore indices of adult and juvenile abundance. The spring series of stratified $\log_e$ re-transformed mean number per tow included 1968 to 2008 while the comparable indices from the winter survey were 1992 to 2007 (Figure 15). Mean lengths at age were predicted from a growth curve averaged from available studies and length-weight equation parameters were from fitted length-weight data collected on NMFS surveys. Total catch (mt) was commercial landings since 1968, recreational landings since 1981 estimated by MRFSS and 1968 to 1980 estimates derived from commercial inshore fishery landings, recreational discard losses since 1981 and commercial discard estimates since 1989. The model was not restricted to fitting the catch exactly by assuming error in the catch estimates. The model was fitted to survey length frequencies greater than 30 cm to counter the lack of discard length data in the fishery length frequencies. Selectivity periods were chosen based on regulatory changes in the fisheries. The three periods were 1968 to 1997, 1998 to 2000 and 2001 to 2007. The model was allowed to fit the initial fishing mortality in phase two.

Models were developed with a range of natural mortalities under an assumption of either a constant or logistic pattern. Within the logistic model assumption, a variety of logistic model parameters were used to generate a suite of M estimates. A total of 26 various M patterns were evaluated and the SCALE model results are presented in Table 5 and Figures 16-21.

In general, the SCALE model adequately described the length frequency data from the fisheries and the associated catch. The general pattern in the spring and winter survey indices were adequately predicted by the model, although the magnitude of some recruitment events was somewhat reduced. With constant M the model fit as defined by the objective function improved with increasing M until M exceeded 0.8. Similarly the value of the objective function declined with increasing M for the logistic M model. However, reduction in the objective function with increasing M may also be a result of faster removal of fish in the model which ultimately limits variation in model fit. Alternative models using higher M with different values at length are also possible. Within the output for each model run, SCALE produces values for selectivity at length, fishing mortality estimates, biomass and abundance estimates. Annual spawning biomass estimates were developed outside of the model software using population numbers at length multiplied by mean weight at length and proportion mature at length from NEFSC survey data.

New Biological Reference Points

The current overfishing definition for black sea bass is based on F_{MAX} as a proxy for F_{MSY}. The F_{MAX} value was calculated using an M=0.2 and a maximum age of 15 and predicts an F_{MAX}=0.33. The biomass reference point is a 3 year moving average of stratified mean weight per tow of exploitable biomass for 1977-1979. The proposed new reference point incorporates additional fishery and biological information in addition to the NEFSC spring and winter bottom trawl survey indices. Evaluation of natural mortality suggests that M is likely greater than 0.2.

A length based yield per recruit model from the NOAA Fisheries Toolbox was used to develop estimates of reference points. From each of the 26 SCALE models run, the associated M and fishery selectivity parameters were input to the YPR model. Per recruit values from each model run were expanded to population values using the average recruitment from the 1968-2007 time series as estimated by SCALE. Average von Bertalanffy growth parameters from among several studies were used to define growth (Figure 19) and an average selectivity curve from 2001-2007 (Figure 20) was incorporated into the yield per recruit model. Resulting yield per recruit and SSB per recruit at F40% were multiplied by average long-term recruitment (1968-2007) to produce total yield, spawning biomass (sexes combined). These values and F at $F_{40\%}$ were compared to the 2007 SCALE model results (Figures 21 and 22) to evaluate stock status.

Selection of the preferred model for black sea bass was based on a decision matrix using information from recent trends in NEFSC survey indices, comparison of MSY to long term yield and the ratio of 2007 F and total biomass to F and biomass at $F_{40\%}$. The reference point in the existing FMP for sea bass was predicated on the assumption that MSY occurred at some point midway through the decline in landings experienced in the 1950s and 1960s. However, since the decline leveled off in the late 1960s, catch has remained relatively stable around 3,100 mt (the period following implementation of quotas in 1998 was not included in this average). This implies that catches around 3,100 mt may be sustainable, although not necessarily maximum (landings greater than 10,000 mt in 1952 suggests an upper bound of potential landings). Recent trends in survey indices of the entire stock show a steady decline in abundance and biomass since 2003 and 2002, respectively. This declining trend despite restrictive quotas would suggest that the stock is unlikely at or above any optimal biomass level. Therefore the suite of 26 model runs were judged using the proximity of predicted optimal yield relative to average yield since the 1960s which was assumed to be near MSY and the 2007 model estimates of fishing mortality and biomass relative to the associated biomass and F reference points. Among candidate models, only those with both 2007 F to $F_{40\%}$ ratios between 0.8 and 1.4, and predicted equilibrium yield between 3,900 and 4,200 mt were considered candidates as preferred models. Only three models fulfilled the selection criteria: constant M at 0.4 and two logistic models with starting F=0.6 (Table 6). Since there is currently no empirical evidence to suggest that natural mortality declines as a logistic function of size, the model using constant M=0.4 was chosen as the best model.

The preferred model option with a constant M=0.4 has an F at 40% of maximum spawning potential equal to 0.42 and $F_{0.1}$ of 0.37. F_{MAX} equals 0.975 and is poorly defined. The associated spawning stock biomass per recruit at $F_{40\%}$=0.45 and total biomass per recruit= 0.50 (Figure 23). Applying age 1 recruitment (averaged from 1968 to 2007) of 27,875,990 recruits to per recruit values, total biomass at F=0 is 32,816 mt and at $F_{40\%}$ is 13,977 mt. Spawning biomass (sexes combined) at $F_{40\%}$ equals 12,537 mt. The 2007 estimates of F from the SCALE model using the constant M for 0.4 is 0.48 with an estimated total biomass of 12,892 mt and a spawning stock biomass of 11,478 mt. Using $F_{40\%}$ as a proxy for F_{MSY}, the implication is that 2007 fishing mortality (0.48) exceeds F_{MSY} by 15% and 2007 spawning biomass (11,478 mt) is 8% below B_{MSY}. However, the biomass is above the threshold (1/2 B_{MSY}) and would not be considered overfished. The reference points for M = 0.4 are presented in Table 7.

As a check on the scale of the stock size estimates, yield associated with $F_{40\%}$ (a proxy for MSY) under average recruitment would be 3,903 mt. This compares with the estimated average catch since 1968 of 3,100 mt. In addition, the peak landings in the early 1950s of between 10,000 and 12,000 mt would be well above optimal yield and would expected to result in a declining abundance, as was observed.

Although predicted adult survey indices from model results using a constant M=0.4 followed the general trend of the observed values, residuals patterns show predicted indices greater than observed indices for 2004 to 2007 (Figure 24). This would suggest that the predicted abundance was greater than observed and consequently the model may overestimate predicted abundance. Additionally, the sensitivity of the yield per recruit at length and catch at length models has not been fully evaluated for sensitivity to input values.

Developing biological reference points for hermaphroditic species requires consideration of the unique life history characteristics. Simulation modeling studies have shown that protogyny has little effect on yield per recruit if growth rates between sexes are comparable (Shepherd and Idoine 1993). In contrast, the effect of transitioning can have a significant effect on the calculation of female spawning biomass. However, without information about spawning efficiency the optimal approach is to consider spawning biomass as combined male and female biomass (Brooks et al. 2008). In addition, if the efficiency of spawning is a function of the presence of a dominant male, then conservation of the large males may be critical (Alonzo,S.H. 2008, Heppell et al. 2006). However, the effect of removal of males on the sex ratio, and consequently transition rate from female to male, remains unknown for black sea bass.

Suggested improvements

In order to improve the stock assessment of black sea bass and corresponding biological reference points, additional fishery independent surveys for black sea bass may be necessary. An alternative survey gear for sea bass may be fish pots or hand lines. Since pots could cover a wider area, a stock wide fish trap survey should be developed to evaluate relative abundance. Additionally, experimental and field evaluation of spawning behavior is necessary to better understand the implication of exploitation on sea bass.

Age analysis of NEFSC survey samples is currently underway in cooperation with MA DMF and could potentially improve the assessment models. There is some evidence of regional differences in growth that should be further explored.

Tagging data suggests regional differences in migration pathways and possible sub-populations. Although the assessment model results suggest the overall stock is near F_{MSY} and B_{MSY}, local groups of sea bass could vary from this overall status. Consequently, increased catch in some areas may exacerbate already declining abundance. Consideration should be given to evaluating alternative management approaches that account for regional differences in recruitment patterns and abundance.

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