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Black Sea Bass 2009 Stock Assessment Update

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ABSTRACT

The northern stock of black sea bass (*Centropristis striata*) was evaluated using length-based population models. This new assessment approach was accepted by the Data Poor Workshop review panel (NEFSC 2009) and involved estimates of fishing mortality and population size determined from changes in size composition of the population. The panel accepted the 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 spawning stock biomass (SSB) equal to 12,537 mt and MSY at 3,903 mt. The 2008 average F, resulting from a catch of 2,039 mt, was estimated at 0.28 and SSB at 12,882 mt. Therefore, the conclusion is that fishing mortality is below F_{MSY} and the stock is above the optimal level of spawning biomass. These reference points and current stock status should be used with caution due to the uncertainty in the natural mortality estimate and the model input parameters as well in the uncertainty associated with management of protogynous species.

INTRODUCTION

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 (Musick and Mercer 1977, Moser and Shepherd 2009). 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 (New Jersey to Maryland) head offshore to the shelf edge during late autumn, travelling in a southeasterly direction. They also 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.

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 a 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 fishes, 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 it was noted that large males (>45 cm) were present in deeper water and may have been older. Size at age information and Von Bertalanffy curve parameters used as input to model are shown in Table 1. Although growth information is available for use in models, annual age length keys are not, therefore sea bass modeling efforts are length based rather than age based.

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

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. During the same period, a large increase in fish pot effort, and subsequent landings, occurred in New Jersey. 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 1,400 mt. (Table 2). Recreational landings, available from Marine Recreational Fishery Statistics Survey (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, potential causes for these apparent anomalies are unknown.

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. During this offshore period, sea bass are vulnerable to otter trawl gear as part of a multispecies fishery (Shepherd and Terceiro 1994).

Stock assessment history

Black sea bass stock assessments have been reviewed in the SARC/SAW process beginning in 1991 with an index-based assessment (SAWs 1, 9, 11, 20, 25, 27, 39 and 43). In 1995 a Virtual Population Analysis (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 was considered to be 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 a hermaphroditic species. A suggestion was made to use an alternative approach such as a tag/recapture program. 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. That review panel concluded that a simple R/M tag model, as well as an analysis of survey indices, produced acceptable results to determine status. The release of tags continued through 2004 and results of tag models as well as indices were presented to reviewers in 2006. They concluded that the tag model did not meet the necessary assumptions and the variability in the survey indices created uncertainty which prevented reaching a conclusion regarding stock status. The panel did not recommend any alternative reference points, however they did recommend continued work on length-based analytical models.

Biological Reference Points

Development of 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.

The biological reference points in Amendment 13 of the Summer Flounder, Scup and Black Sea Bass Fishery Management Plan (FMP) are a function of the NEFSC spring bottom trawl survey. Those 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 9,900 mt. From that peak through 1965, the landings averaged nearly 4,600 mt whereas from 1966 through 1980 commercial landings averaged 1,200 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 three- 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} could not be reliably estimated for black sea bass.

Biological reference points for black sea bass were addressed at the NEFSC Data Poor Workshop held in December 2008. The panel of experts reviewed the findings of the working group and recommended abandoning the previous reference points in favor of new metrics based on the results of a statistical catch at length model. As part of the revised model, the natural mortality of the stock was assumed equal to 0.4 rather than the previously used 0.2. The Panel recommended an F_{MSY} proxy of $F_{40\%}$, estimated with the new model to be F =0.42, and a related SSB_{MSY} proxy of 12,537 mt.

METHODS

Fisheries Dependent Data

Since annual age information was unavailable, a length based model (SCALE developed by Paul Nitschke of the NEFSC) was explored as a method for evaluating sea bass (NEFSC 2009). SCALE data input includes catch history, survey indices, recruitment indices, growth information, survey length frequencies and catch length frequencies (Figure 3). The updated model covers the period 1968 to 2008 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 have ranged from 300 to 7,768 with an average of 2,956 per year (Table 3).

Annual commercial landings were determined from the NEFSC and state data. In recent years, the predominant gear type for back sea bass has been fish pots, otter trawls and handline. Landings between 1996 and 2006 averaged 1,326 mt, however following quota reductions landings in 2007 declined to 1,016 mt and continued in 2008 to 850 mt. Commercial discards were estimated since 1989 using a standard approach developed for national standardized by-catch reporting. (Wigley et al., 2008). Observer samples 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. Pot and handline discards were estimated using the ratio of reported discards to landings in vessel trip reports, expanded to total annual landings. Since a component of the pot fishery is solely in state waters and not required to submit VTR logs, they are not included in the total. A 50% 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. The total commercial discards estimated for 2008 were 21 mt for all gear types based on the discard to kept ratio for black sea bass in the VTR records.

Complete recreational landings north of Cape Hatteras were only available after 1981. Landings in 2008 were 742 mt, a decrease from 1,031 mt in 2007. Landings were hindcast to 1968 using the relationship between commercial pot and handline landings with 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 recreational landings for 1968 to 1980. Length frequencies of sea bass were based on dockside sampling by MRFSS staff.

Recreational discards were from MRFSS estimates of discards using 25% discard mortality as in previous assessments (Table 2). Discard number until 2004 was converted to weight assuming comparable mean weight as landings. Discard estimates for 2005-2008 were based on mean weight of sea bass discards measured on for-hire vessels as part of the MRFSS program. 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 generally 45% of landed weight. Since 2000, total weight of discard losses of sea bass averaged 497 mt. Black sea bass discard losses in 2007 equaled 339 mt and increased to 426 mt in 2008.

Fishery Independent Data

The NEFSC spring bottom trawl survey conducted since 1968 provides 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, commercial trawl fisheries since the 1930's have had significant landings of sea bass caught 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 not hampered by habitat. Comparison of survey length frequencies and length frequencies of commercial landings suggest the selectivity at length is comparable (Figure 4). Additionally, the winter survey relative abundance time series from 1992 to 2007, which was included in the model as an index of abundance, is 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 is able to sample 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 5).

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 6). Local conditions may alter distributions but the influence on the spring index time series appears to be minimal.

The log 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 7). To reduce the influence of over-dispersion on the estimation of the stratified mean, log-transform indices (i.e., $\log_e (x+1)$ followed by re-transformation) were used in the model. NEFSC spring survey indices before and after transformations are presented in Figures 8a and 8b.

The index of exploitable biomass (defined as fish $\geq$ 22 cm presented as the $\log_e$ re-transformed stratified mean weight per tow) began in 1968 increased to a peak value in 1976 followed by a decline to the series low in 1982 (Figure 9). A slight rise in abundance was evident in the late 1980s but followed by a decade of fluctuations around low levels of abundance. Between 1999 and 2002 the index increased again peaking in the series high in 2002 (1.1 kg per tow), followed once again by a steady decline through 2008 when the index dropped to 0.19 kg per tow. The latest value 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 9).

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 (Figure10). 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 $\leq$ 14 cm would be considered one year old. Indices were calculated as the sum of log 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 11). 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 2008 spring juvenile index was slightly above average.

SCALE Model Input

Included as input to the SCALE model were NEFSC spring and winter offshore indices of abundance. The spring series of stratified ln re-transformed mean number per tow (+1) included 1968 to 2008 while the comparable indices from the winter survey were 1992 to 2007 (Figure 12). Juvenile indices in the spring and winter surveys were computed as the sum of re-transformed indices at length for fish less than or equal to 14 cm. Mean lengths at age were predicted from an average growth curve among available studies and length-weight equation parameters were from fitted length weight data collected on NMFS surveys. Total catch was commercial landings since 1968, recreational landings since 1981 estimated in 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 allowed to fit 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 2008. The model was allowed to fit the initial fishing mortality in phase two. The model was fit with a constant natural mortality of 0.4.

A variety of model configurations were examined. Initial runs suggested that the winter juvenile index for 2007 heavily influenced the results in the terminal year of 2008. Several runs were made removing the 2007 winter recruitment index as well as two runs which included the autumn recruitment index. Additional variations included changes in the weighting for catch, recruitment indices and spring adult indices. A summary of the ten runs used to characterize the range of uncertainty in the model configuration are presented in Table 4.

The final results were based on a model averaging approach (Burnham and Anderson 2002) with the averages weighted by the inverse of the value of the likelihoods normalized to the mean. Confidence intervals (95%) for the average were based on the variation among the 10 models, not from estimates of within model variation. Model output included total biomass, fishing mortality and population number at length. The population numbers at length were used to calculate annual estimates of spawning stock biomass (based on a length–weight equation and maturity at length from NEFSC survey results).

RESULTS

SCALE Model results

Estimated fishing mortality has declined steadily since a recent peak in 2001 of 1.1 (Figure 13). The 2008 value was below F_{MSY} (0.42) with the average among models equal to 0.28, decreasing from the 2007 estimate of 0.37. Consequently, overfishing is not occurring in black sea bass. The model results indicate fishing mortality declined below Fmsy in 2005 and has been declining steadily since 2001.

Biomass exceeded B_{MSY} (13,977 mt) in 2002 through 2004 then declined slightly (Figure 14). Estimates for 2008 (model average of 14,346 mt) increased to above B_{MSY}, although the confidence intervals encompassed B_{MSY}. SSB followed a similar pattern, increasing above SSB_{MSY} (12,537 mt) in 2002-2005 then declining slightly in 2007 but increasing again in 2008 to 12,882 mt (Figure 15). The bounds of the 2008 estimates include the value of the reference point.

Recruitment estimated by the model was relatively constant through the time series with the exception of the 1999 and 2001 year classes (Figure 16). These cohorts appeared to be the driving force behind the increase in biomass and SSB. The estimated recruitment (age one) in

2008 of 27.8 million fish (2007 cohort) is equivalent to the long term average of 27.9 million recruits.

Retrospective analysis was done by sequentially removing the terminal year in the analysis back 5 years to 2003. The analysis was done for Model Run 7 which had comparable results as the model average. Results (Figure 17) suggest minimal retrospective bias in fishing mortality or recruitment. Total biomass shows the potential for overestimation in the terminal year.

Projections

Deterministic projections for black sea bass were made using the SCALE model. Averages across final values from the model results for catch, recruitment, survey indices, etc. were input as fixed values in the SCALE input. Catch estimates for 2009 were assumed equal to the landings quota plus a 3 year average of commercial and recreational discards. Length composition was assumed constant since 2008. Fishing mortality in 2009 was iterated across possible values until the model produced a catch equivalent to the observed 2009 catch. Projections for 2010 were completed by inputting a value for fishing mortality, such as F_{MSY}, and allowing the model to predict the associated catch. Additionally, an iterative process with F was used to produce catch equivalent to MSY.

Under the current 2009 quota, fishing mortality was calculated as 0.18. The subsequent catch in 2010 for a fishing mortality equal to F_{2008} (0.28) projected to be 2,642 mt (Table 5). Similarly, a 2010 F equal to F_{MSY} (0.42) would result in an expected total catch of 3,741 mt, while an F of 0.36, which is midway between F2007 and F_{MSY}, would project to a catch of 3,286 mt. In all cases, the expected total biomass would exceed B_{MSY} beginning in 2009. A similar projection fixing the catch at MSY at 3,900 mt would project to a fishing mortality of 0.445. Total biomass and SSB associated with each F is presented in Table 5. In all cases Jan 1, 2011 spawning biomass remains above SSB_{MSY}.

CONCLUSION

The conclusion of the assessment update is that black sea bass are not overfished and overfishing is not occurring. Projections through 2011 suggest that an increase in fishing mortality up to F_{MSY} will not result in a decrease in biomass below B_{MSY}. However, underlying these conclusions is the uncertainty associated with an assessment of a data poor stock as noted in the Northeast Data Poor Stocks Working Group report (NEFSC 2009),

> "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)."

In addition, tagging results suggest spatial partitioning along the coast that is not yet accounted for in the assessment model. Consequently the results may not reflect the stock condition in all local groups of black sea bass.

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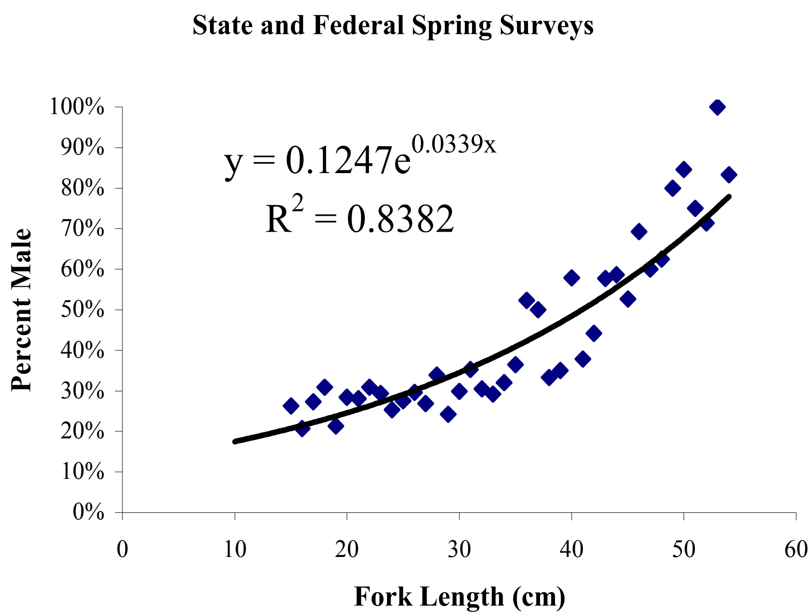

Figure 1. Sex ratio of black sea bass at length (cm) from combined NEFSC and MA DMF spring surveys.

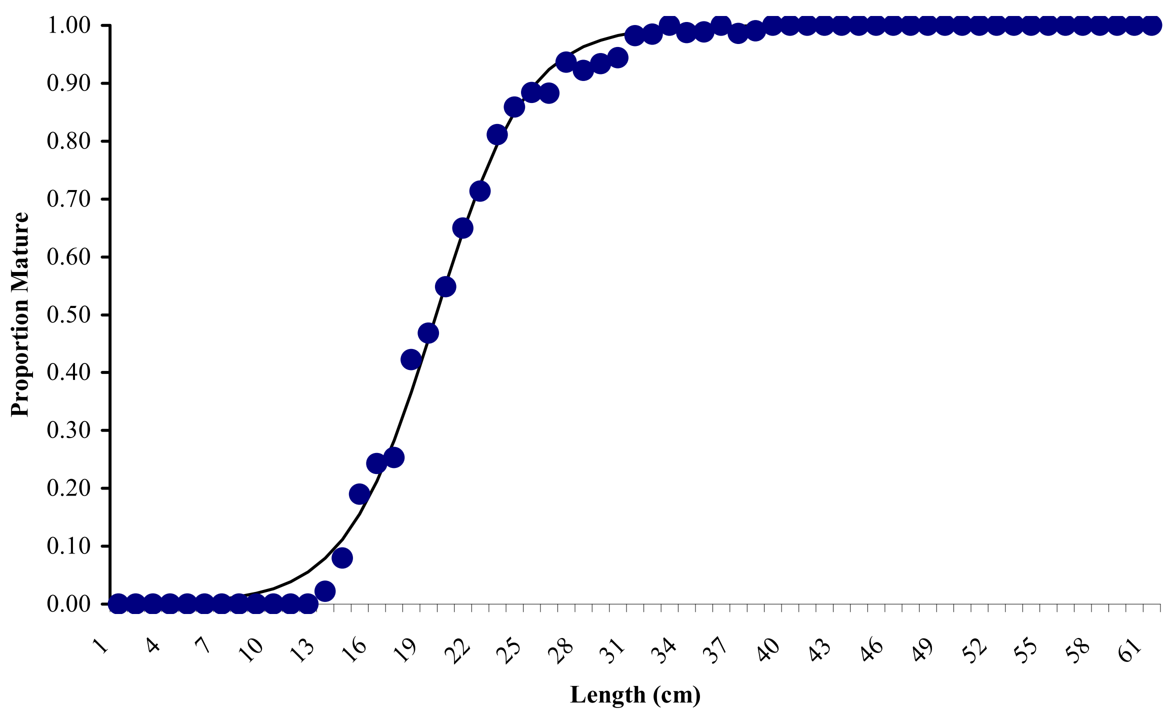

Figure 2. Proportion mature (male and female combined) by length based on samples from NEFSC spring surveys. Data from all years combined.

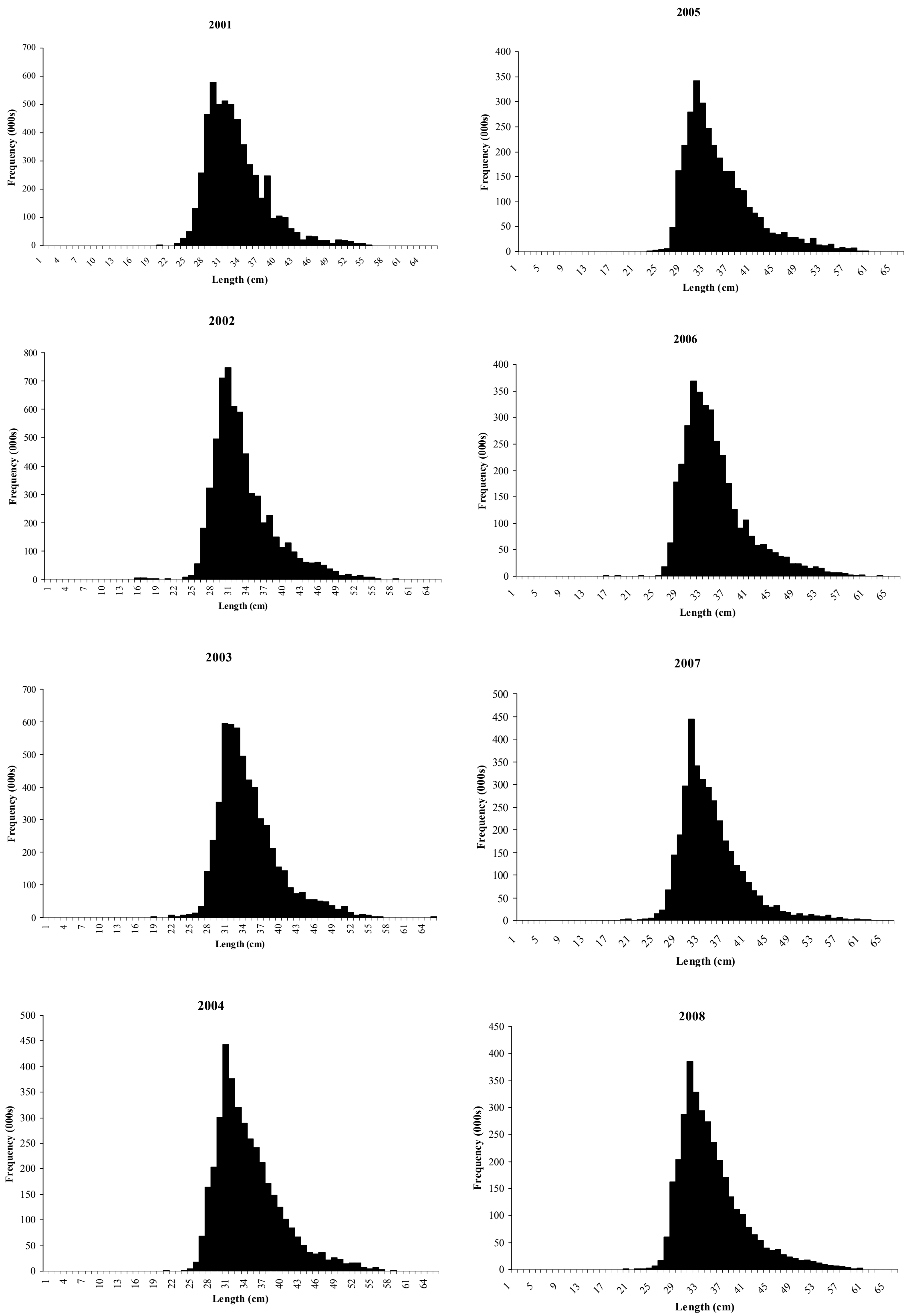

Figure 3. Length frequencies from commercial and recreational black sea bass fisheries, 2001-2008.

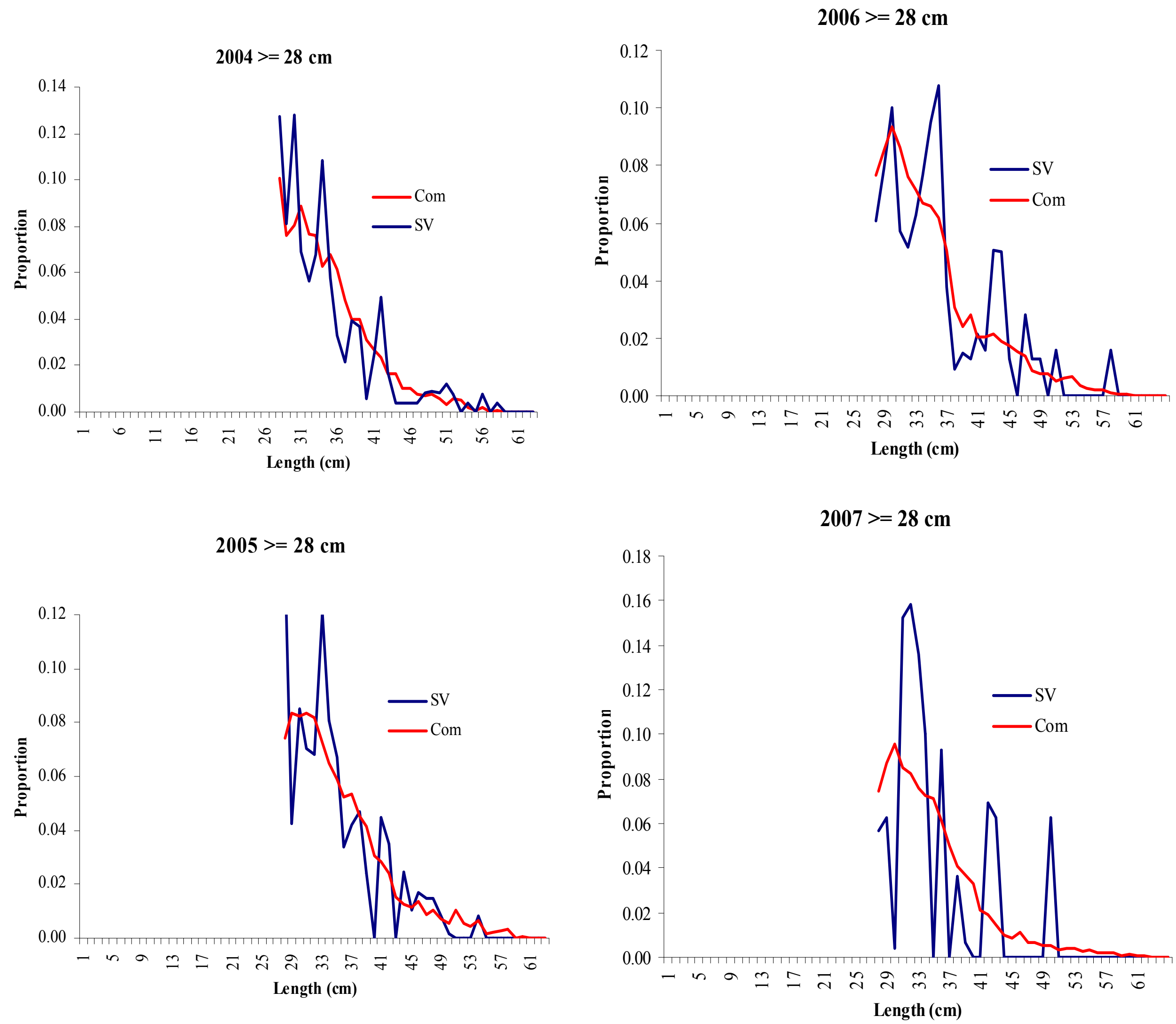

Figure 4. Comparison of proportion at length between commercial fisheries and NEFSC spring offshore survey. Sizes limited to lengths at full recruitment to the fisheries.

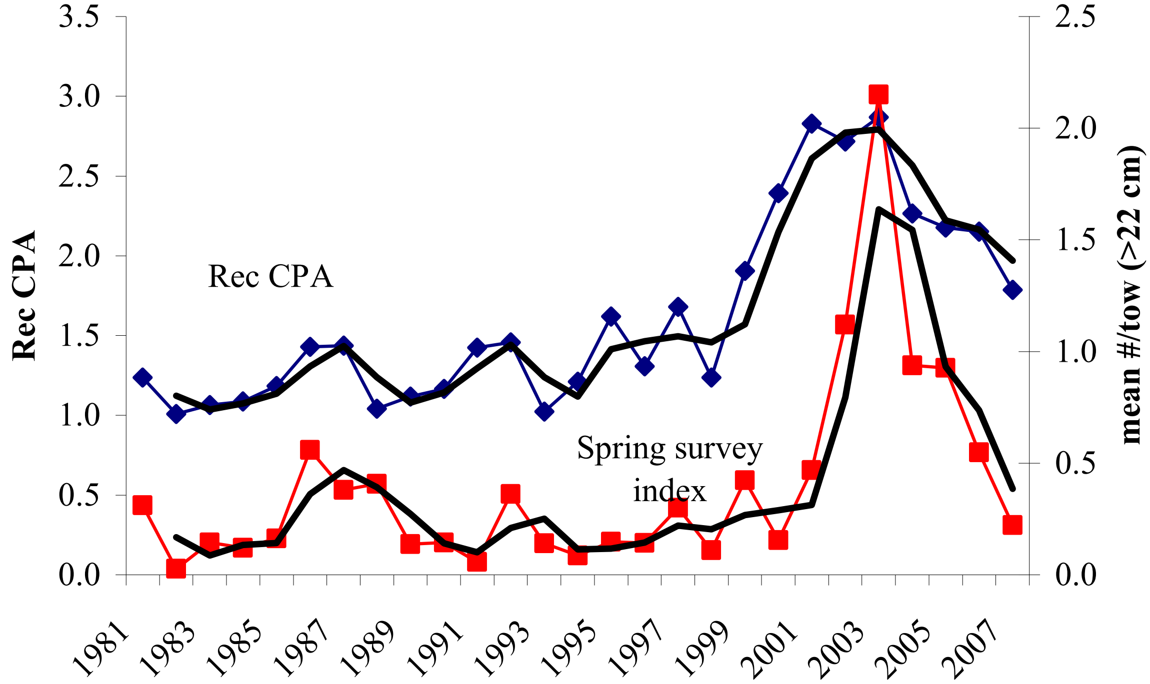

Figure 5. NEFSC Spring offshore survey stratified mean number per tow compared to MRFSS number per angler trip. Heavy solid lines are three point moving averages.

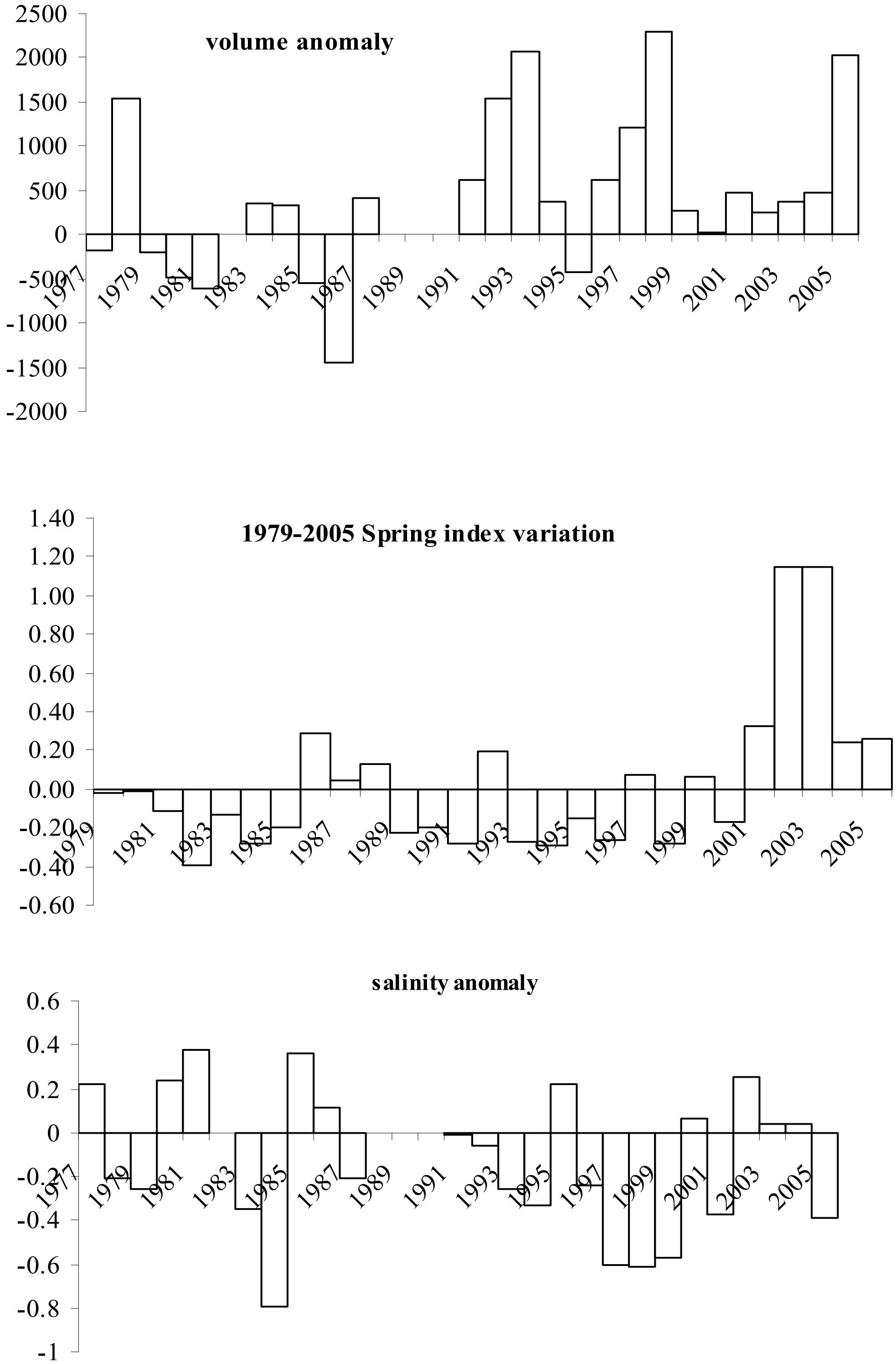

Figure 6. Spring oceanographic anomalies in the Mid-Atlantic and variation from the time series mean of NEFSC spring survey indices.

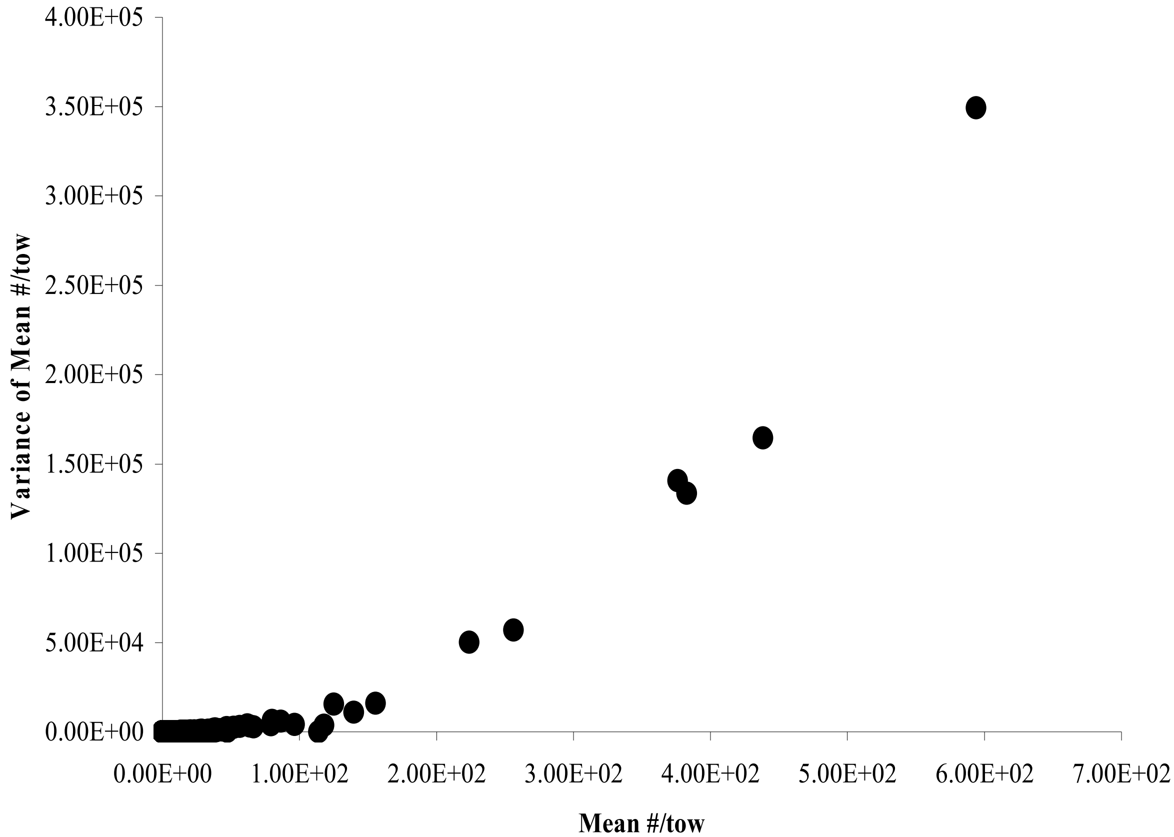

Figure 7. Relationship between black sea bass mean #/tow and associated variance for NEFSC Spring survey. Points represent individual strata for all years.

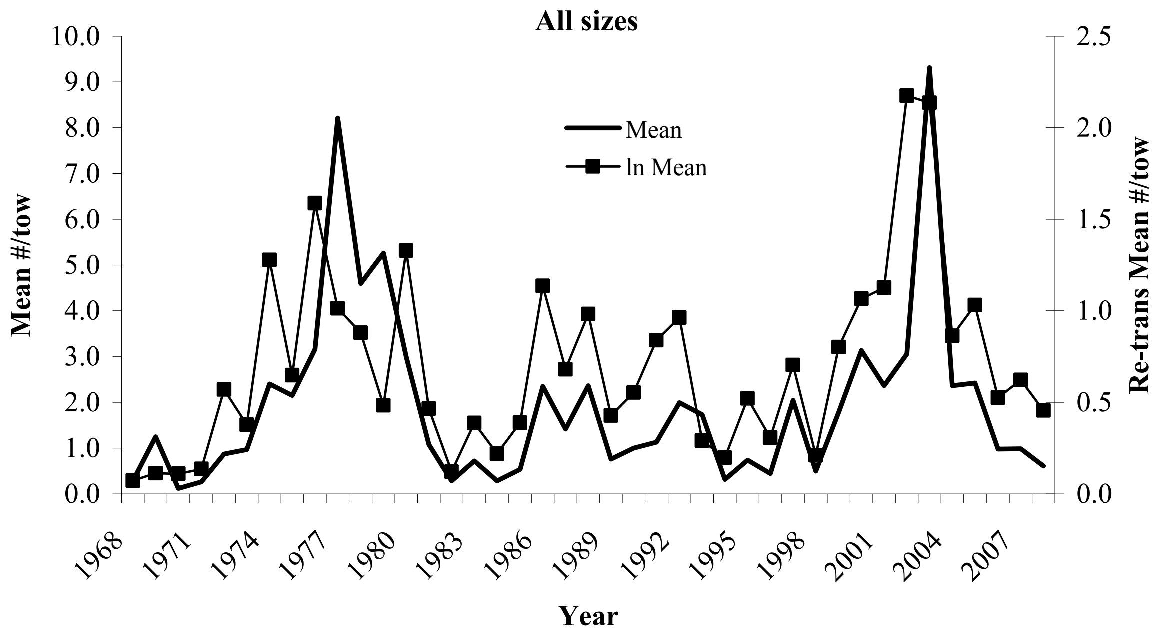

Figure 8a. NEFSC spring offshore stratified mean num/tow and re-transformed loge stratified mean num/tow for black sea bass of all sizes.

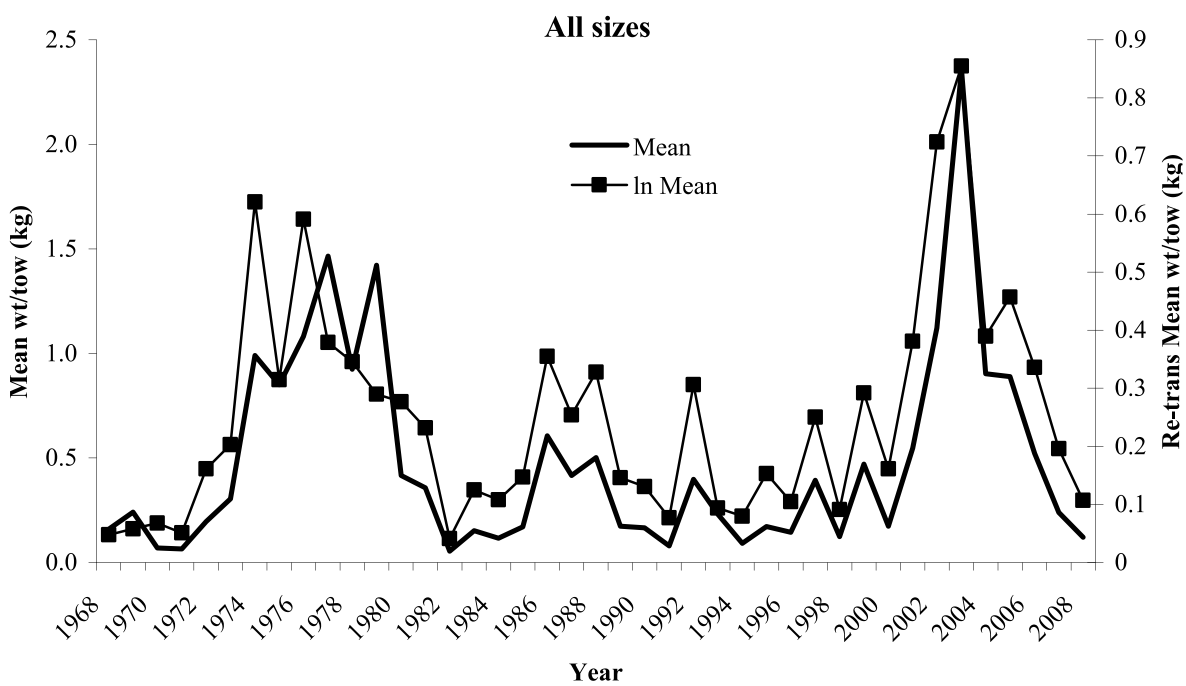

Figure 8b. NEFSC spring offshore stratified mean wt/tow (kg) and re-transformed loge stratified mean wt/tow (kg) for biomass of black sea bass, all sizes.

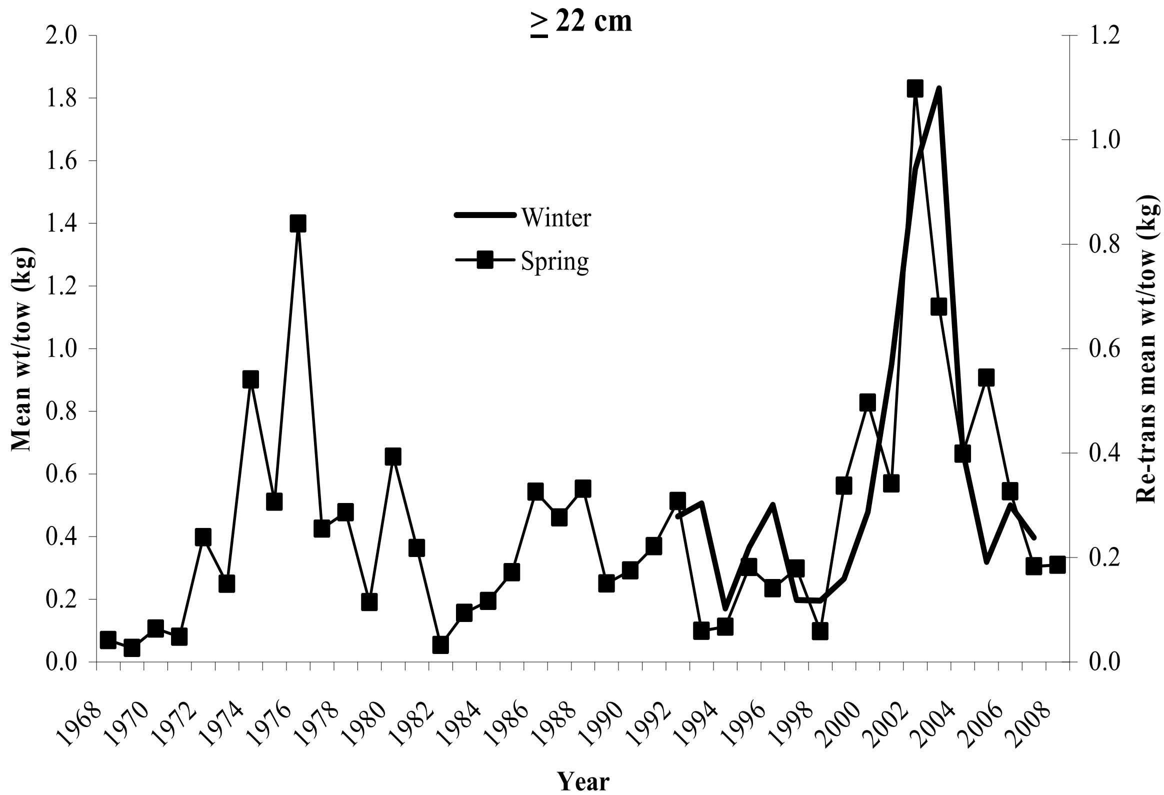

Figure 9. NEFSC spring and winter offshore re-transformed loge stratified mean wt/tow (kg) indices for exploitable biomass of black sea bass (≥ 22 cm).

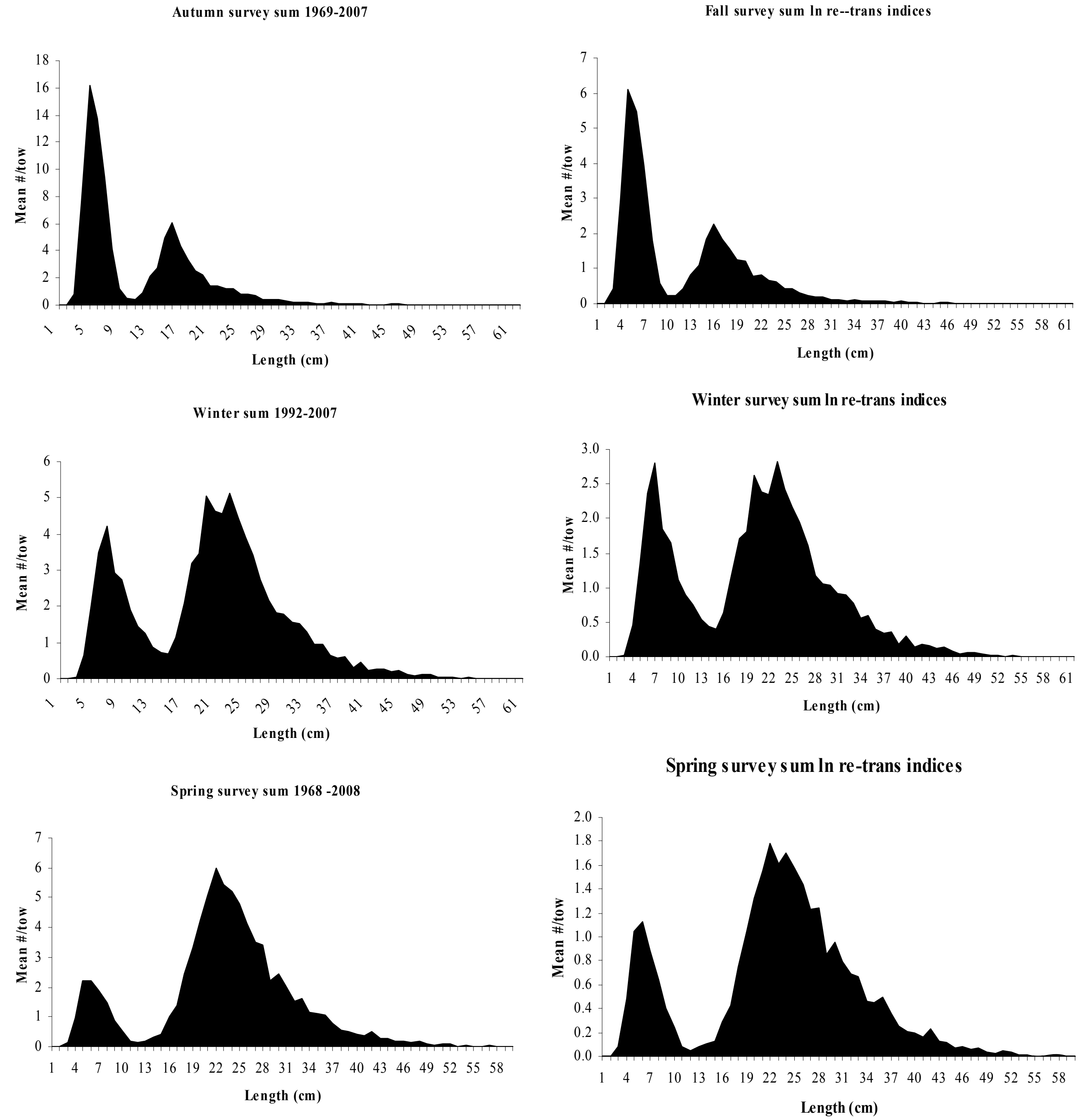

Figure 10. NEFSC spring, winter and autumn length frequencies for combined years. First distinctive mode represents recruits.

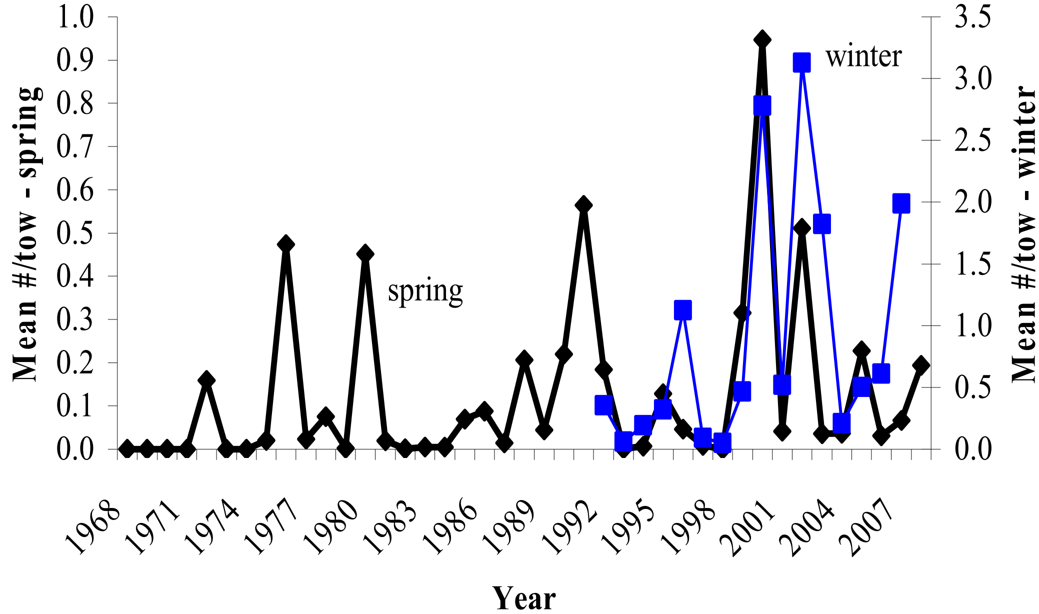

Figure 11. NEFSC spring (diamonds) and winter (squares) indices of juvenile abundance (stratified mean #/tow for sea bass ≤ 14 cm).

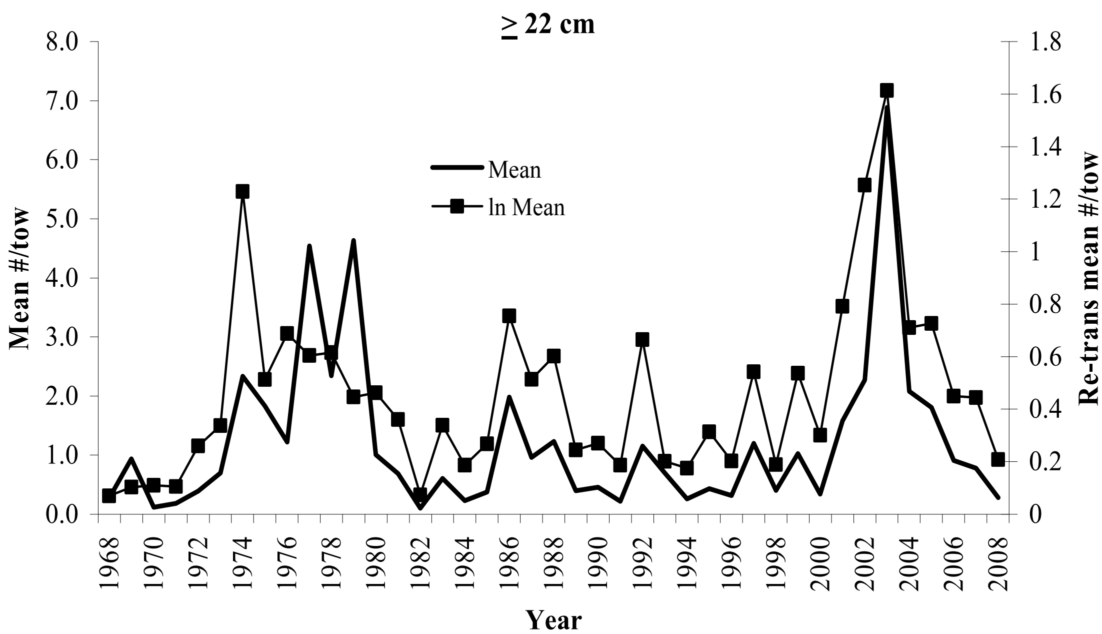

Figure 12. NEFSC spring offshore and winter survey indices (mean #/tow) for black sea bass > 22 cm. Indices of relative abundance used as input to SCALE model.

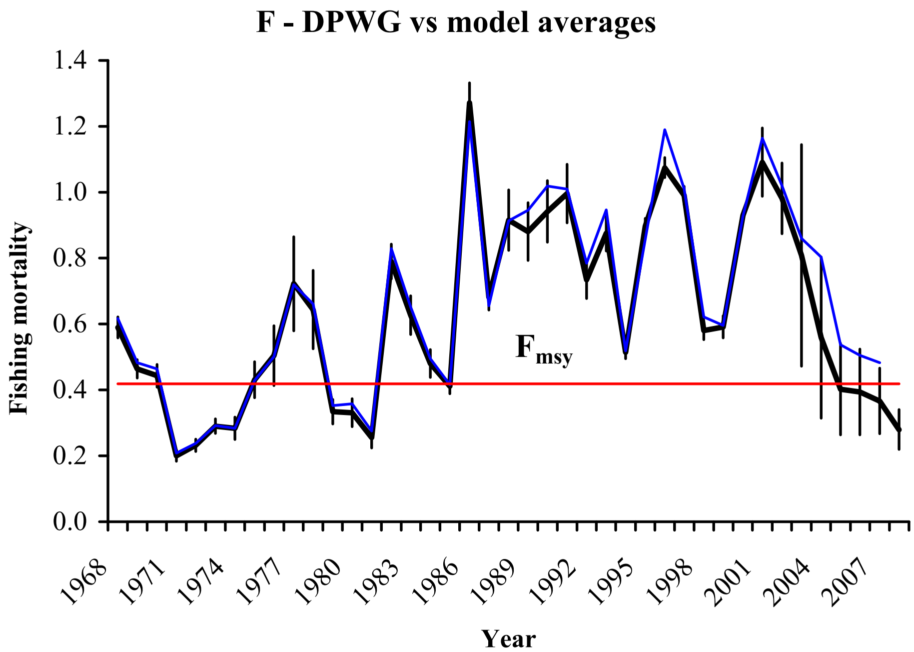

Figure 13. Fishing mortality predicted by SCALE model (thin line) for DPWG model and model average update (heavy line). 95% CI reflect variation among 10 models used in model average. F_{MSY} value from DPWG results.

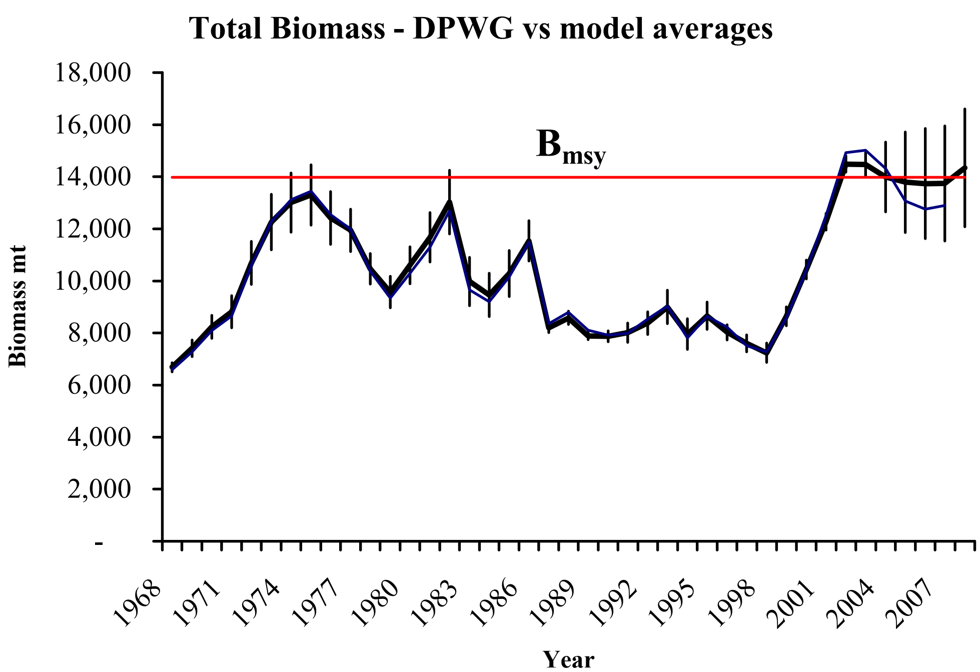

Figure 14. Total biomass predicted by SCALE model (thin line)for DPWG model and model average update (heavy line). 95% CI reflect variation among 10 models used in model average. B_{MSY} value from DPWG results.

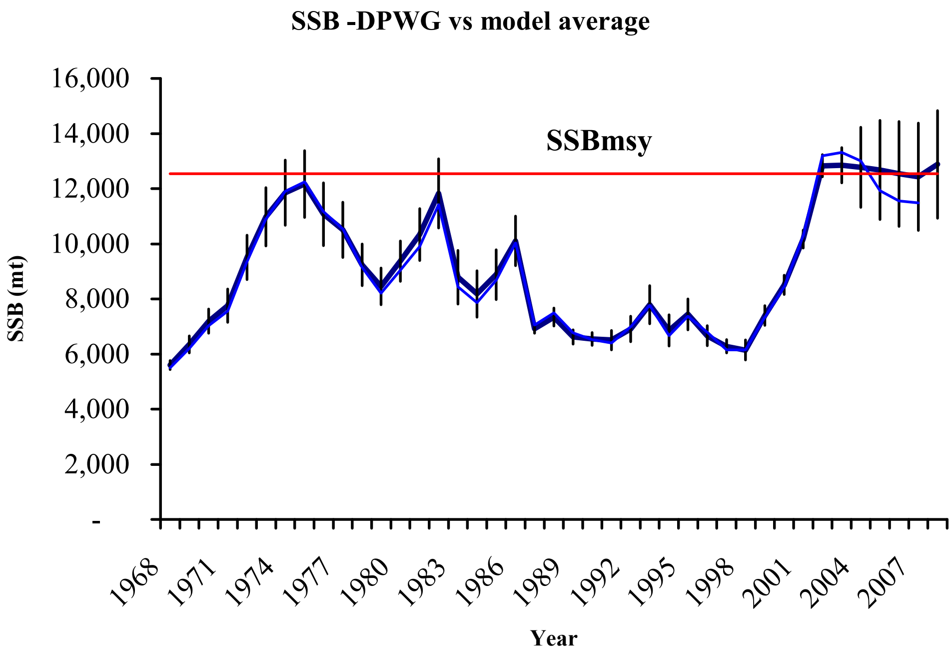

Figure 15. Spawning stock biomass predicted by SCALE model (thin line) for DPWG model and model average update (heavy line). 95% CI reflect variation among 10 models used in model average. SSB_{MSY} value from DPWG results.

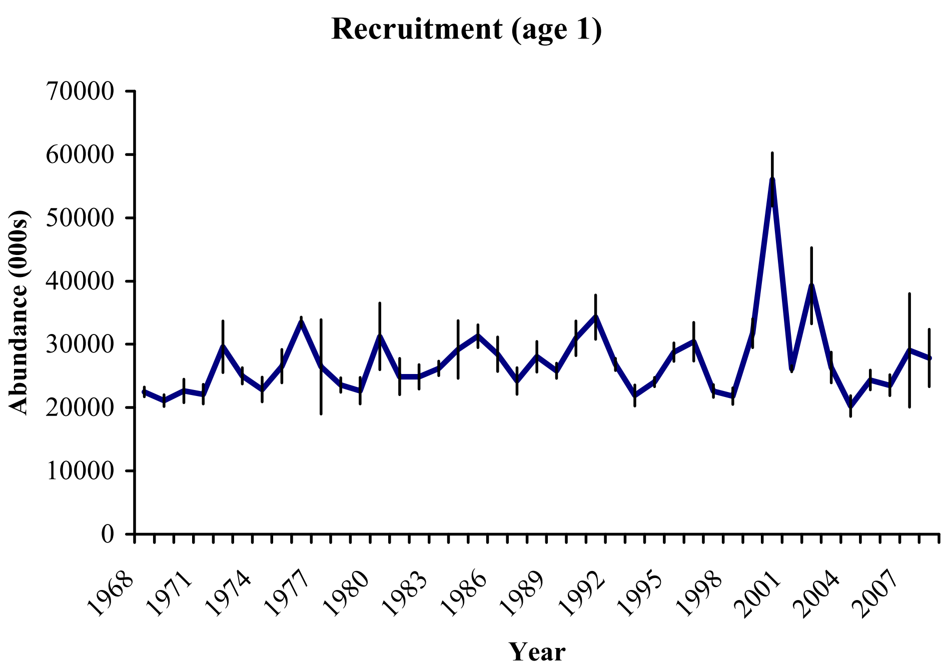

Figure 16. Recruitment predicted by SCALE model (thin line) for DPWG model and model average update (heavy line). 95% CI reflect variation among 10 models used in model average.

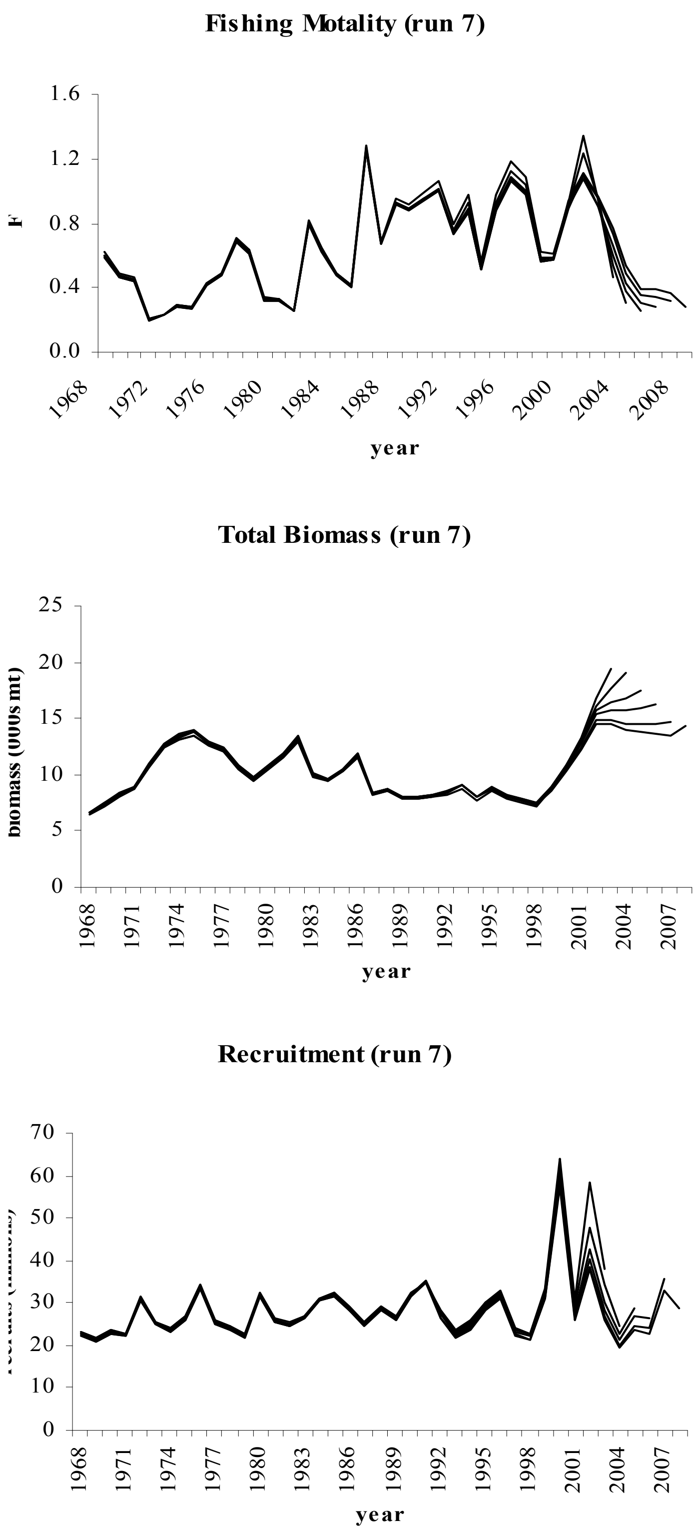

Figure 17. Retrospective pattern for F, total biomass and recruitment using the model average results as well as run 7 which was comparable results to model average.

Table 1. Black sea bass growth curve and associated length at age information available. Average values used for model input.

	Pemberton	Mercer	NMFS winter	NMFS spring	Average
L_{inf}	61.8	65.9	46.2	47.7	55.4
K	0.21	0.16	0.36	0.35	0.27
t_0	0.000	0.000	0.396	0.044	0.11

age	Mean Length (cm)			
1	11.9	9.8	9.0	13.5
2	21.5	18.1	20.2	23.6
3	29.2	25.2	28.1	30.7
4	35.5	31.3	33.6	35.7
5	40.6	36.4	37.4	39.2
6	44.7	40.8	40.0	41.7
7	48.0	44.5	41.9	43.5
8	50.6	47.7	43.2	44.7
9	52.8	50.4	44.1	45.6
10	54.5	52.7	44.8	46.2
11	55.9	54.7	45.2	46.7
12	57.1	56.3	45.5	47.0

Table 2. Commercial and recreational catch (mt) of black sea bass. Recreational landings from 1968 to 1980 were estimated by a hindcast method. See text for details.

	Commercial landings	Commercial discard	Recreational landings	Recreational discards	Foreign landings	Total Catch (mt)
1968	1079		*851*			1930
1969	1097		*772*			1869
1970	970		*1058*			2028
1971	566		*540*			1106
1972	727		*846*			1573
1973	1115		*1145*			2260
1974	1023		*1325*			2348
1975	1680		*1791*			3471
1976	1557		*1895*			3452
1977	1985		*2267*			4252
1978	1662		*1697*		5	3364
1979	1241		*560*		41	1841
1980	977		*1002*		14	1992
1981	1129		558	65	39	1779
1982	1177		4500	74	21	5756
1983	1513		1869	137	14	3533
1984	1965		602	65	18	2650
1985	1551		958	90	33	2632
1986	1901		5621	229	10	7761
1987	1890		880	79	4	2853
1988	1879		1299	252		3430
1989	1324	54	1488	94		2960
1990	1588	32	1256	209		3085
1991	1272	7	1885	247		3411
1992	1364	62	1188	170		2784
1993	1433	126	2194	136		3890
1994	925	12	1333	176		2445
1995	935	19	2815	373		4143
1996	1524	193	1809	280		3805
1997	1186	14	1932	296		3428
1998	1163	59	519	213		1954
1999	1315	21	746	393		2474
2000	1208	24	1816	822		3870
2001	1296	62	1553	739		3650
2002	1571	24	1982	818		4395
2003	1361	35	1498	507		3401
2004	1398	216	761	314		2689
2005	1290	41	854	244		2429
2006	1271	14	902	267		2454
2007	1016	42	1031	339		2429
2008	850	21	742	426		2039

Table 3. Length measurements and landings (mt) from commercial fisheries 1984-2007.

Year	# lengths	Landings (mt)
1984	3841	1965
1985	2509	1551
1986	2922	1901
1987	1545	1890
1988	1376	1879
1989	883	1324
1990	1142	1588
1991	735	1272
1992	605	1364
1993	300	1412
1994	3166	896
1995	3233	925
1996	5295	1472
1997	4414	1186
1998	4171	1163
1999	4650	1315
2000	2196	1208
2001	2196	1296
2002	2196	1571
2003	3684	1361
2004	3684	1398
2005	5265	1290
2006	6000	1271
2007	7768	1016
2008	7250	850

Table 4. Summary of ten model configurations used to develop model average.

Attribute	***Values***									
Run Number	1	2	3	4	7	8	9	10	11	12
Total Objective Function	261.7	257.7	292.7	287.8	263.8	251.5	252.4	248.5	258.3	260.3
Weight on Catch Wt	15	15	15	15	20	20	25	25	25	25
Weight on Recruitment Index 1: spring	15	15	15	15	15	15	15	15	15	20
Winter 2007 juvenile index included	X		X		X	X	X		X	X
Weight on Recruitment Index 2:winter		15	15	15	15	15	15	15	10	10
Autumn juvenile index series included			X	X						
Weight on Recruitment Index 3: fall			15	15						
Weight on Adult Index 1: spring log transformed	15	15	15	15	15	10	10	10	15	15
Weight on Adult Index 2: winter log transformed	15	15	15	15	15	10	10	10	15	15

Table 5. Projection results using SCALE model averages. Projection for ½ to MSY is equivalent to an F halfway between status quo F_{2010} and F when quota equals MSY. Projections at MSY estimate F based on a quota equal to MSY.

	F_{2008}	1/2 to MSY	Fmsy	MSY
F_{2009}	0.18	0.18	0.18	0.18
F_{2010}	0.28	0.36	0.42	0.445
Predicted Catch mt (includes discard)				
2008	2,045	2,045	2,045	2,045
2009	1,487	1,487	1,487	1,487
2010	2,642	3,286	3,741	3,924
Predicted Landings (mt)				
2009	1,223	1,223	1,223	1,223
2010	2,175	2,705	3,079	3,229
Jan 1 Biomass (mt)				
2008	14,322	14,322	14,322	322
2009	15,563	15,563	15,563	563
2010	17,192	17,192	17,192	192
2011	17,181	16,497	16,017	824
Jan 1 SSB (mt)				
2008	12,939	12,939	12,939	939
2009	14,229	14,229	14,229	229
2010	15,935	15,935	15,935	935
2011	15,947	15,263	14,782	589

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