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Working Paper: Black sea bass
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Black sea bass

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Black Sea Bass

Terms of Reference (that apply to black sea bass):

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 states (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 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 curve by Caruso, MA DMF, appeared to be unique, possibly due to geographic growth differences and was not included in the model average). 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 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).

Natural mortality (see below in model section).

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. 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 summary

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 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 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. Their findings were 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.

New analyses

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.

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. Fishing mortality estimates were 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. A draft manuscript detailing the project is provided as *Appendix II*. 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 natural mortality estimate of 0.66. The tag results imply that natural mortality of the black sea bass population exceeds 0.2, which has been used in previous assessments.

Tag recovery data also indicates that extensive seasonal movements occur and are not homogeneous throughout the stock (Moser and Shepherd 2008). 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 of the NEFSC) was explored as a method for evaluating sea bass. The model details are described in *Appendix I.* SCALE data input includes catch history, survey indices, recruitment 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 have ranged from 300 to 7768 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 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.

Complete recreational landings were only available since 1981. 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 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.

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, since the 1930's commercial trawl fisheries 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 5). 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 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 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 8). To reduce the influence of over-dispersion on the estimation of the stratified mean, log-transform indices (followed by re-transformation) were used in the model. NEFSC spring survey indices before and after 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) began 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 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 (1.07 kg per tow), followed once again by a steady decline through 2008 when the index dropped to 0.18 kg per tow. The latest value is below the long-term average of 0.26 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 $\leq$ 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 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 index in the winter survey was above average.

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 they 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 assumption of 100% reporting of high reward tags were relaxed to equal 75% and tag attrition of 9%, 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. Yet, use of a constant high M across all sizes may not be appropriate. Sea bass sex transition likely occurs between ages 2 and 5 (Mercer 1978). A switch from a female to male also imposes behavioral changes during the spawning season. The large males are dominant and defend territory/females for some period prior to spawning. These large males occupy a behavioral niche and aggressively exclude smaller males (aquarium observations suggest the large males are not aggressive toward females). The limited aging data available suggests that few individuals survive beyond age 7, however, it is possible for larger males to be much older. This would imply that once a fish becomes large natural mortality declines. If a male does not become dominant, life expectancy could be much reduced due to factors such as aggressiveness of the large fish or physiological changes that increase senescence. In an attempt to include both a high natural mortality and a subgroup with a longer potential life expectancy, we have included a logistic function for M (Figure 14). The point of inflexion corresponds to the approximate age when transition should be occurring. A logistic model allows a high population M while also allowing a large maximum age than would be expected using a constant value.

Included as input to the SCALE model were spring and winter offshore indices of abundance. The spring series of stratified ln re-transformed mean number per tow included 1968 to 2008 while the comparable indices from the winter survey were 1992 to 2007 (Figure 15). 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 2007. The model was allowed to fit the initial fishing mortality in phase two. The model was fit with a range of natural mortalities under an assumption of either constant or logistic patterns. Scale model results are presented in Tables 5-13, Figures 16-21.

The SCALE model was adequate in describing the length data from the fisheries and the associated catch. The pattern in the spring and winter survey indices were adequately predicted by the model, although some of the magnitude of some recruitment events were somewhat reduced. Model fits for constant M, 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. Alternative models using higher M with the alternative logistic model parameters are also possible.

Biological reference points

The current overfishing definition for black sea bass is based on Fmax 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}=0.32. 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 would incorporate additional fishery information in addition to the NEFSC spring and winter bottom trawl surveys. Recent evaluations of natural mortality suggests that M is likely greater than 0.2. The recommended values for in the new model would be 0.4 to 0.6 with a decrease with increasing size.

The preferred option would be an M=0.6 fitted to a logistic model (Table 14). F at 40% of maximum spawning potential equals 0.22 and F0.1 of 0.194. Fmax equals 0.929 and is poorly defined. The associated SSB/R at F40%=0.488 and total B/R= 0.531 (Figure 21). Using age 1 recruitment averaged from 1968 to 2007 (47,254,240 recruits), total biomass at F=0 equals 59,713 mt and at F40% is 25,093 mt. The 2007 estimates of F from the SCALE model using the logistic M for 0.6 is 0.46 with an estimated total biomass of 15,570 mt and a spawning stock biomass of 13,407 mt. The comparable reference points for alternative values of M are presented in Tables 15-16.

As a check on the scaling of the results, the yield for time series associated with $F_{40\%}$ under average recruitment would be 4,199 mt. This compares with the estimated average catch since 1968 of 3,000 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.

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 is 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. 2007). 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. 2007). 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 coastwide 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 information could improve the assessment models and an age analysis of NEFSC survey samples is currently underway with MA DMF. There is some evidence of regional differences in growth that should be explored further.

Analysis of the tagging data suggests regional differences in migration pathways. The lack of correlation among state surveys also suggest regional differences. Consideration should be given to evaluating alternative management approaches that account for regional differences in recruitment patterns and abundance.

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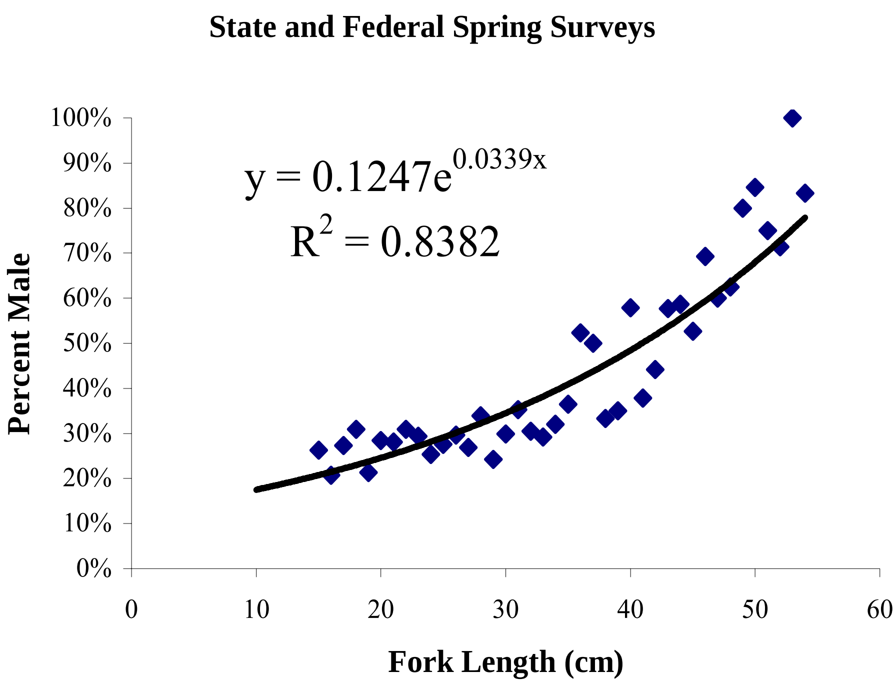


Figure 1. Sex ratio of black sea bass at length (cm) from combined NEFSC and MA DMF spring surveys.

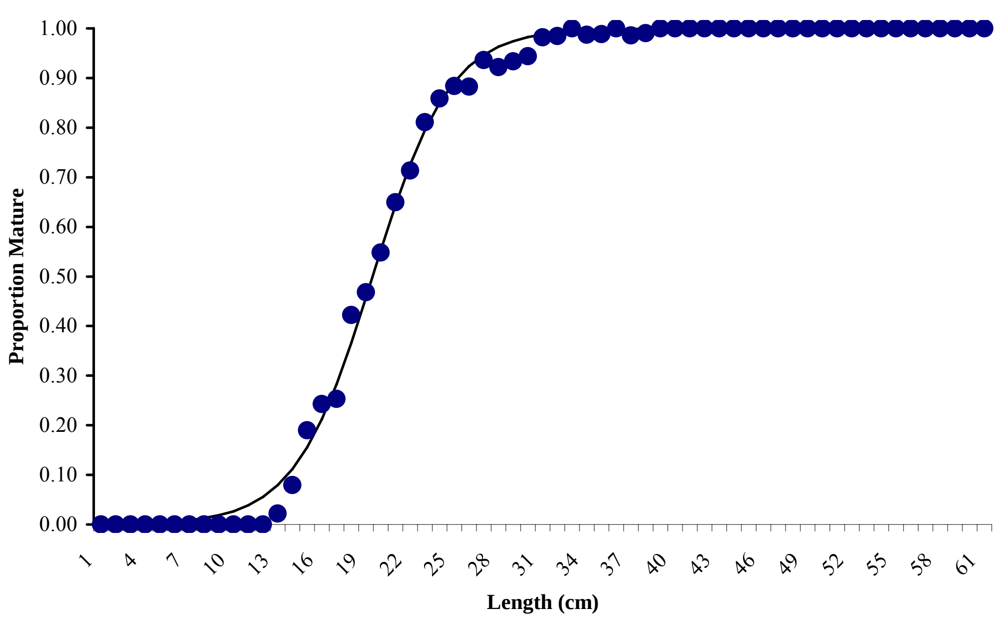


Figure 2. Proportion mature (male and female combined) by length based on samples from NEFSC spring surveys.

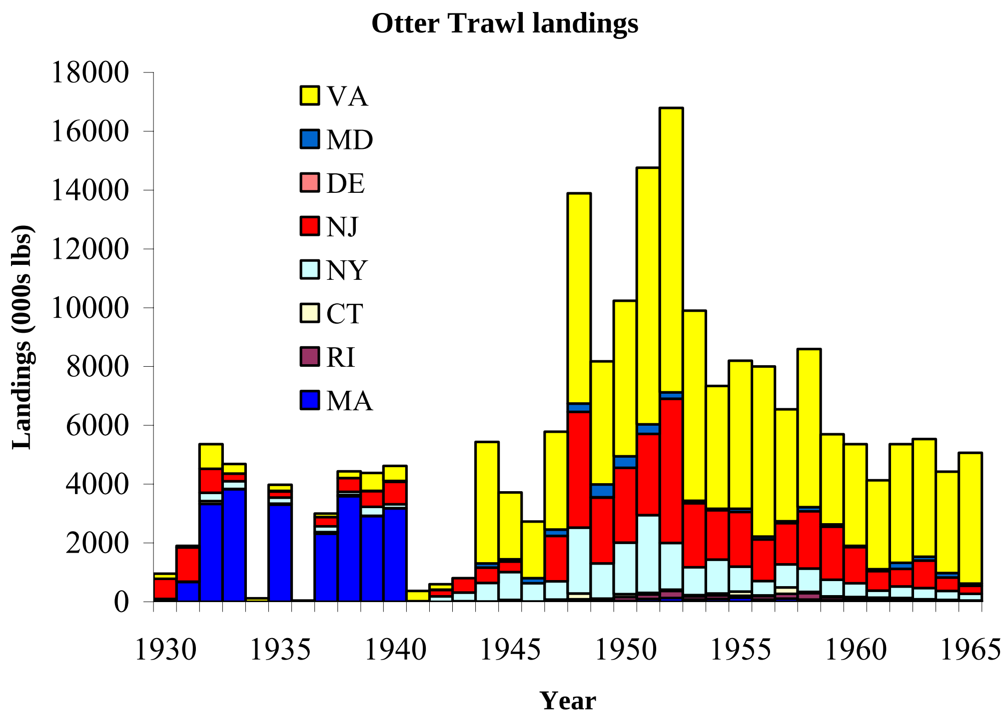


Figure 3. Commercial otter trawl landings (000s lbs) by state for 1930 to 1965. Source Fisheries of the U.S.

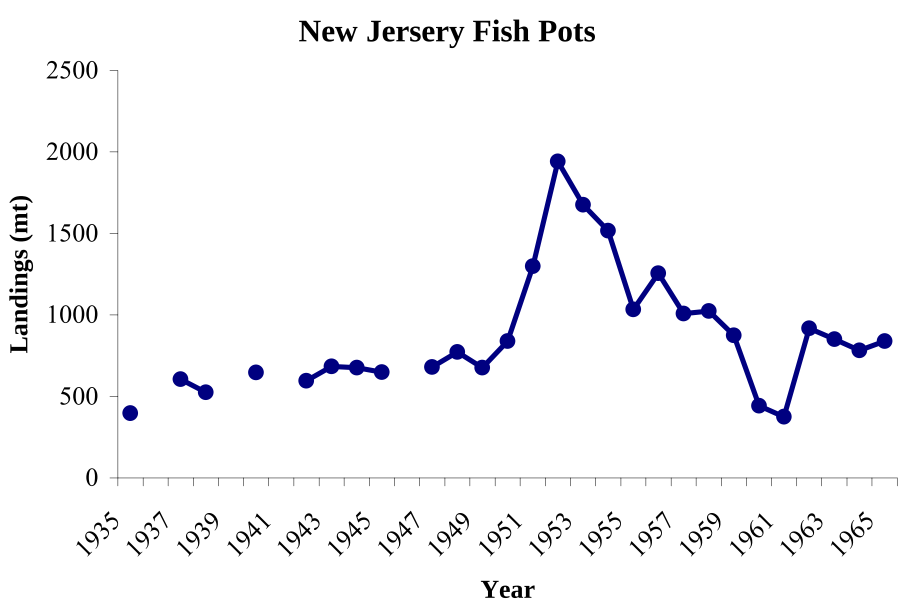


Figure 4. Landings (mt) of sea bass from NJ fish pots, 1935-1965.

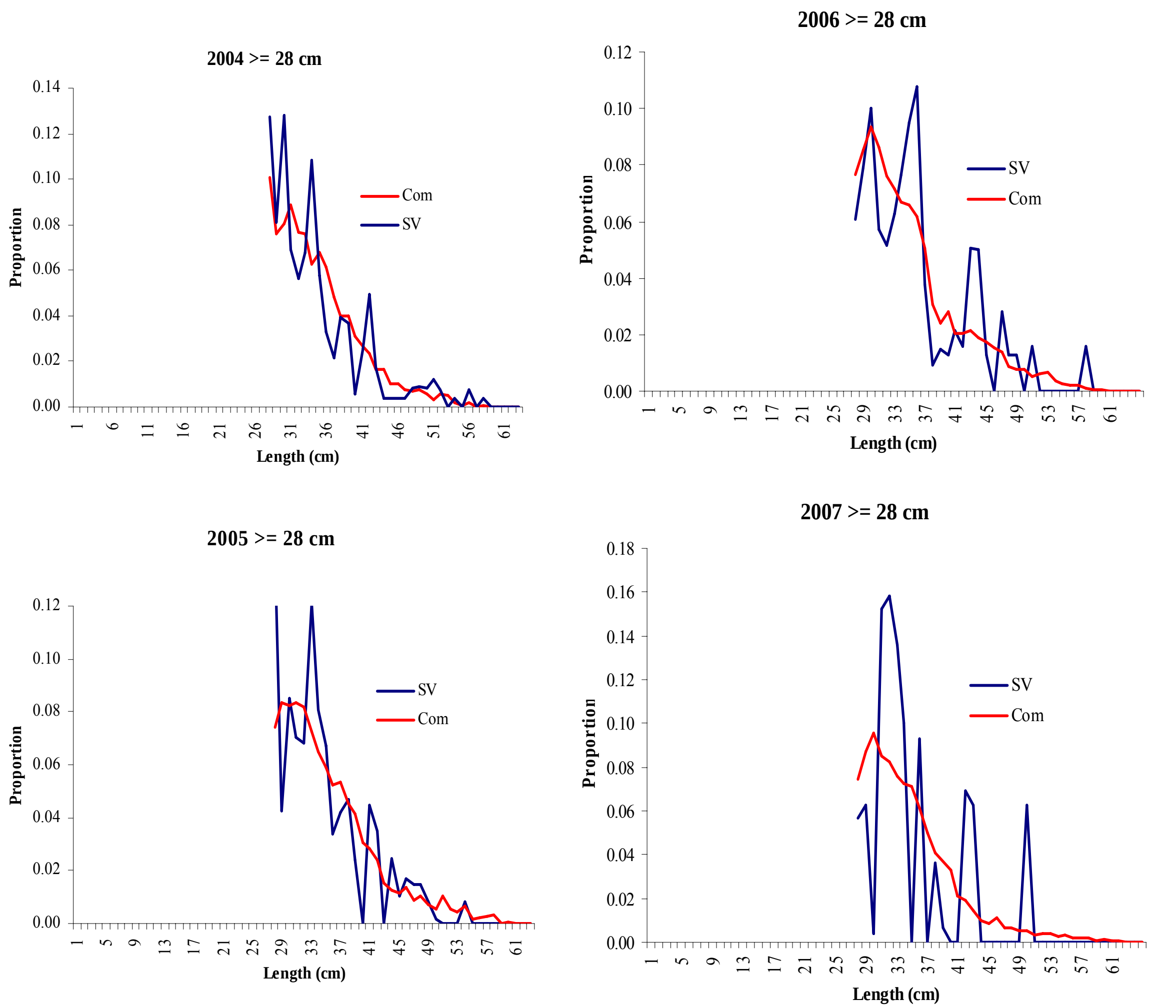


Figure 5. Comparison of proportion at length between commercial fisheries and NEFSC spring offshore survey. Sizes limited to lengths at full recruitment to the fisheries.

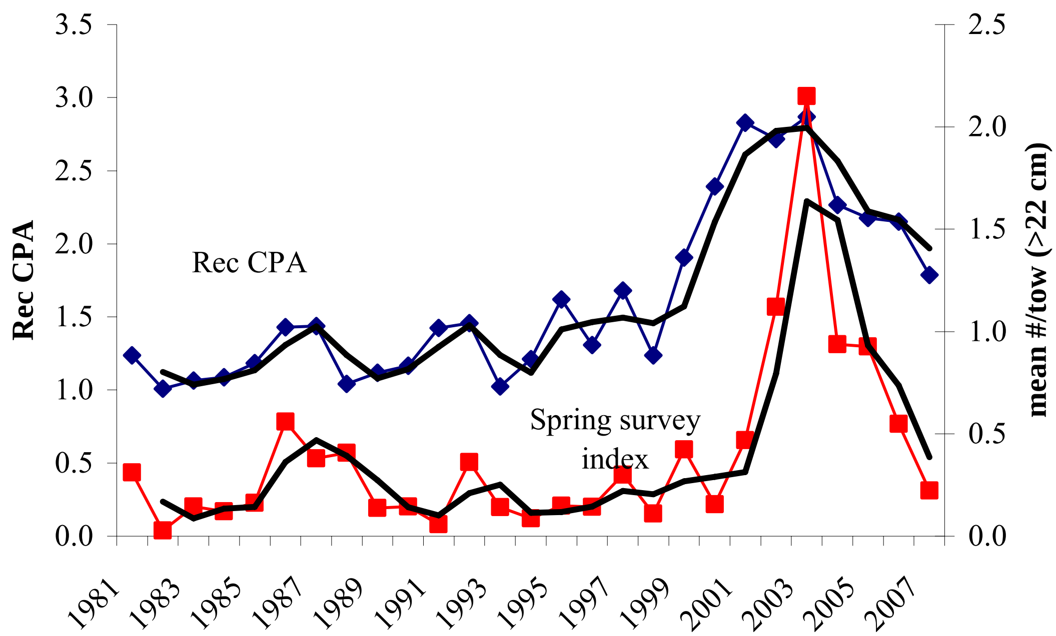


Figure 6. NEFSC Spring offshore survey stratified mean number per tow compared to MRFSS number per angler trip.

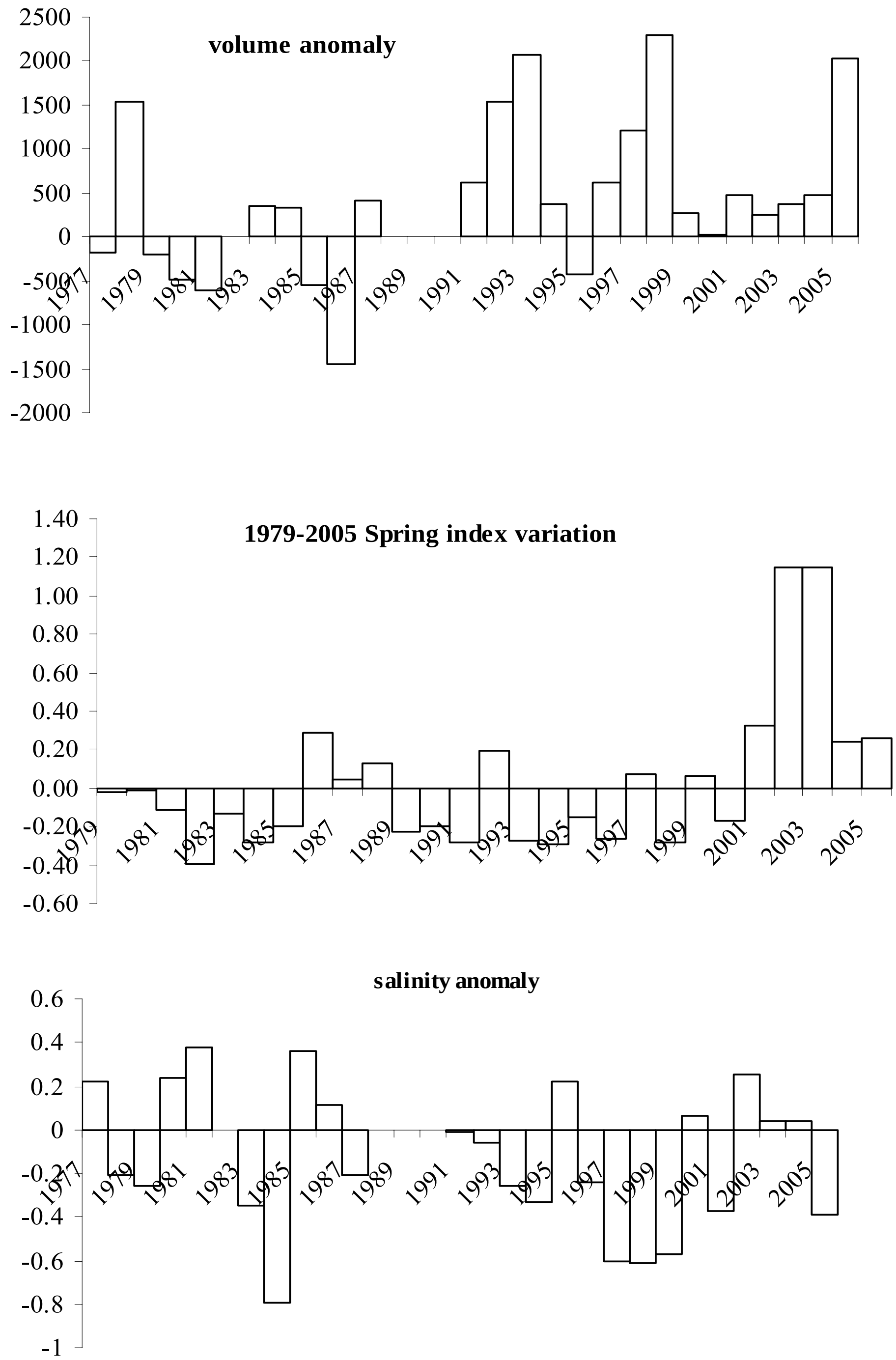


Figure 7. Spring oceanographic anomalies in the mid-Atlantic and variation from the time series mean of NEFSC spring survey indices.

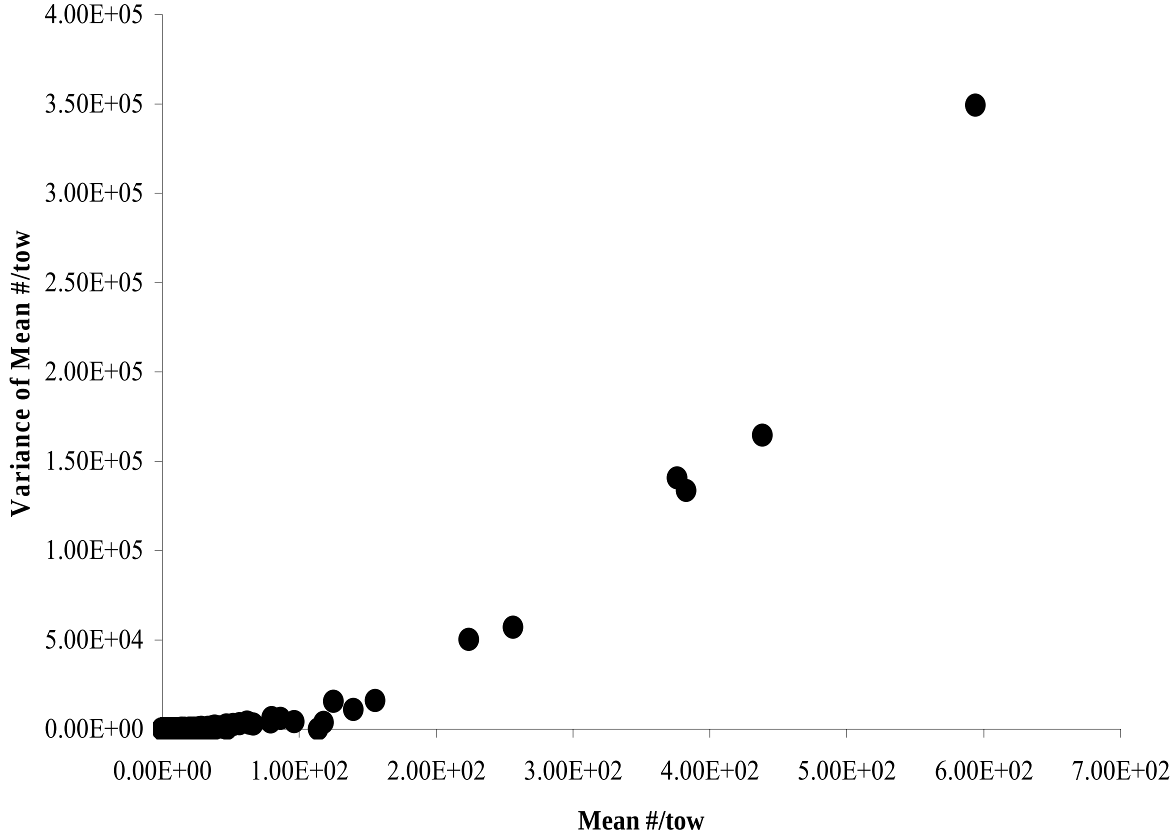


Figure 8. Relationship between black sea bass mean #/tow and associated variance for NEFSC Spring survey.

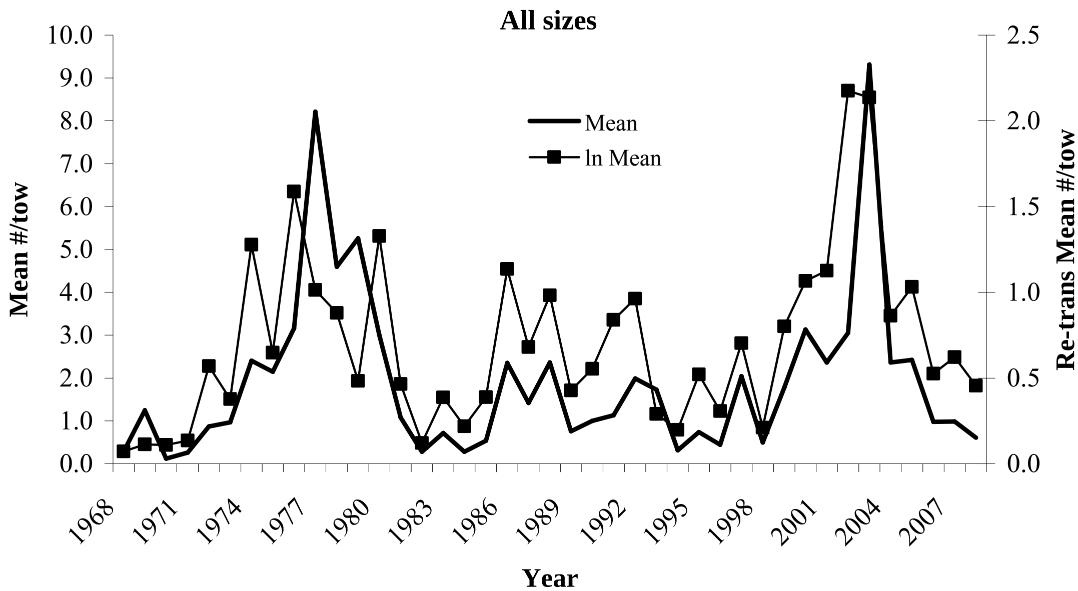


Figure 9a. NEFSC spring offshore stratified mean num/tow and re-transformed loge stratified mean num/tow for black sea bass of all sizes.

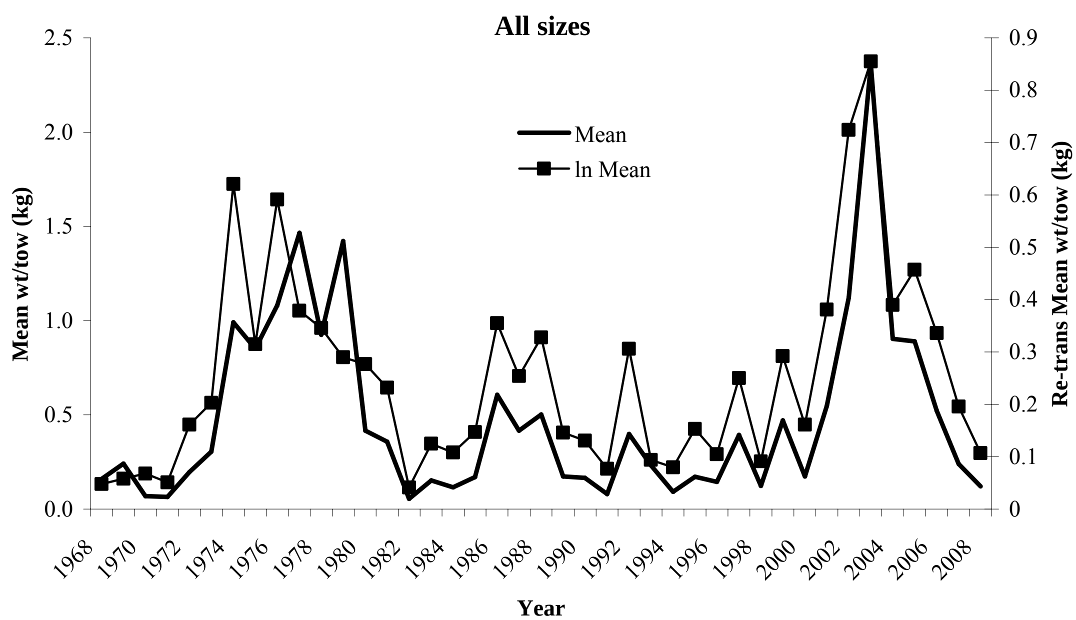


Figure 9b. NEFSC spring offshore stratified mean wt/tow (kg) and re-transformed loge stratified mean wt/tow (kg) for biomass of black sea bass, all sizes.

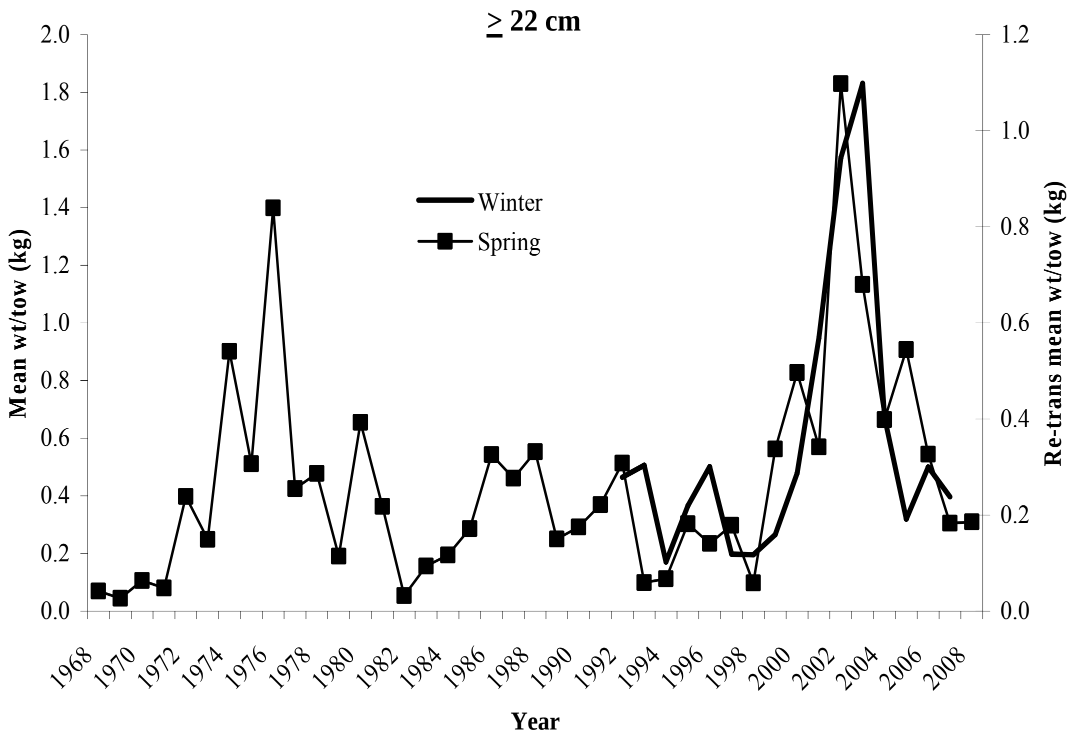


Figure 10. NEFSC spring and winter offshore re-transformed loge stratified mean wt/tow (kg) indices for exploitable biomass of black sea bass (≥ 22 cm).

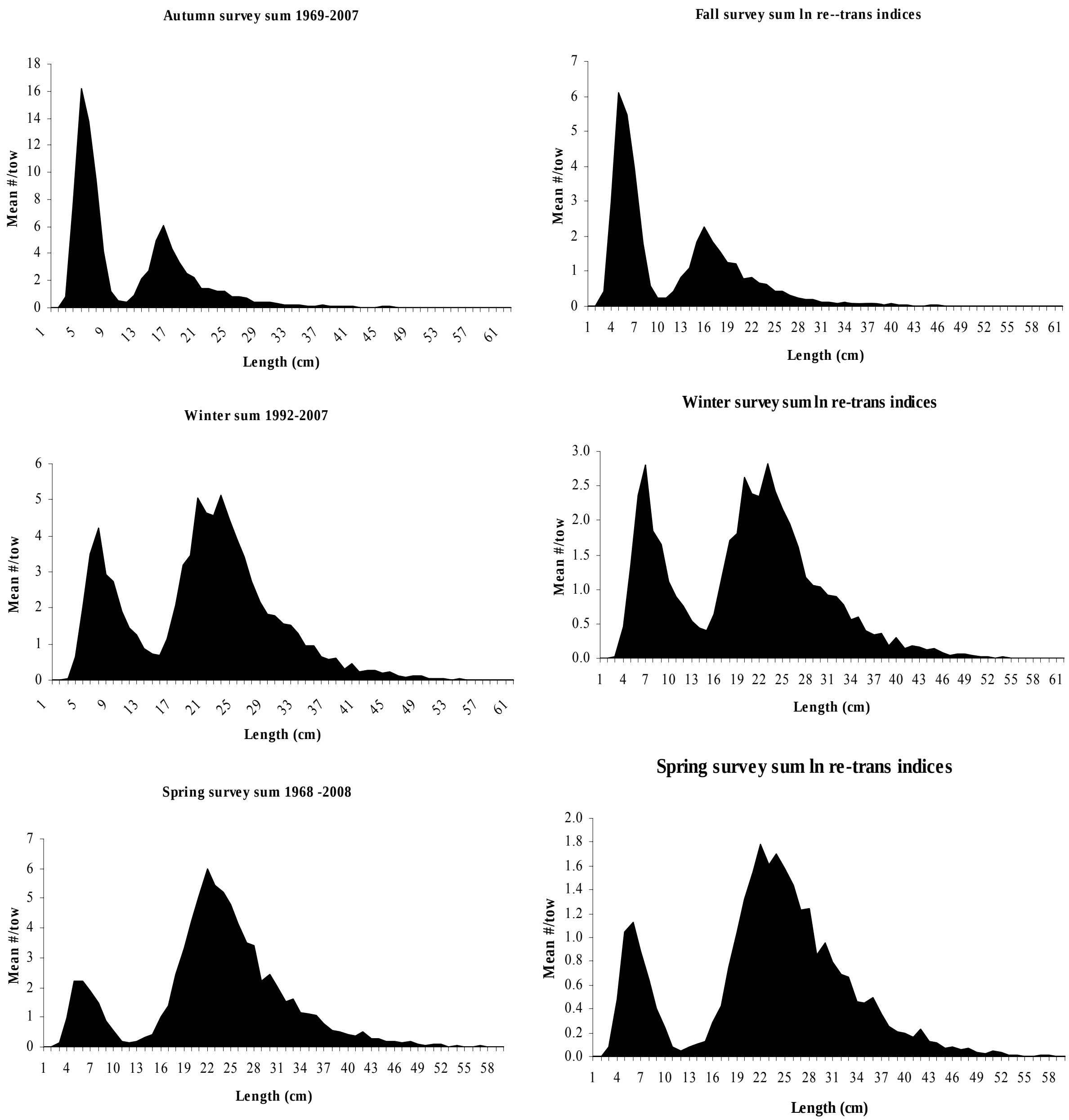


Figure 11. NEFSC spring, winter and autumn length frequencies for combined years. First distinctive mode represents recruits.

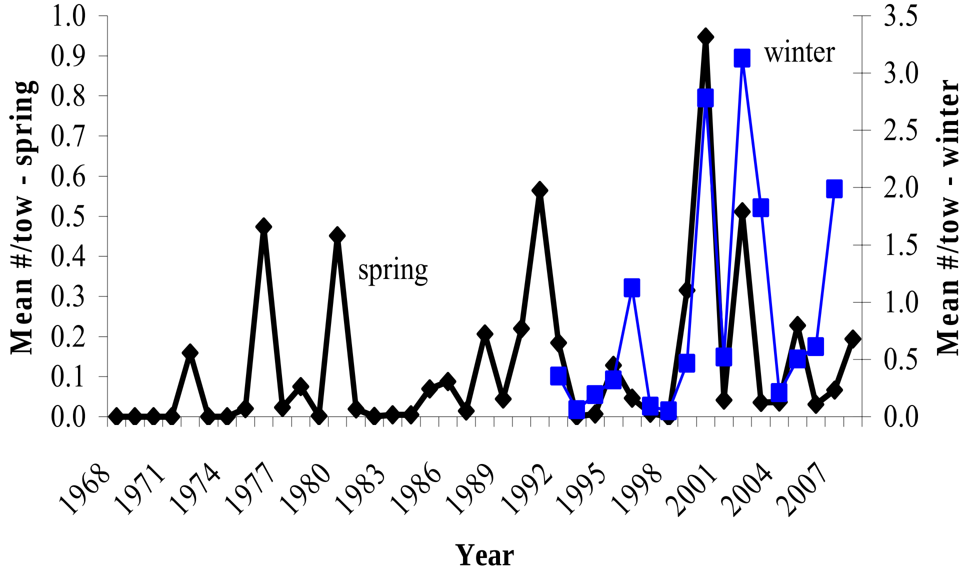


Figure 12. NEFSC spring and winter indices of juvenile abundance (stratified mean #/tow for sea bass ≤ 14 cm).

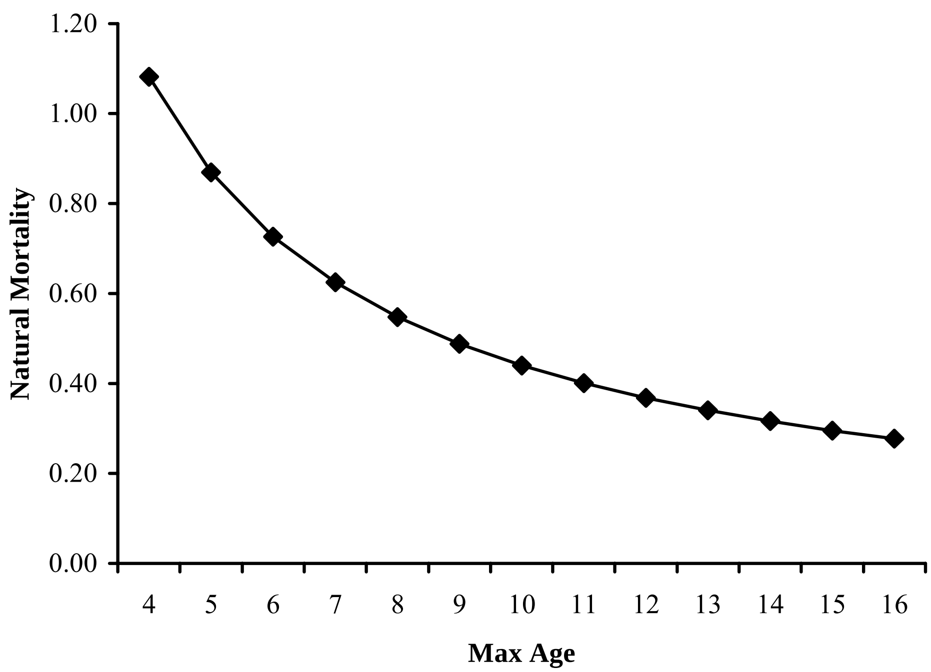


Figure 13. Relationship between maximum age and natural mortality as determined by Hoenig equation.

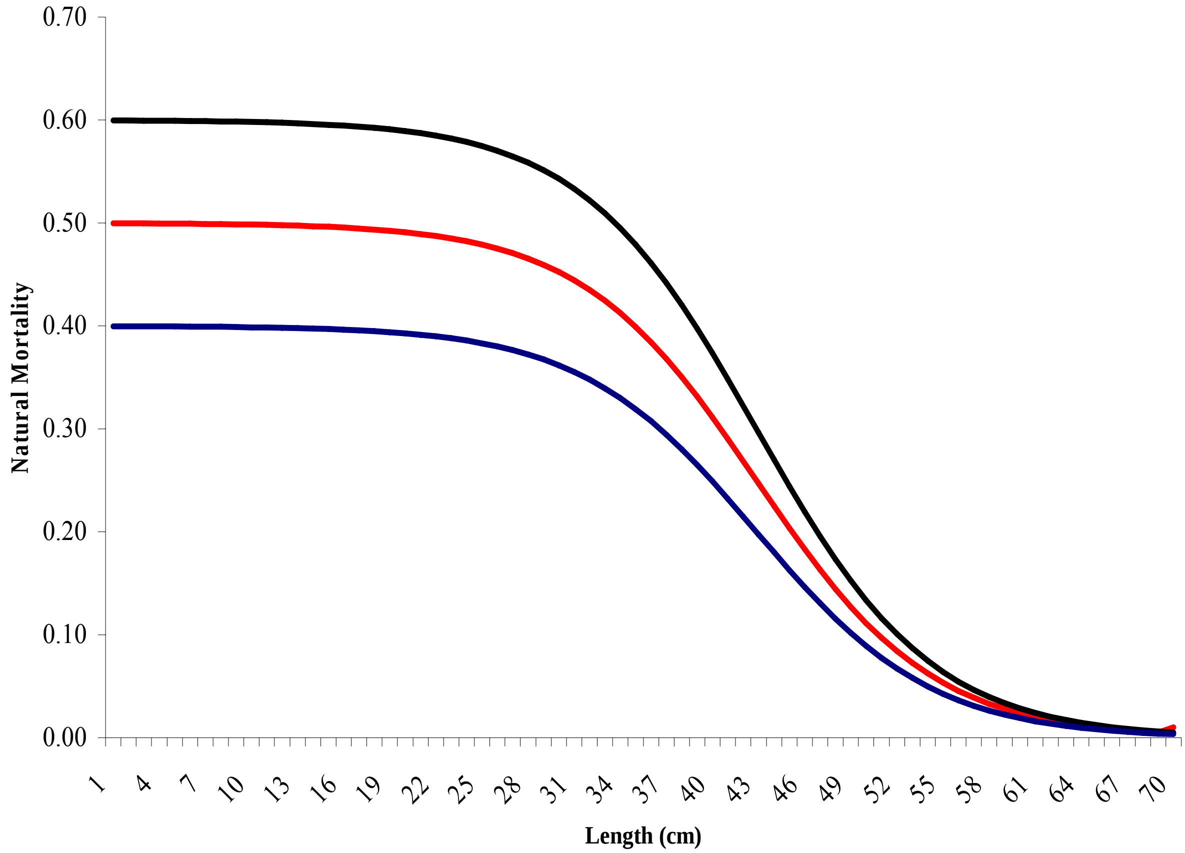


Figure 14. Logistic pattern of natural mortality for used in reference point calculations. Initial M values of 0.4, 0.5 and 0.6.

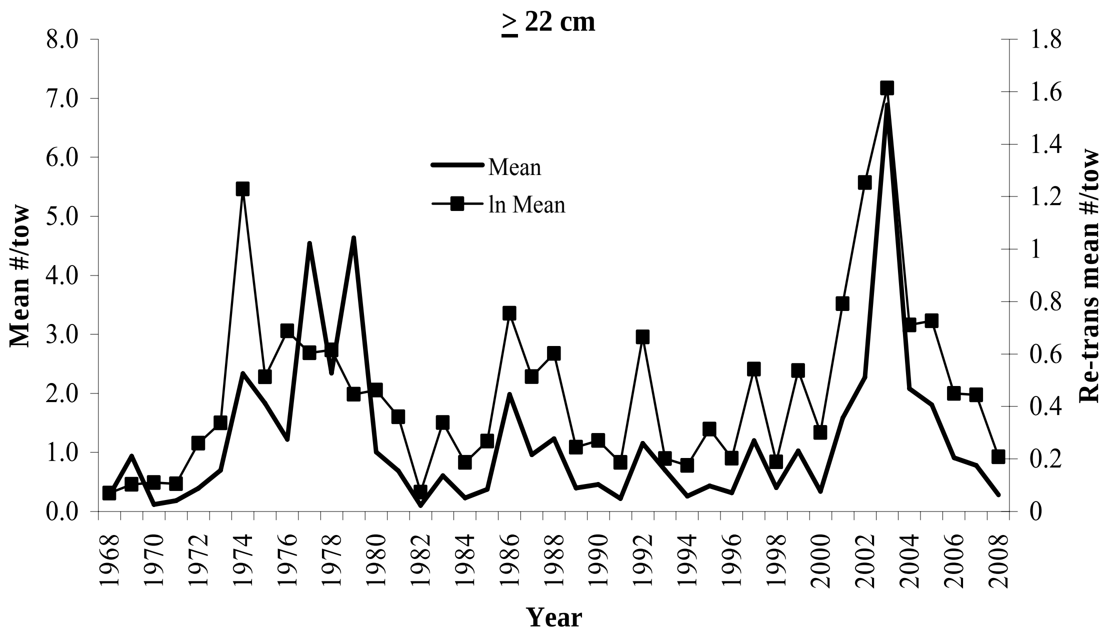
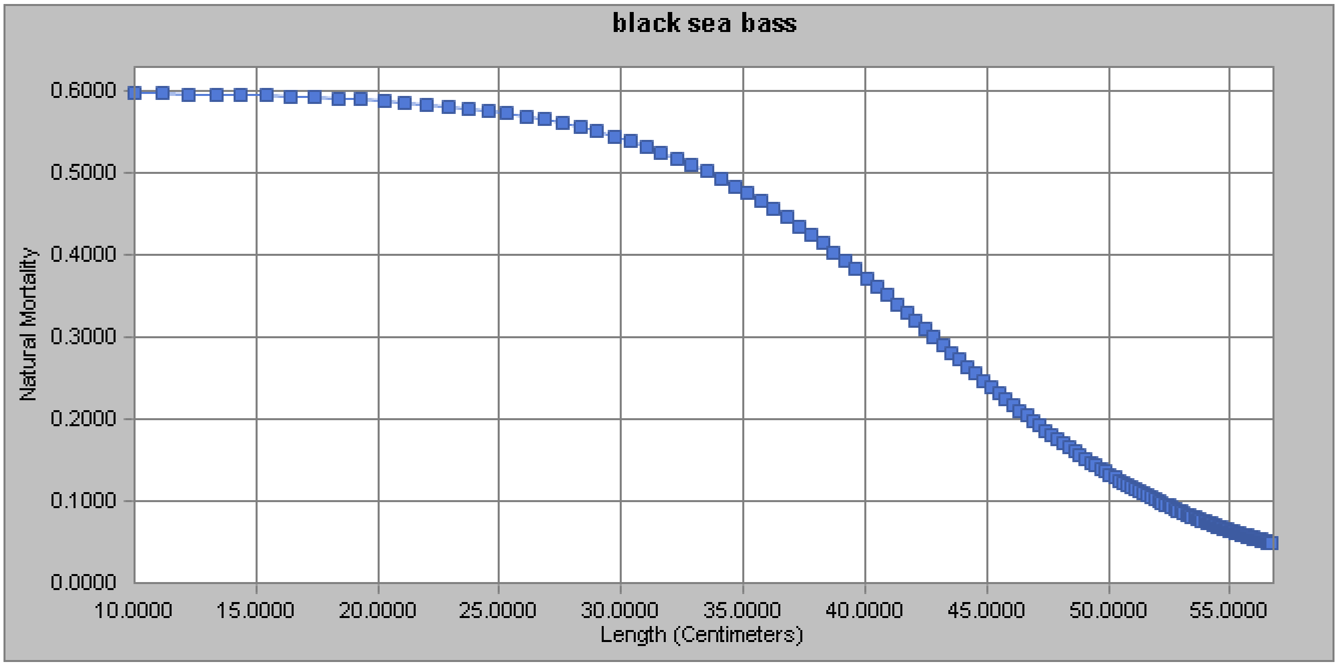


Figure 15. NEFSC spring offshore and winter survey indices (mean #/tow) for black sea bass ≥ 22 cm. Indices of relative abundance used as input to SCALE model.



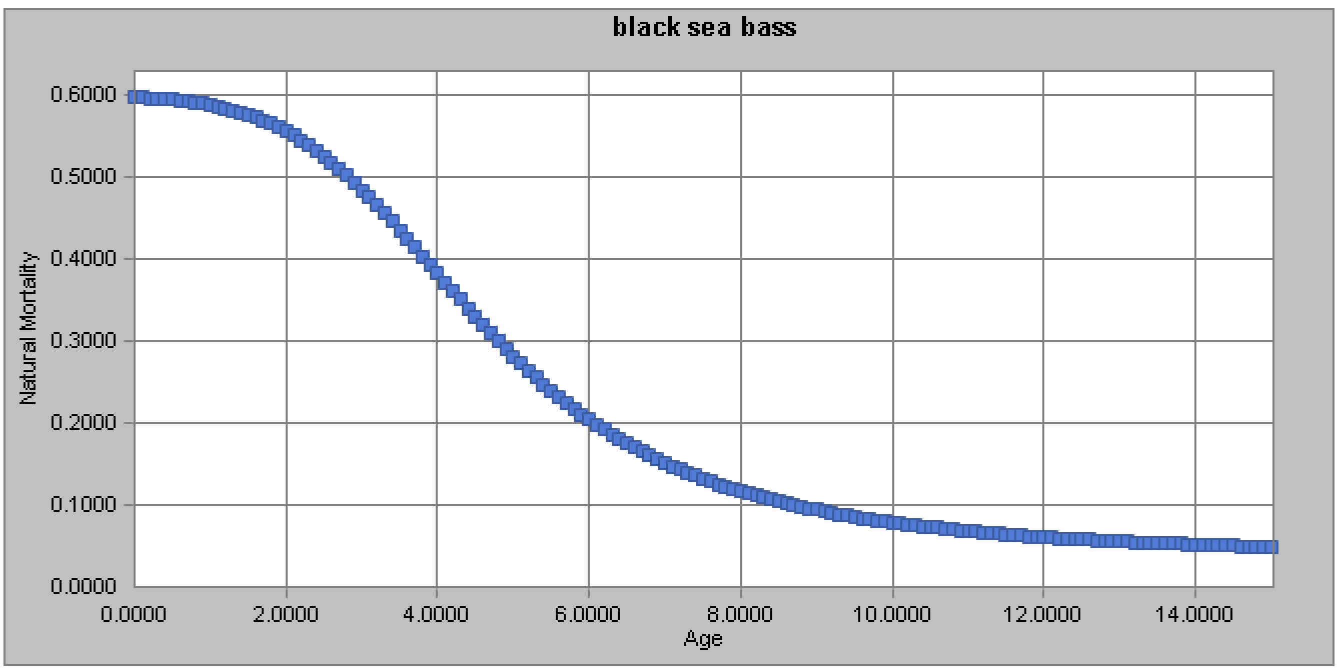


Figure 16. Natural mortality at length and age for M=0.6 with logistic pattern of decay.

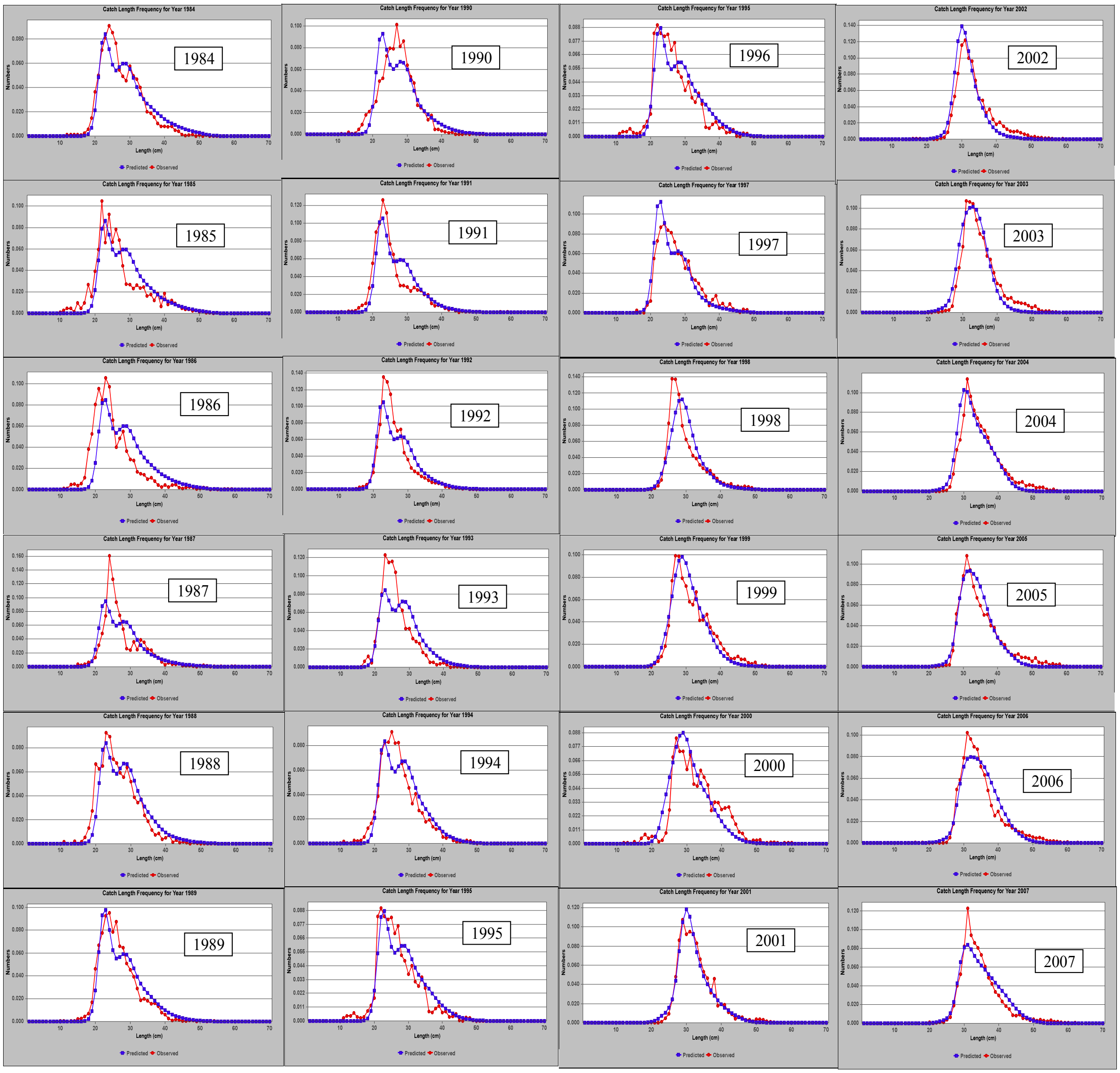


Figure 17. Observed fishery length frequencies 1984-2007 and frequencies predicted by SCALE model.

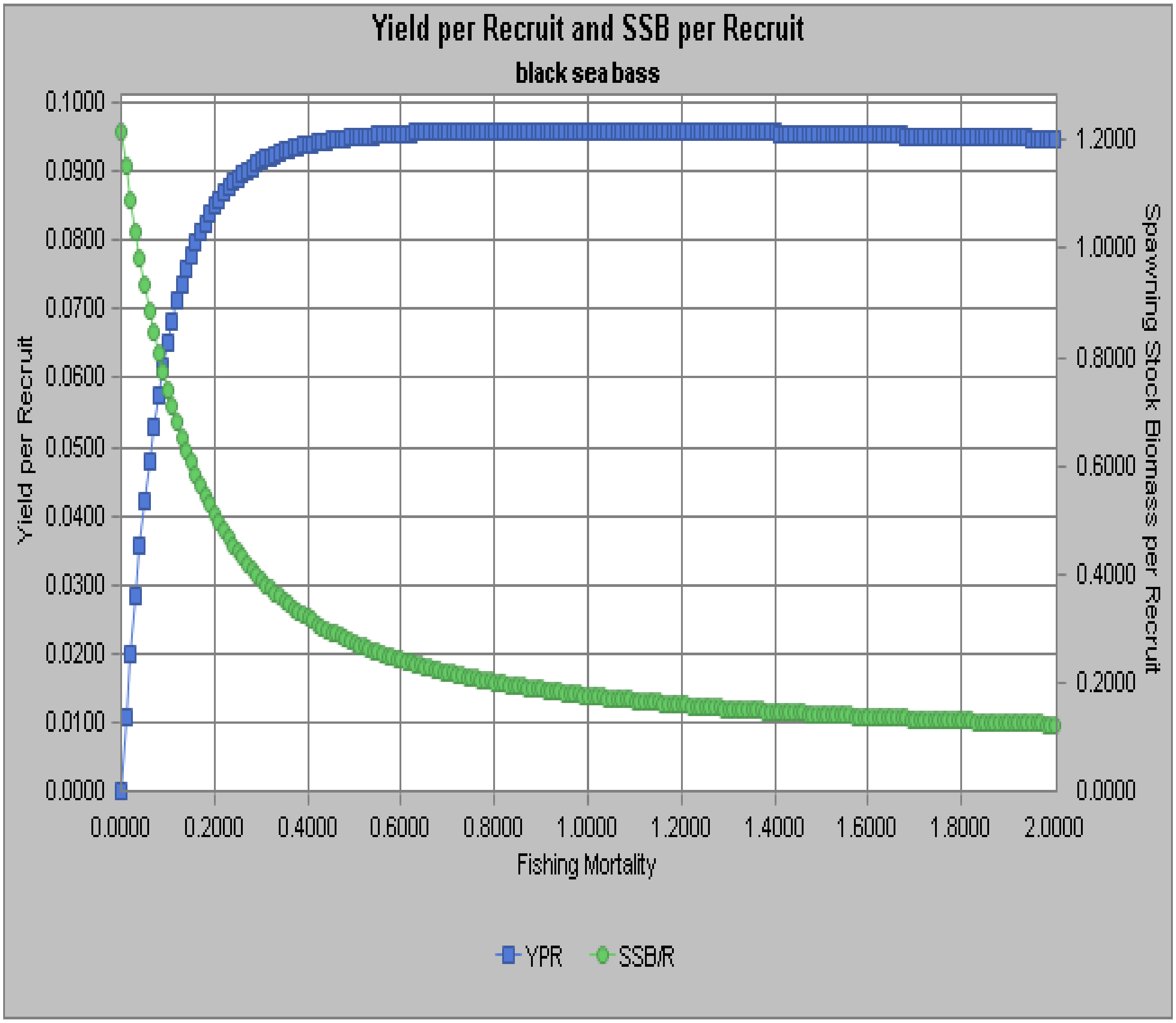


Figure 18. Yield and spawning biomass per recruit for black sea bass using logistic pattern with M=0.6.

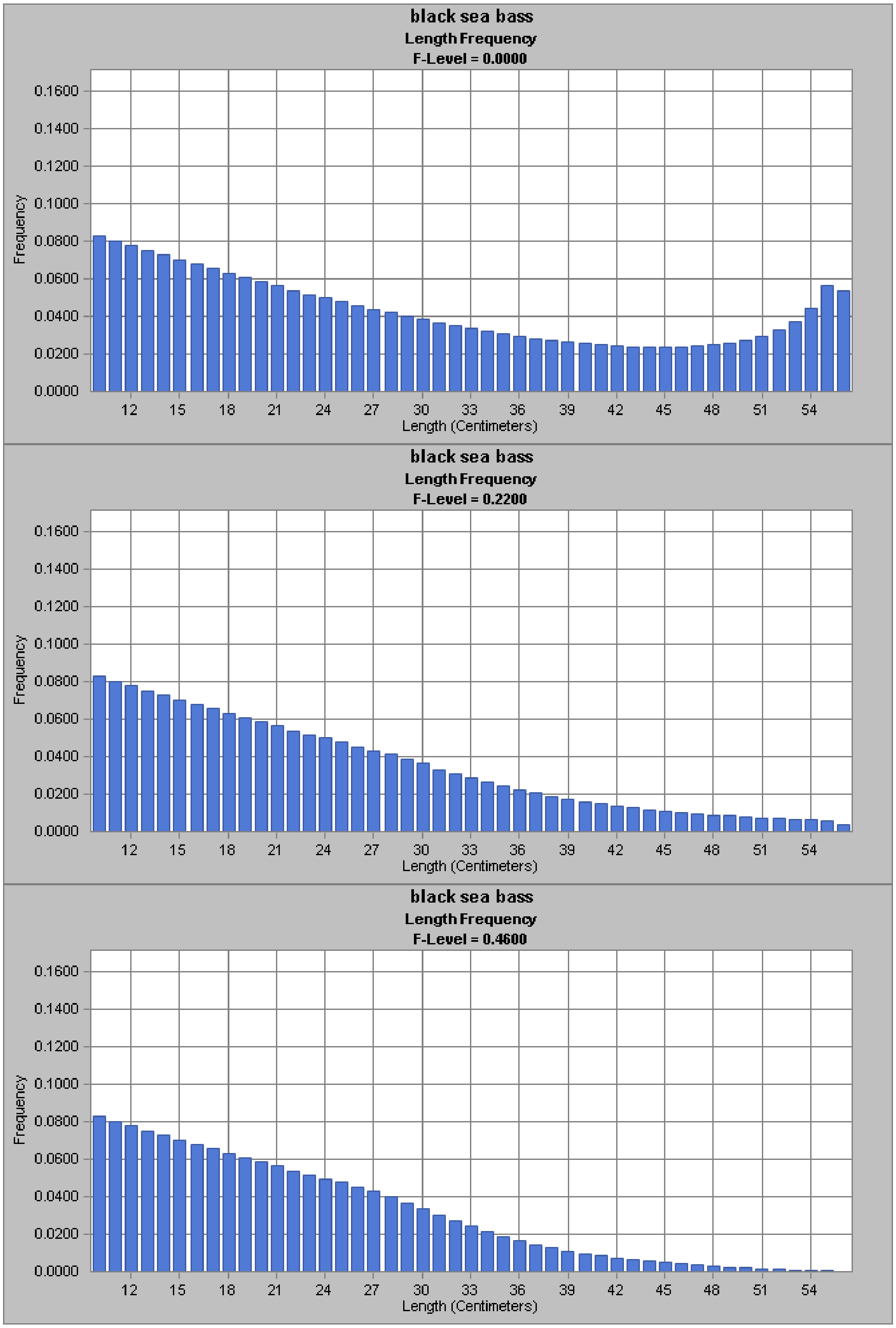


Figure 19. Size distribution of black sea bass at equilibrium with fishing mortality equal to zero, $F_{40\%}$ (0.22) and F_{2007} (0.46).

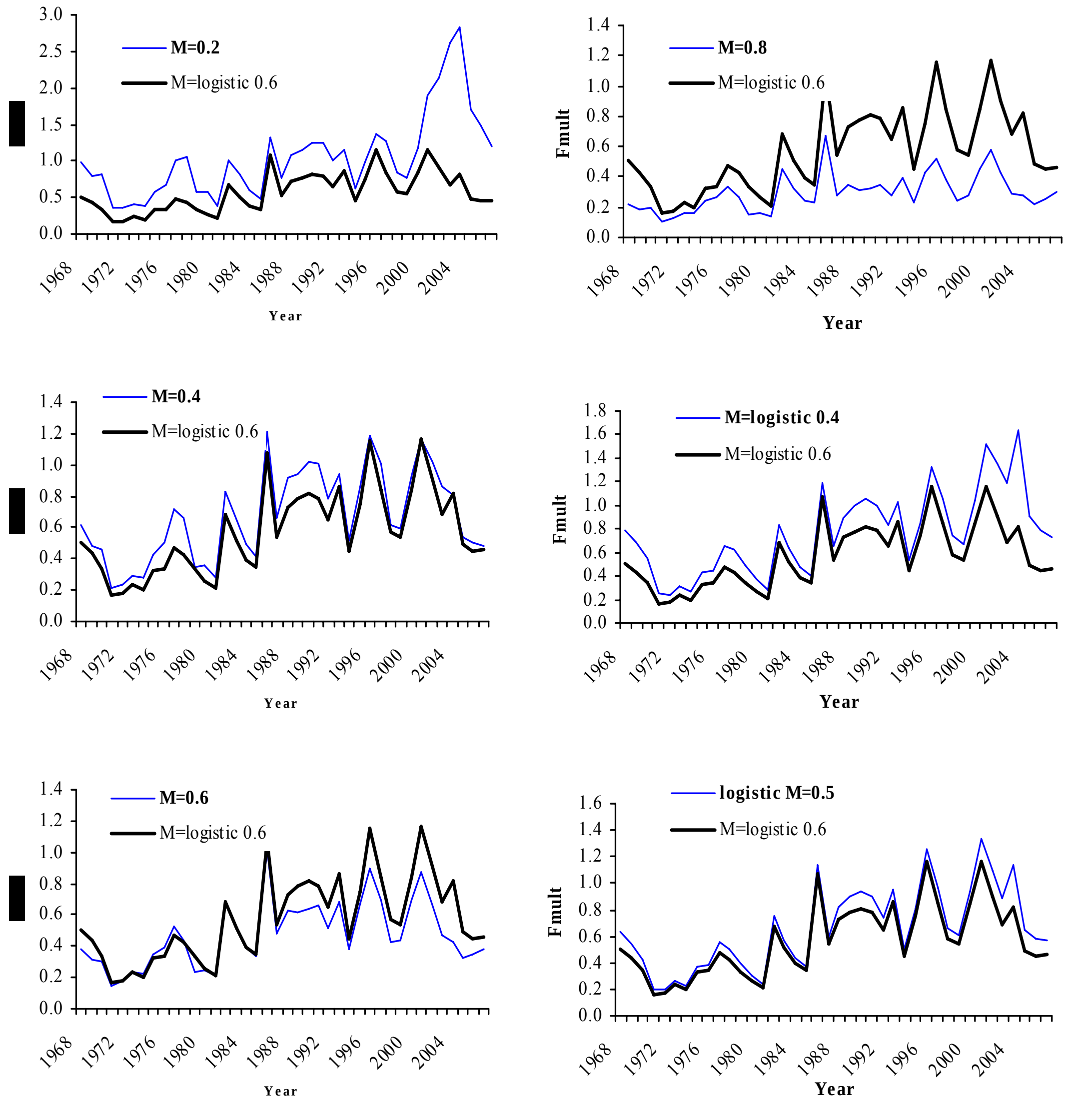


Figure 20. Time series of fishing mortality from the SCALE model under a variety of natural mortality estimates.

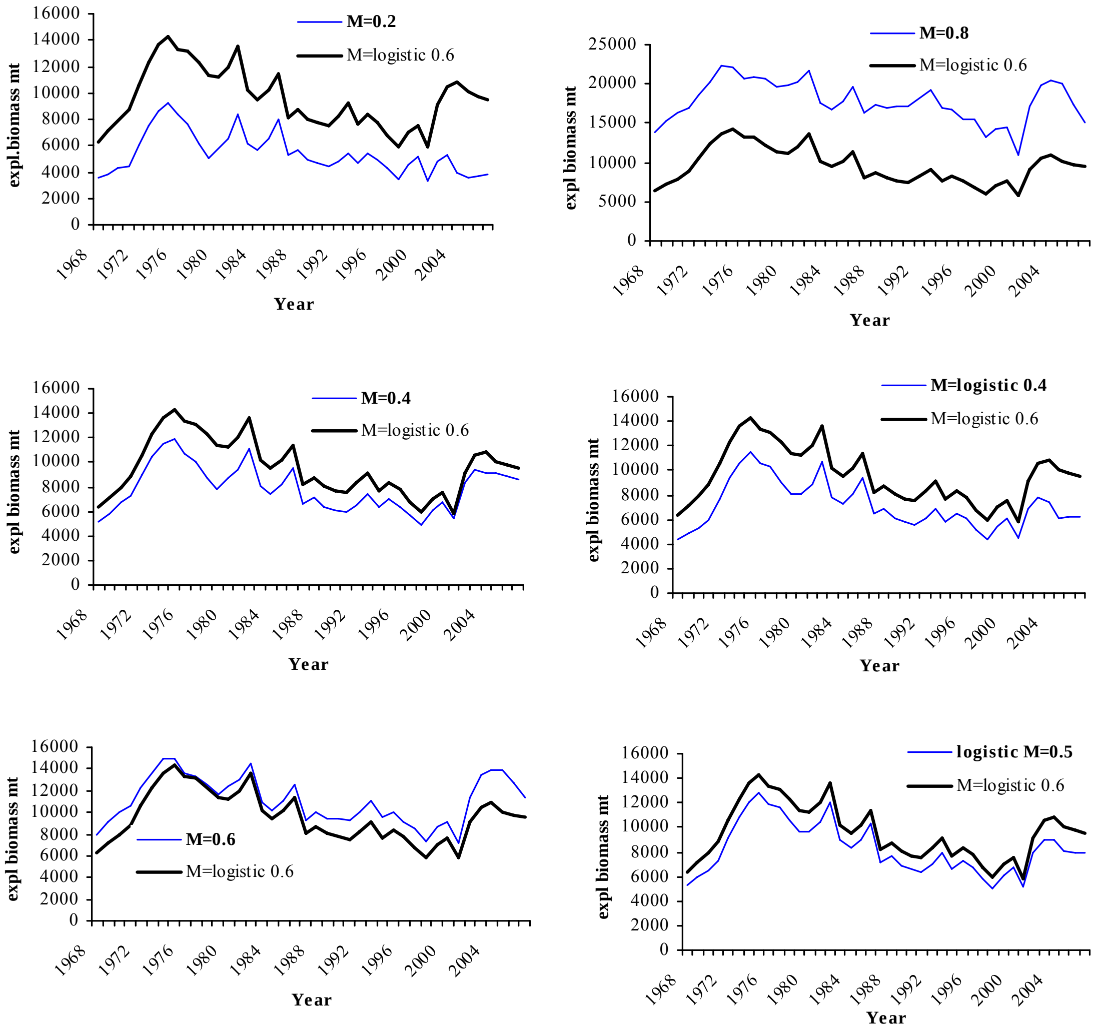


Figure 21. Time series of exploitable biomass (mt) estimates from SCALE under a variety of natural mortalities.

Table 1. Black sea bass growth model results and calculated mean lengths at age.

	Caruso	Pemberton	Mercer	NMFS winter	NMFS spring		avg (w/o Caruso)
linf	66.81	61.84	65.93	46.23	47.71		
K	0.11	0.21	0.16	0.359	0.348		
t_0	0	0	0	0.3964	0.0436		
age	Mean lengh (cm)						avg (w/o Caruso)
1	7.22	**11.89**	**9.79**	**9.01**	**13.51**		11.05
2	13.66	**21.49**	**18.13**	**20.23**	**23.56**		20.85
3	19.41	**29.25**	**25.23**	**28.08**	**30.66**		28.30
4	24.53	**35.51**	**31.27**	**33.55**	**35.67**		34.00
5	29.11	**40.57**	**36.42**	**37.38**	**39.21**		38.39
6	33.18	**44.66**	**40.80**	**40.05**	**41.71**		41.80
7	36.82	**47.96**	**44.53**	**41.91**	**43.47**		44.47
8	40.06	**50.63**	**47.71**	**43.21**	**44.72**		46.57
9	42.95	**52.79**	**50.41**	**44.12**	**45.60**		48.23
10	45.53	**54.53**	**52.72**	**44.76**	**46.22**		49.56
11		**55.93**	**54.68**	**45.20**	**46.66**		50.62
12		**57.07**	**56.35**	**45.51**	**46.97**		51.47

Table 2. Commercial and recreational catch of black sea bass. Italicized landing estimated.

YEAR	Comm landings (mt)	Rec landings (mt)	Rec dicards (mt)	Comm discards (mt)	Total catch (mt)
1939	2,910	*727*			3,637
1940	3,097	*774*			3,871
1941	1,427	*357*			1,784
1942	1,129	*282*			1,411
1943	1,565	*391*			1,956
1944	3,307	*827*			4,133
1945	2,483	*621*			3,103
1946	2,232	*558*			2,790
1947	3,593	*898*			4,492
1948	6,832	*1,708*			8,540
1949	4,555	*1,139*			5,694
1950	5,736	*1,434*			7,170
1951	8,361	*2,090*			10,451
1952	9,883	*2,471*			12,354
1953	6,521	*1,630*			8,151
1954	5,141	*1,285*			6,426
1955	5,130	*1,283*			6,413
1956	5,247	*1,312*			6,559
1957	4,319	*1,080*			5,399
1958	5,241	*1,310*			6,551
1959	3,654	*914*			4,568
1960	3,101	*1,551*			4,652
1961	2,459	*1,230*			3,689
1962	3,554	*1,777*			5,331
1963	3,705	*1,853*			5,558
1964	3,143	*1,572*			4,715
1965	3,481	*1,741*			5,222
1966	1,537	*769*			2,306
1967	1,154	*577*			1,731
1968	1,079	*851*			1,930
1969	1,097	*772*			1,869
1970	970	*1,058*			2,028
1971	566	*540*			1,106
1972	727	*846*			1,573
1973	1,115	*1,145*			2,260
1974	1,023	*1,325*			2,348
1975	1,680	*1,791*			3,471
1976	1,557	*1,895*			3,452
1977	1,985	*2,267*			4,252
1978	1,662	*1,697*			3,359
1979	1,241	*560*			1,801
1980	977	*1,002*			1,979
1981	1,129	546	65		1,740
1982	1,177	4,485	74		5,735
1983	1,513	1,839	137		3,489
1984	1,965	558	65		2,589
1985	1,551	945	90		2,587
1986	1,901	5,618	229		7,748
1987	1,890	870	79		2,839
1988	1,879	1,295	252		3,426
1989	1,324	1,488	94	217	3,122
1990	1,588	1,248	209	128	3,173
1991	1,272	1,875	247	28	3,421
1992	1,364	1,179	170	246	2,960
1993	1,433	2,189	136	505	4,263
1994	925	1,327	176	46	2,475
1995	935	2,809	373	77	4,194
1996	1,524	1,804	280	770	4,378
1997	1,186	1,926	296	56	3,464
1998	1,163	509	213	238	2,122
1999	1,315	726	393	84	2,517
2000	1,208	1,804	822	96	3,930
2001	1,296	1,545	739	246	3,826
2002	1,571	1,961	818	96	4,447
2003	1,361	1,481	507	139	3,489
2004	1,398	760	314	864	3,335
2005	1,290	846	475	165	2,776
2006	1,271	886	492	57	2,706
2007	1,016	1,026	601	169	2,811

Table 3. Annualized fishing and natural mortality rates determined from tagging model.

	F	M
2002	*	*
2003	0.32	1.08
2004	0.39	1.08
2005	0.41	1.08
2006	0.38	1.08
2007	0.37	1.08

Table 4. 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
min	300	
avg	3074	
max	7768	

Table 5. SCALE model diagnostic information of M=0.2 and preferred option of M=0.6 logistic model.

Summary Output Data	**M=0.2**	**logistic m=0.6**
Sexes in Model Combined		
Total Objective Function	262.88	245.42
Residuals from Catch Weight	1.11	0.31
Residuals from Catch Length Frequency	13.57	9.50
Residuals from Variation in Recruitment Penalty (Vrec)	3.05	3.05
Residual from Recruitment Index 1: spring	0.53	0.52
Residual from Recruitment Index 2: winter	0.99	1.00
Residual from Adult Index 1: spring ln	0.81	0.77
Residual from Adult Index 2: winter ln	1.01	1.15
Residual from Survey Length Frequency Index 1	166.91	166.57
Residual from Survey Length Frequency Index 2	15.60	13.18
Q for Recruitment Index 1: spring	7.69E-08	2.41E-08
Q for Recruitment Index 2: winter	1.12E-07	3.47E-08
Q for Adult Index 1: spring ln	8.67E-08	4.89E-08
Q for Adult Index 2: winter ln	1.24E-07	6.97E-08
Weight on Catch Weight	15	15
Effective Sample Size on Catch Length Frequencies	150	150
Penalty Weight on Variation in Recruitment (Vrec)	0.01	0.001
Weight on Recruitment Index 1: spring	15	15
Weight on Recruitment Index 2: winter	15	15
Weight for Adult Index 1: spring ln	15	15
Weight for Adult Index 2: winter ln	15	15
Effective Sample Size on Survey Length Frequency Index 1	125	125
Effective Sample Size on Survey Length Frequency Index 2	125	125
The Size and Larger the Model is Fitting for Adult Abundance Index 1: spring ln	22	22
The Size and Larger the Model is Fitting for Adult Abundance Index 2: winter ln	22	22
The Size and Larger the Model is Fitting for Adult Length Frequency Survey Index 1	30	30
The Size and Larger the Model is Fitting for Adult Length Frequency Survey Index 2	22	22
Alpha Selectivity Parameter for Block 1	21.68	21.95
Beta Selectivity Parameter for Block 1	1.00	0.98
Alpha Selectivity Parameter for Block 2	25.14	25.26
Beta Selectivity Parameter for Block 2	1.00	1.00
Alpha Selectivity Parameter for Block 3	30.65	28.99
Beta Selectivity Parameter for Block 3	0.35	0.79

Table 6. SCALE model diagnostic information of M=0.3 and preferred option of M=0.6 logistic model.

Summary Output Data	**M=0.3**	**logistic m=0.6**
Sexes in Model Combined		
Total Objective Function	258.53	245.42
Residuals from Catch Weight	0.83	0.31
Residuals from Catch Length Frequency	11.62	9.50
Residuals from Variation in Recruitment Penalty (Vrec)	3.10	3.05
Residual from Recruitment Index 1: spring	0.53	0.52
Residual from Recruitment Index 2: winter	1.08	1.00
Residual from Adult Index 1: spring ln	0.80	0.77
Residual from Adult Index 2: winter ln	1.12	1.15
Residual from Survey Length Frequency Index 1	166.52	166.57
Residual from Survey Length Frequency Index 2	15.07	13.18
Q for Recruitment Index 1: spring	5.69E-08	2.41E-08
Q for Recruitment Index 2: winter	8.34E-08	3.47E-08
Q for Adult Index 1: spring ln	7.35E-08	4.89E-08
Q for Adult Index 2: winter ln	1.05E-07	6.97E-08
Weight on Catch Weight	15	15
Effective Sample Size on Catch Length Frequencies	150	150
Penalty Weight on Variation in Recruitment (Vrec)	0.01	0.001
Weight on Recruitment Index 1: spring	15	15
Weight on Recruitment Index 2: winter	15	15
Weight for Adult Index 1: spring ln	15	15
Weight for Adult Index 2: winter ln	15	15
Effective Sample Size on Survey Length Frequency Index 1	125	125
Effective Sample Size on Survey Length Frequency Index 2	125	125
The Size and Larger the Model is Fitting for Adult Abundance Index 1: spring ln	22	22
The Size and Larger the Model is Fitting for Adult Abundance Index 2: winter ln	22	22
The Size and Larger the Model is Fitting for Adult Length Frequency Survey Index 1	30	30
The Size and Larger the Model is Fitting for Adult Length Frequency Survey Index 2	22	22
Alpha Selectivity Parameter for Block 1	21.81	21.95
Beta Selectivity Parameter for Block 1	1.00	0.98
Alpha Selectivity Parameter for Block 2	25.18	25.26
Beta Selectivity Parameter for Block 2	1.00	1.00
Alpha Selectivity Parameter for Block 3	28.80	28.99
Beta Selectivity Parameter for Block 3	0.53	0.79

Table 7. SCALE model diagnostic information of M=0.4 and preferred option of M=0.6 logistic model.

Summary Output Data	**M=0.4**	**logistic m=0.6**
Sexes in Model Combined		
Total Objective Function	253.14	245.42
Residuals from Catch Weight	0.50	0.31
Residuals from Catch Length Frequency	10.31	9.50
Residuals from Variation in Recruitment Penalty (Vrec)	3.07	3.05
Residual from Recruitment Index 1: spring	0.52	0.52
Residual from Recruitment Index 2: winter	1.09	1.00
Residual from Adult Index 1: spring ln	0.80	0.77
Residual from Adult Index 2: winter ln	1.20	1.15
Residual from Survey Length Frequency Index 1	166.48	166.57
Residual from Survey Length Frequency Index 2	14.67	13.18
Q for Recruitment Index 1: spring	4.08E-08	2.41E-08
Q for Recruitment Index 2: winter	6.00E-08	3.47E-08
Q for Adult Index 1: spring ln	6.09E-08	4.89E-08
Q for Adult Index 2: winter ln	8.69E-08	6.97E-08
Weight on Catch Weight	15	15
Effective Sample Size on Catch Length Frequencies	150	150
Penalty Weight on Variation in Recruitment (Vrec)	0.01	0.001
Weight on Recruitment Index 1: spring	15	15
Weight on Recruitment Index 2: winter	15	15
Weight for Adult Index 1: spring ln	15	15
Weight for Adult Index 2: winter ln	15	15
Effective Sample Size on Survey Length Frequency Index 1	125	125
Effective Sample Size on Survey Length Frequency Index 2	125	125
The Size and Larger the Model is Fitting for Adult Abundance Index 1: spring ln	22	22
The Size and Larger the Model is Fitting for Adult Abundance Index 2: winter ln	22	22
The Size and Larger the Model is Fitting for Adult Length Frequency Survey Index 1	30	30
The Size and Larger the Model is Fitting for Adult Length Frequency Survey Index 2	22	22
Alpha Selectivity Parameter for Block 1	21.86	21.95
Beta Selectivity Parameter for Block 1	1.00	0.98
Alpha Selectivity Parameter for Block 2	25.19	25.26
Beta Selectivity Parameter for Block 2	1.00	1.00
Alpha Selectivity Parameter for Block 3	28.55	28.99
Beta Selectivity Parameter for Block 3	0.72	0.79

Table 8. SCALE model diagnostic information of M=0.5 and preferred option of M=0.6 logistic model.

Summary Output Data	**M=0.5**	**logistic m=0.6**
Sexes in Model Combined		
Total Objective Function	247.75	245.42
Residuals from Catch Weight	0.27	0.31
Residuals from Catch Length Frequency	9.66	9.50
Residuals from Variation in Recruitment Penalty (Vrec)	3.07	3.05
Residual from Recruitment Index 1: spring	0.52	0.52
Residual from Recruitment Index 2: winter	1.03	1.00
Residual from Adult Index 1: spring ln	0.80	0.77
Residual from Adult Index 2: winter ln	1.21	1.15
Residual from Survey Length Frequency Index 1	166.59	166.57
Residual from Survey Length Frequency Index 2	14.13	13.18
Q for Recruitment Index 1: spring	2.86E-08	2.41E-08
Q for Recruitment Index 2: winter	4.20E-08	3.47E-08
Q for Adult Index 1: spring ln	5.00E-08	4.89E-08
Q for Adult Index 2: winter ln	7.10E-08	6.97E-08
Weight on Catch Weight	15	15
Effective Sample Size on Catch Length Frequencies	150	150
Penalty Weight on Variation in Recruitment (Vrec)	0.01	0.001
Weight on Recruitment Index 1: spring	15	15
Weight on Recruitment Index 2: winter	15	15
Weight for Adult Index 1: spring ln	15	15
Weight for Adult Index 2: winter ln	15	15
Effective Sample Size on Survey Length Frequency Index 1	125	125
Effective Sample Size on Survey Length Frequency Index 2	125	125
The Size and Larger the Model is Fitting for Adult Abundance Index 1: spring ln	22	22
The Size and Larger the Model is Fitting for Adult Abundance Index 2: winter ln	22	22
The Size and Larger the Model is Fitting for Adult Length Frequency Survey Index 1	30	30
The Size and Larger the Model is Fitting for Adult Length Frequency Survey Index 2	22	22
Alpha Selectivity Parameter for Block 1	21.87	21.95
Beta Selectivity Parameter for Block 1	0.98	0.98
Alpha Selectivity Parameter for Block 2	25.19	25.26
Beta Selectivity Parameter for Block 2	1.00	1.00
Alpha Selectivity Parameter for Block 3	28.71	28.99
Beta Selectivity Parameter for Block 3	0.80	0.79

Table 9. SCALE model diagnostic information of M=0.6 and preferred option of M=0.6 logistic model.

Summary Output Data	**M=0.6**	**logistic m=0.6**
Sexes in Model Combined		
Total Objective Function	243.51	245.42
Residuals from Catch Weight	0.15	0.31
Residuals from Catch Length Frequency	9.26	9.50
Residuals from Variation in Recruitment Penalty (Vrec)	3.09	3.05
Residual from Recruitment Index 1: spring	0.55	0.52
Residual from Recruitment Index 2: winter	0.95	1.00
Residual from Adult Index 1: spring ln	0.76	0.77
Residual from Adult Index 2: winter ln	1.17	1.15
Residual from Survey Length Frequency Index 1	166.80	166.57
Residual from Survey Length Frequency Index 2	13.58	13.18
Q for Recruitment Index 1: spring	1.98E-08	2.41E-08
Q for Recruitment Index 2: winter	2.90E-08	3.47E-08
Q for Adult Index 1: spring ln	4.07E-08	4.89E-08
Q for Adult Index 2: winter ln	5.76E-08	6.97E-08
Weight on Catch Weight	15	15
Effective Sample Size on Catch Length Frequencies	150	150
Penalty Weight on Variation in Recruitment (Vrec)	0.01	0.001
Weight on Recruitment Index 1: spring	15	15
Weight on Recruitment Index 2: winter	15	15
Weight for Adult Index 1: spring ln	15	15
Weight for Adult Index 2: winter ln	15	15
Effective Sample Size on Survey Length Frequency Index 1	125	125
Effective Sample Size on Survey Length Frequency Index 2	125	125
The Size and Larger the Model is Fitting for Adult Abundance Index 1: spring ln	22	22
The Size and Larger the Model is Fitting for Adult Abundance Index 2: winter ln	22	22
The Size and Larger the Model is Fitting for Adult Length Frequency Survey Index 1	30	30
The Size and Larger the Model is Fitting for Adult Length Frequency Survey Index 2	22	22
Alpha Selectivity Parameter for Block 1	21.87	21.95
Beta Selectivity Parameter for Block 1	0.94	0.98
Alpha Selectivity Parameter for Block 2	25.19	25.26
Beta Selectivity Parameter for Block 2	1.00	1.00
Alpha Selectivity Parameter for Block 3	28.95	28.99
Beta Selectivity Parameter for Block 3	0.81	0.79

Table 10. SCALE model diagnostic information of M=0.7 and preferred option of M=0.6 logistic model.

Summary Output Data	**M=0.7**	**logistic m=0.6**
Sexes in Model Combined		
Total Objective Function	240.65	245.42
Residuals from Catch Weight	0.08	0.31
Residuals from Catch Length Frequency	9.01	9.50
Residuals from Variation in Recruitment Penalty (Vrec)	3.11	3.05
Residual from Recruitment Index 1: spring	0.59	0.52
Residual from Recruitment Index 2: winter	0.88	1.00
Residual from Adult Index 1: spring ln	0.72	0.77
Residual from Adult Index 2: winter ln	1.14	1.15
Residual from Survey Length Frequency Index 1	167.14	166.57
Residual from Survey Length Frequency Index 2	13.23	13.18
Q for Recruitment Index 1: spring	1.33E-08	2.41E-08
Q for Recruitment Index 2: winter	1.94E-08	3.47E-08
Q for Adult Index 1: spring ln	3.21E-08	4.89E-08
Q for Adult Index 2: winter ln	4.53E-08	6.97E-08
Weight on Catch Weight	15.00	15
Effective Sample Size on Catch Length Frequencies	150.00	150
Penalty Weight on Variation in Recruitment (Vrec)	0.01	0.001
Weight on Recruitment Index 1: spring	15	15
Weight on Recruitment Index 2: winter	15	15
Weight for Adult Index 1: spring ln	15	15
Weight for Adult Index 2: winter ln	15	15
Effective Sample Size on Survey Length Frequency Index 1	125	125
Effective Sample Size on Survey Length Frequency Index 2	125	125
The Size and Larger the Model is Fitting for Adult Abundance Index 1: spring ln	22	22
The Size and Larger the Model is Fitting for Adult Abundance Index 2: winter ln	22	22
The Size and Larger the Model is Fitting for Adult Length Frequency Survey Index 1	30	30
The Size and Larger the Model is Fitting for Adult Length Frequency Survey Index 2	22	22
Alpha Selectivity Parameter for Block 1	21.87	21.95
Beta Selectivity Parameter for Block 1	0.91	0.98
Alpha Selectivity Parameter for Block 2	25.20	25.26
Beta Selectivity Parameter for Block 2	1.00	1.00
Alpha Selectivity Parameter for Block 3	29.17	28.99
Beta Selectivity Parameter for Block 3	0.80	0.79

Table 11. SCALE model diagnostic information of M=0.8 and preferred option of M=0.6 logistic model.

Summary Output Data	**M=0.8**	**logistic m=0.6**
Sexes in Model Combined		
Total Objective Function	238.96	245.42
Residuals from Catch Weight	0.04	0.31
Residuals from Catch Length Frequency	8.82	9.50
Residuals from Variation in Recruitment Penalty (Vrec)	3.14	3.05
Residual from Recruitment Index 1: spring	0.63	0.52
Residual from Recruitment Index 2: winter	0.81	1.00
Residual from Adult Index 1: spring ln	0.70	0.77
Residual from Adult Index 2: winter ln	1.12	1.15
Residual from Survey Length Frequency Index 1	167.51	166.57
Residual from Survey Length Frequency Index 2	13.10	13.18
Q for Recruitment Index 1: spring	8.40E-09	2.41E-08
Q for Recruitment Index 2: winter	1.23E-08	3.47E-08
Q for Adult Index 1: spring ln	2.37E-08	4.89E-08
Q for Adult Index 2: winter ln	3.35E-08	6.97E-08
Weight on Catch Weight	15	15
Effective Sample Size on Catch Length Frequencies	150	150
Penalty Weight on Variation in Recruitment (Vrec)	0.01	0.001
Weight on Recruitment Index 1: spring	15	15
Weight on Recruitment Index 2: winter	15	15
Weight for Adult Index 1: spring ln	15	15
Weight for Adult Index 2: winter ln	15	15
Effective Sample Size on Survey Length Frequency Index 1	125	125
Effective Sample Size on Survey Length Frequency Index 2	125	125
The Size and Larger the Model is Fitting for Adult Abundance Index 1: spring ln	22	22
The Size and Larger the Model is Fitting for Adult Abundance Index 2: winter ln	22	22
The Size and Larger the Model is Fitting for Adult Length Frequency Survey Index 1	30	30
The Size and Larger the Model is Fitting for Adult Length Frequency Survey Index 2	22	22
Alpha Selectivity Parameter for Block 1	21.89	21.95
Beta Selectivity Parameter for Block 1	0.88	0.98
Alpha Selectivity Parameter for Block 2	25.21	25.26
Beta Selectivity Parameter for Block 2	1.00	1.00
Alpha Selectivity Parameter for Block 3	29.33	28.99
Beta Selectivity Parameter for Block 3	0.78	0.79

Table 12. SCALE model diagnostic information of logistic M=0.4 and preferred option of M=0.6 logistic model.

Summary Output Data	**logistic m=0.4**	**logistic m=0.6**
Sexes in Model Combined		
Total Objective Function	255.66	245.42
Residuals from Catch Weight	0.78	0.31
Residuals from Catch Length Frequency	10.62	9.50
Residuals from Variation in Recruitment Penalty (Vrec)	3.08	3.05
Residual from Recruitment Index 1: spring	0.55	0.52
Residual from Recruitment Index 2: winter	1.05	1.00
Residual from Adult Index 1: spring ln	0.79	0.77
Residual from Adult Index 2: winter ln	1.09	1.15
Residual from Survey Length Frequency Index 1	166.92	166.57
Residual from Survey Length Frequency Index 2	14.23	13.18
Q for Recruitment Index 1: spring	4.54E-08	2.41E-08
Q for Recruitment Index 2: winter	6.52E-08	3.47E-08
Q for Adult Index 1: spring ln	6.77E-08	4.89E-08
Q for Adult Index 2: winter ln	9.64E-08	6.97E-08
Weight on Catch Weight	15	15
Effective Sample Size on Catch Length Frequencies	150	150
Penalty Weight on Variation in Recruitment (Vrec)	0.001	0.001
Weight on Recruitment Index 1: spring	15	15
Weight on Recruitment Index 2: winter	15	15
Weight for Adult Index 1: spring ln	15	15
Weight for Adult Index 2: winter ln	15	15
Effective Sample Size on Survey Length Frequency Index 1	125	125
Effective Sample Size on Survey Length Frequency Index 2	125	125
The Size and Larger the Model is Fitting for Adult Abundance Index 1: spring ln	22	22
The Size and Larger the Model is Fitting for Adult Abundance Index 2: winter ln	22	22
The Size and Larger the Model is Fitting for Adult Length Frequency Survey Index 1	30	30
The Size and Larger the Model is Fitting for Adult Length Frequency Survey Index 2	22	22
Alpha Selectivity Parameter for Block 1	21.82	21.95
Beta Selectivity Parameter for Block 1	1.00	0.98
Alpha Selectivity Parameter for Block 2	25.25	25.26
Beta Selectivity Parameter for Block 2	1.00	1.00
Alpha Selectivity Parameter for Block 3	29.13	28.99
Beta Selectivity Parameter for Block 3	0.62	0.79

Table 13. SCALE model diagnostic information of logistic M=0.5 and preferred option of M=0.6 logistic model.

Summary Output Data	**logistic m=0.5**	**logistic m=0.6**
Sexes in Model Combined		
Total Objective Function	250.40	245.42
Residuals from Catch Weight	0.52	0.31
Residuals from Catch Length Frequency	9.96	9.50
Residuals from Variation in Recruitment Penalty (Vrec)	3.07	3.05
Residual from Recruitment Index 1: spring	0.53	0.52
Residual from Recruitment Index 2: winter	1.04	1.00
Residual from Adult Index 1: spring ln	0.78	0.77
Residual from Adult Index 2: winter ln	1.13	1.15
Residual from Survey Length Frequency Index 1	166.77	166.57
Residual from Survey Length Frequency Index 2	13.66	13.18
Q for Recruitment Index 1: spring	3.35E-08	2.41E-08
Q for Recruitment Index 2: winter	4.82E-08	3.47E-08
Q for Adult Index 1: spring ln	5.79E-08	4.89E-08
Q for Adult Index 2: winter ln	8.27E-08	6.97E-08
Weight on Catch Weight	15	15
Effective Sample Size on Catch Length Frequencies	150	150
Penalty Weight on Variation in Recruitment (Vrec)	0.001	0.001
Weight on Recruitment Index 1: spring	15	15
Weight on Recruitment Index 2: winter	15	15
Weight for Adult Index 1: spring ln	15	15
Weight for Adult Index 2: winter ln	15	15
Effective Sample Size on Survey Length Frequency Index 1	125	125
Effective Sample Size on Survey Length Frequency Index 2	125	125
The Size and Larger the Model is Fitting for Adult Abundance Index 1: spring ln	22	22
The Size and Larger the Model is Fitting for Adult Abundance Index 2: winter ln	22	22
The Size and Larger the Model is Fitting for Adult Length Frequency Survey Index 1	30	30
The Size and Larger the Model is Fitting for Adult Length Frequency Survey Index 2	22	22
Alpha Selectivity Parameter for Block 1	21.90	21.95
Beta Selectivity Parameter for Block 1	1.00	0.98
Alpha Selectivity Parameter for Block 2	25.25	25.26
Beta Selectivity Parameter for Block 2	1.00	1.00
Alpha Selectivity Parameter for Block 3	28.97	28.99
Beta Selectivity Parameter for Block 3	0.72	0.79

Table 14. Biological reference points with M=0.6 (logistic model and constant M).

M=0.6 logistic

	F	YPR	SSB/R	B/R
Fzero	0.000	0.000	1.220	1.264
F0.1	**0.194**	0.084	0.523	0.566
Fmax	0.929	0.096	0.186	0.228
F40%	**0.216**	0.087	0.488	0.531

	yield	SSB	Total Biomass
Fzero	-	57,665	59,713
F0.1	3,984	24,696	26,723
Fmax	4,536	8,808	10,787
F40%	4,089	23,068	25,093

2007 biomass 15,570

2007 F/F40%	2.15		2007
2007 F/F0.1	2.38	SSB/R	0.22
2007B F0.1	0.58	SSB	13,407
2007BF40%	0.62		

M=0.6 constant

	F	YPR	SSB/R	B/R
Fzero	0.000	0.000	0.440	0.483
F0.1	0.603	0.075	0.200	0.249
Fmax	N/A			
F40%	0.847	0.081	0.176	0.218

	yield	SSB	Total Biomass
Fzero	-	25,342	27,805
F0.1	4,318	11,525	14,358
Fmax	-	-	-
F40%	4,645	10,137	12,532

2007 biomass 18,653

2007B -F0.1	0.45
2007 B F40%	0.63
2007 F/F0.1	1.30
2007 F/F40%	1.49

Table 15. Biological reference points with M=0.5 (logistic model and constant M).

M=0.5 logistic

	F	YPR	SSB/R	B/R
Fzero	0.000	0.000	1.931	1.979
F0.1	0.171	0.124	0.829	0.876
Fmax	0.360	0.134	0.476	0.523
F40%	0.189	0.127	0.773	0.820

	yield	SSB	Total Biomass
Fzero	-	65,553	67,185
F0.1	4,199	28,133	29,747
Fmax	4,562	16,162	17,760
F40%	4,301	26,227	27,839

2007 biomass 12,825

2007B F0.1	0.43
2007B F40%	0.46
2007 F/F0.1	3.30
2007 F/F40%	2.97

	2007
SSB/R	0.251
SSB	11,168

M=0.5 constant

	F	YPR	SSB/R	B/R
Fzero	0.000	0.000	0.681	0.728
F0.1	0.478	0.099	0.306	0.352
Fmax	1.597	0.114	0.163	0.209
F40%	0.594	0.104	0.272	0.319

	yield	SSB	Total Biomass
Fzero	-	27,070	28,957
F0.1	3,941	12,171	14,017
Fmax	4,540	6,501	8,294
F40%	4,133	10,828	12,666

2007 biomass 15,790

2007B -F0.1	0.86
2007 B F40%	0.69
2007 F/F0.1	1.13
2007 F/F40%	1.25

Table 16. Biological reference points with M=0.4 (logistic and constant M).

M=0.4 logistic

	F	YPR	SSB/R	B/R
Fzero	0.000	0.000	3.100	3.153
F0.1	0.154	0.186	1.334	1.387
Fmax	0.268	0.199	0.864	0.916
F40%	0.171	0.190	1.240	1.293

	yield	SSB	Total Biomass
Fzero	-	77,659	79,002
F0.1	4,662	33,417	34,743
Fmax	4,977	21,638	22,954
F40%	4,770	31,074	32,398

2007 biomass 10,457

2007B F0.1	0.30
2007B F40%	0.32
2007 F/F0.1	4.76
2007 F/F40%	4.30

	2007
SSB/R	0.279
SSB	9,151

M=0.4 constant

	F	YPR	SSB/R	B/R
Fzero	0.000	0.000	1.124	1.177
F0.1	0.368	0.135	0.486	0.538
Fmax	0.975	0.152	0.268	0.319
F40%	0.419	0.140	0.450	0.501

	yield	SSB	Total Biomass
Fzero	-	31,341	32,816
F0.1	3,774	13,555	14,998
Fmax	4,248	7,472	8,882
F40%	3,903	3,903	13,977

2007 Biomass 12,892

2007B -F0.1	0.86
2007 B F40%	0.92
2007 F/F0.1	1.31
2007 F/F40%	1.15

APPENDIX I

SCALE Model

Introduction

Incomplete or lack of age-specific catch and survey indices often limits the application of a full age-structured assessment (e.g. Virtual Population Analysis and many forward projecting age-structured models). Stock assessments will often rely on the simpler size/age aggregated models (e.g. surplus production models) when age-specific information is lacking. However the simpler size/age aggregated models may not utilize all of the available information for a stock assessment. Knowledge of a species growth and lifespan, along with total catch data, size composition of the removals, recruitment indices and indices on numbers and size composition of the large fish in a survey can provide insights on population status using a simple model framework.

The Statistical Catch At LEngth (SCALE) model, is a forward projecting age-structured model tuned with total catch (mt), catch at length or proportional catch at length, recruitment at a specified age (usually estimated from first length mode in the survey), survey indices of abundance of the larger/older fish (usually adult fish) and the survey length frequency distributions. The SCALE model was developed in the AD model builder framework. The model parameter estimates are fishing mortality and recruitment in each year, fishing mortality to produce the initial population (Fstart), logistic selectivity parameters for each year or blocks of years and Qs for each survey index.

The SCALE model was developed as an age-structured model that does NOT rely on age-specific information on a yearly basis. The model is designed to fit length information, abundance indices, and recruitment at age which can be estimated by using survey length slicing. However the model does require an accurate representation of the average overall growth of the population which is input to the model as mean lengths at age. Growth can be modeled as sex-specific growth and natural mortality or growth and natural mortality can be model with the sexes combined. The SCALE model will allow for missing data.

Model Configuration

The SCALE model assumes growth follows the mean input length at age with predetermined input error in length at age. Therefore a growth model or estimates of the average mean lengths at age is essential for reliable results. The model assumes static growth and therefore population mean length/weight at age are assumed constant over time.

The SCALE model estimates logistic parameters for a flattop selectivity curve at length in each time block specified by the user for the calculation of population and catch age-length matrices or the user can input fixed logistic selectivity parameters. Presently the SCALE model can not account for the dome shaped selectivity pattern.

The SCALE model computes an initial age-length population matrix in year one of the model as follows. First the estimated populations numbers at age starting with age-1 recruitment get normally distributed at one cm length intervals using the mean length at age with the assumed standard deviation. Next the initial population numbers at age are calculated from the previous age at length abundance using the survival equation. An estimated fishing mortality (Fstart) is also used to produce the initial population. This F can be thought of as the average fishing mortality that occurred before the first year in the model. Now the process repeats itself with the total of the estimated abundance at age getting redistributed according to the mean length at age and standard deviation in the next age (age+1).

This two step process is used to incorporate the effects of length specific selectivities and fishing mortality. The initial population length and age distribution is constructed by assuming population equilibrium with an initial value of F, called F_{start}. Length specific mortality is estimated as a two step process in which the population is first decremented for the length specific effects of mortality as follows:

$$N^{*}_{a,len,y_1} = N_{a-1,len,y_1} e^{-\left(PR_{len}F_{start}+M\right)}$$

In the second step, the total population of survivors is then redistributed over the lengths at age *a* by assuming that the proportions of numbers at length at age *a* follow a normal distribution with a mean length derived from the input growth curve (mean lengths at age).

$$N_{a,len,y_1} = \pi_{len,a} \sum_{len=0}^{L_\infty} N^{*}_{a,len,y_1}$$

where

$$\pi_{len,a} = \Phi\left(len+1 \mid \mu_a, \sigma_a^2\right) - \Phi\left(len \mid \mu_a, \sigma_a^2\right)$$

where

$$\mu_a = L_\infty\left(1 - e^{-K(a-t_0)}\right)$$

Mean lengths at age can be calculated from a von Bertalanffy model from a prior study as shown in the equation above or mean lengths at age can be calculated directly from an age-length key. Variation in length at age a = σ_s^2 can often be approximated empirically from the growth study used for the estimation of mean lengths at age. If large differences in growth exist between the sexes then growth can be input as sex-specific growth with sex-specific natural mortality. However catch and survey data are still fitted with sexes combined.

This SCALE model formulation does not explicitly track the dynamics of length groups across age because the consequences of differential survival at length at age a do not alter the mean length of fish at age a+1. However, it does more realistically account for the variations in age-specific partial recruitment patterns by incorporating the expected distribution of lengths at age.

In the next step the population numbers at age and length for years after the calculation of the initial population use the previous age and year for the estimate of abundance. Here the calculations are done on a cohort basis. Like in the previous initial population survival equation the partial recruitment is estimated on a length vector.

$$N^*_{a,len,y} = N_{a-1,len,y-1}\, e^{-\left(PR_{len} F_{y-1} + M\right)}$$

second stage

$$N_{a,len,y} = \pi_{len,a} \sum_{len=0}^{L_\infty} N^*_{a,len,y}$$

Constant M is assumed along with an estimated length-weight relationship to convert estimated catch in numbers to catch in weight. The standard Baranov's catch equation is used to remove the catch from the population in estimating fishing mortality.

$$C_{y,a,len} = \frac{N_{y,a,len}\, F_y\, PR_{len}\left(1 - e^{-\left(F_y PR_{len} + M\right)}\right)}{(F_y \ \ PR_{len}) + M}$$

Catch is converted to yield by assuming a time invariant average weight at length.

$$Y_{y,a,len} = C_{y,a,len} W_{len}$$

The SCALE model results in the calculation of population and catch age-length matrices for the starting population and then for each year thereafter. The model is programmed to estimate recruitment in year 1 and estimate variation in recruitment relative to recruitment in year 1 for each year thereafter. Estimated recruitment in year one can be thought of as the estimated average long term recruitment in the population since it produces the initial population. The residual sum of squares of the variation in recruitment $\sum(\mathrm{Vrec})^2$ is than used as a component of the total objective function. The weight on the recruitment variation component of the objective function (Vrec) can be used to penalize the model for estimating large changes in recruitment relative to estimated recruitment in year one.

The model requires an age-1 recruitment index for tuning or the user can assume relatively constant recruitment over time by using a high weight on Vrec. Usually there is little overlap in ages at length for fish that are one and/or two years of age in a survey of abundance. The first mode in a survey can generally index age-1 recruitment using length slicing. In addition numbers and the length frequency of the larger fish (adult fish) in a survey where overlap in ages at a particular length occurs can be used for tuning population abundance. The model tunes to the catch and survey length frequency data using a multinomial distribution. The user specifies the minimum size (cm) for the model to fit. Different minimum sizes can be fit for the catch and survey data length frequencies.

The number of parameters estimated is equal to the number of years in estimating F and recruitment plus one for the F to produce the initial population (Fstart), logistic selectivity parameters for each year or blocks of years, and for each survey Q. The total likelihood function to be minimized is made up of likelihood components comprised of fits to the catch, catch length frequencies, the recruitment variation penalty, each recruitment index, each adult index, and adult survey length frequencies:

$$\mathrm{L}_{\mathrm{catch}} = \sum_{years}\left(l\,\mathrm{n}(Y_{\mathrm{obs,y}} + 1) - \ln\left(\sum_{a}\sum_{len} \mathrm{Y}_{\mathrm{pred,len,a,y}} + 1 \right)\right)^2$$

$$L_{catch\_lf} = -N_{eff} \sum_{y}\left(\sum_{inlen}^{L_\infty}\left((C_{y,len} + 1)\ln\left(1 + \sum_{a} C_{pred,y,a,len} \right) - \ln(C_{y,len} + 1) \right) \right)$$

$$\mathrm{L}_{\mathrm{vrec}} = \sum_{y=2}^{Nyears} (Vrec_y)^2 = \sum_{y=2}^{Nyears} (R_1 - R_y)^2$$

$$\sum L_{rec} = \sum_{i=1}^{Nrec}\left[\sum_{y}^{Nyears}\left(\ln\left(I_{rec_i,inage_i,y}\right) - \ln\left(\sum_{len}^{L_\infty} N_{y,inage_i,len} * q_{rec\,i} \right)\right)^2 \right]$$

$$\sum L_{adult} = \sum_{i=1}^{Nadult}\left[\sum_{y}^{Nyears}\left(\ln\left(I_{adult_i,inlen+_i,y}\right) - \left(\sum_{a}\sum_{inlen_i}^{L_\infty} \ln\left(N_{pred,y,a,len} * q_{adult\,i}\right)\right)\right)^2 \right]$$

$$\sum L_{lf} = \sum_{i=1}^{Nlf}\left[-N_{eff}\sum_{y}\left(\sum_{inlen_i}^{L_\infty}\left((I_{lf_i,y,len} + 1)\ln\left(1 + \sum_{a} N_{pred,y,a,len} \right) - \ln(I_{lf_i,y,len} + 1) \right)\right)\right]$$

In equation L_{catch_lf} calculations of the sum of length is made from the user input specified catch length to the maximum length for fitting the catch. Input user specified fits are indicated with the prefix “in” in the equations. LF indicates fits to length frequencies. In equation L_{rec} the input specified recruitment age and in L_{adult} and L_{lf} the input survey specified lengths up to the maximum length is used in the calculation.

$$Obj\ \ fcn = \sum_{i=1}^{N} \lambda_i L_i$$

Lambdas represent the weights to be set by the user for each likelihood component in the total objective function.