Black sea bass
Unpublished manuscript
Appendix 1

Estimates of Fishing and Natural Mortality of Black Sea Bass, *Centropristis striata*, in the Mid-Atlantic based on a Release-Recapture Experiment

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Black sea bass; Appendix 1

Abstract

Black sea bass in the Mid_Atlantic Bight, are exploited by recreational and commercial fisheries. 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 greater than 1.0. The estimate of natural mortality includes the effects of all unaccounted tag losses, however the results suggest that natural mortality is likely greater than 0.2 which has been assumed based on a maximum age of 15. Higher overall rates of natural mortality could result from increased vulnerability at sexual transition in this hermaphroditic species.

Introduction

Stock assessments of marine fish populations have long been a key component in managing fishery resources. Information regarding past rates of exploitation, along with potential productivity, allow managers to determine how much future exploitation can be allowed. Traditionally, catch based population models have been the tool of choice in stock assessments but in recent years tag based models have been increasingly used either as independent estimates of exploitation (Latour et al. 2001; Lambert et al. 2006; Jiang et al. 2007) or in conjunction with catch data (Polacheck et al. 2006). If implemented within the framework of a properly designed experiment, tagging programs are capable of providing estimates of exploitation and population size as accurately as catch at age models (Pine et al. 2003).

In the Northwest Atlantic, black sea bass (*Centropristis striata*), support both commercial and recreational fisheries. Although black sea bass are distributed from the Gulf of Maine to the Gulf of Mexico, fish north of Cape Hatteras, NC are considered part of a single management unit. Commercial landings for this stock have remained relatively steady around 1400 mt since 1970, although landings in 1952 peaked at 9,900 mt (Shepherd 2007). Recreational landings, available since 1982, average about 1,600 mt annually. The species affinity for bottom structure during its seasonal period of inshore residency increases the availability to hook and line or trap fisheries while decreasing the 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).

Black sea bass are protogynous hermaphrodites and can be categorized as temperate reef fishes (Steimle et al. 1999). Transition from female to male generally occurs between the ages of two and five (Lavenda 1949; Mercer 1978). Males can follow one of two behavioral pathways, either becoming dominant males, characterized by a larger size and a bright blue nuccal hump during spawning season, or secondary males which have few distinguishing features. Spawning in the Middle Atlantic peaks during spring (May and June) when the fish reside in coastal waters. 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 cue which triggers the transition from females to secondary or dominant male is undocumented, although the bright coloration of males suggests that visual cues may be important in structuring the social hierarchy.

Development of an analytical stock assessment for black sea bass has been hampered by a lack of catch at age information, inadequate fishery independent abundance indices and the unique life history characteristics of this species (NEFSC 2007). A recommendation emanating from an assessment review was to develop a comprehensive coastwide tagging program as an alternative method of determining exploitation on the northern stock and as a way to examine migratory behavior (NEFSC 1998). A secondary goal of the tagging program was to create a cooperative approach to data collection involving both the commercial and recreational industries.

Methods

Tagging protocol

A basic assumption in mark-recapture programs is that the tagged animals will be dispersed equally among untagged animals (Brownie et al. 1985). This can be accomplished either with the tag and release of a single large group, allowing the animals to disperse, or by dispersing the sites of release throughout the tagging area (Ricker 1975). To ensure the greatest geographic dispersal of tagged sea bass throughout the range of the northern stock, we tagged and released fish among coastal states (MA, RI, NY, NJ, DE, MD and VA) relative to state landing quota allocations of the Mid-Atlantic Fishery Management Council (MAFMC). Within each state, tagging sites were distributed at regular spatial intervals.

Sample sizes for releases were determined following the methods of Polacheck and Hearn (2003). A target sample size was 2,500 tags per season based on estimation under a range of exploitation rates (15% to 45%) and assuming a reporting rate of 75%, which demonstrated that any further increase in sample size resulted in minimal reduction in the variance of the exploitation rate. Tagging was conducted annually from 2002 to 2004 within a 30 day period from mid-September to mid-October, as well as a 21day period in May 2003. Several autumn release events occurred within days of this time window, having been delayed by weather. High reward tags ($100) were interspersed among regular tag releases at an approximate rate of 1 per 25 regular tags.

Over the three year period, black sea bass were tagged and released aboard chartered commercial and recreational fishing vessels. Recreational gear was standard hook and line equipment while commercial vessels used fish traps or hook and line gear. Fishing was done in depths ranging from 6 to 46 m and, if necessary, captured fish were placed into a holding tank to await tagging or evaluate condition. The size of fish targeted for tagging were greater than the commercial legal length (28 cm); however, fish as small as 20 cm were tagged. Tag number, date, exact location, total length (to the half-centimeter) and relative condition were recorded for each fish tagged.

The tag type used was a Floy internal anchor tag (FM-84), which has exhibited long term retention in other species (Dunning et al. 1987; Waldman et al. 1991). The tags had a unique identification number, telephone contact number and “Reward” printed on each side and in opposite directions such that the tag number was present at both the base and end of the tag. Tags were either orange, whose reporting was rewarded with a cap, or red which resulted in the $100 reward. In later years of the study, entry into a $250 lottery was offered in lieu of a cap. Tags were inserted into the abdomen below the midpoint of the pectoral fin by removing 2-3 scales and making a 0.5 cm incision into the musculature. Tagged fish were either released immediately or, if necessary, placed into a holding tank for several minutes of observation. Sea bass caught at deeper sites often had extruded swim bladders which were deflated when the abdominal incision was made and tag inserted. Fish judged to be weak or swimming abnormally were not released with a tag.

Recaptured tags were reported by telephone, postal mail, or by an online tag reporting webpage. High reward tags were returned prior to payment. We collected information on the date of capture, fish length, gear type and fishery, port, and longitude and latitude of recapture (or at least some reference point within several miles), condition of the fish at the tag insertion point, and fisherman's contact information.

Tag effects

Tag retention rate and tag induced mortality were determined by holding tagged fish in tanks in three separate studies. The first study was conducted at the Northeast Fisheries Science Center (NEFSC) Woods Hole Aquarium. Fish collected by hook and line were tagged and then placed in a 3,500 L aquarium tank for nine months. A second experiment was conducted in the NEFSC J.J. Howard Laboratory in Sandy Hook, NJ. Fish collected from fish pots were held in 1,500 L for ten to twelve months. A third experiment was conducted by the Rhode Island Department of Environmental Management. Fish collected with fish pots were tagged and held in 1,500 L tanks for twenty-seven days. In each experiment, tag losses and mortality associated with tagging were recorded daily.

Tag Analysis

Black sea bass and their fisheries in the Mid-Atlantic occur during two seasons: May through early October, and late October through April. To account for these seasonal variations and the time of tag releases, the recapture information and subsequent analyses were divided into two periods. One period was May 1st to September 30th and the second period ran from October 1st to April 30th. Tag recapture information was compiled by release cohort and summarized in a recovery matrix as:

$$R = \begin{bmatrix} r_{12} & r_{22} & \cdots & r_{1J} \\ \_ & r_{22} & \cdots & r_{2J} \\ \vdots & \vdots & \ddots & \vdots \\ \_ & \_ & \_ & r_{IJ} \end{bmatrix}$$

where r_{IJ} is the number of tags recovered in period J that were released in period I.

An assumption of tag modeling is that the tagged fish are representative of the untagged population. The time series of tag recaptures from a release group can be treated as a catch cohort, and total mortality (F + M or Z) approximated as a catch curve by calculating the slope of the $\log_e$ of recaptures over time (Ricker 1975). The catch curve method was used to evaluate tag recapture consistency across seasons, after adjusting for reporting rate. The negative slopes of the regressions, estimated within Excel, were averaged across all release years for comparison to the full tag model.

Survival estimates from the mark-recapture data were modeled using a variation of the Brownie model parameterized as instantaneous rates (Hoenig et al. 1998a; Hoenig et al. 1998b). The instantaneous rates (IR) model allows for direct estimation of both fishing (F) and natural (M) mortality. Additionally, F in the first recapture interval can be modeled separately to account for incomplete mixing or partial selectivity to the fishery. The model of expected recoveries can be written as:

$$E(R) = \begin{bmatrix} N_1\phi\lambda_1\mu_1(F_1^*, M) & N_1\phi\lambda_2\mu_2(F_2, M)e^{-(F_1^*+M)} & \cdots\cdots & N_1\phi\lambda_J\mu_J(F_J, M)e^{-(F_1^*+\sum_{k=2}^{J-1}F_k+(J-1)M)} \\ - & N_2\phi\lambda_2\mu_2(F_2^*, M) & \cdots\cdots & N_2\phi\lambda_J\mu_J(F_J, M)e^{-(F_2^*+\sum_{k=3}^{J-1}F_k+(J-2)M)} \\ \vdots & \vdots & \ddots & \vdots \\ - & - & - & N_I\phi\lambda_J\mu_J(F_J, M)e^{-(F_I^*+\sum_{k=I+1}^{J-1}F_k+(J-I)M)} \end{bmatrix}$$

where ϕ is the rate of tag loss at release, λ is the tag reporting rate, F_k is the instantaneous fishing mortality in period k, F* is F during the initial non-mixing period and M is instantaneous rate of natural mortality. In black sea bass fisheries where F and M occur simultaneously, then:

$$\mu_J(F_J, M) = \frac{F_J}{F_J + M}(1 - \exp(-F_J - M))$$

and when *I*=*J* then:

$$\mu_J^*(F_J^*, M) = \frac{F_J^*}{F_J^* + M}(1 - \exp(-F_J^* - M))$$

Since the results are assumed to be a multinomial distribution, the optimal solution of model parameters was determined using maximum likelihood estimation. Comparisons between observed and predicted tag recovery frequencies were made with a chi-square goodness of fit test and evaluation of the best model was done using the quasi-likelihood Akaike's information criterion, $QAIC_c$, which accounts for over-dispersion in the data (Anderson et al.1994; Burnham and Anderson 2002). Profile likelihoods were developed for each parameter in the final model and used to calculate 95% confidence intervals (Gimenez et al. 2005). The model parameterization was developed using the solver function in Microsoft Excel.

Since tagging occurred in October or May, the resulting mortality estimates were not calendar year values. Annual fishing and natural mortalities were re-calculated using monthly values (seasonal mortality estimate / # months within the season) and these values re-configured to a calendar year rather than tagging year. Fishing mortality estimates in 2002 only included October to December and were not used in an annual mortality estimate. Results from the final three months of 2007 were assumed equal to the mean of the same period in 2006.

Reporting rate

Although it is possible to estimate reporting rate λ within the model (Jiang et al 2007), we used an empirical estimate based on high reward tag returns:

$$\lambda_J = \left[\frac{(\sum_{J=1} \text{regular tags returned} / \sum_{J=1} \text{regular tags released})}{(\sum_{J=1} \text{high reward tags returned} / \sum_{J=1} \text{high reward tags released})} \right]$$

The ratio was calculated only for the twelve months at large for each release cohort since the recapture ratio of regular tags to high reward tags in the second year is not independent of the reporting rate in the first year. A constant reporting rate was applied to the recaptures after spring 2005. The monetary award that was thought to ensure that return rates approach 100% was $100 (Murphy and Taylor 1991; Pollock et al. 2001; Taylor et al. 2006). The sensitivity of the model results to the assumption of high reward tag reporting rate was evaluated for rates from 25% to 100%.

Tag induced mortality estimates do not account for mortality associated with the capture and release process during tagging. Hooking mortality in black sea bass has been estimated at 5% (Bugley and Shepherd 1991). To account for potential mortality of tagged fish due to hook and line capture, the tag loss rate was inflated by five percent.

Growth

Growth rate of individuals was calculated as the change in length between release and recapture divided by the number of days at large. Since recapture lengths are provided by the public, these lengths were expected to have a greater measurement error than the release measurements taken by trained personnel. The overall average growth per day was estimated for the entire time series of returns, and for the time series following elimination of data from consecutive days at large. Average growth was calculated from the point where the average growth in the time series remained relatively stable.

Results

Between 2002 and 2004, a total of 13,794 black sea bass of all sizes were tagged and released with either regular or high reward tags. Among those released,12,310 fish were greater than or equal to 26 cm and were tagged with regular reward tags (Table 1, Figure 1). These were considered vulnerable to both recreational and commercial size fisheries within one season following release. From October 2002 to September 2007, 1,683 regular tagged sea bass were recaptured and reported (Figure 2), for an overall recapture rate of 13.7%. Tagged fish were recovered throughout the range from recreational fishermen (57.2%), commercial fishermen (39.2%), research trips (1.0%) and unknown sources (2.6%). The average size at release was 32.2 cm ($\pm$ one std. dev of 4.76) whereas the average size at recapture was 35.8 cm ($\pm$ one std. dev of 5.83). The size distributions of released fish were comparable to the size distributions of sea bass harvested by the recreational and commercial fisheries (Figure 3). Average time-at-large was 257 days and the total distance traveled between tagging and recapture locations averaged 27.0 km or 0.35 km day^{-1}.

Tag retention and tag induced mortality in black sea bass were evaluated in three separate experiments. Sixty-eight (68) fish, ranging in size from 26 to 41 cm, were held in aquaria up to twelve months. No mortalities were observed immediately following tag insertion and over the course of the three experiments, only seven tags were shed (Dr. Mary Fabrizio, NEFSC[2]; Brian Murphy, RIDEM, personal communication). Five of the seven tags were shed within the first several weeks. Tag loss in black sea bass tagged with internal anchor tags was estimated at 10%. In addition, to account for potential hook induced mortalities associated with the initial capture methods, total tag loss and mortality was set at 15%.

Growth of tagged fish was estimated as the difference in size between release and recapture, and the time at large. During the initial days at large, the growth of tagged fish would be expected to be negligible and therefore the difference between length at release and recapture during this period would be due to measurement error. Within the first ten days, the differences in recorded lengths between released and recaptured fish ranged from 0 to 7 cm, averaging 1.1 cm, with the largest discrepancy from legal size fish ($\geq$ 29.5 cm). With increasing time at large, measurement error decreased relative to accumulated growth (Figure 4). Consequently, growth rate declined over the first 90 days but stabilized thereafter. After the initial 90 days, growth averaged 0.012 cm day^{-1} for fish $\geq$26 cm. Assuming constant growth, fish tagged at 26 cm would be expected to attain legal size of 28 cm within 167 days following release.

Estimation of survival in Brownie-type models requires knowledge of the reporting rate of the tags. Included in the tag releases were 662 high reward tagged fish distributed across release periods. Based on the ratio of regular tags to high reward tag recoveries (N=151), seasonal estimates of tag reporting rate ranged from 53% to 80% (Table 2). The rates for the fall-winter period (76%. 80% and 57%) were generally higher than spring-summer (53%, 59% and 62%). Reporting rates in the years without empirical data were held constant at 60%, the average of the last two periods of empirical data. An assumption in reporting rate estimation was 100% reporting of the high reward tags. In the reporting process not all fishermen were willing to provide complete information necessary for payment. Consequently, true reporting rate was unknown but probably slightly less than 100%. The influence of reduced reporting of high reward tags would be an over-estimation of actual reporting rates (Pollock et al. 2001).

An additional model assumption is constant selectivity once the fish reach the size of full recruitment to the fisheries. This assumption was tested using recovery rates by two cm size categories for all data combined (Figure 5). The selectivity for fish greater than 29 cm was tested for a departure from a slope of zero. Results show no significant difference from 0 (Pr = 0.2) indicating a constant selectivity with size.

A simple estimate of total mortality (fishing plus natural mortality) was calculated as the rate of reduction in tag recoveries over time (Figure 6). The rate of decline in recoveries was consistent among release cohorts and total mortality estimates ranged from 1.33 to 1.54. The overall average total mortality using the catch curve method was 1.41. This approach requires a priori information regarding natural mortality to derive fishing mortality. Alternative tagging models, such as the instantaneous rates model, allow partitioning of the sources of mortality and direct estimation of F.

The instantaneous rates non-mixing model can be configured in a variety of ways. Recaptures of fish $\geq$ 29.5 cm were evaluated using seven models which included: (1) a fully parameterized model with time specific F, F* and M; (2) constant F and M with time specific F*; (3) constant F, F* and M; (4) time specific estimates of F* by period, time specific F for periods 1 through 6 with constant F across periods 7 to 10 and constant M; (5) constant estimates per period across years for all parameters; (6) constant annual estimates (no seasonal effect); and (7) period F* and F estimates with constant M. The constant F for periods 7 to 10 was chosen to

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account for small sample sizes in the upper right corner of the matrix. Results of the chi-square test indicated that predicted values were not statistically different than those expected, with Pr>0.05 for models 1, 4 and 7. Based on the QAIC value, model 1 provided the best combination of parsimony and fit (Table 3). However, the parameter estimates were not robust to the starting values in the solution algorithm as the F estimates in the final 3 periods converged to different solutions depending on initial values. The reduced model, model 4, provided a more robust solution and was selected as the most appropriate model configuration. A comparison of observed and expected tag recaptures (Figure 7) indicated that recaptures can be adequately predicted using this model. The residuals show a pattern of consistent under-estimation of tag recaptures from the spring 2003 release (Figure 8), although the magnitude of the residuals is very small. The residuals from the three fall releases show no trend.

Comparison of mixing and non-mixing estimates of fishing mortality suggest that black sea bass were more vulnerable to exploitation during the initial release period. In each of the three release cohorts where both a non-mixed and mixed F could be estimated, the non-mixing F was higher (Table 4). The difference was particularly obvious in the spring 2004 release where the non-mixing F for the initial period (F^*_3) was 0.18 whereas subsequent F_3 estimates were 0.10. Fall releases (F_2 and F_4) differed between mixing and non-mixing estimates by 15 and 20%, respectively.

Average seasonal mortality estimates were derived from the model partial Fs. During the October to December/January to April period, fishing mortality averaged 0.16 per month, compared to the partial F from May through September period when fishing mortality averaged 0.22. The annualized fishing mortality standardized to calendar year, increased from 0.32 in 2003 to 0.41 in 2005 but then declined in 2007 to 0.37 (Table 5). Natural mortality, estimated as constant across years and seasons, was 1.08 (Table 4).

The tagging results indicate that fishing mortality has been relatively stable since 2002. Profile likelihoods and the associated 95% confidence intervals for the suite of seasonal F, F* and M estimates are presented in Figures 9 and 10. The distinctiveness of the minimum likelihood decreases for the parameters furthest from the initial release period resulting in a greater uncertainty in the estimates at the end of the recovery time series.

The tag recaptures in the model are influenced by both tag retention and reporting rates. The reporting rate adjustments assume that all high reward tags recaptured are recovered. However, in situations where fish are being quickly discarded, tagged fish may not be recovered and may die soon after discarding. To examine the sensitivity of the natural mortality estimate to under-reporting, we incrementally decreased high reward reporting rates. Overall reporting rate decreased linearly with decreased high reward reporting and the estimate of natural mortality decrease was curvilinear (Figure 11). When the high reward reporting was equal to 28.2%, the model estimate of natural mortality was 0.2.

Discussion

Recent developments in mark-recapture models have advanced their use for evaluating the exploitation of marine fishes. In particular, the parameterization of the Brownie bird banding models into instantaneous rates makes tagging model results similar to traditional catch at age stock assessment models. The lack of an analytical stock assessment was the impetus for developing a tag recapture program for black sea bass. Consequently, the results from the tagging models may help in determining status of black sea bass in the Mid-Atlantic. The most recent estimate of the fishing mortality that produces the maximum yield per recruit (i.e. F_{max})

was calculated to be F=0.33 (NEFSC 2007). The tagging results imply that fishing mortality exceeds this level, although the distribution of the 95% confidence interval shows that there is some probability that F is actually below F_{max}.

Seasonal patterns in fishing mortality reflect differences in the black sea bass fisheries. During the inshore period, sea bass are exposed to a coastwide recreational fishery and a directed pot fishery, whereas the offshore fishery is generally a non-directed trawl fishery targeting species such as summer flounder or *Loligo* squid (Shepherd and Terceiro 1994). The locations of optimal inshore black sea bass habitat, such as artificial reefs, are generally well known to fishermen and are routinely targeted. Among several tag release locations on artificial reefs, the recovery rate was as high as 25 to 35%. Movement of black sea bass is highly seasonal and did not occur until several weeks after tagging. Consequently, the exploitation of tagged fish was greater before they mixed during migration but the non-mixing model was able to adjust for this pre-migration period.

The parameterization of the Brownie model into instantaneous rates allowed potential estimation of natural mortality. Fishing mortality is determined from tag recoveries while the estimation of natural mortality is based on unaccounted tags (Hoenig et al. 1998b). Consequently, the parameter M is true natural mortality but is influenced by biases resulting from tag attrition over time, overestimated reporting rates, changes in selectivity with size, permanent emigration from the study area, increased predation on tagged fish, etc. and any other process which could result in unaccounted for tag losses. Any of these processes could result in an over-estimation of natural mortality in the model.

In fisheries stock assessments, natural mortality is often based on the lifespan of the species (Hewitt and Hoenig 2005) and assuming a life expectancy of 15 years for black sea bass (Musick and Mercer 1977), M has been set at 0.2 in recent stock assessments (NEFSC 2007). The tag based estimate of 1.08 is significantly higher and contradictory to M predicted from maximum age. A biased estimate of M in the tagging model could be the result of model misspecification or biased tag data. However, model misspecification does not appear to be a problem as reflected in the residuals and profile likelihoods. Among tag return biases necessary to overestimate M, it would be difficult to create a scenario resulting in an M equal to 0.2. Initial tag loss (type 1), modeled as 15%, differs from long term attrition of tags (type 2) (Beverton and Holt 1957). Tag attrition can be parameterized similar to M but to reduce M to 0.2 based on misspecification of retention, tag attrition would have to approach 0.88. There is no direct evidence to suggest a loss of this magnitude. Holding studies demonstrated that tags could be retained for at least one year. An immunological response to tags resulting in encapsulation and expulsion has been documented in some species (Vogelbein and Overstreet 1987) but while this may have been possible in sea bass, there would have to be comparable chronic tag loss rates among all release cohorts. Reduction in tag legibility could also create tag attrition problems in the returns (Henderson-Arzapalo et al. 1999). However, there were few reports among fishermen returning tags that legibility was an issue.

Over estimation of reporting rates resulting from violation of the 100% reporting assumption of high reward tags could bias natural mortality estimates. A reporting rate of 30% on high reward tags would have been needed to produce an M of 0.2. This would be highly unlikely and would also imply an unrealistically high exploitation rate. Another possible bias could result from release of tagged fish independent of local abundance followed by non-mixing, but an area based model produced comparable results for M and the use of a non-mixing model should account for initial distribution problems. A potential bias resulting from a dome-shaped selectivity pattern was also discounted after examining the recovery rate by size.

Since tag recovery biases alone do not adequately explain the high natural mortality estimated in the tag models, the possibility exists that M on black sea bass is actually greater than expected. Sea bass are structure oriented, protogynous hermaphrodites with a transition from female to male generally between ages 3 to 5, which was approximately the size of fish tagged and released. During spawning, large dominant males undergo physiological changes and begin aggressively defending territory. The importance of secondary male *C. striata* to spawning success is not documented but in congeneric species the importance of secondary males has ranged from irrelevant to critical contributors to the gene pool (Petersen 1991). If these male *C. striata* only provide a pool of potential dominant males, there would be little evolutionary advantage for the population to maintain a large number of secondary males to compete with smaller females and the large males. The consequence could be a higher natural mortality from such things as senescence, increased aggression by dominant males or higher predation rates if the secondary males are forced into marginal habitats. If life expectancy of tagged fish was only three or four years beyond the age at release, the natural mortality of these fish could be significantly greater than 0.2. This does not imply that a high M was constant across all ages, but rather increases in the post transitional ages.

The tagging program for black sea bass in the Middle Atlantic was designed to simultaneously distribute tagged fish throughout the stock, test for tag induced mortality and tag loss, estimate annual reporting rates, and document recapture information. The release-recapture matrix was examined with an analytical tagging model that incorporated temporal variations in exploitation, and by association, spatial changes in exploitation. The results imply that this stock of black sea bass may be experiencing exploitation above the level currently considered optimal. The tagging results also suggest that our understanding of natural mortality developed from gonochoristic species may not be appropriate for this protogynous hermaphrodite. Biases in parameter estimation due to tag loss, etc. may explain in part the high value for natural mortality, but the magnitude of the value suggests that natural mortality is greater than would be predicted from maximum observed age.

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Table 1. Regular tags release and recapture totals by season for black sea bass ≥ 26 cm marked and released in the Middle Atlantic, 2002-2004.

		Recaptures				
Release Period	Total # Released	Oct 2002-Apr 2003	May 2003-Sept 2003	Oct 2003-Apr 2004	May 2004-Sept 2004	Oct 2004-Apr 2005
Fall 2002	3,391	202	108	40	26	11
Spring 2003	2,314		176	58	55	13
Fall 2003	2,863			253	136	32
Spring 2004	0				-	-
Fall 2004	3,742					223
Total	12,310	202	284	351	217	279

Release Period	May 2005-Sept 2005	Oct 2005-April 2006	May 2006-Sept 2006	Oct 2006-April 2007	May 2007-Sept 2007	never seen again
Fall 2002	14	3	1	0	0	2,986
Spring 2003	15	5	5	0	0	1,987
Fall 2003	20	9	7	1	1	2,404
Spring 2004	-	-	-	-	-	-
Fall 2004	164	49	39	9	8	3,250
Total	213	66	52	10	9	10,627

Table 2. Regular and high reward tag release and recapture totals used in calculation of reporting rates. Totals limited to released sea bass ≥ 29.5 cm and recaptures in the first and second seasons.

	Recaptures					
Total # Released	Oct 2002 - April 2003	May 2003 - Sept 2003	Oct 2003 - April 2004	May 2004 - Sept 2004	Oct 2004 - April 2005	May 2005 - Sept 2005
High Reward tags						
251	21	13				
57		10	2			
208			26	19		
0				-		
146					20	12
Regular tags						
2688	172	76				
1942		173	53			
1941			200	104		
0				-		
2079					163	106
Reporting rate						
Fall 2002	76%	53%				
Spring 2003		51%	78%			
Fall 2003			82%	59%		
Spring 2004				-		
Fall 2004					57%	62%
Average	76%	52%	80%	59%	57%	62%

Table 3. Summary of black sea bass tagging models evaluated.

model	likelihood	QAIC	# parameters	df	T	Pr	c hat
1	-7078.85	8893.50	23	10	14.67	0.145	1.60
2	-7125.06	3526.84	6	27	145.12	<0.001	4.05
3	-7144.74	2908.94	3	30	147.59	<0.001	4.92
4	**-7086.00**	**10142.09**	**11**	**22**	**29.14**	**0.120**	**1.40**
5	-7094.88	8212.20	6	27	46.48	0.011	1.73
6	-7098.60	5211.32	13	20	95.95	<0.001	2.74
7	-7080.46	14122.22	14	19	17.22	0.575	1.00

Table 4. Seasonal estimates of fishing mortality for non-mixing (F*) and following mixing (F). Natural mortality (M) held constant for time series.

F_1*	0.13
F_2*	0.24
F_3*	0.18
F_5*	0.17
F_2	0.20
F_3	0.10
F_4	0.27
F_5	0.15
F_6	0.25
F_7	0.19
F_8	0.19
F_9	0.19
F_{10}	0.19
$M_{1\text{-}10}$	0.54

Table 5. Annualized estimates of instantaneous fishing and natural mortality for black sea bass.

	F	M
2002	*	1.1
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

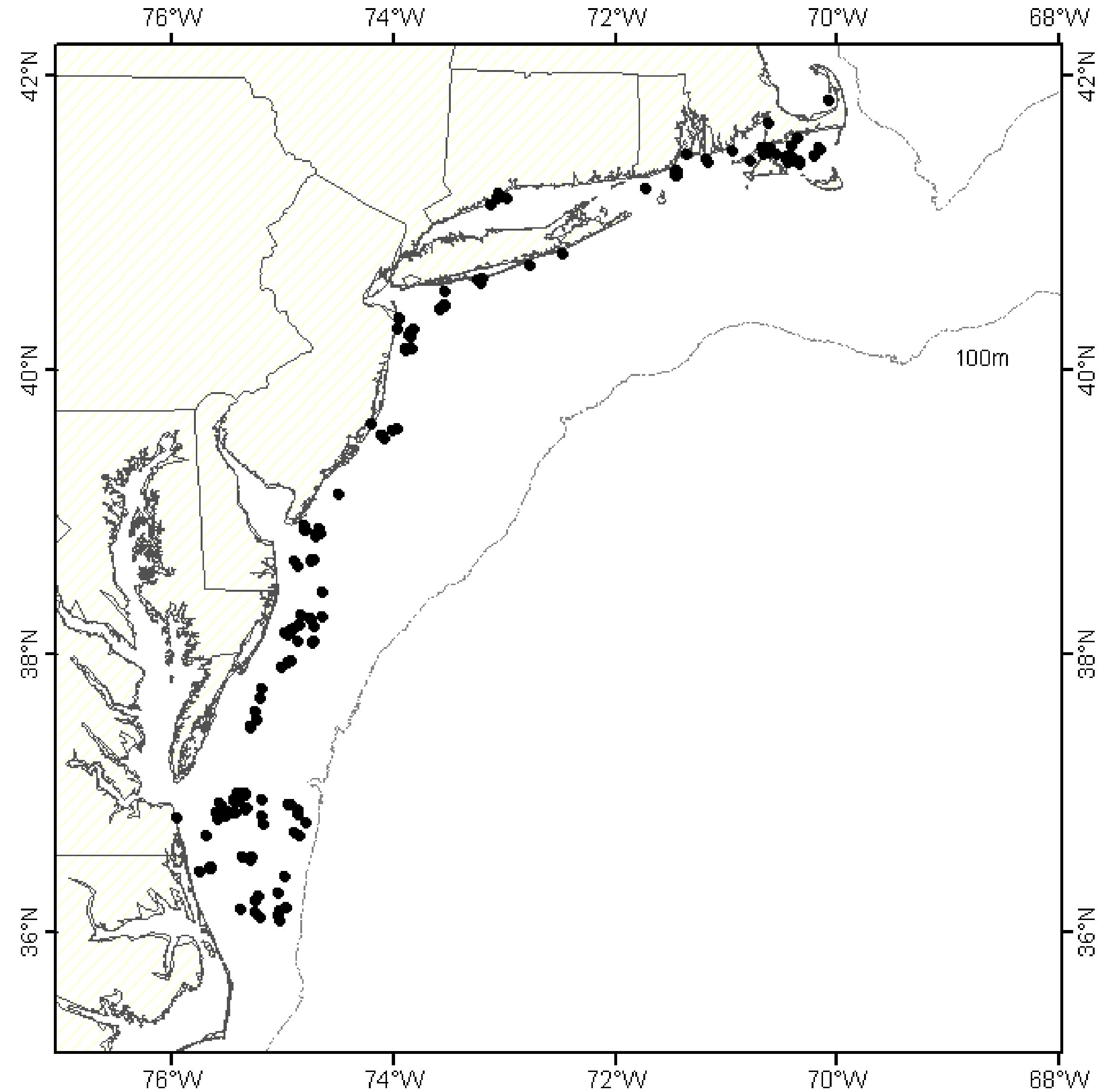

Figure 1. Distribution of black sea bass tag releases, 2002-2004.

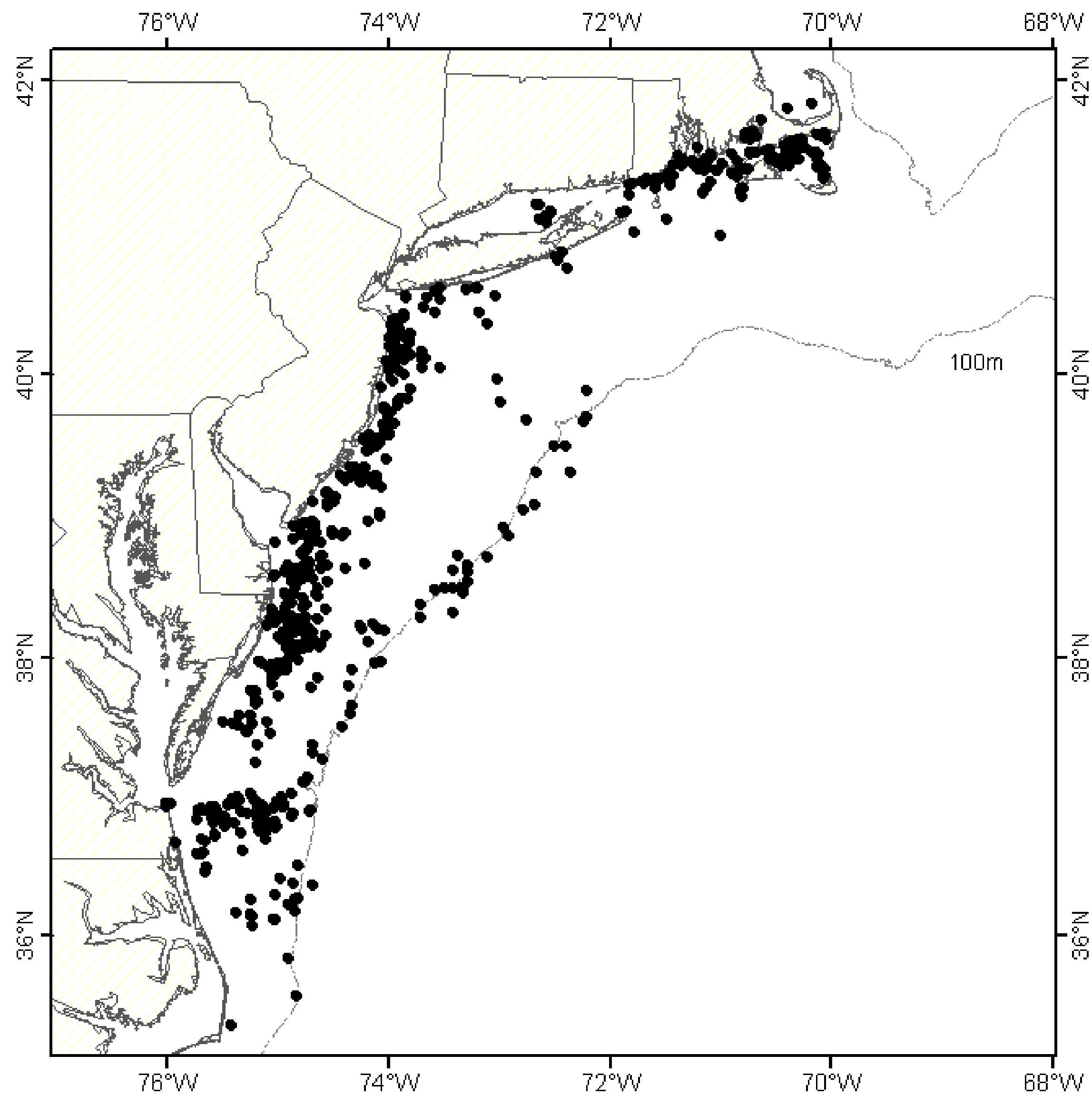

Figure 2. Black sea bass tag recapture locations, 2002-2007.

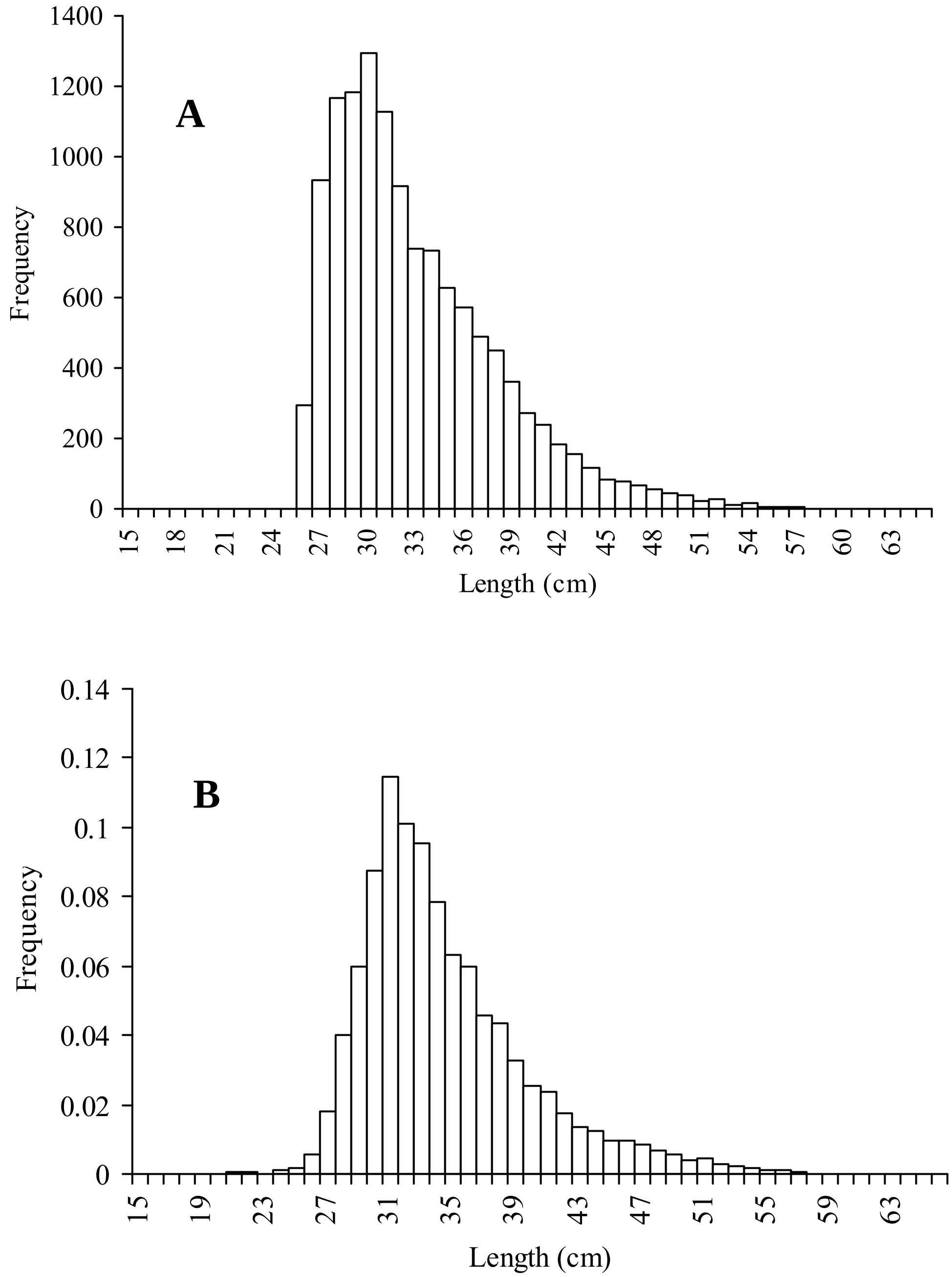

Figure 3. A: Length frequency distribution of marked and released black sea bass (2002-2004) and B: length frequency distribution from recreational and commercial fisheries (2002-2004).

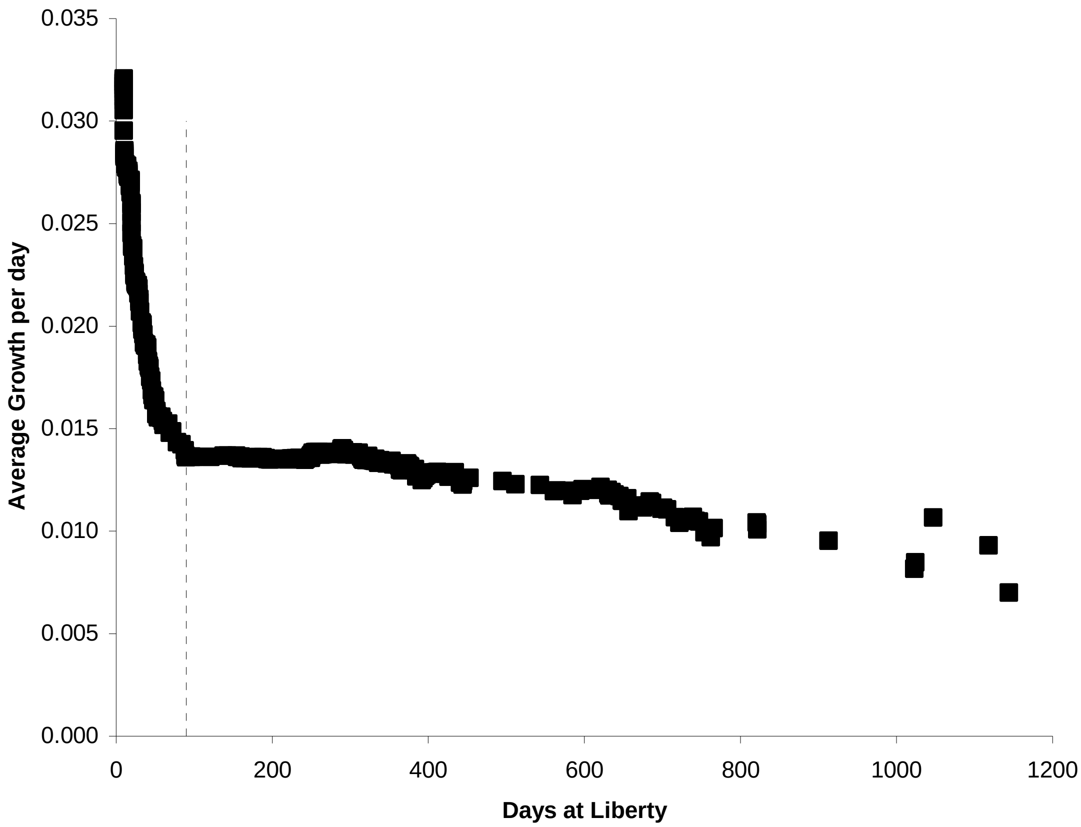

Figure 4. Consecutive moving average growth per day by the days at liberty. The 90 day point indicated by vertical line.

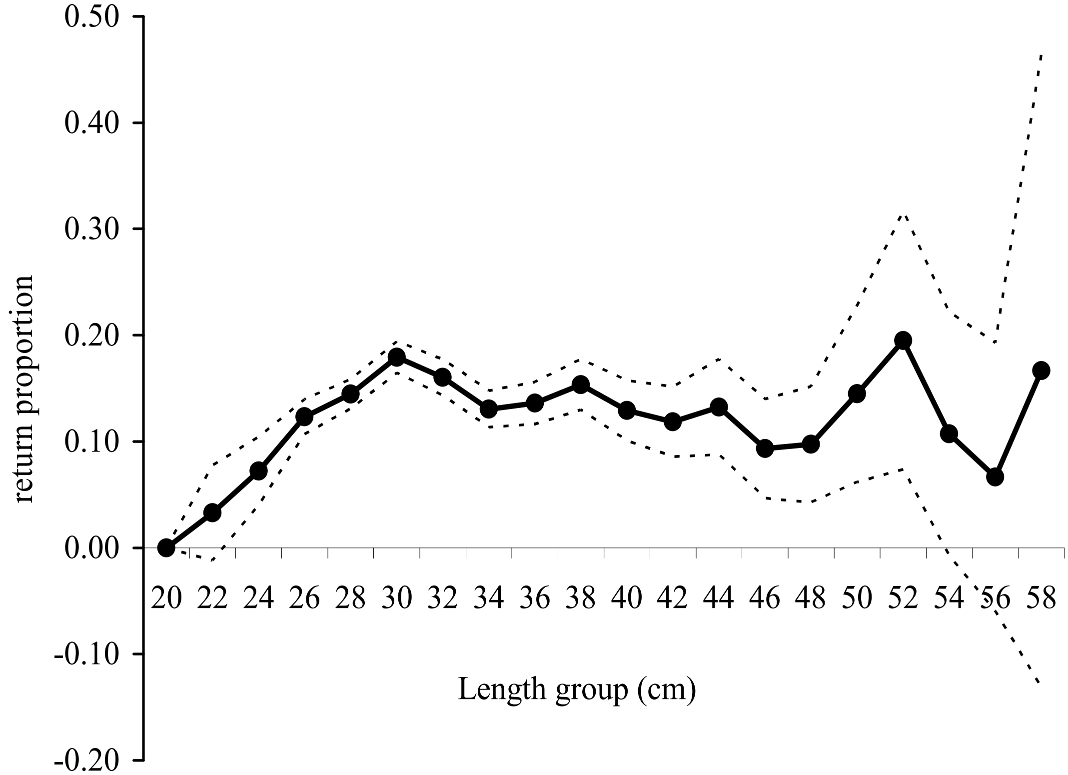

Figure 5. Selectivity by 2 cm length group represented by return proportion among all recoveries.

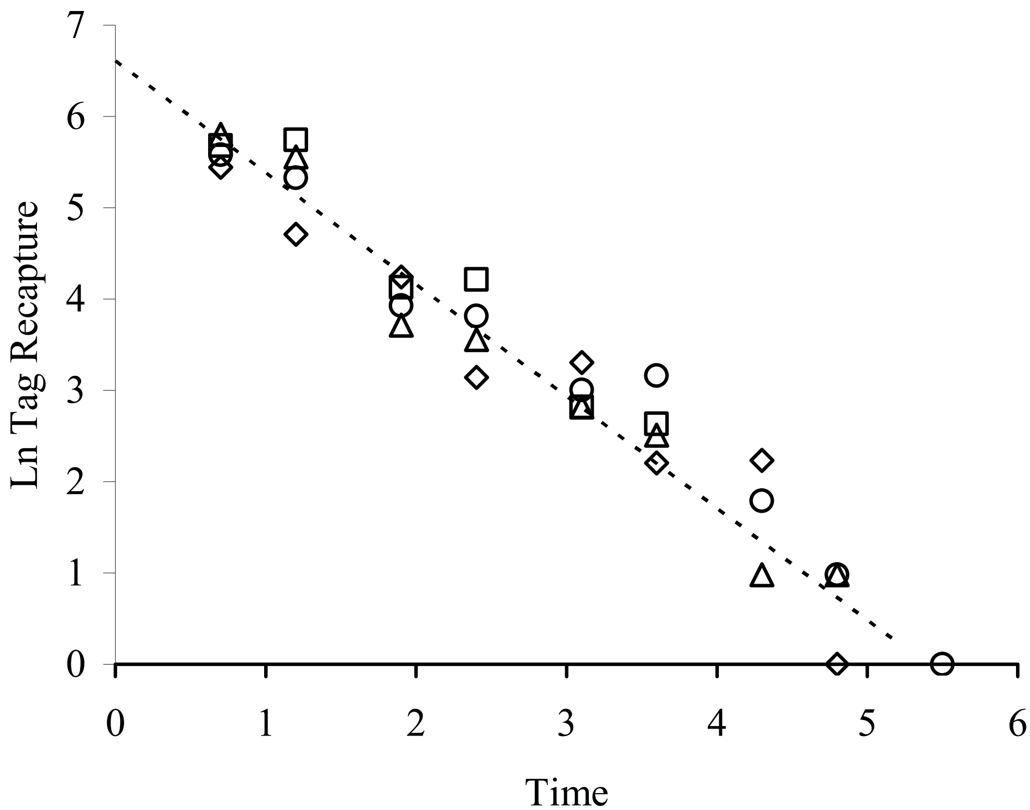

Figure 6. Catch curve equivalent of tag recaptures among all release cohorts. Different symbols represent release cohorts.

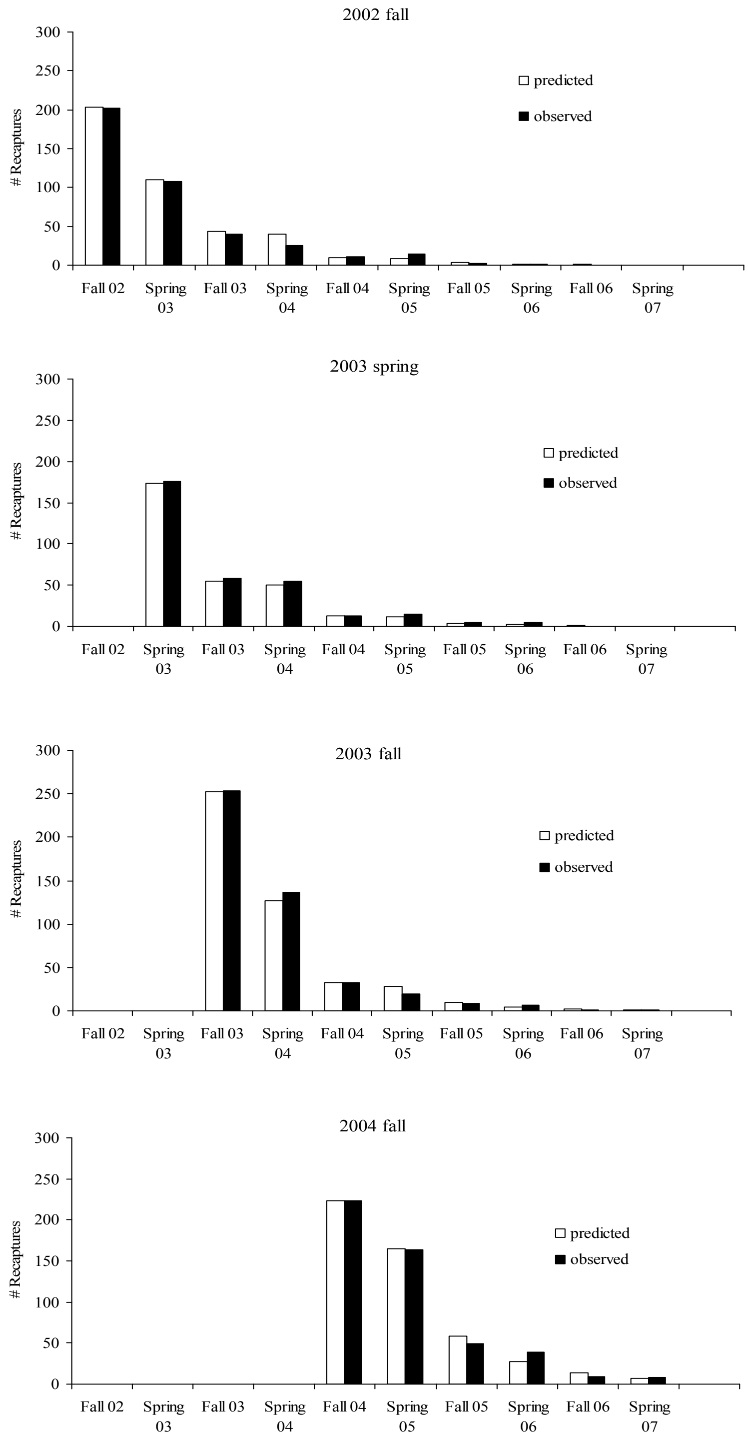

Figure 7. Comparison of observed and predicted tag recaptures by release cohort and season of recapture (model 4).

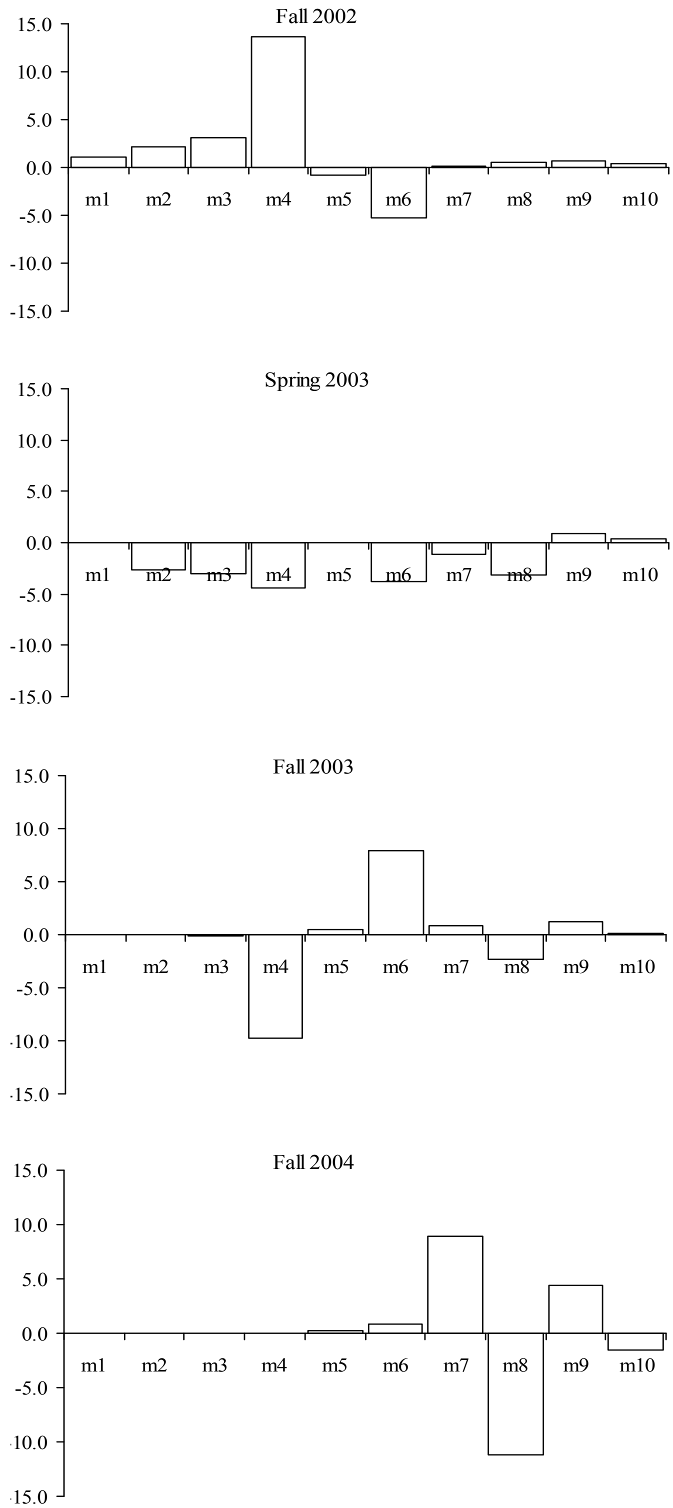

Figure 8. Residual difference between observed and predicted black sea bass tag recaptures, by release cohort and season (model 4).

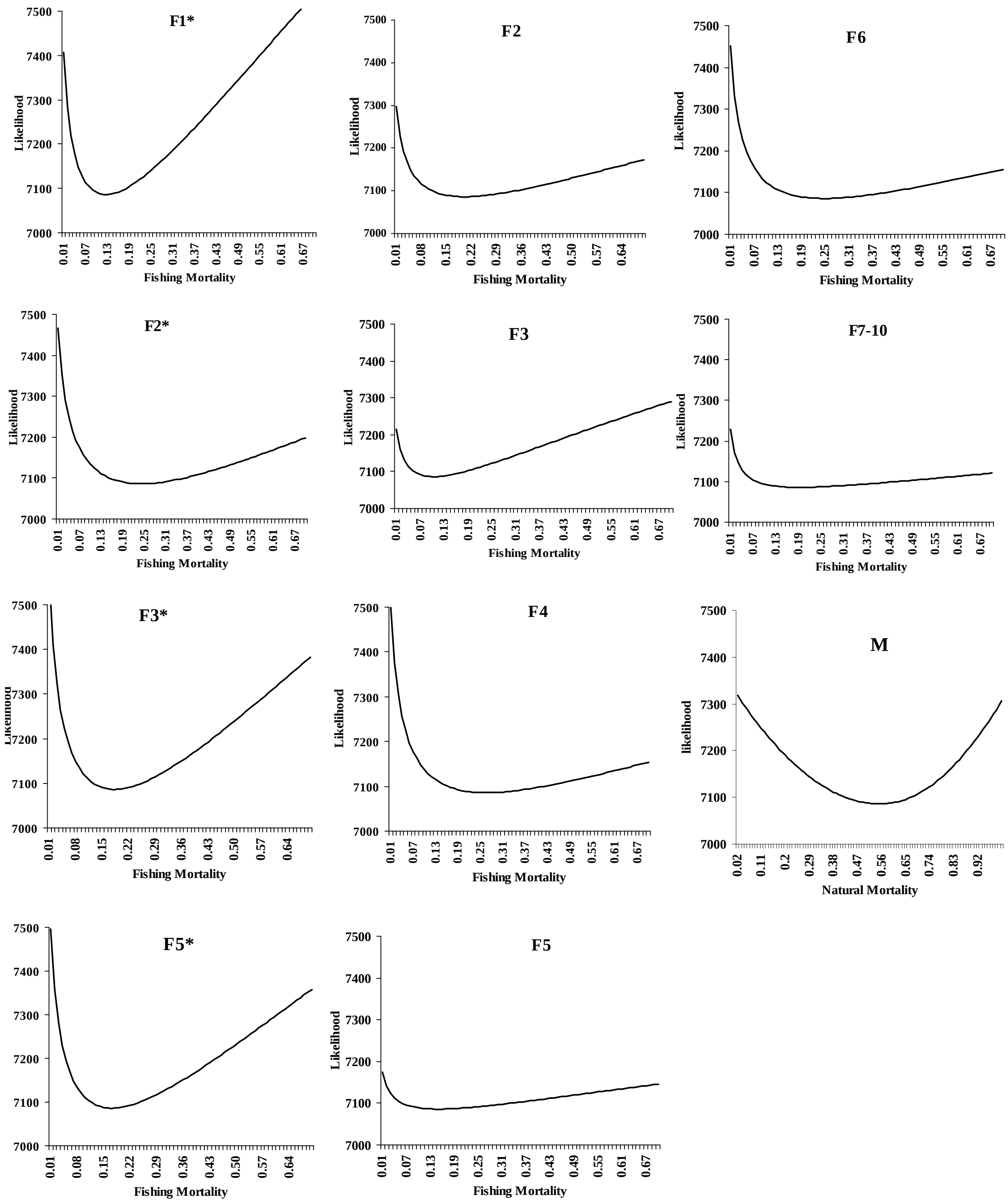

Figure 9. Profile likelihoods of parameter estimates in black sea bass tag model.

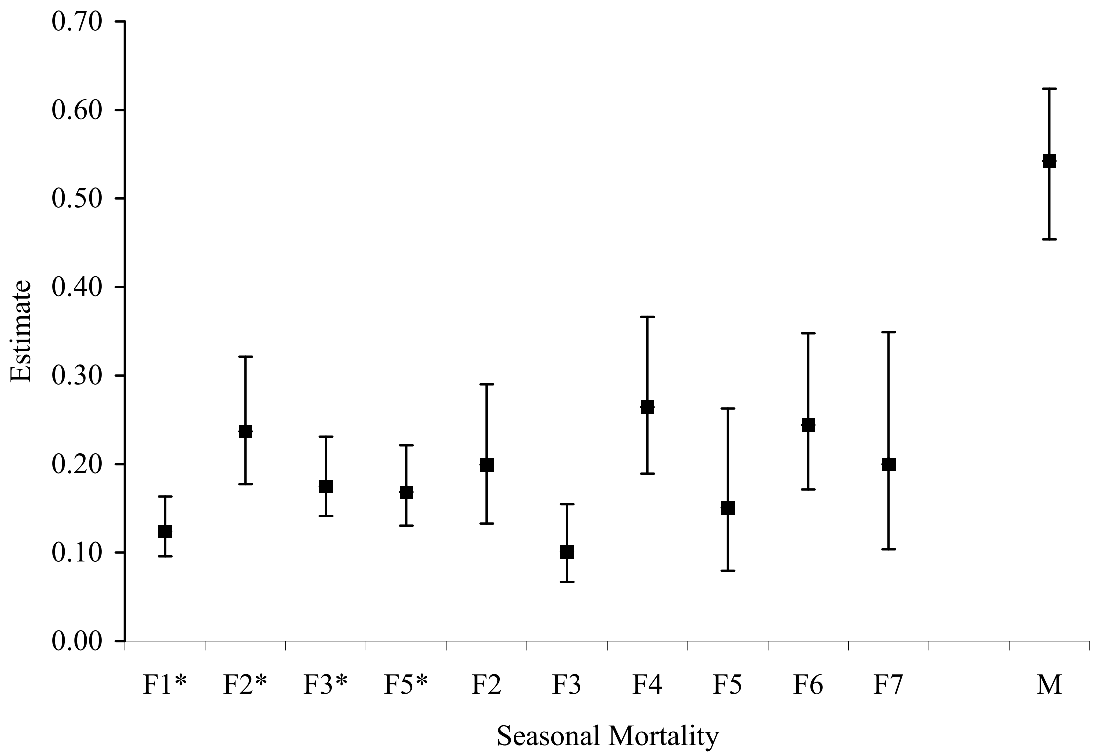

Figure 10. Estimates of fishing mortality for the non-mixed and mixed periods (F* and F) by fishing season and natural mortality (M) (model 4). Values shown with ± 95% confidence intervals derived from profile likelihoods.

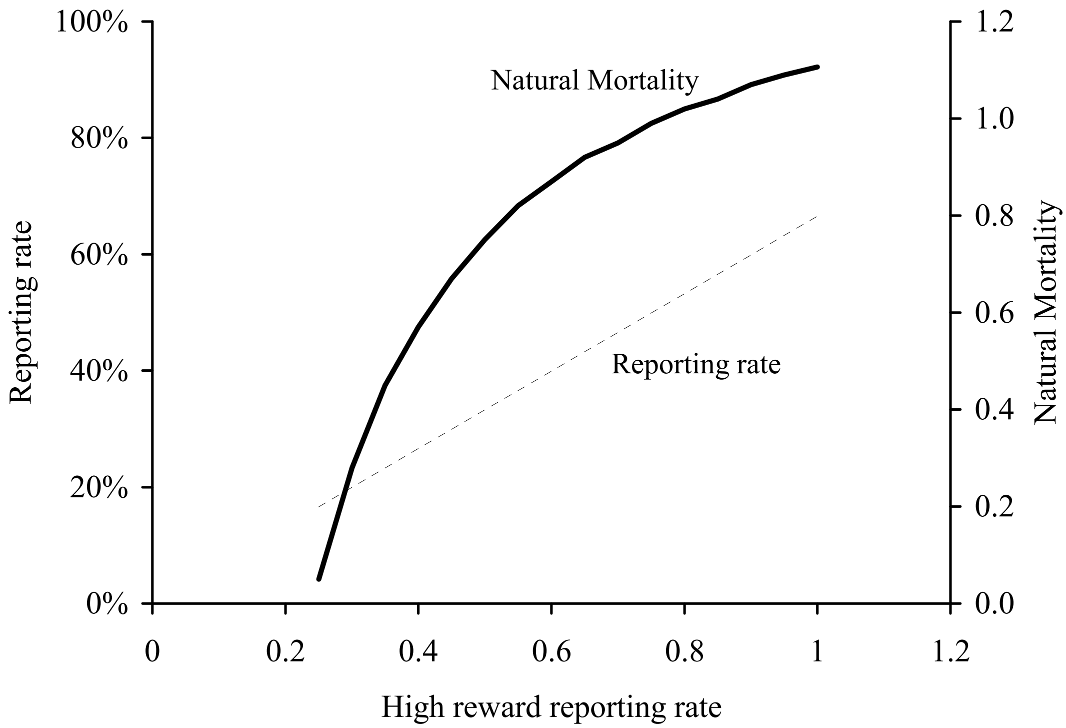

Figure 11. Effect of changes in high reward reporting rate assumption on overall reporting rate and natural mortality estimate.

Black sea bass; Appendix 2

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.

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

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 $\sum(\text{Vrec})^2$ 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:

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

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

$$\mathrm{L}_{\mathrm{vrec}} = \sum_{y=2}^{Nyears}\left(Vrec_{y}\right)^{2} = \sum_{y=2}^{Nyears}\left(R_{1}-R_{y}\right)^{2}$$

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

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

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

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.