Stock Assessments of Gulf of Mexico Greater Amberjack Using Data through 1998

Stephen C. Turner, Nancie J. Cummings and Clay E. Porch

National Marine Fisheries Service
Southeast Fisheries Science Center
Sustainable Fisheries Division
75 Virginia Beach Drive, Miami, FL 33149

Document: SFD 99/00 - 100

July 2000

****

Introduction

Stock assessments of greater amberjack, *Seriola dumerili*, were conducted for the purpose of providing advice to the Gulf of Mexico Fishery Management Council on the status of the resource. Basic inputs to the assessments were obtained from other documents to be presented with this document: catch at age and selectivity were provided by Cummings and McClellan (2000), an index of abundance from private and charter boats was presented by Cummings (2000), and Turner provided indices of abundance from the headboat and handline fisheries (Turner 2000a and 2000b).

Methods

VPA

A calibrated virtual population analysis (VPA) was conducted using methods similar to the ADAPT approach (Powers and Restrepo 1992) to obtain estimates of population abundance and mortality rates. Porch and others (Porch 1999a, Restrepo et al in press, Butterworth and Geromont 1999) have added to the ADAPT and have provided the ability to estimate additional parameters. In multiple tests with data from various species over several years Porch's program (vpa-2box) has been found to produce results identical to ADAPT given the same input data and parameters. Vpa-2box was selected because it permitted examination of alternative assumptions about the level of fishing mortality (F) on the oldest age group in the analysis.

Vpa-2box minimizes the negative log-likelihood (L)

$$L = \sum_{k} \sum_{y} \frac{(\log_e I_{ky} - \log_e \hat{I}_{ky})^2}{V_{\log_e I_k}} \qquad (1)$$

where I is the observed value of abundance index k in year y and V_{logI} is the variance of $\log_e I$ (Porch 1999a). The expected value for index k in year y is

$$\hat{I}_{ky} = q_k \sum_a SN_{ay}B_a \tag{2}$$

where q_k is the catchability coefficient, S is a selectivity vector, N_{ay} is the VPA estimated abundance at age a in year y and B_a is the average weight at age when the index is in biomass (otherwise it is 1).

Let fishery specific fishing mortality be defined as

$$F_{kay} = \frac{C_{kay}F_{ay}}{C_{ay}} \tag{3}$$

Historically S has been calculated by age and year (Conser 1989, Powers and Restrepo 1992, Porch 1999a, Butterworth and Geromont 1999) as

$$S_{kay} = \frac{F_{kay}}{\underset{a}{MAX}\left(F_{kay}\right)} \tag{4}$$

Porch (1999a) and Butterworth and Geromont (1999) noted that equation 4 implied that there could be annual changes in q if there were changes in the age composition of the catch associated with an index. Equation 4 will be referred to as year-variable index selectivities. Butterworth and Geromont noted that year to year variation in selectivities would be expected if age specific abundances varied geographically. However they noted that the index standardization process attempts to standardize for spacial and within year temporal effects, and therefore if targeting were constant, selectivity should be constant over years. They proposed year-constant selectivity be defined as

$$S_{kay} = \frac{\sum_y F_{kay}}{\underset{a}{MAX}(\sum_y F_{kay})}. \tag{5}$$

Whether to use year-variable or year-constant selectivity was examined by comparing the log-likelihood statistics from VPAs using each type.

Another change from the 1996 assessment was considered. In 1996 the fit between the estimated abundances and the indices was assumed to be normally distributed. Standard practice is now to use a log-normal distribution assumption, and that assumption is currently being used in Atlantic greater amberjack, Gulf of Mexico reef fish and mackerel assessments as well as for most other species.

The effects of these changes in assumptions (error distribution - normal to lognormal - and index selectivity - year variable to year constant) and changes in the natural mortality rate (M, see below) and data revisions were investigated in two ways. First by re-running the 1996 VPA with the old data (catch at age and indices) and the new assumptions, and second by analyzing the current data only through 1995 with the new assumptions.

Uncertainty in the VPA was addressed through sensitivity analysis and through bootstrapping of three sets of inputs selected to represent a range of possible population conditions. Sensitivity analyses included examination of various combinations of the three indices available for tuning, truncation of the time series for the three indices to a period in which size limits were generally constant, examination of alternatives (fixing or estimating) for the F ratios, and examination of assumed level of M.

Usually it is not possible to estimate fishing mortality rates for all of the ages in the most recent year in a VPA. To calculate the terminal year F's on ages which could not be estimated, the relative selectivity of each of those ages to one of the estimated ages was determined from the SVPA conducted by Cummings (2000a, Table 20 run 9).

Index values were weighted by the corresponding coefficients of variation estimated in the standardization process (input variance weighting). Initial analyses with all three indices in all years indicated better fits to the MRFSS index than to either the handline or headboat indices. Because the MRFSS index had a different pattern over years than the handline and headboat indices and those latter two indices had relatively similar patterns, addditional trials were made. One used only the MRFSS index and the second used both the handline and headboat indices without the MRFSS index. Because of concerns about possible effects of the assumption of year-constant index selectivity when changes in selectivity occurred as a result of the imposition of size limits in 1990, a third set of additional trials was made using only the values from 1991-1998 from all three indices.

The fishing mortality rate on the oldest age group was calculated as being equal to or some proportion of the fishing mortality rate on the next younger age (Powers and Restrepo 1994). Three alternatives were investigated: (1) fixing the F-ratio at 1, (2) estimating one F-ratio for all years, and (3) estimating the F-ratio in the earliest year, 1987, and then permitting each subsequent F-ratio to vary up to 20% from the previous F-ratio.

We wanted to investigate a range in natural mortality rates and chose to use three values over a range of 0.2. In selecting the mid value we considered our expectations of M for a species which may live 20 years or more. Thompson et al (1999) reported ages to 15 for Gulf of Mexico greater amberjack up to 144 cm; however Cummings and McClellan (2000) report observations of Gulf greater amberjack to nearly 200 cm. Thus we assumed that fish substantially larger than the largest in the Thompson et al. (1999) data set were probably older than 15. We also considered Potts et al.'s (1998) estimates of natural mortality rate from life history characteristics and in some cases environmental temperature. For the 1996 assessment an M of 0.3 had been assumed (Cummings and McClellan 1996). Had we adopted that value then a range of 0.2 to 0.4 would have been investigated, and we felt that an M of 0.4 was probably too high for a fish which may live to 20 or older. We thought that a slightly lower range of 0.15-0.35 might be more reasonable. The median of the values calculated by Potts et al was 0.27 (mean 0.32 Cummings and McClellan 1999), the range was 0.14-0.55, while the median of their estimates which incorporated an environmental parameter was 0.23 (mean 0.20 Cummings and McClellan 1999) and the range was 0.14-0.40. We decided to investigate M's of 0.15, 0.25 and 0.35, with the mid value representing a small change from the M assumed for the 1996 assessment primarily because of our belief that maximum age may be 20 or more.

The status of Gulf of Mexico greater amberjack with respect to management bench marks was investigated primarily with static spawner per recruit analyses. $F_{30\%SPR}$ was used as a proxy for $F_{MSY.}$ Spawning stock biomass at MSY (SSB_{MSY}) was estimated as the equilibrium SSB at $F_{30\%SPR}$ under the assumption of 0% mature at ages 0-2, 50% mature at age 3 and 100% mature for ages 4 and older. Beverton and Holt stock recruitment relationships did not produce reasonable fits to the observed data (see below), so two alternative stock recruitment relationships - hockey stick (similar to the approach in Barrowman and Meyers 2000) and historical mean recruitment were assumed in bench mark calculations and for projections. Optimum yield was defined as the yield which would occur when fishing at $F_{40\%SPR.}$

Uncertainty about VPA results were incorporated through bootstrapping. The bootstrapping employed non-parametric re-sampling of the residuals from each index re-scaled by the corresponding input coefficients of variation (Porch 2000b). Uncertainty about the natural mortality rate (M) was incorporated by aggregating bootstrapped population estimates from all three levels of natural mortality. To reflect the belief that M was more likely to be nearer 0.25 than 0.15 or 0.35, 400 bootstraps were run with M of 0.25 and 200 bootstraps were run at both M of 0.15 and 0.35. The selectivity pattern used for the per recruit analyses and the projections were calculated from the geometric mean of the selectivities in the most recent three years. Porch (1999b) reported very high variability in the most recent recruitment estimates and recommended replacement of such estimates with estimates from a stock recruitment relationship when conducting projections and per recruit analyses. Therefore the recruitments in the most recent three years in each bootstrap were replaced with deterministic estimates from the assumed stock recruitment relationship. Uncertainty in future recruitments was modeled by allowing lognormal deviations from the level expected from the stock-recruitment relationship with a coefficient of variation of 0.4. For the projections, an estimated total 2,035,632 lb was assumed killed in 1999 and 2000.; of that 1,959,507 was assumed landed based on Cummings and McClellan (2000), and 76,125 lb was assumed discarded dead (based on 1996-1997 average estimated discards at age).

Specific estimates of interest (MSY, yield in 2001 under F_{MSY}, etc) were bias corrected following the recommendations of Efron 1982, Legault 1999 and Porch 1999b. Because bootstraps estimates were combined across three levels of M, the deterministic estimate of a parameter at M of 0.25 was used for determining the statistical bias of all bootstraps; this approximation was considered reasonable given the equal numbers of bootstraps at M's of 0.15 and 0.35. Bias correction was not attempted for ratios of parameter estimates (such as SSB/SSB_{MSY}); research on bias of ratios of bootstrapped parameters is recommended.

The status of the resource with respect to the limit and target control rules was examined. $F_{30\%}$ was used as the proxy for F_{MSY}, and the B_{MSY} was calculated from the number of spawners expected at $F_{30\%}$ under equilibrium conditions. $F_{40\%}$ was used as the target fishing mortality rate. The minimum stock size threshold (MSST) was calculated as a proportion (1-M) of B_{MSY}. Proxies and ratios of statistics of interest were computed for each bootstrap and generally presented as medians with 80% empirical confidence intervals.

Results

Inputs

The catch at age was obtained from Cummings and McClellan (2000) who provided tabulations to age 19 using the growth curve for Gulf of Mexico greater amberjack estimated by Beasley (1995) and Thompson et al. (1999). Those authors showed wide variation in size at age (Figure 6 in Thompson et al. 1999). That equation indicates that Gulf of Mexico greater amberjack achieve 75% of their estimated maximum size by age 5 at which age the average fish grows about 7 cm (3 inches) per year, and they achieve 86% and 95% of the maximum size by ages 7 and 10 respectively (Figure 1). Given their relatively slow growth after age 5 and apparent high variability in size at age, two sets of catch at age were considered from use in the VPAs - one with a 5 plus group and one with a 7 plus group (Table 1). While Cummings and McClellan presented catch at age for some fisheries from 1981 to 1998, there was not catch at age for all fisheries prior to 1987; therefore only 1987-1998 catch at age was used in the VPA. A substantially lower catch at ages 2 and 3 in 1990 was noted.

For the VPA weight at age (Table 2) was calculated from mid year length at age estimated from the Thompson et al. (1999) curve and the Manooch and Potts (1997) weight-length equation for greater amberjack in the Gulf of Mexico.

Three indices of abundance from various fisheries were available (Table 3). Cummings (2000b) presented an index derived from catch rates from the charter and private boat fisheries in the Gulf of Mexico in 1981-1998 sampled by the Marine Recreational Fisheries Statistical Survey (MRFSS). Turner (2000a and 2000b) presented three indices from the handline fishery derived from trip reports recorded in the reef fish logbook data base for 1990-1998 and three indices from the headboat fishery in the Gulf derived from the Southeast U.S. Headboat Survey during 1986-1998. The handline index from vessels which did not target amberjack on trips reporting 1-9 hooks per line was used, and for the headboat fishery the index from full day trips was used. The MRFSS index showed a general declining trend over the time period while the handline and headboat indices showed increases from about 1990 and 1987 respectively to 1995 or 1996 and then showed declines through 1997 (Figure 2).

Comparison with 1996 Assessment

The VPA programs used to conduct the 1996 analysis and this analysis were different. Therefore a run was made using the same data, parameters and terminal fishing mortality rates (not allowing the program to search for a solution); the calculated fishing mortality rates were essentially identical (differed slightly at the third decimal place) to those estimated by McClellan and Cummings (1996). Allowing the program to search for a solution with the 1996 data and parameters resulted in minor differences in estimated fishing mortality rates. Additional small differences were associated with assuming a log-normal error for the fit between observed and estimated indices of abundance; however the change from assuming year variable index selectivity to year-constant selectivity resulted in an increase in estimated fishing mortality rate (Figure 3).

In addition to changes in the population model assumed in the VPA, there were changes in the assumed natural mortality rate, the basic catch at age (Cummings and McClellan 2000), the age of the plus group (5 pus in this assessment compared to 7 plus in 1996) and in the indices of abundance. Two VPAs were run, one with the 1996 data (7+ ages, 1996 indices, M=0.3, year constant selectivity for an index) and another trial with the new data (5+, new indices, M=0.25, year constant selectivity for an index). The estimated fishing mortality rate at age 4 (the oldest age estimated in both assessments) showed similar patterns in most years (Figure 4); the terminal year (1995) estimates differed. This showed that results were not substantially influenced by the changes in inputs (M, catch at age and indices).

Deterministic VPA

Initial VPAs were attempted with all 3 indices of abundance, three levels of M, estimating F on 3 ages in 1998, and (1) fixing the F-ratio (F_{5+}/F_4) at one, (2) estimating one F-ratio for all years or (3) estimating the 1987 F-ratio and permitting subsequent F-ratios to randomly vary from year to year within constraints. At first catches at age with 5+ and 7+ groups were examined. No solutions could be obtained with 7+, so all subsequent analyses were made only with 5+. Usually it was not possible to estimate fishing mortality rates on 3 ages (2, 3 and 4) in 1998, while it was always possible to estimate fishing mortality rates on 2 ages (Table 4). Generally only two F's in 1998 could be estimated and when three F's could be estimated the asymptotic coefficient of variation for one of the estimates was substantially higher than when two were estimated.

Examination of the fits between the indices and the estimated indices, when F's on ages 3 and 4 in 1998 were estimated and when the F ratio was fixed at 1, indicated that the model was fitting to MRFSS index in a higher proportion of the years than the other indices, particularly the headboat index (Figure 5). Estimating the F ratio produced different estimates from the VPAs with the F ratio fixed at 1, but there were only relatively small differences between estimated abundances when one F ratio was used for all years or when the F ratio was estimated for1987 and successive estimates were permitted to vary (Figure 6). The fits to the indices when one F ratio was estimated indicated an improved fit to the handline index while fits to the MRFSS and headboat indices were similar to the run when the F ratio was fixed at 1 (Figure 7).

The differences in the fits suggested additional sets of deterministic VPA's: one with the MRFSS index only and another with the handline and headboat indices (Tables 5 and 6). The fits to the indices when the F ratio was fixed at 1 are shown in Figures 8 and 9. When F ratios were estimated in the VPA using only MRFSS, they were close to 1 (Table 5) and there was relatively little difference in the estimated abundances (Figure 10). When F ratios were estimated in the VPAs which used the handline and headboat indices, fishing mortality rates were extremely low (Table 6), producing spawning stock size estimates about 2-3 orders of magnitude larger than the other VPAs and recruitment estimates 1-2 orders greater; these results were considered unrealistic..

Additionally there was concern that (1) the change in selectivity associated with the imposition of size limits in 1990 (Figure 11), and (2) the assumption of year-constant index selectivity might have impacted the fits to the handline and headboat indices. Therefore a third set of additional deterministic VPAs was run with all three indices only in 1991-1998 (Table 7). Model fits to the indices for those VPAs are shown in Figure 12. The estimated F ratios from these VPAs were low - between those when all years were included for the three indices and the handline and headboat estimates.

The estimated abundances of spawners and recruits from the VPAs using different combinations of indices when the F ratio was fixed at 1, were similar for all but the handline and headboat index analysis (Figure 13).

The estimated F ratios (F_{5+}/F_4) from the various analyses represented a continuum with the analyses using only the MRFSS index with estimates of about 0.9 to 0.95 at one extreme and the analyses with the handline and headboat indices and the analyses with all three indices in 1991-1998 at the other with estimated F ratios of about 0.15-0.35 (Tables 6-8). The analyses with all three indices for all years were intermediate with estimated F ratios of about 0.35-0.55 (Table 5). The analyses with all three indices in 1991-1998 also had very low fishing mortality rates. F ratios less than 1 can be caused by multiple factors including differential selectivity in the fishery, problems in ageing, and substantial under-representation of larger amberjack in the catch at size. The combination of low F ratio and low F result in very high estimates of stock size of the older ages, while often the recruitment series does not increase proportionately, resulting in estimation of an abundant but highly unproductive resource (low MSY). For instance the handline and headboat analyses resulted in rough estimates of billions of pounds of spawners (roughly 2 orders of magnitude higher that most of the other assessments) with recruits only about 1 order of magnitude greater than most of the other assessments due to estimating very low vulnerability of fish ages 5 and older to the fishery. This results in estimates of per capita productivity which are very low and a stock which would support relatively low yields over the long term under a stock-recruitment relationship in which recruitment is responsive to spawning stock size. The low F ratio and low F analyses were considered unlikely to represent the true population condition and so were not considered for further sensitivity analysis.

The possibility of retrospective pattern in the data was explored by running three additional VPAs with the data truncated at 1997, 1996 and 1995 using three indices in all years, the F ratio fixed at 1 and estimating ages 3 and 4. No clear pattern was observed for those ages (Figure 14). For age 4, the most recent estimate tended to be lower than in a VPA with one more year of data.; however because no pattern was seen for the other ages no adjustment was made in projections.

To provide an example of the estimates of abundance and fishing mortality rate for all years and ages the results from the analysis of three indices in all years with the F ratio fixed at 1 are presented in Tables 8 and 9.

To explore the range of population estimates which might be extracted from these data, four analyses were selected for further sensitivity analysis through bootstrapping. Three VPAs with the F ratio fixed at 1 were conducted with all 3 indices all years, MRFSS only, and handline plus headboat. The fourth bootstrapped VPA was run using all three indices and estimating one F ratio for all years in each bootstrap.

Current Status and Projected Abundance

To project the bootstrapped population estimates into the future and to examine the status of the resource with respect to MSST, stock recruitment relationships were investigated. The most recent three years of recruitment observations were not included in evaluations of the stock-recruitment relationships because typically they are highly uncertain (Porch 1999b). The general pattern of stock and recruitment observations were similar among the deterministic estimates (Figure 15), though levels of spawning stock biomass differed between the cases with the F ratio fixed at 1 and the case with it estimated. Attempts to fit the data with Beverton and Holt curves produced enormous estimates of stock biomass at MSY, because of the near linearity of the relationship between estimated stock and recruitment. Therefore two alternative stock-recruitment relationships were used. A hockey stick (Barrowman and Meyers 2000) stock recruitment relationship was estimated for each bootstrap with a linear relationship fit from zero to the largest observed spawning stock biomass and then constant level of recruitment at possible larger stock sizes (Figure 15). The second alternative was that future recruitment vary about the historical mean.

The status of Gulf of Mexico greater amberjack in 1998 with respect to F_{MSY} and MSST was examined using the 800 bootstraps for each case - combination of indices, F ratio and stock recruitment assumption. The results are shown in Figure 16. In 1998 the bootstrap results indicated 53% to 98% empirical probabilities that SSB was less that MSST and 72% to 100% probabilities that SSB was less that $SSB_{SPR30\%}$ (Figure 16). Those results also indicated that in 1998 there was a 36% to 94% empirical probability that F exceeded $F_{SPR30\%}$ and 60% to 99% probabilities that F exceeded $F_{SPR40\%}$. The cases based on all three indices with the estimated F ratio indicated the lowest probabilities of being overfished (F > reference F) and overfishing (SSB < reference SSB) while the cases based on MRFSS only and those with three indices with the F ratio fixed at 1 indicated higher probabilities of being overfished and overfishing (Figure 16).

Bootstrapped 80% empirical confidence intervals about median SSB relative to MSST under the hockey stick stock recruitment assumption are shown in Figure 17 for 1987 through 2020 with fishing at $F_{30\%}$. The empirical confidence intervals were substantially larger for the case with 3 indices and estimated F ratio than for the three cases with the fixed F ratio; for 1999 (the last abundance from the bootstrapped VPAs) the 80% confidence intervals about the relative SSB from the cases with F ratio fixed at 1 ranged from 0.09 to 1.05 while the interval for the case with the estimated F ratio ranged from 0.23 to 6.45. Despite the differences in the range of the confidence intervals the median SSB's were relatively similar (Figure 18). There were differences in the median projected recruitments under the hockey stick assumption between the cases with the fixed F ratio and the case with the estimated F ratio (Figure 19).

Management Reference Points

Bias corrected biological reference points (Efron 1982, Legault 1999 and Porch 1999b) were calculated using $F_{30\%SPR}$. as the proxy for F_{MSY}. The median of the bootstraps can be regarded as an indicator of the bias in the deterministic estimates of parameters which is due to the non-linear estimation process. The method maintains the range of the distribution of the bootstrapped estimates, but shifts the distribution of the estimates within that range based on the degree of divergence between the deterministic estimate (in this case deterministic at M of 0.25) and the bootstrapped median (Legault 1999).

Uncorrected and bias corrected biological reference points are presented in Tables 10 and 11and figures of the cumulative distributions for MSY and optimum yield in 2001 are shown in Figures 19 and 20. Median bias corrected estimates of MSY ranged from about 4 to about 13 million pounds for the hockey stick stock recruitment assumption. The MSYs from the VPA's with the F ratio fixed at 1 ranged from about 10 to about 13 million pounds. The bias corrected estimates derived using the mean recruitment assumption ranged from about 7 to about 9 million pounds. The lower estimates of MSY for the case based on 3 indices with the F ratio estimated appeared to be primarily due to a lower estimate of recruitment under equilibrium conditions (Figure 18). The broader range of estimates of MSY for that case reflected the greater uncertainty in initial conditions (1999) than for the cases with the F ratio fixed (Figure 17). Bias corrected estimates of optimum yield (yield at $F_{40\%}$) in 2001 ranged from 1.1 to 3.9 million pounds.

Discussion

VPA methods necessarily assume that the catch at age is known exactly. Unfortunately, such is not the case for Gulf Amberjack. The age composition of the catch had to be inferred from the length composition using a growth curve (age slicing). The age slicing approach does not account for the effects of different year-class strengths and mortality on the observed length distributions or for the degree of overlap between the length distributions of adjacent age groups. Moreover, gaps in the length composition data had to be filled by substituting values from other strata.. Analyses are presently being conducted using an age-structured length-based model that is designed to handle these sorts of difficulties in a statistical manner (for a description see Porch, 1999c). Preliminary results indicate that the length composition data may not be sufficient to accurately estimate the degree of variability in length at age. The variability in growth of Gulf Amberjack with age needs to be better characterized.

Additional further analyses are also recommended to explore the effects of alternative assumptions concerning index weighting (such as equal weighting rather than weighting by the coefficient of variation of the index) and concerning sensitivity to the assumed level of discards.

Literature Cited

Barrowman, N.J. and R.A. Meyers. 2000. Still more spawner-recruitment curves: the hockey stick and its generalizations. Can. J. Fish. Aquat. Sci. 57: 665-676.

Beasley, Marty L.1993. Age and growth of greater amberjack, *Seriola dumerili*, from the northern Gulf of Mexico. M.S. Thesis. Department of Oceanography and Coastal Sciences, Louisiana State University, 1993. 85 p.

Butterworth, D.S. and H.F. Geromont. 1999. Some aspects of ADAPT VPA as applied to North Atlantic bluefin tuna. Int. Comm. Conserv. Atl. Tunas. Col. Vol. Sci. Pap. 49(2):233-241.

Conser, R.J. 1989. An examination of the utility of integrated approaches for bluefin tuna catch-at-age analysis. Int. Comm. Conserv. Atl. Tunas. Col. Vol. Sci. Pap. 30(2):283-301.

Cummings, N. 2000. Gulf of Mexico greater amberjack abundance indices for recreational charter and private boat anglers from 1981-1998. NMFS Sustainable Fisheries Division Contribution SFD-99/00-98.

Cummings, N. and D.B. McClellan. 2000. Trends in the Gulf of Mexico greater amberjack fishery through 1998: commercial landings, recreational catches, observed length frequencies, estimates of landed and discarded catch at age, and selectivity at age. NMFS Sustainable Fisheries Division Contribution SFD-99/00-99. 151p.

Efron, B. 1982. The jackknife, the bootstrap and other resampling plans. CBMS Monograph #38, Society for Industrial and Applied Mathematics, Philidelphia.

Legault, C.M. 1999. Simulation study of percentile and bias corrected percentile confidence intervals for allowable biological catch. NMFS Sustainable Fisheries Division Contribution SFD-98/99-48. 9p.

Manooch, C. and J. C. Potts. 1997. Age, growth, and mortality of greater amberjack, *Seriola dumerili,* from the U.S. Gulf of Mexico headboat fishery. Bull. Mar. Sci. 61(3): 671-683.

McClellan, D. and N.J. Cummings. 1996. Stock assessment of Gulf of Mexico greater amberjack through 1995. NMFS Miami Laboratory Report MIA-96/97-03 69p.

Porch, C. E. 1999a. A Bayesian VPA with randomly walking parameters. Int. Comm. Conserv. Atl. Tunas. Col. Vol Sci. Pap. 49(2): 314-326.

Porch, C.E. 1999b. Bootstrap estimates of the precision and bias of the 1996 base case assessment of West Atlantic bluefin tuna. Int. Comm. Conserv. Atl. Tunas. Col. Vol Sci. Pap. 49(2): 306-313.

Potts, J. M.L. Burton, and C. Manooch. 1998. Trends in catch and estimated static SPRvalues for fifteen species of reef fish landed along the southeastern United States. NMFS, SEFSC Beaufort Laboratory. Unpublished manuscript. 45p.

Restrepo, V.R. and C.E. Porch. In press. Options for conducting swordfish sex-specific assessments. Int. Comm. Conserv. Atl. Tunas.SCRS/99/51.

Thompson, B.A., M. Beasley and C.A. Wilson. 1999. Age distribution and growth of greater amberjack, *Serioal dumerili*, from the north-central Gulf of Mexico. Fish. Bull. 97:362-371

Turner, S.C. 2000a. Catch rates of greater amberjack caught in the handline fishery in the Gulf of Mexico in 1990-1998. NMFS Sustainable Fisheries Division Contribution SFD-99/00-92

Turner, S.C. 2000b. Catch rates of greater amberjack caught in the headboat fisheries in the Gulf of Mexico in 1986-1998. NMFS Sustainable Fisheries Division Contribution SFD-99/00-107

Table 1a. Catch (number) at age considered for use in the assessments derived from Cummings and McClellan. (2000).

	age					
year	0	1	2	3	4	5+
1987	84615	400055	202226	61064	32570	31998
1988	105460	508170	188886	61301	14987	18117
1989	128967	315107	173584	92966	58053	92965
1990	17302	36184	25407	15579	15645	32746
1991	7615	23723	138482	119937	28320	21983
1992	4628	17118	122604	161446	59622	32554
1993	3093	11541	61912	112441	65205	34085
1994	3385	12059	41252	85378	32190	26859
1995	3608	12719	43332	24106	19593	16129
1996	1035	14753	51837	40064	18001	17119
1997	3963	7626	21173	35442	28228	13352
1998	966	4996	20234	40251	19171	14472

	age							
year	0	1	2	3	4	5	6	7+
1987	84615	400055	202226	61064	32570	12335	8190	11473
1988	105460	508170	188886	61301	14987	6599	4920	6598
1989	128967	315107	173584	92966	58053	44664	16520	31781
1990	17302	36184	25407	15579	15645	16526	7979	8241
1991	7615	23723	138482	119937	28320	11782	6371	3830
1992	4628	17118	122604	161446	59622	14742	9143	8669
1993	3093	11541	61912	112441	65205	22235	4739	7111
1994	3385	12059	41252	85378	32190	11959	5916	8984
1995	3608	12719	43332	24106	19593	11693	3114	1322
1996	1035	14753	51837	40064	18001	10501	3237	3381
1997	3963	7626	21173	35442	28228	7664	3213	2475
1998	966	4996	20234	40251	19171	8499	5048	925

Table 2. Weights (lb) at age used in the VPA.

age	0	1	2	3	4	5+
weight	2.0	7.4	15.1	23.8	32.4	47.4

age	0	1	2	3	4	5	6	7+
weight	2.0	7.4	15.1	23.8	32.4	40.4	47.5	61.1

Table 3. Indices used in VPA.

	MRFSS charter+private		handline 1-9 hooks/trip		headboat full day	
	index n fish	cv	index pounds	cv	index n fish	cv
1987	2.499	0.115			0.057	0.557
1988	0.957	0.285			0.077	0.497
1989	1.317	0.252			0.081	0.469
1990	0.486	0.465	1.768	0.358	0.066	0.524
1991	1.727	0.170	2.050	0.292	0.082	0.501
1992	1.407	0.118	1.953	0.299	0.106	0.435
1993	1.047	0.203	2.660	0.276	0.088	0.466
1994	1.240	0.215	2.833	0.276	0.108	0.463
1995	0.487	0.446	3.138	0.277	0.120	0.427
1996	0.988	0.213	2.948	0.274	0.098	0.527
1997	0.856	0.302	2.316	0.278	0.074	0.566
1998	0.642	0.309	2.234	0.286	0.099	0.514

Table 4. Deterministic VPA results for analyses using all indices in all years.

M	CV F_2	CV F_3	CV F_4	CV F Ratio	F Ratio Random Walk	log likelihood	F Ratio	F_3	F_4
0.15	0.75	0.51	0.27	-	-	11.23	1.00	0.35	0.26
0.15	-	0.32	0.26	-	-	11.22	1.00	0.44	0.25
0.15	-	0.31	0.25	0.36	-	15.38	0.33	0.39	0.23
0.15	-	0.30	0.36	0.14-0.20	TRUE	16.26	0.26-0.44	0.35	0.24
0.25	-	bound	-	-	-	-	1.00	-	-
0.25	-	0.31	0.25	-	-	13.02	1.00	0.38	0.22
0.25	-	0.30	0.24	0.28	-	16.16	0.44	0.31	0.20
0.25	-	0.29	0.24	0.14-0.20	TRUE	16.97	0.36-0.59	0.28	0.22
0.35	-	bound	-	-	-	-	1.00	-	-
0.35	-	0.31	0.24	-	-	14.76	1.00	0.31	0.20
0.35	-	0.28	0.24	0.23	-	16.90	0.55	0.24	0.17
0.35	-	0.28	0.24	0.14-0.20	TRUE	17.65	0.47-0.73	0.23	0.21

Table 5. Deterministic VPA results for analyses using only the MRFSS index.

M	CV F_2	CV F_3	CV F_4	CV F Ratio	F Ratio Rando m Walk	log likelihood	F Ratio	F_3	F_4
0.15	0.68	1.26	0.35	-	-	5.77	1.00	1.05	0.23
0.15	-	0.44	0.37	-	-	5.75	1.00	0.66	0.23
0.15	-	0.44	0.37	0.68	-	5.75	0.95	0.66	0.24
0.15	-	0.43	0.37	0.14-0.20	TRUE	5.83	0.79-0.88	0.63	0.25
0.25	0.56	1.57	0.35	-	-	6.14	1.00	1.15	0.23
0.25	-	0.40	0.38	-	-	6.11	1.00	0.51	0.25
0.25	-	0.39	0.38	0.63	-	6.11	0.94	0.50	0.25
0.25	-	0.39	0.38	0.14-0.20	TRUE	6.25	0.71-0.88	0.49	0.25
0.35	-	bound	-	-	-	-	1.00	-	-
0.35	-	0.36	0.39	-	-	6.53	1.00	0.39	0.26
0.35	-	0.36	0.40	0.60	-	6.55	0.89	0.37	0.27
0.35	-	0.29	0.43	0.14-0.20	TRUE	7.79	0.14-0.21	0.11	0.10

Table 6. Determinitistic VPA results for analyses using the handline and headboat indices in all years.

M	CV F_2	CV F_3	CV F_4	CV F Ratio	F Ratio Rando m Walk	log likelihood	F Ratio	F_3	F_4
0.15	bound	-	-	-	-	-	1.00	-	-
0.15	-	0.51	0.36	-	-	7.00	1.00	0.19	0.26
0.15	-	0.47	0.50	0.19	-	17.84	0.14	0.01	0.01
0.15	-	0.47	0.50	0.14-0.20	TRUE	17.96	0.13-0.15	0.01	0.01
0.25	bound	-	-	-	-	-	1.00	-	-
0.25	-	0.51	0.35	-	-	8.59	1.00	0.17	0.20
0.25	-	0.46	0.47	0.13	-	18.00	0.23	0.00	0.00
0.25	-	0.45	0.47	0.13-0.20	TRUE	18.14	0.21-0.25	0.01	0.00
0.35	1.23	0.40	0.38	-	-	11.20	1.00	0.05	0.17
0.35	-	0.50	0.34	-	-	10.37	1.00	0.14	0.16
0.35	-	0.44	0.06	0.10	-	18.34	0.33	0.00	0.00
0.35	-	0.44	0.07	0.14-0.20	TRUE	18.46	0.30-0.38	0.00	0.00

Table 7. Deterministic VPA results from analyses using all three indices for 1991-1998 only.

M	CV F_2	CV F_3	CV F_4	CV F Ratio	F Ratio Random Walk	log likelihood	F Ratio	F_3	F_4
0.15	1.02	0.38	0.28	-	-	15.03	1.00	0.33	0.29
0.15	-	0.34	0.27	-	-	14.92	1.00	0.51	0.28
0.15	-	0.31	0.42	0.25	-	21.44	0.15	0.19	0.09
0.15	-	0.30	0.39	0.13-0.20	TRUE	22.25	0.12-0.19	0.12	0.06
0.25	1.03	0.38	0.27	-	-	16.46	1.00	0.29	0.25
0.25	-	0.34	0.26	-	-	16.37	1.00	0.44	0.25
0.25	-	0.31	0.40	0.16	-	21.56	0.24	0.15	0.07
0.25	-	0.30	0.38	0.13-0.20	TRUE	22.50	0.20-0.30	0.10	0.06
0.35	1.05	0.38	0.26	-	-	17.84	1.00	0.26	0.22
0.35	-	0.33	0.25	-	-	17.79	1.00	0.37	0.22
0.35	-	0.31	0.39	0.12	-	21.66	0.33	0.11	0.06
0.35	-	0.30	0.37	0.13-0.20	TRUE	22.69	0.27-0.42	0.07	0.05

Table 8. Estimated abundance from a VPA using 3 indices in all years with the F ratio fixed at 1, M of 0.25 and estimating fishing mortality rate on ages 3 and 4 in 1998.

age: year	0	1	2	3	4	5+
1987	1389243	976758	493004	219998	128948	126683
1988	1224335	1007575	412975	208183	118000	142644
1989	1162405	860884	344875	157782	108622	173945
1990	731393	792079	396097	118343	42786	89555
1991	503894	554389	585058	286152	78499	60933
1992	297951	385733	410899	334530	118648	64783
1993	478131	227972	285358	212998	120653	63070
1994	499682	369647	167399	168057	68679	57305
1995	368322	386174	277275	94303	57001	46923
1996	202827	283675	289566	177954	52374	49807
1997	281906	157051	207957	180100	103539	48975
1998	83027	216061	115607	143368	109227	82455

Table 9. Estimated fishing mortality rates from a VPA using 3 indices in all years with the F ratio fixed at 1, M of 0.25 and estimating fishing mortality rate on ages 3 and 4 in 1998.

age: year	0	1	2	3	4	5+
1987	0.07	0.61	0.61	0.37	0.33	0.33
1988	0.10	0.82	0.71	0.40	0.15	0.15
1989	0.13	0.53	0.82	1.06	0.90	0.90
1990	0.03	0.05	0.08	0.16	0.53	0.53
1991	0.02	0.05	0.31	0.63	0.52	0.52
1992	0.02	0.05	0.41	0.77	0.82	0.82
1993	0.01	0.06	0.28	0.88	0.92	0.92
1994	0.01	0.04	0.32	0.83	0.74	0.74
1995	0.01	0.04	0.19	0.34	0.49	0.49
1996	0.01	0.06	0.23	0.29	0.49	0.49
1997	0.02	0.06	0.12	0.25	0.37	0.37
1998	0.01	0.03	0.22	0.38	0.22	0.22

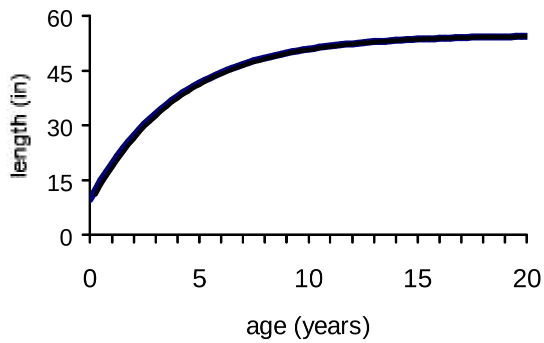


Figure 1. Thompson et al. (1999) estimated growth of Gulf of Mexico greater amberjack.

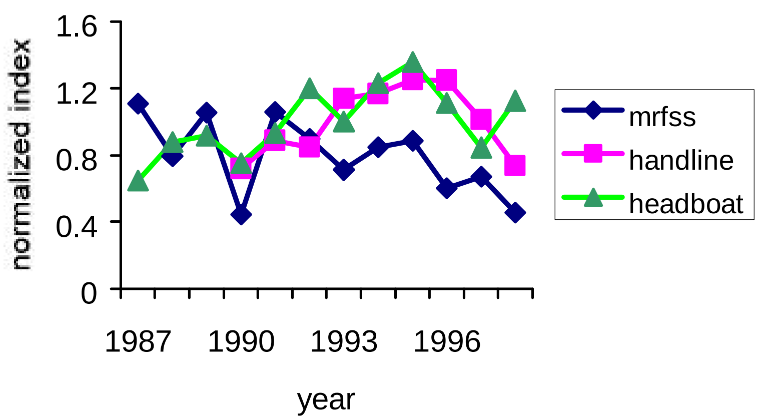


Figure 2. Indices of abundance scaled to their means.

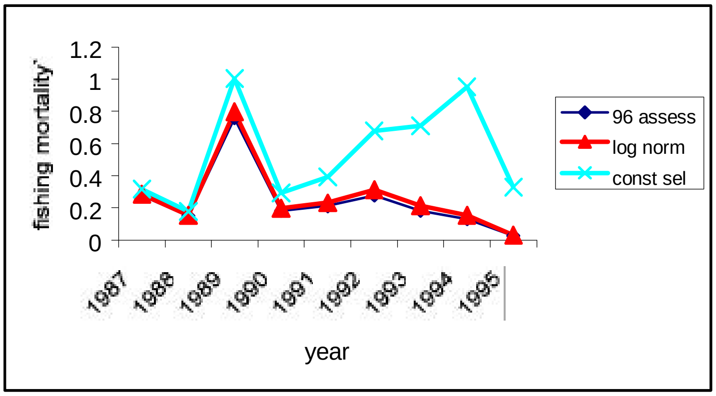


Figure 3. Effects of modeling changes on estimates of fishing mortality rate on age 6 using data from the 1996 assessment.

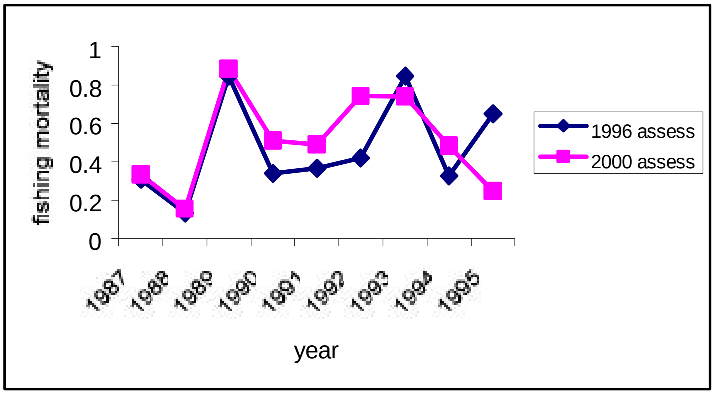
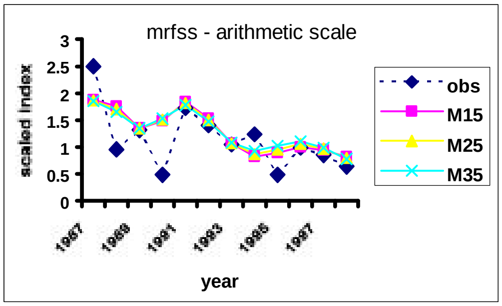
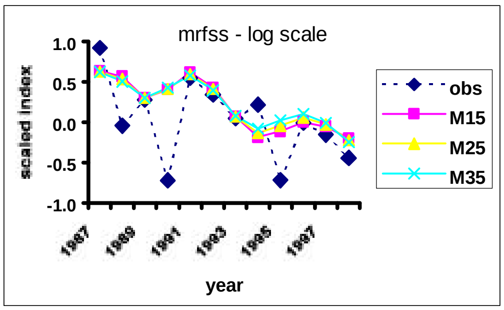
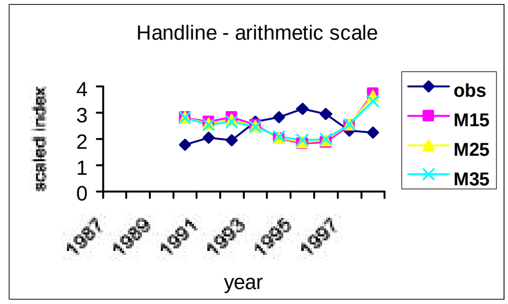


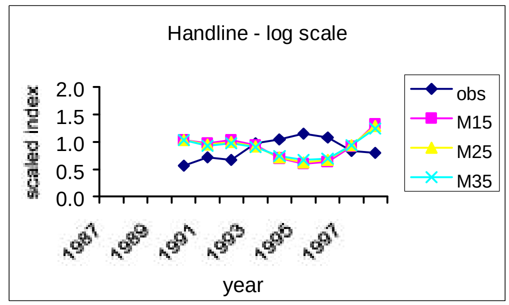
Figure 4. Estimates of fishing mortality rate on age 4 using the data from the 1996 assessment and data through 1995 from this assessment (see text for parameter differences)..



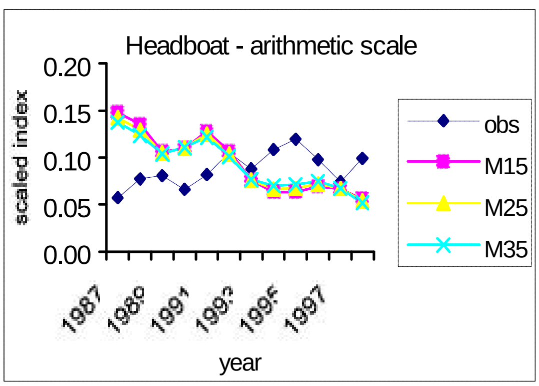


panel A





panel B



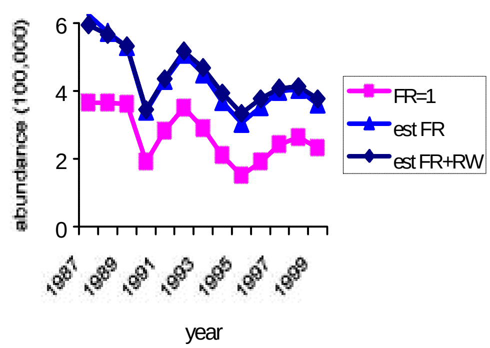
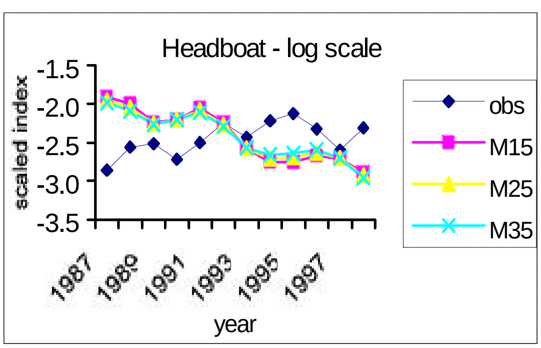
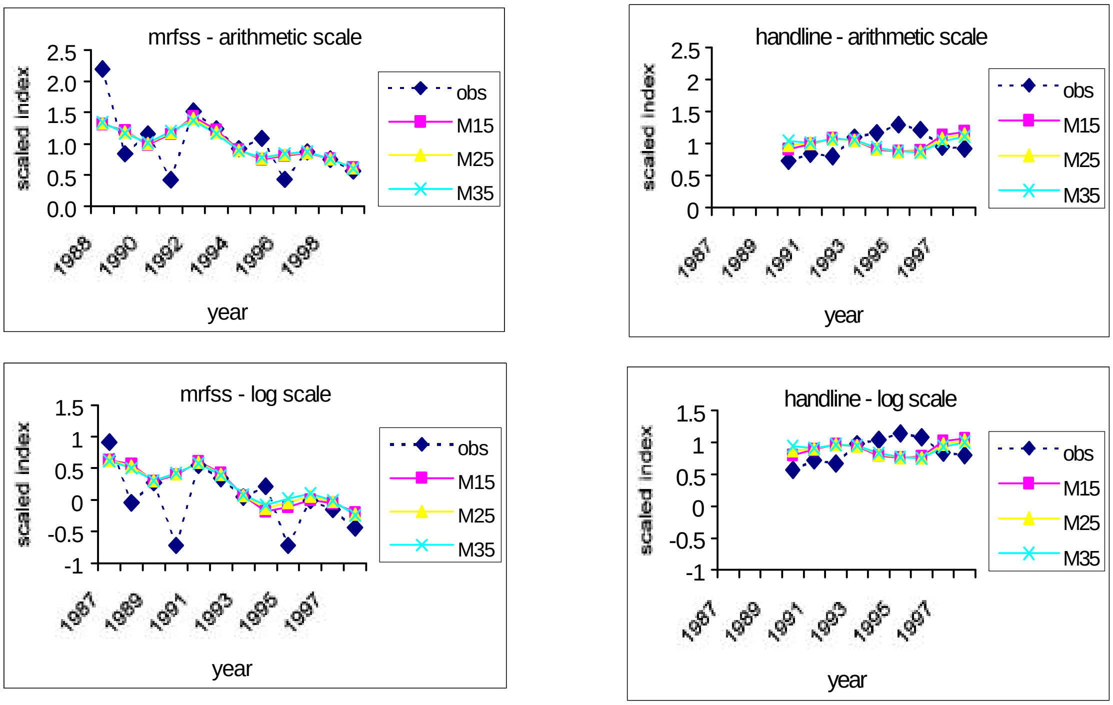


Figure 6. Effect on estimated abundance of mature fish [ages 3 (50%), 4-5+ (100%)] of fixing, estimating, or estimating F ratio with a random walk from VPA using 3 indices in all years with M of 0.25.



panel C

Figure 5. Fits to indices from VPA using 3 indices in all years and estimating ages 3 and 4 in 1998 with F ratio fixed at 1.



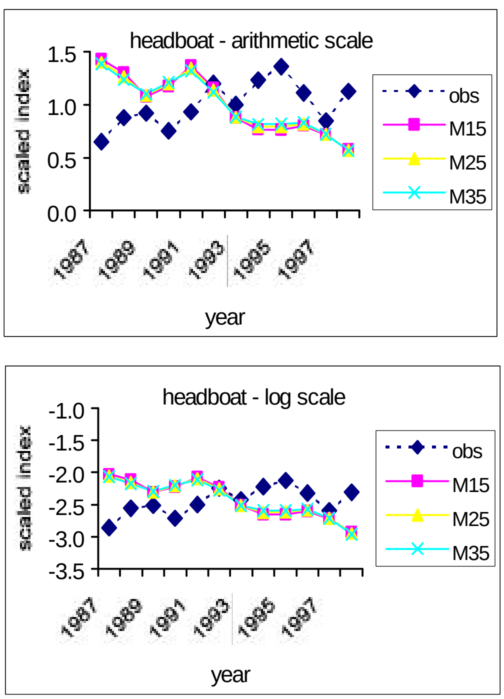


Figure 7. Fits to indices used in VPA using 3 indices in all years and estimating ages 3 and 4 and one F ratio for all years.

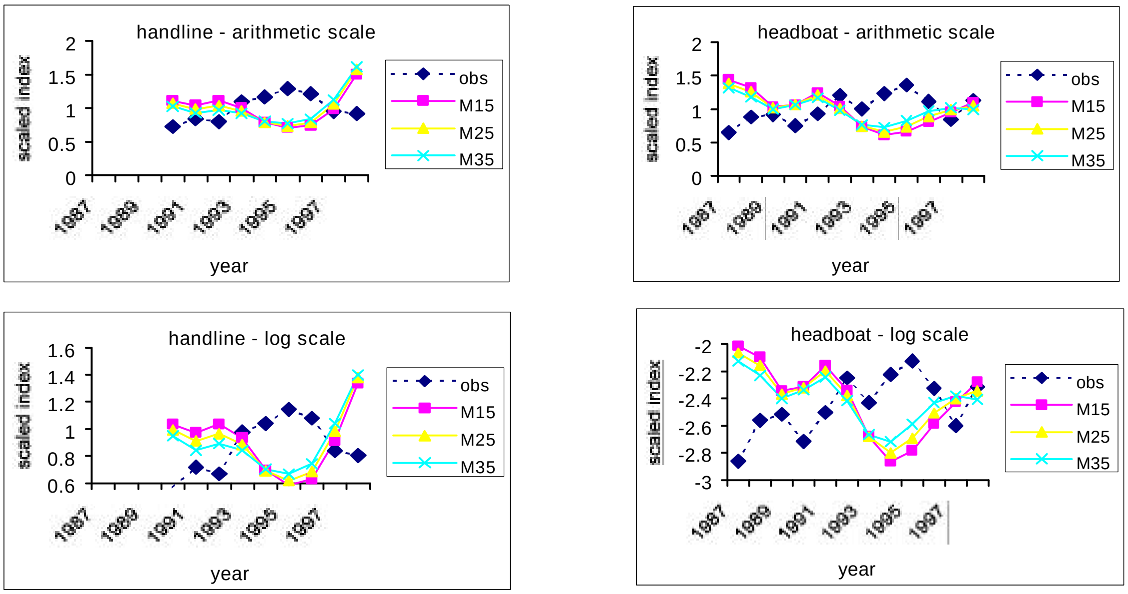


Figure 8. Fits to indices in VPA using handline and headboat in all years with F ratio fixed at 1.

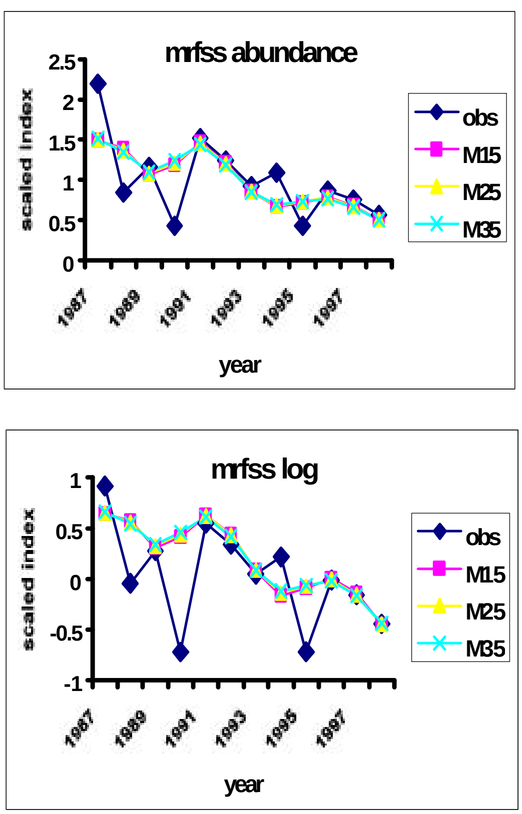


Figure 9. Fits to index from VPA using only MRFSS with the F ratio fixed at 1.

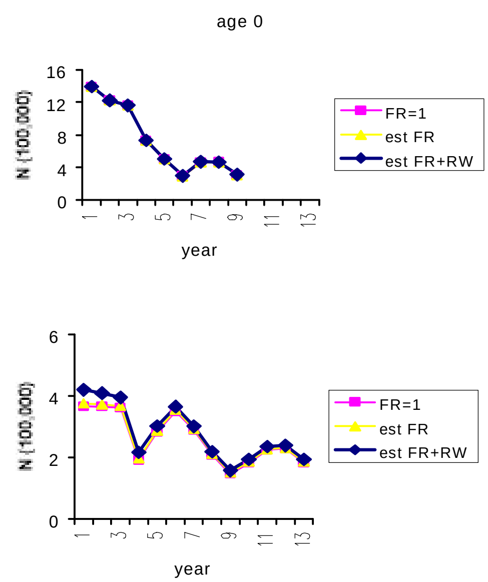


Figure 10. Estimated abundance of recruits (upper panel) and spawners (lower panel, 50% age 3, 100% ages 4 and 5+) from VPAs using MRFSS index only, M of 0.25 and with the F ratio fixed , one F ratio estimated for all years, and the 1987 F ratio estimated with successive ratios permited to vary.

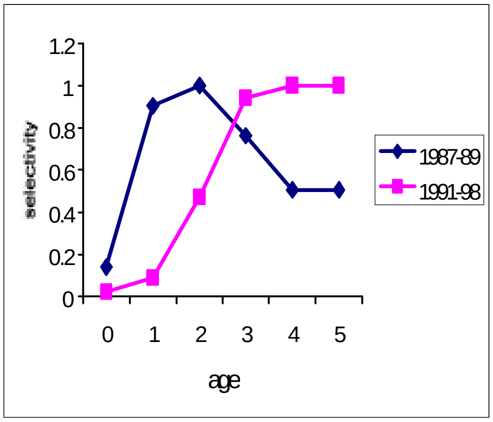


Figure 11. Geometric mean selectivities during 1987-1989 and 1991-1998 from a deterministic VPA with 3 indices and the F-ratio fixed at 1.

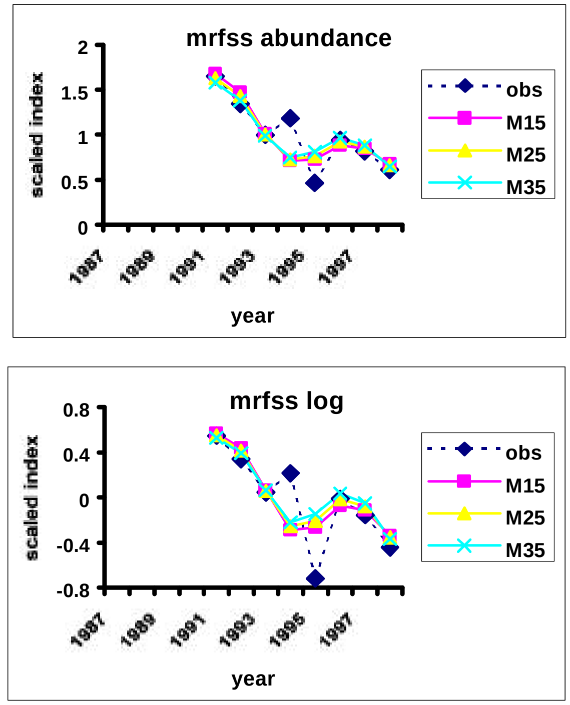


Figure 12. Panel A.

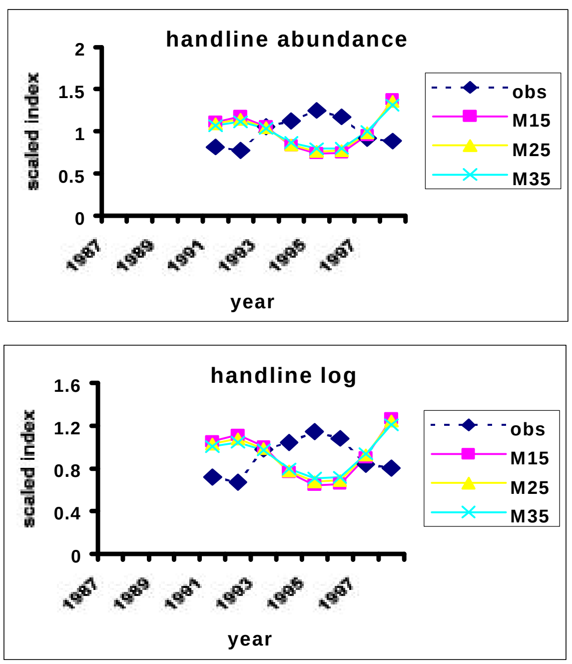


Figure 12. Panel B.

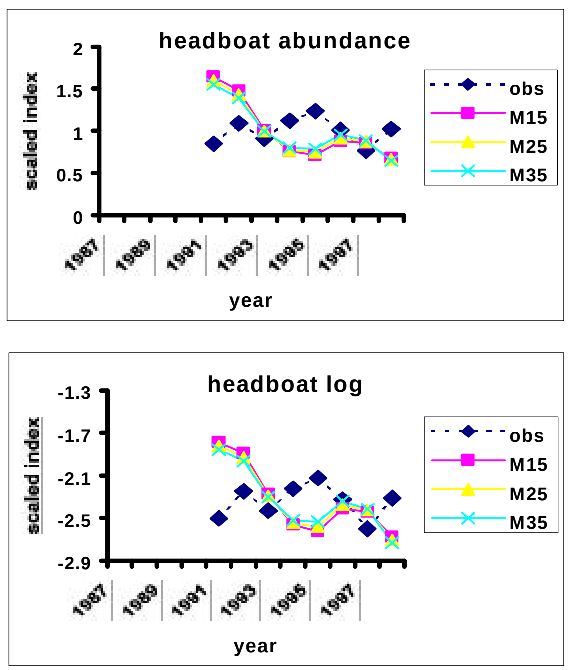


Figure 12. Panel C

Figure 12. Fits to indices from VPAs with 3 indices in 1991-1998 with the F ratio fixed at 1.

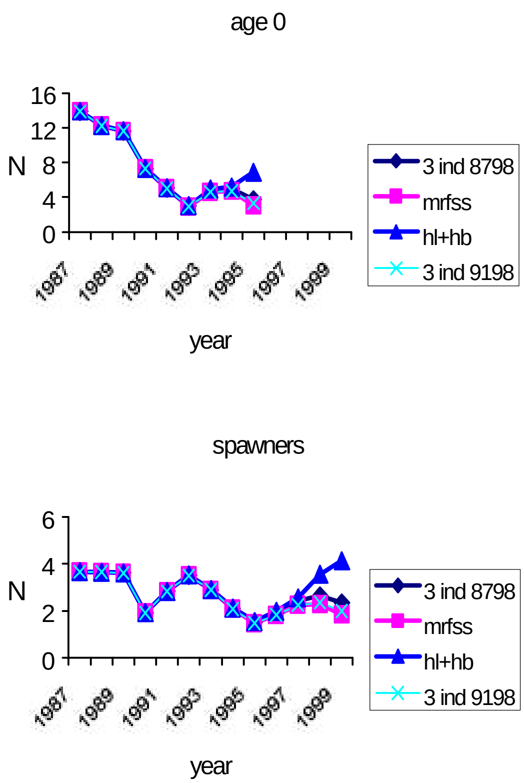


Figure 13. Estimated abundance of recruits and spawners [age 3 (50%) and ages 4-5+ (100%)] from 4 deterministic VPAs when the F ratio was fixed at 1 and M at 0.25. The handline and headboat estimates (trianagles) diverge from the other indices in some years..

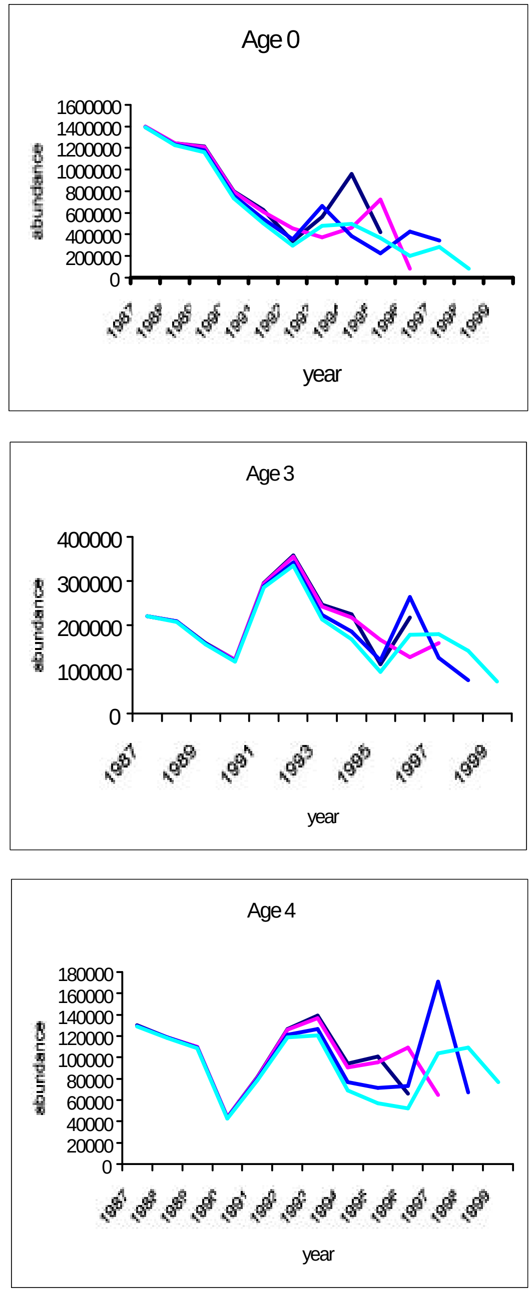


Figure 14. Abundance estimates for ages 1, 3 and 4 from VPAs with data through 1995, 1996, 1997 and 1998.

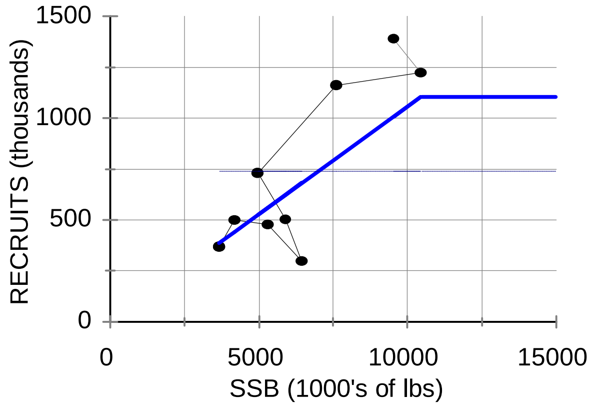


Figure 15a. 3 indices, F ratio = 1.

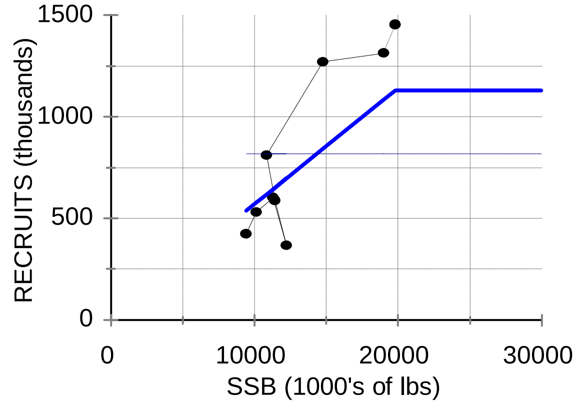


Figure 15b. 3 indices, F ratio estimated.

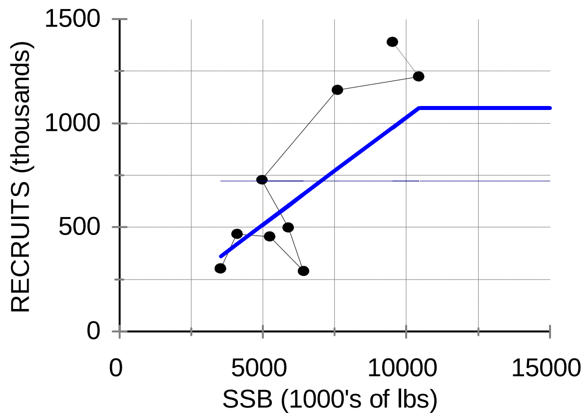


Figure 15c. MRFSS, F ratio = 1.

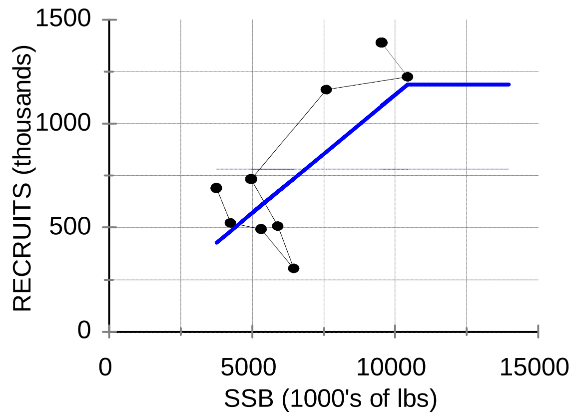
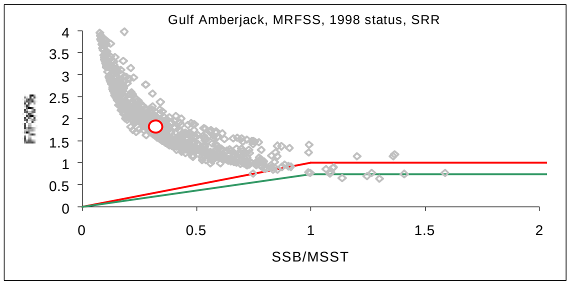
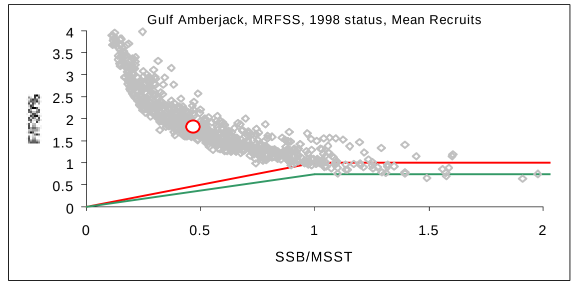


Figure 15d. 2 indices, F ratio = 1.

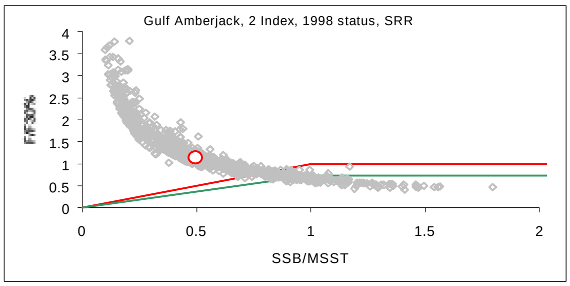
Figure 15. Stock-recruitment relationships for bootstrapped analyses showing the mean recruitment and the hockey stick formulations used in developing management reference points. Note the different scale for SSB in panel b.



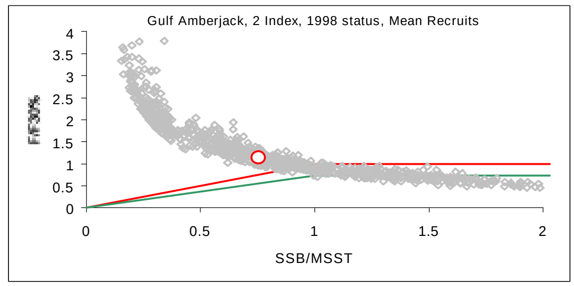
P(SSB<MSST)	P(SSB<SSB30%)	P(F>F30%)	P(F>F40%)
0.98	0.99	0.94	0.99



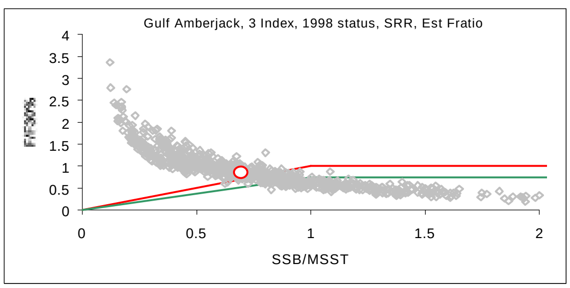
P(SSB<MSST)	P(SSB<SSB30%)	P(F>F30%)	P(F>F40%)
0.92	0.98	0.94	0.99



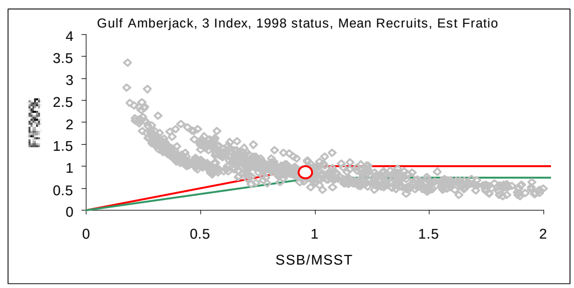
P(SSB<MSST)	P(SSB<SSB30%)	P(F>F30%)	P(F>F40%)
0.89	0.99	0.61	0.85



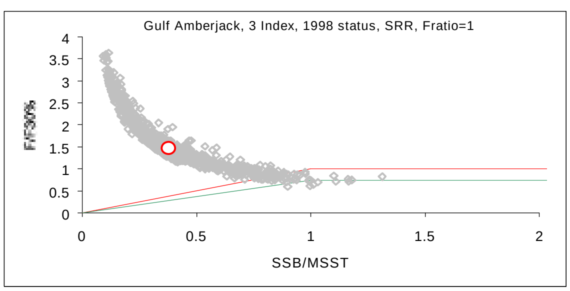
P(SSB<MSST)	P(SSB<SSB30%)	P(F>F30%)	P(F>F40%)
0.89	0.82	0.61	0.85



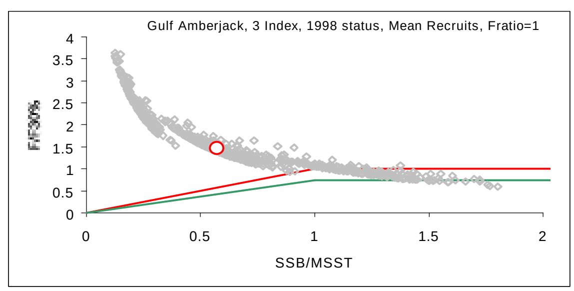
P(SSB<MSST)	P(SSB<SSB30%)	P(F>F30%)	P(F>F40%)
0.74	0.90	0.36	0.60



P(SSB<MSST)	P(SSB<SSB30%)	P(F>F30%)	P(F>F40%)
0.53	0.72	0.36	0.60



P(SSB<MSST)	P(SSB<SSB30%)	P(F>F30%)	P(F>F40%)
0.99	1.00	0.84	0.99



P(SSB<MSST)	P(SSB<SSB30%)	P(F>F30%)	P(F>F40%)
0.80	0.98	0.84	0.99

Figure 16. Status of greater amberjack in 1998 with respect to MSST and $F_{SPR30\%}$ for eight combinations of indices, methods of handling the F ratio and stock recruitment assumptions (hockey stick = SRR and mean recruits). Each open diamond represents a bootstrap result and the open circle represents the deterministic result. The limit and threshold controls rules are shown in each graph.

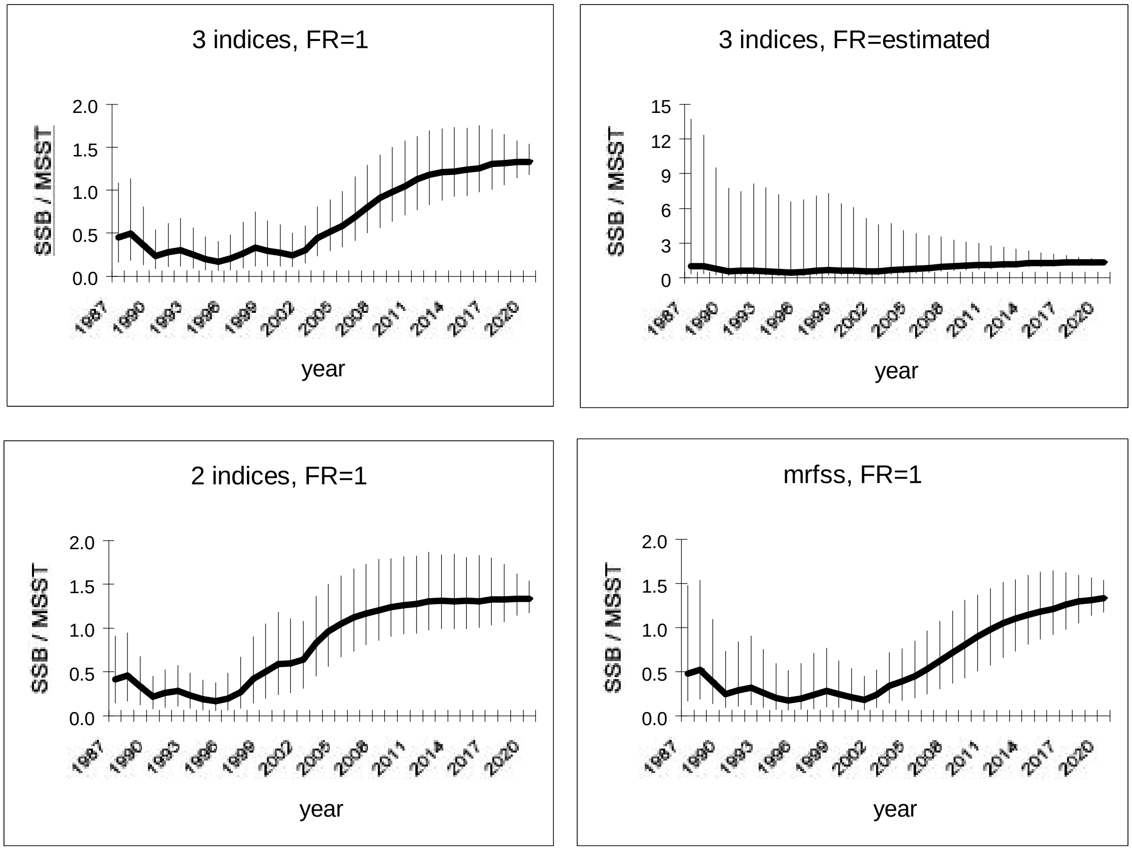


Figure 17. Median and 80% empirical confidence intervals for SSB relative to MSST based on 800 bootstraps with M at 0.15, o.25 or 0.35 under the hockey stick SR assumption for four cases with different sets of indices or differences in F ratio treatment. Note the different scale for SSB/MSST for 3 indices with the F ratio estimated.

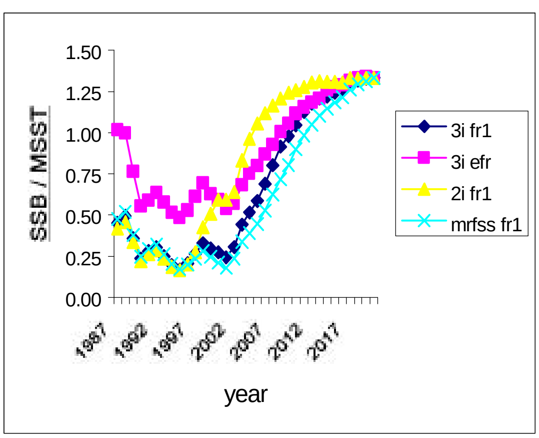


Figure 18. Median estimates of SSB/ MSST from bootstrapped VPAs and projections using the hockey stick stock recruitment assumption.

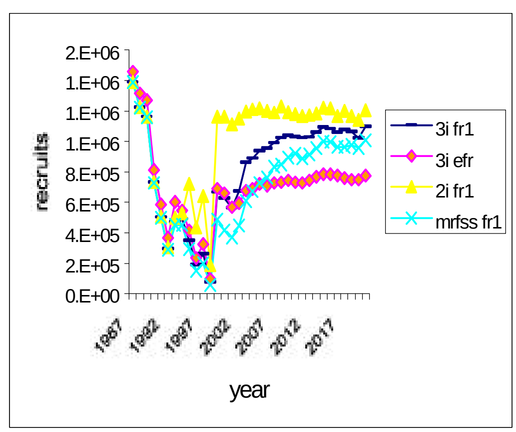


Figure 19. Median estimates of recruitment from bootstrapped VPAs and projections using the hockey stick stock recruitment assumption.

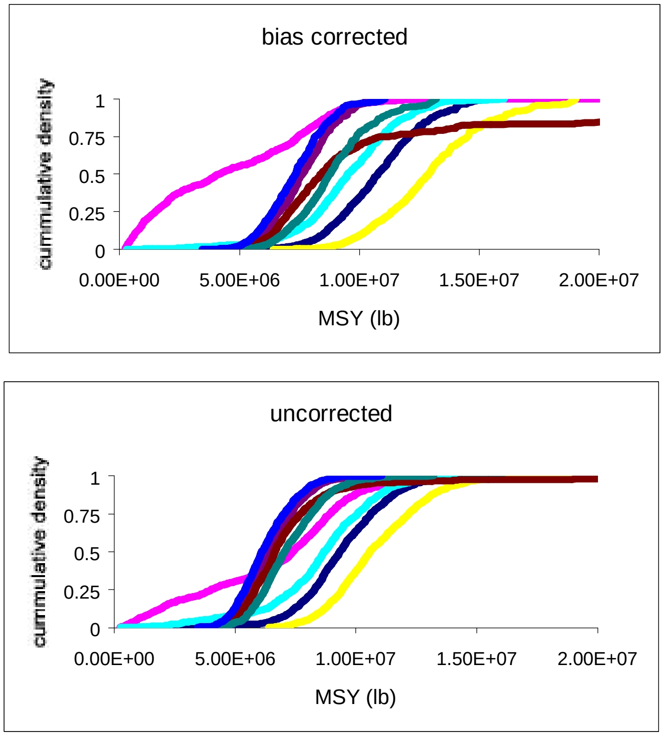


Figure 20. Cumulative densities (CDs) for bootstrapped and bias corrected bootstrapped MSYs. The four curves with low CDs at about 6E+06 in the bias corrected and about 5E+06 lb in the uncorrected plots are for the mean recruitment assumptions. The curve with the low CD near 0 lb is the hockey stick estimate from the case with the estimated F ratio.

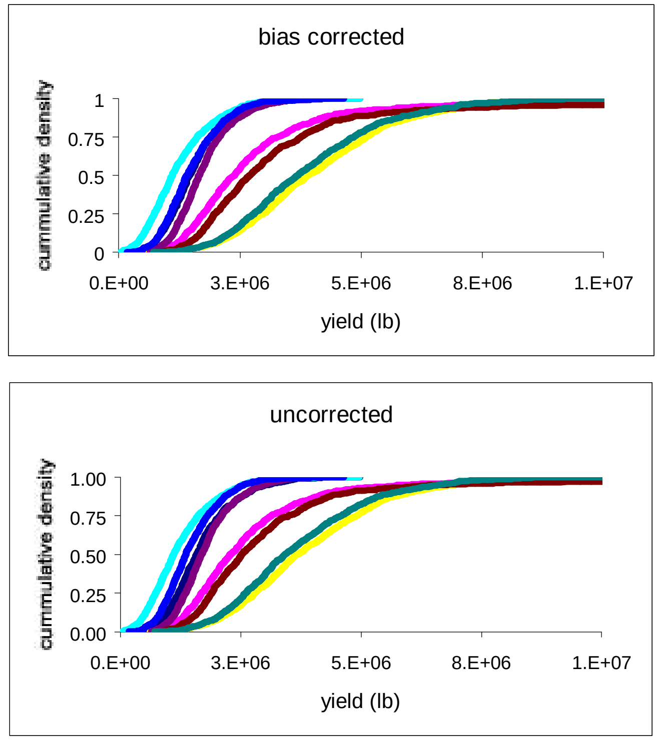


Figure 21. Cumulative densities (CDs) of yield (lb) in 2001 from projections of bootstrapped VPAs. The four curves which are close together at lower projected yields are from the mean recruitment cases and the four with projected higher yields are from the hockey stick stock recruitment assumptions.