Stock Assessment Analyses on Atlantic Greater Amberjack

Christopher M. Legault and Stephen C. Turner

NOAA Fisheries
Southeast Fisheries Science Center
Sustainable Fisheries Division
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Miami, FL 33149
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Stock assessments and projections of acceptable biological catches for Atlantic greater amberjack were conducted over a wide range of biological parameters due to insufficient knowledge about the true values. This approach is a different from previous assessments, which used only one estimate for stock assessment and did not compute maximum sustainable yields. Given the current limited knowledge of greater amberjack biology, and the fishery catches, in the Atlantic ocean, the resulting ranges of possible stock status and future yields are large. If improvements in the understanding of greater amberjack biology and fishery statistics can be made, these wide ranges will narrow.

The stock assessments for Atlantic greater amberjack consisted of tuned virtual population analysis. The catch at age data used in the assessment are provided in Cummings (1999) and the tuning indices used are described in Cummings et al. (1999). A number of assessments were conducted using different indices, values for the natural mortality rate, and maturity ogives. Fecundity at age was set as the product of weight and maturity at age. A Monte Carlo/bootstrap approach was used to examine uncertainty within each assessment. The default control rule was used to evaluate the current stock status for each assessment. Each assessment was projected into the future to estimate acceptable biological catches (ABC) under two alternative fishing mortality rates which might be considered as proxies for F_{MSY} : (1) $F_{40\%SPR}$, the fishing mortality rate which generates a 40% static spawning potential ratio, and (2) $F_{0.1}$. Risk associated with selecting different ABC levels was examined across all combinations of assessments and projections.

VPA Methods

A tuned VPA (ADAPT) method (Powers and Restrepo 1992, Restrepo 1996) was used to obtain statistical estimates of population parameters. The method is a non-linear least squares (LS) estimation process in which observed indices of abundance are fit to population estimates from cohort analyses for appropriate age groups:

$$\min_p LS = \sum_i W_i \sum_t \left[X_{it} - q_i \sum_j \left(b_{ijt} N_{ijt} \right) \right]^2$$

where W_i is an index specific weighting factor, X_{it} is the index i in year t, N_{ijt} is the abundance in year t of the j ages represented in index i and the b_{ijt} are appropriate conversion factors for that index and age (for example conversion from numbers to weight, conversion of the abundance from the beginning of the year to mid-year, or conversion of selectivity by age within the age group). The relationship between the scaled abundance ($q_i \Sigma b_{ijt} N_{ijt}$) and the index values was assumed to be lognormal. The scaling parameters q_i are computed by maximum likelihood during the minimization process, they are not estimated directly. Since all indices were scaled to their own mean prior to fitting to the VPA the absolute values of the q_i are not meaningful relative to the original data used to create the index. Each index was assigned equal weight in the objective function. The population parameters, p, are the key parameters to be estimated. In each analysis, the fishing mortality rates at age in the 1997/998 (May-April) fishing year (terminal year) were the parameters estimated. Note that this is analytically equivalent to estimating the population abundance in the next year at the next age but allows estimation for the plus group. An additional assumption made in each analysis was that the fishing mortality rate was the same in the plus group and the previous age for all years.

Not all fishing mortality rates could be estimated in the terminal year. The ages that were not directly estimated were computed based on an input selectivity pattern and a linkage to one of the ages estimated. For example, if selectivity for ages 5 and 6 were input as 0.2 and 0.4, respectively, and the age 6 F was estimated as 0.6, then the age 5 selectivity would be 0.3 (=0.6*0.2/0.4). Separable VPA was used to investigate recent selectivity patterns. Initially data from ages 0-18 in fishing years 1995/96-1997/98 were examined. Initial basic inputs to the model were a natural mortality rate of 0.3, 1997/98 fishing mortality rate on fully selected ages of 0.3 and a reference age (fully selected) of 8. Initial results indicated that full selectivity occurred at age 9 or 10, and so for subsequent analyses a reference age of 10 was used. Preliminary analyses indicated large numbers of negative residuals in 1993/94 and 1994/95 and large residuals in several years for ages 0 and 1 and 15 to 18. Limitation of the data set to 1994/95-1997/98 did not reduce the problem for 1994/95. Therefore only data from 1995/96-1997/98 and ages 2-14 were used for subsequent analyses. Analyses with the selectivity of age 14 set at 1.0 times that of age 10, indicated very low selectivity at ages 2-6 and rapidly increasing selectivity to ages 9 and 10 (Table 1 and Figure 1). Those results and results with the selectivity of age 14 0.5 and 1.5 times that at age 10 suggested a possible decrease in selectivity at ages 11 and older. There does not seem to be a biological nor fishery based reason for a decrease in selectivity for older fish, and thus selectivity was assumed to be flat-topped for ages 9 and older. Preliminary investigations in which fishing mortality rates were estimated for multiple ages resulted in selectivity patterns that were extremely dome-shaped. Therefore the assumed constant selectivity at older ages in the terminal years was imposed by estimating fishing mortality for only age 9 in 1997/98.

Characterization of Uncertainty

The uncertainty in the assessment estimation was characterized by both sensitivity analyses on selected components and by mixed Monte Carlo/bootstrap simulations of the tuned VPA. There were three types of sensitivity analyses: the indices used for tuning, the natural mortality rate and the maturity at age schedule. Examination of the results from fitting the indices one at a time showed that the MRFSS private index produced a different pattern in estimated recruitment and plus group abundance than the other indices (Figure 2). Since this index is tuned to exactly the same part of the predicted population as the MRFSS charter and the tagging indices, it was separated from the others and two sets of VPA assessments conducted, one with only the MRFSS private index and the other with the remaining four indices. The MRFSS private index is the only one of the four showing an overall increasing trend over time, but has the largest amount of uncertainty associated with it (Cummings et al 1999).

Since little is known regarding natural mortality (M), three levels were chosen; 0.20, 0.25, and 0.30. These values were selected based on the value used in the previous assessment, 0.3, and work done by Potts et al. 1998 who estimated M using a number of different published equations and chose 0.2 and 0.25 for calculations of spawning potential ratios. Even though the range of M estimated by Potts et al. 1998 (0.14 to 0.55) is much larger than the range examined here, the relationship between M and stock status is so predictable that the results for M values outside the range presented can be inferred.

Maturity at age was assumed to follow one of two patterns, early and late, based on the current limited knowledge of amberjack fecundity (Figure 3). These two maturity ogives were selected based on the work of Burch (1979) who found some mature at sizes 61-77 cm and full maturity at sizes 77-91 cm. Using the Manooch and Potts (1997) growth curve, these lengths correspond to ages 3-5 for some maturity and ages 5-7 for full maturity. The early maturity ogive uses the younger ages (3 and 5) as 50% and 100% mature while the late maturity ogive uses the older ages (5 and 7). The age at maturity does not effect the fitting of the VPA; rather summary statistics from the results, such as spawning potential ratio and stock recruitment relationships, change under different maturity ogives. Thus, the mixed Monte Carlo/bootstrap assessments were conducted six times (two sets of indices by three levels of M) and results of spawning stock related values were presented under the two maturity schedules.

The VPA Monte Carlo/bootstrap runs were conducted 400 times for each of the six assessments. The Monte Carlo component consisted of randomly selecting from a lognormal distribution of directed catch at age assuming the point estimate represented the mean and the variance was characterized by a CV of 25%. The bootstrap component consisted of observed deviations between the indices of abundance and the predicted population model from the original VPA fit. The results, for example recruitment in 1987/88 or the spawning potential ratio in 1997/98, were accumulated and sorted to provide probability statements of relevant statistics. Probability distributions from these observations were used to construct 80% pseudo-confidence intervals using the percentile method (removing the 10% lowest and highest observations). The 1200 results from the three M values for a given selectivity pattern and age at maturity were also combined and 80% confidence intervals calculated using the percentile method. These "All three M values" results are shown to reflect the total amount of uncertainty if the level of M cannot be determined from values amongst those presented individually.

Projections

Population abundances at age in the terminal year of the VPA (1997/98 fishing year) were projected into the 1998/99 fishing year according to the estimated F and assumed M at age values in the terminal year. Due to the lack of information for the two most recent cohorts in the VPA table (1996/97 and 1997/98), these values were replaced by values from an estimated stock-recruitment relationship (SRR) (further described below). This replacement of the most recent recruitment values was recommended by Porch (1998) based on results from bootstrapping experiments which showed extremely high variability in these values when catches are low for these cohorts. Recruitments for all years after the 1997/98 fishing year were also computed from the SRR. In the deterministic case, the recruitment values were set equal to that from the SRR. In the stochastic runs, a separate SRR was computed for each Monte Carlo/bootstrap and recruitment values were estimated by adding a lognormal error to the predicted value. The selectivity pattern for the projected years was computed for each bootstrap as the average pattern resulting from the estimated F at age for the fishing years 1994/95-1997/98. This selectivity pattern was used to match either an input catch in weight or used to solve for an input static spawning potential ratio. When computing projected landings in weight, a constant discard proportion at age was subtracted from the predicted catch in numbers. This discard proportion at age was computed based on the catch and estimated discards (in numbers) at age averaged over the fishing years 1994/95 to 1997/98 (Table 2).

Projections assumed the landings for the 1998/99 and 1999/2000 fishing years were equal to the average of the 1994/95 to 1997/98 catch in weight (3,248,896 pounds of landings and discards). The acceptable biological catch (ABC) for the 2000/2001 fishing year was computed from each Monte Carlo/bootstrap run as the estimated landings (not including discards) that results from application of either the static $F_{40\%SPR}$ or the $F_{0.1}$ specific to that run. The 400 ABC estimates for each of the six cases form the distribution of catch in fishing year 2000/2001 that would result in either of the two proxies assumed for the overfishing definition. Given the uncertainty characterized in the assessment and projection methods, selecting the median from the distribution as the quota would be a risk-neutral selection, on average the stock would undergo overfishing half of the time. While selecting a value above or below the median would be risk-prone or risk-averse, with greater or less than a 50% probability of undergoing overfishing, respectively. If a stock is overfished, the choice of where in the ABC distribution to select the quota also has implications for recovery time, selecting above the median will slow the rate of recovery relative to that expected, while selecting below the median will speed the rate of recovery. Long-term projections were not conducted due to the difficulty in estimating a stock recruitment relationship (described below).

The current status of the Atlantic greater amberjack stock was examined through the default control rule for each of the six combinations of M and terminal year selectivity. The F_{MSY} proxy was either $F_{40\%SPR}$ or $F_{0.1}$, as described above, and the BMSY proxy was computed as the product of the expected spawners per recruit under that F value and the expected value of future recruitment for that Monte Carlo/bootstrap run. These proxies were computed for each Monte Carlo/ bootstrap run and ratios of the values in the 1998/99 fishing year to the proxies computed such that the estimated status could be determined for each run.

Results

The six assessments (2 sets of tuning indices by three M values) resulted in different log likelihood values both in magnitude and pattern and different estimates of fishing mortality in the terminal year (Table 3). Lower M values produced better fits to the data when only the MRFSS Private index was used, while lower M values produced worse fits to the data when the other four tuning indices were used. Due to the different number of observations in the two sets of tuning index assessments, the magnitude of the results cannot be used to classify one as better than the other. Likelihood ratio tests were not conducted because the ability to distinguish amongst these cases statistically was not believed given the level of uncertainty associated with the input data. The F estimates were approximately four to five times larger for the four tuning indices case relative to the one tuning index case under a given level of M. Lower M values produced higher F estimates within a set of tuning indices and had lower coefficients of variation.

Index fits and diagnostics from the deterministic stock assessments when M=0.25 are presented in Tables 4-5. The deterministic fits to the indices for all three M values are shown graphically in Figures 4 and 5. For each set of tuning indices, the three M values produced similar fits. Considering that only one age was estimated in the terminal year, the predicted values match those observed quite well. However, estimating only one age in the terminal year does not allow for radical changes in predicted values when different M values are assumed.

Deterministic estimates of population abundance in numbers and fishing mortality rates by age and fishing year when M=0.25 are presented in Tables 6 and 7. Medians and 80% confidence intervals for selected population parameters when M=0.25 are shown in Figures 6 and 7. These figures show the estimated population trends in numbers, average F weighted by number at age, and stock biomass (pounds) for specific age ranges from the 400 Monte Carlo/bootstrap runs of each case. The median values for the three M values under a given set of tuning indices are plotted in Figures 8 and 9. The 1200 Monte Carlo/bootstrap runs (400 runs by 3 M values) for a given set of tuning indices are summarized in Figures 10 and 11. For a given M value and set of tuning indices, the confidence intervals in each plot decrease backwards in time due to the well-known backward convergence property in virtual population analyses. The trends that arise from different M values under a given set of tuning indices are always similar, but differ in magnitude. The trends between sets of tuning indices are more different for some of the population summaries, however. For example, the total population biomass is estimated as increasing under the MRFSS Private tuning index, while the trend first decreases then increases for the multiple tuning indices case. Combining the three M values for a set of tuning indices produces more consistent ranges of uncertainty over time in all plots.

Annual static spawning potential ratios (a measure of potential fecundity in the fished versus unfished state if that year's F pattern was continued for many years) were computed under two maturity schedules for the three M values and two sets of tuning indices (Figures 12 and 13). The static SPR showed a strong response to the level of M used, higher M produced higher static SPR values, as expected. The static SPR also showed a strong response to the maturity schedule, later maturity produced lower static SPR values, again as expected. Both sets of tuning indices produced a wide range of static SPR estimates (approximately 0.3 to 0.8) depending upon the M and maturity schedule selected, but the trends differed. When only the MRFSS Private tuning index was used, the static SPR shows an increasing trend from fishing year 1992/93 to present. In contrast, when the four tuning indices were used, the static SPR remains constant from the 1992/93 fishing year until the 1996/97 fishing year and then increases. The uncertainty within a particular combination of M, age at maturity, and tuning indices was low (the confidence interval bands were often indistinguishable from the median line), and thus choosing values for the three parameters essentially determines the static SPR value. To the degree that more precise estimates or knowledge of these parameters can be obtained, improvements in stock status evaluations can be made.

For the projections, the selectivity pattern was computed as the average of fishing years 1994/95 to 1997/98 as described above (Figure 14). The average selectivity trends show an agreement with the separable VPA results of a rapid increase in selectivity from ages 6 to 8, a peak at age 9, and a drop for later ages in all six cases. The average selectivity patterns were similar for different levels of M given a set of tuning indices. The average selectivity pattern from the MRFSS Private tuning index had a more pronounced dome than the four tuning indices cases. In all cases full maturity is achieved before 50% selectivity. This means that even under high levels of fishing mortality, many fish will be able to spawn at least once before dying. If in fact fecundity is more dependent upon age than weight, then both the fecundity at age curves used here will underestimate the impact of fishing on spawning potential ratios. Due to this possibility, $F_{40\%SPR}$ is used as the proxy for F_{MSY}, but results are presented also for $F_{0.1}$, a more conservative benchmark that does not depend upon fecundity at age estimates. Equilibrium spawning potential ratio and yield per recruit curves using these average selectivity patterns, M values, and fecundity at age curves are presented in Table 8 and Figures 15 and 16 for the deterministic runs.

The stock recruitment relationship was not well defined for any of the twelve combinations of M, tuning indices used, and maturity schedule (Figure 17). When only the MRFSS Private index was used with the early maturity schedule, the recruitment estimates increased for nearly constant spawning stock sizes for fishing years 1987/88 through 1992/93 followed by increases in both stock and recruits for all three M values examined. When only this tuning index was used with the late maturity schedule, the increases in spawning stock sizes at the end of the time series were not as pronounced. In contrast, when four tuning indices were used (Handline, MRFSS Charter, Headboat, and Tagging), there is an inverse relationship between spawning stock size and recruitment for all M values and both maturity schedules examined. The traditional stock recruitment curves would not produce reasonable residual patterns in any of the cases. Instead, a constant recruitment value was estimated for each of the Monte Carlo/bootstrap runs for each case. The recruitment estimates for the most recent years depend on the selectivity pattern assumed, slight changes in the assumed selectivities have large effects on the recruitment estimates. Thus, only the recruitment estimates from fishing years 1987/88 through 1992/93 are used to calculate the expected constant recruitment that replaces the 1996/97 and 1997/98 values and is used for future recruitment values. For the deterministic runs, this value is used directly, while for the stochastic runs the average for that Monte Carlo/bootstrap run is used as the mean of a lognormal distribution with given coefficient of variation (approximately 20%) and a value is chosen randomly from this distribution for each year.

The status of the Atlantic greater amberjack stock for the fishing year 1998/99, given the assumed recruitment levels for fishing years 1996/97 through 1998/99, was calculated using the default control rule under two proxies for F_{MSY} by computing the number of Monte Carlo/bootstrap runs out of the 400 total that were in a given classification region (Table 9). In all 24 combinations of F_{MSY} proxy, M, tuning indices, and maturity schedule considered here, the stock is classified as not overfished. In all but five of the 24 combinations, the stock is not undergoing overfishing. In three cases there is a 5% probability the stock is undergoing overfishing and in two cases there is a 56% probability the stock is undergoing overfishing (see Table 9 for the cases). Note that when using $F_{0.1}$ as the proxy for F_{MSY}, only the spawning stock ratios change for different maturity schedules, the F ratios are independent of the maturity schedule. There is currently not a set definition of the probability level associated with classifying a stock as overfished or undergoing overfishing. Thus, for the five cases when the probability of undergoing overfishing is greater than zero, but less than one, the status of the stock cannot be defined.

Examples of the control rule plots are given in Figures 18 and 19 for the M=0.25 cases. The scatter of points from any given case is nearly linear due to only estimating a single age in the terminal year. If more ages could have been estimated, then the scatter of points would be much greater because the projected selectivity pattern would vary much more among Monte Carlo/bootstrap runs.

The maximum sustainable yield (MSY) for each of the 24 combinations used to classify the status of the stock was also computed. There are only 18 unique combinations because MSY using $F_{0.1}$ as the F_{MSY} proxy is independent of the maturity schedule. The median and inner 50% range for MSY for each of the 18 cases are given in Table 10 and the cumulative probability distributions are shown in Figure 20. Of all the variables considered, the choice of tuning indices had the greatest effect on estimated MSY levels. When only the MRFSS Private index is used to tune the VPA, the MSY values are two to three times greater than when the four indices are used to tune the VPA. This difference is mainly due to differences in the estimated level of future recruitment, as seen by the similarities in the YPR values in Table 9. Given that future recruitment is one of the most uncertain variables in any stock assessment, and is even more so in this case because a stock recruitment relationship could not be determined, the patterns formed by different choices of parameter values should be given more weight than the absolute values of the MSY estimates.

The long term risk to the stock should also be considered if these MSY values are used to set constant catch quotas. The risk of overfishing under any constant catch, given the assumptions made regarding future recruitments, M, maturity schedule, etc. can be determined from Figure 20. If a quota is chosen such that all 400 Monte Carlo/bootstrap run estimates of MSY are below that level of catch, then there is a 100% probability that the stock will become overfished, under that set of assumptions. Thus, if any MSY value from any of the cases using only the MRFSS Private tuning index is used to set a constant catch quota, then there is a 100% probability that the stock will become overfished if reality actually follows any of the cases using the four tuning indices. Similarly, if a quota is set such that there is an X% cumulative frequency of that constant catch achieving the given F_{MSY} proxy, there is an X% probability that the stock will become overfished under that constant catch if reality follows that set of assumptions. For example, if the quota is set based on the median of the $F_{40\%SPR}$, M=0.25, early maturity, four tuning indices case (4.91 million pounds), then there is a 50% probability of the stock becoming overfished if reality follows those assumptions and the assumption made regarding future recruitment. However, a 4.91 million pound constant catch quota has a 96% probability of causing the stock to become overfished if reality follows the four tuning indices, M=0.2, $F_{40\%SPR}$ proxy, and late maturity assumptions, while this same quota has a zero probability of causing the stock to become overfished if reality follows any of the one tuning index cases. Thus, the benefit of increased yield must be balanced by the risk of causing the stock to become overfished.

Some of the estimates of acceptable biological catches for fishing year 2000/2001 were extreme (greater than 100 million pounds) compared to recent harvest levels (including estimated discards) of about 3.2 million pounds. Those large potential catches occurred because the projected stock sizes were substantially larger than the stock size at MSY (Figures 18 and 19) and the projected selectivity patterns allowed a few years of reproduction before the fish were highly selected. Median acceptable biological catches ranged from 1.5 to 8 times MSY. Note that if fishing were to remove that surplus biomass, subsequently recommended harvest levels would decrease to MSY or below depending on the status of the resource. Many of the acceptable biological catch levels would be associated with high risk to the stock if alternative assumptions, especially regarding recruitment levels, fecundity at age, and future selectivity patterns, were actually true. Because all estimates of current stock size are larger than the default proxy for stock size relative to stock size at MSY (Table 9 for all M and Figures 18 an 19 for M = 0.25), cautious catch levels might be selected from the lower bound of the 50% range about MSY (Table 10) all of which are above current catch levels.

Discussion

There is currently limited knowledge of the Atlantic greater amberjack biological parameters and fishery statistics. The most important piece of information in terms of reducing uncertainty in stock status and acceptable biological catches is the natural mortality rate. This is due to the strong relationships between M and both stock status classification and acceptable biological catch. Lower M causes higher probability of overfishing and overfished classifications and a lower TAC, when all other parameters are held fixed. While M is always difficult to estimate for marine species, increased aging of the catch could provide better estimates of the maximum age of the fish, which could then be used to estimate M. Alternatively, an intensive tagging program could provide estimates of M, but the limited amount of catch for this species makes this approach less appealing.

Another important source of uncertainty in the results presented here is fecundity at age. The hypothesized maturity ogives also result in differences in management advice with the earlier ogive indicating a higher SPR than the later ogive. The use of either ogive and weight at age to produce fecundity at age trends probably does not capture the relative importance of different ages in the total spawning potential for the stock. Direct estimates of egg production at age would be the best measure of fecundity.

Additional aging of the catch would also provide improved catch at age information. The inability to distinguish strong cohorts in the current catch matrix could be cause for concern if it was believed that cohort strength has in fact changed. Greater numbers of samples could allow for the detection of strong cohorts in the catch itself. A related source of uncertainty is the release mortality rate. The catch at age used in this assessment assumed a 20% release mortality rate and given distributions at age (see Cummings and McClellan 1999). Given the relatively large numbers of fish released since the implementation of the minimum size regulation in 1992, a different value of the release mortality rate could change the catch at age table substantially. Improvements to the indices of abundance especially through increased age specificity might also improve the ability to detect changes in cohort strengths using tuned virtual population analysis or other age structured population models.

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Editorial note: Years labeled as a single number, for example 1987, refer to May of the fishing year (May-April) in all tables and figures.

Table 1. *Results of Separable VPA analysis.*

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NATURAL MORTALITY =  .300
        TERMINAL F=  .300
        TERMINAL S= 1.000

  AGE          2        3        4        5        6        7        8
  S(J)      .004     .010     .018     .043     .103     .389     .833

  AGE          9       10       11       12       13       14
  S(J)     1.079    1.000     .722     .765     .820    1.000


  LOG CATCH RATIO RESIDUALS

  YEAR      1995     1996
  AGE
   1       -.022     .037     .014
   2        .093    -.089     .004
   3       -.115     .112    -.002
   4       -.131     .126    -.005
   5       -.110     .104    -.005
   6       -.277     .273    -.005
   7        .046    -.050    -.004
   8        .184    -.188    -.004
   9       -.003    -.001    -.004
  10        .038    -.042    -.004
  11        .062    -.066    -.004
  12        .220    -.224    -.004

           -.016    -.008    -.024
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Table 2. *Derivation of the discard proportions at age used for projections. Catch and discards (in numbers at age) are averages from the period 1994-1997.*

Age	Catch	Discards	Discard Proportion
0	0.5	47	0.99
1	434	667	0.61
2	1360	2020	0.60
3	3101	1332	0.30
4	4164	1120	0.21
5	6752	980	0.13
6	13622	575	0.04
7	23319	895	0.04
8	25587	864	0.03
9	16806	573	0.03
10	8354	391	0.04
11	4261	178	0.04
12+	6837	382	0.05

***Table 3**. Deterministic results from the six stock assessments. The one tuning index is MRFSS Private, the four tuning indices are Handline, MRFSS Charter, Headboat, and Tagging. L denotes the log likelihood values, larger values denote a better fit to the index data. F is the estimated fishing mortality on fully selected ages in the terminal year and CV is the coefficient of variation of this F estimate.*

M	# Indices	L	F	CV
0.2	one	7.33	0.076	28.42
0.25	one	7.53	0.061	29.31
0.3	one	7.69	0.050	30.80
0.2	four	53.29	0.310	15.14
0.25	four	52.13	0.269	15.87
0.3	four	50.53	0.230	16.96

***Table 4**. Index fits for M=0.25 and only the MRFSS Private index used for tuning.*

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      INDEX RESULTS

ML estimate of variance (all indices):    0.0773

 Fit results for index = MRFSS Private
 Index Fitted to Mid-Year  Stock Size in NUMBERS
         Scaled     Obj.Function   Predicted     Residual Scaled resid

87/88    0.6863       -0.3765       -0.4254       0.0489      0.1758
88/89    0.5408       -0.6147       -0.2674      -0.3473     -1.2490
89/90    0.7720       -0.2587       -0.4145       0.1558      0.5604
90/91    0.5020       -0.6892       -0.3014      -0.3878     -1.3946
91/92    0.9005       -0.1048       -0.5686       0.4639      1.6681
92/93    1.5532        0.4403        0.2669       0.1734      0.6236
93/94    1.6683        0.5118        0.2135       0.2984      1.0730
94/95    0.9883       -0.0118        0.3800      -0.3918     -1.4088
95/96    1.1967        0.1796       -0.0067       0.1863      0.6699
96/97    0.7867       -0.2399       -0.0675      -0.1724     -0.6199
97/98    1.4051        0.3401        0.3675      -0.0273     -0.0983

    ML estimate of catchability:  0.19376E-05
    Pearsons (parametric) correlation:   0.712 P= 0.0000
    Kendalls (nonparametric) Tau:        0.418 P= 0.0080

        Selectivity at age from Partial Catches
 year   1     2     3     4     5     6     7     8     9     10    11    12
87/88 0.000 0.012 0.021 0.020 0.064 0.103 0.193 0.114 0.417 0.793 1.000 0.937
88/89 0.001 0.006 0.019 0.024 0.050 0.175 0.131 0.430 0.680 0.694 1.000 0.858
89/90 0.004 0.001 0.009 0.015 0.022 0.082 0.167 0.514 1.000 0.494 0.765 0.717
90/91 0.004 0.005 0.021 0.023 0.065 0.209 0.153 0.427 1.000 0.819 0.655 0.509
91/92 0.000 0.002 0.005 0.010 0.118 0.230 0.128 0.181 0.440 0.560 1.000 0.566
92/93 0.000 0.003 0.015 0.023 0.106 0.486 0.648 0.889 0.989 0.753 1.000 0.632
93/94 0.001 0.001 0.001 0.021 0.072 0.364 0.693 1.000 0.986 0.540 0.779 0.547
94/95 0.000 0.002 0.000 0.013 0.103 0.384 0.584 1.000 0.911 0.960 0.603 0.436
95/96 0.000 0.000 0.005 0.005 0.017 0.097 0.251 0.616 1.000 0.906 0.763 0.936
96/97 0.000 0.000 0.003 0.004 0.018 0.057 0.204 0.371 0.530 1.000 0.729 0.724
97/98 0.000 0.000 0.002 0.006 0.018 0.051 0.241 0.458 0.756 1.000 0.317 0.556
```

***Table 5.** Index fits for M=0.25 and four indices (Handline, MRFSS Charter, Headboat and Tagging) used for tuning.*

INDEX RESULTS

ML estimate of variance (all indices): 0.0792

Fit results for index = Handline
Index Fitted to Mid-Year Stock Size in BIOMASS

	Scaled	Obj.Function	Predicted	Residual	Scaled resid
92/93	0.8555	-0.1561	-0.0069	-0.1492	-0.5303
93/94	0.8579	-0.1533	-0.0775	-0.0758	-0.2693
94/95	1.2529	0.2254	0.2229	0.0026	0.0091
95/96	1.2535	0.2259	-0.3662	0.5921	2.1045
96/97	0.9605	-0.0403	0.0656	-0.1059	-0.3765
97/98	0.8198	-0.1987	0.0651	-0.2638	-0.9376

ML estimate of catchability: 0.15784E-06
Pearsons (parametric) correlation: -0.190 P= 0.3839
Kendalls (nonparametric) Tau: -0.067 P= 0.5590

Selectivity at age from Partial Catches

year	1	2	3	4	5	6	7	8	9	10	11	12
92/93	0.002	0.008	0.011	0.013	0.023	0.050	0.176	0.387	0.475	0.836	0.898	1.000
93/94	0.002	0.008	0.014	0.026	0.042	0.098	0.261	0.423	0.514	0.462	0.865	1.000
94/95	0.001	0.012	0.013	0.023	0.044	0.185	0.513	1.000	0.896	0.724	0.377	0.459
95/96	0.001	0.003	0.007	0.012	0.019	0.038	0.130	0.473	1.000	0.677	0.538	0.435
96/97	0.001	0.005	0.008	0.022	0.043	0.092	0.508	0.778	0.904	1.000	0.603	0.600
97/98	0.003	0.004	0.010	0.017	0.038	0.090	0.317	0.729	0.785	0.665	1.000	0.889

Fit results for index = MRFSS Charter
Index Fitted to Mid-Year Stock Size in NUMBERS

	Scaled	Obj.Function	Predicted	Residual	Scaled resid
87/88	1.2438	0.2181	0.0991	0.1191	0.4232
88/89	0.9085	-0.0959	0.2357	-0.3316	-1.1787
89/90	1.0644	0.0624	0.0709	-0.0085	-0.0303
90/91	1.0257	0.0254	0.1106	-0.0852	-0.3029
91/92	1.0541	0.0527	-0.2112	0.2639	0.9379
92/93	0.9641	-0.0366	0.3889	-0.4255	-1.5124
93/94	1.1145	0.1084	0.2959	-0.1875	-0.6665
94/95	0.9218	-0.0814	0.3251	-0.4066	-1.4450
95/96	0.9804	-0.0198	-0.2632	0.2434	0.8649
96/97	0.9248	-0.0782	-0.6128	0.5347	1.9003
97/98	0.7980	-0.2257	-0.5097	0.2840	1.0096

ML estimate of catchability: 0.35318E-05
Pearsons (parametric) correlation: 0.379 P= 0.0527
Kendalls (nonparametric) Tau: 0.127 P= 0.3118

Selectivity at age from Partial Catches

year	1	2	3	4	5	6	7	8	9	10	11	12
87/88	0.000	0.015	0.027	0.026	0.071	0.107	0.195	0.116	0.419	0.794	1.000	0.937
88/89	0.001	0.007	0.024	0.029	0.065	0.192	0.135	0.428	0.688	0.694	1.000	0.858
89/90	0.009	0.002	0.011	0.019	0.027	0.106	0.183	0.530	1.000	0.502	0.773	0.724
90/91	0.011	0.010	0.031	0.026	0.076	0.242	0.187	0.447	1.000	0.794	0.639	0.496
91/92	0.001	0.004	0.009	0.015	0.127	0.259	0.143	0.215	0.461	0.573	1.000	0.566
92/93	0.000	0.008	0.028	0.035	0.122	0.423	0.600	0.831	1.000	0.696	0.918	0.580
93/94	0.002	0.003	0.003	0.039	0.108	0.415	0.606	0.971	1.000	0.598	0.824	0.579
94/95	0.000	0.005	0.001	0.026	0.171	0.526	0.634	0.847	0.897	1.000	0.654	0.472
95/96	0.000	0.001	0.009	0.009	0.030	0.135	0.308	0.656	0.891	0.938	0.815	1.000
96/97	0.000	0.000	0.005	0.006	0.024	0.074	0.238	0.405	0.561	1.000	0.784	0.779
97/98	0.000	0.000	0.002	0.006	0.018	0.051	0.241	0.458	0.756	1.000	0.317	0.556

Fit results for index = Headboat
Index Fitted to Mid-Year Stock Size in NUMBERS

	Scaled	Obj.Function	Predicted	Residual	Scaled resid
87/88	1.9995	0.6929	0.8670	-0.1742	-0.6190

88/89	1.3338	0.2880	0.6413	-0.3533	-1.2556
89/90	1.4665	0.3829	0.0700	0.3129	1.1122
90/91	0.7012	-0.3550	-0.0967	-0.2583	-0.9181
91/92	1.0017	0.0017	0.1290	-0.1272	-0.4523
92/93	0.8805	-0.1273	-0.5819	0.4546	1.6158
93/94	0.8660	-0.1438	-0.4312	0.2874	1.0214
94/95	0.9115	-0.0926	-0.2076	0.1150	0.4086
95/96	0.4942	-0.7049	-0.4682	-0.2367	-0.8413
96/97	0.7633	-0.2702	-0.4152	0.1450	0.5155
97/98	0.5818	-0.5416	-0.3764	-0.1652	-0.5872

ML estimate of catchability: 0.12833E-05
Pearsons (parametric) correlation: 0.818 P= 0.0000
Kendalls (nonparametric) Tau: 0.527 P= 0.0010

Selectivity at age from Partial Catches

year	1	2	3	4	5	6	7	8	9	10
87/88	0.210	0.769	1.000	0.778	0.691	0.455	0.470	0.377	0.536	0.226
88/89	0.237	0.481	0.407	0.440	0.469	1.000	0.915	0.599	0.892	0.920
89/90	0.381	0.197	0.134	0.187	0.124	0.168	0.601	0.679	1.000	0.303
90/91	0.122	0.188	0.275	0.155	0.128	0.426	0.457	0.814	1.000	0.484
91/92	0.038	0.091	0.134	0.338	1.000	0.801	0.631	0.483	0.897	0.829
92/93	0.011	0.037	0.055	0.067	0.177	0.391	0.727	0.946	0.367	1.000
93/94	0.016	0.026	0.053	0.215	0.472	0.442	0.447	0.605	1.000	0.136
94/95	0.011	0.021	0.039	0.176	0.659	0.880	1.000	0.235	0.324	0.303
95/96	0.005	0.013	0.037	0.112	0.434	0.565	0.367	1.000	0.453	0.168
96/97	0.008	0.010	0.038	0.084	0.233	0.399	1.000	0.529	0.656	0.363
97/98	0.049	0.006	0.019	0.042	0.173	0.272	0.924	1.000	0.555	0.448

Fit results for index = Tagging
Index Fitted to Mid-Year Stock Size in NUMBERS

	Scaled	Obj.Function	Predicted	Residual	Scaled resid
90/91	1.2416	0.2164	0.1000	0.1165	0.4139
91/92	1.1345	0.1262	-0.2219	0.3481	1.2371
92/93	1.5459	0.4356	0.3783	0.0573	0.2038
93/94	1.1225	0.1156	0.2853	-0.1697	-0.6032
94/95	0.9262	-0.0767	0.3145	-0.3911	-1.3901
95/96	0.9546	-0.0465	-0.2738	0.2274	0.8081
96/97	0.6948	-0.3641	-0.6235	0.2593	0.9218
97/98	0.3798	-0.9681	-0.5204	-0.4477	-1.5913

ML estimate of catchability: 0.34943E-05
Pearsons (parametric) correlation: 0.735 P= 0.0003
Kendalls (nonparametric) Tau: 0.500 P= 0.0101

Selectivity at age from Partial Catches

year	1	2	3	4	5	6	7	8	9	10	11	12
90/91	0.011	0.010	0.031	0.026	0.076	0.242	0.187	0.447	1.000	0.794	0.639	0.496
91/92	0.001	0.004	0.009	0.015	0.127	0.259	0.143	0.215	0.461	0.573	1.000	0.566
92/93	0.000	0.008	0.028	0.035	0.122	0.423	0.600	0.831	1.000	0.696	0.918	0.580
93/94	0.002	0.003	0.003	0.039	0.108	0.415	0.606	0.971	1.000	0.598	0.824	0.579
94/95	0.000	0.005	0.001	0.026	0.171	0.526	0.634	0.847	0.897	1.000	0.654	0.472
95/96	0.000	0.001	0.009	0.009	0.030	0.135	0.308	0.656	0.891	0.938	0.815	1.000
96/97	0.000	0.000	0.005	0.006	0.024	0.074	0.238	0.405	0.561	1.000	0.784	0.779
97/98	0.000	0.000	0.002	0.006	0.018	0.051	0.241	0.458	0.756	1.000	0.317	0.556

***Table 6**. Deterministic results for M=0.25 and only the MRFSS Private index used to tune the VPA.*

Stock sizes at the beginning of the year

	87	88	89	90	91	92	93	94	95	96	97	98
0	2014355.	2673670.	3074020.	4875261.	6113495.	8106436.	16302815.	14019498.	19724987.			
1	1200370.	1568755.	2082184.	2393538.	3795969.	4760657.	6313249.	12696561.	10918345.	15361795.		
2	949202.	930870.	1217104.	1612507.	1859422.	2953715.	3706796.	4915492.	9886787.	8502412.	11962634.	
3	689772.	702474.	708162.	943775.	1251532.	1445519.	2297406.	2884208.	3824348.	7696918.	6618834.	9314222.
4	646450.	516773.	531603.	545952.	728639.	969607.	1122238.	1786383.	2244033.	2974133.	5988386.	5151591.
5	355344.	484758.	391981.	405731.	416921.	562140.	751614.	868620.	1386978.	1743797.	2310922.	4658611.
6	270743.	254972.	364124.	299883.	310277.	312887.	430645.	576081.	667171.	1074487.	1350600.	1795005.
7	208493.	198175.	183998.	271269.	222337.	227022.	228616.	316714.	425836.	510349.	825548.	1045220.
8	216203.	149076.	142419.	131640.	203724.	165855.	157522.	155252.	218988.	315177.	371638.	627770.
9	129747.	158459.	103313.	93403.	88888.	148771.	106176.	100694.	93983.	144684.	219854.	275007.
10	63947.	80321.	104412.	58800.	53535.	55189.	93735.	66696.	63874.	51754.	97942.	161030.
11	31670.	37757.	52674.	67227.	34550.	30357.	31640.	63169.	43536.	39258.	33071.	71737.
12	135225.	96766.	87215.	81943.	93250.	60632.	50551.	49195.	79422.	79145.	81293.	83765.

Fishing mortality rates

	87	88	89	90	91	92	93	94	95	96	97
0	0.0000	0.0000	0.0002	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000		
1	0.0043	0.0038	0.0056	0.0025	0.0009	0.0002	0.0003	0.0001	0.0001	0.0001	
2	0.0510	0.0234	0.0043	0.0034	0.0018	0.0013	0.0009	0.0010	0.0004	0.0004	0.0002
3	0.0388	0.0287	0.0101	0.0087	0.0052	0.0031	0.0016	0.0010	0.0014	0.0010	0.0006
4	0.0378	0.0264	0.0202	0.0196	0.0094	0.0047	0.0062	0.0031	0.0022	0.0023	0.0011
5	0.0819	0.0362	0.0178	0.0182	0.0371	0.0165	0.0160	0.0139	0.0053	0.0055	0.0026
6	0.0620	0.0762	0.0444	0.0492	0.0624	0.0638	0.0573	0.0522	0.0180	0.0136	0.0063
7	0.0854	0.0804	0.0849	0.0363	0.0431	0.1155	0.1370	0.1190	0.0509	0.0672	0.0239
8	0.0607	0.1167	0.1719	0.1427	0.0644	0.1960	0.1975	0.2519	0.1645	0.1102	0.0511
9	0.2296	0.1671	0.3136	0.3066	0.2266	0.2119	0.2150	0.2052	0.3466	0.1402	0.0614
10	0.2769	0.1719	0.1903	0.2817	0.3173	0.3063	0.1446	0.1766	0.2368	0.1979	0.0614
11	0.2951	0.1834	0.2848	0.2198	0.4956	0.3378	0.2633	0.0970	0.1906	0.1260	0.0614
12	0.2951	0.1834	0.2848	0.2198	0.4956	0.3378	0.2633	0.0970	0.1906	0.1260	0.0614

***Table** 7. Deterministic results for M=0.25 and four indices (Handline, MRFSS Charter, Headboat, and Tagging) used to tune the VPA.*

Stock sizes at the beginning of the year

	87	88	89	90	91	92	93	94	95	96	97	98
0	1117936.	1110196.	1006615.	1250877.	1455971.	1889029.	3745990.	3208142.	4504501.			
1	895531.	870624.	864550.	783441.	973296.	1133373.	1471127.	2917296.	2498452.	3508069.		
2	701511.	693462.	673399.	664214.	605478.	755415.	881865.	1144444.	2270687.	1944993.	2730942.	
3	513010.	509586.	523270.	520337.	513001.	468947.	585369.	684150.	887453.	1765494.	1511911.	2124573.
4	465396.	379115.	381386.	401959.	398867.	394439.	361684.	453047.	530626.	686877.	1368989.	1174315.
5	300779.	343759.	284776.	288743.	304780.	305313.	303673.	276301.	348575.	409395.	529607.	1061021.
6	241536.	212484.	254318.	216392.	219167.	225556.	230630.	227229.	205879.	265780.	311369.	407716.
7	192641.	175431.	150912.	185758.	157319.	156075.	160610.	160963.	154190.	151102.	195736.	235870.
8	196959.	136733.	124708.	105878.	137130.	115221.	102291.	102319.	97763.	103652.	91951.	137298.
9	120896.	143472.	93703.	79619.	68835.	96914.	66790.	57736.	52847.	50406.	55260.	57239.
10	59831.	73435.	92748.	51333.	42826.	39594.	53410.	36071.	30474.	19883.	24618.	32888.
11	29667.	34557.	47315.	58151.	28745.	22039.	19530.	31789.	19716.	13319.	8312.	14651.
12	126676.	88564.	78342.	70880.	77584.	44019.	31203.	24757.	35969.	26851.	20433.	17108.

Fishing mortality rates

	87	88	89	90	91	92	93	94	95	96	97
0	0.0000	0.0001	0.0007	0.0009	0.0005	0.0000	0.0000	0.0000	0.0000		
1	0.0057	0.0069	0.0136	0.0077	0.0034	0.0009	0.0011	0.0006	0.0004	0.0004	
2	0.0696	0.0316	0.0079	0.0083	0.0055	0.0050	0.0039	0.0043	0.0017	0.0019	0.0011
3	0.0525	0.0398	0.0137	0.0158	0.0128	0.0097	0.0062	0.0041	0.0062	0.0044	0.0027
4	0.0529	0.0361	0.0283	0.0268	0.0173	0.0115	0.0193	0.0121	0.0094	0.0100	0.0048
5	0.0975	0.0514	0.0246	0.0257	0.0510	0.0305	0.0400	0.0442	0.0212	0.0237	0.0116
6	0.0698	0.0922	0.0641	0.0688	0.0895	0.0896	0.1096	0.1378	0.0593	0.0559	0.0277
7	0.0928	0.0913	0.1044	0.0535	0.0614	0.1725	0.2009	0.2486	0.1471	0.2467	0.1046
8	0.0669	0.1279	0.1987	0.1806	0.0971	0.2953	0.3219	0.4107	0.4124	0.3790	0.2240
9	0.2485	0.1863	0.3518	0.3701	0.3030	0.3458	0.3661	0.3890	0.7275	0.4666	0.2689
10	0.2989	0.1896	0.2168	0.3299	0.4143	0.4567	0.2689	0.3540	0.5777	0.6221	0.2689
11	0.3183	0.2021	0.3226	0.2587	0.6319	0.5000	0.4674	0.2024	0.4794	0.4260	0.2689
12	0.3183	0.2021	0.3226	0.2587	0.6319	0.5000	0.4674	0.2024	0.4794	0.4260	0.2689

Table 8*. Common reference points,F40%SPR and F(0.1), under the average selectivity trend at age offor three levels of M, two sets of tuning indices, and two maturity at age schedules for the deterministic cases. The columns give the maximum F at age (F), spawning potential ratio (SPR), yield per recruit (YPR) (pounds), and spawners per recruit (S/R).*

Early Maturity

		F40%SPR				F(0.1)			
M	# Indices	F	SPR	YPR	S/R	F	SPR	YPR	S/R
0.2	one	0.481	0.400	4.643	23.861	0.378	0.449	4.376	26.748
0.25	one	0.727	0.400	3.241	13.612	0.481	0.475	2.942	16.160
0.3	one	1.097	0.400	2.309	8.149	0.595	0.501	2.010	10.210
0.2	four	0.426	0.400	4.598	23.885	0.335	0.451	4.329	26.886
0.25	four	0.632	0.400	3.202	13.614	0.430	0.474	2.920	16.112
0.3	four	0.927	0.400	2.280	8.158	0.542	0.496	2.008	10.096

Late Maturity

		F40%SPR				F(0.1)			
M	# Indices	F	SPR	YPR	S/R	F	SPR	YPR	S/R
0.2	one	0.445	0.400	4.564	23.239	0.378	0.434	4.376	25.228
0.25	one	0.649	0.400	3.169	13.158	0.481	0.458	2.942	15.038
0.3	one	0.942	0.400	2.245	7.813	0.595	0.481	2.010	9.383
0.2	four	0.398	0.400	4.528	23.214	0.335	0.437	4.329	25.380
0.25	four	0.570	0.400	3.135	13.158	0.430	0.457	2.920	15.004
0.3	four	0.813	0.400	2.222	7.807	0.542	0.475	2.008	9.279

Table 9*. Probabilities of being overfished or undergoing overfishing in 1998/99 fishing year using default control rule based on 400 Monte Carlo/bootstrap runs for two Fmsy proxies, three levels of M, two sets of tuning indices, and two maturity schedules.*

Fmsy proxy = F40%SPR

		Early Maturity		Late Maturity	
M	# Indices	P(overfishing)	P(overfished)	P(overfishing)	P(overfished)
0.2	one	0	0	0	0
0.25	one	0	0	0	0
0.3	one	0	0	0	0
0.2	four	0	0	0.05	0
0.25	four	0	0	0	0
0.3	four	0	0	0	0

Fmsy proxy = F0.1

		Early Maturity		Late Maturity	
M	# Indices	P(overfishing)	P(overfished)	P(overfishing)	P(overfished)
0.2	one	0	0	0	0
0.25	one	0	0	0	0
0.3	one	0	0	0	0
0.2	four	0.56	0	0.56	0
0.25	four	0.05	0	0.05	0
0.3	four	0	0	0	0

Table 10*. Maximum sustainable yield (MSY) medians and inner 50% range from 400 Monte Carlo/ bootstrap runs of 18 combinations of tuning indices used, M, Fmsy proxy, and maturity schedule.*

# Indices	M	Fmsy Proxy	Maturity Schedule	MSY (million pounds) Median	Inner 50% Range		
one	0.2	F40%SPR	Early	12.50	10.48	-	15.38
one	0.2	F40%SPR	Late	11.51	9.65	-	14.14
one	0.2	F0.1	N/A	10.67	8.95	-	13.12
one	0.25	F40%SPR	Early	15.54	12.61	-	18.98
one	0.25	F40%SPR	Late	14.07	11.42	-	17.18
one	0.25	F0.1	N/A	12.48	10.14	-	15.24
one	0.3	F40%SPR	Early	19.53	15.78	-	23.95
one	0.3	F40%SPR	Late	17.42	14.08	-	21.36
one	0.3	F0.1	N/A	14.70	11.90	-	18.02
four	0.2	F40%SPR	Early	4.43	4.13	-	4.78
four	0.2	F40%SPR	Late	4.09	3.82	-	4.42
four	0.2	F0.1	N/A	3.79	3.54	-	4.09
four	0.25	F40%SPR	Early	4.94	4.58	-	5.37
four	0.25	F40%SPR	Late	4.48	4.16	-	4.88
four	0.25	F0.1	N/A	4.00	3.71	-	4.34
four	0.3	F40%SPR	Early	5.80	5.33	-	6.36
four	0.3	F40%SPR	Late	5.18	4.77	-	5.68
four	0.3	F0.1	N/A	4.42	4.07	-	4.84

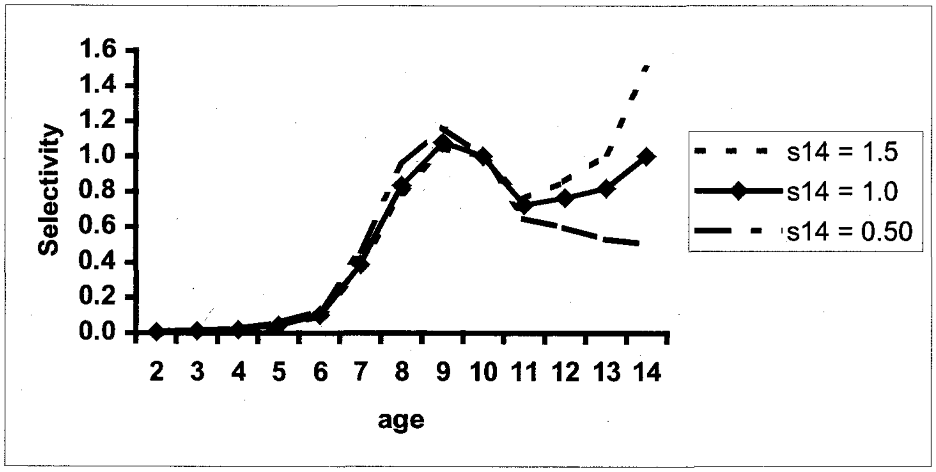
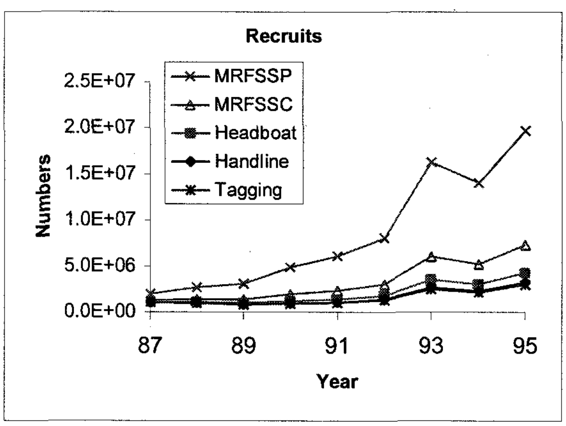


Figure 1. *Selectivity at age estimated by SVPA from 1995/96-1997/98 catch at age under three levels of assumed selectivity at age 14 relative to the reference age (10).*



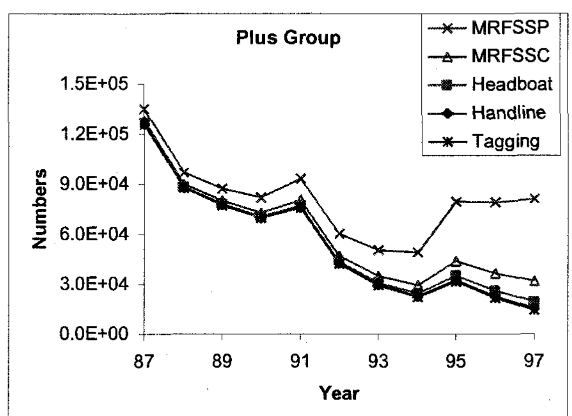


Figure 2. *Estimated recruitment and population abundance in the 12+ group when each index was used individually to tune the VPA.*

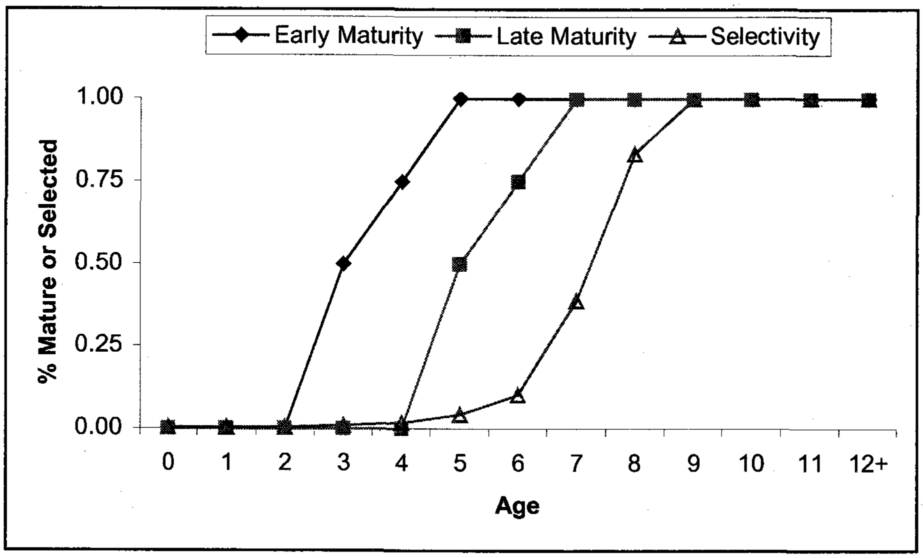


Figure 3. Maturity at age schedules and terminal year selectivity pattern assumed.

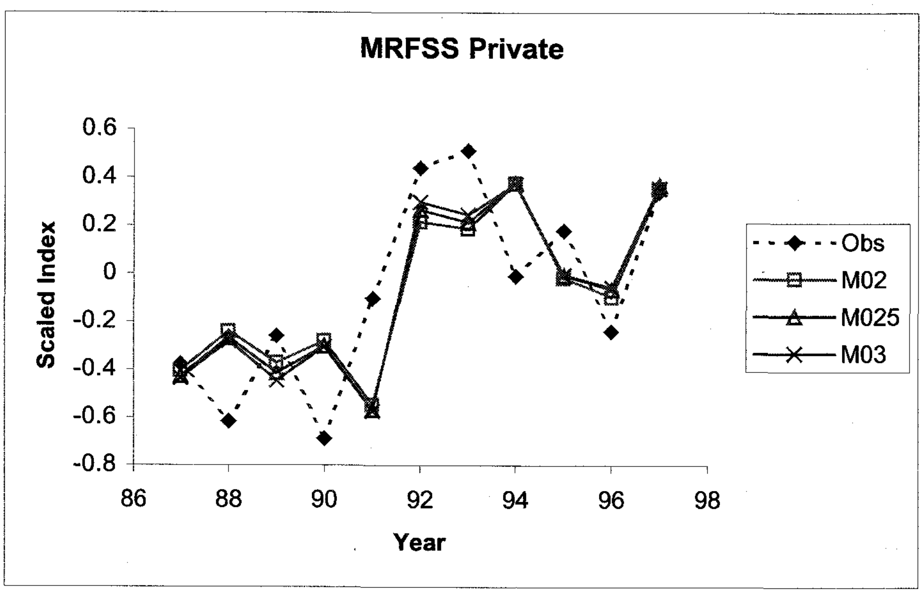


Figure 4. Index fits for three M values when only the MRFSS Private index is used to tune the VPA.

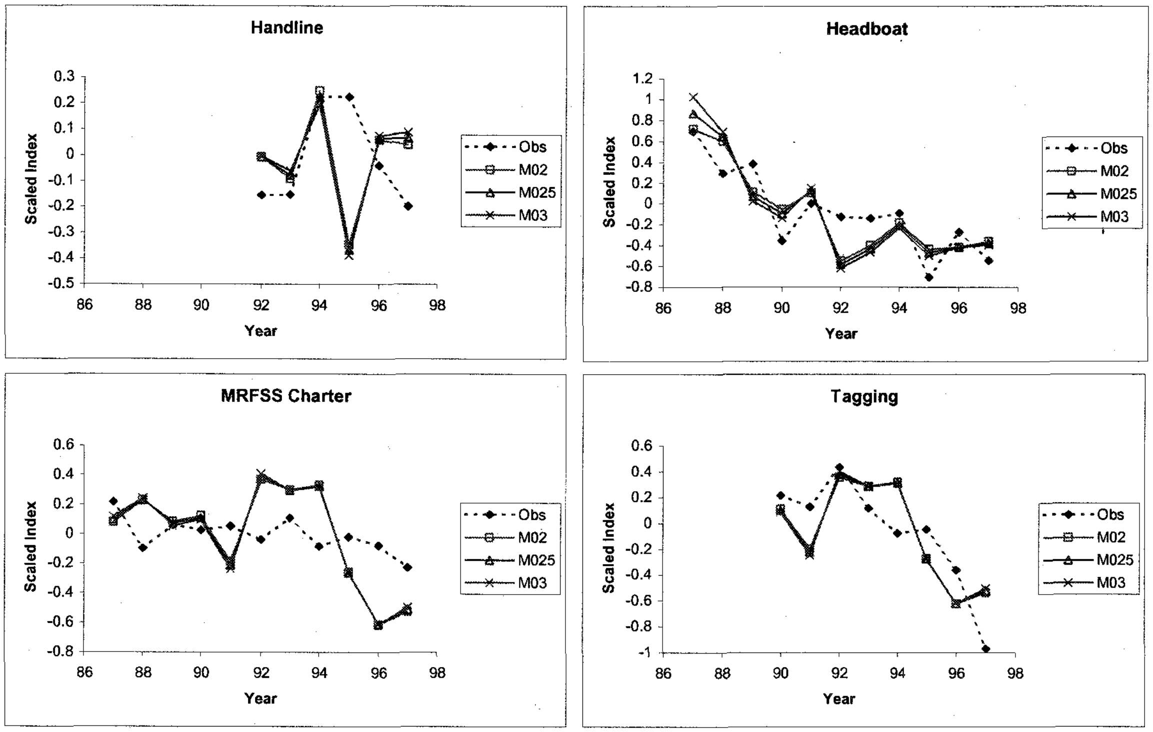


***Figure 5**. Index fits for three M values when four indices are used to tune the VPA.*

M = 0.25 MRFSS Private Tuning Index

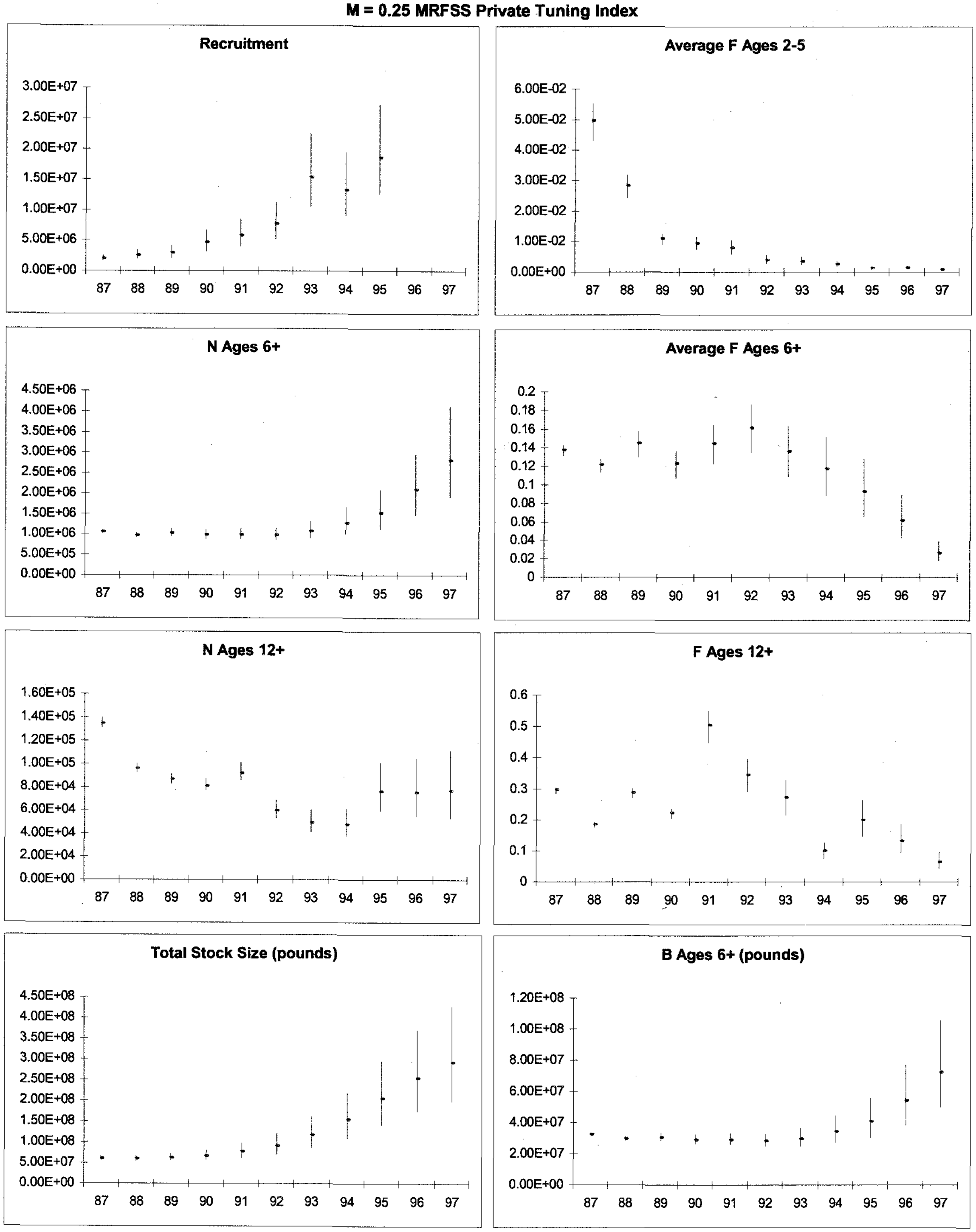


Figure 6. Median and 80% confidence intervals for selected population trends under M of 0.25 when only the MRFSS Private index is used to tune the VPA.

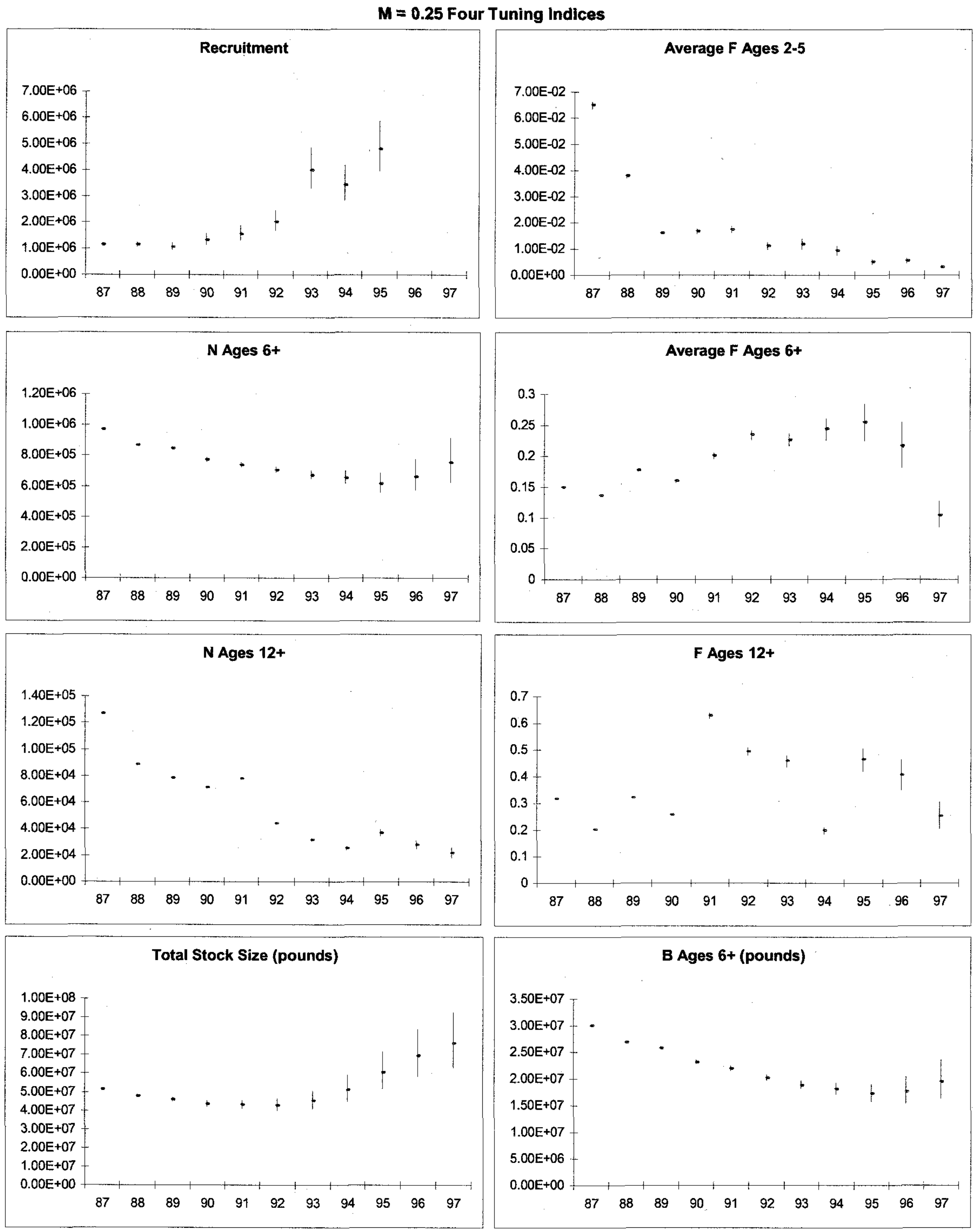


***Figure** 7. Median and 80% confidence intervals for selected population trends under M of 0.25 when four indices (Handline, MRFSS Charter, Headboat and Tagging) are used to tune the VPA.*

MRFSS Private Tuning Index

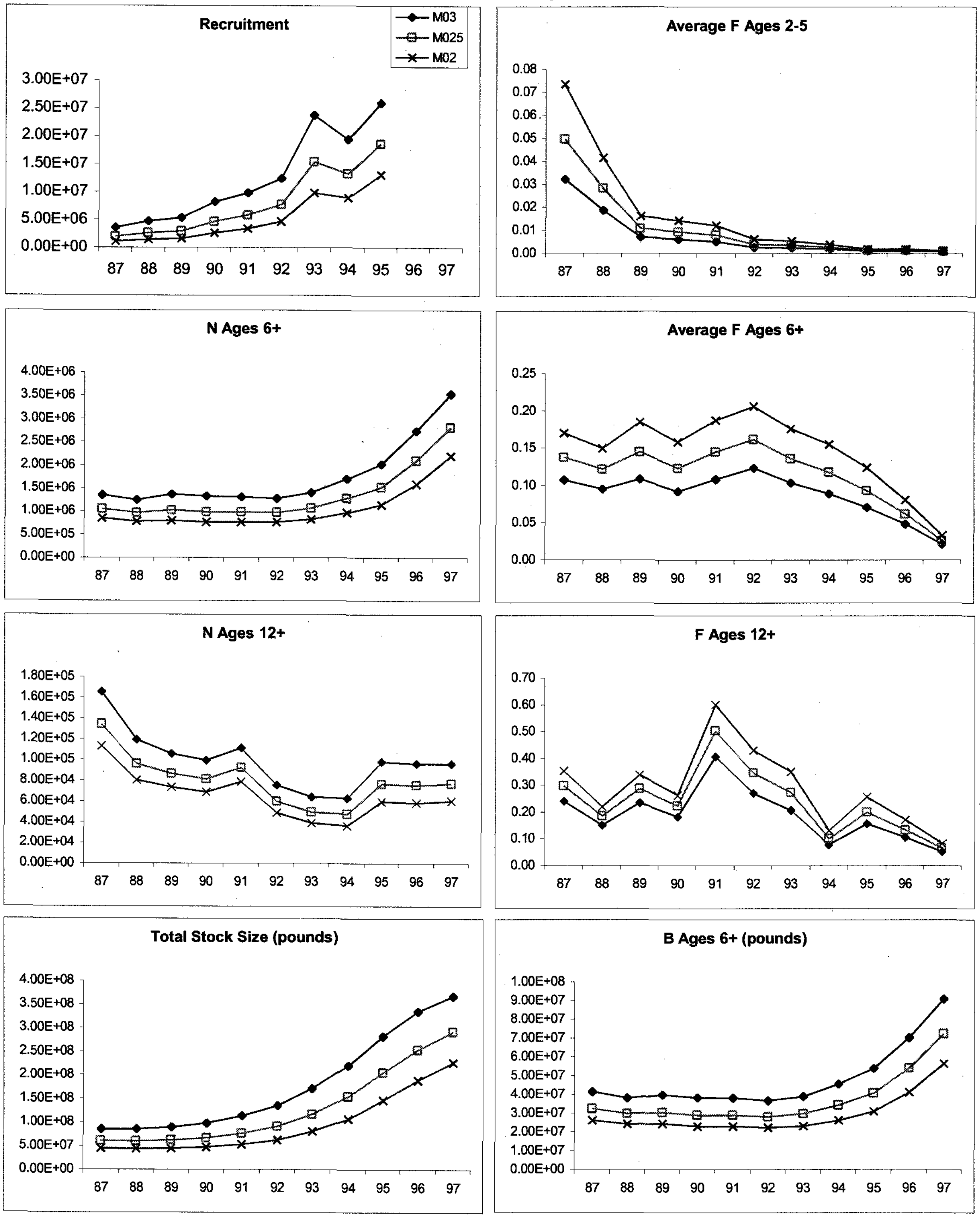


***Figure 8**. Medians from 400 Monte Carlo/bootstrap runs for three different levels of M when only the MRFSS Private index is used to tune the VPA.*

Four Tuning Indices

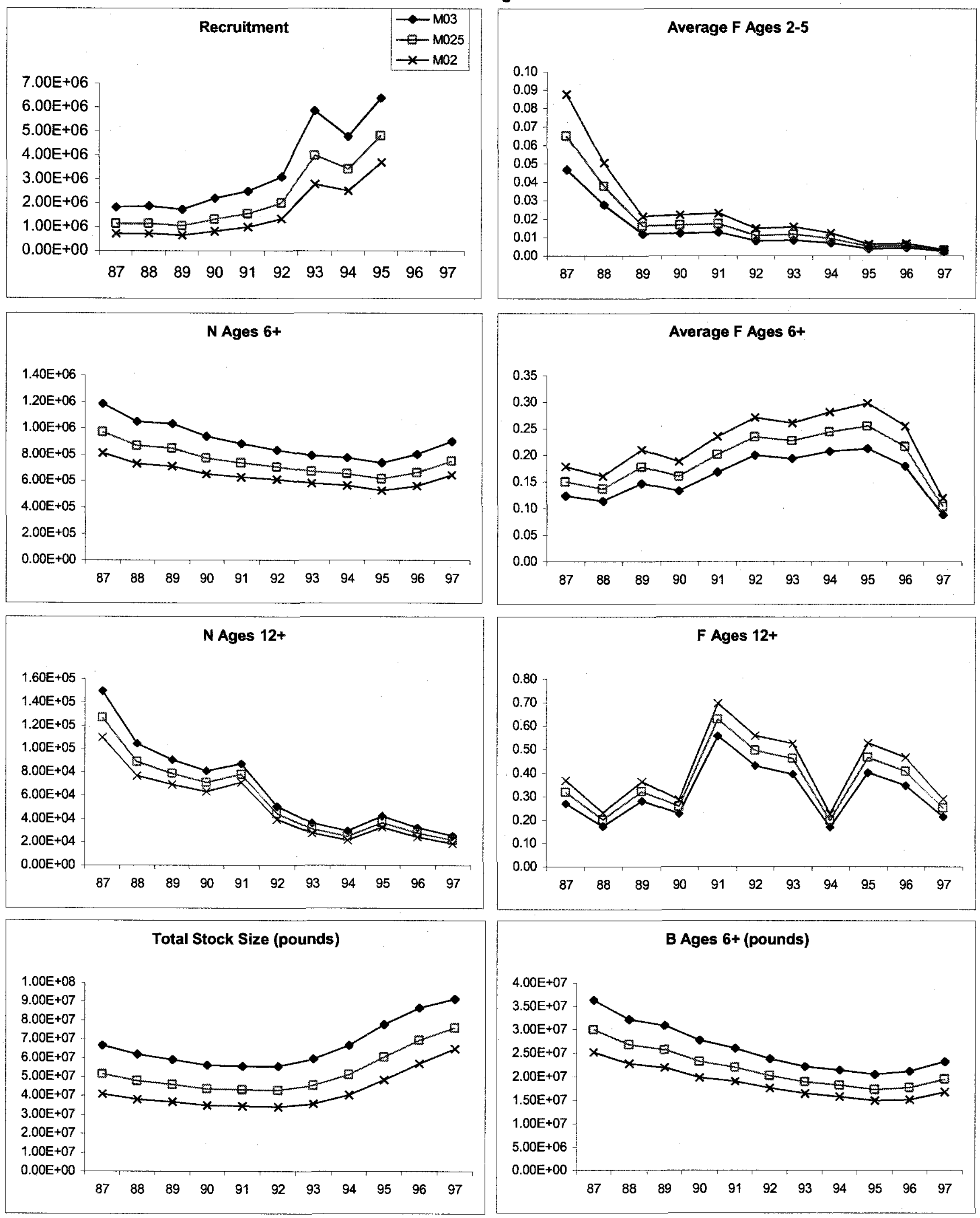


Figure 9. *Medians from 400 Monte Carlo/bootstrap runs for three different levels of M when four indices (Handline, MRFSS Charter, Headboat and Tagging) are used to tune the VPA.*

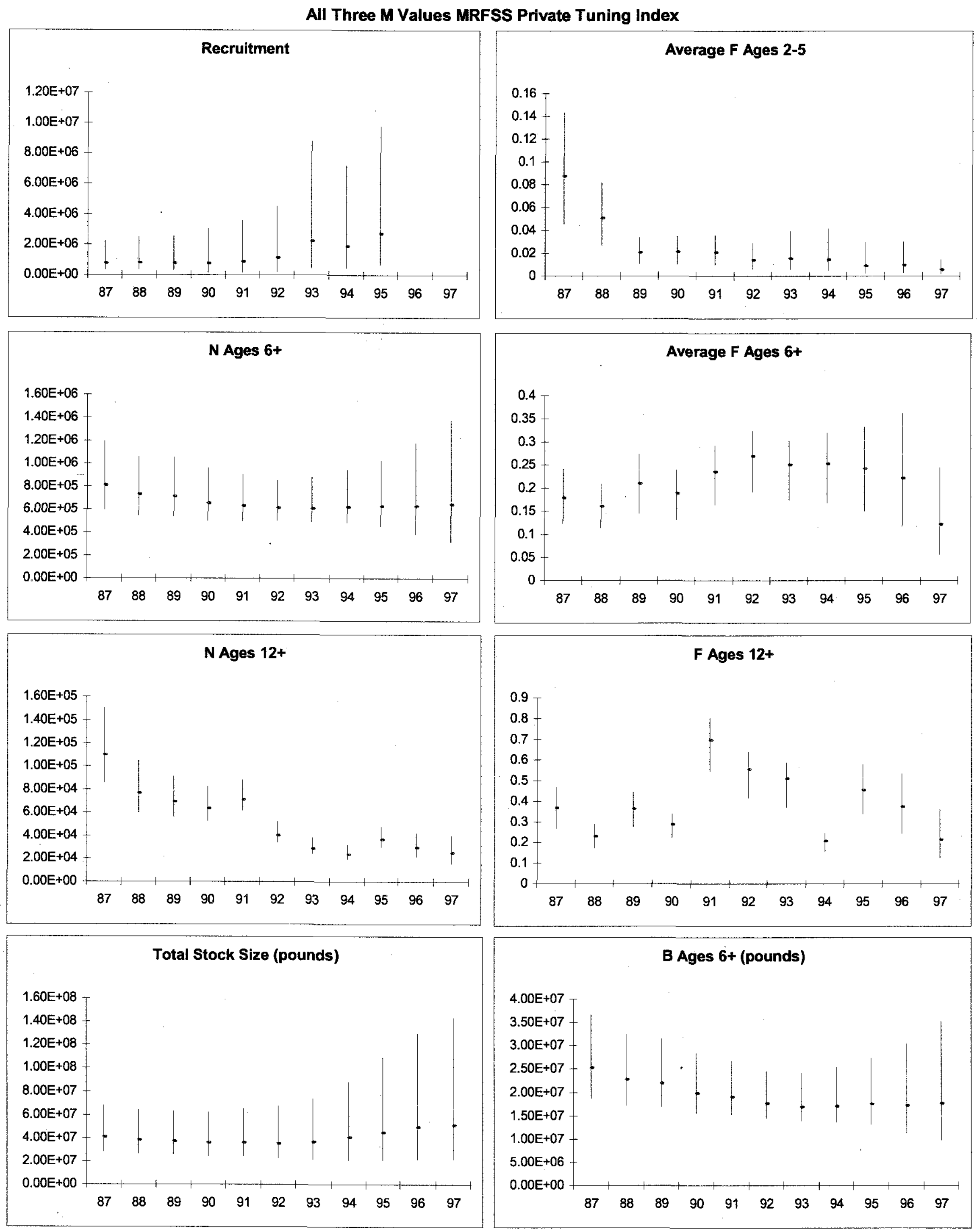


Figure 6. *Medians and 80% confidence intervals for the 1200 Monte Carlo/bootstrap runs (400 runs by 3 M values)when only the MRFSS Private index is used to tune the VPA.*

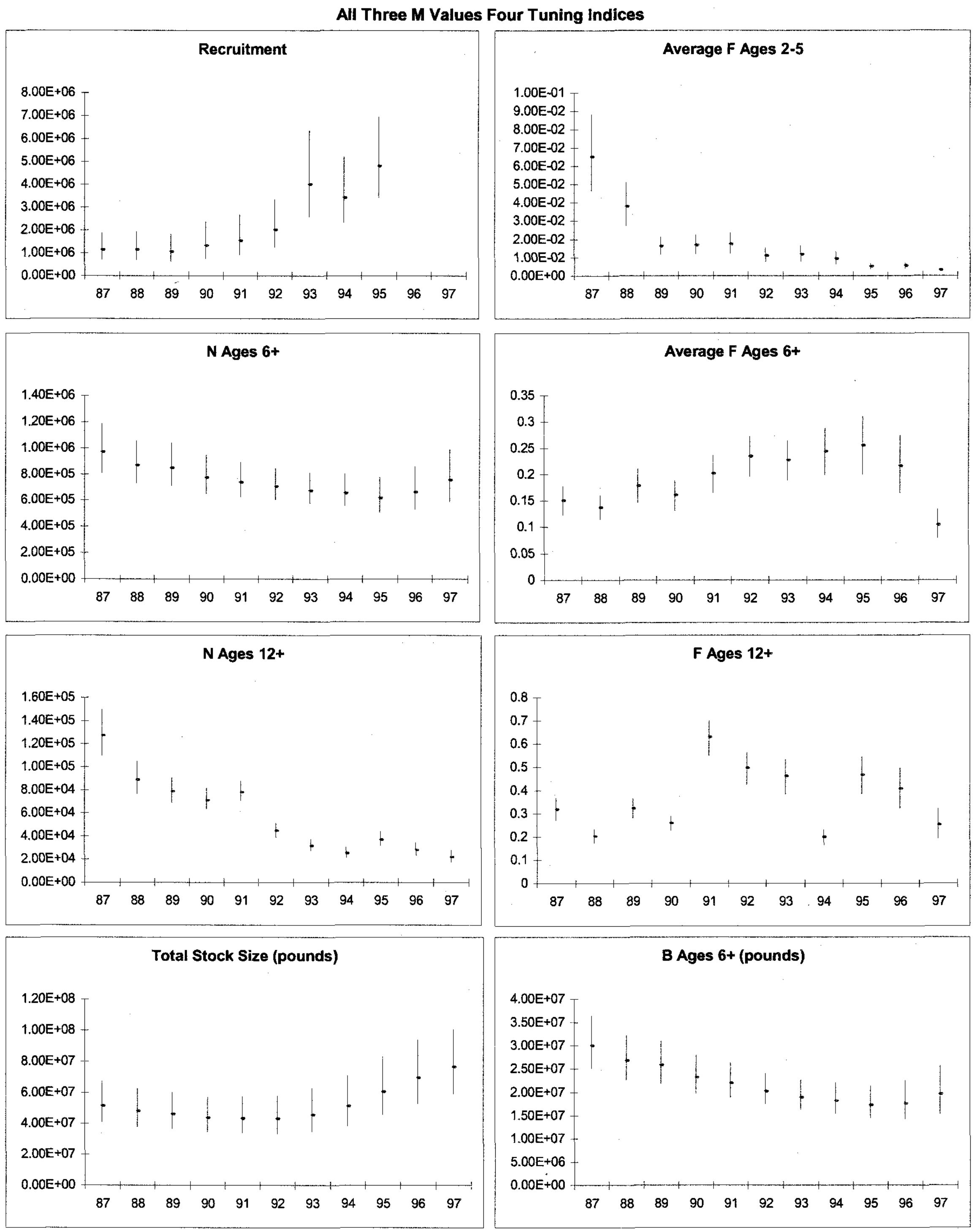


***Figure** 7. Medians and 80% confidence intervals for the 1200 Monte Carlo/bootstrap runs (400 runs by 3 M values) when four indices (Handline, MRFSS Charter, Headboat and Tagging) are used to tune the VPA.*

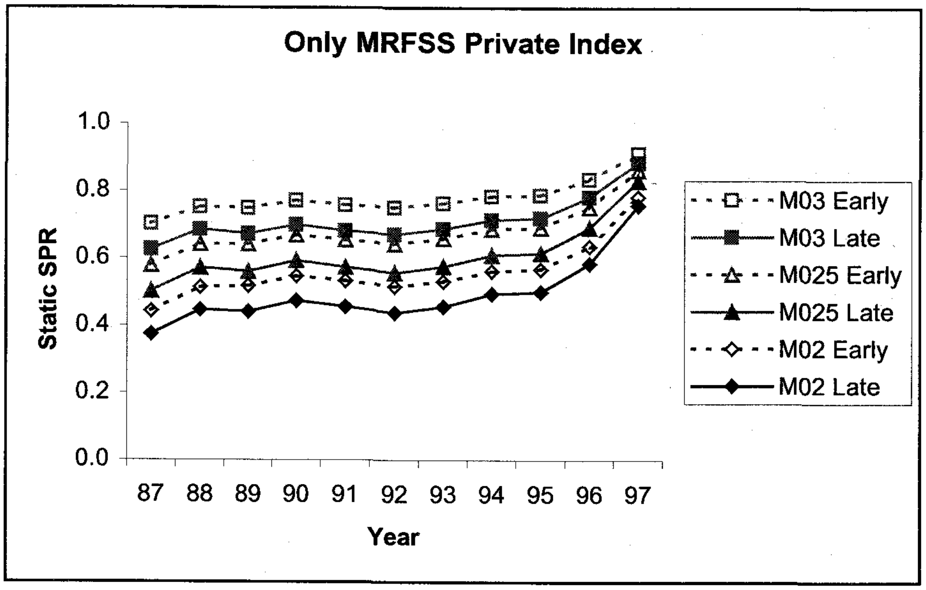


Figure 12. Median spawning potential ratios by year for three levels of M and two maturity schedules when only the MRFSS Private index is used to tune the VPA.

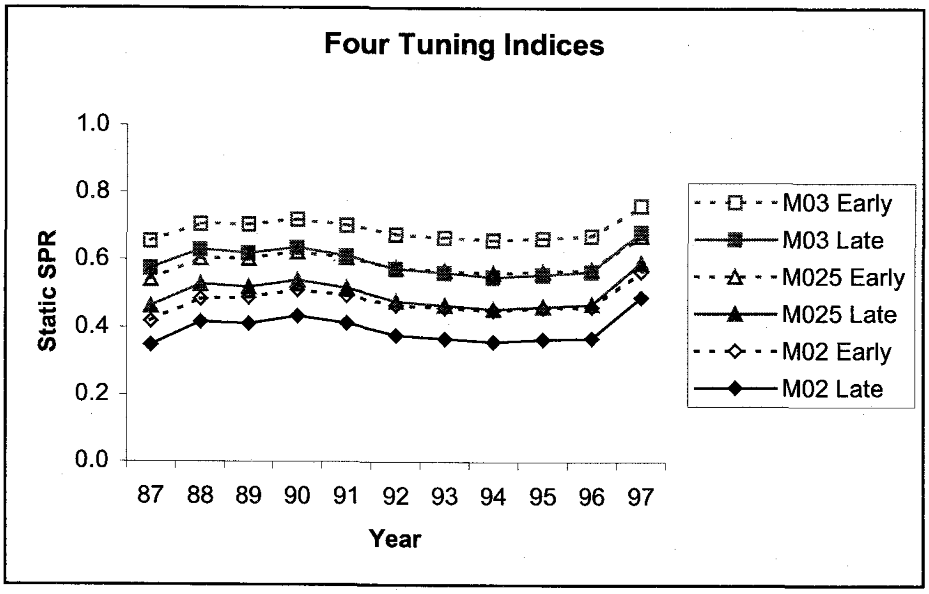


Figure 13. Median spawning potential ratios by year for three levels of M and two maturity schedules when four indices (Handline, MRFSS Charter, Headboat and Tagging) are used to tune the VPA.

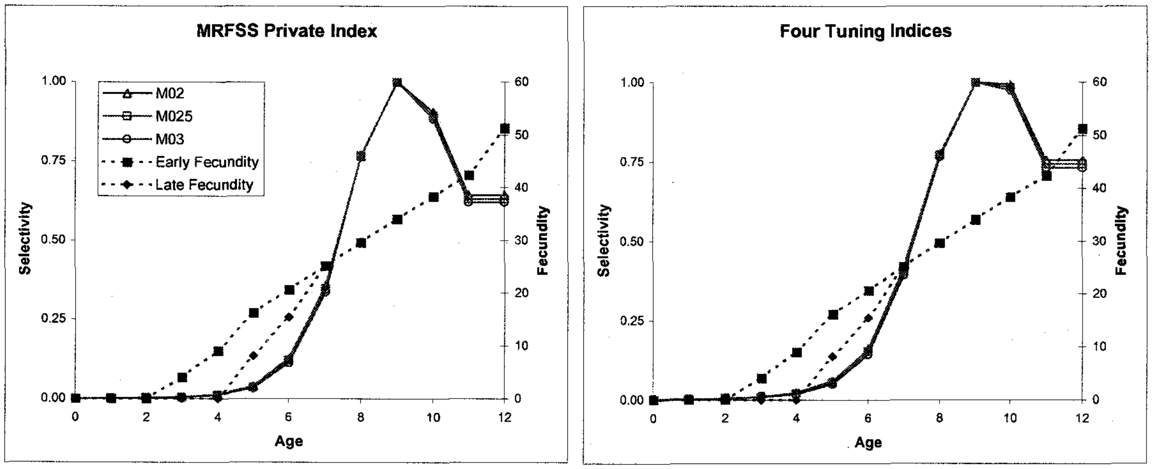


***Figure 14**. Selectivity patterns used in projections plotted with fecundity at age using early and late maturity schedules for three levels of M and two sets of tuning indices.*

Early Maturity Schedule

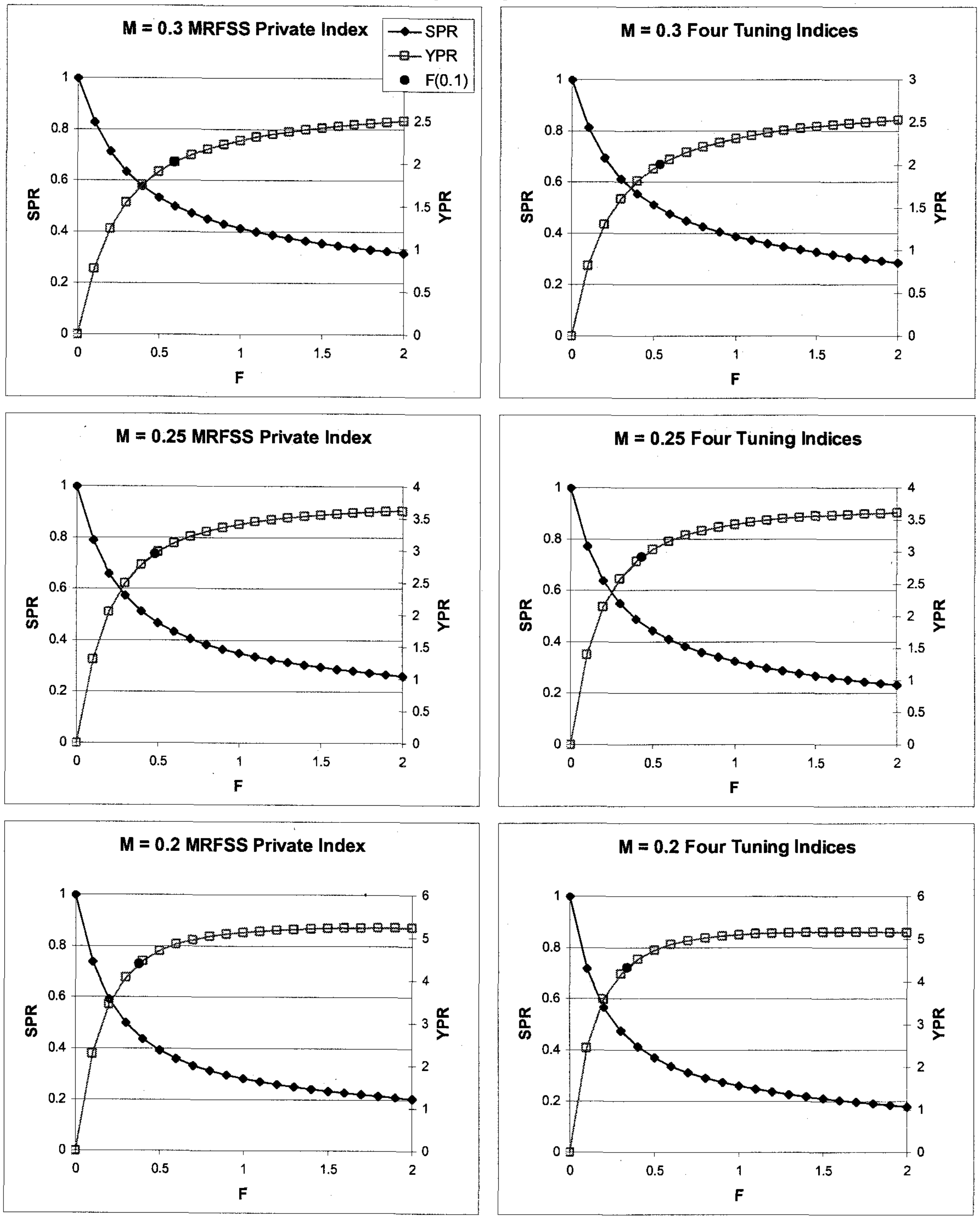


Figure 15. Equilibrium spawning potential ratio (SPR) and yield per recruit (YPR) using the average selectivity trend and early maturity schedule for three levels of M and two sets of tuning indices. The value of F(0.1) is also plotted for reference.

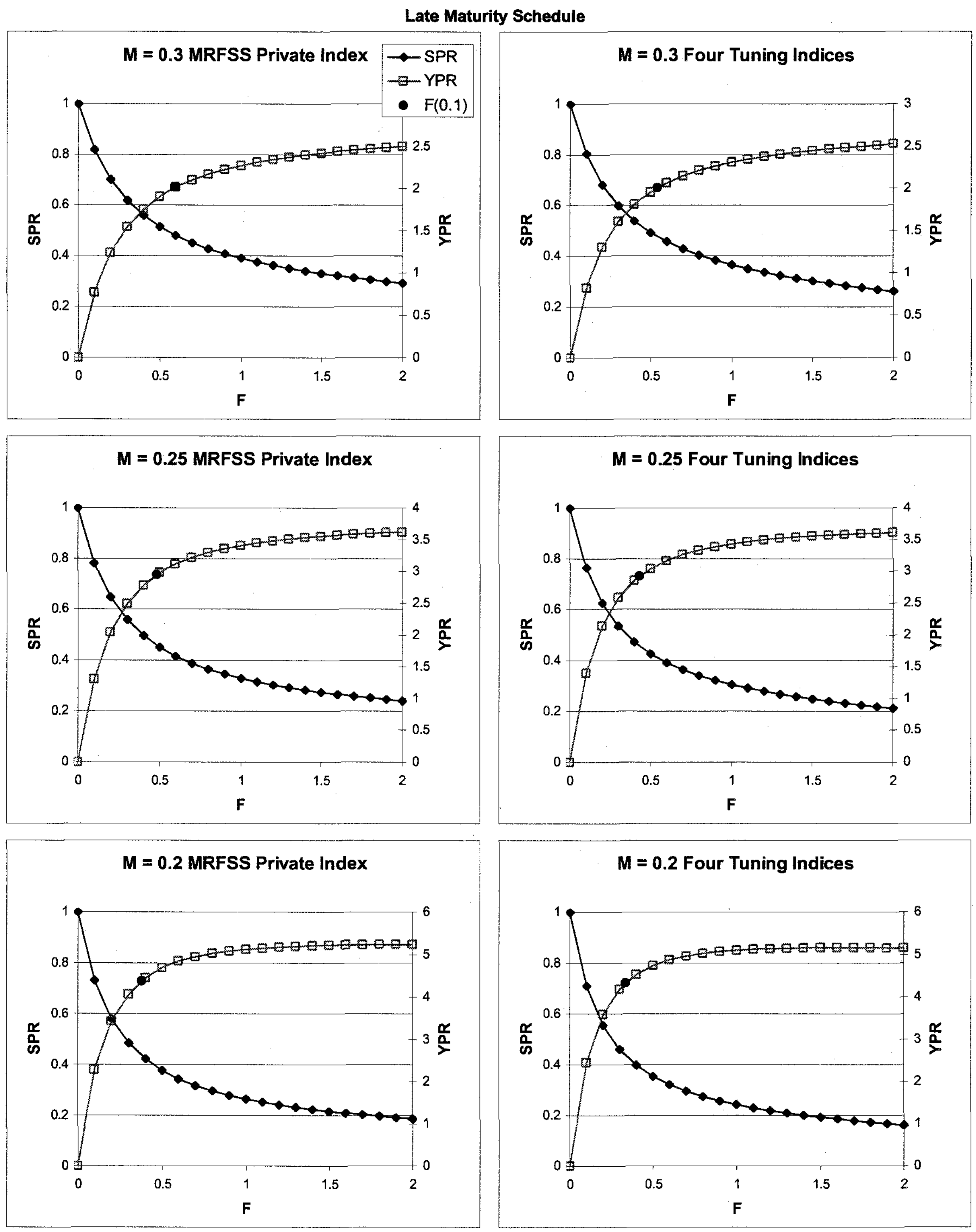


Figure 16. *Equilibrium spawning potential ratio (SPR) and yield per recruit (YPR) using the average selectivity trend and late maturity schedule for three levels of M and two sets of tuning indices. The value of F(0.1) is also plotted for reference.*

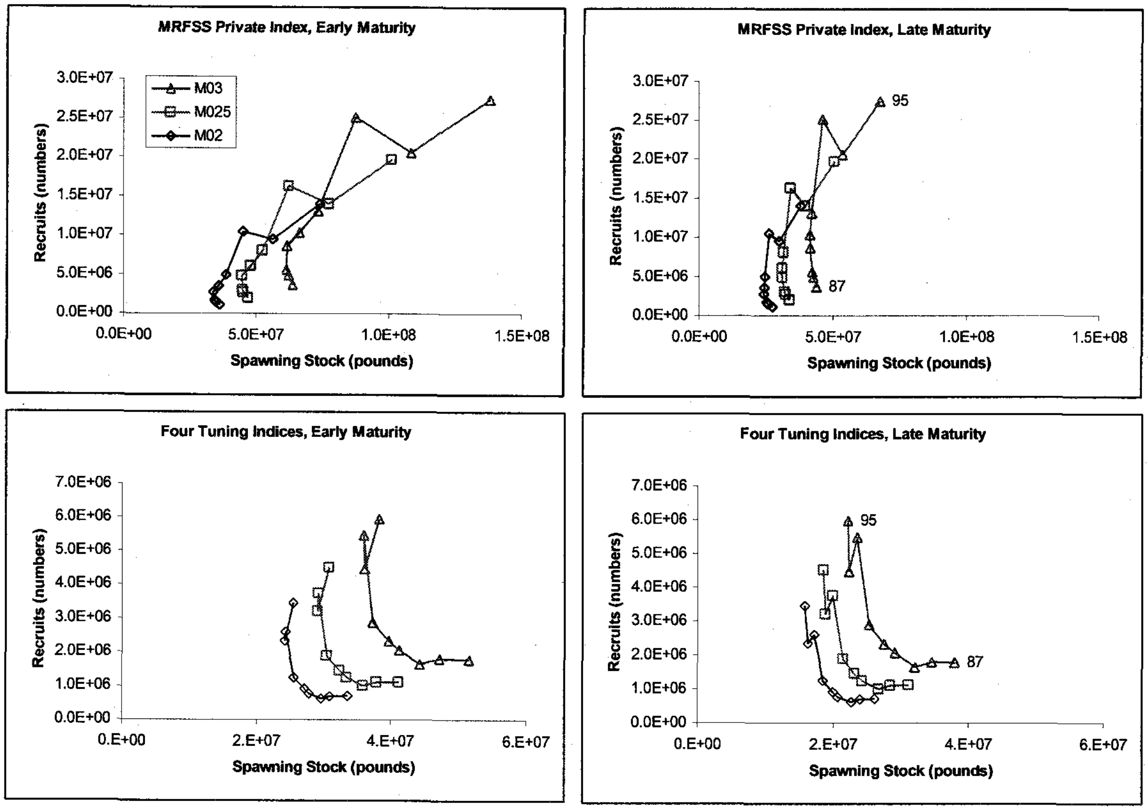


***Figure 17**. Spawning stock and recruitment estimates from the deterministic VPAs under two sets of tuning indices, three levels of M and two maturity schedules. Note the different axis scales between the results from the two sets of tuning indices.*

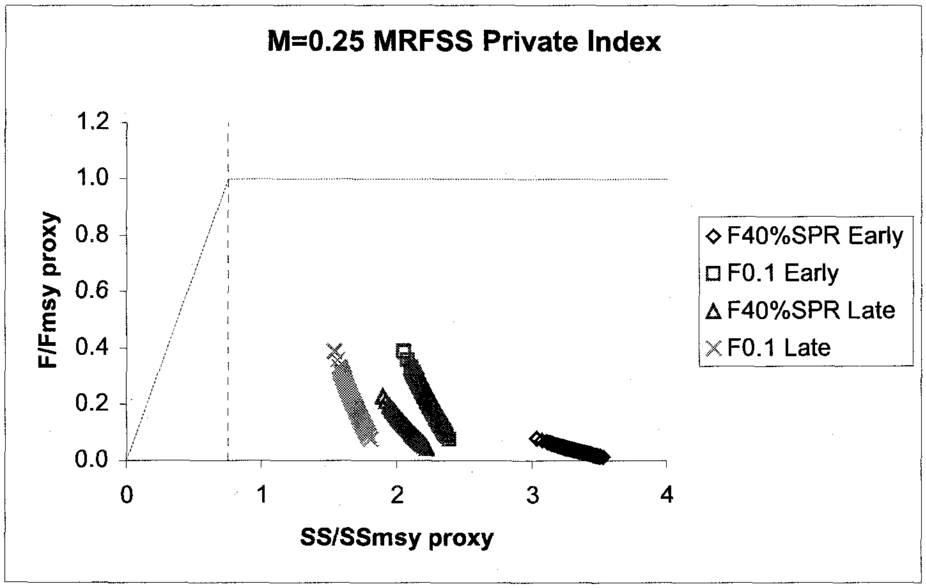


Figure 18. *Status of the stock when M=0.25 and only the MRFSS private index is used under the default control rule under two Fmsy proxies (F40%SPR and F0.1) and two maturity schedules (early and late). Each point represents one of the 400 Monte Carlo/bootstrap runs for that case. The solid line denotes the maximum fishing mortality threshold (MFMT), values above the line are undergoing overfishing. The dotted line denotes the minimum spawning stock threshold (MSST), values to the left of the line are overfished.*

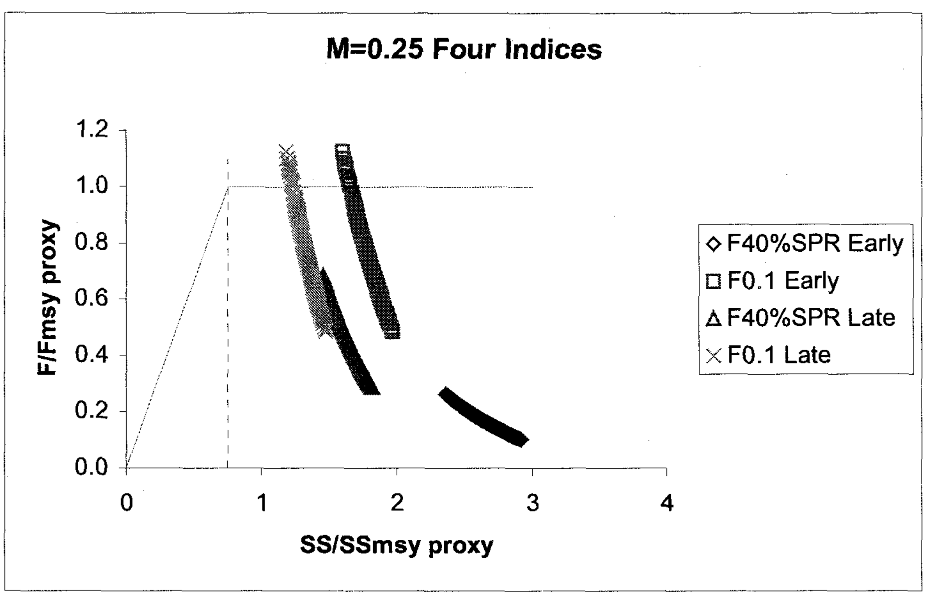


Figure 19. *Status of the stock when M=0.25 and four tuning indices are used (see Figure 18 legend for details).*

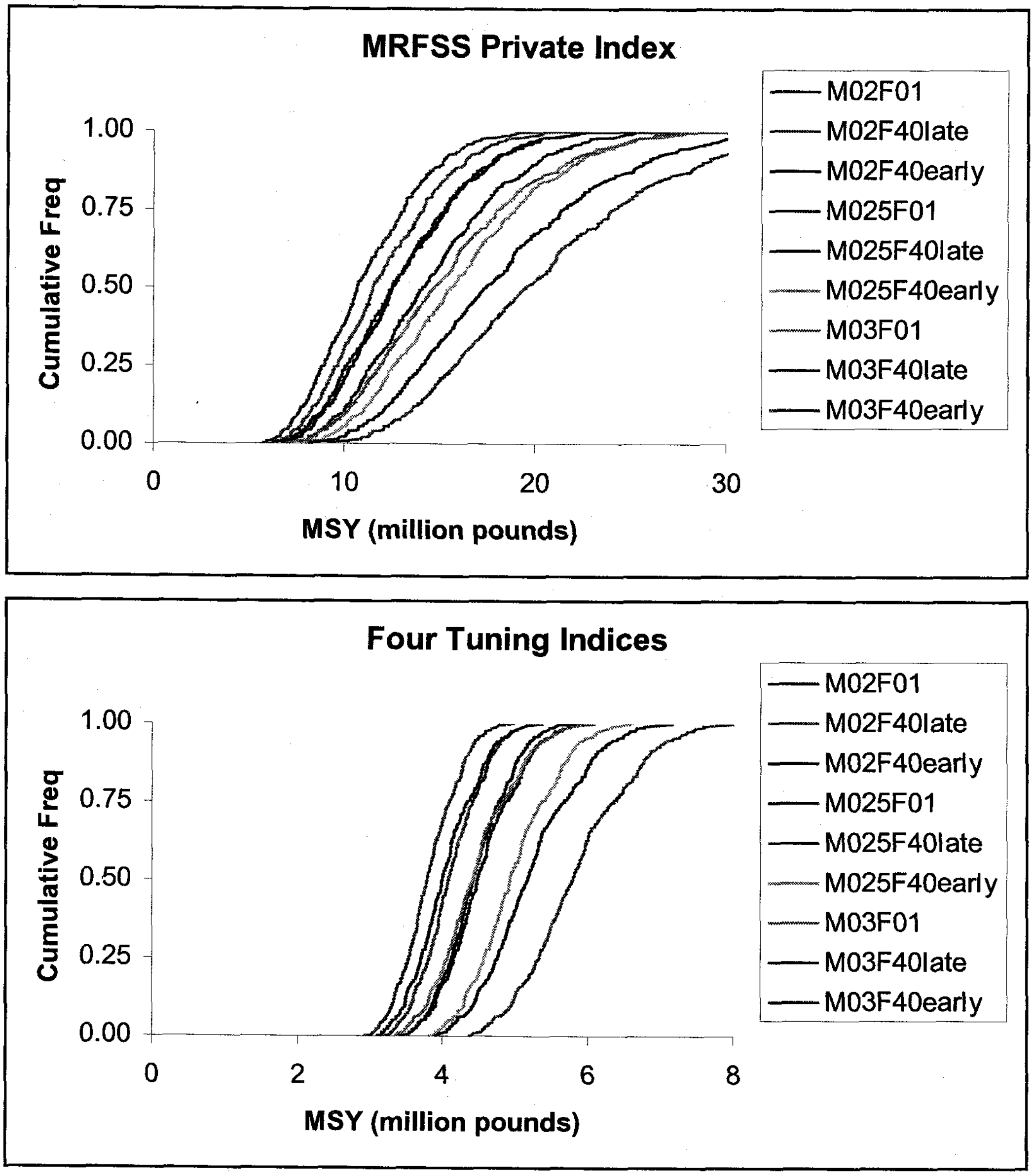


***Figure 20**. Cumulative frequency distributions for maximum sustainable yield (MSY) in millions of pounds for 18 combinations of tuning indices used, M, Fmsy proxy, and maturity schedule. Note the different x axis scales in the two plots.*