ASSESSMENT OF SOUTHEASTERN U.S. ATLANTIC WRECKFISH STOCK FOR FISHING YEARS 1988-1998

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INTRODUCTION

The material included in this report updates that provided in the January 1997 stock assessment report (Vaughan et al. 1997) and the January 1998 data summary report (Vaughan 1998) to the South Atlantic Fishery Management Council's (SAFMC) Snapper Grouper Assessment Group. Included are the latest summary of landings and length frequency data from the fishery for 1988 through 1998 fishing years, analyses of length at age data, application of virtual population analysis approaches (separable VPA and FADAPT) to the catch at age matrices, and analyses of yield per recruit (YPR) and percent spawning potential ratio (static SPR). New aging data for wreckfish from samples collected during 1995-1998 were used to develop a catch matrix for that period.

CATCH AND SIZE FREQUENCY DATA

Commercial wreckfish landings (in whole weight) by fishing year (April 16 through April 15 of following year) are summarized in **Table 1**. Estimates of monthly and total landings in weight given in the 1992 Snapper Grouper Assessment Group Wreckfish Report were used for the **1988-1990** fishing years, and total landings in numbers were estimated using seasonal mean weight per fish from biological samples. Landings in weight and numbers, and effort in trips, days, and hours, for **1991-1998** are from the logbook data file (Hardy 1999). Landings are assumed complete for the 1998-1999 fishing year.

No fishing is presently permitted following January 14 of each year until the new fishing year begins on April 16. During 1990, the quota of 2 million pounds was reached and the fishery was closed at the end of August. During the last two years, wreckfish have only been landed in Florida and South Carolina.

Catch per effort (CPE) has been estimated from the logbook data file using three potential measures of effort (trips, days fishing, and hours fishing). Further, three ways of estimating these indices of CPE were considered (**Figure 1**). First, CPE for each measure was estimated from catch in numbers of fish for all vessels; and, secondly, from five vessels that were most active from 1991-1998 (referred to as 'Hi 5'). Only 3 of the 'Hi 5' vessels fished in 1998, and none of the remaining vessels. Thirdly, an Analysis of Variance (ANOVA) model (PROC GLM, General Linear Model) was used to develop annual estimates of CPE for the calibration process, restricted to data from the 'Hi 5' vessels. Model effects were fishing year, season nested within fishing year, vessel (nested within state), and the cross product of year and state. Model fits were all highly significant with r-squared values of 0.51 for trips, 0.55 for days, and 0.36 for hours.

Although a downward trend in catch per trip or catch per day is apparent, there is no suggestion of a downward trend in catch per hour. While direct estimates of catch per trip and catch per day seem to indicate an upturn in these indices in the most recent year or two, this trend was not indicated in the GLM CPE indices.

Commercial length data were obtained from the SEFSC TIP data file (Laura Bishop, NMFS Galveston Laboratory, and Joshua Bennett, NMFS Miami Laboratory) for Florida, Georgia, South Carolina, and North Carolina. Additional data from North Carolina were provided by Paul Phalen (NC Division of Marine Fisheries; Jan. 1991 through Jan. 1992).

Length frequency distributions are developed from biological samples of commercial landings in terms of total lengths in 1-inch increments. Historically, only minor differences are noted between the length frequency distributions developed for samples from Florida and South Carolina, since fishermen from these two states are fishing in the same general geographic area (Blake Plateau). Hence, samples from these states are pooled together. Length frequency distributions are developed by fishing year (1991-1998 in **Figure 2**). These length frequency distributions are used with annual age length keys to estimate the catch-at-age matrix (referred to simply as catch matrix). A comparison of the cumulative distribution of these annual length frequency distributions shows a flattening of the peak or modal value, with greater proportion of lengths in both tails of the distribution (**Figure 3**). Sampling for wreckfish lengths, from a sample size perspective, have been excellent with over 35% of the wreckfish landed in 1998 being measured for length (**Table 1**).

These biological samples are used to estimate mean lengths (total length in inches) and mean weights (whole weight in pounds calculated from length using a weight-length relation) of individual fish (summarized annually and seasonally in **Table 2**). Monthly estimates of mean weight of fish from the logbook data file are compared with those calculated from the biological samples (**Figure 4**). No trends are noted in these estimates between 1991 and the present.

AGE AND REPRODUCTION

Wreckfish otoliths and corresponding lengths and weights are available for years 1988-1992 (n = 730), and new aging for this analysis with fish collected during 1995-1998 (n = 116). We continue to use the following relationships estimated using the earlier data (1988-1992): (1) total length (TL) versus fork length (FL), (2) total or whole weight (TW) versus gutted weight (GW), and (3) whole weight versus total length. These equations are estimated as follows:

$$TL(mm) = 4.607 + 1.041\ FL(mm),\ n = 226,\ r^2 = 0.99, \quad (1)$$

$$TW(kg) = -0.367 + 1.141\ GW(kg),\ n = 223,\ r^2 = 0.98, \quad (2)$$

$$TW(kg) = \exp(-17.681+2.956\ ln(TL(mm))+0.5*0.009), \quad (3)$$

$$TW(lbs) = \exp(-\ 7.327+2.956\ ln(TL(in))+0.5*0.009), \quad (4)$$

$$n = 284,\ r^2 = 0.87.$$

Sectioned sagittal otoliths collected from wreckfish landed between 1995 and 1998 were aged by the two junior authors. Mean lengths per age are very different from this study compared with the previously reported. We feel that the assigned ages from this most recent set of otoliths have been more correctly determined than those assigned previously for several reasons. First, the aging lab has better equipment. Second, the readings, done independent of the 1988-92 set, were agreed upon by the two readers rather than one. Finally, recent aging was done after consultation with a researcher from New Zealand who has worked with a congeneric species for many years. He felt that our earlier samples were underaged. We do not feel that the difference in assigned ages from the two data sets is due to heavy fishing pressure causing a change in the growth rates of the wreckfish. We recommend that as many of the otoliths from the original aging study be reaged prior to the next stock assessment.

Using the newer aged data set from 1995-1998, estimates of the parameters were obtained for the von Bertalanffy growth equation:

$$L = L_\infty(1 - \exp(-K(t - t_0)), \quad (5)$$

where L is total length in millimeters and t is age in years. For each fish, only observed lengths at age adjusted for time of year collected was used (Vaughan and Burton 1994). Parameter estimates and standard errors are given as (n = 116 fish):

Parameter	Estimate	Standard Error
L_∞	1678.5 mm (66.1 in)	137.2 mm (5.4 in)
K	0.030 yr^{-1}	0.006 yr^{-1}
t_0	-13.32 yr	1.87 yr

The estimate for L_∞ is smaller than that given in our previous assessment (L_∞ = 1796.6 mm TL) and K is smaller (K = 0.044) (Vaughan et al. 1997). Estimates of total length and weight at age for these two curve fits for the von Bertalanffy growth equation are compared (**Figure 5**).

Annual age-length keys (**Table 3**) were needed for estimating catch in numbers at age from commercial landings and length frequency data. We continued to use an age plus group defined as 18 and older (18+), and 47 inches as a size plus group. The annual age-length key for 1990 was based on averaging the keys for 1989 and 1991. Because of sample size available with the new aging data, it was necessary to accumulate lengths in 2" intervals for the 1995-1998 key rather than 1" intervals for the earlier data set. Linear interpolation between the 1995-1998 age-length key and the 1991 age-length key was used to estimate age-length keys for 1992-1994.

Natural mortality is estimated from life history characteristics as suggested in Pauly (1979) and Hoenig (1983). Pauly's (1979) approach uses estimates of L_∞ (cm) and K (yr^{-1}) from the von Bertalanffy growth curve (Eq. 7) and mean temperature (T°C):

$$\log_{10} M = 0.0066 - 0.279 \log_{10} L_\infty + 0.6543 \log_{10} K + 0.4634 \log_{10} T. \quad (6)$$

Values for L_∞ and K (1988-1992: 179.7 cm and 0.044 yr^{-1}; and 1995-1998: 167.8 cm and 0.030 yr^{-1}) and mean estimated temperature for the Blake Plateau (provided earlier by Glenn Ulrich) for different months were used to obtain the following estimates of M:

Month	Temperature (°C)	M (yr^{-1}) 1988-1992	M (yr^{-1}) 1995-1998
August	13.2	0.10	0.08
September	15.2	0.11	0.09
October	8.4	0.08	0.07

Hoenig (1983) suggested the following relationship based on maximum age expected in the unfished stock (t_{max}):

$$ln\ M = 1.46 - 1.01\ ln\ t_{max}. \quad (7)$$

The maximum age was 31 years old in the early data set and 30 years old in the later data set, giving an estimate of M of about 0.13-0.14 yr^{-1}. Older ages (t_{max}) gave lower estimates of M; e.g., 0.12 yr^{-1} at 35 years and 0.10 yr^{-1} at 40 years. In addition to the preferred value of M equals 0.10, estimates of M equal 0.05 and 0.15 which bracket our expected M are also used in our assessment.

As in previous assessments (Vaughan et al. 1994, 1995, 1996, 1997), limited data were available for a wreckfish maturity schedule with one female wreckfish immature at about 620 mm TL (age 4). All other female wreckfish that were checked for maturity were at least 850 mm TL in length (age 8 and older) and found to be mature. Hence, a linear relation was used to approximate these data assuming 0% female wreckfish mature at age 4, 25% mature at age 5, 50% mature at age 6, 75% at age 7, and 100% mature at age 8 and older.

Data on wreckfish fecundity from David Wyanski (SC WMRD, Charleston) were fitted to a linear relationship between fecundity or number of ova (E) and female biomass or weight (W) to produce the following relationship (Vaughan et al. 1997):

$$E = -200109 + 53012\ W\ (lbs), \quad (8)$$

where n = 25, and $r^2 = 0.80$.

VIRTUAL POPULATION ANALYSIS

Application of the annual age-length keys (**Table 3**) to commercial landings and length frequency distributions allow estimation of catch in numbers at age (**Table 4**). As in past assessments (Vaughan et al. 1992, 1993, 1994, 1995, 1996, 1997), virtual population analysis (VPA) was initially conducted by means of **separable** VPA (SVPA, Doubleday 1976). This analysis assumes a single stock with all sources of man-induced mortality (e.g., fishery landings) represented in the catch at age matrix (this assumption was explored in Appendix A of Vaughan et al. (1995) relative to eastern North Atlantic information).

Parallel runs of SVPA were made with varying natural mortality, M, assumed as 0.05, 0.10 or 0.15 yr^{-1}. Starting F in 1998 was obtained from F = Z - M where Z was obtained from the catch curve analysis from the average of the 1980-1982 cohorts (mean Z for ages 12-17 equals 0.53 yr^{-1}). F for age 11 was equated to F at age 17 to reflect a flat-topped partial recruitment vector for all fully recruited ages (11-17). Trends in estimates of mean F over fully recruited ages (11-17) and total population biomass (ages 5-17) are summarized in **Figures 6 and 7**. Full F shows two peaks, one in 1989 when landings peaked, and a second higher peak in 1994. Meanwhile, total population biomass shows a steady decline to very low values in the most recent years.

A change in partial recruitment is noted between application of the SVPA program to the catch matrix for years 1994-1998 and 1995-1998. Model estimates of catch CV and SE dropped precipitously between these two runs (e.g., CV dropped from 47.8 to 33.4 for M = 0.10), suggesting that partial recruitment for the period between 1995-1998 had changed from the earlier years. It is believed that this change in pattern may be largely due to the new age-length key for the most recent years (1995-1998). Regardless, the SVPA is a less sophisticated modeling approach because a constant structure in partial recruitment is assumed and calibration indices are not used. However, an additional set of runs (for different values of M) was made on the catch matrix for 1996-1998 to obtain estimates of partial recruitment for inclusion in subsequent runs of the calibrated VPA described next.

Computer runs with the calibrated VPA known as ADAPT (Gavaris 1988, Conser and Powers 1990) were conducted using various fishery-dependent indices of catch per effort (CPE) for levels of M described earlier, using all three indices together and separately. The three indices of CPE are based on catch in numbers per trip, catch in numbers per day and catch in numbers per hour based on the wreckfish logbook data from five vessels ('Hi 5') participating significantly during 1991-1998 provided by

Linda Hardy (NMFS Beaufort Laboratory). Data based on these five vessels was used to reduce the tautological effect of using CPE from all vessels, data from which also contributed significantly to the development of the catch matrices.

The particular software used in this analysis was obtained from Dr. Victor Restrepo (U. Miami, CIMAS) and is referred to as 'FADAPT'. In all FADAPT runs, only CPE indices based on the GLM model were used for calibration purposes, either singly on together. These partial recruitment vectors were obtained from corresponding SVPA applied to 1996-1998 catch matrix, the time period that produced a minimum coefficient of variation (CV). All fishing mortality rates for earlier years are estimated by the program with the assumption proposed by Murphy (1965) that F in the oldest two ages are equal in the same fishing year.

Estimates of full F (mean F over ages 11-18) are compared for three levels of M and for runs with separate CPE indices for three measures of effort (**Figure 6**). Estimates of full F from FADAPT are considerably smaller than those from SVPA. Again, two peaks are noted (also in 1989 and 1994). With respect to runs with separate CPE indices, the catch per hour produces the lowest estimates in full F, while catch per trip and catch per day produce very similar estimates in full F. FADAPT was allowed to estimate the appropriate weighting among indices when all three were used together. This weighting was typically 50% for catch per day, 35% for catch per trip, and 15% for catch per hour.

The pattern in total population biomass (ages 5-18) was also developed from FADAPT for three levels of M and for runs with individual CPE indices (**Figure 7**). The pattern starts off like the SVPA with declining population biomass until about 1994-1995, when the population biomass increases. The greatest increase in population biomass is noted with the FADAPT run based solely on catch per hour. The remaining runs suggest that recent population biomass is at 1/3 to 1/2 the population biomass available in 1988-1989.

Two additional FADAPT runs were made using M = 0.1 and combined CPE indices, but reducing the catch matrix to 1988-1996 and 1988-1997 to consider possibly retrospective bias (**Figures 6 and 7**). The limited retrospective runs that consider full F seem to suggest that initial estimates in the most recent year may be slightly underestimated. The retrospective bias in total population biomass is less clear.

Mean conditions are compared among the FADAPT runs for the period 1995-1997 (1998 was deleted for retrospective considerations) (**Table 5**). Mean F for this period is summarized for ages 5-10 separately and for the average over ages 11-18 (full F). For comparison the estimate of full F for 1998 is also

included in this table.

Estimates of F summarized in **Table 5** were used in estimating yield per recruit (Y/R) based on Ricker's approach for different assumed values of M (0.05, 0.10 and 0.15 yr^{-1}, respectively). Additionally, these fishing mortality estimates were combined with proportion of females (50%) and an age-specific maturity schedule to estimate percent maximum spawning potential (%MSP or static SPR) (Gabriel et al. 1989). Static SPR, based on female biomass, was calculated using Eqs. 4 and 7 to model length and weight from age. Because fecundity was found to be approximately linear with female biomass, little difference was found between estimates of static SPR based on female biomass and egg production, the latter is emphasized in **Table 5** and only used in **Figure 8 and 9.**

Static SPR is stable over 1989-1998 from the SVPA analyses, while it is seen to improve in recent years in the FADAPT analyses, with static SPR based on the FADAPT run with catch per hour showing the best conditions for the stock (**Figure 8**). For the period 1995-1997, the only FADAPT run that produces an estimate of static SPR below 30% is with M = 0.05 (**Table 5**).

Corresponding plots of Y/R and %MSP are compared for the mean F estimated for 1996 based on separable VPA from the seasonal catch matrix (USA - Blake Plateau) with M = 0.05, 0.10, and 0.15 yr^{-1} (**Figure 9**). A summary of traditional biological reference points (BRP) from Y/R and static SPR analyses (based on egg production) are summarized in **Table 5** and compared to the current estimate of fully recruited F (ages 11-18) from the FADAPT analyses. Lowest values of current F are associated with FADAPT tuned to catch-per-hour, and highest estimates with SVPA. Estimates for F_{max} varies between 0.19 for M = 0.05 and values that exceed 4.5 times full F for the period 1995-1997 for the other FADAPT runs. Meanwhile, $F_{0.1}$ ranges from 0.1 for M = 0.5 to about 0.23 for M = 0.15, with 0.14-0.15 estimated for runs with M = 0.1. Estimated values for F_{30} (30% static SPR) seem to be intermediate between $F_{0.1}$ and F_{max} with values of about 0.35 for M = 0.10.

SUMMARY

The results of the FADAPT VPA analysis are preferred over those from the SVPA analysis. The FADAPT allows calibration with the fishery-dependent indices of abundance and does not require constant partial recruitment over the study time period. For FADAPT, the range of estimates of static SPR between 25 and 63% for the period 1995-1997 fishing years (**Table 5**), and higher values for 1998, suggests at worst only minor concerns of recruitment overfishing, because most of the recent estimates are above the value of 30% used to define recruitment overfishing by SAFMC. Only the FADAPT run with M = 0.05 produces a value of static SPR less than 30% in recent years. With the apparent improvement in total population biomass (**Figure 7**) and improving values in static SPR (**Figure 8**), the stock appears to be recovering from any damage due to the extremely large landings in 1989. In reference to other potential biological reference points, recent estimates of full F are near, but slightly above values for $F_{0.1}$. However, at this time it does not appear necessary to raise the static SPR definition of overfishing of 30% as long as this value is viewed as a threshold, and not a target.

No general trend in mean weight of wreckfish was noted from 1991 through 1998, either calculated from logbook data or from biological sample data **(Figure 4)**. Because recent landings have been well below the 2 million pound quota, it is necessary to question assumptions built into the models used in this analysis. The primary assumption for all VPA models is that the catch matrix represents all losses due to man's activity. There is evidence that wreckfish are fished upon in other area(s) for which landings and size data are not available. Specific data supporting this concern are the occurrence of various small hooks (dissimilar to those used by U.S. fisheries) on wreckfish caught on the Blake Plateau. This assumption was addressed in a limited fashion in Vaughan et al. (1995, Appendix A). Those analyses, based on data through 1994, suggested that, if wreckfish landed from the total North Atlantic are treated as a single stock, then values of static SPR were generally below 20% (for 1990-1994: 8-14% for M = 0.11 yr^{-1} and 13-22% for M = 0.15 yr^{-1}) and were indicative of recruitment overfishing. However, until more data is available for the entire stock (especially from the eastern North Atlantic areas defined as FAO 27 and 37), the analyses presented in this report should be viewed with some degree of skepticism, although they are based on "best available data".

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Table 1. Wreckfish landings in pounds and numbers, sample size for length frequency, and percent of fish landed that were sampled.

Year	Landings		Number Sampled	Percent Sampled
	Pounds	Number		
1988	617,662	16,137	498	3.1
1989	4,161,965	107,389	308	0.2
1990	1,970,299	58,621	1267	2.2
1991	1,926,088	57,704	10381	18.0
1992	1,270,557	38,205	6394	16.7
1993	1,144,726	33,803	7231	21.4
1994	1,203,265	35,770	4100	11.5
1995	644,997	19,256	4579	24.8
1996	396,868	11,657	2605	22.3
1997	249,715	7,299	1197	16.4
1998	210,800	6,172	2089	35.4

Table 2. Wreckfish mean lengths and weights from biological sampling of commercial landings by fishing year 1988-1998 and season for 1992-1998 [Early: Apr-Jun, Middle: Jul-Sep, and Late: Oct-Jan]. Note that weight is calculated from fish length using Eq. 4.

Fishing Year	Season	Sample Size	Total Length (in) TL	SD	Whole Weight (lbs) W	SD
1988		498	38.9	4.0	34.1	11.6
1989		308	38.3	3.1	32.1	8.1
1990		1267	38.7	3.0	33.3	7.9
1991		10381	38.8	3.1	33.4	8.1
1992		6394	38.3	2.9	32.2	7.4
1993		7231	38.6	3.1	32.9	8.2
1994		4100	38.2	2.9	31.8	7.4
1995		4579	37.9	2.9	31.1	7.2
1996		2605	38.3	3.3	32.4	8.0
1997		1197	37.7	4.0	31.1	9.4
1998		2089	37.8	4.6	31.8	11.3
1992	E	744	38.3	3.0	32.1	7.7
	M	2156	38.4	2.9	32.5	7.5
	L	3494	38.3	2.9	32.1	7.3
1993	E	2839	38.3	2.9	32.1	7.3
	M	2048	38.4	2.8	32.4	7.3
	L	2344	39.0	3.5	34.2	9.6
1994	E	1564	38.3	2.9	32.3	7.5
	M	859	38.5	2.9	32.5	7.1
	L	1677	37.9	2.9	31.1	7.3
1995	E	2353	37.8	2.9	31.0	7.2
	M	1055	37.6	2.7	30.4	6.8
	L	1171	38.2	3.0	31.8	7.4
1996	E	1053	38.2	3.3	32.1	8.0
	M	542	38.7	3.7	33.4	9.5
	L	1010	38.3	3.0	32.2	7.4
1997	E	417	37.7	4.2	31.2	10.2
	M	240	37.7	3.8	31.0	8.7
	L	540	37.8	3.6	31.2	8.8
1998	E	553	37.4	5.0	31.1	12.0
	M	756	38.1	4.6	32.5	11.5
	L	780	37.8	4.5	31.6	10.8

Table 3. Age-length keys for wreckfish based on total length (1 inch increments) and ages 5 through 18+.

TL (in)	Age (yr) 5-	6	7	8	9	10	11	12	13	14	15	16	17	18+
							1988 Annual Age-Length Key (n = 109)							
30-	0.643	0.286	0.071	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0	0.588	0.412	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	0.0	0.0	0.542	0.417	0.041	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	0.0	0.0	0.414	0.483	0.103	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	0.0	0.0	0.063	0.531	0.406	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	0.0	0.0	0.0	0.333	0.467	0.200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	0.0	0.0	0.0	0.200	0.600	0.200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0	0.0	0.0	0.0	0.600	0.333	0.067	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	0.0	0.0	0.0	0.0	0.067	0.533	0.333	0.067	0.0	0.0	0.0	0.0	0.0	0.0
39	0.0	0.0	0.0	0.0	0.0	0.556	0.111	0.333	0.0	0.0	0.0	0.0	0.0	0.0
40	0.0	0.0	0.0	0.0	0.0	0.0	0.437	0.438	0.125	0.0	0.0	0.0	0.0	0.0
41	0.0	0.0	0.0	0.0	0.0	0.0	0.300	0.500	0.200	0.0	0.0	0.0	0.0	0.0
42	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.108	0.406	0.378	0.108	0.0	0.0	0.0
43	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.237	0.237	0.395	0.131	0.0	0.0
44	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.100	0.300	0.150	0.200	0.250	0.0
45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.056	0.222	0.111	0.389	0.111	0.111
46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.333	0.250	0.167	0.250
47+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0

Table 3. (cont.)

TL (in)	Age (yr) 5-	6	7	8	9	10	11	12	13	14	15	16	17	18+
1989 Annual Age-Length Key (n = 314)														
30-	0.643	0.286	0.071	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0	0.588	0.412	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	0.0	0.0	0.542	0.417	0.041	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	0.0	0.0	0.414	0.483	0.103	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	0.0	0.0	0.077	0.538	0.385	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	0.0	0.0	0.0	0.136	0.546	0.318	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	0.0	0.0	0.0	0.036	0.428	0.500	0.036	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0	0.0	0.0	0.029	0.177	0.588	0.206	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	0.0	0.0	0.0	0.0	0.179	0.571	0.214	0.036	0.0	0.0	0.0	0.0	0.0	0.0
39	0.0	0.0	0.0	0.0	0.182	0.318	0.295	0.205	0.0	0.0	0.0	0.0	0.0	0.0
40	0.0	0.0	0.0	0.0	0.0	0.146	0.479	0.333	0.042	0.0	0.0	0.0	0.0	0.0
41	0.0	0.0	0.0	0.0	0.0	0.0	0.250	0.464	0.250	0.036	0.0	0.0	0.0	0.0
42	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.074	0.370	0.445	0.111	0.0	0.0	0.0
43	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.384	0.385	0.231	0.0	0.0	0.0
44	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.100	0.300	0.150	0.200	0.250	0.0
45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.056	0.222	0.111	0.389	0.111	0.111
46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.333	0.250	0.167	0.250
47+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0

Table 3. (cont.)

TL (in)	Age (yr) 5-	6	7	8	9	10	11	12	13	14	15	16	17	18+
1990 Annual Age-Length Key (Mean of 1989 and 1991 Keys)														
30-	0.643	0.286	0.071	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0	0.544	0.456	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	0.0	0.0	0.549	0.403	0.048	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	0.0	0.0	0.357	0.517	0.126	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	0.0	0.0	0.038	0.519	0.443	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	0.0	0.0	0.0	0.287	0.492	0.221	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	0.0	0.0	0.0	0.097	0.451	0.408	0.044	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0	0.0	0.0	0.014	0.208	0.556	0.222	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	0.0	0.0	0.0	0.009	0.167	0.488	0.251	0.085	0.0	0.0	0.0	0.0	0.0	0.0
39	0.0	0.0	0.0	0.0	0.091	0.254	0.410	0.245	0.0	0.0	0.0	0.0	0.0	0.0
40	0.0	0.0	0.0	0.0	0.0	0.198	0.511	0.270	0.021	0.0	0.0	0.0	0.0	0.0
41	0.0	0.0	0.0	0.0	0.0	0.0	0.256	0.470	0.244	0.030	0.0	0.0	0.0	0.0
42	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.091	0.388	0.412	0.109	0.0	0.0	0.0
43	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.311	0.311	0.313	0.065	0.0	0.0
44	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.100	0.300	0.150	0.200	0.250	0.0
45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.056	0.222	0.111	0.389	0.111	0.111
46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.333	0.250	0.167	0.250
47+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0

Table 3. (cont.)

TL (in)	Age (yr) 5-	6	7	8	9	10	11	12	13	14	15	16	17	18+
						1991 Annual Age-Length Key (n = 307)								
30-	0.643	0.286	0.071	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0	0.500	0.500	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	0.0	0.0	0.555	0.389	0.056	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	0.0	0.0	0.300	0.550	0.150	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	0.0	0.0	0.0	0.500	0.500	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	0.0	0.0	0.0	0.437	0.438	0.125	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	0.0	0.0	0.0	0.158	0.474	0.316	0.052	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0	0.0	0.0	0.0	0.238	0.524	0.238	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	0.0	0.0	0.0	0.019	0.154	0.404	0.288	0.135	0.0	0.0	0.0	0.0	0.0	0.0
39	0.0	0.0	0.0	0.0	0.0	0.190	0.524	0.286	0.0	0.0	0.0	0.0	0.0	0.0
40	0.0	0.0	0.0	0.0	0.0	0.250	0.542	0.208	0.0	0.0	0.0	0.0	0.0	0.0
41	0.0	0.0	0.0	0.0	0.0	0.0	0.262	0.476	0.238	0.024	0.0	0.0	0.0	0.0
42	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.108	0.406	0.378	0.108	0.0	0.0	0.0
43	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.237	0.237	0.395	0.131	0.0	0.0
44	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.100	0.300	0.150	0.200	0.250	0.0
45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.056	0.222	0.111	0.389	0.111	0.111
46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.333	0.250	0.167	0.250
47+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0

Table 3. (cont.)

TL (in)	Age (yr) 5-	6	7	8	9	10	11	12	13	14	15	16	17	18+
1992 Annual Age-Length Key (Linear interpolation between 1991 and 1995)														
30-	0.636	0.234	0.111	0.019	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0	0.375	0.375	0.111	0.111	0.028	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	0.0	0.0	0.416	0.403	0.153	0.028	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	0.0	0.0	0.225	0.413	0.113	0.083	0.083	0.083	0.0	0.0	0.0	0.0	0.0	0.0
34	0.0	0.0	0.0	0.375	0.375	0.083	0.083	0.083	0.0	0.0	0.0	0.0	0.0	0.0
35	0.0	0.0	0.0	0.328	0.329	0.135	0.055	0.055	0.055	0.028	0.014	0.0	0.0	0.0
36	0.0	0.0	0.0	0.119	0.355	0.279	0.095	0.055	0.055	0.028	0.014	0.0	0.0	0.0
37	0.0	0.0	0.0	0.0	0.179	0.393	0.202	0.012	0.024	0.059	0.048	0.047	0.024	0.012
38	0.0	0.0	0.0	0.014	0.115	0.303	0.240	0.113	0.024	0.059	0.048	0.047	0.024	0.012
39	0.0	0.0	0.0	0.0	0.0	0.143	0.393	0.215	0.021	0.021	0.021	0.021	0.042	0.125
40	0.0	0.0	0.0	0.0	0.0	0.187	0.407	0.156	0.021	0.021	0.021	0.021	0.042	0.125
41	0.0	0.0	0.0	0.0	0.0	0.0	0.197	0.357	0.179	0.018	0.0	0.0	0.018	0.232
42	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.081	0.305	0.283	0.081	0.0	0.018	0.232
43	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.178	0.178	0.296	0.098	0.0	0.250
44	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.075	0.225	0.113	0.150	0.187	0.250
45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.042	0.167	0.083	0.292	0.083	0.333
46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.250	0.187	0.125	0.437
47+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0

Table 3. (cont.)

TL (in)	Age (yr) 5-	6	7	8	9	10	11	12	13	14	15	16	17	18+
1993 Annual Age-Length Key (Linear interpolation between 1991 and 1995)														
30-	0.629	0.181	0.151	0.039	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0	0.250	0.250	0.222	0.223	0.055	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	0.0	0.0	0.277	0.417	0.251	0.055	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	0.0	0.0	0.150	0.275	0.075	0.167	0.167	0.167	0.0	0.0	0.0	0.0	0.0	0.0
34	0.0	0.0	0.0	0.250	0.250	0.167	0.167	0.167	0.0	0.0	0.0	0.0	0.0	0.0
35	0.0	0.0	0.0	0.219	0.219	0.146	0.111	0.111	0.111	0.055	0.028	0.0	0.0	0.0
36	0.0	0.0	0.0	0.079	0.237	0.241	0.137	0.111	0.111	0.055	0.028	0.0	0.0	0.0
37	0.0	0.0	0.0	0.0	0.119	0.262	0.167	0.024	0.047	0.119	0.095	0.095	0.047	0.024
38	0.0	0.0	0.0	0.009	0.077	0.202	0.191	0.091	0.047	0.119	0.095	0.095	0.047	0.024
39	0.0	0.0	0.0	0.0	0.0	0.095	0.262	0.143	0.041	0.041	0.041	0.042	0.083	0.250
40	0.0	0.0	0.0	0.0	0.0	0.125	0.271	0.104	0.041	0.041	0.041	0.042	0.083	0.250
41	0.0	0.0	0.0	0.0	0.0	0.0	0.131	0.238	0.119	0.012	0.0	0.0	0.355	0.465
42	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.054	0.203	0.189	0.054	0.0	0.355	0.465
43	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.119	0.119	0.197	0.065	0.0	0.500
44	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.050	0.150	0.075	0.100	0.125	0.500
45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.028	0.111	0.055	0.195	0.055	0.555
46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.167	0.125	0.083	0.625
47+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0

Table 3. (cont.)

TL (in)	Age (yr) 5-	6	7	8	9	10	11	12	13	14	15	16	17	18+
1994 Annual Age-Length Key (Linear interpolation between 1991 and 1995)														
30-	0.622	0.129	0.191	0.058	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0	0.125	0.125	0.333	0.334	0.083	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	0.0	0.0	0.139	0.430	0.348	0.083	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	0.0	0.0	0.075	0.137	0.037	0.250	0.251	0.250	0.0	0.0	0.0	0.0	0.0	0.0
34	0.0	0.0	0.0	0.125	0.125	0.250	0.251	0.250	0.0	0.0	0.0	0.0	0.0	0.0
35	0.0	0.0	0.0	0.109	0.109	0.157	0.167	0.167	0.167	0.083	0.042	0.0	0.0	0.0
36	0.0	0.0	0.0	0.039	0.119	0.204	0.179	0.167	0.167	0.083	0.042	0.0	0.0	0.0
37	0.0	0.0	0.0	0.0	0.059	0.131	0.131	0.036	0.071	0.179	0.143	0.143	0.071	0.036
38	0.0	0.0	0.0	0.005	0.039	0.101	0.143	0.070	0.071	0.179	0.143	0.143	0.071	0.036
39	0.0	0.0	0.0	0.0	0.0	0.047	0.131	0.071	0.062	0.062	0.062	0.063	0.125	0.375
40	0.0	0.0	0.0	0.0	0.0	0.063	0.135	0.052	0.062	0.062	0.062	0.063	0.125	0.375
41	0.0	0.0	0.0	0.0	0.0	0.0	0.065	0.119	0.059	0.006	0.0	0.0	0.053	0.697
42	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.027	0.101	0.095	0.027	0.0	0.053	0.697
43	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.059	0.059	0.099	0.033	0.0	0.750
44	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.025	0.075	0.037	0.050	0.063	0.750
45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.014	0.055	0.028	0.097	0.028	0.778
46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.083	0.063	0.042	0.813
47+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0

Table 3. (cont.)

TL (in)	Age (yr) 5-	6	7	8	9	10	11	12	13	14	15	16	17	18+
1995-1998 Annual Age-Length Key (n = 116)														
30-	0.615	0.077	0.231	0.077	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0	0.0	0.0	0.444	0.445	0.111	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	0.0	0.0	0.0	0.444	0.445	0.111	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	0.0	0.0	0.0	0.0	0.0	0.333	0.334	0.333	0.0	0.0	0.0	0.0	0.0	0.0
34	0.0	0.0	0.0	0.0	0.0	0.333	0.334	0.333	0.0	0.0	0.0	0.0	0.0	0.0
35	0.0	0.0	0.0	0.0	0.0	0.167	0.222	0.222	0.222	0.111	0.056	0.0	0.0	0.0
36	0.0	0.0	0.0	0.0	0.0	0.167	0.222	0.222	0.222	0.111	0.056	0.0	0.0	0.0
37	0.0	0.0	0.0	0.0	0.0	0.0	0.095	0.048	0.095	0.238	0.191	0.190	0.095	0.048
38	0.0	0.0	0.0	0.0	0.0	0.0	0.095	0.048	0.095	0.238	0.191	0.190	0.095	0.048
39	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.083	0.083	0.083	0.084	0.167	0.500
40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.083	0.083	0.083	0.084	0.167	0.500
41	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.071	0.929
42	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.071	0.929
43	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
44	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
47+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0

Table 4. Catch in numbers at age matrices based on annual age-length keys for wreckfish, 1988-1998.

	Fishing Year										
Age	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
5-	186	250	228	186	97	106	178	59	186	157	258
6	147	873	262	313	150	90	77	7	23	20	32
7	634	3979	1158	1170	688	375	264	22	70	59	97
8	1684	8688	4353	5187	3269	1895	1305	221	117	318	323
9	3562	27260	10174	8974	5195	3051	1924	214	93	299	291
10	3780	43087	16158	13313	7379	4886	3872	1457	636	560	441
11	2499	20456	11776	13563	7286	5305	4760	2256	1076	704	507
12	2364	9925	6338	6816	3910	3261	3319	1951	900	630	462
13	1083	4949	3058	2587	2044	2252	2811	1878	1019	526	361
14	672	4622	2476	2131	2025	2463	3341	2320	1334	609	397
15	406	1825	1342	1479	1408	1839	2574	1778	1050	466	304
16	252	841	688	855	1043	1513	2205	1533	939	395	254
17	148	565	406	495	883	1376	2049	1330	896	414	298
18+	675	2216	731	635	2828	5391	7091	4228	3318	2143	2147
Sum	18092	129536	59148	57704	38205	33803	35770	19256	11657	7300	6172

Table 5. Mean fishing mortality rates at age, percent spawning potential ratio (egg production), and biological reference points for wreckfish, based on the time period, 1995-1997 and fishing mortality rate estimated for the current year 1998.

Variable	M=0.05	M=0.10				M=0.15
	Combined	Combined	Catch/Trip	Catch/Day	Catch/Hour	Combined
F on Age 5	0.002	0.001	0.002	0.002	0.000	0.001
F on Age 6	0.000	0.000	0.000	0.000	0.000	0.000
F on Age 7	0.002	0.002	0.002	0.002	0.001	0.001
F on Age 8	0.019	0.014	0.014	0.018	0.005	0.009
F on Age 9	0.025	0.019	0.020	0.024	0.007	0.013
F on Age 10	0.129	0.099	0.106	0.123	0.039	0.072
F on Ages 11-18+	0.196	0.152	0.162	0.189	0.060	0.111
F on Ages 11-18+ in current year	0.094	0.076	0.082	0.101	0.025	0.058
Static SPR (Biomass)	26.5	45.8	44.5	41.7	66.0	65.4
Static SPR (Egg)	24.8	43.7	42.4	39.4	64.4	63.5
$F_{0.1}$	0.10	0.14	0.15	0.15	0.13	0.23
F_{max}	0.19	a	a	a	a	a
F_{30} (Eggs)	0.14	0.36	0.36	0.35	a	a

[a] Exceeds 4.5 times the full F (mean over ages 11-18+).

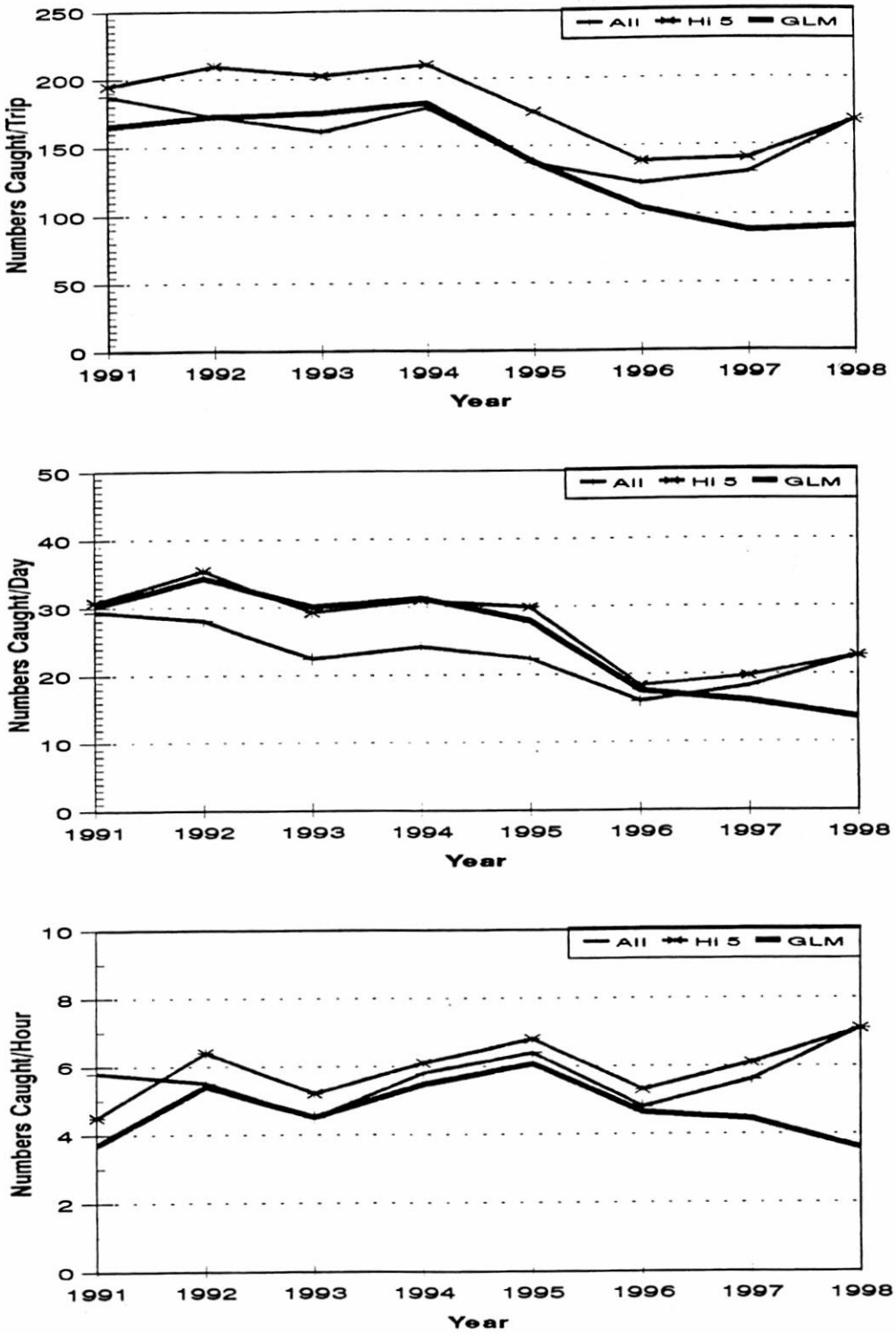

Figure 1. Wreckfish landings in numbers per unit of effort (trip, day, and hour) from logbooks, 1991-1998 fishing years. Comparisons in each panel are from all data, most active vessels ('Hi 5') and GLM applied to 'Hi 5' data.

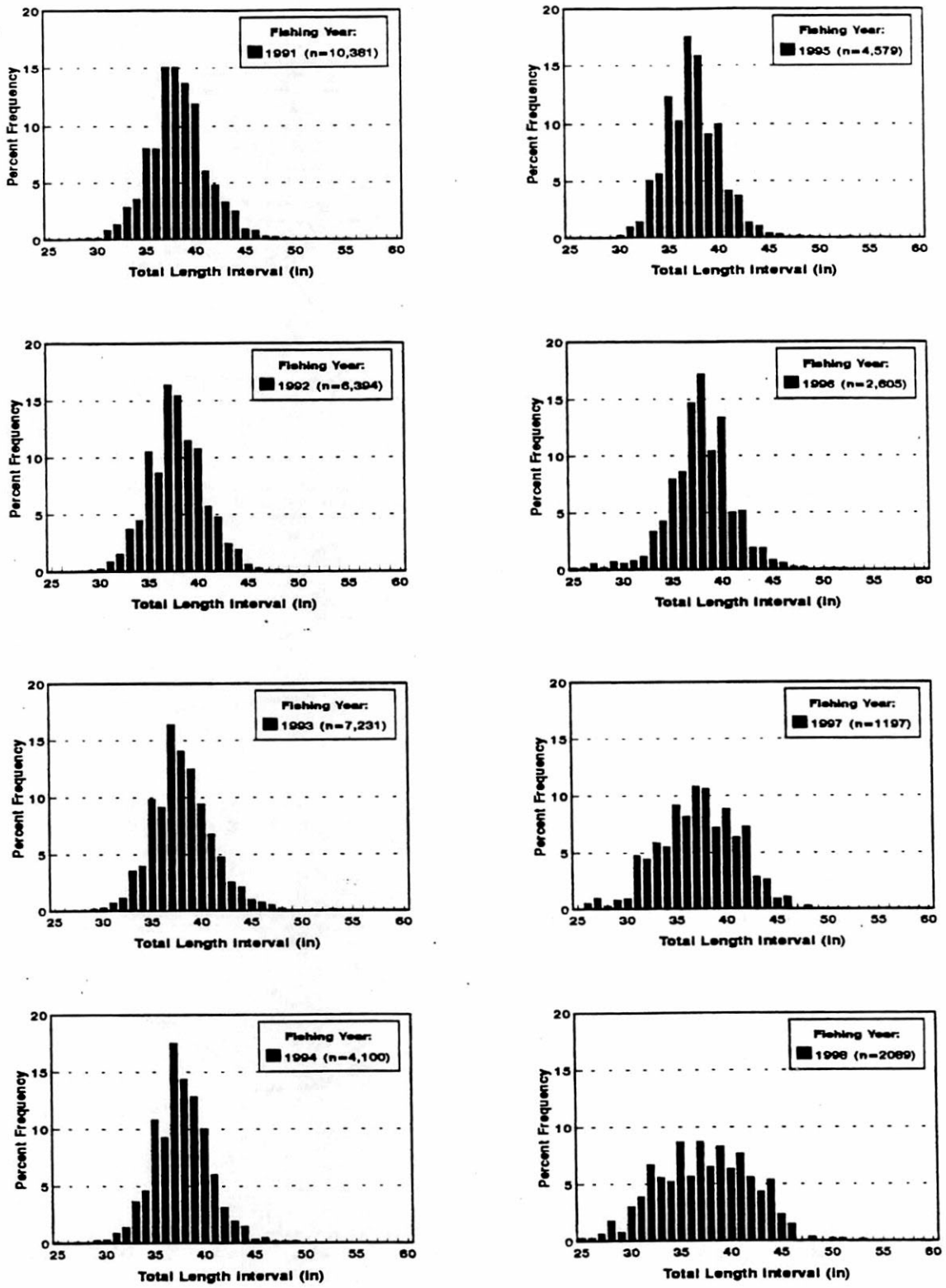

Figure 2. Wreckfish annual length frequency plots, 1991-1998 fishing years.

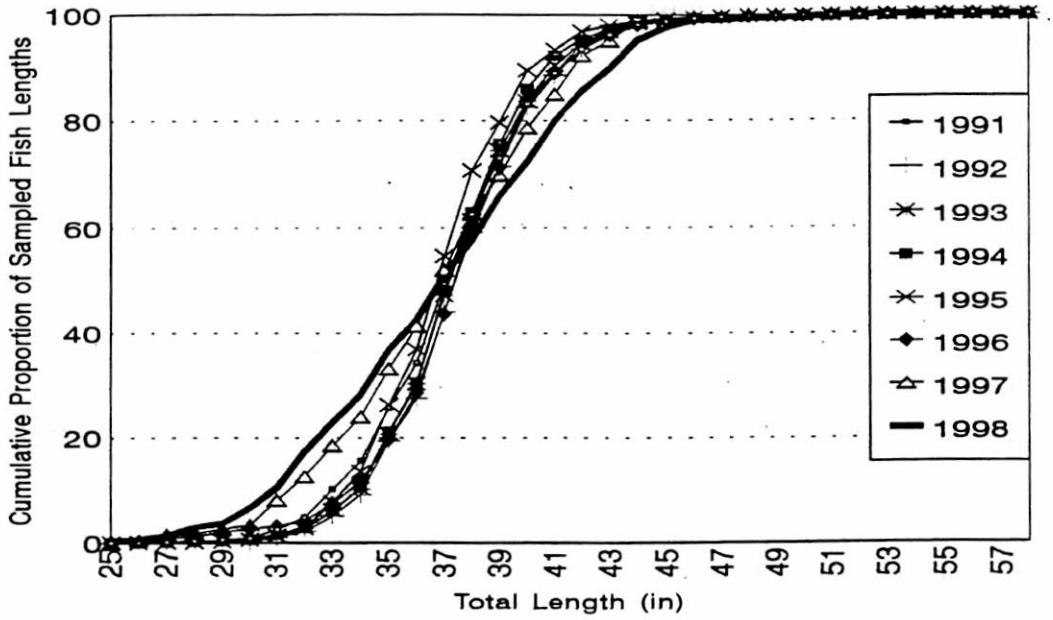

Figure 3. Wreckfish cumulative percent frequency by year weighted by catch in numbers, 1991-1998 fishing years.

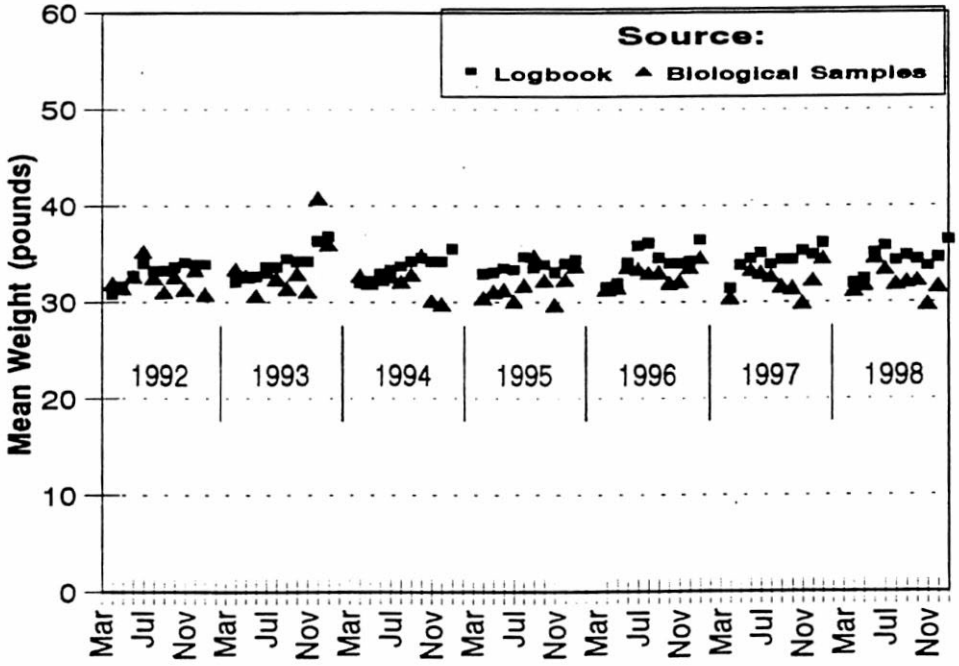

Figure 4. Monthly mean weight of wreckfish from commercial landings, 1992-1998 fishing years.

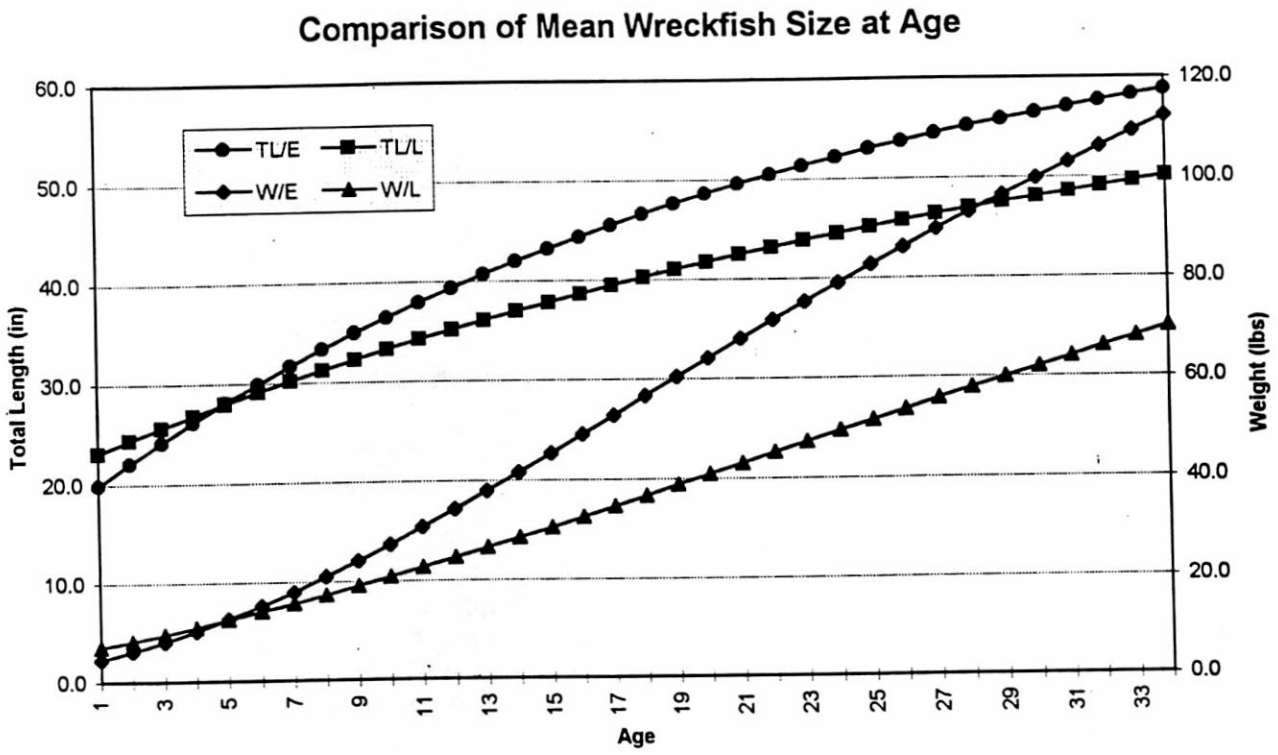

Figure 5. Predicted total length (TL) and weight (W) of wreckfish from two aging studies (E, 1988-1992; and L, 1995-1998).

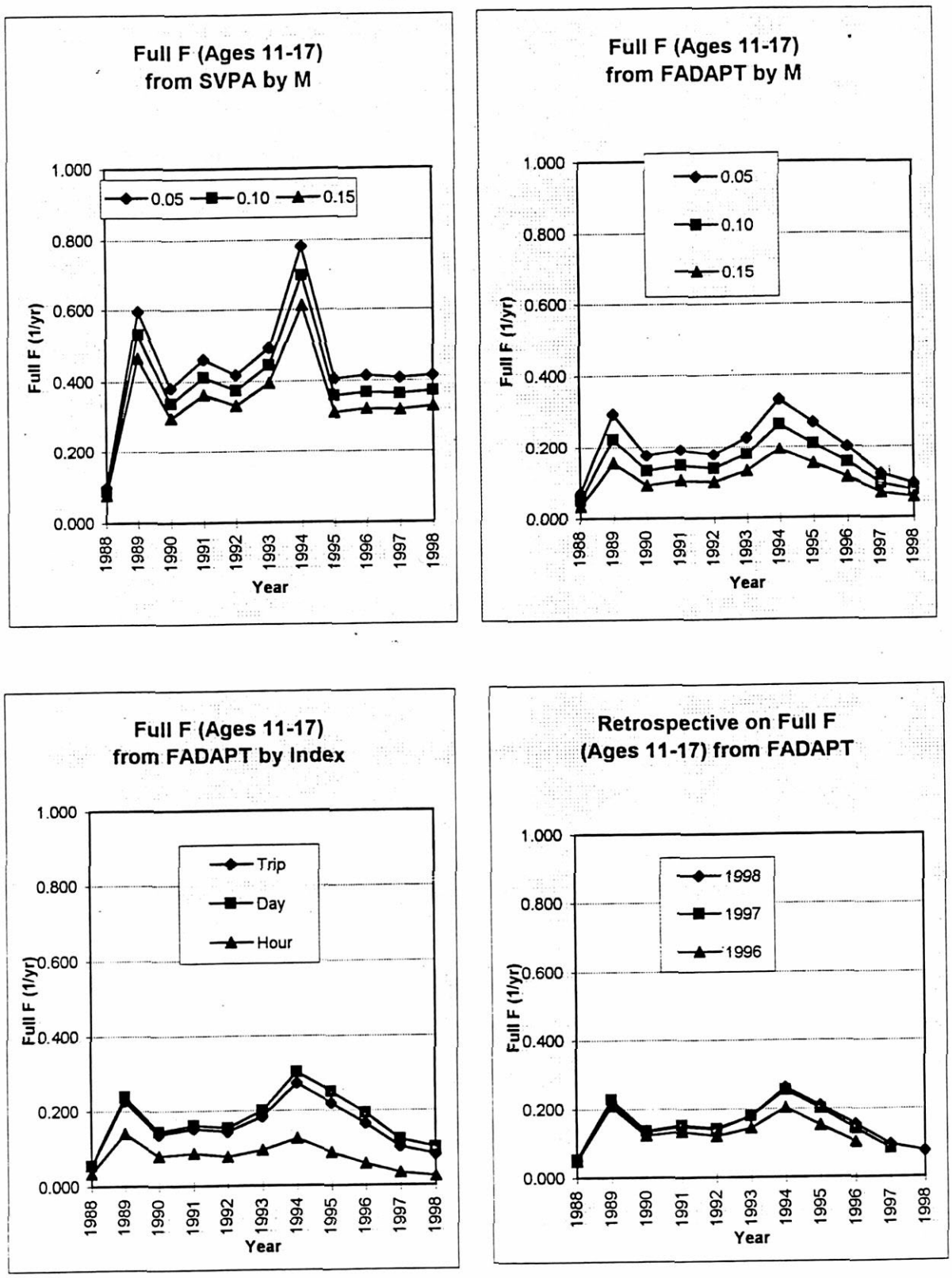

Figure 6. Estimates of full F for 1988-1998 arranged in four panels: SVPA estimates compared for three levels of M; FADAPT estimates compared for three levels of M (all CPE indices used); FADAPT estimates compared for M = 0.1, with three CPE indices applied separately; and limited retrospective comparison with FADAPT using M = 0.1 and all CPUE indices.

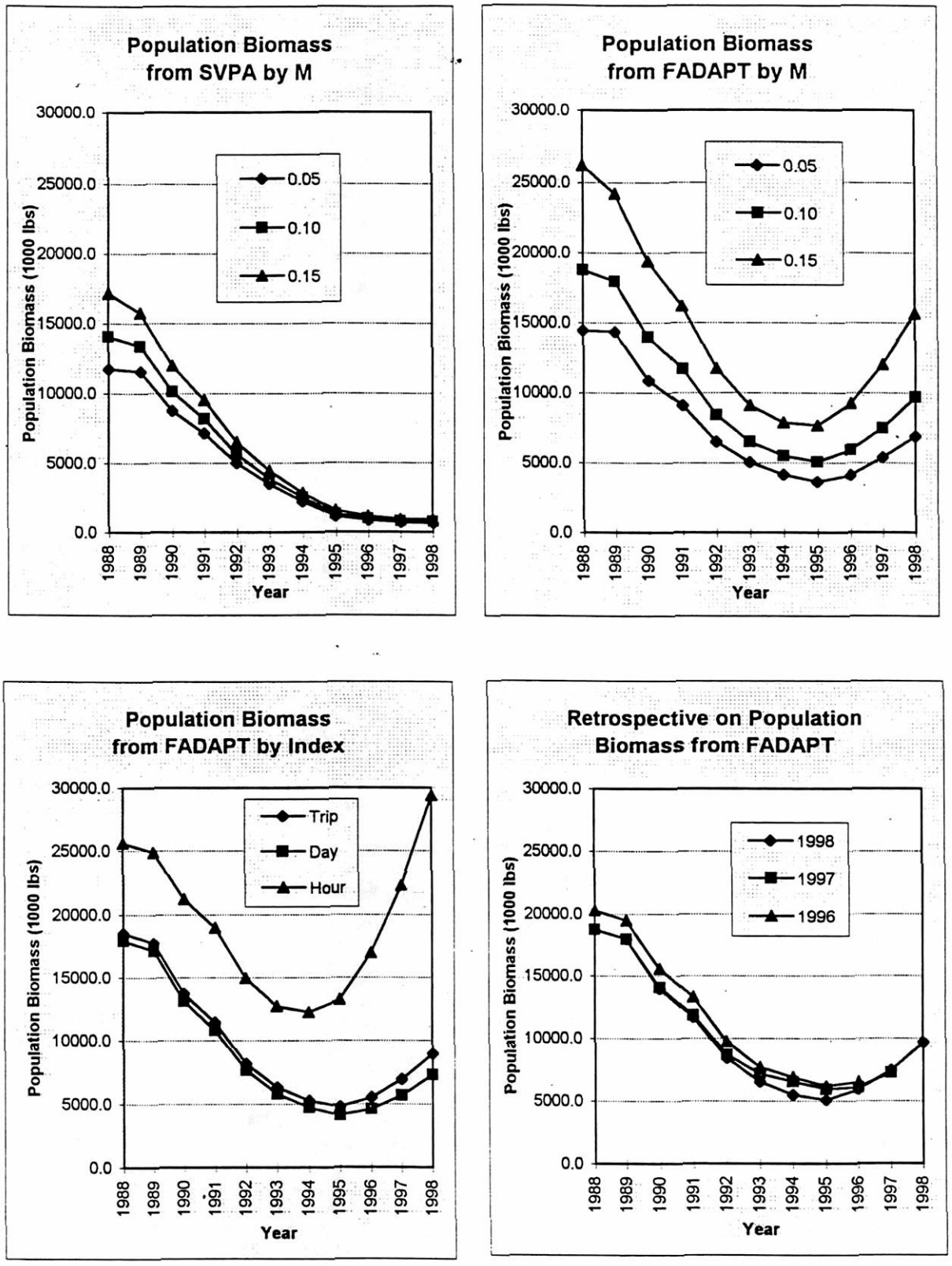

Figure 7. Estimates of total population biomass for 1988-1998 arranged in four panels: SVPA estimates compared for three levels of M; FADAPT estimates compared for three levels of M (all CPE indices used); FADAPT estimates compared for M = 0.1, with three CPE indices applied separately; and limited retrospective comparison with FADAPT using M = 0.1 and all CPUE indices.

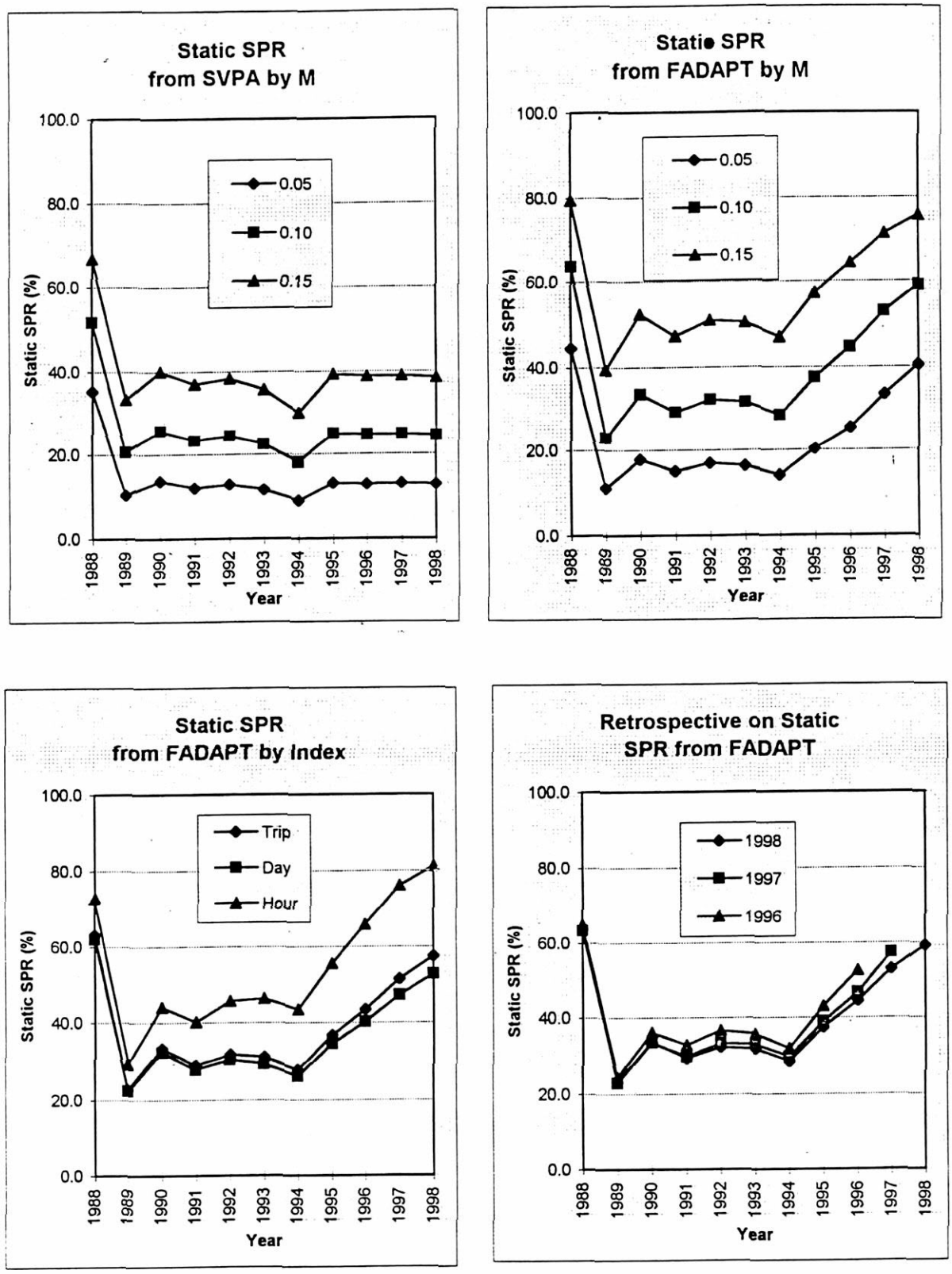

Figure 8. Estimates of static SPR for 1988-1998 arranged in four panels: SVPA estimates compared for three levels of M; FADAPT estimates compared for three levels of M (all CPE indices used); FADAPT estimates compared for M = 0.1, with three CPE indices applied separately; and limited retrospective comparison with FADAPT using M = 0.1 and all CPUE indices.

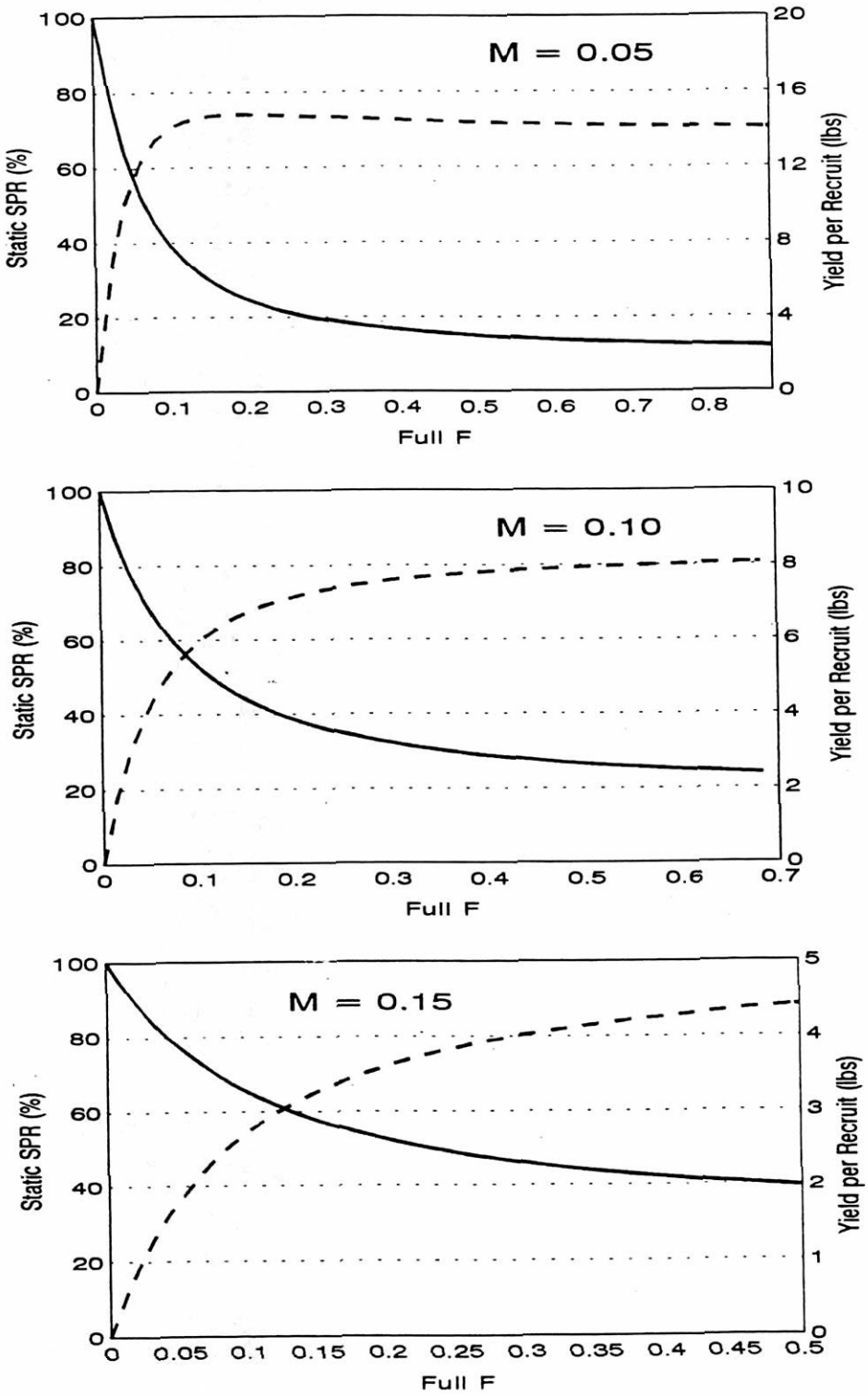

Figure 9. Yield per recruit and static SPR plotted against full F (mean over ages 11-18) for wreckfish using mean F for 1995-1997 with three levels of M.