GULF OF MEXICO GREATER AMBERJACK STOCK ASSESSMENT

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Sustainable Fisheries Division Contribution SFD - 2005 - 035

SUMMARY

Two production models, one with and one without age structure, were fit to data for greater amberjack (Seriola dumerili) in the Gulf of Mexico. Both the simple surplus production model (ASPIC) and the age structured production model (SSASPM) indicated that the stock was overfished and that overfishing was occurring. Several sensitivity analyses were performed by applying different release mortalities to estimate discards (ASPIC), and by fixing M at different levels and by exploring different mean values of steepness in the stock-recruit relationship (SSASPM). In most, but not all, cases the estimate of stock status was overfished with overfishing occurring.

INDEXES OF ABUNDANCE

Documents SEDAR9-DW-20 and SEDAR9-DW-10 presented greater amberjack standardized indexes of abundance for the recreational and commercial fisheries, respectively. The SEDAR9-DW recommended the use of four indices of abundance for the greater amberjack stock assessment: 1) commercial handline (1-9 hooks per line), 2) commercial longline, 3) recreational headboat and 4) recreational charter boat and private boat combined. Following the advice of the SEDAR9-DW, the indexes were revised and new estimates are presented in Table 1. Trip selection for the CPUE analysis followed the species composition method developed by Stephens and McCall (2004), which was presented during the SEDAR9-DW. The 'default' threshold value estimated by this method was reduced between 25% and 50% to increase the number of trips included in the final data sets to be analyzed. Initial exploratory analysis showed that CPUE trends did not change when the threshold value was reduced. Trip selection for the commercial handline (1-9 hooks per line) and the combined private boat and charter boat fisheries were performed by reducing the threshold value by 50%, in the case of the commercial longline fishery the threshold was reduced by 25%. For the headboat fishery, all available trips were used for the analysis of indexes of abundance. All indices received equal weighting in the model.

ASSESSMENT MODELS

(1) Surplus Production model ASPIC

Version 5.10 of ASPIC was used to fit a non-equilibrium production model conditioned on yield to the Gulf of Mexico greater amberjack data. In ASPIC, it is possible to include data from multiple fisheries operating on the same stock and 'tunes' the model to one or more indices of abundance. Catch and CPUE series for the 4 fisheries described in the previous section were used as input. The catch-CPUE series analyzed with ASPIC corresponded only to the period 1986-2004 because the condition on yield used on the ASPIC model requires catch information for each fishery for every year, and yield for the charterboat fishery is not available prior to 1986.

Figure 1 shows the estimated Gulf of Mexico greater amberjack yield by fishery used for input in the ASPIC program. The recreational charterboat-private boat fishery is the major contributor to the total landings of this species followed by the commercial handline fishery.

Initial trials in ASPIC compared the generalized versus the logistic production model. The generalized model estimates the shape parameter while the logistic model assumes that maximum surplus production occurs when the stock is at half the unfished level K/2. For this comparison, the two models assumed 0% release mortality and used an initial value of $B_1/K = 0.5$. Upon selection of the model to use (logistic versus generalized), subsequent ASPIC runs were performed for three different scenarios of release mortalities: 0%, 20% and 40%. For each case, three different initial estimates of B_1/K were used: 1.0, 0.5, and 0.2. All runs were performed allowing the program to estimate the parameters B_1/K, MSY, and K, as well as selectivity q for each fishery. Bootstrap analyses were performed to estimate variability around the estimated parameters and projection analyses were also performed assuming different levels of constant F or constant yield.

(2) State Space Age Structure Production Model SSASPM

A Bayesian implementation of a State Space Age Structured Production Model (SSASPM) was developed by Porch (2002). The SSASPM represents a step-up in model complexity from a surplus production model, as it can incorporate age-specific differences in model parameters such as growth, fecundity, and gear vulnerability (selectivity). In the case of long-lived, late-maturing fish or when there are multiple fisheries that exploit different age classes, having the flexibility to incorporate age-specific information could lead to a better fit to observation data. Currently, this SSASPM allows specification of age-specific vectors for fecundity, maturity, and selectivity. Length and weight at age are calculated within the model based on user-specified growth functions. Natural mortality at age and a stock recruitment function are additional model parameters. The stock recruit function is parameterized in terms of virgin recruitment (R0) and maximum lifetime reproductive rate, α, which is related to steepness:

$$\alpha = \frac{4 * steepness}{1 - stepness}$$ (Myers et al. 1999)

A Beverton-Holt stock recruit function was applied. The years modeled are partitioned into a historic and modern period. The stock is assumed to be unexploited at the start of the first year of the historic period. One of three effort trends (constant, linear, or exponential) is estimated during the historic period. In the modern period, a constant level of effort with annual deviation is estimated.

Statistics of the commercial handline fishery extend back to 1963 while the commercial longline fishery began in 1979. In the case of the recreational fishery, landings of the headboat fishery are available from 1986 and from MRFSS since 1981. 'Historical' catches for the recreational sector were estimated for the period 1963-1980 (G. Scott, pers. comm.) assuming that the fishery evolved following a pattern similar to the handline fishery during the same period and as a function of coastal population size (Table 2). Catches for the combined recreational charterboat-private boat fishery and the headboat fishery for the period 1981-1985 were estimated using the landings ratio between the headboat and charterboat fisheries for 1986. Values of biological input parameters followed the recommendations made by the SEDAR9-DW (Table 3). A natural mortality of 0.25 and 0% discard mortality were chosen as input values for the base model. Results from exploratory runs showed that the program behaved better if it estimated effort only for the period 1963-1967. This effort was estimated assuming a linear increase. Catches for the historic period 1963-1980 were downweighted compared to the rest of the catch series. Because there was no index reflecting the abundance of age 0 fish (e.g. shrimp bycatch), all runs were performed without attempting to estimate any annual recruitment deviations.

Gear selectivity was estimated from age samples. Selectivity for handline, longline, and the combined recreational charteboat-private boat fisheries were assumed to follow a logistic curve. Full selectivity for the recreational charteboat-private fishery was attained at age 3 while for the HL and LL fisheries full selectivity was attained at ages 5 and 6, respectively (Figure 2). Selectivity for the charterboat fishery appeared dome shaped, and it was modeled by a double logistic (Figure 2).

RESULTS

(1) Surplus Production model ASPIC

Initial runs of the production model ASPIC showed no convergence problems. Table 4 shows the results of a logistic versus generalized fit. The estimated value of the exponent by the generalized model (exponent=2.33) was not significantly different (P=0.3824) from the logistic model exponent (exponent=2). Estimates of the other parameters B_1/K, MSY, and K were similar. The result of this comparison showed that the logistic model provided as good a fit as the generalized. Therefore, the more parsimonious model (the logistic) was selected for subsequent evaluations. Table 5 shows the predicted values of B_1/K, MSY and K by ASPIC under different initial values of B_1/K and three different levels of assumed release mortality. In general, the model reached similar values for the estimated parameters for all initial conditions and release mortalities. Estimated carrying capacity K ranged from 22.04 to 24.41 million lbs, while MSY ranged from 4.21 to 5.41 million lbs.

The estimated values of B_1/K increased with higher values of estimated release mortality. Figure 3 shows the observed and predicted CPUE series for each fishery assuming a 20% release mortality. Figure 4 shows the estimated values of relative fishing mortality F/F_{MSY} and relative biomass B/B_{MSY} under different initial values of B_1/K and release mortality. No differences were observed in the ratios estimated using different initial values of B_1/K and the trends were identical between the results obtained with different release mortality. Based on the results presented in Table 5, an initial value of B_1/K=0.679 was chosen to run sensitivities for three levels of constant release mortality (0%, 20%, and 40%). The estimated trajectories of relative F and relative B were very similar for the three levels of release mortality (Figure 5). The results of the surplus production model showed that the Gulf of Mexico greater amberjack stock has experienced overfishing conditions since at least 1986, and that it has been overfished since 1988. Relative SSB showed that a period of recovery started in 1998, two years after the implementation of the 1 fish bag limit for the recreational fishery. Although the recovery period continued until the present, the greater amberjack stock still remains overfished and overfishing is occurring.

The case of 20% release mortality and initial value of B_1/K=0.697 was chosen for bootstrap and projection analysis. Initial runs with 1000 bootstraps showed no differences between the $10\text{-}90^{th}$ and the 50^{th} percentiles when compared to 500 bootstrap run. Thus, to reduce computation time, 500 bootstraps were selected for the analysis. Relative biomass projections for years 2005-2020 were obtained for (1) different scenarios of future F/F_{2004} (values from 0.5 to 1 by 0.1 intervals) and (2) by keeping the 2004 yield constant. Figure 6 shows the estimated relative biomass with the 10^{th}-90^{th} percentiles of the bootstrap, as well as projected B/B_{MSY} under different values of F/F_{2004}.

Projections indicated that the greater amberjack stock could be recovered from its overfished condition by the year 2011 only by reducing the fishing mortality from its current level (F=0.49) by at least 20% (F=0.39). Obviously, further reductions of the fishing mortality rate will recover the stock at a faster rate. Figure 7 presents the control rule plot for $F_{2005\text{-}2020}=F_{2004}$ (status quo F scenario) and clearly indicates that under the current estimated levels of F, the greater amberjack stock is projected to remain overfished and overfishing is projected to continue. Table 7 presents projected yields under different scenarios of constant F/F_{2004}.

Projections under constant yield showed a different scenario. If the current yield of 3.1 million lbs is kept constant, the greater amberjack stock is projected to recover from the overfished condition by the year 2008 and overfishing will not occur after 2005 (Fig. 8). The recovery is projected to reach a plateau at a relative biomass of 1.66 by year 2015.

(2) Age Structure Production Model SSASPM

The base case run of the SSASPM was performed with constant natural mortality M=0.25 (fixed), 0% release mortality, and α in the stock recruit function initialized to correspond to a steepness of 0.7. Initial results from ASPIC showed that model results were not sensitive to three different levels of release mortality (0%, 20%, and 40%). Thus, 0% release mortality was chosen for the SSASPM base case. Two other runs were performed as a sensitivity analysis by fixing M=0.20 and M=0.35. In addition, two sensitivities for the stock recruit prior on α were conducted by shifting the mode of the prior to correspond to steepness values of 0.8 and 0.9. SSASPM estimated parameters for the base case and the sensitivity runs are presented in Table 6.

Figure 9 shows the estimated and observed yield and CPUE series for the base model. Estimated yield showed a good fit to the observed values. However, fits to the CPUE series were poor, particularly for all recreational fisheries. Figure 10 shows the estimated relative fishing mortality rates (F/F_{MSY}) and spawning stock biomass (SSB/SSB_{MSY}) for the base model and the alternative cases (M=0.2 and M=0.35). All three cases showed similar trends and stock status estimates. Overfishing conditions started in 1986 and the stock became overfished in 1990 (Fig. 11). Relative SSB showed that a period of recovery started around the mid 90's and overfishing did not occur during 1998-2002. Relative F increased afterwards and overfishing occurred once again in 2002-2004 (F_{2004}/F_{MSY}=1.18 for base case). Although the stock showed a recovery after 1994, it still remained overfished until the present. After 1995, relative SSB reached the highest value in 2002 (SSB_{2002}/SSB_{MSY}=0.99), but it declined in 2003 and 2004 (SSB_{2004}/SSB_{MSY}=0.91). The model estimated that the stock is currently 2/3 depleted (SSB_{2004}/SSB_{virgin}=0.33) with a fishing mortality rate of 0.2. Relative population benchmarks are given in Table 8.

Higher steepness implies greater stock resilience. At the upper limit a steepness of 1 would imply constant recruitment. The steepness sensitivity runs showed little differences between 0.7 and 0.8 (Figure 12, Table 6). For a steepness of 0.9, which implies a highly resilient stock, the model estimated that the stock was never overfished and never experienced overfishing (Fig. 13).

Model Uncertainty

A significant amount of work was needed to arrive at a model configuration that seemed to provide reasonable outcomes and fits to the data. The model was sensitive to the treatment of the longline fishery during the early years when there was no catch. Stable results were obtained by setting the early catches to an arbitrary low value of 100 lbs per year and fixing the effective effort level during the first year to a small non-zero value.

The point estimates for model parameters obtained from each model run minimize the overall objective function. One method to characterize the uncertainty of those model estimates is to perform likelihood profiling. AD model Builder calculates likelihood profiles by assuming that the posterior probability distribution is well approximated by a multivariate normal distribution (Otter Research 2001). For the SSASPM base case, profile likelihoods are plotted for the stock recruitment parameters α and R0, and for the estimates of current spawning stock biomass and fishing mortality rate, SSB_{2004} and F_{2004} (Figure 14). The prior on α was lognormal and the peak (9.33) corresponded to a steepness of 0.7, while the mode of the likelihood profile (6.2) corresponded to a steepness of 0.61. While this suggests that the data contained information that stock resiliency was lower than implied by the prior, the prior mode is contained within the 95% likelihood profile confidence interval (Table 9).

DISCUSSION

ASPIC had no problems converging under various initial conditions used in the analysis and the results obtained were similar for the sensitivity cases explored. In general, a larger assumed release mortality resulted in a larger estimate of B1/K. For example, if a release mortality of 40% is assumed, then the stock biomass at the beginning of the time series (1986) was estimated to have been approximately 70% of the virgin biomass (K). Conversely, for 0% release mortality the stock biomass was estimated to have been approximately 55% of the virgin biomass in 1986. Basically, higher levels of release mortality resulted in higher yields that required B1 to correspond to higher proportions of K. Similarly, the current estimate of relative biomass assuming 40% release mortality is larger than that estimated with lower release mortalities (i.e., 20% and 0%). This follows from the model starting at a higher value of B1/K. However, all the results obtained using the different levels of release mortality showed the same trends.

Overall, the conclusions from ASPIC are that the Gulf of Mexico greater amberjack stock remains overfished and overfishing is occurring. Despite the recovery observed after the implementation of the 1 fish bag limit for the recreational sector, further reductions of the fishing mortality rate are required for the stock to recover from its current overfished status. According the the ASPIC projection results, maintaining the status quo fishing mortality rate will not achieve recovery of the stock; a 30% reduction in fishing mortality is projected to result in a rebuilt stock in 7 years.

The age structured production model SSASPM showed similar results and trends when compared to the ASPIC results (Table 10). MSY estimated by SSASPM was about half of that estimated by ASPIC. Estimated current relative F was similar for both models, but current relative biomass estimated by ASPIC was 43% lower than that estimated by SSASPM. Although SSASPM results indicated that the stock is not as overfished as the ASPIC results suggested, both models indicated that overfishing is occurring, therefore, the sustainability of the stock in the long term is questionable. These differences in the status of the stock are related to the basic nature of the models. ASPIC treats the stock as a unit with no differences in selectivity or fecundity for different ages. In contrast, SSASPM takes into account differences in selectivity and fecundity at age and uses a proxy for MSY that is conditioned on the estimated selectivity vectors. Age of 50% maturity for the Gulf of Mexico greater amberjack stock was assumed to be 3 years old. Since most of the fisheries have full selectivity at age three or older (Figure 2), a proportion of adult fish is expected to survive fishing and reproduce. SSASPM takes this factor into account to estimate stock productivity to be higher than ASPIC's. This higher productivity translates into a faster recovery of the stock as observed by the higher relative biomass estimated by SSASPM when compared to ASPIC. This difference is also shown by the fact that SSASPM estimated $SSB_{MSY}/SSB_0 = 0.36$ (Table 7); while, by definition, ASPIC's relative biomass $B_{MSY}/B_0 = 0.5$. Consequently, SSASPM estimated a lower standard to which the greater amberjack stock has to recover (36% of SSB_0) compared to ASPIC (50% of B_0) which translated into a faster recovery of the stock (Figure 15).

An alternative SSASPM using weight as a proxy for fecundity was performed to test its potential effect on the estimated relative biomass. As expected, this change reduced the estimated SSB's by around 3 orders of magnitude due to the change in units, but the relative SSB did not change (0.912 *vs.* 0.906). This result suggested that some of the differences between both models may be due to differences in the analyzed time series (1963-2004 for SSASPM *vs.* 1986-2004 for ASPIC), in addition to the aforementioned differences in model structure. To evaluate the differences due to the time series, one final ASPIC run was conducted using the imputed historical catch series. For consistency with SSASPM assumptions, B_1/K was fixed at 1.0 and 0% discard mortality was assumed. Unlike SSASPM, however, it was not possible to downweight the imputed catch data relative to the observed values. The result from this run yielded B/B_{MSY} and F/F_{MSY} values that were closer to SSASPM, and an MSY estimate of 3.75E+06 lbs, which was also closer to the SSASPM base model.

References

Diaz, G. A. 2005. Standardized catch rates of Gulf of Mexico greater amberjack for the commercial longline and handline fisheries 1990-2004. SEDAR-DW-10. Sustainable Fisheries Division Contribution No SFD-2005-017.

Diaz, G. A. 2005. Standardized catch rates of Gulf of Mexico greater amberjack for the recreational fishery (MRFSS, Headboat) 1981-2004. SEDAR-DW-20. Sustainable Fisheries Division Contribution No SFD-2005-018.

Myers, R.A., K.G. Bowen, and N.J. Barrowman. 1999. Maximum reproductive rate of fish at low population sizes. Can. J. Fish. Aquat. Sci. 56:2404-2419.

Otter Research Ltd. 2001. An introduction to AD MODEL BUILDER Version 6.0.2. Box 2040, Sidney B. C. V8L 3S3, Canada. 141 p.

Porch, C. E. 2002. A preliminary assessment of Atlantic white marlin (*Tetrapturus albidus*) using a state-space implementation of an age-structured model. SCRS/02/68 23pp

Table 1: Estimated indexes of abundance and associated coefficient of variation (CV) for the combined private and chaterboat fishery (MRFSS), recreational headboat, and commercial longline and handline using 1-9 hooks per line (Handline 1-9 HPL).

	MRFSS		Headboat		Longline		Handline 1-9 HPL	
Year	index	CV	index	CV	index	CV	index	CV
1981	0.185	0.745						
1982	0.078	1.152						
1983	0.156	0.719						
1984	0.181	0.857						
1985	0.054	1.739						
1986	0.285	0.199	0.206	0.192				
1987	0.289	0.240	0.092	0.282				
1988	0.184	0.299	0.098	0.252				
1989	0.431	0.244	0.133	0.213				
1990	0.068	0.700	0.056	0.391				
1991	0.254	0.243	0.044	0.514				
1992	0.218	0.180	0.051	0.435				
1993	0.131	0.324	0.036	0.518	0.264	0.299	3.200	0.128
1994	0.103	0.438	0.035	0.586	0.257	0.286	2.893	0.127
1995	0.070	0.739	0.056	0.437	0/326	0.276	3.559	0.122
1996	0.066	0.571	0.040	0.645	0.220	0.295	2.940	0.121
1997	0.045	0.658	0.039	0.537	0.279	0.273	2.283	0.129
1998	0.041	0.495	0.044	0.575	0.255	0.289	2.219	0.146
1999	0.055	0.306	0.043	0.626	0.246	0.293	2.621	0.140
2000	0.081	0.222	0.055	0.520	0.297	0.281	2.657	0.149
2001	0.087	0.238	0.092	0.362	0.319	0.276	2.856	0.139
2002	0.175	0.133	0.118	0.350	0.511	0.245	2.717	0.137
2003	0.153	.145	0.109	0.376	0.564	0.236	4.084	0.132
2004	0.077	0.196	0.135	0.418	0.682	0.259	3.825	0.152

Table 2: Greater amberjack yield (lbs) for the period 1963-2004. Imputed historical data are in italics. Refer to text for details on the estimation of the historic data (1963-1980).

	CB+PB	HB	HL	LL	TOTAL
1963	*14,318*	*1,700*	7,018	*100*	23,136
1964	*17,684*	*2,100*	6,176	*100*	26,060
1965	*21,832*	*2,592*	5,053	*100*	29,577
1966	*26,939*	*3,199*	6,738	*100*	36,976
1967	*3,326*	*3,945*	29,197	*100*	36,568
1968	*40,963*	*4,864*	11,510	*100*	57,437
1969	*50,480*	*5,994*	72,898	*100*	129,472
1970	*62,184*	*7,384*	13,663	*100*	83,331
1971	*77,637*	*9,219*	38,461	*100*	125,417
1972	*96,827*	*11,497*	41,643	*100*	150,067
1973	*120,640*	*14,325*	28,261	*100*	163,326
1974	*150,167*	*17,831*	41,736	*100*	209,834
1975	*186,754*	*22,175*	78,139	*100*	287,168
1976	*232,062*	*27,555*	86,467	*100*	346,184
1977	*288,134*	*34,213*	119,870	*100*	442,317
1978	*357,487*	*42,447*	150,672	*100*	550,706
1979	*443,219*	*52,627*	148,748	2,714	647,308
1980	549,141	65,204	173,632	4,754	792,731
1981	1,043,546	123,909	212,666	22,450	1,402,571
1982	5,924,108	703,418	184,403	39,106	6,851,035
1983	2,835,244	336,652	233,233	45,571	3,450,700
1984	1,446,678	171,776	465,166	60,616	2,144,236
1985	1,845,062	219,079	645,207	108,229	2,817,577
1986	4,779,781	678,660	903,545	196,562	6,558,548
1987	4,489,630	359,138	1,288,095	249,456	6,386,319
1988	1,348,090	210,334	1,709,427	321,553	3,589,404
1989	5,679,784	244,852	1,636,113	295,908	7,856,657
1990	940,377	173,795	1,085,450	124,595	2,324,217
1991	3,427,895	121,409	1,369,133	6,047	4,924,484
1992	2,320,599	330,957	940,832	50,324	3,642,712
1993	2,847,441	243,942	1,489,607	80,003	4,660,993
1994	2,043,843	212,288	1,201,265	68,688	3,526,084
1995	712,905	142,929	1,177,210	81,850	2,114,894
1996	1,344,207	151,552	1,210,030	56,802	2,762,591
1997	945,735	123,054	1,055,346	59,410	2,183,545
1998	646,933	89,219	643,827	54,854	1,434,833
1999	800,407	76,351	714,753	60,437	1,651,948
2000	955,546	96,371	851,303	70,492	1,973,712
2001	1,235,599	90,583	685,581	47,253	2,059,016
2002	1,887,625	200,801	712,632	77,771	2,878,829
2003	2,494,241	194,954	873,636	125,515	3,688,346
2004	2,031,254	108,785	872,346	82,442	3,094,827

Table 3: Biological inputs for the SSASPM base model. The value of t_0 was adjusted for a birthday of June 1st.

Parameter	value	prior
Maturity	Age 1-2:0.0 Age3: 0.5 Age4+: 1.0	(constant)
Steepness	0.7 (α=9.33)	LN (mean=0.7 CV=0.35)
R_0	1.00E+04	Uniform [1.0E+03-1.0E+06]
M	0.25	(constant)
L_∞	138.9 cm (FL)	(constant)
K	0.25	(constant)
t0	-0.3773	(constant)
L-W scalar	7.5438E-05	(constant)
L-W exponent	2.81	(constant)
Batch Fecundity (at age) slope	458.601	(constant)
Batch Fecundity (at age) intercept	254,065	(constant)

Table 4: Parameter values estimated by ASPIC using the logistic and generalized model fit.

Parameter	Logistic	Generalized
Exponent	2	2.33
B_{MSY}/K	0.50	0.53
B_1/K	0.626	0.604
MSY	4,161,000	4,459,000
K	21,690,000	20,075,000
AIC	-122.648	-120.873

Table 5: ASPIC parameter estimates for three different initial values of B_1/K and three different levels of release mortality.

Assumed released mortality	Estimated Parameters	Initial input value for B_1/K		
		1.0	0.5	0.2
0 %	B_1/K	0.515	0.583	0.61
	MSY	4,588,000	4,311,000	4,207,000
	K	24,160,000	22,470,000	22,040,000
	B_{MSY}	12,080,000	11,230,000	11,020,000
	F_{MSY}	0.380	0.384	0.382
	B/B_{MSY} (2004)	0.457	0.494	0.510
	F/F_{MSY} (2004)	1.264	1.250	1.245
20%	B_1/K	0.697	0.697	0.560
	MSY	4,709,000	4,710,000	5,217,000
	K	22,220,000	22,230,000	24,090,000
	B_{MSY}	11,110,000	11,120,000	12,050,000
	F_{MSY}	0.424	0.427	0.433
	B/B_{MSY} (2004)	0.560	0.560	0.492
	F/F_{MSY} (2004)	1.163	1.165	1.181
40%	B_1/K	0.733	0.725	0.7533
	MSY	5,408,000	5,322,000	5,368,000
	K	22,810,000	24,050,000	22,470,000
	B_{MSY}	11,400,000	12,020,000	11,240,000
	F_{MSY}	0.474	0.443	0.478
	B/B_{MSY} (2004)	0.575	0.583	0.578
	F/F_{MSY} (2004)	1.107	1.118	1.111

Table 6: SSASPM estimates of fishing mortality rate (F_{MSY}), yield (Y_{MSY}), spawning stock biomass (SSB_{MSY}), spawning potential ratio (SPR_{MSY}) and number of recruits at MSY for base case (M=0.25 / h=0.7) and sensitivities (refer to text for explanation of sensitivity runs).

Parameters	F_{MSY}	Y_{MSY}	SSB_{MSY}	SPR_{MSY}	$Recruits_{MSY}$
M=0.25 / h=0.7	**0.201**	**2.39E+06**	**7.24E+10**	**0.467**	**2.69E+05**
M=0.20 / h=0.7	0.183	2.32E+06	7.42E+10	0.439	2.08E+05
M=0.35 / h=0.7	0.226	2.46E+06	6.98E+10	0.515	4.14E+05
M=0.25 / h=0.8	0.222	2.43E+06	6.74E+10	0.440	2.66E+05
M=0.25 / h=0.9	0.356	3.42E+06	5.71E+10	0.291	3.40E+05

Table 7: ASPIC projected yields for constant values of F/F_{2004}.

	0.5	0.6	0.7	0.8	0.9	1.0
2005	2.021E+06	2.368E+06	2.697E+06	3.010E+06	3.307E+06	3.589E+06
2006	2.627E+06	2.971E+06	3.265E+06	3.513E+06	3.718E+06	3.885E+06
2007	3.144E+06	3.482E+06	3.742E+06	3.930E+06	4.055E+06	4.124E+06
2008	3.524E+06	3.865E+06	4.104E+06	4.251E+06	4.316E+06	4.310E+06
2009	3.774E+06	4.126E+06	4.359E+06	4.483E+06	4.510E+06	4.450E+06
2010	3.926E+06	4.292E+06	4.529E+06	4.645E+06	4.649E+06	4.555E+06
2011	4.014E+06	4.394E+06	4.639E+06	4.753E+06	4.747E+06	4.631E+06
2012	4.064E+06	4.455E+06	4.707E+06	4.825E+06	4.815E+06	4.686E+06
2013	4.092E+06	4.490E+06	4.750E+06	4.872E+06	4.861E+06	4.726E+06
2014	4.107E+06	4.511E+06	4.776E+06	4.902E+06	4.892E+06	4.754E+06
2015	4.116E+06	4.523E+06	4.791E+06	4.921E+06	4.914E+06	4.774E+06
2016	4.120E+06	4.530E+06	4.801E+06	4.933E+06	4.928E+06	4.788E+06
2017	4.123E+06	4.534E+06	4.807E+06	4.941E+06	4.937E+06	4.798E+06
2018	4.124E+06	4.536E+06	4.810E+06	4.946E+06	4.944E+06	4.805E+06
2019	4.125E+06	4.537E+06	4.812E+06	4.949E+06	4.948E+06	4.810E+06

Table 8: SSASPM relative benchmarks for the base case (M=0.25, h=0.7).

Type	F_{2004}	Y/R	SSB_{2004}/SSB_0	SPR	Recruits
Virgin	0.000	0.00	1.000	1.000	3.45E+05
MSY	**0.201**	**8.88**	**0.364**	**0.467**	**2.69E+05**
MAX YPR	0.524	10.30	0.054	0.207	8.97E+04
F0.1	0.235	9.31	0.310	0.422	2.53E+05
20% SPR	0.540	10.30	0.046	0.200	7.86E+04
30% SPR	0.362	10.10	0.165	0.300	1.89E+05
40% SPR	0.253	9.48	0.285	0.401	2.45E+05
50% SPR	0.178	8.52	0.405	0.502	2.79E+05
60% SPR	0.124	7.27	0.524	0.601	3.01E+05

Table 9: SSASPM base model estimated mode and 95% confidence interval limit from profile likelihoods.

Parameter	Mode	95% Confidence interval	
		Lower bound	Upper bound
α	6.2	3.66	9.9
R0	3.45E+05	3.01E+05	4.01E+05
SSB_{2004}	6.62E+10	3.58E+10	1.18E+11
F_{2004}	0.22	0.1	0.39

Table 10: Estimated benchmarks by ASPIC and SSASPM base cases.

Benchmark	ASPIC	SSASPM
MSY	4.7E+06	2.39E+06
F_{MSY}	0.43	0.18
F_{1986}	0.57	0.23
F_{2004}	0.50	0.23
B_{1986}/B_{MSY}	1.24	1.46
B_{2004}/B_{MSY}	0.52	0.91
F_{1986}/F_{MSY}	1.33	1.19
F_{2004}/F_{MSY}	1.18	1.20

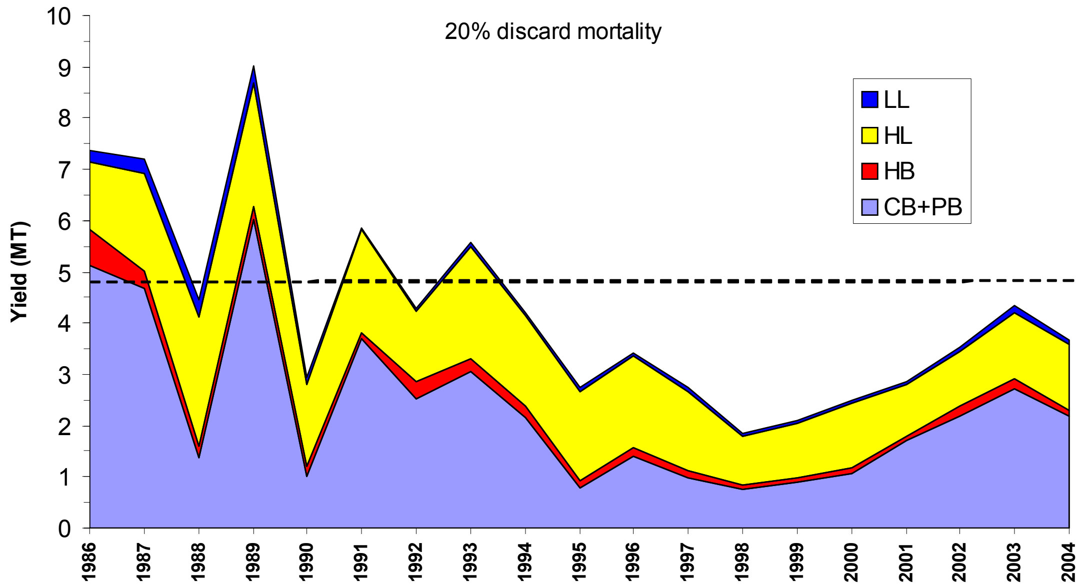


Figure 1: Biomass (in mt) of Gulf of Mexico greater amberjack landed and released dead (assuming 20% release mortality) by the commercial longline (LL), and handline (HL) fisheries and the recreational headboat (HB) and charter-private boat fisheries (CB+PB). Dashed line indicates MSY as estimated by ASPIC base model.

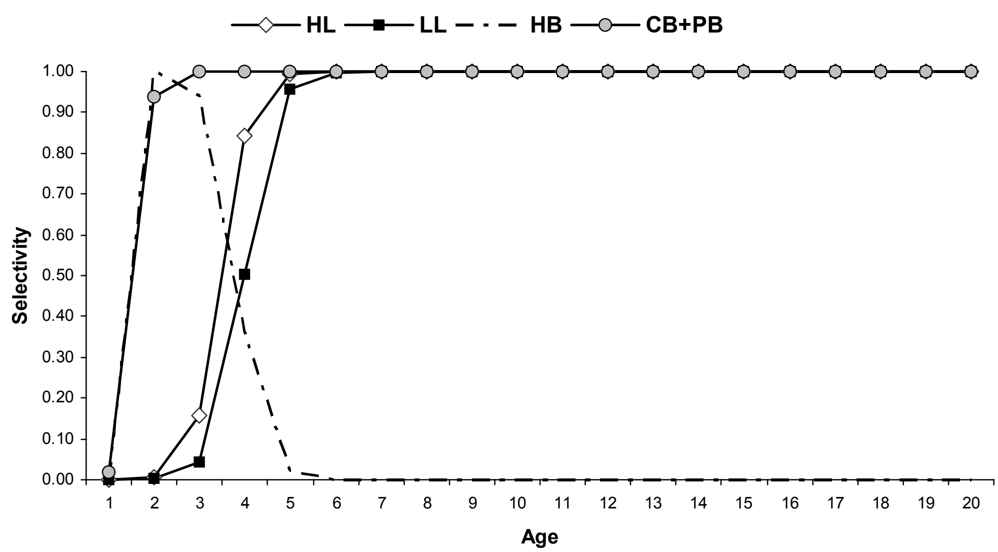


Figure 2: Selectivity curves for each fishery in the SSASPM. HL correspond to commercial handline gear, LL to longline, HB to the recreational headboat fishery and CB+PB to the combined charterboat and private boat recreational fishery.

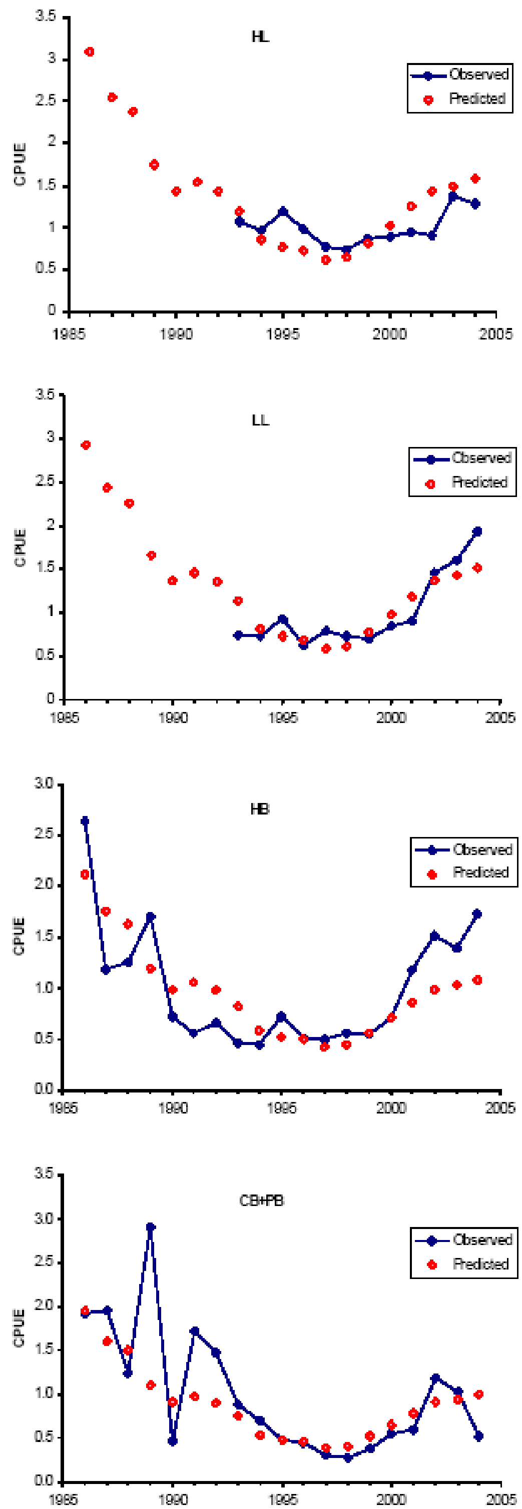


Figure 3: ASPIC estimated and observed CPUE series for the commercial handline (HL), and longline fisheries (LL), and the recreational headboat (HB) and charterboat-private boat (CB+PB) fisheries.

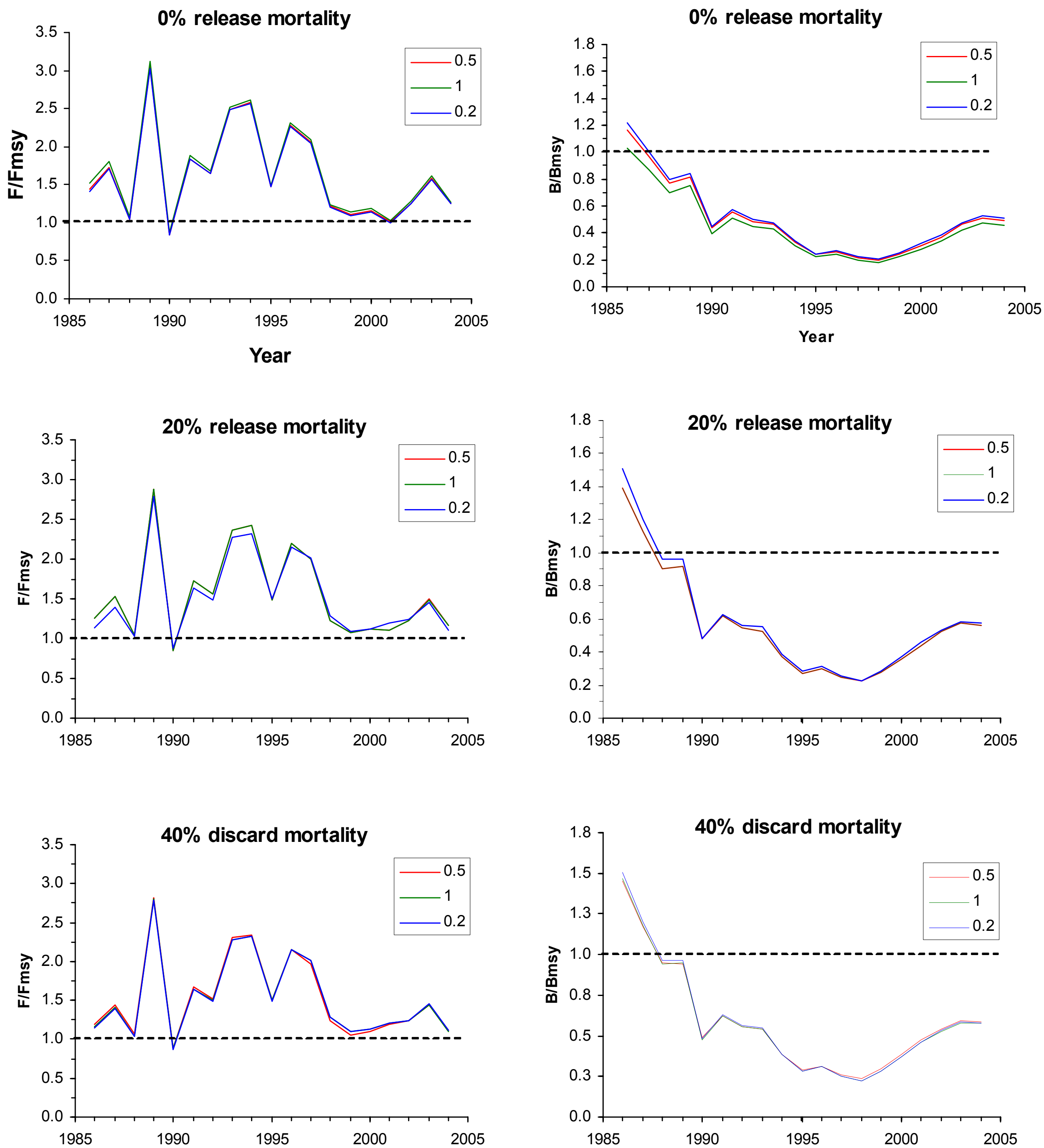


Figure 4: ASPIC estimated F/F_{MSY} and B/B_{MSY} trajectories under three different initial estimates of B_1/K (0.2, 0.5, 1.0) and different assumptions of release mortality (0%, 20%, and 40%).

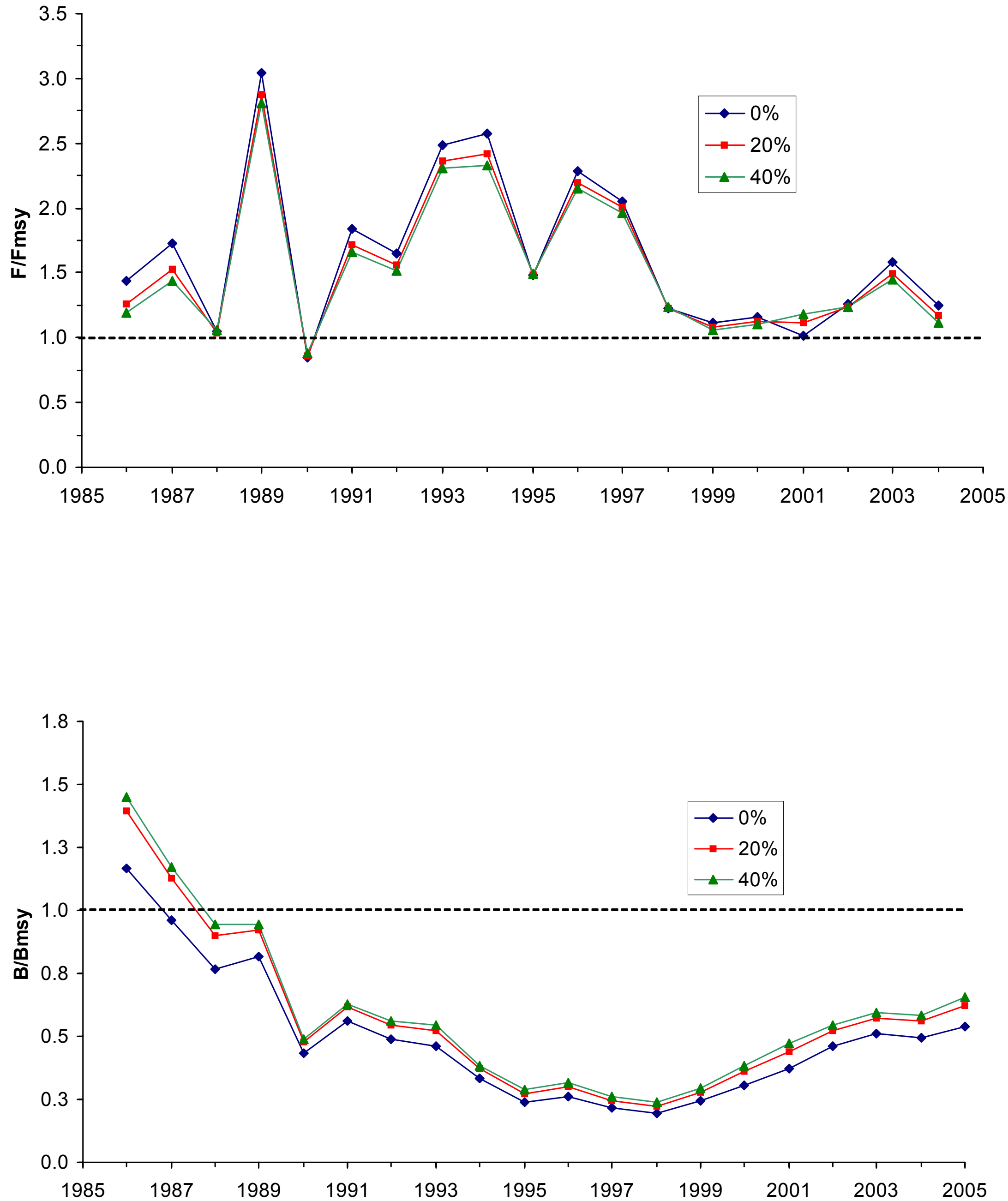


Figure 5: ASPIC estimated relative fishing mortality rate and relative biomass for three different levels of release mortality (0%, 20%, and 40%) using an initial value of B_1/K =0.697.

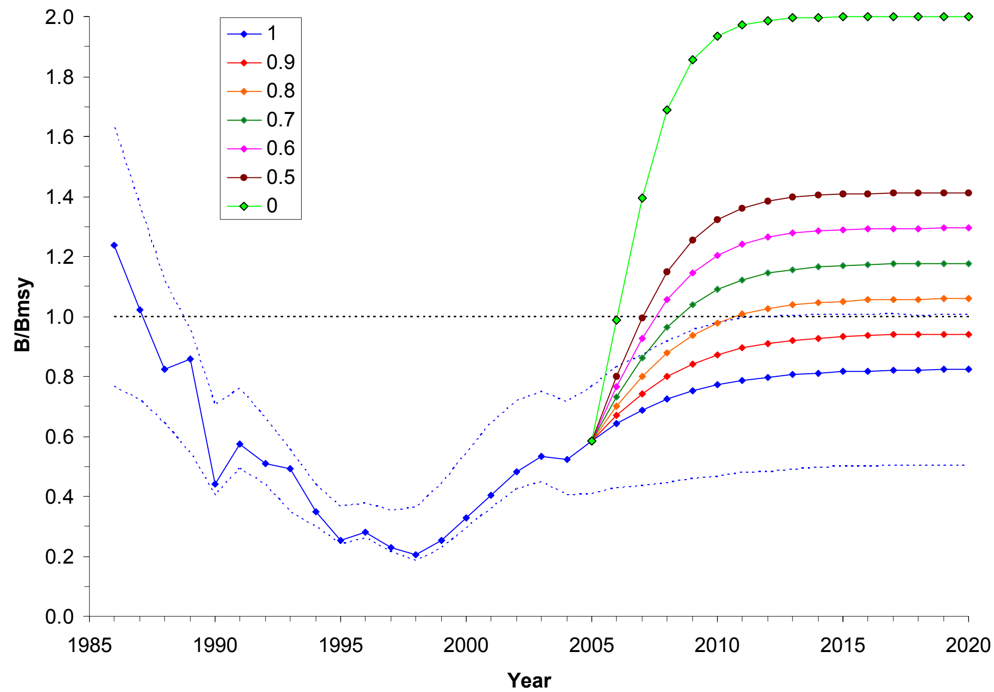


Figure 6: ASPIC estimated (blue) and projected (colored) median B/B_{MSY} trajectories from bootstrap analysis assuming 20% discard mortality and initial B_1/K=0.697. Projected were estimated for constant values of F/F_{2004} from 0.5 to1.0 by 0.1 intervals and for F/F_{2004}=0 (see figure legend). Dashed blue lines indicate 10^{th}-90^{th} percentiles of bootstrap replications for the base case model with future F fixed at F_{2004}.

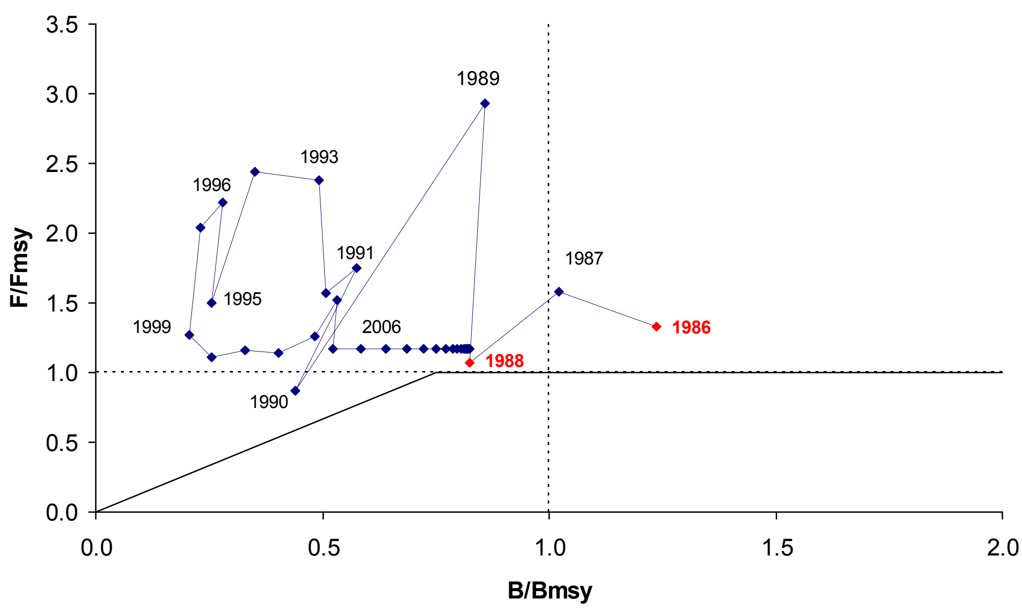
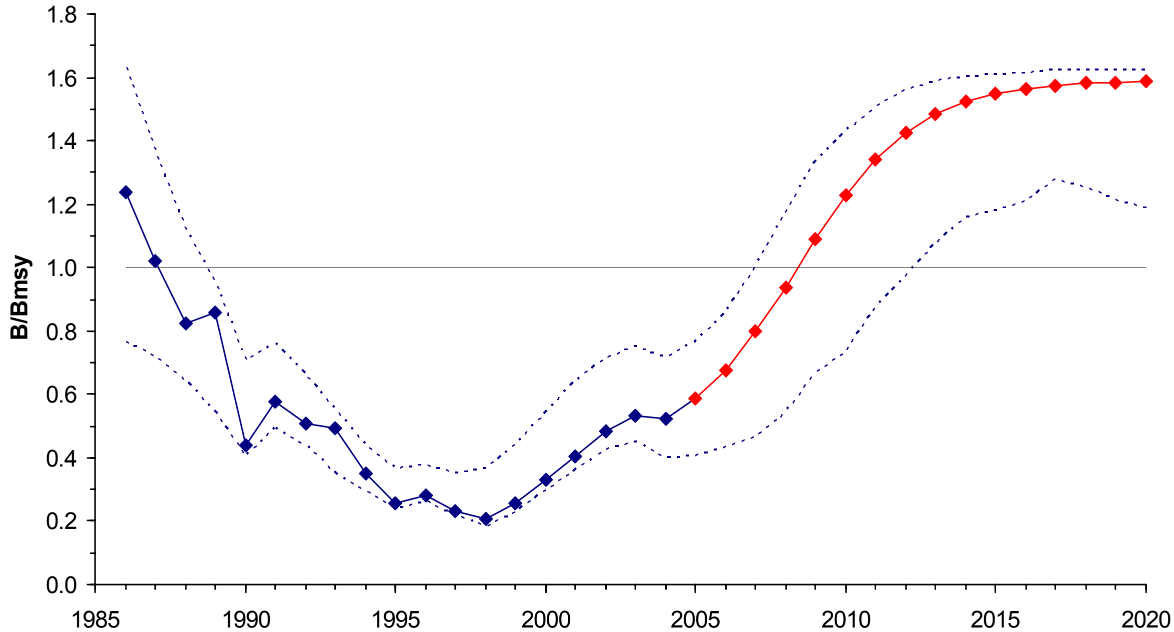


Figure 7: ASPIC control rule plot (1986-2020) assuming status quo fishing mortality rate for the projected period 2005-2020.



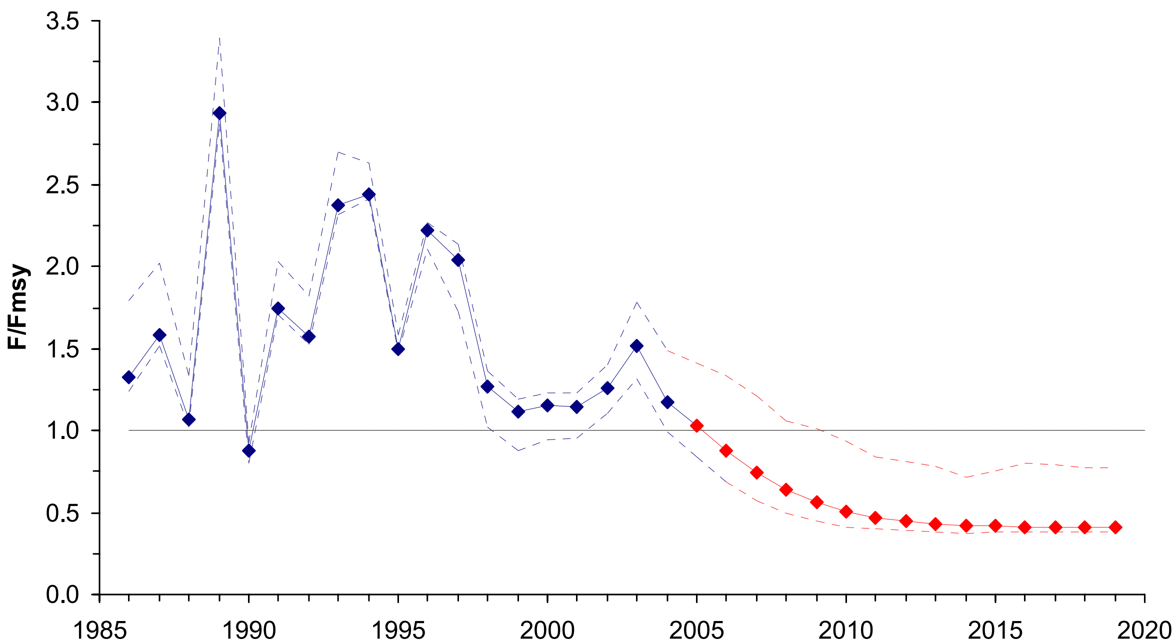


Figure 8: ASPIC estimated (blue) and projected (red) median B/B_{MSY} and F/F_{MSY} trajectories from bootstrap analysis assuming 20% discard mortality and initial B_1/K=0.697. Projections were estimated for constant values of $Yield_{2004}$ (3.1 million pounds). Dashed lines indicate 10^{th}-90^{th} percentiles of bootstrap for base case model.

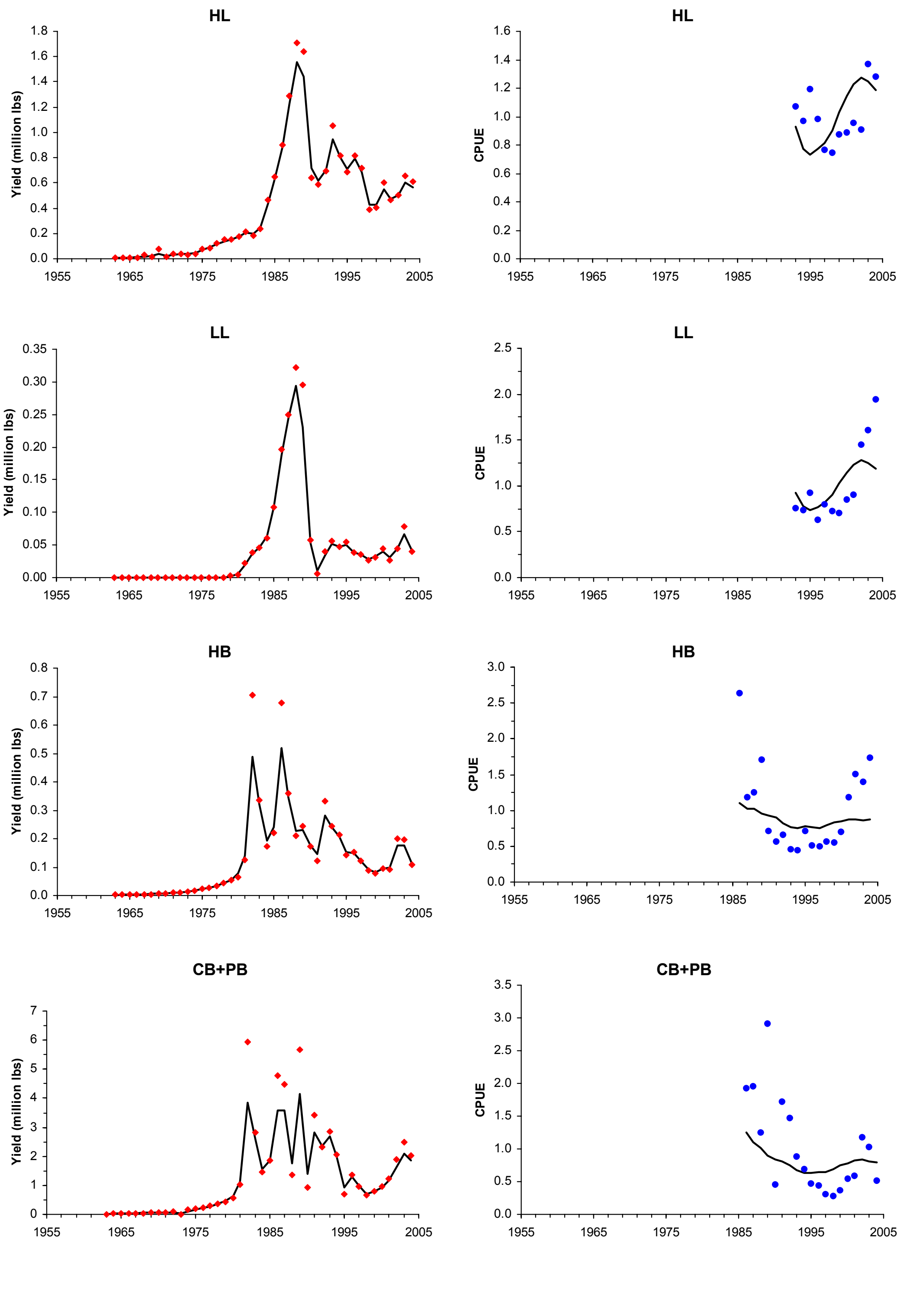


Figure 9: SSASPM fits to yield (left panels) and indices of abundance (right panels).

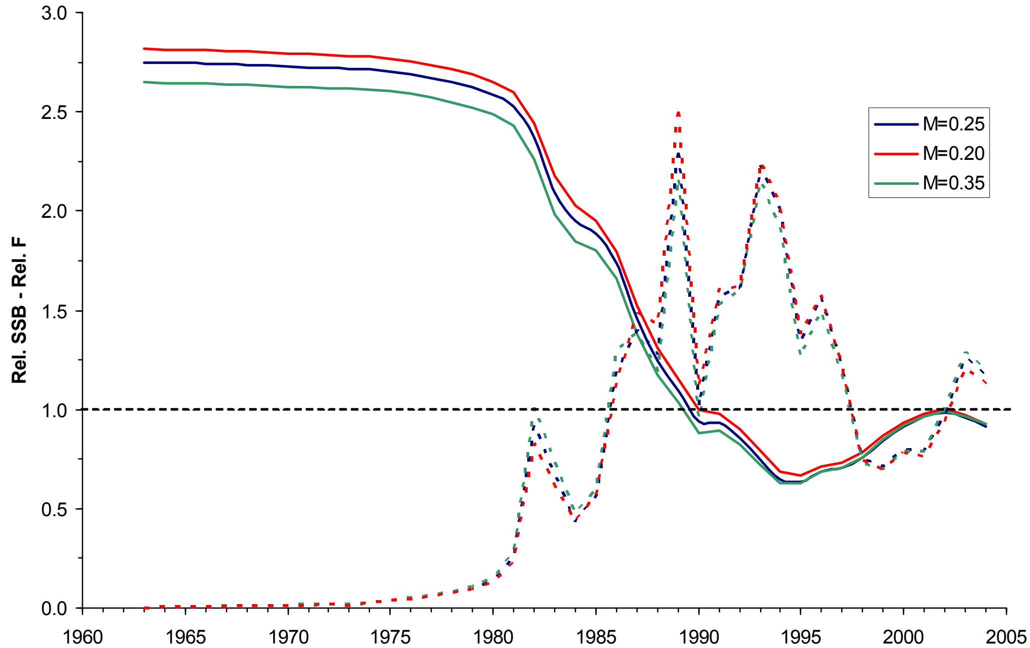


Figure 10: SSASPM estimated trajectory of relative SSB (SSB/SSB_{MSY}) (solid lines) and relative F (F/F_{MSY}) (dashed lines) for three levels of constant M.

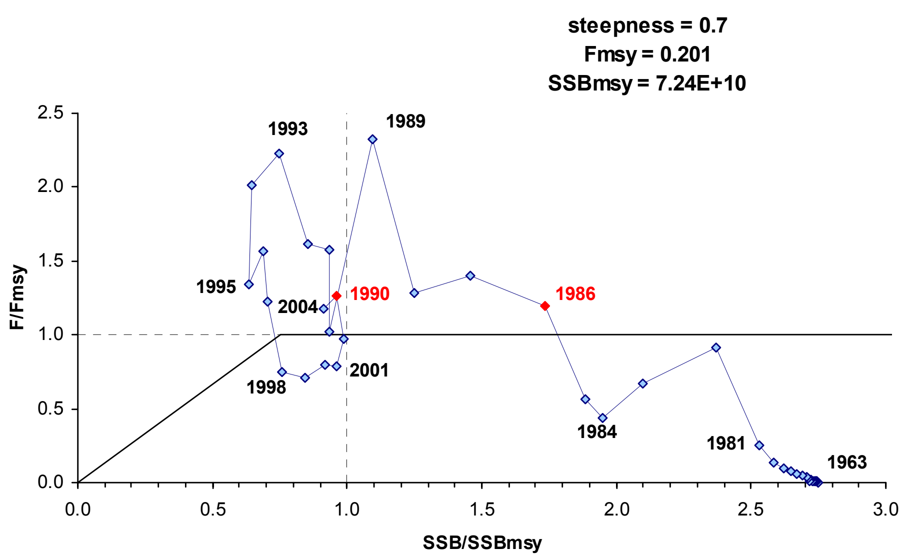


Figure 11: SSASPM control plot for base case indicating that overfishing conditions started in 1986 and the stock became overfished in 1990.

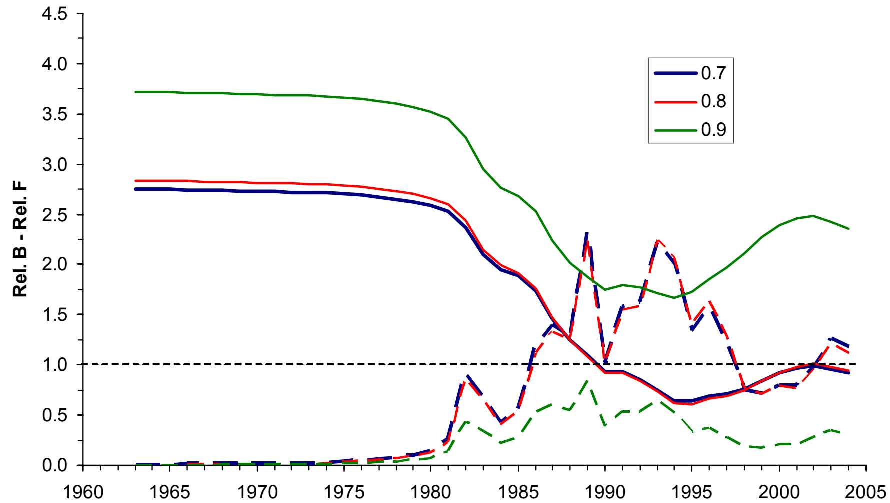


Figure 12: SSASPM estimated trajectory of relative SSB (SSB/SSB_{MSY}) (solid lines) and relative F (F/F_{MSY}) (dashed lines) for M=0.25 and three levels of the mode for the steepness prior.

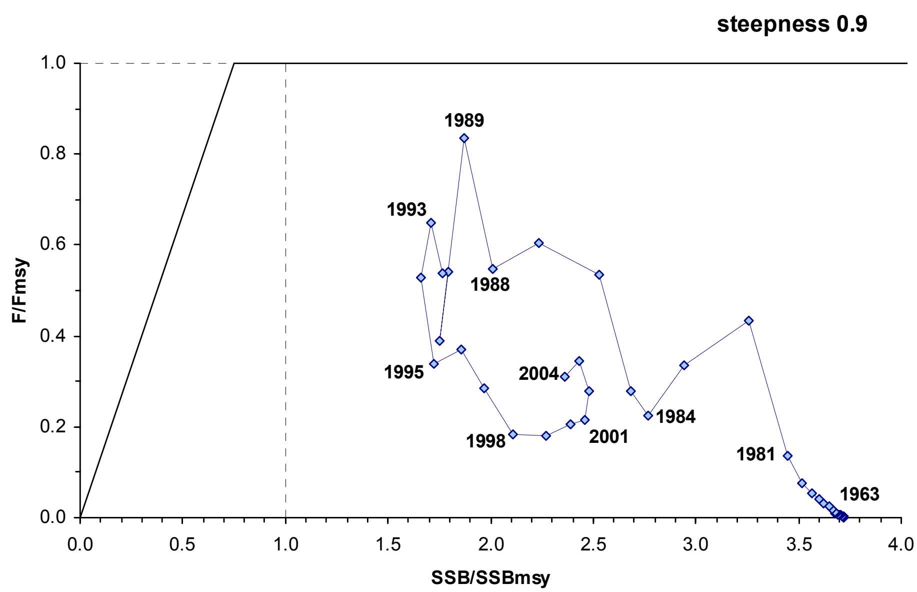


Figure 13: SSASPM control plot for constant M=0.25 and steepness h=0.9 indicating that, under this conditions, the stock never experienced overfishing conditions and never became overfished.

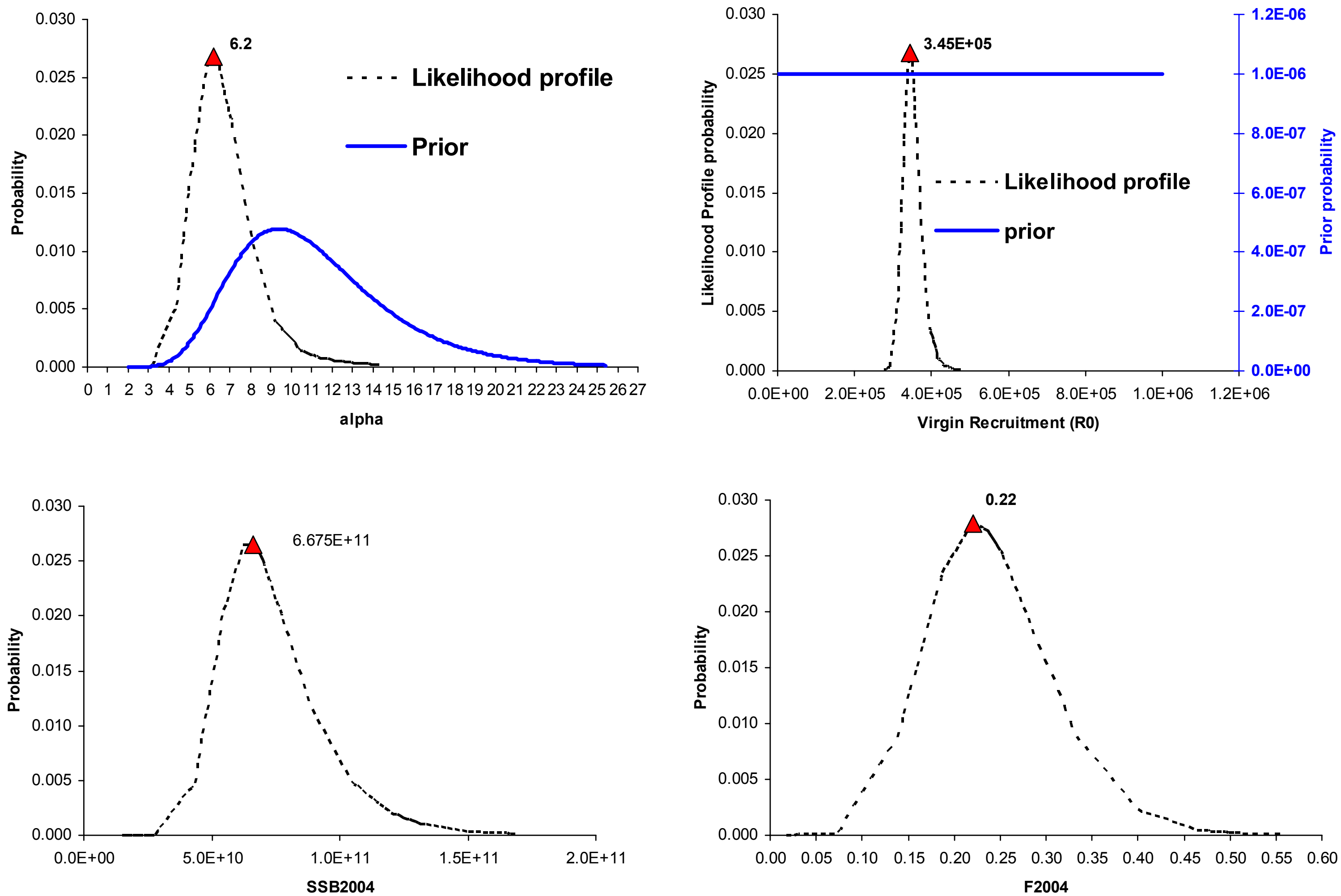


Figure 14: Likelihood profiles of several model parameters for the SSASPM base case. The stock recruit parameters were given priors which are plotted (solid line) with their corresponding likelihood profiles.

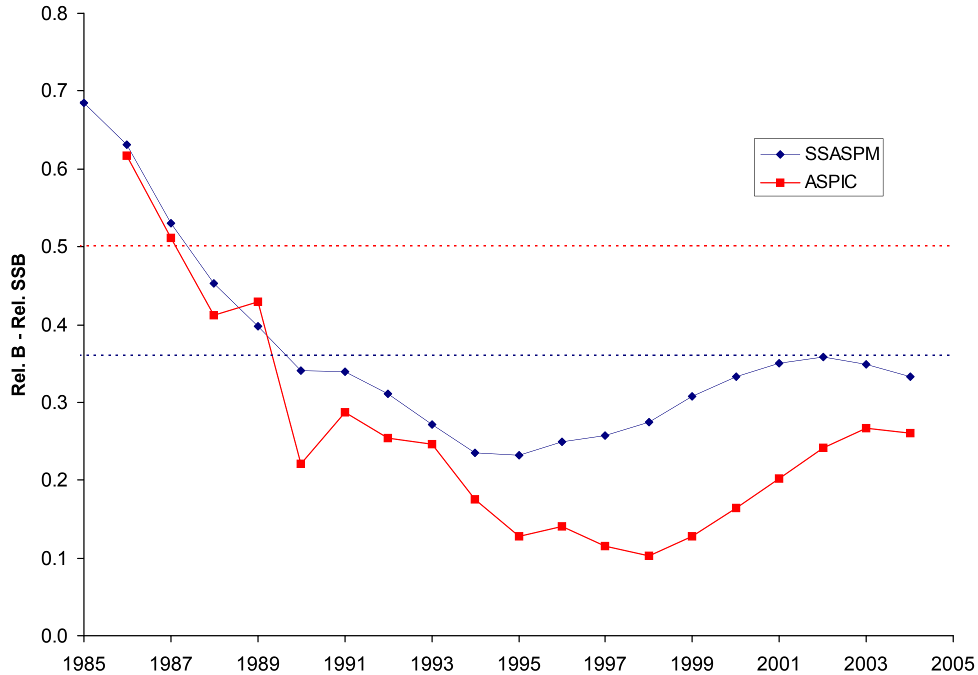


Figure 12: Relative biomass (B/B_0) and relative spawning stock biomass (SSB/SSB_0) estimated by ASPIC (red line) and SSASPM base models (blue line), respectively. Dashed lines show benchmarks (B/B_{MSY} , SSB/SSB_{MSY}) for each model.

APPENDIX 1

Additional ASPIC and SSASPM runs were performed using a revised catch series that included higher commercial catches for the period 1990-2004 (Table 11).

Greater amberjack projections for SSASPM were performed with the program PRO-2BOX developed by C. Porch (2002). PRO-2BOX projects the future status of the stock from estimates of its present state and making certain assumptions about fishery selectivity and the reproductive capability of the stock.

PRO-2BOX has the capability of making separate projections for the different fisheries of the stock (e.g. recreational, commercial longline, etc.). In this case, all projections were made for all fisheries combined to compare with ASPIC projections.

PRO-2BOX bootstrap analyses were performed to estimate variability around the estimated parameters and projection analyses were performed for 8 different scenarios: current yield (3.1 million lbs), F_{2004}, F_{MSY}, and five levels of F/F_{2004}. All bootstraps were performed fixing the stock recruitment relationship to a steepness=0.7.

RESULTS

1) ASPIC

Table 12 shows the predicted values of B_1/K, MSY and K by ASPIC under different initial values of B_1/K and three different levels of assumed release mortality. In general, the model reached similar values for the estimated parameters for all initial conditions and release mortalities. Estimated carrying capacity K ranged from 19.9 to 21.5 million lbs, while MSY ranged from 4.11 to 5.67 million lbs. In general, higher levels of released mortality resulted in higher estimates of K, MSY and F_{MSY} and lower estimates of B_{MSY}. ASPIC runs with starting conditions for $B_1/K=1$ for release mortality 20% and 40% did not produce feasible results ($B_1/K > 1$, total objective function approximately doubled the value of previous runs).

Figure 16 shows the estimated values of relative fishing mortality F/F_{MSY} and relative biomass B/B_{MSY} under different initial values of B_1/K and release mortality. No differences were observed in the ratios estimated using different initial values of B_1/K and the trends were identical between the results obtained with different release mortality. Using a initial value of $B_1/K=0.5$, sensitivities were run for three levels of constant release mortality (0%, 20%, and 40%). The estimated trajectories of relative F and relative B were very similar for the three levels of release mortality (Figure 17) and were within the 10^{th}-90^{th} percentiles of bootstrap for the base case.

Using F_{MSY} and B_{MSY} as benchmarks, the greater amberjack stock has experienced overfishing conditions since at least 1986 (with the exception of 1988 and 1990) and it has been overfished since 1989. Relative SSB showed that a period of recovery started in 1998, two years after the implementation of the 1 fish bag limit for the recreational fishery. Although the recovery period continued until the present, the greater amberjack stock still remains overfished.

The case of 20% release mortality and initial value of $B_1/K=0.5$ was chosen for bootstrap (500 runs) and projection analysis. Relative biomass projections for years 2005-2020 were obtained for (1) different scenarios of future F/F_{2004} (values from 0.5 to 1 by 0.1 intervals) and (2) by keeping the 2004 catch constant (yield + 20% of discards). Figure 18 shows the estimated relative biomass with the 10^{th}-90^{th} percentiles of the bootstrap, as well as projected values under different values of F/F_{2004}.
Projections (Fig. 18) indicated that the greater amberjack stock could be recovered from its overfished condition between 2006 and 2008 depending on the reduction of fishing mortality from its current level (F=0.49). Keeping the current level of fishing mortality will still maintain the stock slightly overfished thorugh year 2020 ($B_{2020}/B_{MSY}=0.98$). Figure 19 presents the control rule plot for $F_{2005\text{-}2020}=F_{2004}$ (status quo F scenario) and it indicates that under the current estimated levels of F, the greater amberjack stock is projected to remain slightly overfished and overfishing is projected to continue. Table 13 presents projected yields under different scenarios of constant F/F_{2004}.

Projections under constant yield showed a better scenario. If the current catch (yield+20% discard mortality) of 3.67 million lbs is kept constant, the greater amberjack stock is projected to recover from the overfished condition by the year 2007 and overfishing will not occur after 2005 (Fig. 20). The recovery is projected to reach a plateau at a relative biomass of 1.48 by year 2017.

Figure 20 and 21 compared the estimated relative F and B and projected values under scenarios of constant catch and F for each catch series. Results were very similar for the case of constant yield (3.67 million and 3.24 million lbs for the revised and original catch series, respectively). Results were a little different for the case of constant F (F=0.49 and F=0.50 for the alternative and original catch series, respectively). The alternative catch series showed that relative B was projected to recover to a value of 0.982 by 2019; while the original catch series only showed a recovery to $B_{2019}/B_{MSY}=0.823$. Although the B/B_{MSY} trajectory of the original series is lower than the estimated with the revised catch series, the projected relative B was within the 10^{th} - 90^{th} percentiles of bootstrap estimates of the alternative series.

(2) Age Structure Production Model SSASPM

SSASPM runs with the revised catch series were performed for the same cases used with the original catch series. Estimated parameters for the base case and the sensitivity runs are presented in Table 14. Like in the previous case, estimated yield showed a good fit to the observed values. However, fits to the CPUE series were poor, particularly for all recreational fisheries.

Figure 22 shows the estimated relative fishing mortality rates (F/F_{MSY}) and spawning stock biomass (SSB/SSB_{MSY}) for the base model and the alternative cases (M=0.2 and M=0.35). All three cases showed similar trends and stock status estimates. Overfishing conditions started in 1986 and the stock became overfished around 1991 (Fig. 22). Relative SSB showed that a period of recovery started around the mid 90's and overfishing did not occur after 1998. However, a decline in relative SSB was observed for the last two years of the series. The model estimated that the stock is currently almost 2/3 depleted (SSB_{2004}/SSB_{virgin}=0.36) with a fishing mortality rate of 0.214. Control rule plot for the base case is presented in Figure 23.

Higher steepness implies greater stock resilience. At the upper limit a steepness of 1 would imply constant recruitment. The model showed that at higher steepness the status of the stock is better. For example, for a steepness of 0.9, which implies a highly resilient stock, the model estimated that the stock was never overfished and never experienced overfishing (Fig. 24). Table 15 shows benchmarks for base case.

To test the sensitivity of the results to gear selectivity, an additional run was performed for the base case reducing the age at 50% selectivity of each gear by one year (Fig. 25). The results (Fig. 26) indicated that reducing the age at 50% selectivity did not change the relative SSB and F trends. However, unlike the original selectivity, the alternative selectivity shows a scenario where the stock did not recover from its overfished condition and overfishing still occurs.

Projection for the revised catch series results indicated that at the present level of yield (3.1 million lbs), the stock will become overfished once again by 2016 and overfishing conditions will reappear in 2006 (Fig.27). In contrast, the model predicts that current levels of F ($F_{current}$= 0.214 as estimated by SSASPM) will maintain the stock from becoming overfished or under overfishing condition. PRO-2BOX projected yields for different scenarios of F/F_{2004} are presented in Table 16 and estimated benchmarks in Table 17.

The projections for the original catch series showed a different scenario (Fig. 28). The stock is not sustainable at the present level of yield and it will collapse by year 2020 (SSB_{2020}/SSB_{MSY}=0.03). Recovery from overfished status and stopping overfishing conditions will require to reduce the current level of F by more than 10%. PRO-2BOX projected yields for different scenarios of F/F_{2004} for the original catch series are presented in Table 18 and estimated benchmarks in Table 19. Figure 29 shows the control rule plot for the original catch series with constant F_{2004} for the projected period 2005-20202.

Figure 29 shows the estimated relative SSB and F for both catch series.

DISCUSSION

Overall, results from both models using the revised catch series showed that the greater amberjack stock is in a slightly better condition than the results obtained with the original catch series. In the case of ASPIC, both models indicated that the stock is overfished at the present time. But, relative B is 0.7 with the revised catch series compared to 0.52 with the original one. In the case of SSASPM, the observed improvement in stock condition did changed the status of the stock. When using MSY as a benchmark, the old catch series showed that in 2004 the stock was still overfished (Rel. SSB=0.91) while the revised   cath series indicated the contrary (Rel. SSB=1.1).These results also indicated that only minor reductions in yield and/or F are required to keep the stock for being overfished.

For both models, the results suggested that to maintain a higher level of yield (as shown in the revised catch series), the greater amberjack stock is required to have a higher productivity than initially estimated. This higher productivity translated into a stock in better condition.

Table 11: Original (HL1-LL1) and revised (HL2-LL2) greater amberjack commercial yield (lbs) by gear for the period 1963-2004. Refer to text for details on the estimation of the historic data (1963-1980). Yield from recreational gears was the same between the two series.

	HL1	LL1	HL2	LL2	HL difference	LL Difference
1963	7,018	*100*	7,018	*100*	0	0
1964	6,176	*100*	6,176	*100*	0	0
1965	5,053	*100*	5,053	*100*	0	0
1966	6,738	*100*	6,738	*100*	0	0
1967	29,197	*100*	29,197	*100*	0	0
1968	11,510	*100*	11,510	*100*	0	0
1969	72,898	*100*	72,898	*100*	0	0
1970	13,663	*100*	13,663	*100*	0	0
1971	38,461	*100*	38,461	*100*	0	0
1972	41,643	*100*	41,643	*100*	0	0
1973	28,261	*100*	28,261	*100*	0	0
1974	41,736	*100*	41,736	*100*	0	0
1975	78,139	*100*	78,139	*100*	0	0
1976	86,467	*100*	86,467	*100*	0	0
1977	119,870	*100*	119,870	*100*	0	0
1978	150,672	*100*	150,672	*100*	0	0
1979	148,748	2,714	148,748	2,714	0	0
1980	173,632	4,754	173,632	4,754	0	0
1981	212,666	22,450	212,666	22,450	0	0
1982	184,403	39,106	184,403	39,106	0	0
1983	233,233	45,571	233,233	45,571	0	0
1984	465,166	60,616	465,166	60,616	0	0
1985	645,207	108,229	645,207	108,229	0	0
1986	903,545	196,562	903,545	196,562	0	0
1987	1,288,095	249,456	1,288,095	249,456	0	0
1988	1,709,427	321,553	1,709,427	321,553	0	0
1989	1,636,113	295,908	1,636,113	295,908	0	0
1990	638,360	57,268	1,085,450	124,595	447,090	67,327
1991	585,150	6,047	1,369,133	6,047	783,983	0
1992	691,440	39,428	940,832	50,324	249,392	10,896
1993	1,050,500	56,112	1,489,607	80,003	439,107	23,891
1994	819,540	47,722	1,201,265	68,688	381,725	20,966
1995	686,310	54,845	1,177,210	81,850	490,900	27,005
1996	812,490	38,346	1,210,030	56,802	397,540	18,456
1997	716,580	35,858	1,055,346	59,410	338,766	23,552
1998	387,210	26,326	643,827	54,854	256,617	28,528
1999	405,370	31,452	714,753	60,437	309,383	28,985
2000	602,380	44,355	851,303	70,492	248,923	26,137
2001	464,790	27,024	685,581	47,253	220,791	20,229
2002	505,840	43,898	712,632	77,771	206,792	33,873
2003	656,720	77,658	873,636	125,515	216,916	47,857
2004	609,300	39,980	872,346	82,442	263,046	42,462

Table 12: ASPIC parameter estimates for three different initial values of B_1/K and three different levels of release mortality for the revised yield series.

Assumed released mortality	Estimated Parameters	Initial input value for B_1/K		
		1.0	0.5	0.2
0 %	B_1/K	0.726	0.683	0.664
	MSY	4.113E+06	4.250E+06	4.295E+06
	K	2.025E+07	2.011E+07	2.037E+07
	B_{MSY}	1.012E+07	1.006E+07	1.018E+07
	F_{MSY}	0.406	0.422	0.422
	B/B_{MSY} (2004)	0.641	0.618	0.610
	F/F_{MSY} (2004)	0.890	0.894	1.122
20%	B_1/K		0.8399	0.8387
	MSY		4.815E+06	4.815E+06
	K		1.987E+07	1.990E+07
	B_{MSY}		9.937E+06	9.948E+06
	F_{MSY}		0.485	0.484
	B/B_{MSY} (2004)		0.706	0.691
	F/F_{MSY} (2004)		1.017	0.961
40%	B_1/K		0.984	0.810
	MSY		5.456E+06	5.671E+06
	K		2.075E+07	2.153E+07
	B_{MSY}		1.038E+07	1.076E+07
	F_{MSY}		0.526	0.527
	B/B_{MSY} (2004)		0.765	0.721
	F/F_{MSY} (2004)		0.955	0.966

Table 13: ASPIC projected yields for constant values of F/F_{2004} for the revised catch series.

	0.5	0.6	0.7	0.8	0.9	1.0
2005	2.253E+06	2.644E+06	3.017E+06	3.372E+06	3.711E+06	4.034E+06
2006	2.802E+06	3.193E+06	3.534E+06	3.830E+06	4.084E+06	4.297E+06
2007	3.181E+06	3.573E+06	3.894E+06	4.149E+06	4.342E+06	4.479E+06
2008	3.407E+06	3.806E+06	4.120E+06	4.353E+06	4.511E+06	4.600E+06
2009	3.529E+06	3.937E+06	4.252E+06	4.477E+06	4.617E+06	4.678E+06
2010	3.591E+06	4.008E+06	4.326E+06	4.550E+06	4.683E+06	4.729E+06
2011	3.623E+06	4.045E+06	4.368E+06	4.592E+06	4.722E+06	4.760E+06
2012	3.638E+06	4.064E+06	4.390E+06	4.617E+06	4.746E+06	4.780E+06
2013	3.645E+06	4.074E+06	4.402E+06	4.630E+06	4.760E+06	4.793E+06
2014	3.649E+06	4.079E+06	4.408E+06	4.638E+06	4.768E+06	4.801E+06
2015	3.651E+06	4.081E+06	4.412E+06	4.642E+06	4.773E+06	4.805E+06
2016	3.652E+06	4.083E+06	4.414E+06	4.645E+06	4.776E+06	4.808E+06
2017	3.652E+06	4.083E+06	4.415E+06	4.646E+06	4.778E+06	4.810E+06
2018	3.652E+06	4.084E+06	4.415E+06	4.647E+06	4.779E+06	4.811E+06
2019	3.652E+06	4.084E+06	4.416E+06	4.647E+06	4.780E+06	4.812E+06

Table 14: SSASPM estimates of fishing mortality rate (F_{MSY}), yield (Y_{MSY}), spawning stock biomass (SSB_{MSY}), spawning potential ratio (SPR_{MSY}) and number of recruits at MSY for base case (M=0.25 / h=0.7) and sensitivities (refer to text for explanation of sensitivity runs) for the revised yield series.

Parameters	F_{MSY}	Y_{MSY}	SSB_{MSY}	SPR_{MSY}	$Recruits_{MSY}$
M=0.25 / h=0.7	**0.224**	**2.69E+06**	**7.65E+10**	**0.452**	**2.93E+05**
M=0.20 / h=0.7	0.200	2.61E+06	7.93E+10	0.428	2.29E+05
M=0.35 / h=0.7	0.259	2.78E+06	7.28E+10	0.495	4.49E+05
M=0.25 / h=0.8	0.267	2.90E+06	6.95E+10	0.399	3.02E+05
M=0.25 / h=0.9	0.379	3.63E+06	6.07E+10	0.295	3.56E+05

Table 15: SSASPM relative benchmarks for the base case (M=0.25, h=0.7).

Type	F	Y/R	SSB/SSB_0	SPR	Recruits
Virgin	0.000	0.00	1.000	1.000	3.70E+05
MSY	**0.224**	**9.17**	**0.358**	**0.452**	**2.93E+05**
MAX YPR	0.550	10.40	0.079	0.213	1.38E+05
F0.1	0.241	9.36	0.334	0.431	2.87E+05
20% SPR	0.583	10.40	0.064	0.200	1.18E+05
30% SPR	0.387	10.20	0.181	0.300	2.23E+05
40% SPR	0.268	9.62	0.299	0.400	2.76E+05
50% SPR	0.188	8.66	0.416	0.500	3.07E+05
60% SPR	0.130	7.39	0.533	0.600	3.28E+05

Table 16: PRO-2BOX projected median yields under different scenarios of F and F/F_{2004} for the revised catch series.

YEAR	Fmsy	Fcurrent	90% F current	80% Fcurrent	70% F current	60% F current	50% F current
2005	3.09E+06	3.00E+06	2.73E+06	2.45E+06	2.16E+06	1.87E+06	1.57E+06
2006	3.09E+06	2.99E+06	2.76E+06	2.52E+06	2.26E+06	1.98E+06	1.70E+06
2007	3.01E+06	2.95E+06	2.76E+06	2.56E+06	2.33E+06	2.08E+06	1.80E+06
2008	3.02E+06	2.93E+06	2.77E+06	2.59E+06	2.39E+06	2.15E+06	1.89E+06
2009	2.99E+06	2.95E+06	2.82E+06	2.66E+06	2.46E+06	2.24E+06	1.99E+06
2010	2.98E+06	2.94E+06	2.83E+06	2.69E+06	2.52E+06	2.31E+06	2.06E+06
2011	2.97E+06	2.93E+06	2.84E+06	2.72E+06	2.57E+06	2.37E+06	2.13E+06
2012	2.94E+06	2.91E+06	2.84E+06	2.73E+06	2.59E+06	2.41E+06	2.18E+06
2013	2.98E+06	2.93E+06	2.86E+06	2.75E+06	2.62E+06	2.44E+06	2.22E+06
2014	2.93E+06	2.92E+06	2.86E+06	2.76E+06	2.63E+06	2.47E+06	2.25E+06
2015	2.93E+06	2.89E+06	2.83E+06	2.75E+06	2.64E+06	2.48E+06	2.27E+06
2016	2.87E+06	2.84E+06	2.80E+06	2.73E+06	2.62E+06	2.48E+06	2.28E+06
2017	2.88E+06	2.85E+06	2.82E+06	2.74E+06	2.64E+06	2.48E+06	2.28E+06
2018	2.88E+06	2.86E+06	2.80E+06	2.74E+06	2.64E+06	2.50E+06	2.31E+06
2019	2.89E+06	2.87E+06	2.82E+06	2.75E+06	2.65E+06	2.51E+06	2.32E+06
2020	2.91E+06	2.87E+06	2.85E+06	2.78E+06	2.69E+06	2.55E+06	2.36E+06

Table 17: PRO-2BOX estimated benchmarks by 500 bootstraps for the revised catch series. Lower CL and Upper CL corresponds to 80% confidence intervals of the estimated Median, RUN0 indicates deterministic estimate of parameters.

MEASURE	LOWER CL	MEDIAN	UPPER CL	AVERAGE	RUN 0	STD. DEV.
F at MSY	0.209	0.232	0.268	0.237	0.218	0.027
MSY	2.56E+03	2.67E+03	2.77E+03	2.67E+03	2.67E+03	8.13E+01
Y/R at MSY	8.768	9.102	9.387	9.089	9.104	0.237
S/R at MSY	2.56E+05	2.60E+05	2.63E+05	2.60E+05	2.60E+05	2.82E+03
SPR AT MSY	0.444	0.451	0.456	0.450	0.451	0.005
SSB AT MSY	7.46E+07	7.63E+07	7.78E+07	7.62E+07	7.65E+07	1.22E+06
F at max. Y/R	0.515	0.574	0.667	0.586	0.536	0.072
Y/R maximum	10.093	10.361	10.563	10.345	10.343	0.182
S/R at Fmax	1.08E+05	1.20E+05	1.31E+05	1.20E+05	1.21E+05	9.03E+03
SPR at Fmax	0.187	0.209	0.228	0.208	0.210	0.016
SSB at Fmax	1.05E+07	1.58E+07	2.06E+07	1.57E+07	1.63E+07	3.91E+06
F 0.1	0.232	0.250	0.294	0.258	0.236	0.033
Y/R at F0.1	9.158	9.329	9.456	9.318	9.316	0.116
S/R at F0.1	2.29E+05	2.46E+05	2.61E+05	2.45E+05	2.47E+05	1.25E+04
SPR at F0.1	0.396	0.426	0.453	0.425	0.428	0.022
SSB at F0.1	6.28E+07	7.01E+07	7.68E+07	6.99E+07	7.07E+07	5.42E+06
F 20% SPR	0.508	0.597	0.715	0.607	0.558	0.084
Y/R at F20	10.086	10.358	10.552	10.338	10.340	0.179
S/R at F20	1.16E+05	1.16E+05	1.16E+05	1.16E+05	1.16E+05	6.90E+01
SSB at F20	1.39E+07	1.40E+07	1.40E+07	1.40E+07	1.40E+07	2.99E+04
F 30% SPR	0.346	0.397	0.466	0.404	0.372	0.051
Y/R at F30	9.817	10.148	10.415	10.135	10.148	0.233
S/R at F30	1.74E+05	1.74E+05	1.74E+05	1.74E+05	1.74E+05	1.18E+02
SSB at F30	3.89E+07	3.90E+07	3.91E+07	3.90E+07	3.90E+07	5.13E+04
F 40% SPR	0.245	0.276	0.321	0.281	0.259	0.033
Y/R at F40	9.154	9.531	9.847	9.518	9.537	0.269
S/R at F40	2.32E+05	2.32E+05	2.32E+05	2.32E+05	2.32E+05	1.76E+02
SSB at F40	6.39E+07	6.40E+07	6.41E+07	6.40E+07	6.41E+07	7.61E+04
F 90% max Y/R	0.229	0.251	0.290	0.257	0.235	0.031
Y 90% max Y/R	2.54E+03	2.66E+03	2.77E+03	2.66E+03	2.67E+03	8.83E+01
Y/R 90% max Y/R	9.075	9.319	9.502	9.306	9.305	0.164
S/R 90% max Y/R	2.34E+05	2.47E+05	2.57E+05	2.46E+05	2.48E+05	8.79E+03
SSB 90% max Y/R	6.52E+07	7.06E+07	7.50E+07	7.04E+07	7.10E+07	3.81E+06
F 75% of Fmax	0.386	0.431	0.500	0.440	0.402	0.054
Y 75% of Fmax	1.90E+03	2.12E+03	2.30E+03	2.11E+03	2.14E+03	1.53E+02
Y/R at 75% Fmax	9.969	10.241	10.451	10.226	10.223	0.186
S/R at 75% Fmax	1.49E+05	1.61E+05	1.71E+05	1.61E+05	1.62E+05	8.45E+03
SSB at 75% Fmax	2.83E+07	3.35E+07	3.78E+07	3.33E+07	3.39E+07	3.66E+06

Table 18: PRO-2BOX projected median yields under different scenarios of F and F/F_{2004} for the original catch series.

YEAR	Fmsy	Fcurrent	90% Fcurrent	80% Fcurrent	70% Fcurrent	60% Fcurrent	50% Fcurrent
2005	2.34E+06	2.72E+06	2.47E+06	2.22E+06	1.96E+06	1.70E+06	1.43E+06
2006	2.39E+06	2.70E+06	2.49E+06	2.28E+06	2.05E+06	1.81E+06	1.55E+06
2007	2.39E+06	2.64E+06	2.49E+06	2.32E+06	2.12E+06	1.90E+06	1.65E+06
2008	2.43E+06	2.61E+06	2.48E+06	2.33E+06	2.16E+06	1.97E+06	1.74E+06
2009	2.47E+06	2.63E+06	2.53E+06	2.41E+06	2.25E+06	2.07E+06	1.85E+06
2010	2.50E+06	2.61E+06	2.53E+06	2.42E+06	2.29E+06	2.13E+06	1.92E+06
2011	2.51E+06	2.60E+06	2.55E+06	2.46E+06	2.34E+06	2.18E+06	1.98E+06
2012	2.50E+06	2.58E+06	2.53E+06	2.47E+06	2.37E+06	2.22E+06	2.03E+06
2013	2.56E+06	2.62E+06	2.57E+06	2.50E+06	2.40E+06	2.27E+06	2.09E+06
2014	2.53E+06	2.57E+06	2.54E+06	2.49E+06	2.41E+06	2.28E+06	2.11E+06
2015	2.53E+06	2.56E+06	2.54E+06	2.50E+06	2.42E+06	2.31E+06	2.14E+06
2016	2.51E+06	2.52E+06	2.50E+06	2.47E+06	2.39E+06	2.30E+06	2.14E+06
2017	2.50E+06	2.49E+06	2.51E+06	2.48E+06	2.43E+06	2.32E+06	2.16E+06
2018	2.53E+06	2.51E+06	2.52E+06	2.49E+06	2.43E+06	2.33E+06	2.19E+06
2019	2.55E+06	2.53E+06	2.54E+06	2.51E+06	2.44E+06	2.35E+06	2.21E+06
2020	2.55E+06	2.53E+06	2.54E+06	2.53E+06	2.48E+06	2.39E+06	2.24E+06

Table 19: PRO-2BOX estimated benchmarks by 500 bootstraps for the original catch series. Lower CL and Upper CL corresponds to 80% confidence intervals of the estimated Median, RUN0 indicates deterministic estimate of parameters.

MEASURE	LOWER CL	MEDIAN	UPPER CL	AVERAGE	RUN 0	STD. DEV.
F at MSY	0.193	0.214	0.252	0.220	0.196	0.029
MSY	2.26E+03	2.37E+03	2.46E+03	2.36E+03	2.37E+03	7.84E+01
Y/R at MSY	8.467	8.822	9.117	8.807	8.823	0.250
S/R at MSY	2.65E+05	2.69E+05	2.72E+05	2.69E+05	2.69E+05	2.85E+03
SPR AT MSY	0.459	0.466	0.472	0.466	0.467	0.005
SSB AT MSY	7.05E+07	7.22E+07	7.36E+07	7.21E+07	7.24E+07	1.17E+06
F at max. Y/R	0.505	0.562	0.673	0.582	0.512	0.084
Y/R maximum	10.008	10.276	10.478	10.260	10.253	0.185
S/R at Fmax	1.03E+05	1.17E+05	1.28E+05	1.16E+05	1.18E+05	9.80E+03
SPR at Fmax	0.178	0.202	0.223	0.202	0.204	0.017
SSB at Fmax	3.84E+06	9.56E+06	1.44E+07	9.38E+06	1.00E+07	3.97E+06
F 0.1	0.230	0.248	0.316	0.262	0.230	0.041
Y/R at F0.1	9.100	9.280	9.409	9.267	9.260	0.123
S/R at F0.1	2.22E+05	2.41E+05	2.57E+05	2.40E+05	2.42E+05	1.36E+04
SPR at F0.1	0.385	0.417	0.446	0.416	0.420	0.023
SSB at F0.1	5.29E+07	6.06E+07	6.74E+07	6.03E+07	6.13E+07	5.58E+06
F 20% SPR	0.496	0.567	0.690	0.584	0.519	0.082
Y/R at F20	9.993	10.274	10.472	10.253	10.253	0.187
S/R at F20	1.16E+05	1.16E+05	1.16E+05	1.16E+05	1.16E+05	7.00E+01
SSB at F20	9.23E+06	9.27E+06	9.31E+06	9.27E+06	9.29E+06	2.88E+04
F 30% SPR	0.339	0.382	0.459	0.392	0.349	0.051
Y/R at F30	9.690	10.036	10.313	10.022	10.034	0.244
S/R at F30	1.74E+05	1.74E+05	1.74E+05	1.74E+05	1.74E+05	1.23E+02
SSB at F30	3.30E+07	3.31E+07	3.31E+07	3.31E+07	3.31E+07	5.08E+04
F 40% SPR	0.239	0.268	0.318	0.275	0.245	0.035
Y/R at F40	9.013	9.402	9.735	9.390	9.412	0.282
S/R at F40	2.31E+05	2.32E+05	2.32E+05	2.32E+05	2.32E+05	1.90E+02
SSB at F40	5.68E+07	5.69E+07	5.70E+07	5.69E+07	5.69E+07	7.83E+04
F 90% max Y/R	0.225	0.247	0.300	0.257	0.227	0.038
Y 90% max Y/R	2.21E+03	2.34E+03	2.45E+03	2.33E+03	2.34E+03	9.32E+01
Y/R 90% max Y/R	9.004	9.243	9.426	9.229	9.227	0.167
S/R 90% max Y/R	2.29E+05	2.44E+05	2.55E+05	2.43E+05	2.45E+05	9.77E+03
SSB 90% max Y/R	5.59E+07	6.19E+07	6.63E+07	6.15E+07	6.22E+07	4.02E+06
F 75% of Fmax	0.379	0.422	0.505	0.436	0.384	0.063
Y 75% of Fmax	1.44E+03	1.70E+03	1.89E+03	1.68E+03	1.72E+03	1.75E+02
Y/R at 75% Fmax	9.878	10.153	10.363	10.139	10.132	0.189
S/R at 75% Fmax	1.45E+05	1.58E+05	1.69E+05	1.57E+05	1.59E+05	9.38E+03
SSB at 75% Fmax	2.11E+07	2.66E+07	3.10E+07	2.62E+07	2.70E+07	3.86E+06

Table 20: Estimated benchmarks by ASPIC and SSASPM base cases for the revised catch series.

Benchmark	ASPIC	SSASPM
MSY	4.82E+06	2.69E+06
F_{MSY}	0.485	0.224
F_{1986}	0.51	0.212
F_{2004}	0.49	0.214
B_{1986}/B_{MSY}	1.68	1.84
B_{2004}/B_{MSY}	0.71	1.09
F_{1986}/F_{MSY}	1.04	0.95
F_{2004}/F_{MSY}	1.02	0.96

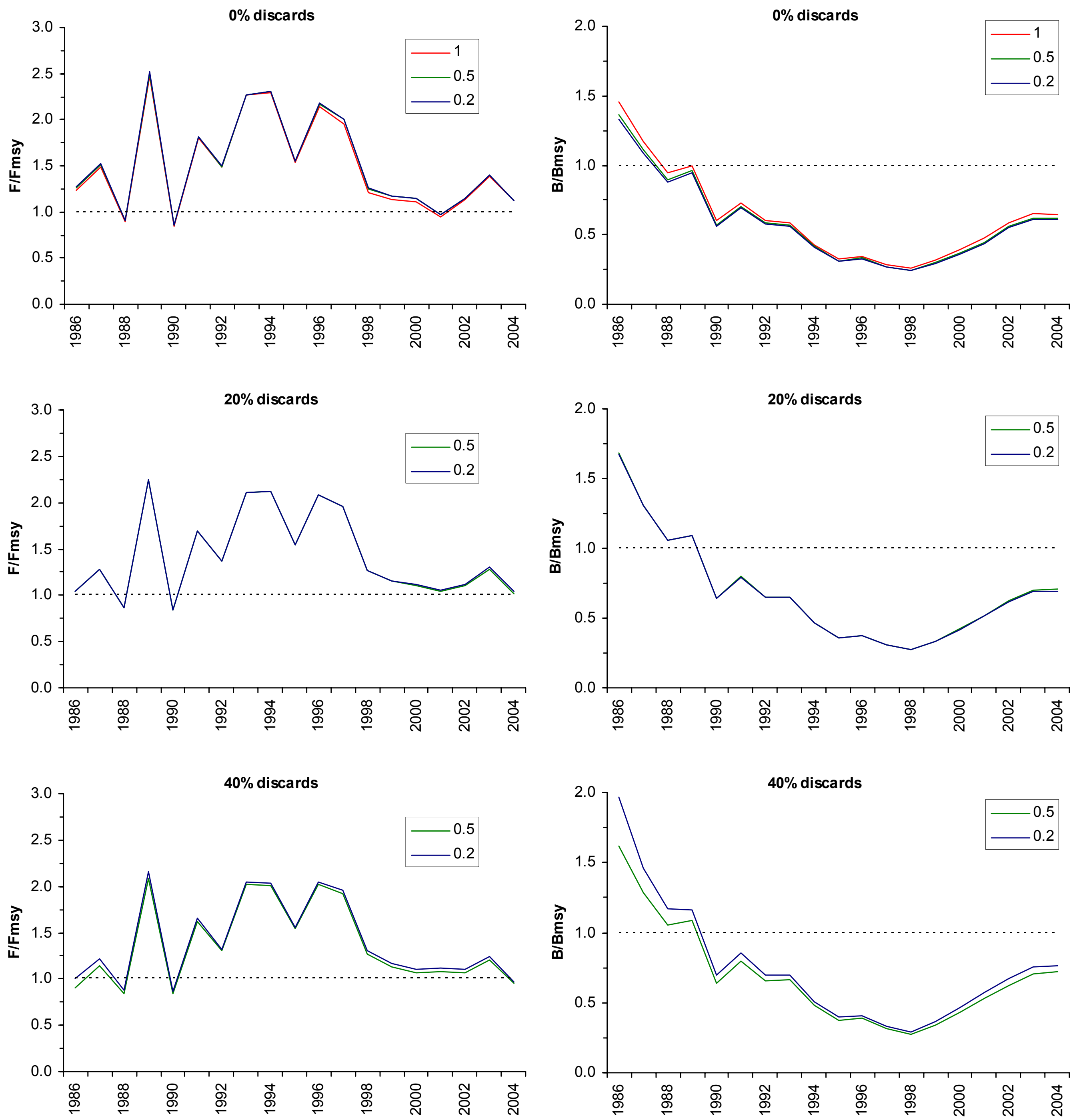


Figure 16: ASPIC estimated relative F (F/F_{MSY}) and relative B (B/B_{MSY}) for three levels of discard mortality and initial values of B_1/K for the alternative catch series.

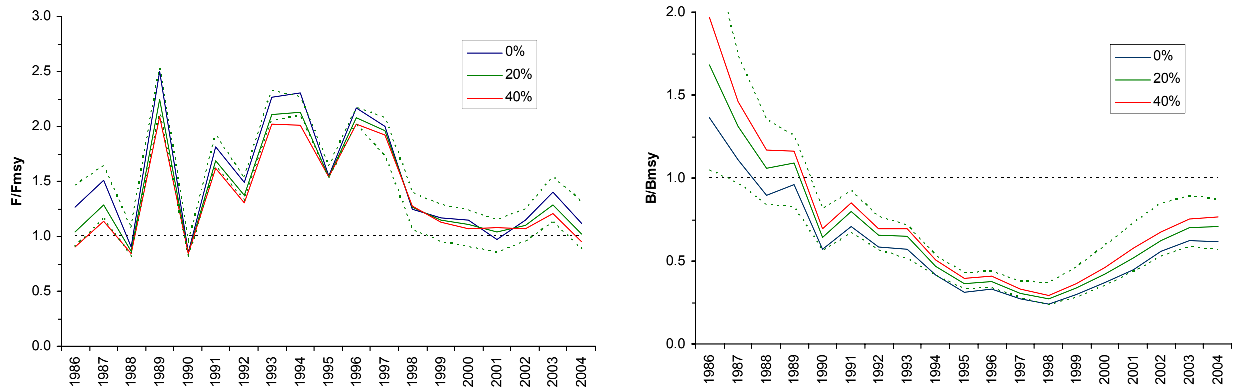


Figure 17: ASPIC estimated relative F (F/F_{MSY}) and relative B (B/B_{MSY}) for three levels of discard mortality and initial value of B_1/K=0.5 for the alternative catch series. Dashed lines correspond to 10th - 90th percentiles of bootstrap.

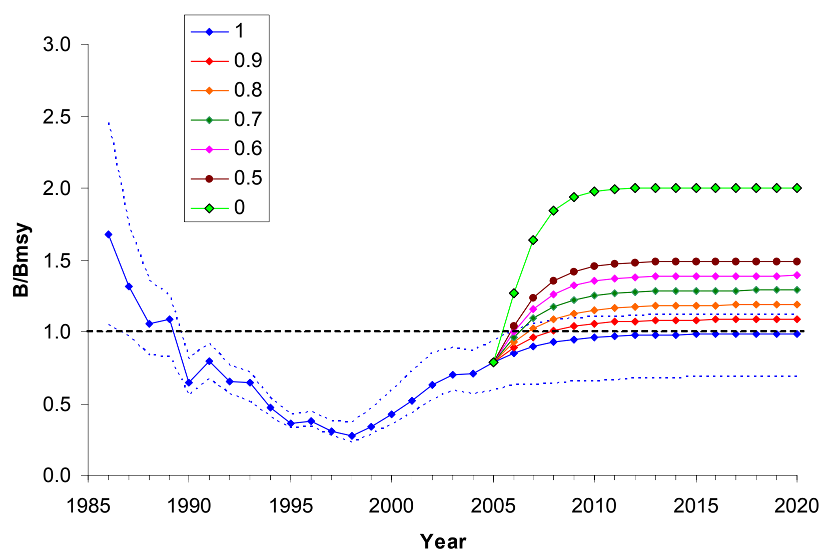


Figure 18: Aspic estimated relative biomass (B/B_{MSY}) and projected values for different constant values of F/F_{2004} for the alternative cath series.

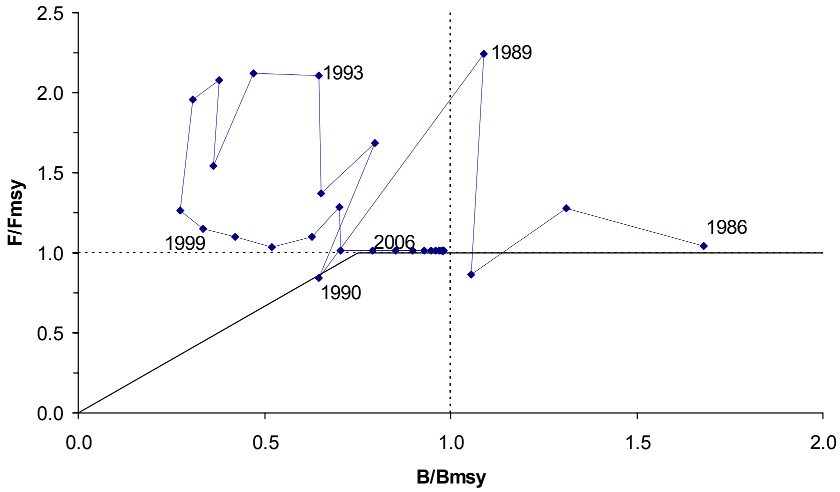


Figure 19: ASPIC control rule plot (1986-2020) assuming status quo fishing mortality rate for the projected period 2005-2020 for the alternative catch series.

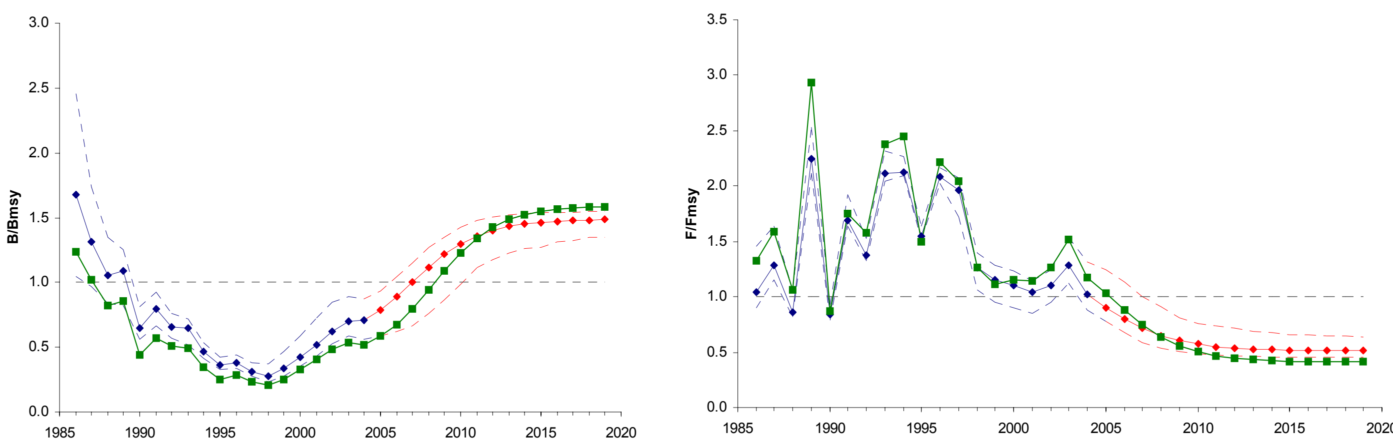


Figure 20: ASPIC estimated and projected relative biomass (B/B_{MSY}) and relative F (F/F_{MSY}) for the alternative catch series (blue line and symbols correspond to historical data, red to projected values) and original catch series (green line and symbols) for constant values of catch for 2005-2019. Dashed lines correspond to 10^{th} - 90^{th} percentiles of bootstrap.

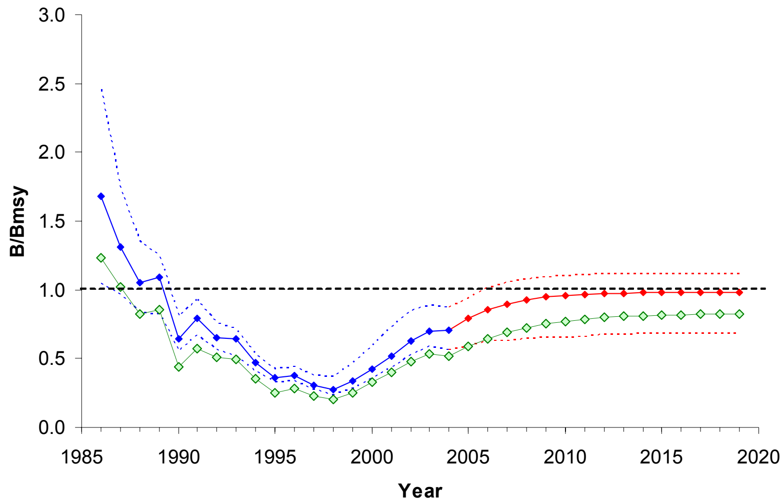


Figure 21: ASPIC estimated and projected relative biomass (B/B_{MSY}) for the alternative catch series (blue line and symbols correspond to historical data, red to projected values) and original catch series (green line and symbols) for constant values of F for 2005-2019. Dashed lines correspond to 10^{th} - 90^{th} percentiles of bootstrap.

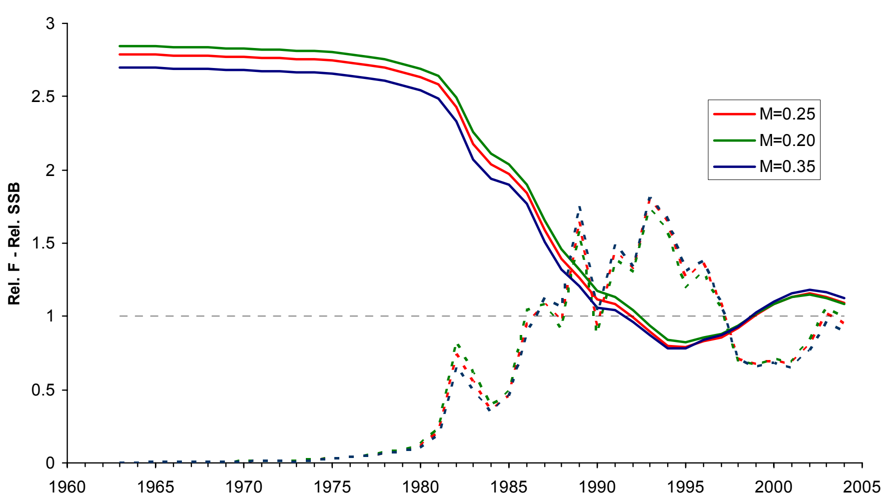


Figure 22: SSASPM estimate trajectories of relative SSB (SSB/SSB_{MSY}) (solid lines) and relative F (F/F_{MSY}) (dashed lines) for three levels of constant M for the alternative catch series.

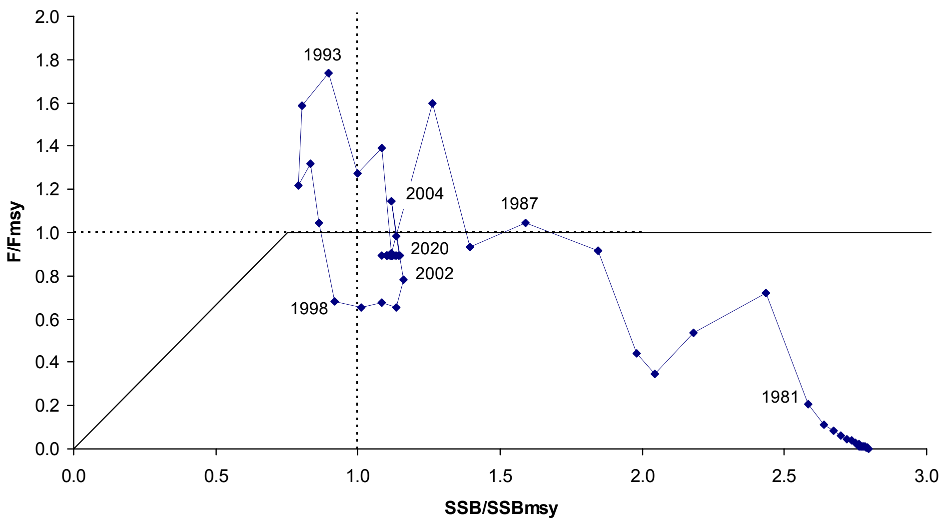


Figure 23: PRO-2BOX control rule plot for base case assuming status quo fishing mortality rate for the period 2005-202 for the revised catch series.

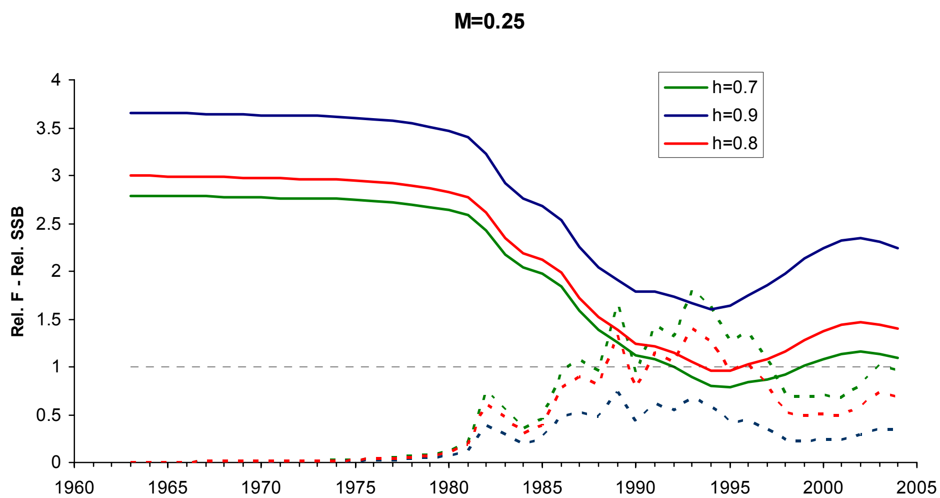


Figure 24: SSASPM estimated trajectory of relative SSB (SSB/SSB_{MSY}) (solid lines) and relative F (F/F_{MSY}) (dashed lines) for M=0.25 and three levels of the model for the steepness prior for the alternative catch series.

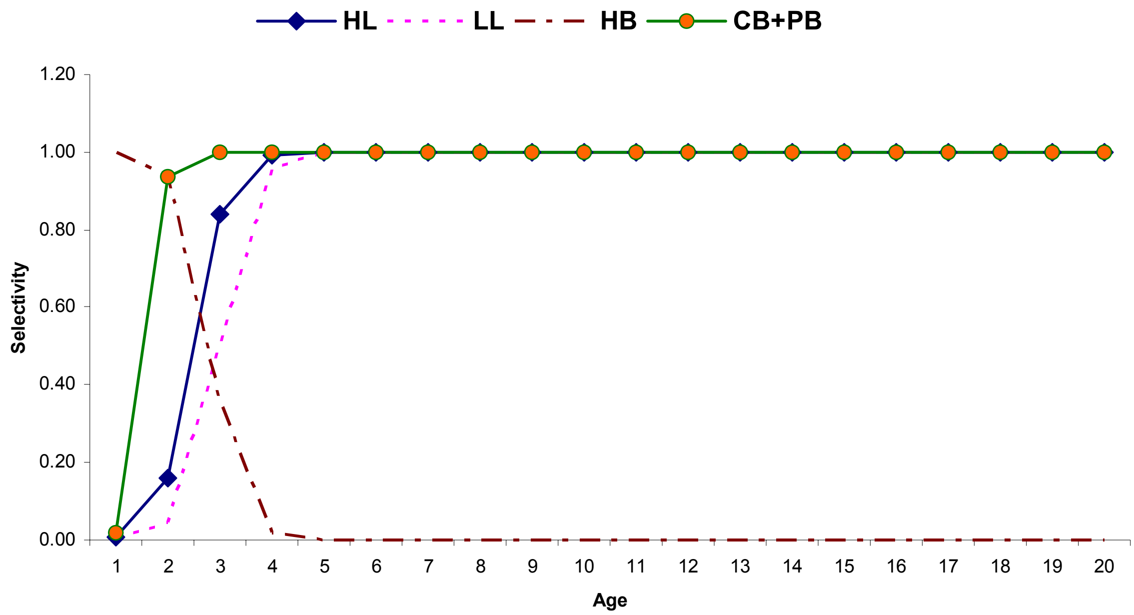


Figure 25: SSASPM alternative gear selectivity estimated reducing age at 50% selectivity by 1 year.

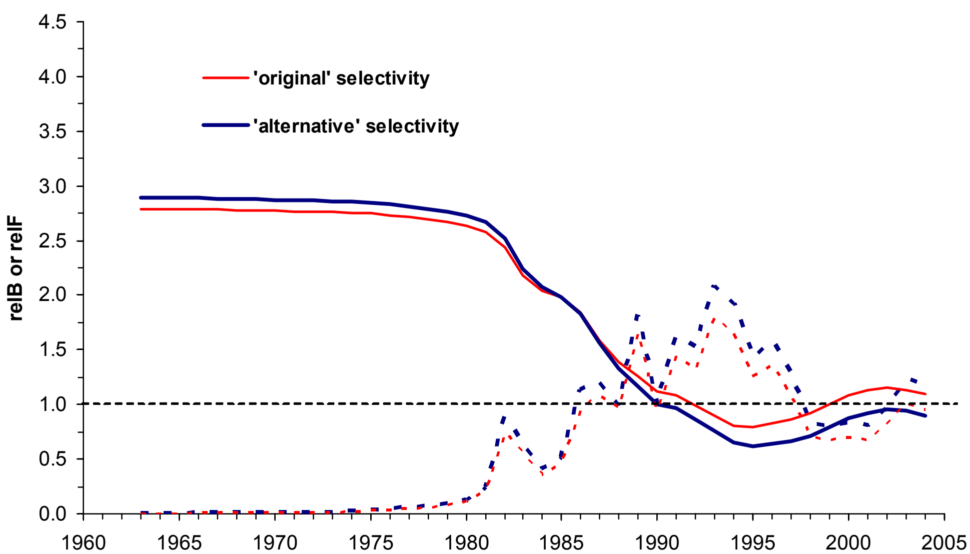


Figure 26: SSASPM estimated trajectory of relative SSB (SSB/SSB_{MSY}) (solid lines) and relative F (F/F_{MSY}) (dashed lines) for M=0.25 and two different gear selectivities for the revised catch series.

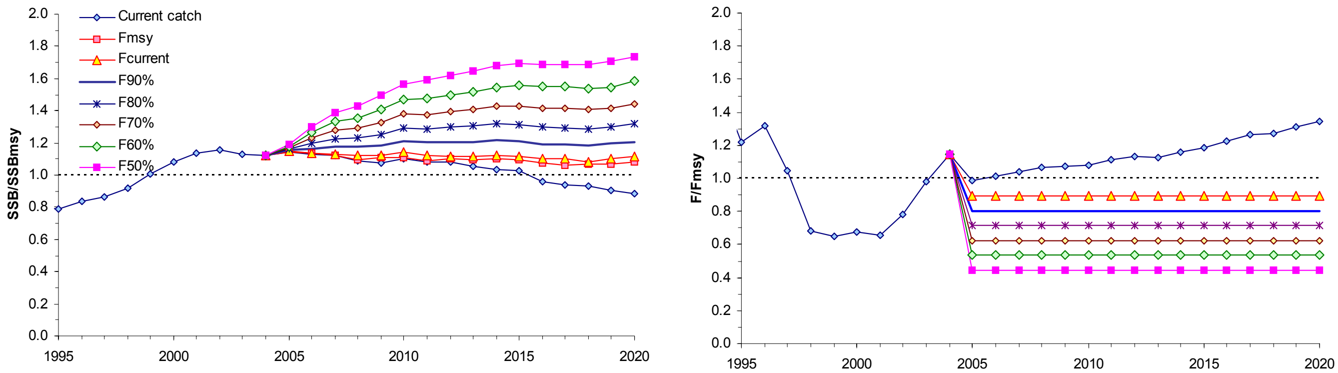


Figure 27: SSASPM projected relative SSB (SSB/SSB_{MSY}) and relative F (F/F_{MSY}) for constant yield, F_{MSY} and different scenarios of F/F_{2004} for the revised catch series.

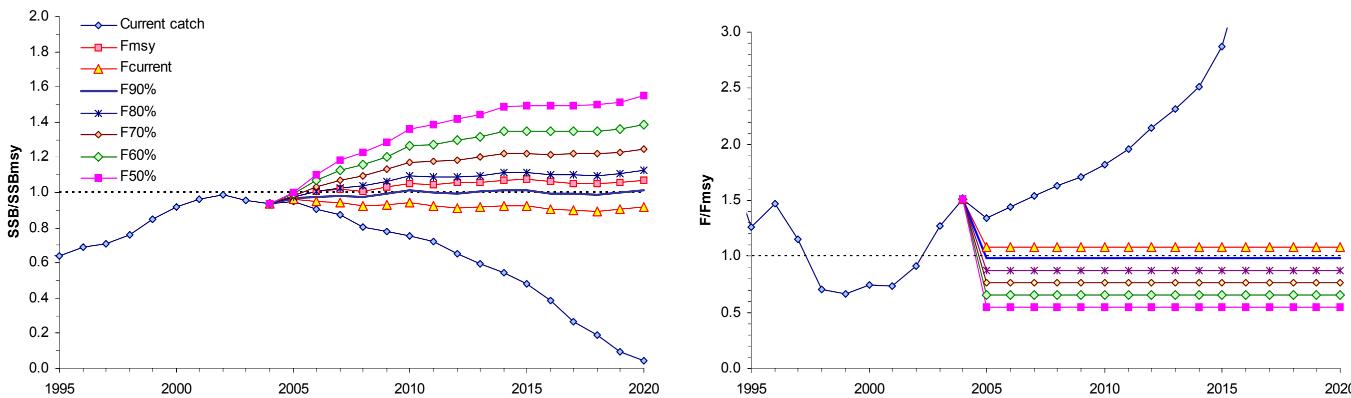


Figure 28: SSASPM projected relative SSB (SSB/SSB_{MSY}) and relative F (F/F_{MSY}) for constant yield, F_{MSY} and different scenarios of F/F_{2004} for the revised catch series.

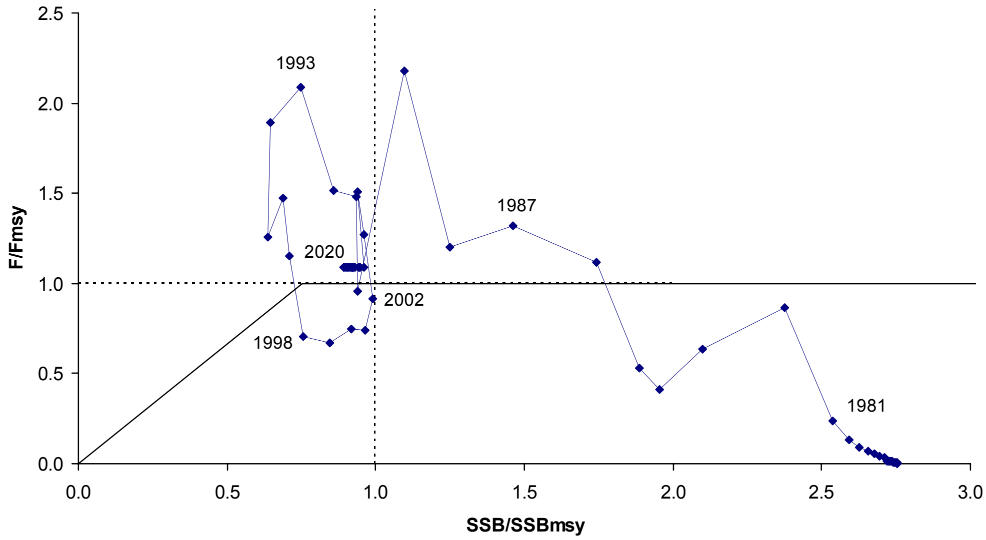


Figure 29: PRO-2BOX control rule plot for base case assuming status quo fishing mortality rate for the period 2005-202 for the original catch series.

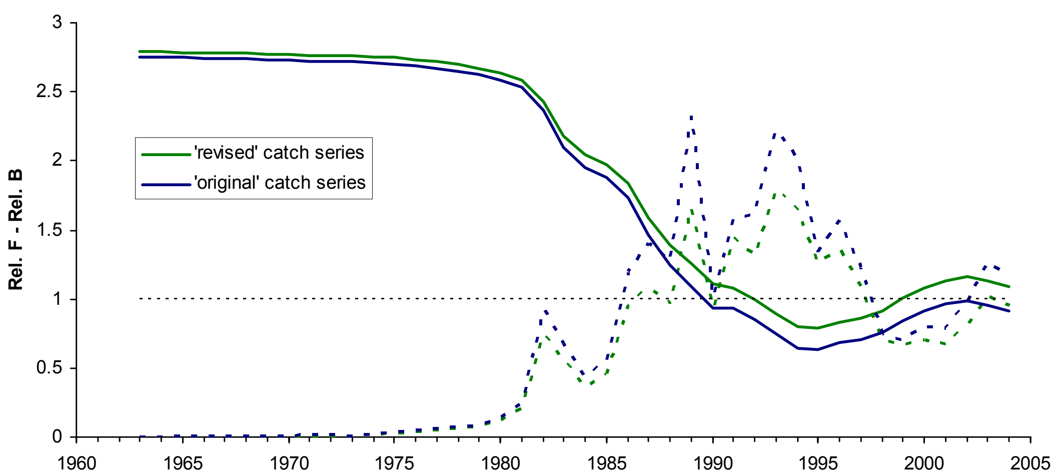


Figure 30: SSASPM estimated trajectory of relative SSB (SSB/SSB_{MSY}) (solid lines) and relative F (F/F_{MSY}) (dashed lines) for M=0.25 and two different catch series.