ASSESSMENTS OF GULF OF MEXICO RED SNAPPER DURING 1984-2003 USING A GULFWIDE IMPLEMENTATION OF ASAP, INCLUDING CONTINUITY CASES

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INTRODUCTION

Based on decisions made at the August, 2004, red snapper assessment discussions, a range of ASAP model fits to fleet-specific catch and effort data spanning 1984-2003 were made to provide guidance on the status of the Gulf-wide red snapper resource. In addition, continuity cases are presented that update the 1999 red snapper assessment using the ASAP model structure of Schirripa and Legault (1999). This paper documents the model structures and resulting fits to data as well as forecast status under a number of future management options.

METHODS

All assessment model runs were made using ASAP, an AD-Model builder implementation of a forward-projection, age-structured assessment program described in detail by Legault and Restrepo (1998). An earlier version of this program was used in previous assessments of red snapper (Schirripa and Legault, 1999). Modifications to ASAP since the previous assessment allow ASAP to:

1. Accommodate two independent sets of age composition data for the directed component of each fleet (directly observed and modeled age comp).
2. Allow the relative F's of all fleets to be modified during projections, rather than just the non-directed fleets.
3. Accommodate total landings/discards in number or weight.
4. Allow tuning indices to be linked to spawning biomass (fecundity)
5. Allow different weight at age matrices to be used for the landings and discards of each fleet.
6. Accommodate year and fleet-specific CV's for total catch

In addition, projections now use the average estimated selectivity of the most recent three years and the parameter N_year1_devs uses natural mortality (M) in the initial year rather than total mortality (Z).

Two continuity cases are presented; to the extent possible these have the model configured as closely as possible to the model configuration used for the 1999 assessment (Schirripa and Legault, 1999) while using the current versions of the available data (1984-2003). The most recent version of ASAP5 was used, as discussed above, as well as the updated fecundity function reported by Porch (SEDAR7-AW-05). The continuity case specifies 6 fleets, the 5 fleets used by Schirripa and Legault: commercial handline east (CMHL-E), commercial handline west (CMHL-W), commercial longline gulf-wide (CMLL-GW), recreational gulf-wide (REC-GW) and shrimp bycatch gulf-wide (SHRIMP-BYCATCH), and a sixth fleet, the commercial discards during the closed season (CLSD-SEAS-GW). Like the previous assessment, modeled ages were Age 0 to the plus group Age 15+. The continuity case used two tuning indices, the MRFSS index (MRFSS-GW) and the SEAMAP Age 1 trawl index (SEAMAP-Age 1-GW) developed by Nichols (SEDAR7-DW-01). Indices, and annual index estimates were assigned equal weighting. In every case, the model parameter representing the log virgin stock size was estimated freely.

Eight additional runs are also presented; these use the inputs available at present and a revised current model configuration. The specifications were identical to the continuity cases, with the following exceptions. Five indices were used for tuning, the gulf-wide MRFSS index (MRFSS-GW), the SEAMAP Age 0 and Age 1 trawl indices (SEAMAP-Age0-GW; SEAMAP-Age 1-GW) developed by Nichols (SEDAR7-DW-01) the gulf-wide video index (VIDEO_GW) and the gulf-wide SEAMAP ichthyoplankton index (LARV_B_GW). Overall, the indices were weighted equally. However, annual variability was modeled using CVs rescaled to the average for each index.

Data (catch series, indices, years selectivity was allowed to vary, etc.) used during the 1984-2003 ASAP model runs are summarized in Appendix 1 and 2. Parameter estimates, weightings, and other model specifications used during the continuity runs and the revised runs are described in Appendix 3.

RESULTS AND DISCUSSION

RUNS WITH 2004 DATA AND 1999 MODEL CONFIGURATION

Continuity runs use data developed for the 2004 red snapper assessment and 1999 model specifications (when possible). Virgin recruitment was estimated for both continuity runs. Preliminary runs using fixed virgin recruitment, as had been done for the 1999 assessment, produced unrealistic results.

Continuity Run 1 (Steepness = 0.90; Bycatch fleets undirected)

Continuity Run 1 used a steepness fixed at 0.90. The fits to the catch series are summarized in Figure 1. In general, there is a good correlation between the observed and predicted catches except for the shrimp bycatch where catches tend to be underestimated during the 1990's. The model fits to the indices of abundance are acceptable (Fig. 2)

Annual trends in the fleet specific F multipliers (the maximum age-specific value for each fleet) are shown in Figure 3. The F multiplier associated with shrimp bycatch is higher than the other fleets and typically varies between 0.5 and 0.85, except for year 1998 when it reaches a value of 1.0.

The F multipliers of the other fleets are generally less than 0.13 with the exception of the recreational fishery with values between 0.1 and 0.32. A recent sharp increase in the F multiplier of this fishery was observed with F doubling from 0.16 in 1996 to 0.32 in 2003.

Predicted recruitment is shown in Figure 4. This run suggests that recruitment was higher than expected, given the stock recruitment relationship, from 1989-1995. These elevated recruitments then allowed the modeled spawning stock to rebuild during this interval. Since 1997, predicted recruitment has been lower than expected (except for year 1999).

Annual trends in yield, MSY, spawning stock (SS), SS_{MSY}, F, F_{MSY} and tSPR are summarized in Figure 5. The results of the run suggest that red snapper were overfished, and that overfishing was occurring in 1984 ($SS_{1984}/SS_{MSY} = 0.03$; $F_{1984}/F_{MSY} = 3.2$). The population continued at low levels until 1990, when it began to recover. By 2003, this model estimates spawning stock had increased to only 18% of SS_{MSY} and fishing mortality still remained at around 138% of F_{MSY}. The results indicate that the red snapper stock continues to be overfished and under overfishing conditions in 2003. Benchmark statistics are summarized in Table 1 and indicate that MSY (maximum sustainable yield to the commercial and recreational fisheries) was about 33 million pounds (mp), well above the current TAC of 9.12 mp.

The base projection (Fig. 6) was deterministic, and assumed a continuation of the current total allowable catch of 9.12 million pounds through 2032, and a reduction in shrimp effort of 40% in 2008, and steepness was fixed at 0.9. The projection indicates that, under this scenario, fishing mortality could decline to F_{MSY} levels in 2008, while spawning stock is projected to recover to SS_{MSY} in 2022. The results of this projection are also described in Table 2.

Continuity Run 2 (Steepness = 0.95; Bycatch fleets undirected)

Continuity Run 2 used a steepness fixed at 0.95. The fits to the catch series and the indices of abundance are identical to the previous run.

Annual trends in the fleet specific F multipliers follow exactly the same trend as the previous runs but with slightly higher values (Fig. 7). Predicted recruitment also follows the same trend shown in the previous run but with slightly lower values (Fig. 8).

Annual trends in yield, MSY, spawning stock (SS), SS_{MSY}, F, F_{MSY} and tSPR are summarized in Figure 9. Like the previous run, the results indicate that in 1984 the red snapper stock was overfished and that overfishing was occurring ($SS_{1984}/SS_{MSY} = 0.03$; $F_{1984}/F_{MSY} = 4.1$). The recovery that started in 1990 yields similar results to the previous run ($SS_{2003}/SS_{MSY} = 0.14$; $F_{2003}/F_{MSY} = 1.7$). Benchmark statistics are summarized in Table 1.

The base projection (Fig. 10) indicates that under this scenario, fishing mortality could decline to F_{MSY} levels in 2009, while spawning stock is projected to recover to SS_{MSY} in 2022. The results of this projection are also described in Table 2.

Comparison of continuity runs with the 1999 assessment

The continuity runs are similar to results from the previous red snapper assessment (Schirripa and Legault, 1999; Table 3). In all cases, red snapper are undergoing overfishing (F_{1998} /Fmsy > 2.5) and also appear overfished ($tSPR_{1998}$ < 9%; tSPR at MSY > 35%). However, the 2004 continuity cases are more optimistic, with regard to transitional SPR, than the 1999 assessment ($tSPR_{1998}$ = 5-9% compared to 2-6% reported in 1999). Maximum sustainable yield (MSY) estimates obtained from the 1999 assessment are also considerably higher than those estimated during the 2004 continuity runs, 41-66 million pounds versus 20-22 million pounds, respectively.

RUNS WITH 2004 DATA AND REVISED MODEL CONFIGURATION

Eight updated ASAP runs were made at two steepness values (0.90 and 0.95) and two levels of natural mortality "High" natural mortality runs used the vector M(0) = 0.98, M(1) = 0.59; M(2-15+) = 0.1 while "low" natural mortality runs used M(0) = 0.48, M(1) = 0.29; M(2-15+) = 0.1. Bycatch fleets were modeled as either directed or undirected. "All Fleets Directed" runs assume that all six fleets are effectively directed and jointly subject to management for the purpose of population projection. This assumption, within the ASAP framework, results in calculations of MSY reference points (F and biomass) on the basis of the joint selectivity of all fleets simultaneously. "Bycatch Fleets Undirected" runs assume the shrimp fleet and the closed season fleets are not directed and effectively not subject to direct joint management effects for the purpose of projections. Within the ASAP framework, this leads to MSY reference point calculations which treat the bycatch and closed season fleet selectivity as unmodifiable from the standpoint of reference point calculations.

RUN A (Steepness = 0.90; M(1) = 0.59; All fleets directed)

Run A used a steepness fixed at 0.90. The fits to the catch series are summarized in Figure 11. In general, there is a good correlation between the observed and predicted catches except for the shrimp bycatch where catches tend to be underestimated during the 1990's. The model fits to the indices of abundance are acceptable (Fig. 12)

Annual trends in the fleet specific F multipliers (the maximum age-specific value for each fleet) are shown in Figure 13. The F multiplier associated with shrimp bycatch is higher

than the other fleets and typically varies between 0.3 and 0.9. High values were observed during the 1990s and ranged from 0.5-0.75. The F multiplier showed a sharp decrease in 2000 (0.36) but has increased since then, and reached the highest value of the series in 2003 (0.9).

The F multipliers of the other fleets are generally less than 0.1 with the exception of the commercial handline fisheries in the west with F multipliers ranging from 0.19 to 0.09 and the recreational fishery with values between 0.12 and 0.45. A recent increase in the F multiplier of this fishery is quite noticeable increasing from 0.15 in 1996 to 0.45 in 2003.

Predicted recruitment is summarized in Figure 14. Run A results suggest that recruitment was higher than expected, given the stock recruitment relationship, from 1989-1996. These elevated recruitments then allowed the modeled spawning stock to rebuild during this interval. Since 2000, predicted recruitment has been substantially lower than expected. In fact, predicted recruitment in 2003 is the lowest in the time series.

Annual trends in yield, MSY, spawning stock (SS), SS_{MSY}, F, F_{MSY} and tSPR are summarized in Figure 15. The results of Run A suggest that red snapper were overfished, and that overfishing was occurring in 1984 ($SS_{1984}/SS_{MSY} = 0.04$; $F_{1984}/F_{MSY} = 4$). The population continued at low levels until 1990, when it began to recover. By 2003, this model estimates spawning stock had increased to 19% of SS_{MSY} and fishing mortality still remained at around 285% of F_{MSY}. Run A results indicate that the red snapper stock continue to be overfished and under overfishing conditions in 2003. Benchmark statistics are summarized in Table 4 and indicate that MSY was about 16.7 million pounds (mp), well above the current TAC of 9.12 mp.

The base projection (Fig. 16) was deterministic, and assumed a continuation of the current total allowable catch of 9.12 million pounds through 2032, and a reduction in shrimp effort of 40% in 2008. All fleets were specified as directed fisheries, and steepness was fixed at 0.9. The projection indicates that under this scenario, fishing mortality could decline to F_{MSY} levels in 2015, while spawning stock is projected to recover to SS_{MSY} in 2029. The results of this projection are also described in Table 5.

RUN B (Steepness = 0.90; M(1) = 0.59; Bycatch fleets undirected)

Run B has the same steepness as Run A, 0.90, but in this case the bycatch fleets (shrimp bycatch and commercial discards during the closed season) were specified as undirected. The model fits to the catches and indices of abundance are indistinguishable from those of Run A (Figs. 11-12). Likewise, F multipliers by fleet and recruitment trends are also identical to those of Run A, (Fig. 13-14).

Annual trends in yield, MSY, spawning stock (SS), SS_{MSY}, F, F_{MSY} and tSPR are presented in Figure 17. Run B results are similar in trend to Run A. The fishery was in poor condition in 1984 ($SS_{1984}/SS_{MSY} = 0.09$; $F_{1984}/F_{MSY} = 3.3$). A relatively rapid recovery period began in 1990 and it accelerated in 2000. By 2003, spawning stock had increased to 124% of SS_{MSY} and fishing mortality had decreased to 128% of F_{MSY}. In 2003, estimated transitional SPR

was approximately 11%. Run B results indicate that red snapper stock although not overfished, is still undergoing overfishing in 2003. Benchmark statistics are summarized in Table 4.

The base projection indicates that fishing mortality could decline to F_{MSY} levels in 2010, while spawning stock is projected to recover to SS_{MSY} in 2023. By 2032, $SS/SS_{MSY} = 1.49$ and $F/F_{MSY} = 0.34$. Transitional SPR increases from about 11% in 2003 to 25% by 2032. The results of this projection are also described in Table 5 and Fig. 18.

RUN C (Steepness = 0.90; M(1) = 0.29; All fleets directed)

Run C steepness was also fixed at 0.90, but used the "low" natural mortality vector. The model fits to the catches (Fig. 11) and indices (Fig.. 12) are identical to the previous runs. F multipliers by fleet are similar in trend to Runs A and B, but the F multipliers are slightly lower (Fig. 19). Recent fishing mortalities for the shrimp bycatch increased from 0.39 in 2000 to 0.91 in 2003, and recreational fishing mortality rises from 0.11 in 1996 to 0.32 in 2003.

The annual trend in recruitment predicted by Run C is similar to the previous runs (Fig 20). From 1989 to 1996 recruitment was higher than expected. Like previous runs, recruitment has been lower than predicted by the SRR since 1997 (except for year 1998), and the lowest estimated recruitment occurs in 2003.

Annual trends in yield, MSY, spawning stock (SS), SS_{MSY}, F, F_{MSY} and tSPR are presented in Figure 21. Estimated stock condition in 1984 is similar to run A ($SS_{1984}/SS_{MSY} = 0.03$; $F_{1984}/F_{MSY} = 3.9$), but recovery since that time has been a little stronger. By 2003, spawning stock increased to 19% of SS_{MSY}, although fishing mortality continued to greatly exceed F_{MSY} ($F/F_{MSY} = 2.5$). Like Run A, Run C indicates that red snapper are overfished, and that overfishing continues. Benchmark statistics are summarized in Table 4.

The base projections indicate 2026 as the recovery year from the spawning stock and 2011 for F. By 2032, the spawning stock exceeds SS_{MSY} by 44% and F_{2032} is only 19% of F_{MSY}. The results of this projection are also described in Table 5 and Fig. 22.

RUN D (Steepness = 0.90; M(1) = 0.29; Bycatch fleets undirected)

Run D steepness was fixed at 0.90. The model fits to the catches and indices of abundance are identical to the previous runs (Figs. 11-12). F multipliers by fleet and predicted recruitment are identical in trend and values to Run C, Figures 19 and 20, respectively.

Annual trends in yield, MSY, spawning stock (SS), SS_{MSY}, F, F_{MSY} and tSPR are presented in Fig. 23. Estimated stock condition in 1984 is similar to run B ($SS_{1984}/SS_{MSY} = 0.07$;

F_{1984}/F_{MSY} = 3.1), but this run shows a stronger recovery than all the previous runs. By 2003, spawning stock increased to 128% of SS_{MSY}, and fishing mortality decreased to 89% of F_{MSY}. Benchmark statistics are summarized in Table 4.

The base projections indicate 2019 as the recovery year from the spawning stock and 1995 for F. By 2032, the spawning stock is 186% of SS_{MSY} and F_{2032} is only 19% of F_{MSY}. Run D shows not only the strongest, but also the fastest recovery of all Runs A-D. The results of this projection are also described in Table 5 and Fig. 24.

RUN E (Steepness = 0.95; M(1) = 0.59; All fleets directed)

Run E steepness was fixed at 0.95. The model fits to the catches and indices of abundance are nearly identical to the previous runs (Figs. 11-12). F multipliers by fleet are similar in trend to previous runs, but the F multipliers are generally higher for most fleets (Fig. 25).

The annual trend in recruitment predicted by Run E is similar to the previous runs (Fig 26). From 1989 to 1999 recruitment was higher than expected. Recruitment has been lower than predicted by the SRR since 2000, and like previous runs the lowest estimated recruitment occurs in 2003.

Annual trends in yield, MSY, spawning stock (SS), SS_{MSY}, F and F_{MSY} are presented in Fig. 27. Like previous runs, in 1984 the red snapper stock was overfished and undergoing overfishing (SS_{1984}/SS_{MSY} = 0.05; F_{1984}/F_{MSY} = 4.4). In 1990 the stock started a period of recovery, but by 2003 the spawning stock has only recovered to 12% of SS_{MSY} and F_{2003}/F_{MSY} has only decreased to 3.19. Thus, the overfished and overfishing conditions remained through 2003. Benchmark statistics are summarized in Table 6.

Base projections (Fig. 28) indicate years 2030 and 2018 as the recovery years for the spawning stock and F, respectively. The results of this projection are also described in Table 7.

RUN F (Steepness = 0.95; M(1) = 0.59; Bycatch fleets undirected)

Run F used a steepness fixed at 0.95. The model fits to the catches and indices of abundance are nearly identical to the previous runs (Figs. 11-12). F multipliers by fleet and predicted recruitment are identical in trend and values to Run E, Figures 25 and 26, respectively.

Annual trends in yield, MSY, spawning stock (SS), SS_{MSY}, F, F_{MSY} and tSPR are summarized in Figure 29. In 1984, spawning stock was 11% of SS_{MSY}, and F was 359% of F_{MSY}. A period of recovery started in 1990 and by 2003 spawning stock was 78% of SS_{MSY} though fishing mortality continued to exceed F_{MSY} (F/F_{MSY} = 1.49) Benchmark statistics are summarized in Table 6.

At steepness 0.95, the base projection indicates that current removals will lead to a stock recovery, with shrimp effort reduction of 40% in 2008. Spawning stock is projected to be 139% of SS_{MSY} in 2032, while F decreases to the F_{MSY} level by 2015 and continues decreasing to be only 39% of F_{MSY} by 2032. The results of this projection are described in Table 7 and Figure 30.

RUN G (Steepness = 0.95; M(1) = 0.29; All fleets directed)

Run G used a steepness fixed at 0.95. F multipliers by fleet and predicted recruitment are summarized in Figures 31 and 32. In general, they are very similar to the previous runs. Annual trends in yield, MSY, spawning stock (SS), SS_{MSY}, F, F_{MSY} and tSPR are shown in Figure 33. According to run F, in 1984 the stock was in extremely poor condition with the spawning stock at only 3% of SS_{MSY} and F at 453% of F_{MSY}. Conditions remained poor until 1990 when a period of recovery began. In 2003 spawning stock was still low at only 12% of SS_{MSY} and F_{2003}/F_{MSY} = 2.87. Thus, the stock remained overfished and undergoing overfishing. Benchmark statistics are summarized in Table 6.

At steepness 0.95, the base projection indicates that current removals will also lead to a stock recovery, with shrimp effort reduction of 40% in 2008. Spawning stock is projected to reach SS_{MSY} level in 2026 and 154% of SS_{MSY} in 2032, while F decreases to the F_{MSY} level by 2012 and continues decreasing to 17% of F_{MSY} by 2032. The results of this projection are described in Table 7 and Figure 34.

RUN H (Steepness = 0.95; M(1) = 0.29; Bycatch fleets undirected)

Run H used a steepness fixed at 0.95. F multipliers by fleet and predicted recruitment are identical in trend and values to Run G, Figures 31 and 32, respectively.

Annual trends in yield, MSY, spawning stock (SS), SS_{MSY}, F, F_{MSY} and tSPR are shown in Figure 35. Like all previous runs, the stock was overfished and undergoing overfishing in 1984 (SS_{1984}/SS_{MSY} = 0.09; F_{1984}/F_{MSY} = 3.5). A period of rapid recovery started in 1990, and by 2003 the spawning stock increased to 87% of SS_{MSY} and fishing mortality had declined to F/F_{MSY} = 1.08. Benchmark statistics are summarized in Table 6.

The base projections indicate that recovery years for the spawning stock and F are projected to be 2020 and 2008, respectively. By 2032, spawning stock reaches 190% of SS_{MSY} and F decreases to only 22% of F_{MSY}. The results of this projection are described in Table 7 and Figure 36.

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Table 1. Benchmark Statistics for ASAP 1984-2004 continuity runs.

Model Description	**Run Continuity 1**	**Run Continuity 2**
Steepness	Fixed = 0.90	Fixed = 0.95
M(0) = M(1) = M(2-15+)	0.48 0.29 0.10	0.48 0.29 0.10
Shrimp bycatch and closed season discards directed?	Undirected	Undirected
Benchmark Statistic		
$F_{0.1}$	0.259	0.235
F_{MAX}	0.334	0.305
$F_{30\%SPR}$	0.371	0.337
$F_{40\%SPR}$	0.282	0.255
F_{MSY}	0.298	0.279
F_{2003}	0.412	0.484
SS_{MSY}	8.45E+07	6.31E+07
SS_{2003}	1.53E+07	8.66E+06
MSY	3.30E+07	3.30E+07
virgin	2.46E+08	1.89E+08
F_{2003}/F_{MSY}	1.382	1.737
SS_{2003}/SS_{MSY}	0.1806362	0.1371254
tSPR 2003	0.114	0.068
tSPR @ SS_{MSY}	0.3713	0.3532
Current Yield	9.66E+06	9.66E+06

Table 2. Projection results for ASAP 1984-2004 continuity runs.

Model Description	**Run Continuity 1**	**Run Continuity 2**
Steepness	Fixed = 0.90	Fixed = 0.95
M(0) = M(1) = M(2-15+)	0.48 0.29 0.10	0.48 0.29 0.10
Shrimp bycatch and closed season discards directed?	Undirected	Undirected
SScurrent/SSmsy		
1984	0.029	0.028
2003	0.181	0.137
2032	1.813	1.904
Recovery Year	**2022**	**2022**
Fcurrent/Fmsy		
1984	3.243	4.136
2003	1.382	1.737
2032	0.140	0.136
Recovery Year	**2008**	**2009**
Y/MSY		
1984	0.122	0.140
2003	0.293	0.293
2032	0.260	0.259
tSPR		
1995	0.07	0.04
2003	0.11	0.07
2032	0.69	0.67

Table 3. Comparison of the results of the 2004 continuity runs and the 1999 models (Schirripa and Legault, 1999).

Biological Reference Point	**1999 "Low Recruitment" Steepness = 0.90**	**2004 Continuity 1 Steepness 0.90**	**1999 "Low Recruitment" Steepness = 0.95**	**2004 Continuity 2 Steepness 0.95**
F 1998 / Fmsy	2.82	2.56	3.72	3.00
MSY	41 million lbs	19.5 million lbs	66 million lbs	21.7 million lbs
tSPR 1998	5.8%	9.0%	1.8%	5.2%
tSPR @ MSY	36%	37%	32.7%	35.3%

Table 4. Benchmark Statistics for ASAP 1984-2004 revised runs at steepness 0.90.

Model Description	**Run A**	**Run B**	**Run C**	**Run D**
Steepness	Fixed = 0.90	Fixed = 0.90	Fixed = 0.90	Fixed = 0.90
M(0) = M(1) = M(2-15+)	0.98 0.59 0.10	0.98 0.59 0.10	0.48 0.29 0.10	0.48 0.29 0.10
Shrimp bycatch and closed season discards directed?	Directed	Undirected	Directed	Undirected
Benchmark Statistic				
$F_{0.1}$	0.241	0.199	0.281	0.200
F_{MAX}	0.312	0.270	0.361	0.270
$F_{30\%SPR}$	0.359	0.000	0.421	0.000
$F_{40\%SPR}$	0.272	0.000	0.320	0.000
F_{MSY}	0.313	0.158	0.356	0.157
F_{2003}	0.894	0.203	0.916	0.140
SS_{MSY}	6.20E+07	9.46 E+06	9.94E+07	1.47 E+07
SS_{2003}	1.18 E+07	1.18 E+07	1.87 E+07	1.87 E+07
MSY	1.67 E+07	5.13 E+06	1.88 E+07	7.31 E+06
virgin	1.70 E+08	1.70 E+08	2.70 E+08	2.70 E+08
F_{2003}/F_{MSY}	2.852	1.286	2.574	0.889
SS_{2003}/SS_{MSY}	0.1899	1.2454	0.1884	1.2766
tSPR 2003	0.113	0.113	0.129	0.129
tSPR @ SS_{MSY}	0.3823	0.1119	0.3864	0.1094
Current Yield	9.69 E+06	9.69 E+06	9.66 E+06	9.66 E+06

Table 5. Projection results for ASAP 1984-2004 revised runs at steepness 0.90.

Model Description	**Run A**	**Run B**	**Run C**	**Run D**
Steepness	Fixed = 0.90	Fixed = 0.90	Fixed = 0.90	Fixed = 0.90
M(0) = M(1) = M(2-15+)	0.98 0.59 0.10	0.98 0.59 0.10	0.48 0.29 0.10	0.48 0.29 0.10
Shrimp bycatch and closed season discards directed?	Directed	Undirected	Directed	Undirected
SScurrent/SSmsy				
1984	0.043	0.095	0.028	0.074
2003	0.190	1.246	0.188	1.277
2032	1.212	1.497	1.444	1.865
Recovery Year	**2029**	**2023**	**2026**	**2019**
Fcurrent/Fmsy				
1984	3.999	3.323	3.942	3.145
2003	2.852	1.286	2.574	0.889
2032	0.272	0.337	0.191	0.191
Recovery Year	**2015**	**2010**	**2011**	**1995**
Y/MSY				
1984	0.150	0.260	0.102	0.200
2003	0.581	1.887	0.515	1.321
2032	0.344	0.498	0.285	0.339
tSPR				
1995	0.06	0.06	0.07	0.07
2003	0.11	0.11	0.13	0.13
2032	0.51	0.25	0.60	0.31

Table 6. Benchmark Statistics for ASAP 1984-2004 revised runs at steepness 0.95.

Model Description	**Run E**	**Run F**	**Run G**	**Run H**
Steepness	Fixed = 0.95	Fixed = 0.95	Fixed = 0.95	Fixed = 0.95
M(0) = M(1) = M(2-15+)	0.98 0.59 0.10	0.98 0.59 0.10	0.48 0.29 0.10	0.48 0.29 0.10
Shrimp bycatch and closed season discards directed?	Directed	Undirected	Directed	Undirected
Benchmark Statistic				
$F_{0.1}$	0.204	0.181	0.220	0.185
F_{MAX}	0.266	0.248	0.285	0.252
$F_{30\%SPR}$	0.303	0.000	0.330	0.000
$F_{40\%SPR}$	0.229	0.000	0.250	0.000
F_{MSY}	0.277	0.186	0.292	0.186
F_{2003}	0.882	0.277	0.839	0.202
SS_{MSY}	4.51E+07	7.13E+06	6.97E+07	1.01E+07
SS_{2003}	5.54 E+06	5.54E+06	8.73E+06	8.73E+06
MSY	2.09 E+07	6.49E+06	2.32E+07	8.11E+06
virgin	1.27 E+08	1.27E+08	1.94E+08	1.94E+08
F_{2003}/F_{MSY}	3.190	1.486	2.874	1.085
SS_{2003}/SS_{MSY}	0.1229	0.7765031	0.1252274	0.8660923
tSPR 2003	0.056	0.056	0.064	0.064
tSPR @ SS_{MSY}	0.3635	0.0854	0.3695	0.0816
Current Yield	9.69 E+06	9.69E+06	9.66E+06	9.66E+06

Table 7. Projection results for ASAP 1984-2004 revised runs at steepness 0.95.

Model Description	**Run E**	**Run F**	**Run G**	**Run H**
Steepness	Fixed = 0.95	Fixed = 0.95	Fixed = 0.95	Fixed = 0.95
M(0) = M(1) = M(2-15+)	0.98 0.59 0.10	0.98 0.59 0.10	0.48 0.29 0.10	0.48 0.29 0.10
Shrimp bycatch and closed season discards directed?	Directed	Undirected	Directed	Undirected
SScurrent/SSmsy				
1984	0.048	0.113	0.032	0.092
2003	0.123	0.777	0.125	0.866
2032	1.206	1.391	1.543	1.900
Recovery Year	**2030**	**2026**	**2026**	**2020**
Fcurrent/Fmsy				
1984	4.468	3.595	4.532	3.501
2003	3.190	1.486	2.874	1.085
2032	0.251	0.392	0.167	0.222
Recovery Year	**2018**	**2015**	**2012**	**2008**
Y/MSY				
1984	0.188	0.336	0.131	0.274
2003	0.464	1.492	0.416	1.191
2032	0.311	0.544	0.259	0.399
tSPR				
1995	0.03	0.03	0.03	0.03
2003	0.06	0.06	0.032	0.06
2032	0.46	0.19	0.125	0.25

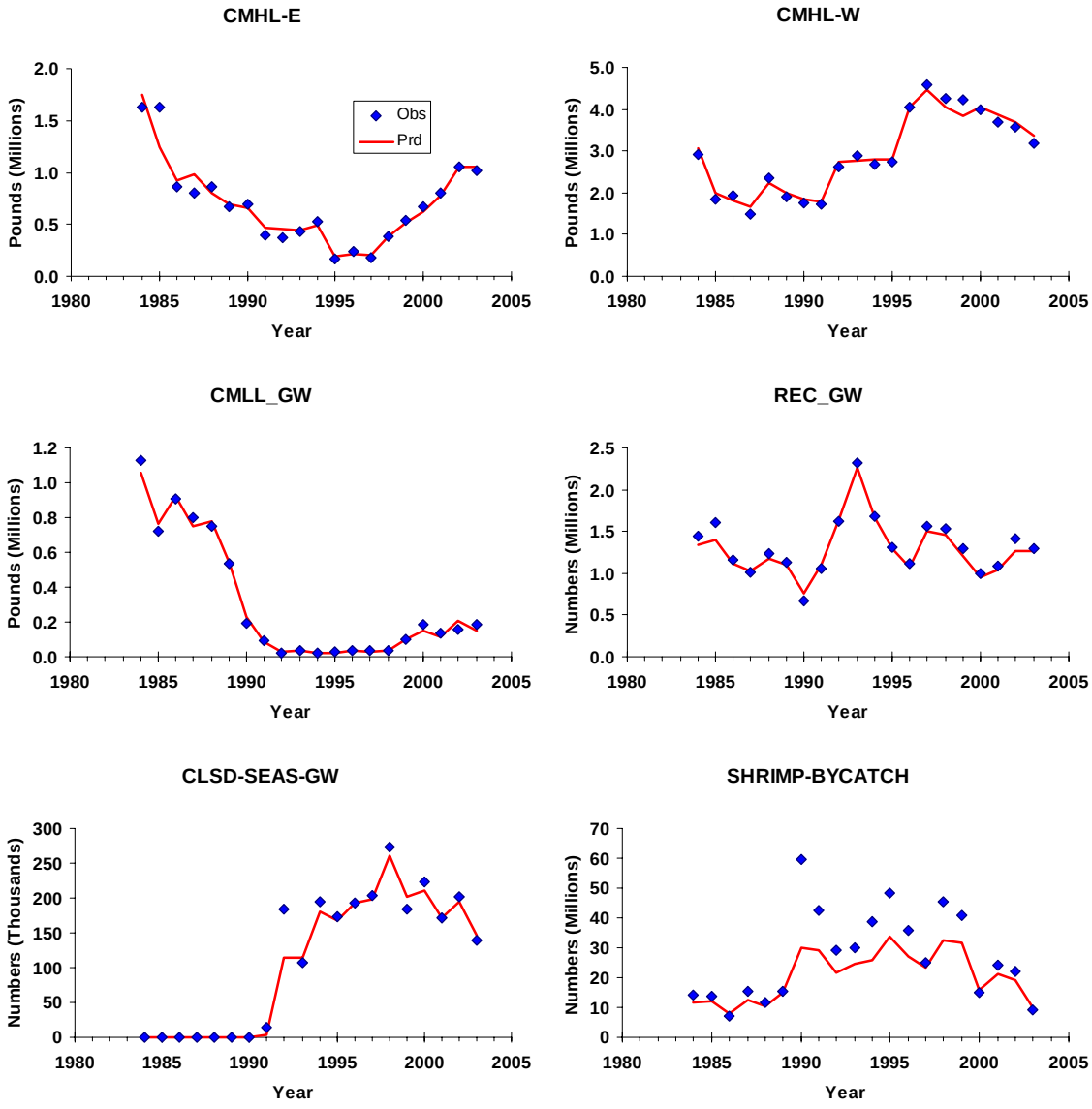

Figure 1: Fits to catches for continuity runs 1 and 2

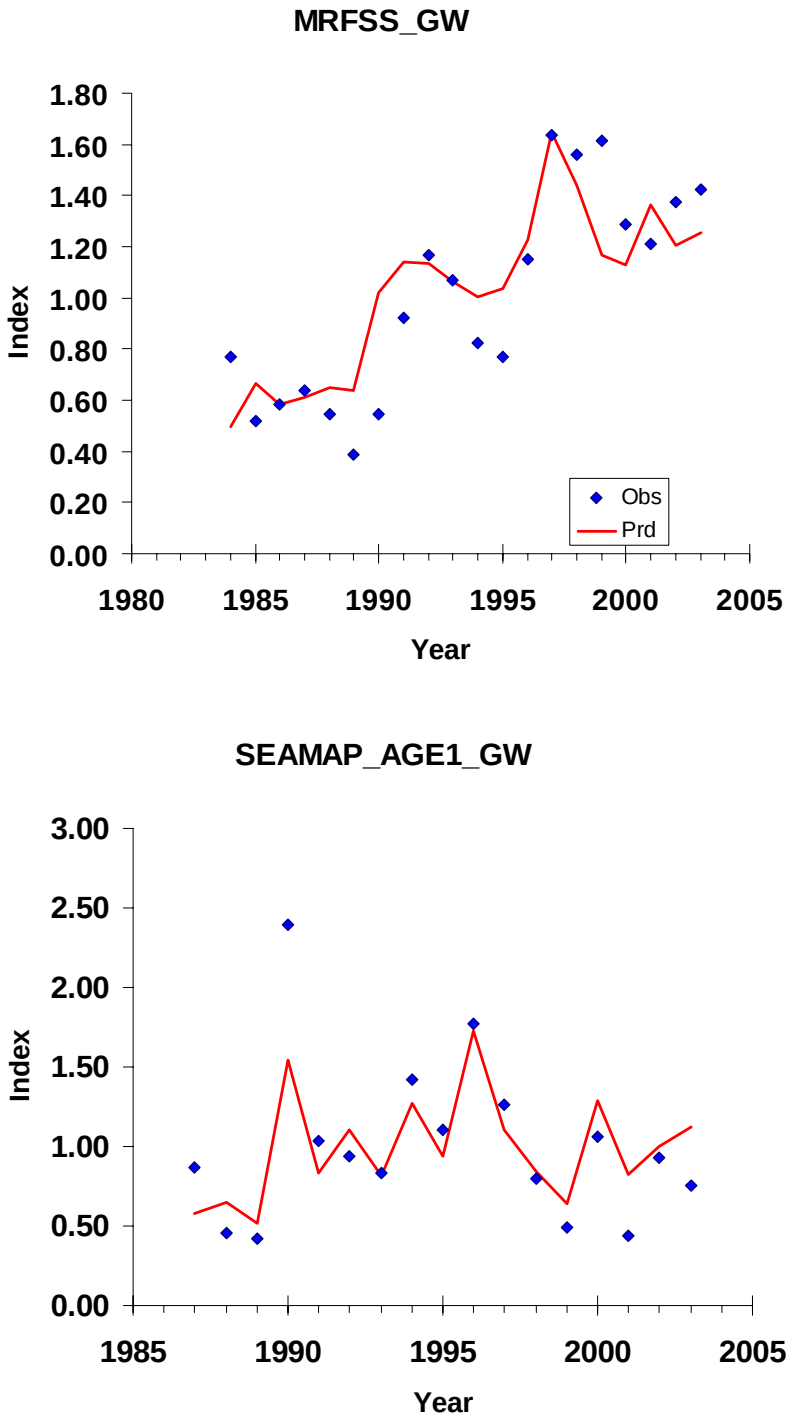

Figure 2. Fits to indices for continuity runs 1 and 2.

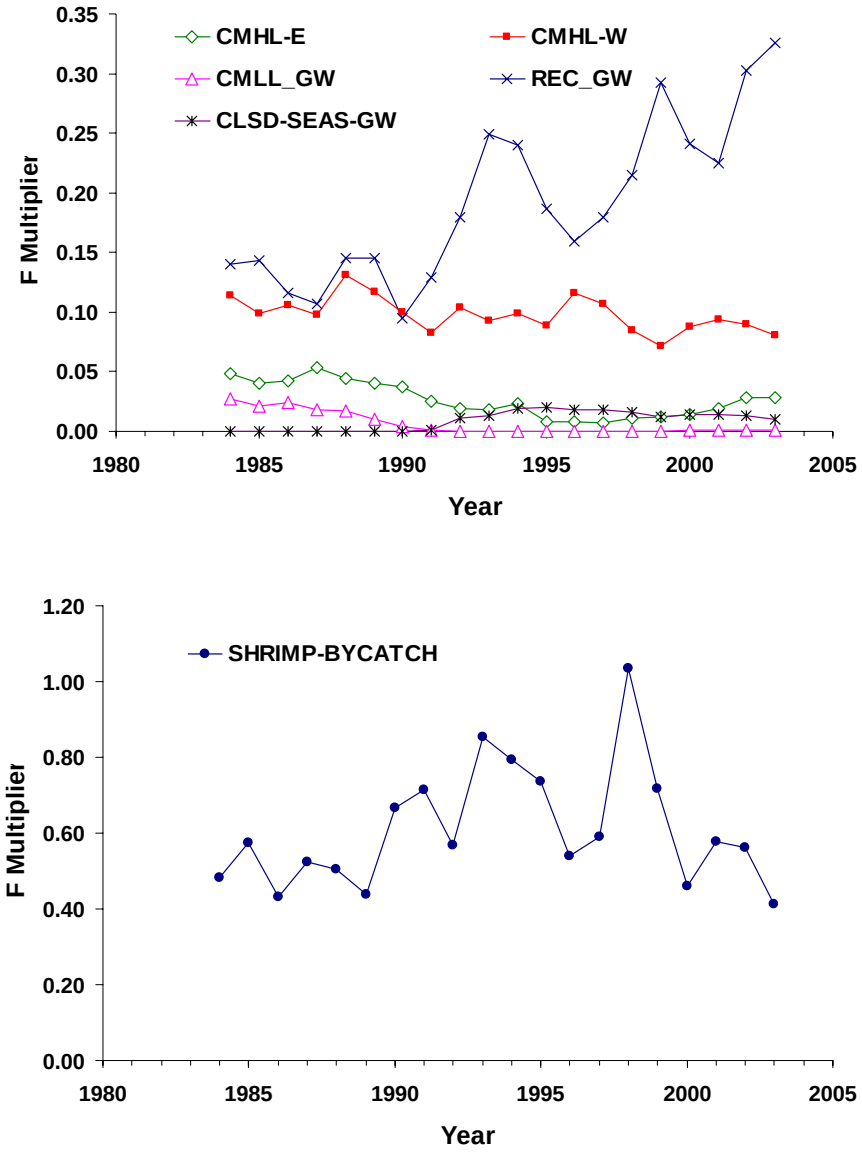

Figure 3: F multipliers by fleet for continuity run 1

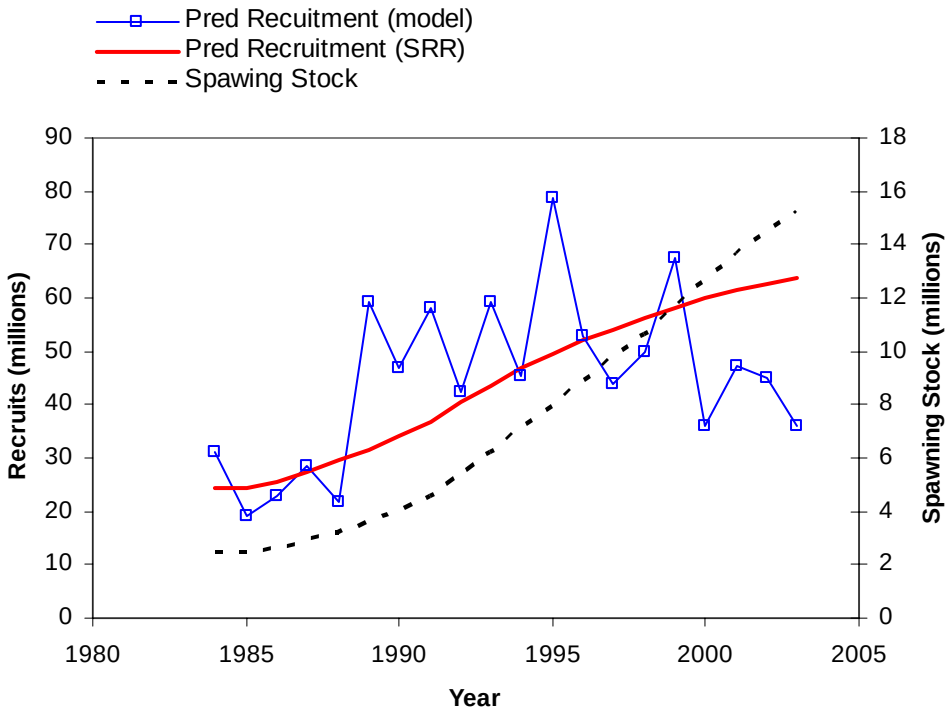

Figure 4: Spawning stock and recruitment estimates for continuity run 1

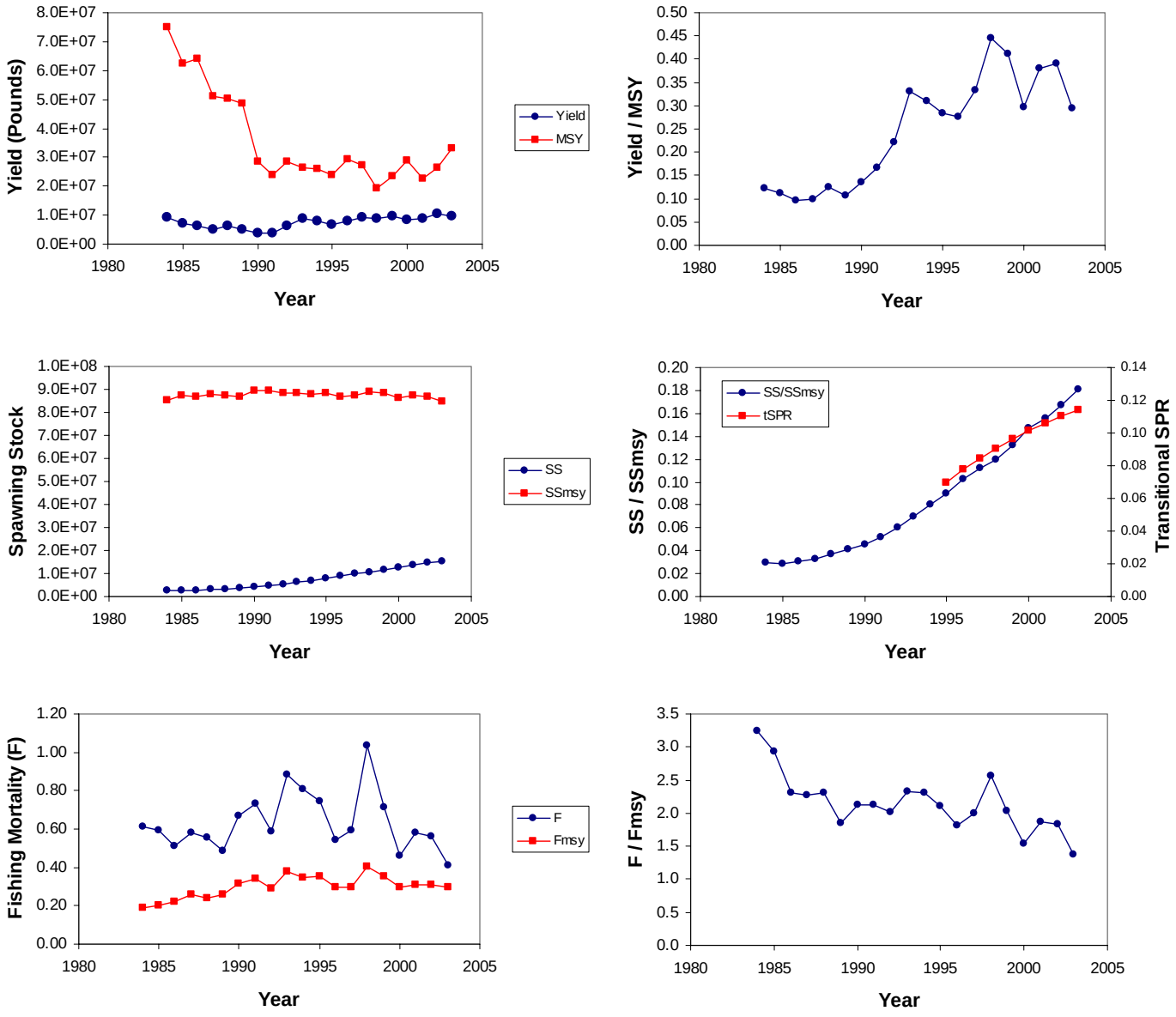

Figure 5: Trajectories of Yield, F, Spawning stock (SS), MSY, F_{MSY}, SS_{MSY} and tSPR for continuity run 1.

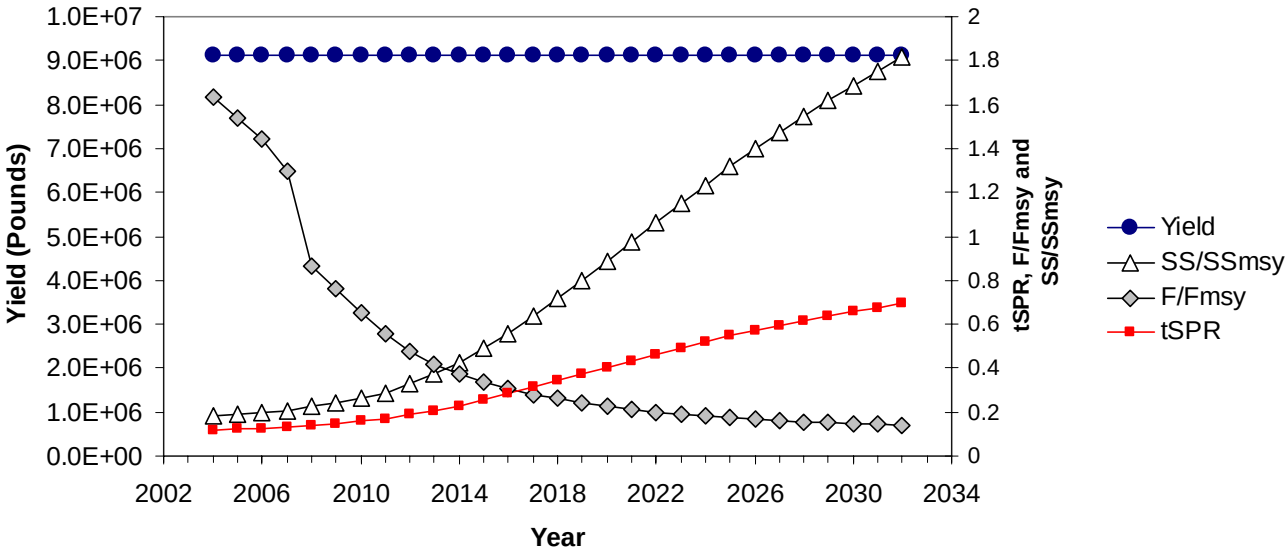

Figure 6: Projection of yield, transitional SPR, SS/SS_{MSY} and F/F_{MSY} for continuity run 1. The projection assumes a constant TAC of 9.12 million pounds 2004-2032, and a 40% reduction in the effort of the shrimp fleet in 2008.

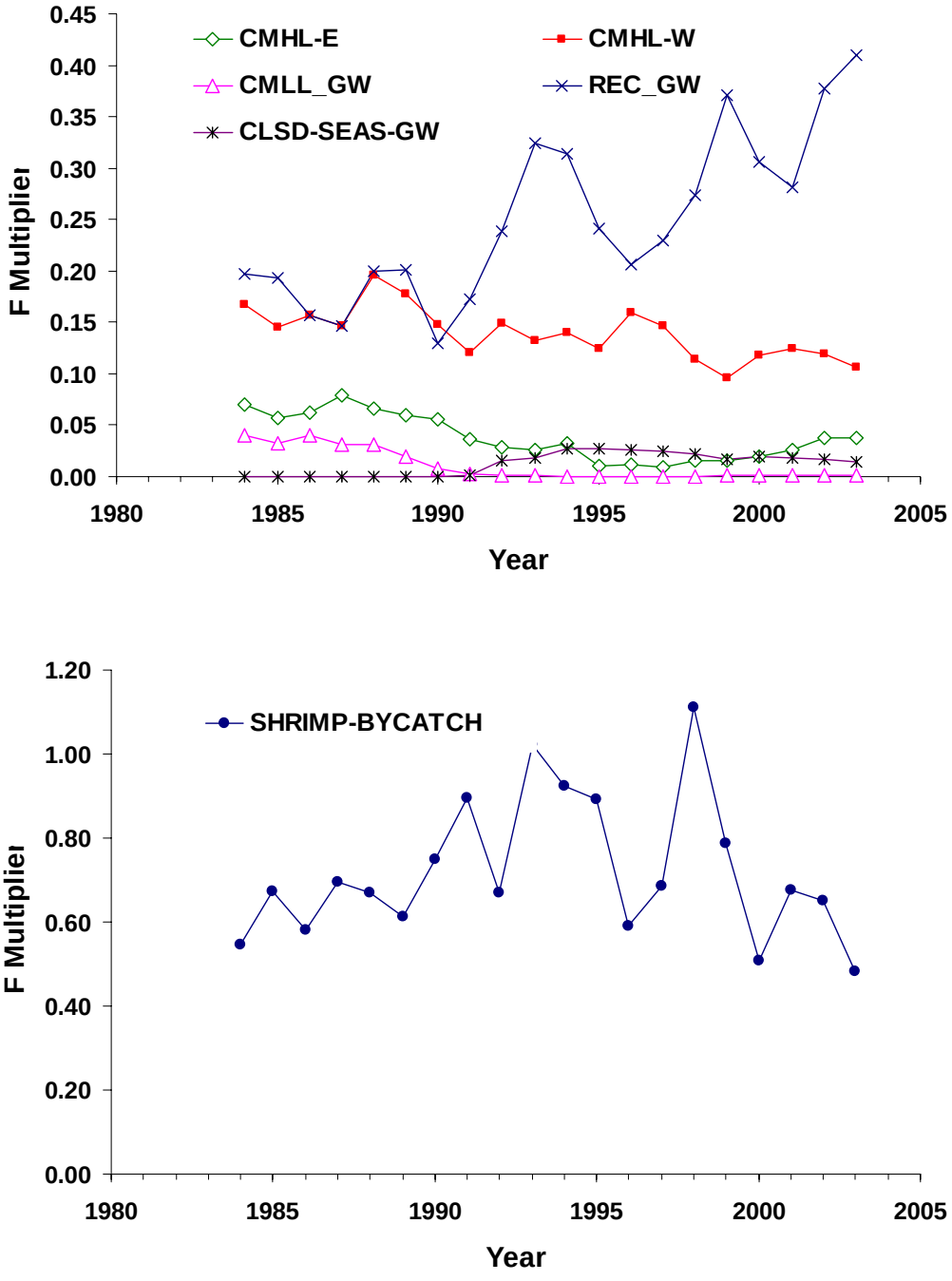

Figure 7: F multipliers by fleet for continuity run 2.

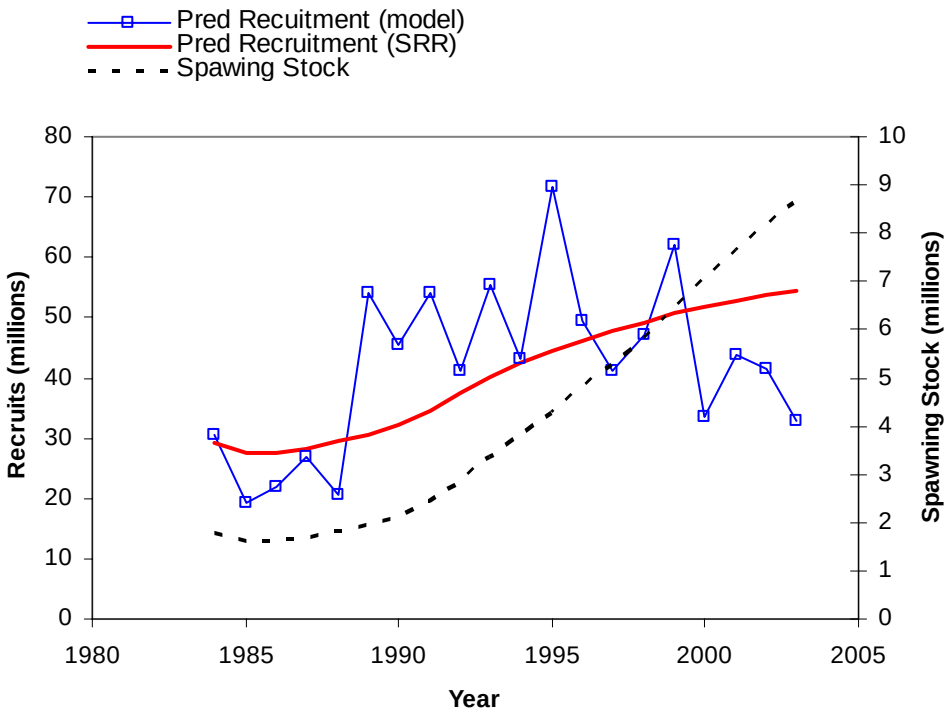

Figure 8: Spawning stock and recruitment estimates for continuity run 2.

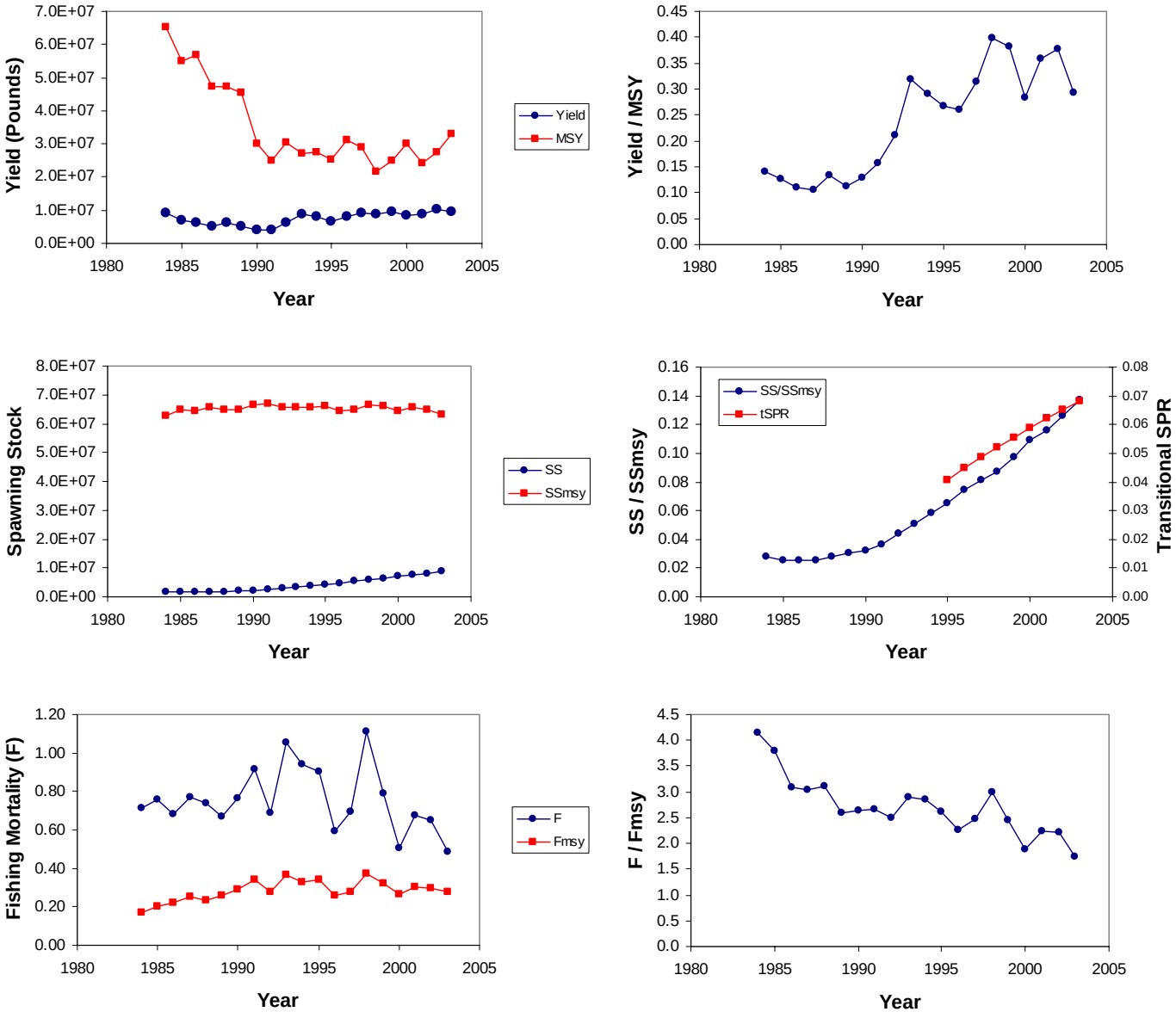

Figure 9: Trajectories of Yield, F, Spawning stock (SS), MSY, F_{MSY}, SS_{MSY} and tSPR for continuity run 2.

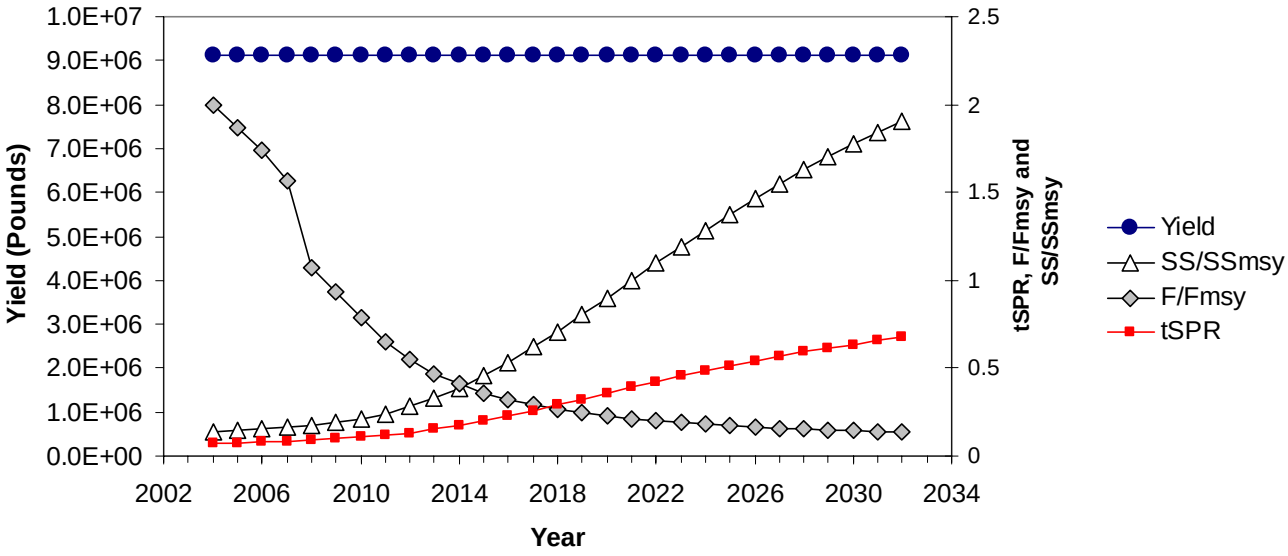

Figure 10: Projection of yield, transitional SPR, SS/SS_{MSY} and F/F_{MSY} for continuity run 2. The projection assumes a constant TAC of 9.12 million pounds 2004-2032, and a 40% reduction in the effort of the shrimp fleet in 2008.

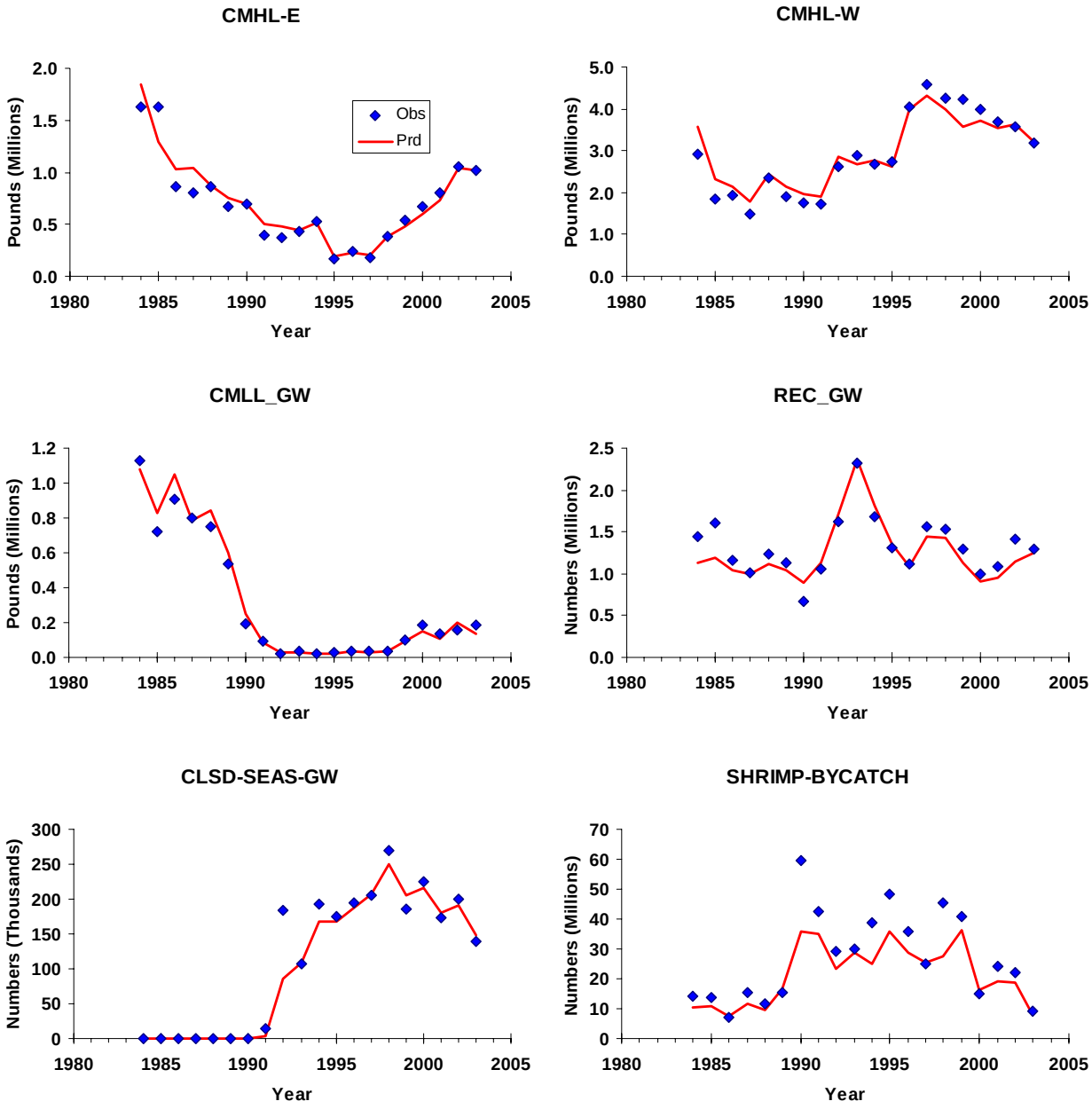

Figure 11: Fits to total catch by fleet for Runs A-H.

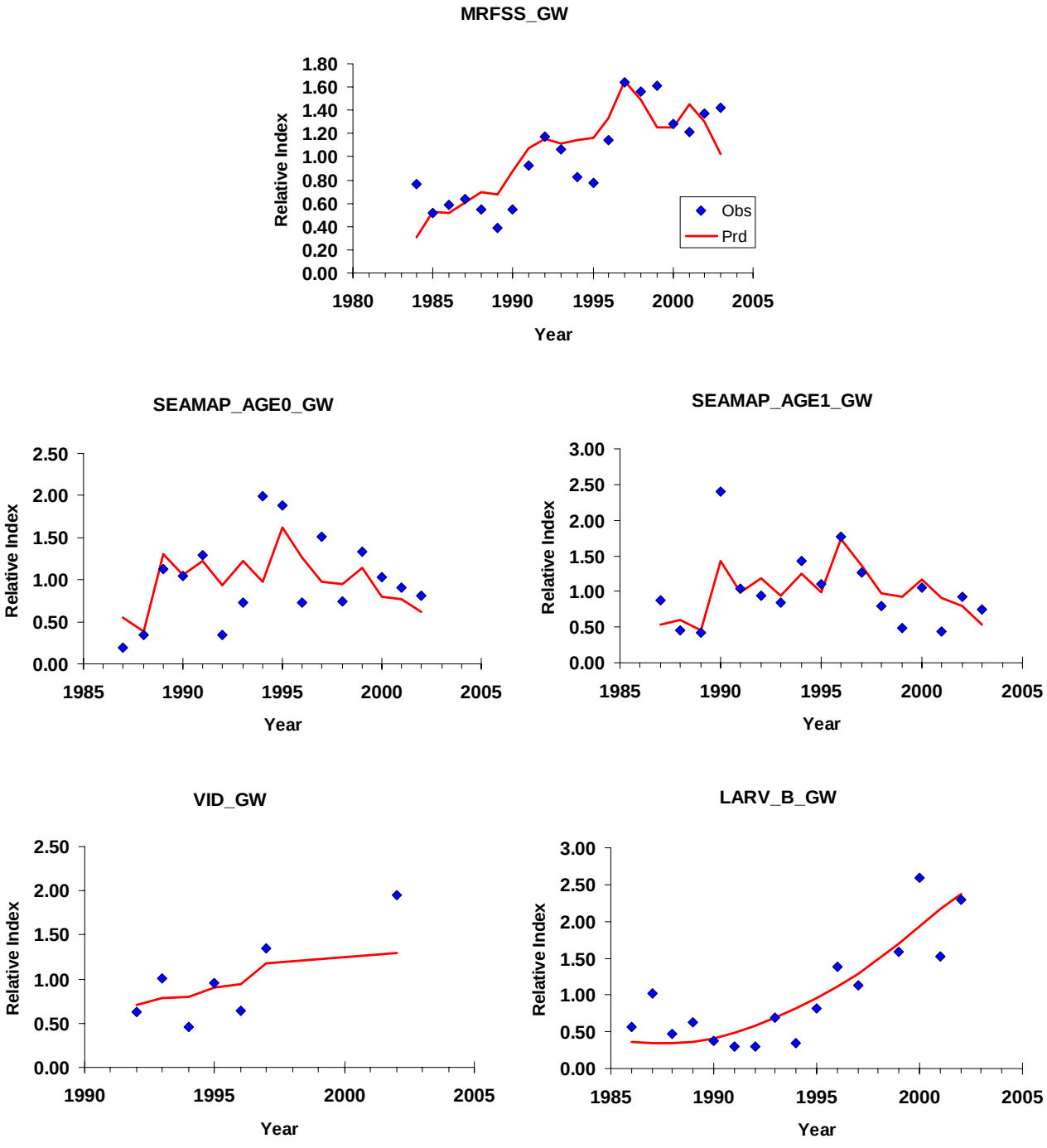

Figure 12: Fits to indices of abundance for Runs A-H .

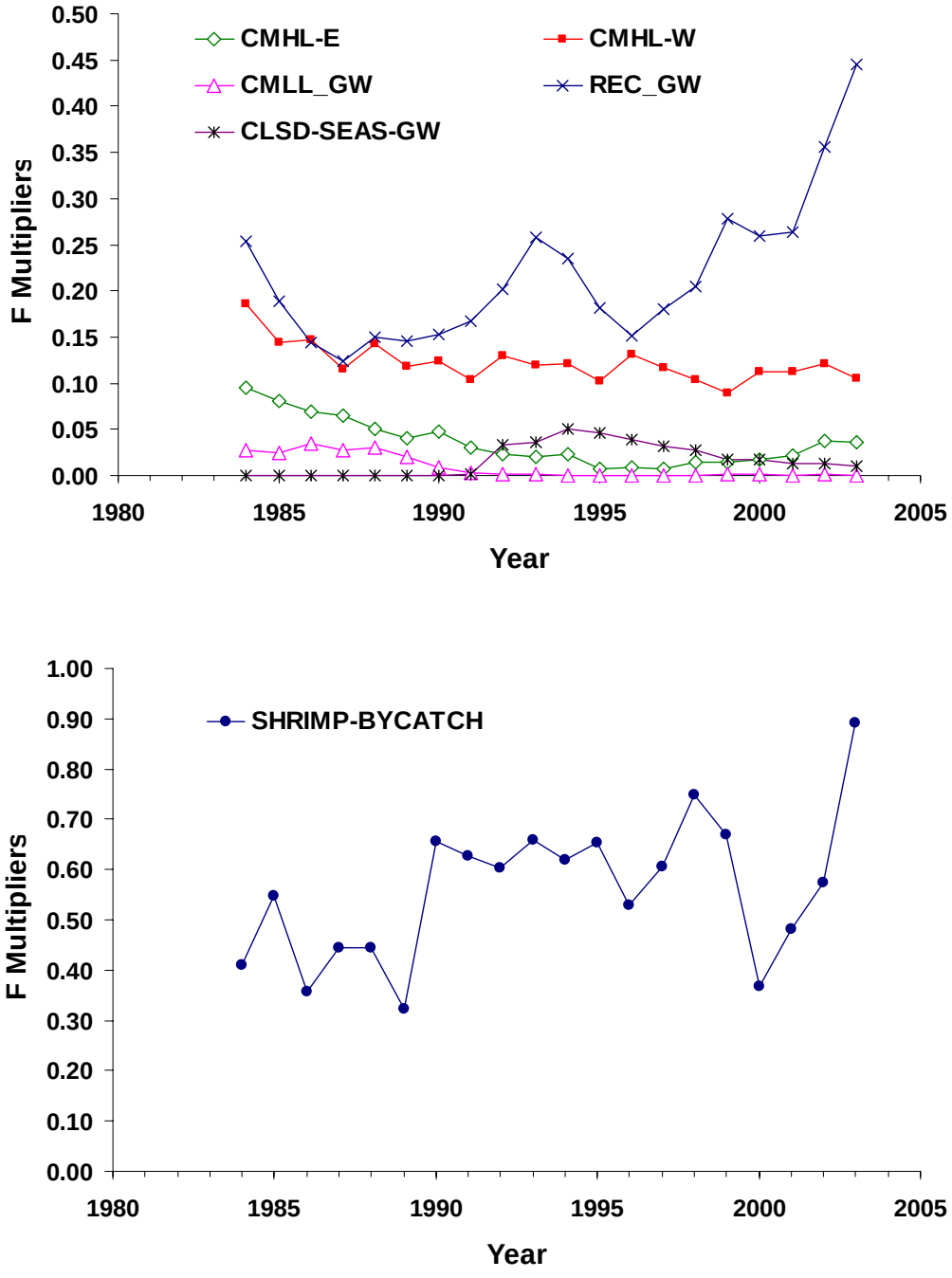

Figure 13: F multipliers by fleet for Runs A-B (Steepness = 0.90).

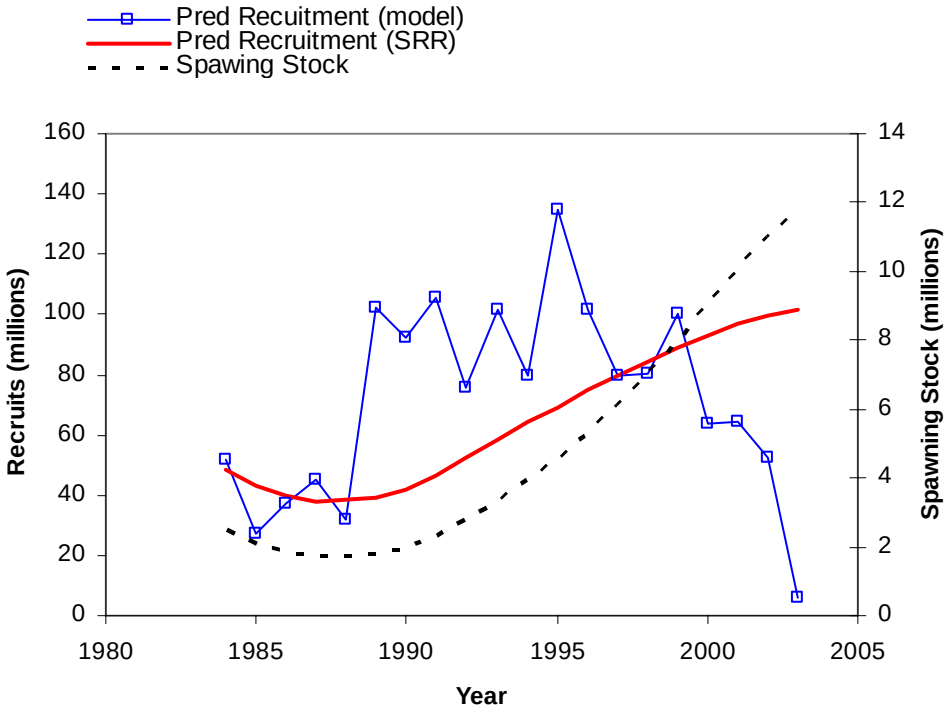

Figure 14: Spawning stock and recruitment estimates for Runs A-B (Steepness = 0.90).

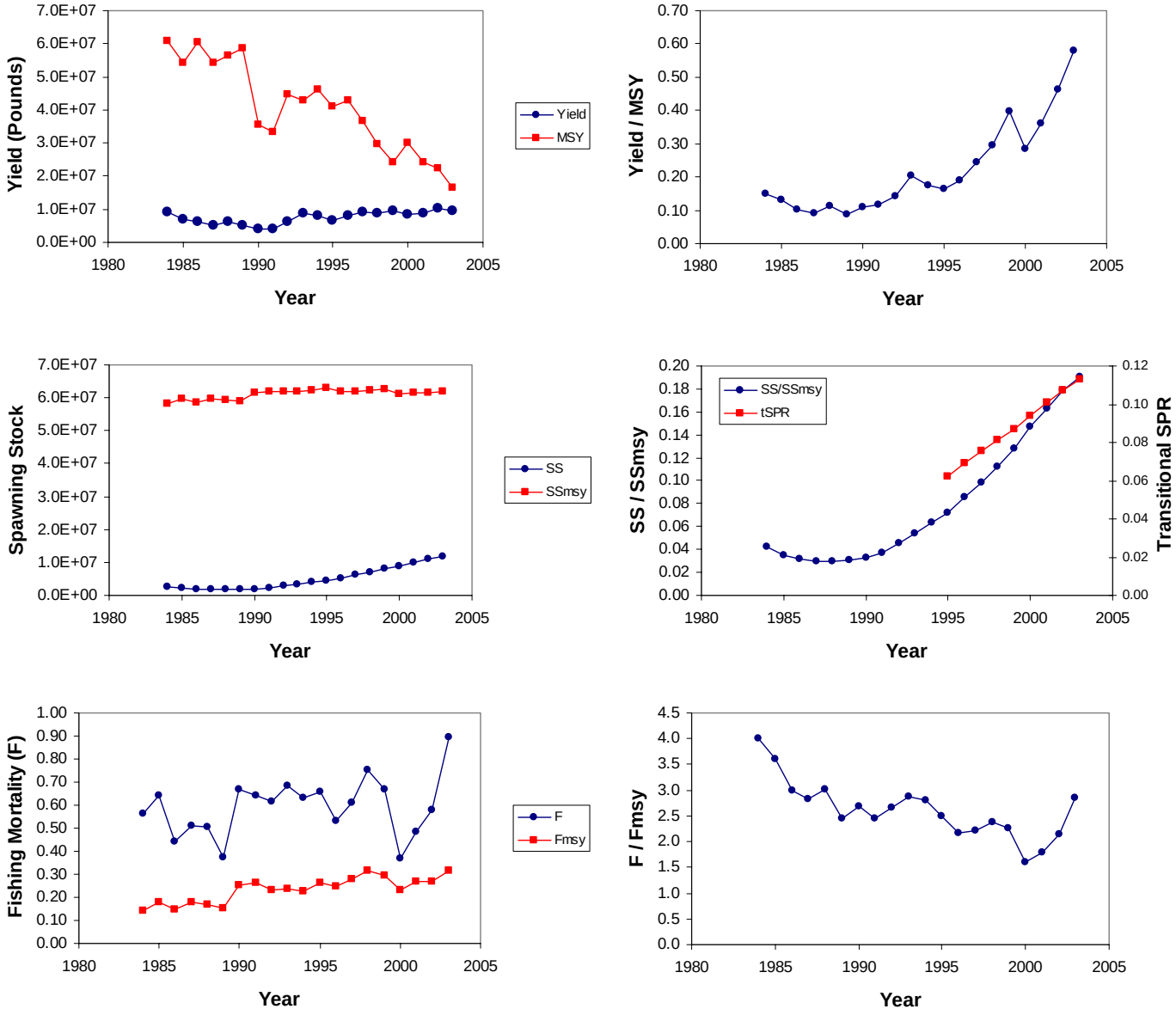

Figure 15: Trajectories of Yield, F, Spawning stock (SS), MSY, F_{MSY}, SS_{MSY} and tSPR for Run A (Steepness = 0.9).

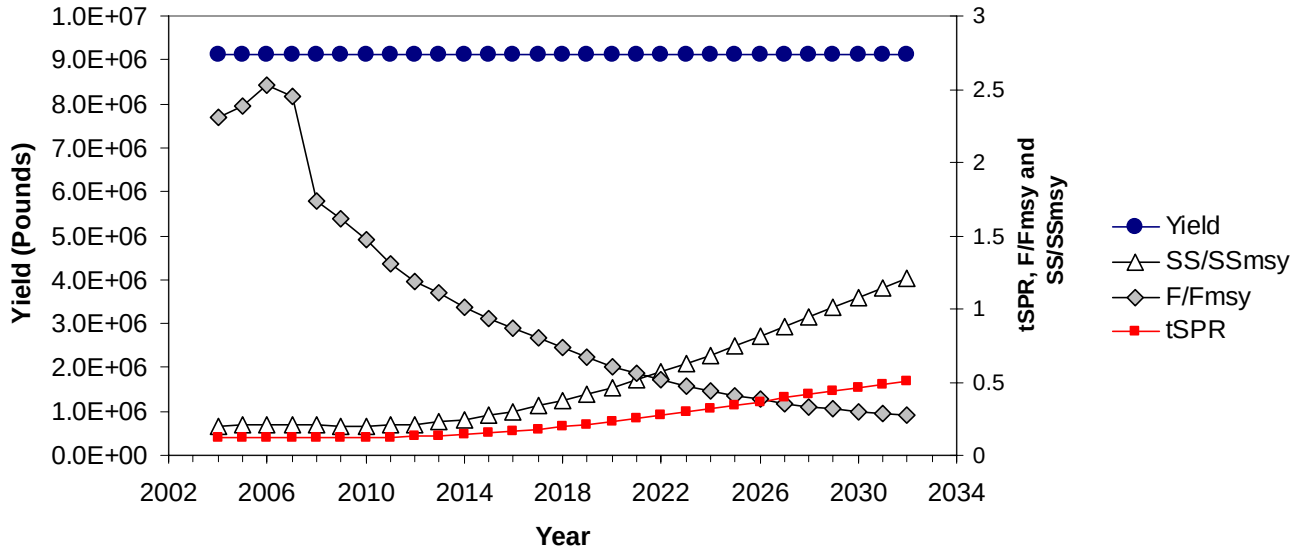

Figure 16: Projection of yield, transitional SPR, SS/SS_{MSY} and F/F_{MSY} for Run A. The projection assumes a constant TAC of 9.12 million pounds 2004-2032, and a 40% reduction in the effort of the shrimp fleet in 2008.

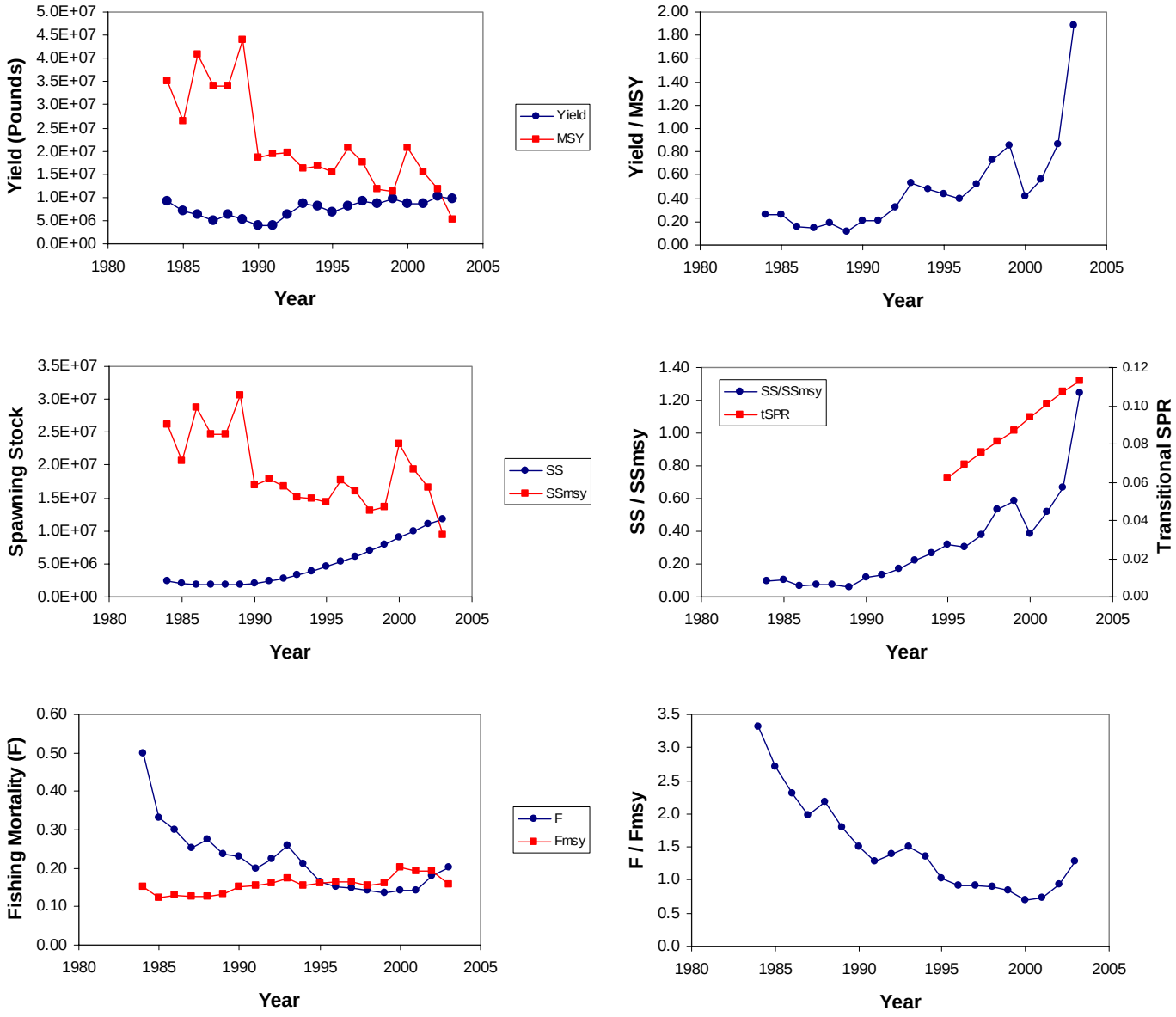

Figure 17: Trajectories of Yield, F, Spawning stock (SS), MSY, F_{MSY}, SS_{MSY} and tSPR for Run B (Steepness = 0.9).

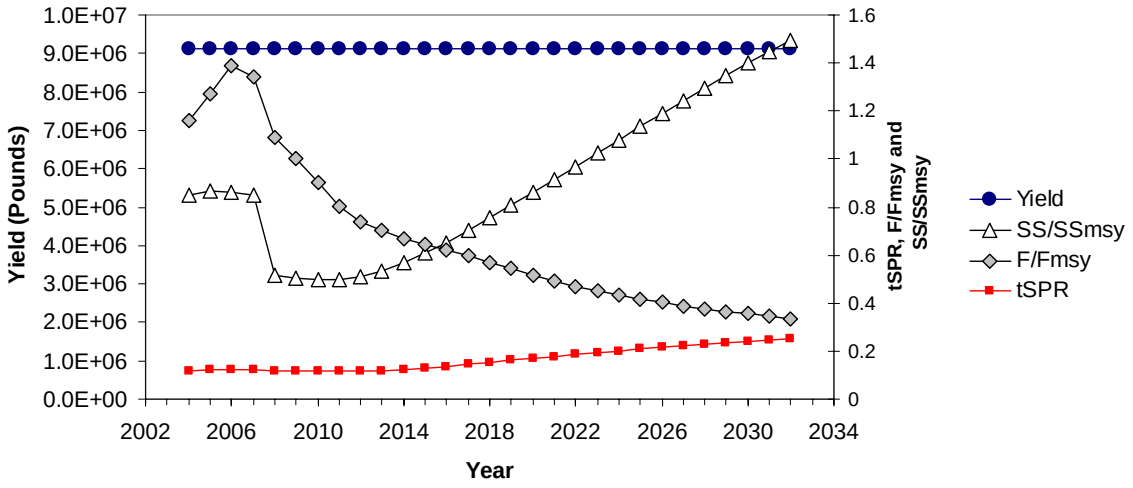

Figure 18: Projection of yield, transitional SPR, SS/SS_{MSY} and F/F_{MSY} for Run B. The projection assumes a constant TAC of 9.12 million pounds 2004-2032, and a 40% reduction in the effort of the shrimp fleet in 2008.

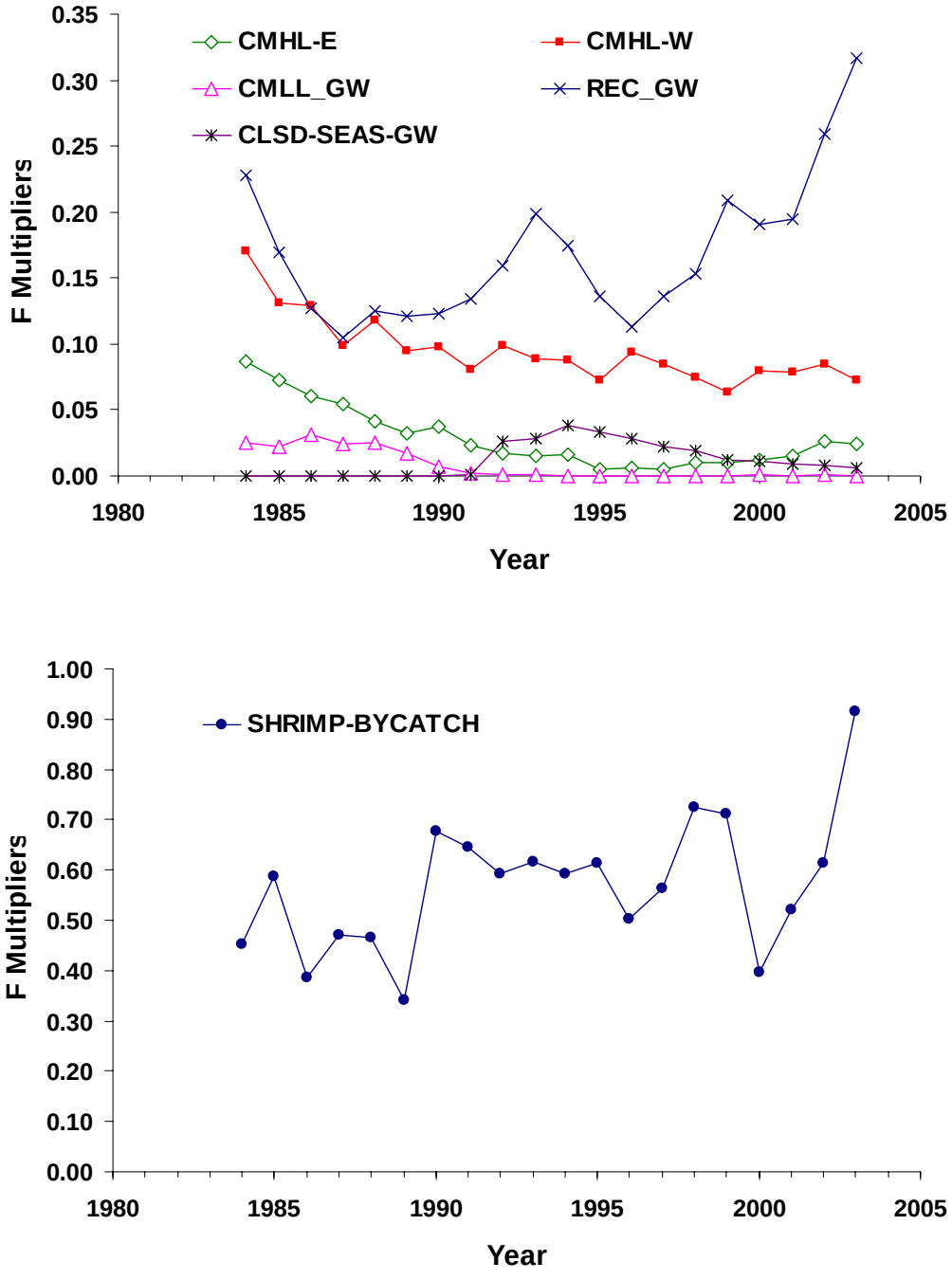

Figure 19: F multipliers by fleet for Runs C-D.

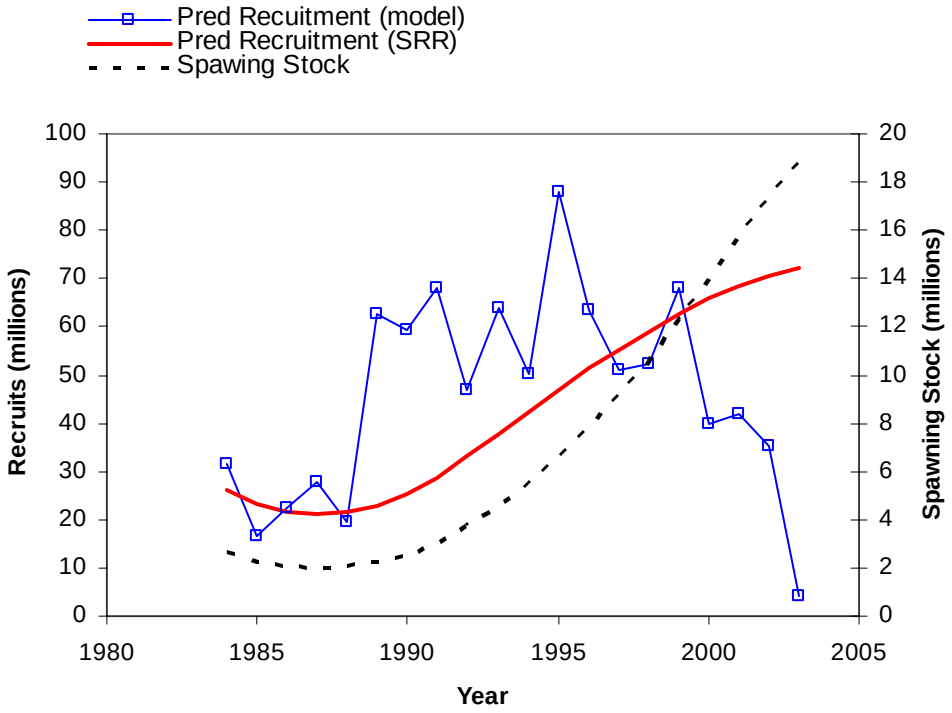

Figure 20: Spawning stock and recruitment estimates for Run C-D (Steepness = 0.90).

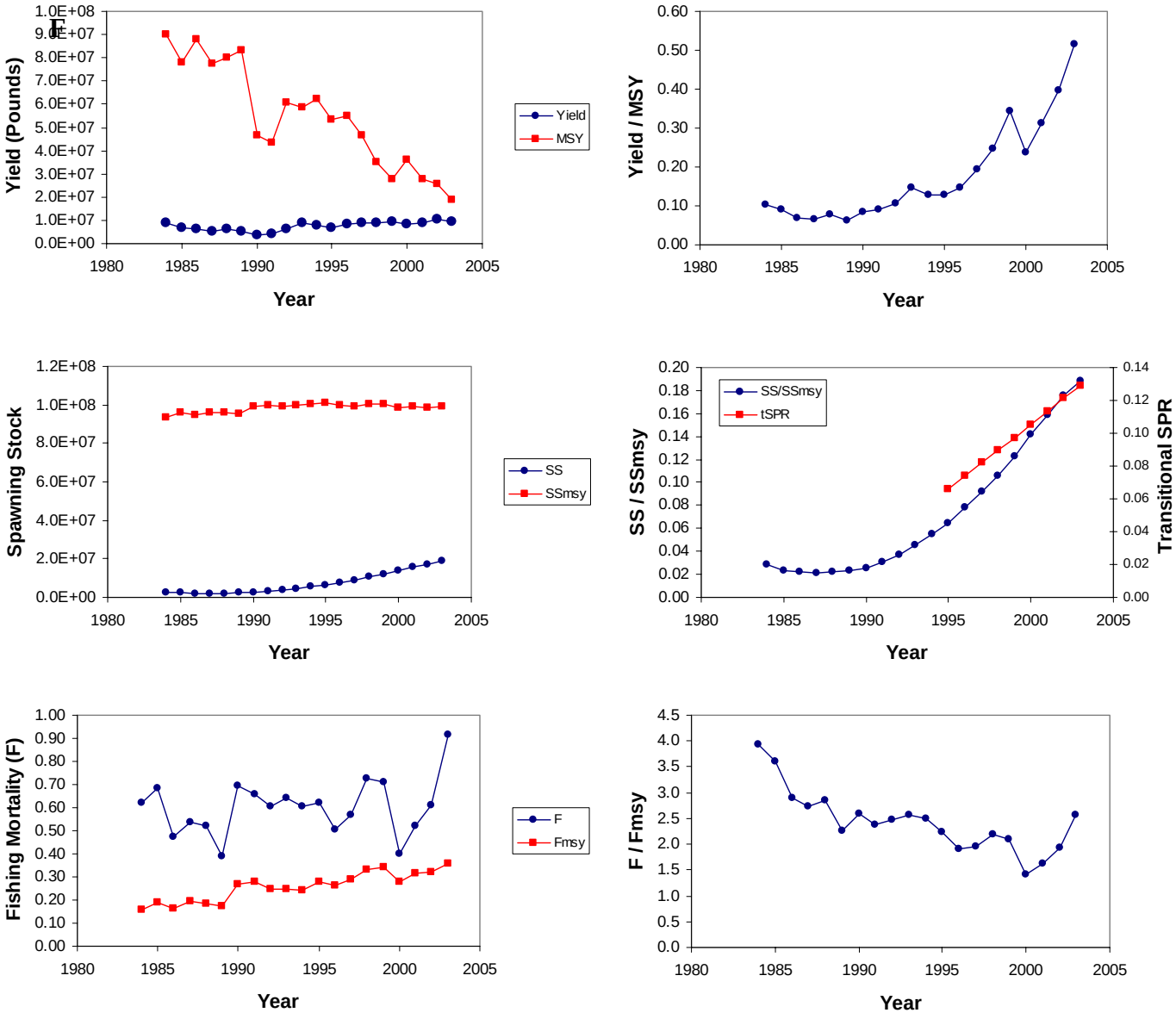

Figure 21: Trajectories of Yield, F, Spawning stock (SS), MSY, F_{MSY}, SS_{MSY} and tSPR for Run C (Steepness = 0.9).

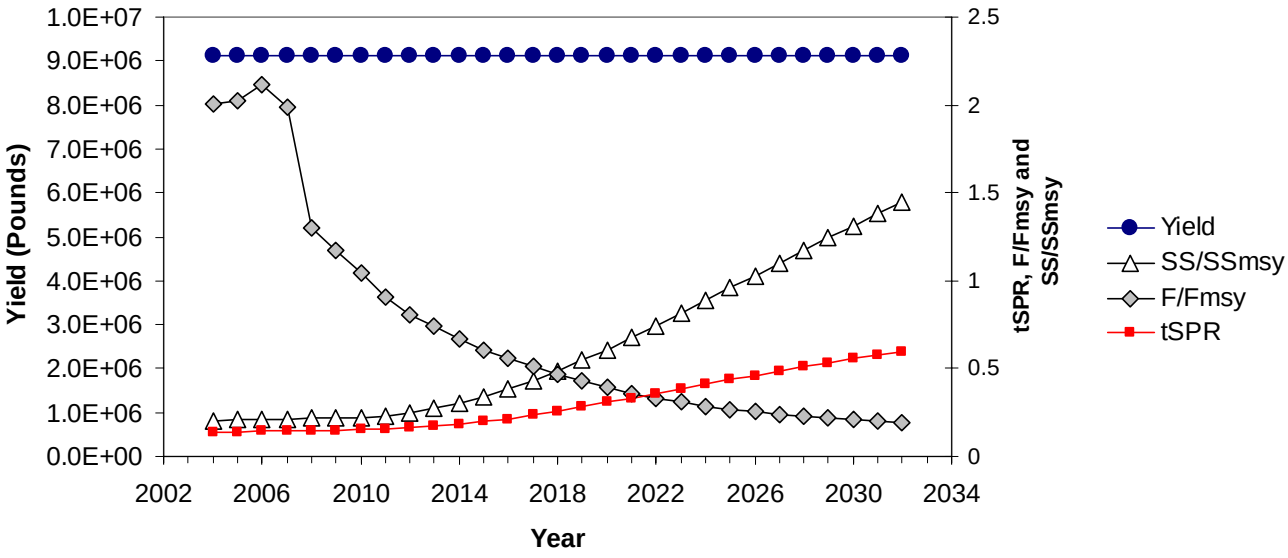

Figure 22: Projection of yield, transitional SPR, SS/SS_{MSY} and F/F_{MSY} for Run C. The projection assumes a constant TAC of 9.12 million pounds 2004-2032, and a 40% reduction in the effort of the shrimp fleet in 2008.

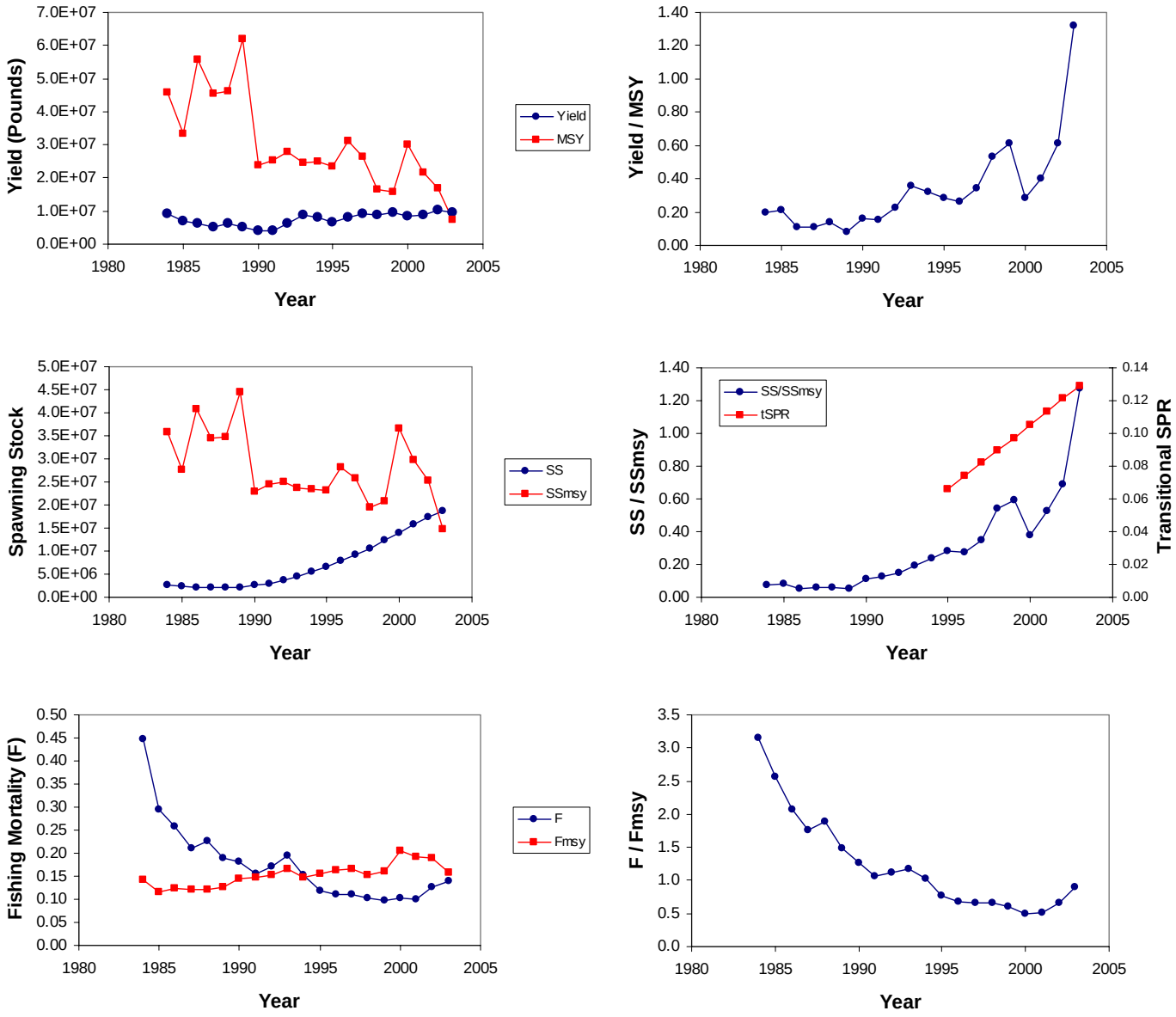

Figure 23: Trajectories of Yield, F, Spawning stock (SS), MSY, F_{MSY}, SS_{MSY} and tSPR for Run D (Steepness = 0.9).

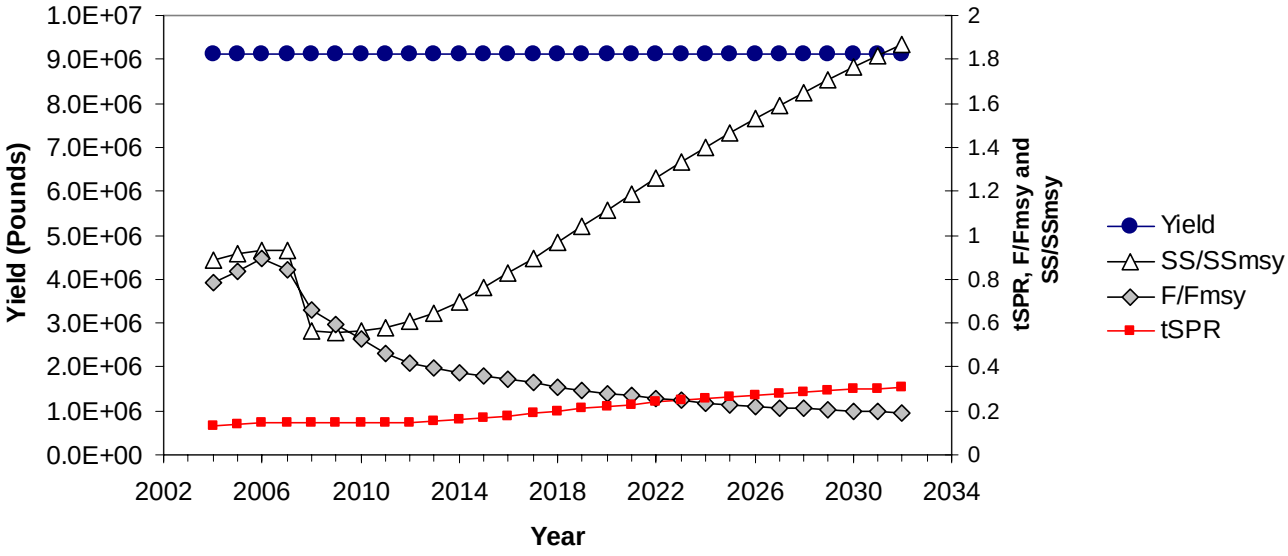

Figure 24: Projection of yield, transitional SPR, SS/SS_{MSY} and F/F_{MSY} for Run D. The projection assumes a constant TAC of 9.12 million pounds 2004-2032, and a 40% reduction in the effort of the shrimp fleet in 2008.

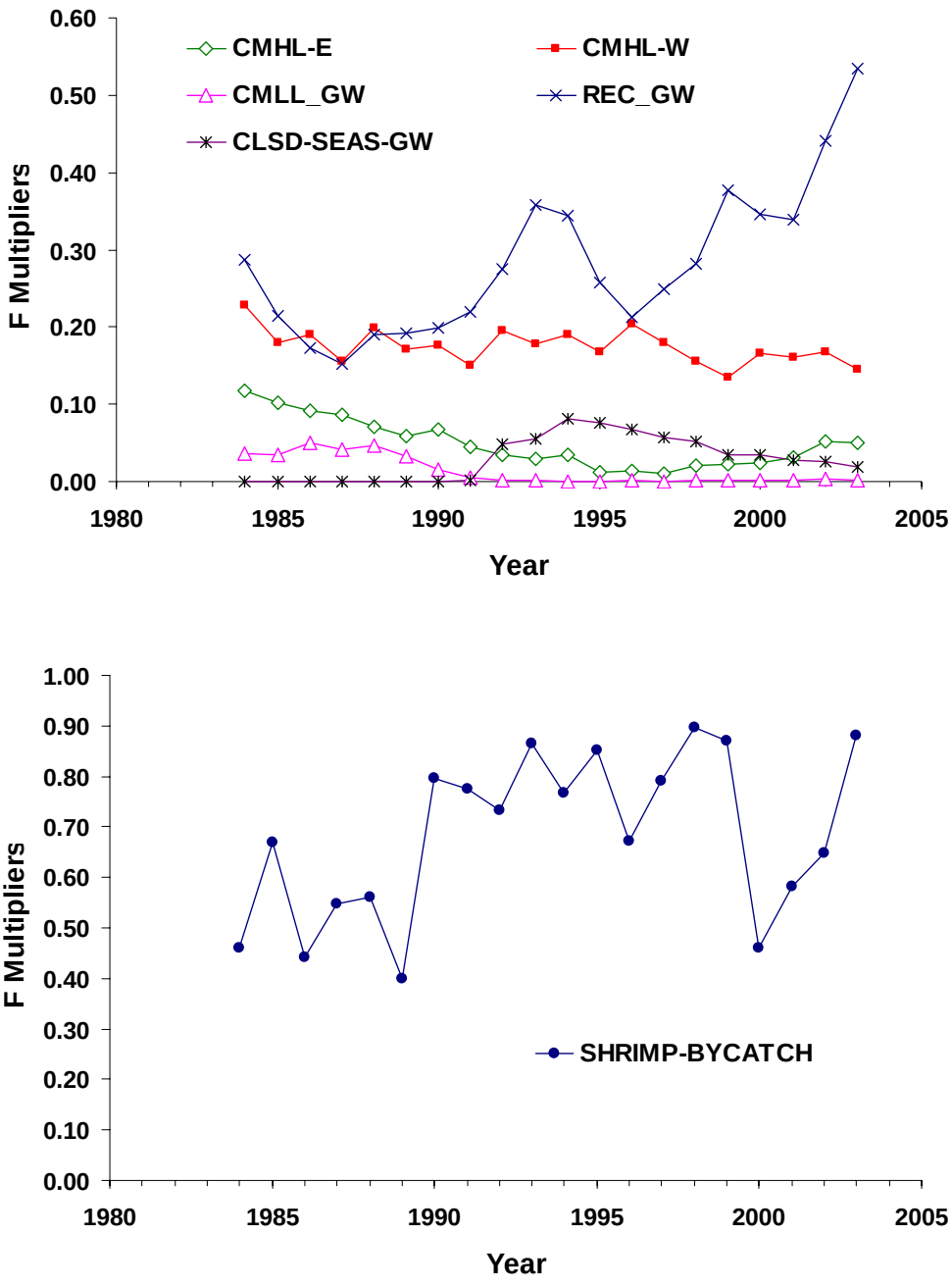

Figure 25: F multipliers by fleet for Runs E-F (Steepness = 0.95).

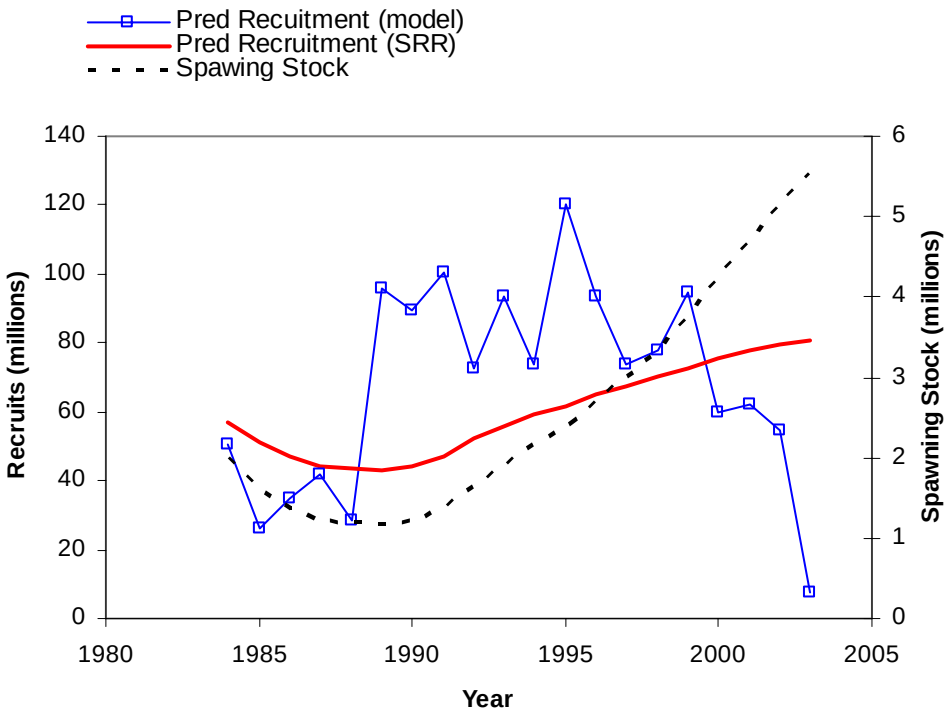

Figure 26: Spawning stock and recruitment estimates for Runs E –F (Steepness = 0.95)

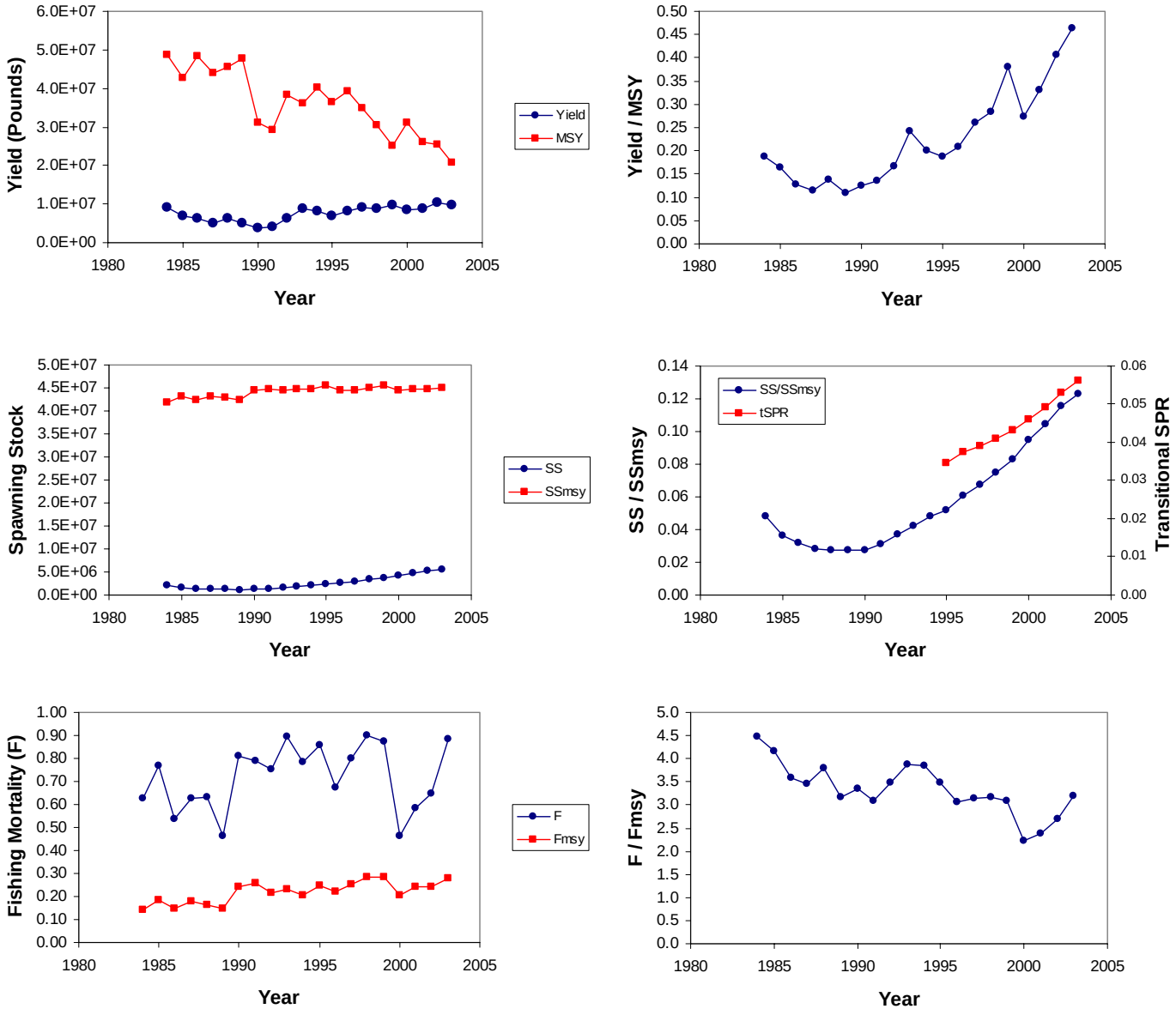

Figure 27: Trajectories of Yield, F, Spawning stock (SS), MSY, F_{MSY} , SS_{MSY} and tSPR for Run E (Steepness = 0.95).

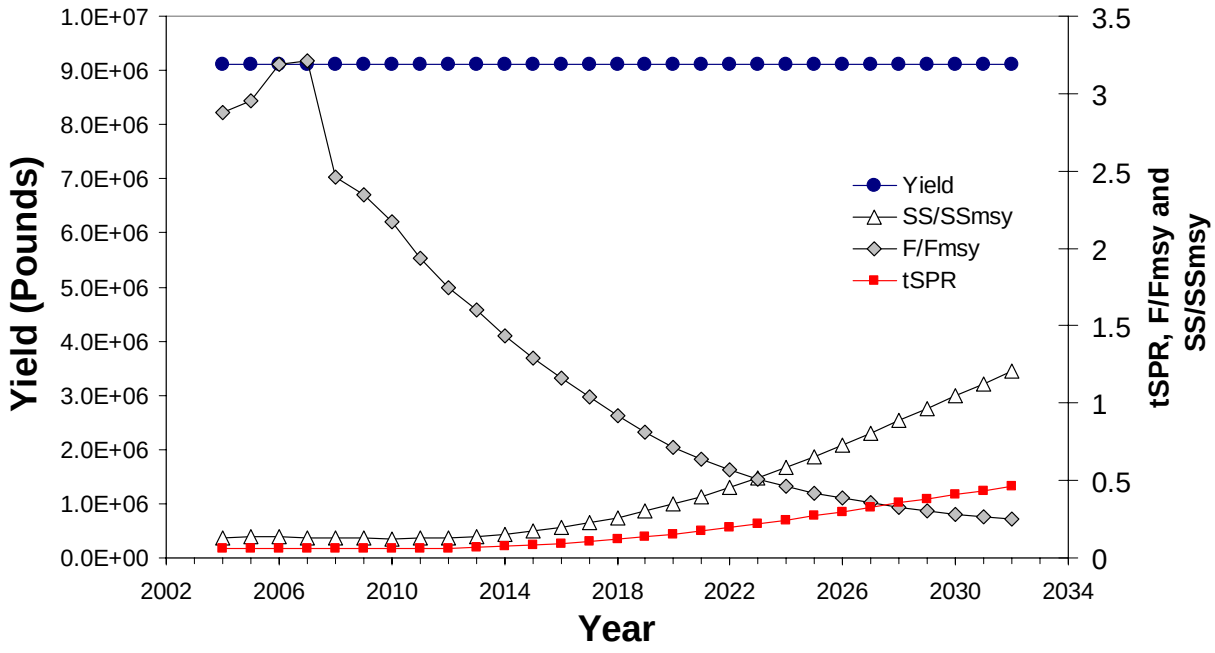

Figure 28 Projection of yield, transitional SPR, SS/SS_{MSY} and F/F_{MSY} for Run E. The projection assumes a constant TAC of 9.12 million pounds 2004-2032, and a 40% reduction in the effort of the shrimp fleet in 2008.

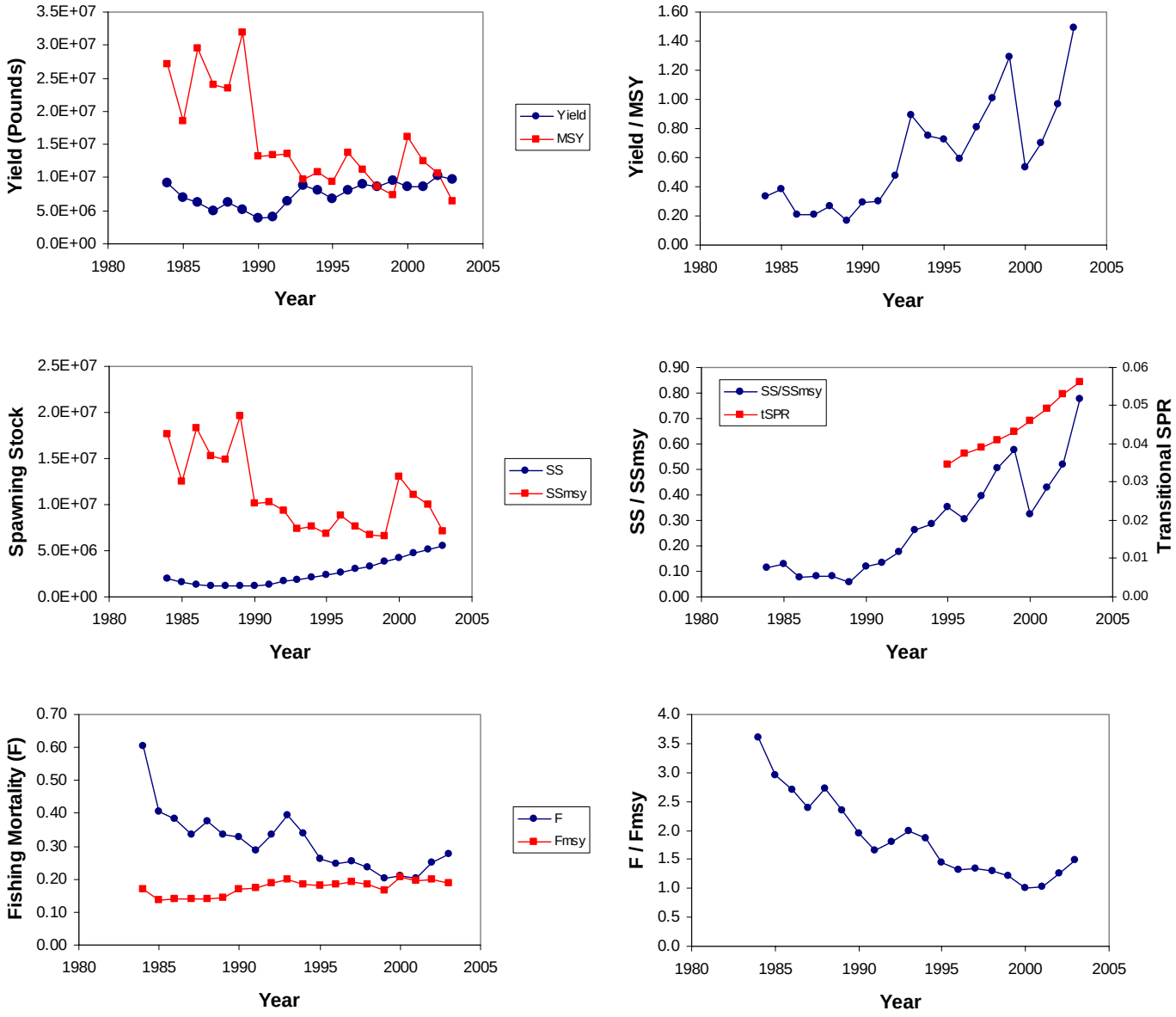

Figure 29: Trajectories of Yield, F, Spawning stock (SS), MSY, F_{MSY}, SS_{MSY} and tSPR for Run F (Steepness = 0.95).

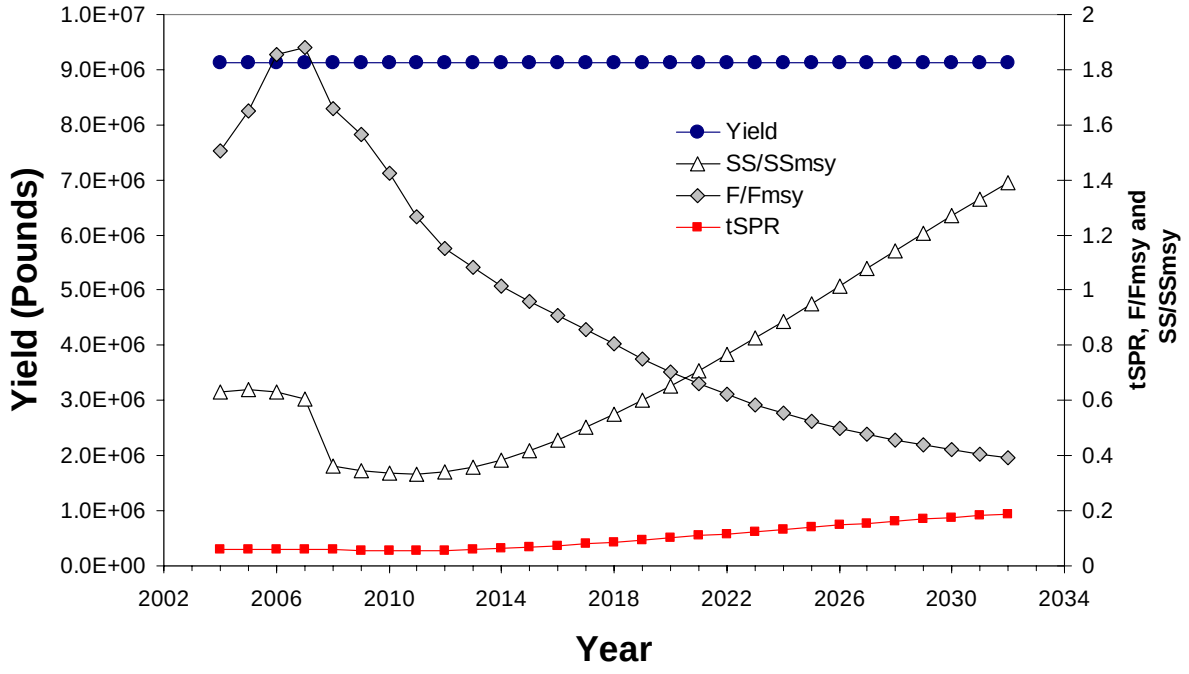

Figure 30: Projection of yield, transitional SPR, SS/SS_{MSY} and F/F_{MSY} for Run F. The projection assumes a constant TAC of 9.12 million pounds 2004-2032, and a 40% reduction in the effort of the shrimp fleet in 2008.

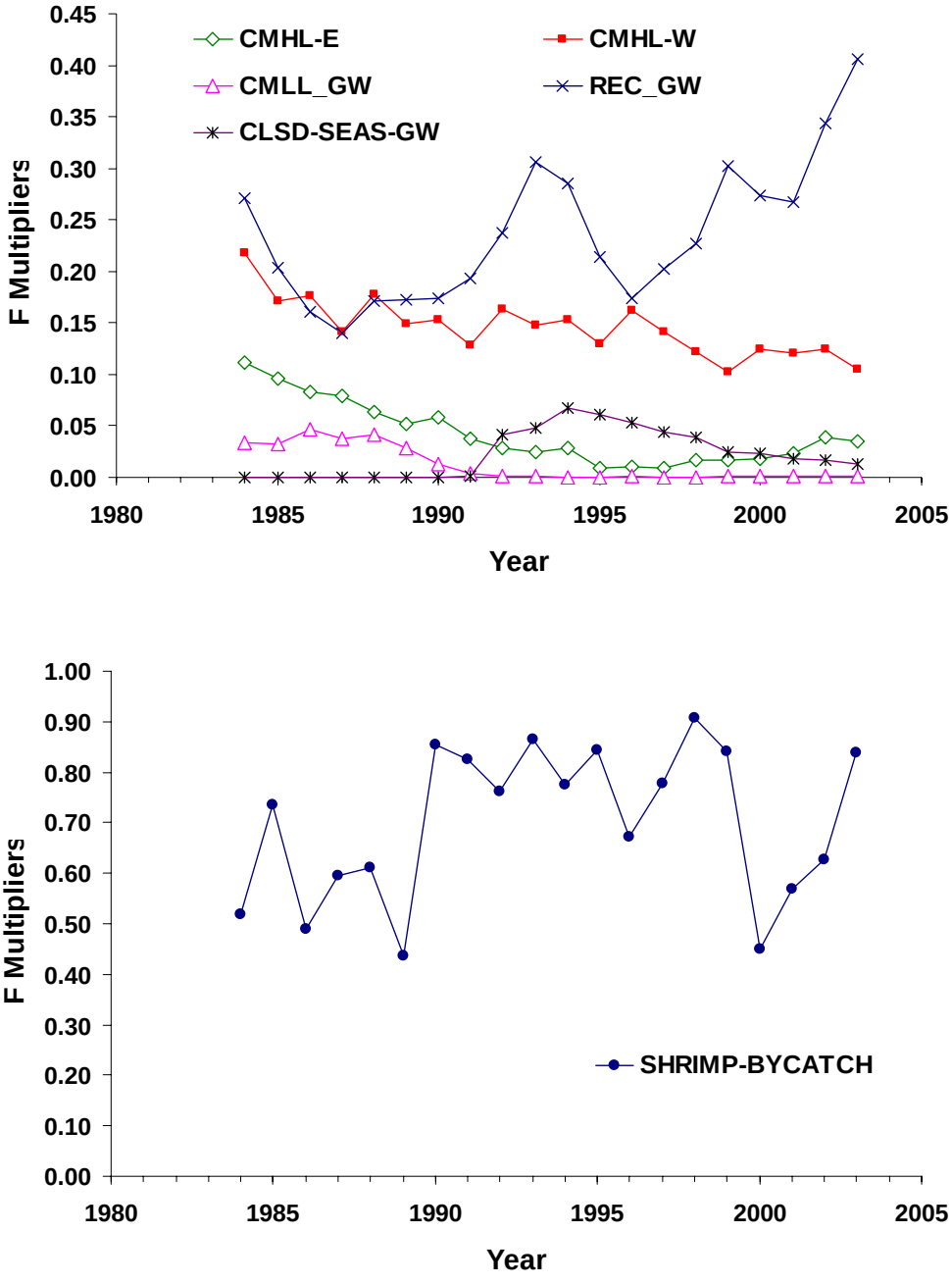

Figure 31: F multipliers by fleet for Runs G-H (Steepness 0.95).

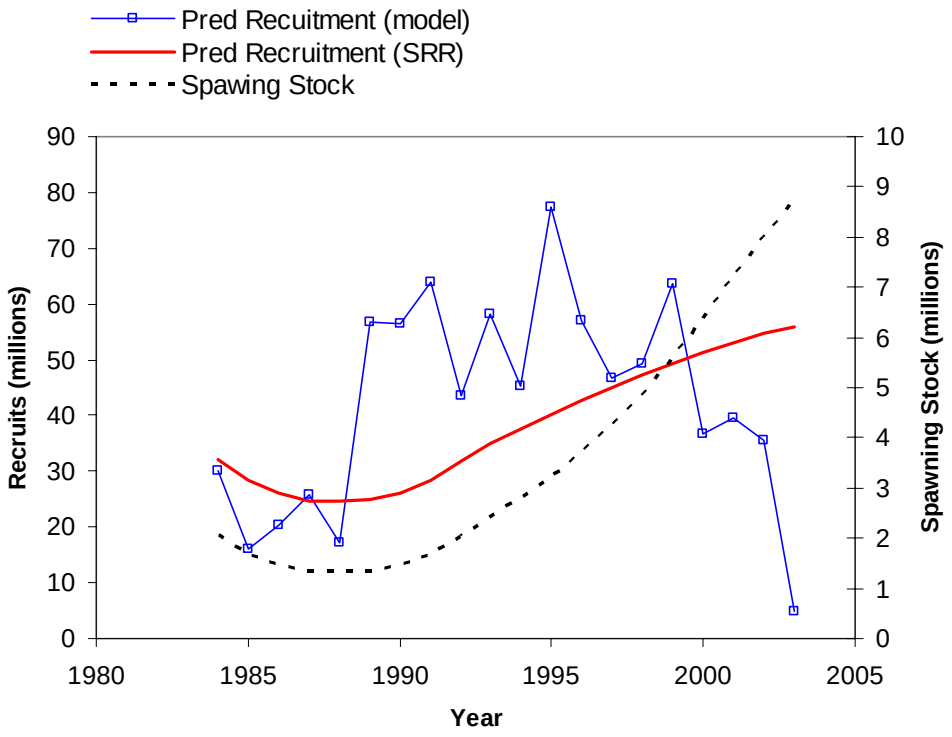

Figure 32: Spawning stock and recruitment estimates for Runs G and H (Steepness = 0.95)

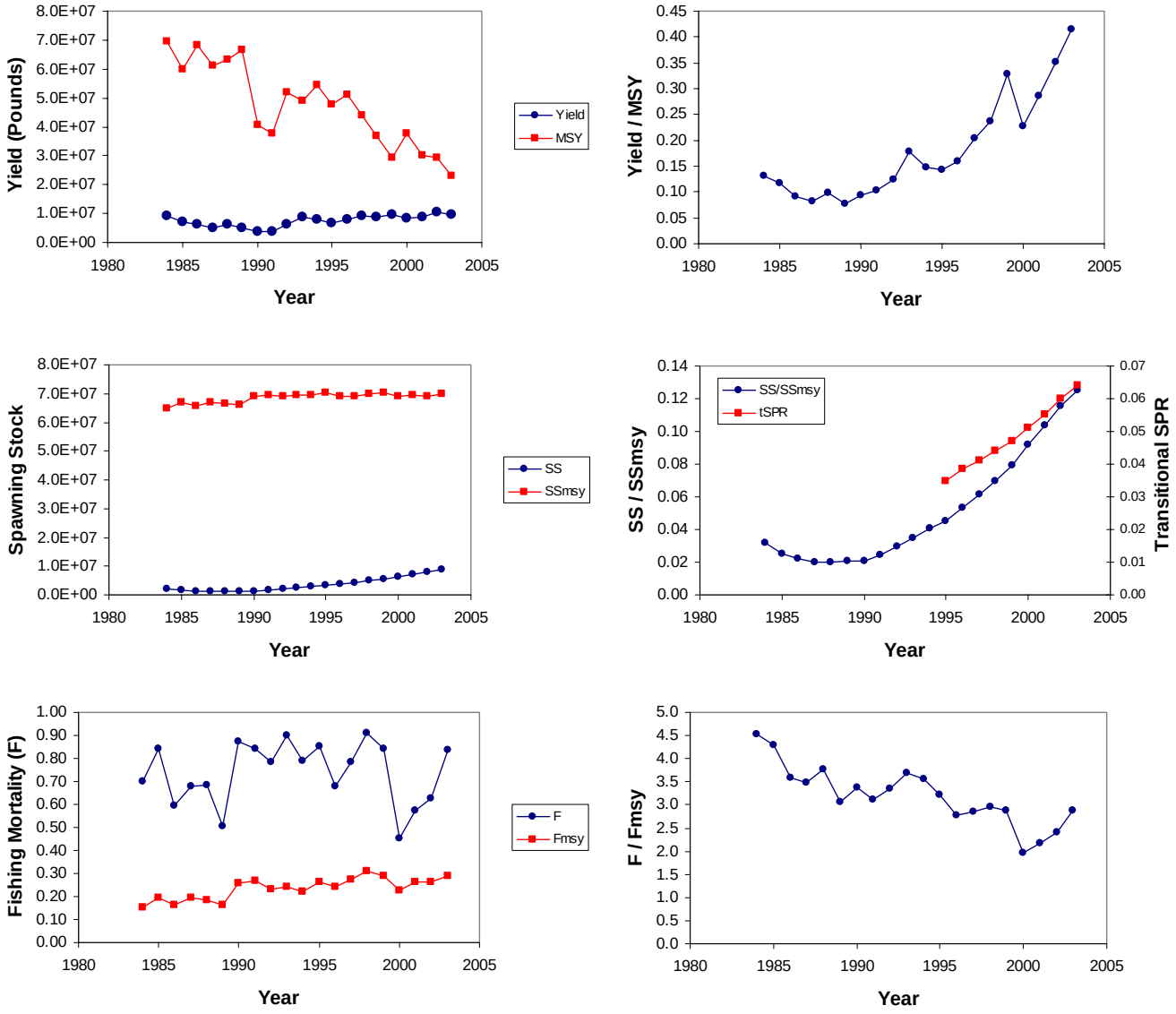

Figure 33: Trajectories of Yield, F, Spawning stock (SS), MSY, F_{MSY}, SS_{MSY} and tSPR for Run G (Steepness = 0.95).

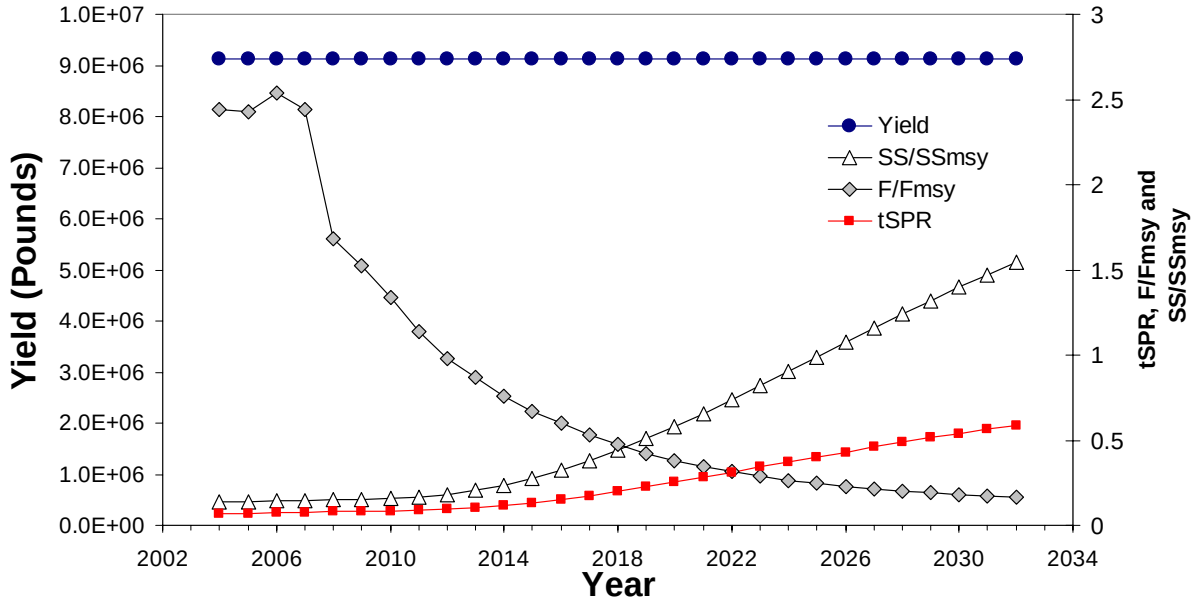

Figure 34: Projection of yield, transitional SPR, SS/SS_{MSY} and F/F_{MSY} for Run G. The projection assumes a constant TAC of 9.12 million pounds 2004-2032, and a 40% reduction in the effort of the shrimp fleet in 2008.

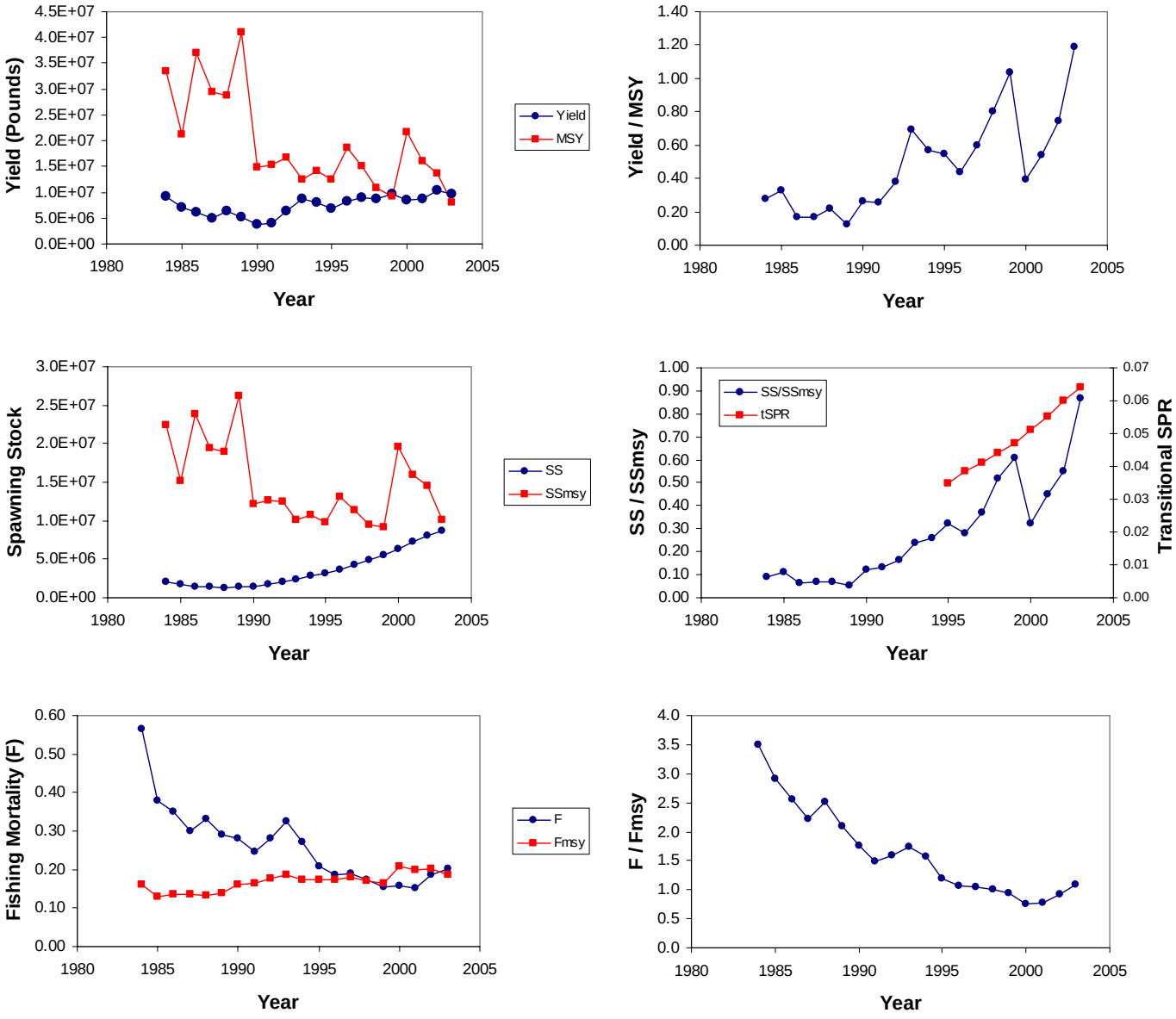

Figure 35: Trajectories of Yield, F, Spawning stock (SS), MSY, F_{MSY}, SS_{MSY} and tSPR for Run H (Steepness = 0.95).

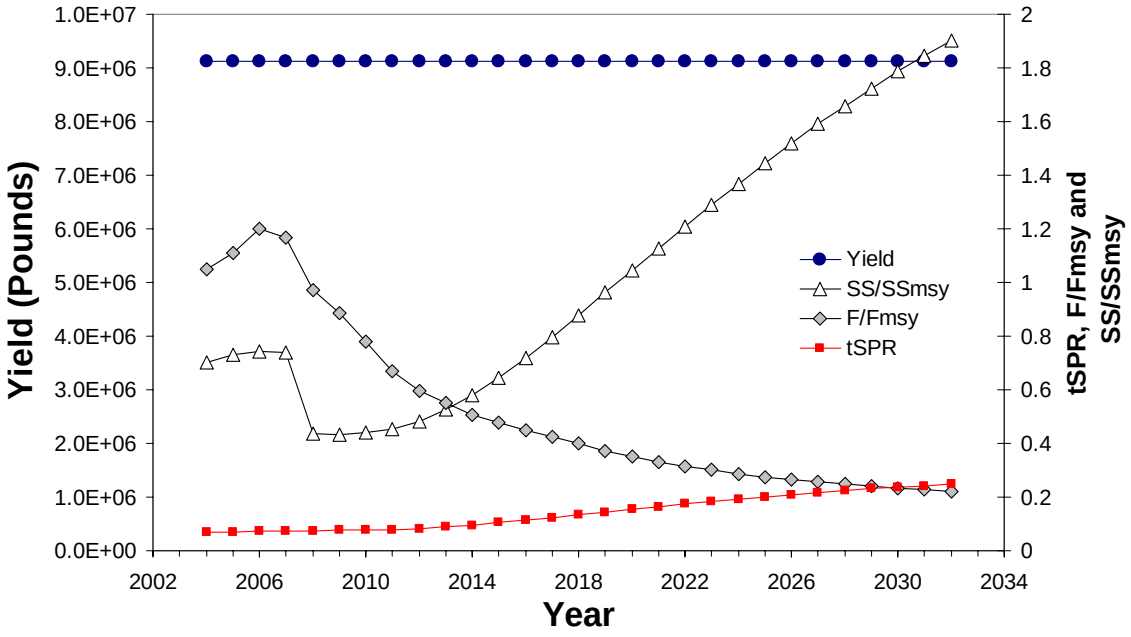

Figure 36: Projection of yield, transitional SPR, SS/SS_{MSY} and F/F_{MSY} for Run H. The projection assumes a constant TAC of 9.12 million pounds 2004-2032, and a 40% reduction in the effort of the shrimp fleet in 2008.