Exhibit C.3
Supplemental Attachment 5
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A Rebuilding Analysis of the West Coast Pacific Whiting (Hake) stock

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Introduction

Pacific whiting (*Merluccius productus*), also called Pacific hake, is a codlike species distributed off the west coast of North America from 25^0 N. to 51^0N. lat. It is among 11 other species of hakes from the genus, *Mercuccidae*, which are distributed in both hemispheres of the Atlantic and Pacific Oceans and constitute nearly two millions t of catches annually (Alheit and Pitcher 1995). The coastal stock of Pacific whiting is currently the most abundant groundfish population in the California current system. The fishery for Pacific whiting has supported total annual catches that have averaged 208,000 t and 282,000 t since 1966 and 1992, respectively (Table 1).

Age-structured assessment models have been used to assess Pacific whiting since the early 1980's. The most recent Pacific whiting assessment was conducted by Helser et al. (2002) using the age-structured model developed by Dorn et al. (1999) and implemented with the AD Model Builder software (Fournier 1996). Based on the 2002 assessment, mature female biomass in 2001 was estimated to be 20% of an unfished stock (Figure 1). Mature female biomass, however, was projected to rise gradually over the next three years due to the relatively strong 1999 year-class as it enters the mature biomass of the stock. Because mature female spawning biomass was estimated to be less than 25% of an unfished stock abundance (overfished threshold), the National Marine Fisheries Service declared the Pacific whiting stock to be overfished in 2002. A rebuilding analysis was undertaken, the results of which are presented in this report.

Input Data and Assumptions

The rebuilding analyses presented were performed using software developed by Punt (2002; V 2.0). The essence of the analysis is based on an age-structured stochastic projection model in which the initial age composition of the population is projected forward in time assuming time-invariant life history parameters and random realizations of future recruits drawn from the pool of historical recruitments estimated by the assessment model. Data inputs associated with initial conditions were taken from outputs generated from the age-structured Pacific whiting stock assessment by Helser et al. (2002), and include: 1) average fishery weights, 2) percentage of females mature, 3) female multiplier (proportion of females at age), 4) spawning output (product of weight at age, fraction mature and female multiplier), 5) average fishery selectivity, and 6) the initial population vector (numbers at age) (Table 2). The assessment model is structured for a U.S. and Canadian fishery in which catch and weights at age are used to estimate separate fishery selectivity patterns. Since the rebuilding software is not presently set up to deal with separate fisheries, the weights at age and selectivity at age used as inputs for the rebuilding analysis were taken as the averages at each age, weighted by the year- and age-specific catches from 1973-2001. For generating future recruitment, recruits to age 2 were selected at random from the entire historical times series, 1972-2001 (Table 1). Resampling recruits from the entire time period is consistent with the current calculation of B0 (unfished biomass)(Helser et al. 2002). Also, this choice assumes no relationship between spawning output and subsequent recruitment, but rather variation in recruitment pattern through time is environmentally driven (Figure 2). Furthermore, the projection results do assume that the environmental regime that has given rise to the observed life history characteristics and both the magnitude and variation in recruitment will on average persist over the rebuilding period. Population projections were configured to begin in 2001 (last year of the assessment) with the first projection year being 2002, in which catches were specified at 234,000 t and 162,000 t for the 2001 and 2002 fishing years, respectively.

Determination of Rebuilding

As indicated, unfished biomass (B0) was calculated as the product of virgin spawners-per-recruit (output from input life history vectors) and the average of the historical time series of recruitment (1972-2001). The estimated unfished biomass was 2,058,000 t with a target spawning output at 40%B0 (823,000 t) (Table 3). These estimates are substantially influenced by the very large 1980 (12 billion) and 1984 (9 billion) year classes. While recruitment events such as these are infrequent they have occurred greater than 5% within a 30 year period and should therefore be considered within reasonable bounds. Therefore, calculation of unfished biomass using the recruitment series excluding the very large year classes was not considered.

In the analysis that follows, the rebuilding strategy was based on the probability that the spawning output was exceeded by *X* percent during any year within the ten year rebuilding period. This definition allows for stocks such as Pacific whiting with extremely variable recruitment to recover to 40%B0 and then subsequently drop below this level. Fishing mortality rates associated with the different probability levels were set equal to F_{MSY} once the rebuilding target was met. If however, spawning biomass fell below the target then the 40:10 rule, which modifies the fishing rate gradually in response to declining stock sizes, was implemented.

The maximum rebuilding time for Pacific whiting was approximately 9 years, while the minimum rebuilding time was approx. 3 years (Table 3). The median time to rebuild depended upon the harvesting strategy during the interim rebuilding period, but in all cases the stock was able to rebuild within 10 years (Table 4). For instance, under the F40% (40:10) rule the median rebuilding time was 2.9 years with an 82 probability that spawning biomass would exceed the target in 10 years. On the other extreme, rebuilding the stock took there 7.7 years under the fishing rates consistent with a 50 probability of recovery within 10 years.

Rebuilding Strategies

Estimates of fishing mortality, optimal yield, probability of recovery (as defined above) and median time to rebuild were computed for five rebuilding strategies. These strategies were defined as the reference fishing mortality rates calculated in order to rebuild the stock by Tmax with specified probabilities as 1) 50%, 2) 60%, 3) 70%, 4) 80%, and 5) 40-10 harvest policy. The 40:10 rule option implements rule by modification of F_{MSY} immediately. As indicated earlier, the 40:10 rule is implemented for all other strategies when spawning biomass falls below the biomass target after recovery. The fishing mortality rates corresponding 50%, 60% and 70% probability of the stock rebuilding within 10 years were 0.41, 0.68 and 1.0, respectively. These mortality rates are all in excess of the current overfishing definition corresponding to F40%. At the 80% probability level the corresponding F was approx. 0.26. An F of 1.0 was the maximum allowable rate (user specified) and was used to contrast outcomes of the different strategies only, not to provide viable alternative strategies for F in excess of the overfishing definition. Under the most optimistic rebuilding policy, 50% probability of rebuilding within 10 years, the corresponding fishing mortality rate was 1.0 with a corresponding 2003 OY of 551,000 t (Table 4. Rebuilding under this strategy took 7.7 years and was roughly twice as long as the F (F=0.41) implemented to achieve a 70% probability of recovery. Under the later strategy, median time to rebuild was only 4.2 years with a 2003 OY of 277,000t. Thus, the general trend is that if higher probabilities to recover to the target within 10 years are required then more conservative harvest policies need to be implement, producing shorter rebuilding times and lower 2003 OYs. It should be noted that the probability of overfishing once the target has been reached increases with rebuilding strategies corresponding to higher rebuilding probabilities. This is because the shorter time it takes to rebuild to the target (lower Fs) the higher the likelihood the stock will become depleted again within the time remaining 10 year rebuilding time frame.

Although each of the rebuilding strategies were technically able to meet the specified "rebuilding" criterion in 10 years or less further examination of the trajectories of spawning biomass / target biomass ratios show that each of these are not equivalent with regards to risk to the stock. These risks are shown as the degree to which the spawning biomass / target biomass trajectory for each rebuilding strategy falls below a value of unity (biomass/target=823,000 t). Thus, any individual year within a given strategy's trajectory which falls below a value of 0.63 is below the overfished criterion (25%B0). For instance, the strategy having a 50% probability of rebuilding within 10 years shows a biomass/target ratio of less than 0.5 (~400,000 t) in the short term (Figure3). Since these are medians from 1000 simulations, this means that under this strategy there is greater than 50% chance that the stock will become overfished again. Under more conservative rebuilding strategies, such as the F corresponding to a 70% probability of recovery, the stock incurs relatively less risk of becoming overfished again in the short term. Figure 4 provides a more detailed examination of the spawning biomass / target biomass ratio trajectories showing the 5th, 25th, 50th, 75th, and 95th percentiles of the simulated realizations for the 50%, 60%, 70% and 80% probability strategies (detailed output for the 40:10 shown in Figure 3). It should be noted that each strategy converges to approximately the same spawning biomass / target biomass ratio over the long term. However, the fact that these trajectories stabilize at a ratio of less than 1.0 suggests that the biomass / target ratio distributions are extremely skewed owing most like to the fact that the underlying sampling distribution of recruitment is very skewed (Figure 4).

Outcomes from the rebuilding analysis also differ depending on the target SPR rates (F_{MSY} proxy) chosen. In the short term, moving from an F40% to F45% or F50% results in lower 2003 yields while the probability of rebuilding increases from 81.5% to 87.8% (Table 4). An interesting result to note is that risks of overfishing after the stock has been rebuilt decreases with a higher target SPR rate; F40%=32%, F45%=19.8%, and F50%=12.5% (Table 4). This feature is illustrated by the spawning biomass / target biomass trajectories (Figure 3a-3c). Here the spawning biomass / target biomass ratio converges to nearly the same value for all rebuilding strategies but depending on the SPR target rates (F_{MSY} proxy) the magnitude approaches the biomass target as the F_{MSY} proxy changes from F40% to F50% (Figure 3a-3c).

References

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Table 1. Historical time series of estimated biomass, recruitment, and utilization for 1972-2001 (Helser et al. 2002). Total exploitation rate is the catch in biomass divided by the total biomass of age 3+ fish at the start of the year. Population biomass is in millions of tons of age-3 and older fish at the start of the year. Recruitment is given in billions of age-2 fish.

Year	Population biomass (million t)	Female spawning biomass	Recruits (billion)	Total Catch (thousands t)	Total exploitation rate
1966	-	-	-	138	-
1967	-	-	-	214	-
1968	-	-	-	122	-
1969	-	-	-	180	-
1970	-	-	-	235	-
1971	-	-	-	155	-
1972	1.566	0.852	4.753	118	7.5%
1973	2.783	1.177	0.621	163	5.8%
1974	2.674	1.275	0.555	211	7.9%
1975	2.430	1.242	1.817	221	9.1%
1976	2.515	1.210	0.406	238	9.4%
1977	2.157	1.085	0.398	133	6.2%
1978	1.919	0.985	0.247	104	5.4%
1979	1.874	1.044	3.061	137	7.3%
1980	2.599	1.180	0.430	90	3.5%
1981	2.420	1.205	0.575	139	5.7%
1982	1.863	1.193	12.264	108	5.8%
1983	4.603	1.861	0.361	114	2.5%
1984	4.887	2.316	0.115	138	2.8%
1985	4.267	2.164	0.250	110	2.6%
1986	3.585	2.086	9.646	211	5.9%
1987	5.854	2.563	0.142	234	4.0%
1988	4.905	2.418	0.439	251	5.1%
1989	4.139	2.192	2.712	311	7.5%
1990	4.036	2.005	1.307	260	6.5%
1991	3.872	1.944	0.246	322	8.3%
1992	2.989	1.581	1.741	295	9.9%
1993	2.723	1.369	0.705	200	7.3%
1994	2.310	1.178	0.238	359	15.5%
1995	1.710	0.927	1.662	248	14.5%
1996	1.664	0.831	1.587	301	18.1%
1997	1.732	0.826	0.724	324	18.7%
1998	1.451	0.714	0.703	320	22.0%
1999	1.139	0.561	0.392	311	27.3%
2000	0.958	0.482	0.316	231	24.1%
2001	0.712	0.415	2.796	236	33.1%
Avg. 1972-98	2.744	1.363	1.707	208	10.31%

Table 2. Biological parameters used for Pacific whiting rebuilding analysis. Weights and fishery selectivities at each age shown were calculated as the catch (in numbers) weighted year and age specific weights and selectivity from the U.S. and Canadian fisheries (See Helser et al. 2002). Spawning output is the product of average weight, percent mature and the female multiplier

Age	Ave. fishery weight (kg)	Percent Mature	Female Multiplier	Spawning Output	Natural Mortality	Fishery Selectivity	2001 Age Composition (millions)
2	0.288	0.176	0.510	0.026	0.230	0.105	2796
3	0.407	0.661	0.511	0.137	0.230	0.473	238
4	0.491	0.890	0.510	0.223	0.230	0.756	145
5	0.563	0.969	0.512	0.279	0.230	0.881	175
6	0.612	0.986	0.522	0.315	0.230	0.930	110
7	0.654	0.996	0.525	0.342	0.230	0.979	131
8	0.691	1.000	0.535	0.370	0.230	1.000	101
9	0.726	1.000	0.543	0.394	0.230	0.992	10
10	0.756	1.000	0.547	0.414	0.230	0.967	19
11	0.810	1.000	0.569	0.461	0.230	0.919	27
12	0.846	1.000	0.568	0.480	0.230	0.856	2
13	0.911	1.000	0.572	0.521	0.230	0.783	9
14	0.919	1.000	0.581	0.533	0.230	0.580	14
15	0.949	1.000	0.589	0.559	0.230	0.230	84

Table 3. Outputs generated from rebuilding analysis determining maximum rebuild time, minimum rebuilding time and other reference points for different target SPR rates.

Outputs	Target SPR Rate (MSY Proxy) F40%	F45%	F50%
FMSY proxy	0.353	0.283	0.229
FMSY SPR / SPR(F=0)	0.400	0.450	0.500
Virgin SPR	1.205	1.205	1.205
Generation time	8	8	8
Minimum Rebuild Time	3	3	3
Maximum Rebuild Time	9	9	9
Selected rebuild time	9	9	9
Year for rebuild	2012	2012	2012
Virgin Spawning Output	2058	2058	2058
Target Spawning Output	823	926	1029
Current Spawning Output	387	387	387

Table 4. Estimates of fishing mortality, optimal yield, probability of recovery and median time to rebuild for five rebuilding strategies and applying F40%, F45% and F50% targets.

F40% Target SPR (MSY Proxy)

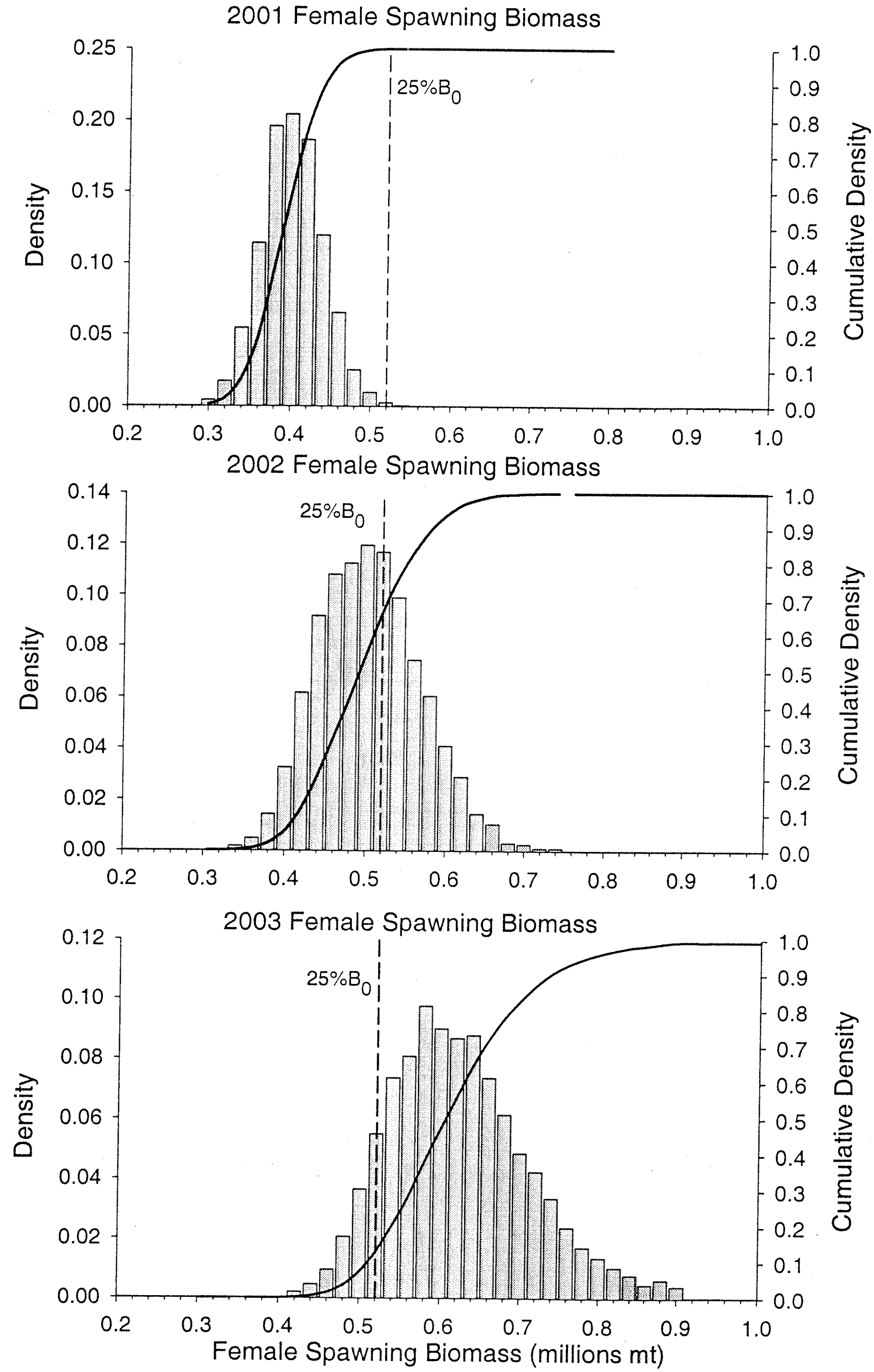
Quantity	50%	60%	70%	80%	F = 0	40:10 Rule
Fishing rate	1	0.675	0.4094	0.2562	0	0
OY	550.8	414.6	277.1	182.9	0	151.3
Prob to rebuild by Tmax	54.7	60	70	80	97.5	81.6
Median time to rebuild	7.7	5.9	4.2	3	1.5	2.9
Prob overfished after rebuild	23	24.8	29.1	31.9	0.5	31.9

F45% Target SPR (MSY Proxy)

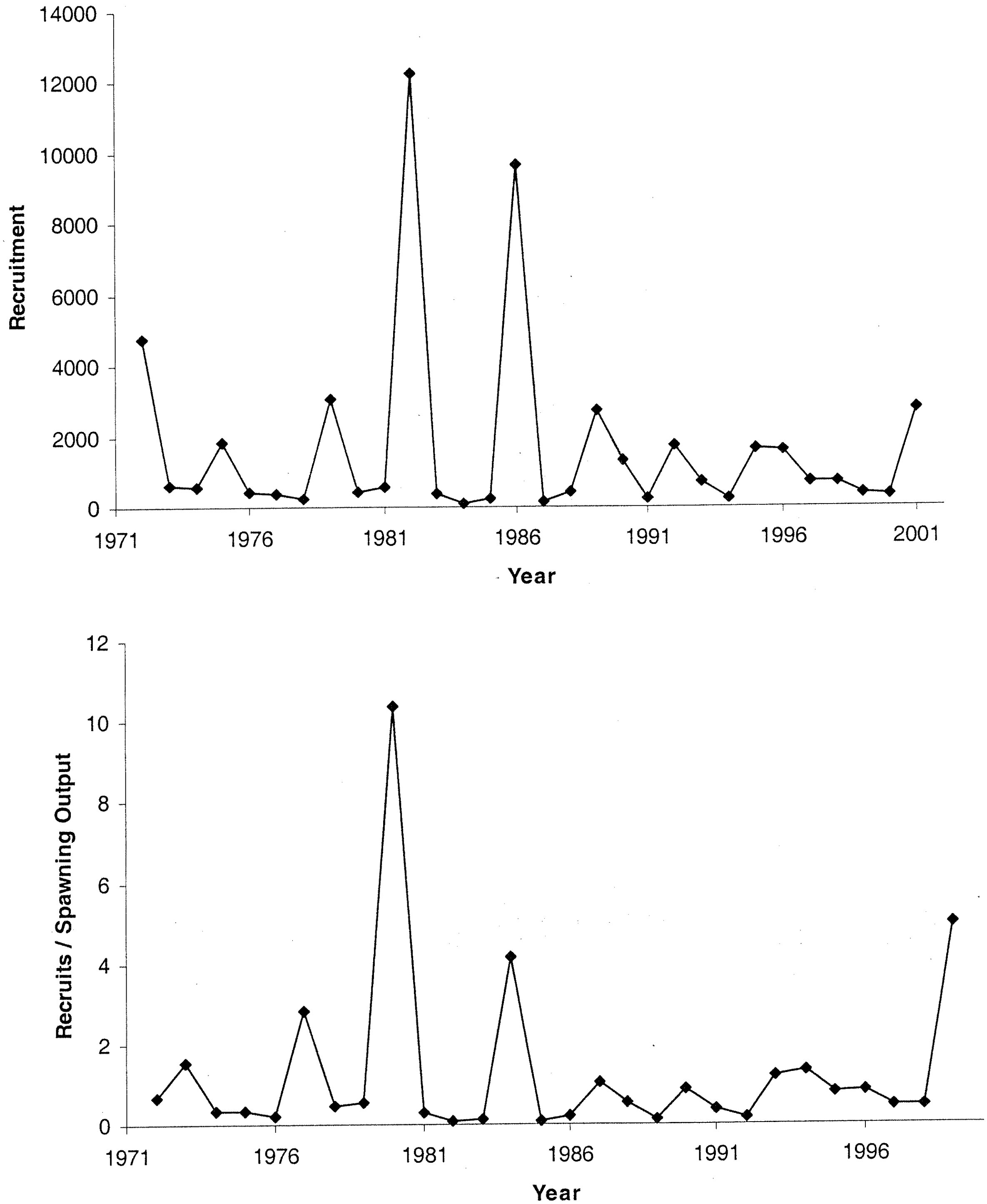
Quantity	50%	60%	70%	80%	F = 0	40:10 Rule
Fishing rate	1	0.675	0.4094	0.2562	0	0
OY	548.4	411.1	274.9	182.9	0	122.8
Prob to rebuild by Tmax	54.7	60	70	80	97.5	84.4
Median time to rebuild	7.7	5.9	4.2	3	1.5	2.7
Prob overfished after rebuild	12.4	13.5	16.9	19.7	0.5	19.8

F50% Target SPR (MSY Proxy)

Quantity	50%	60%	70%	80%	F = 0	40:10 Rule
Fishing rate	1	0.675	0.4094	0.2562	0	0
OY	542.3	411.1	273.5	182.5	0	100.7
Prob to rebuild by Tmax	54.7	60	70	80	97.5	87.8
Median time to rebuild	7.7	5.9	4.2	3	1.5	2.4
Prob overfished after rebuild	6.8	7.8	11	12	0.5	12.5



Fgure 1. Estimates of female spawning biomass of Pacific whiting in 2001, 2002, and 2003. Empirical distributions were derived from 1,000,000 Markov Chain Monte Carlo simulations (source: Helser et al. 2002).



Fgure 2. Time series of recruitment and recruits per spawning output used in Pacific whiting rebuilding analysis. Recruitment at age-2 in millions from Helser et al. 2002.

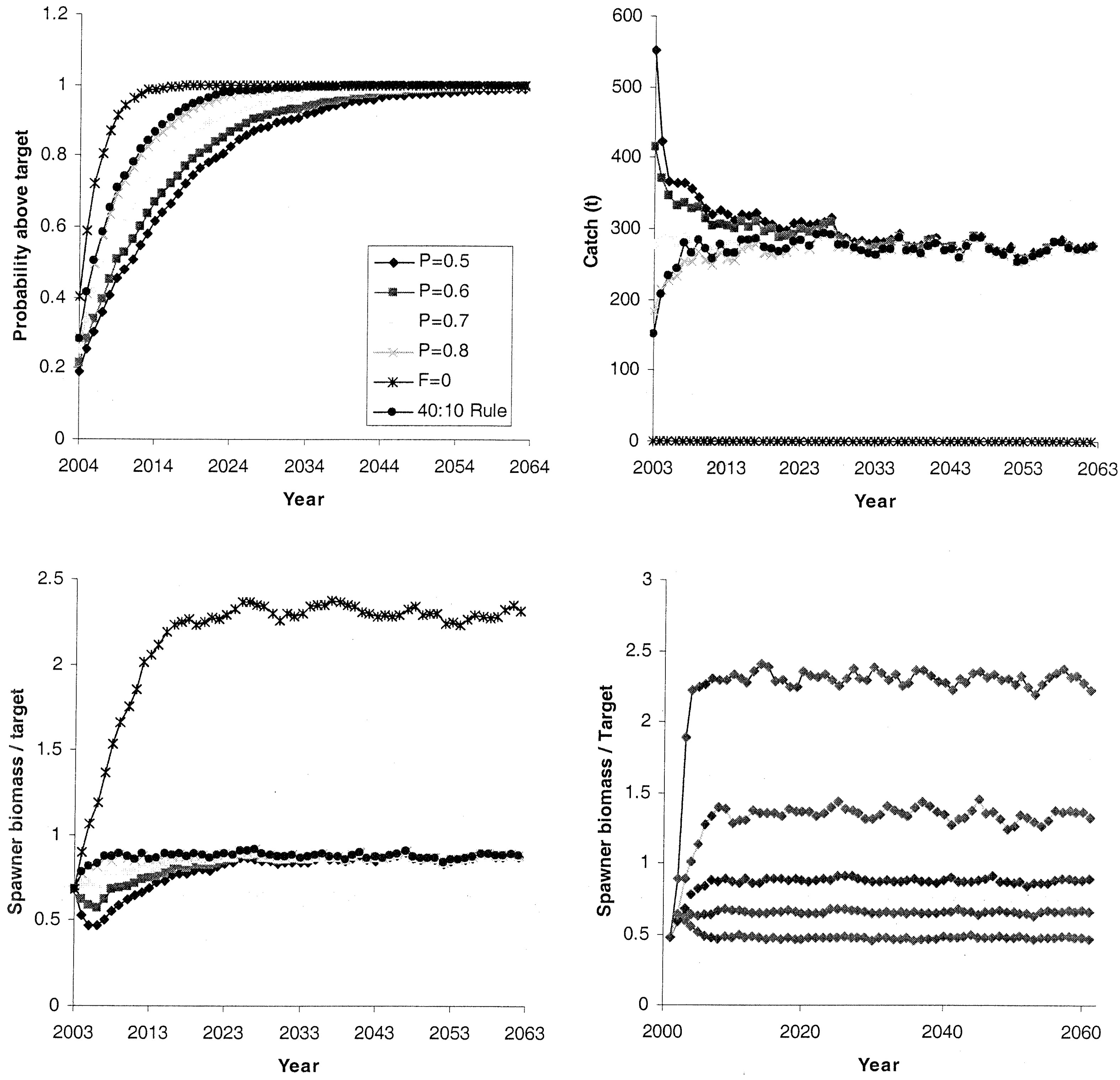


Figure 3a. Times series of probability above spawning biomass target, catch and spawning biomass to target biomass ratio for each rebuilding strategy under the F40% target SPR ratio (FMSY proxy). Lower right panel shows detailed output for the 40:10 rule.

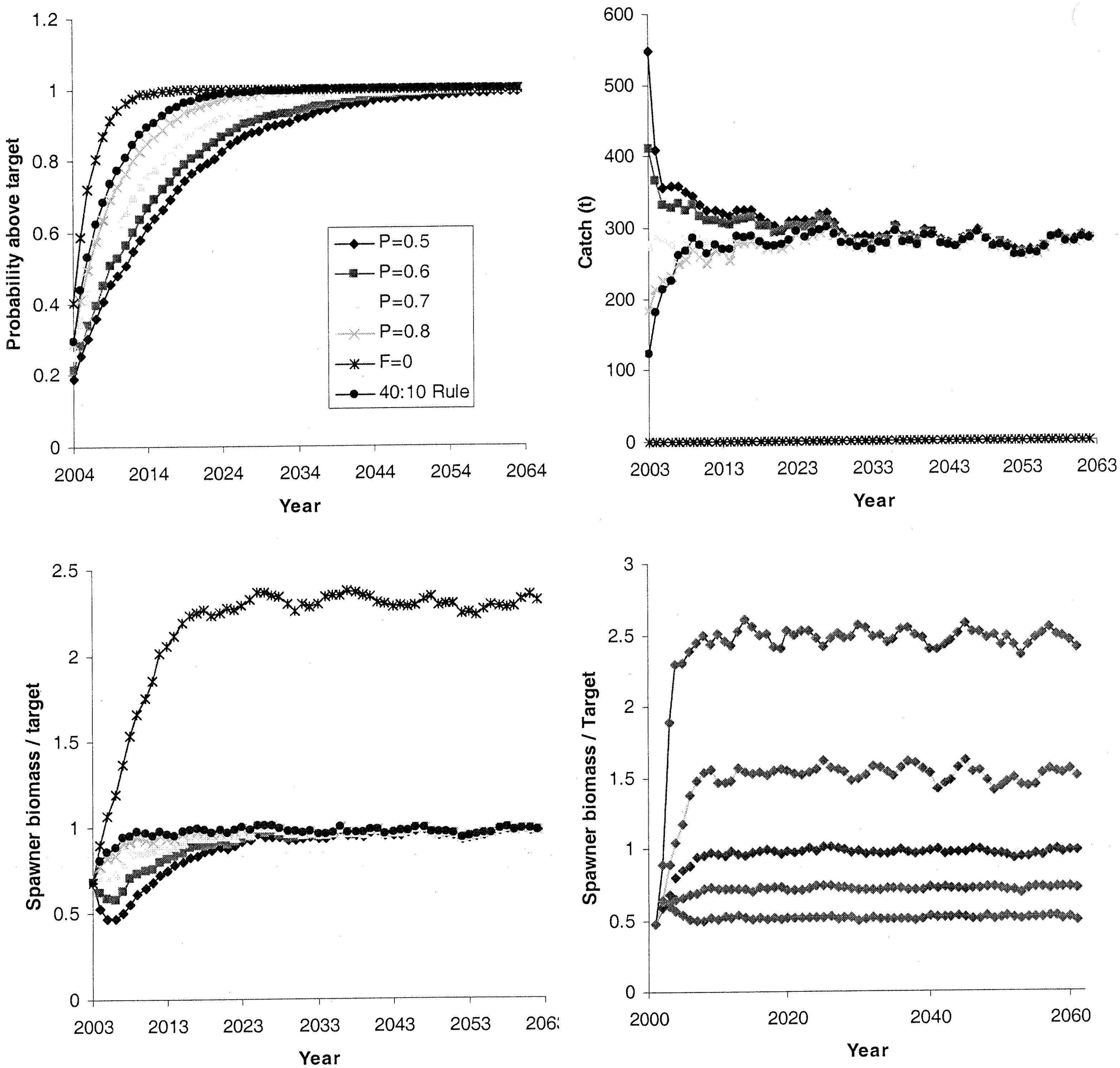


Figure 3b. Times series of probability above spawning biomass target, catch and spawning biomass to target biomass ratio for each rebuilding strategy under the F45% target SPR ratio (FMSY proxy). Lower right panel shows detailed output for the 40:10 rule.

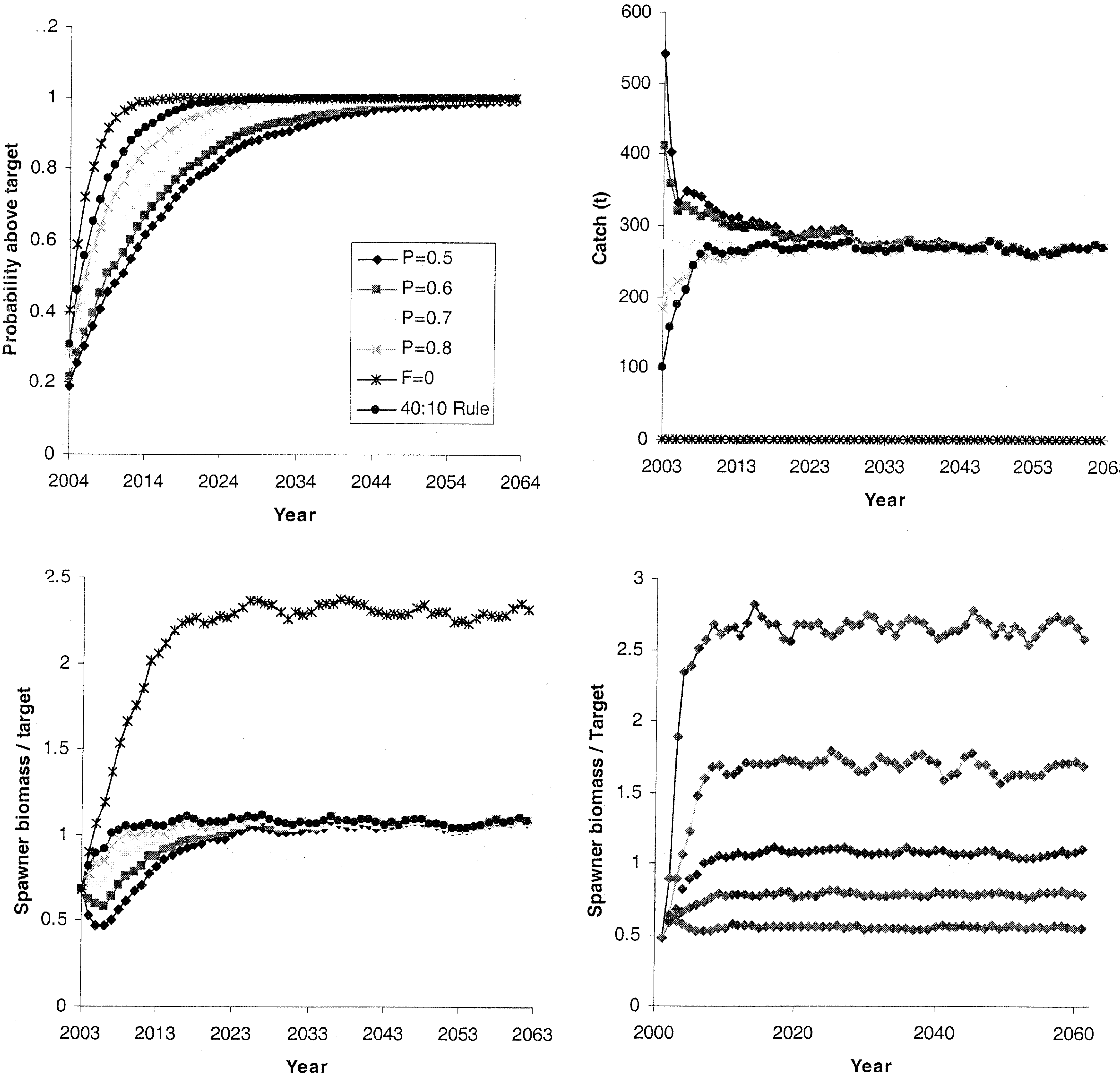


Figure 3c. Times series of probability above spawning biomass target, catch and spawning biomass to target biomass ratio for each rebuilding strategy under the F45% target SPR ratio (FMSY proxy). Lower right panel shows detailed output for the 40:10 rule.

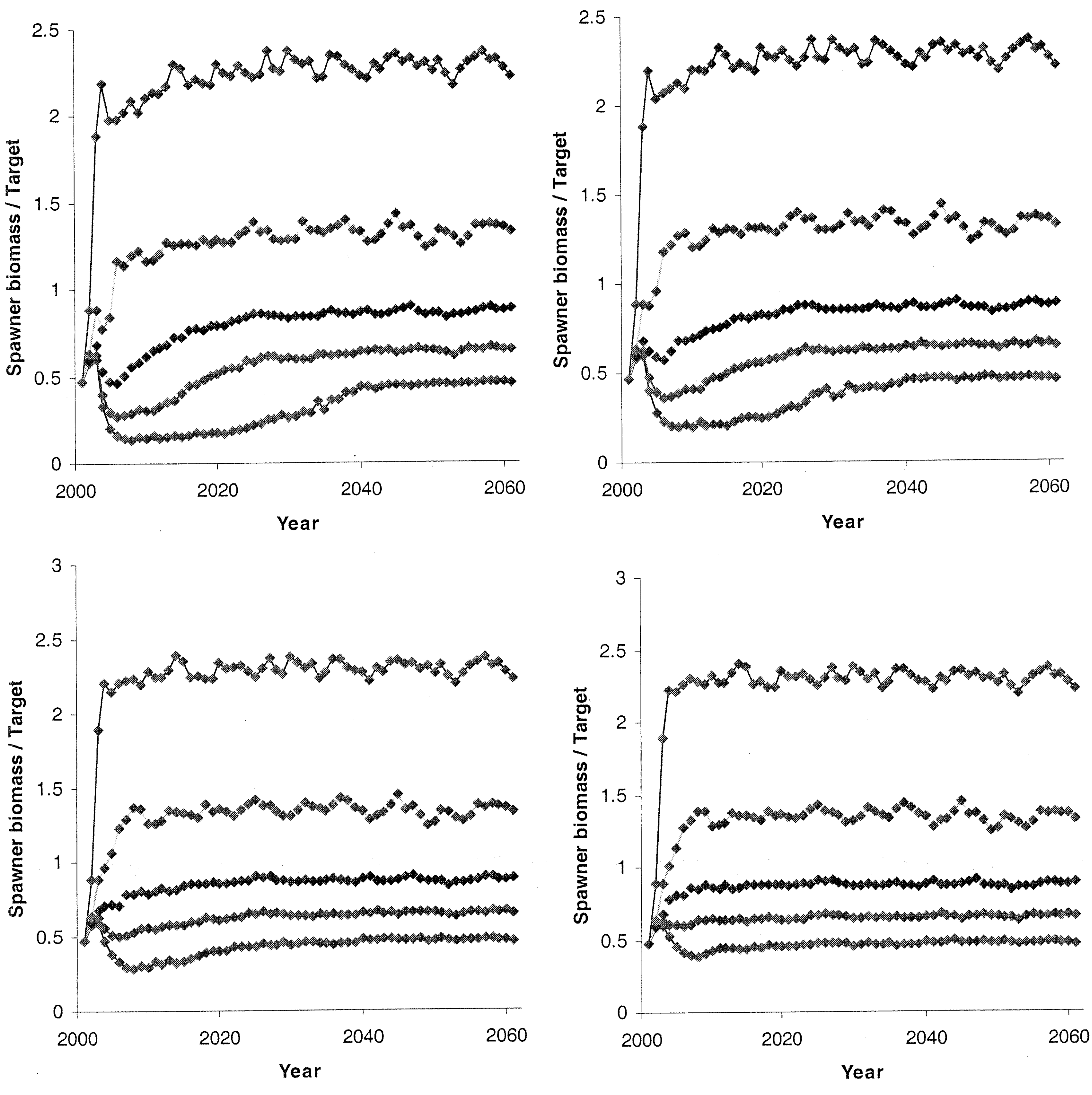


Figure 4. Detailed output from rebuilding program showing times series of spawning biomass to target ratios for the 50% probability (upper left), 60% probability (upper right), 70% probability (lower left) and 80% probability (lower right) rebuilding strategies. Detailed out for the 40:10 are shown in figure 3.