Rebuilding Analysis for Widow Rockfish

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Introduction

In 1998, the PFMC adopted Amendment 11 of the Groundfish Management Plan, which established a minimum stock size threshold of 25% of unfished biomass. Based on the most recent abundance estimates (Williams et al. 2000), widow rockfish has been declared formally to be overfished, thereby requiring development of a rebuilding plan. This rebuilding analysis provides information needed to develop the rebuilding plan for widow rockfish, and is in accord with the SSC Terms of Reference for Groundfish Rebuilding Plans.

The 2000 widow rockfish stock assessment included rebuilding projections, but those calculations contained an error and that analysis should be discarded. This rebuilding analysis supersedes the rebuilding analysis in the stock assessment document.

The stock has declined since fishing began in the late 1970's (Table 1). The relative decline in overall biomass has has been somewhat less than that for spawning output (the best measure of stock reproductive potential). Older, larger fish have a higher fecundity per body weight than do young fish. Widow rockfish bear their offspring live as larvae, and spawning output is measured in million fertilized eggs, at a stage prior to parturition of larvae.

Table 1. Current status of widow rockfish relative to pre-fishery years.

	Age 3+ Biomass (mt)	Spawning Output (million eggs)
Avg. 1968-79	197998	33490
1999	60551	8223
percentage	30.6%	24.6%

Data and Parameters

Stock and recruitment histories are taken from the assessment by Williams et al. (2000). Life history parameters are a simplification of the two-area, two- sex model, time-varying selectivity model used in the assessment. The simplified model is tuned to the most recent three years of the assessment (E. Williams, Pers. Comm.), and achieves a close match to the characteristics of the full model (Appendix 1).

Management Reference Points

Bmsy: The rebuilding target is the spawning abundance level that produces MSY. This cannot be determined easily, but experience in other fisheries has shown that B_{MSY} is often near 40% of the average initial unfished spawning abundance (B_0), and this value ($B_{40\%}$) is used as a proxy for B_{MSY} (see the SSC's Terms of Reference). Spawning abundance is measured in units of spawning output. Values of B_0 are estimated by dividing mean recruitment by the spawning output per recruit at F=0 (1.057 million eggs of spawning output per thousand recruits). Two estimates of B_0 were developed, based on use of pre-fishery recruitments (1965 to 1979 yearclasses) and all recruitments (Table 2). There is a strong statistical difference between pre-fishery (pre-1982) recruitments and post-fishing-down (post-1982) recruitments, as shown by a t-test (one-tailed, P=0.002). This difference is presumably due to the decline in spawning abundance, but also may be associated with a less favorable climate in the later period.

Table 2. Calculation of B_0 and rebuilding targets of spawning output (million eggs).

Source of recruitments	Pre-exploitation (1965-79)	All years
Mean recruitment	39615	31570
Estimated B_0	37480	29870
Rebuilding target	14992*	11948

* default target

Simulation of an unfished 1000-year history by re-sampling recruitments from the respective data sets provides frequency distributions of initial abundance that can be compared with the early abundances estimated in the stock assessment (Figure 1). The range of pre-exploitation biomasses given by the stock assessment is consistent with either frequency distribution, but the values from the assessment are somewhat low given the estimated sizes of pre-exploitation recruitments. Several explanations can be considered. Foreign fishing for whiting during the 1960s and 1970s probably had an incidental take (perhaps several hundred tons annually) of widow rockfish, so population biomasses estimated for the early (pre-exploitation) years of the assessment may not truly reflect pre-exploitation conditions. Low frequency climate variability could also have generated somewhat lower recruitment levels prior to 1965. Also, the initial conditions and earliest years of recruitments in the assessment model are prone to model mis-specification and may be less reliable than values estimated for later years.

The relationship between current stock status and the rebuilding target is shown relative to the historical stock-recruitment relationship in Figure 2. The rebuilding target of 14992 is similar to the stock status at the end of the 1980's, and tended to produce somewhat higher recruitments than have been seen recently.

Mean generation time: If the stock cannot be rebuilt in ten years, then the maximum time allowed for rebuilding is the length of time required to rebuild at F=0 plus one generation time. Mean generation time can be estimated from the net maternity function (product of survivorship and fecundity at age, Figure 3), and for widow rockfish is estimated to be 14.92 years, which is rounded to an integer value of 15 years.

Simulation Model

The simulation model tracks abundances at age, with an accumulator at age 20+. Values of weights at age, selectivity and fecundity are given in Appendix 1. Population simulations begin with the 1999 age composition estimated by the stock assessment (age 3 and older). Recruitments for birth years 1997 and 1998 are treated differently from later years. The 1997 value (recruited at age 3 in 2000) is based on the average value of the source data (recruits or recruits-per-spawning output). The 1998 value corresponds to an El Niño year, and is treated as equivalent to the corresponding value from 1992, another recent El Niño year. Subsequent recruitments or recruits per spawning output values are generated in two alternative ways. In the "R" simulations, recruitment values themselves are drawn randomly from those estimated for the spawning years 1983 to 1996. In the "R/S" method, recruitments are generated by a random draw of one of the historical values of R/S from the same years, which is multiplied by current spawning output (S) to obtain the following year's recruitment. One hundred simulations were conducted for each management scenario, using the same sets of random numbers across alternative model formulations in order to maximize comparability.

Tmax (Time to Rebuild at F=0): Four sets of simulations were run following the logical classification in the SSC's Terms of Reference, corresponding to the two alternative $B_{40\%}$ rebuilding targets in Table 2 and use of the "R" vs. "R/S" simulation approaches. Results are shown in Figure 4, and are summarized in Table 3.

Table 3. Median rebuilding times for the case of F=0 (* indicates default case).

	$B_{40\%}$ =14992 (early years)	$B_{40\%}$ =11948 (all years)
Recent R/S	median T = 19yr*	median T = 11yr
Recent R	median T = 10yr	median T = 6yr

The "S/R" simulations have much longer rebuilding times than the "R" simulations. This is due to the effect of the currently low biomass, which results in much smaller recruitments in the initial years of rebuilding. The recent history of R/S has been stable, whereas recruitments themselves have been declining (Figure 5). The tendency for R to decline in more recent years (and at lower spawning abundances) is reason to reject the right-hand and lower cases in Table 3. Based on a median time of 19 years to rebuild, the maximum allowable median time to rebuild (Tmax) is 34 years.

Rebuilding Projections

Rebuilding projections used $B_{40\%}$ =14992 as the rebuilding target, and the "R/S" simulation method. Three constant fishing rate policies are presented, corresponding to 50%, 60% and 70% probabilities of reaching the rebuilding target in 34 years (Figure 6, Table 4). Increasing the rebuilding probability is equivalent to setting a slightly earlier median time to rebuild. The envelope of rebuilding trajectories is shown in Figure 7 for spawning output, and in Figure 8 for optimum yields. One half of the results fall between the 25 and 75 percentile lines, and 80 percent of the results fall between the 10 and 90 percentile lines. The highest fishing rate allowable has a 50% probability of success within the time limit, and corresponds to F81% (i.e., the spawning potential ratio is 81% of the unfished level).

Table 4. Alternative constant rate rebuilding policies.

Fishing rate	0.0319	0.0287	0.0267	0
OY_{2002} (mt)	1047	944	879	0
Prob. rebuild by Tmax (34yr)	50%	60%	70%	100%
Median time to rebuild (yr)	34	33	31	19

Relationship to Rebuilding Analysis by Williams et al.

The rebuilding analysis in Williams et al. (2000) erroneously doubled the recruitment values obtained in their stock assessment. This can be seen by comparing the recruitment levels in the rebuilding forecasts (their Table 20) with recent historical recruitments (their Table 18). Other differences between the previous analysis and this analysis are explored in Table 5.

Table 5. Effects of altering the present model to incorporate specifications used in the analysis by Williams et al. (2000).

	Median rebuilding time (F=0)
Base run (this analysis)	19
Specification from Williams et al.	
Double recruitment	8
Target = 13960	16
C = 0 in 2000 and 2001	16
Use average R in 1998	18

Long-term outlook

The stock-recruitment data used in this analysis indicate that the rebuilt resource will be able to sustain an annual harvest of about 3900mt at a harvest rate near F60%. The stock and recruitment history of widow rockfish indicate that the resource is incapable of sustaining F50% at recent biomass levels and under recent environmental conditions. The resource would decline further at that fishing rate. It is widely suspected that the weak recruitments during the 1990's have been associated with unusually warm environmental conditions and low plankton abundances. Present understanding of environmental influences is severely limited, and the reliability of climate forecasts for the next few decades is insufficient to allow an environmentally-tuned rebuilding plan. However, if future decades are more favorable than the past decade for widow rockfish reproduction, higher productivity will result both in an earlier transition to normal harvest levels, and in higher sustainable yields once the stock is rebuilt.

References

Williams, E. H., A. D. MacCall, S. V. Ralston, and D. E. Pearson. 2000. Status of the widow rockfish resource in Y2K. In: Appendix to Status of the Pacific coast groundfish fishery through 2000 and recommended acceptable biological catches for 2001. Stock assessment and fishery evaluation. Pacific Fishery Management Council. 2130 SW Fifth Avenue, Suite 224, Portland, OR, 97201.

Appendix: Data used in rebuilding analysis

The following information is based on the assessment by Williams et al. (2000)

Age	Fecundity	Avg. Wt.	Selectivity	N(1999)
	million eggs	kg.		thousand
1	0		0	
2	0		0	
3	5.72E-05	0.281983	0.000592	5917
4	0.000192	0.396261	0.00566	15177
5	0.014959	0.515881	0.054496	12493
6	0.064162	0.634955	0.361235	13726
7	0.161188	0.749169	0.84571	4123
8	0.276595	0.856006	0.998124	11155
9	0.368665	0.953966	0.963223	4544
10	0.441151	1.042556	0.903957	3339
11	0.508537	1.121786	0.846069	3292
12	0.566615	1.192006	0.79177	2669
13	0.618765	1.25388	0.740729	1085
14	0.665202	1.308095	0.692332	1350
15	0.706389	1.355401	0.645889	1034
16	0.742759	1.396557	0.600647	282
17	0.774749	1.432296	0.555768	342
18	0.802838	1.463212	0.510347	773
19	0.827409	1.489972	0.463542	478
20+	0.883903	1.550257	0.414862	1870

M = 0.15/yr
SPR(F=0) = 1.057million eggs per thousand recruits

Year	Rect(age3)	SpOutput
	thousand	million eggs
1968	29603	30662
1969	39748	30664
1970	37990	30668
1971	47532	30716
1972	39929	30910
1973	112579	31371
1974	42955	32096
1975	20667	33298
1976	11070	35254
1977	23596	37731
1978	39407	39189
1979	2219	39316
1980	73666	38032
1981	48325	32253
1982	24940	25329
1983	47876	19457
1984	62307	17592
1985	21667	17055
1986	13094	16665
1987	32540	16481
1988	28129	15782
1989	16110	14978
1990	29622	13019
1991	25813	11553
1992	18452	11079
1993	18265	10632
1994	31413	9860
1995	8327	9533
1996	21956	8985
1997	16901	8664
1998	17637	8261
1999	5917	8223

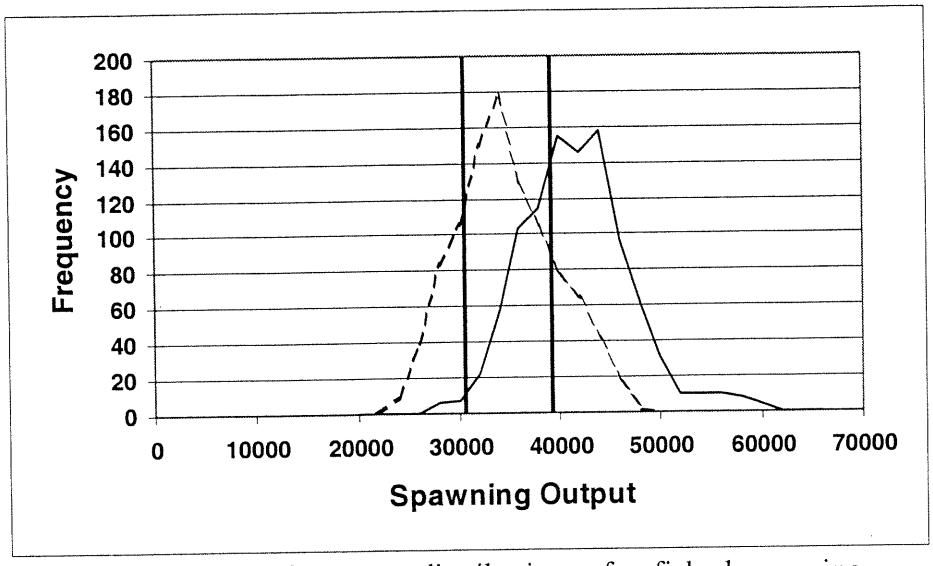

Figure 1. Simulated frequency distributions of unfished spawning output based on pre-fishery recruitments (solid line) and all recruitments (dashed line). Vertical lines represent the range of pre-fishery spawning abundances estimated by the stock assessment.

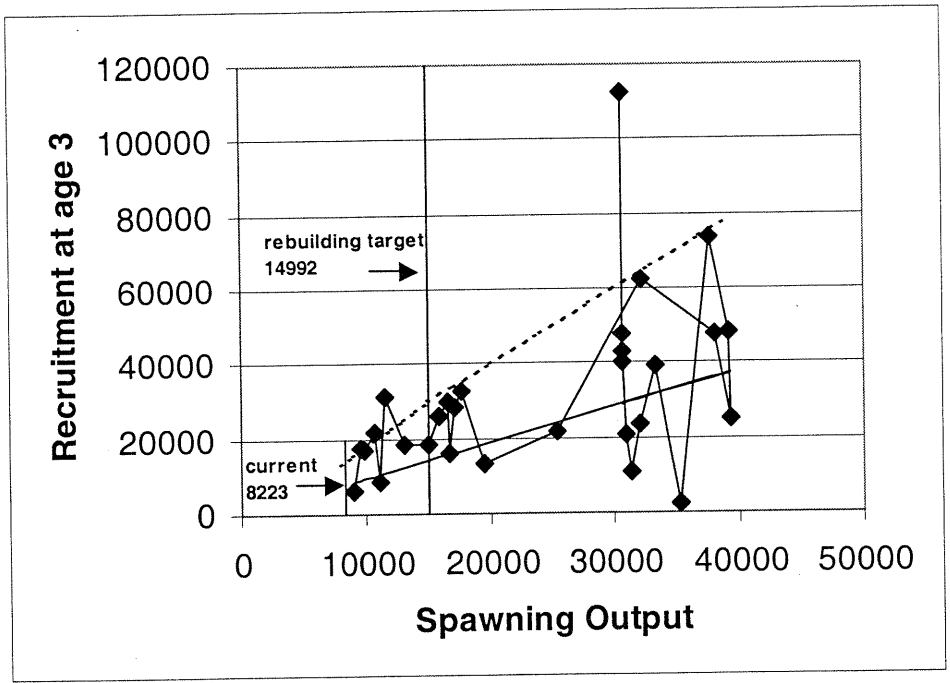

Figure 2. Historical stock-recruitment relationship for widow rockfish, showing relationship of $B_{40\%}$ rebuilding target to current spawning abundance (vertical lines). Solid diagonal line is replacement level of recruitment at F=0; dashed diagonal line is replacement level of recruitment under F50% policy with 40-10 adjustment.

Figure 3. Net maternity function for widow rockfish.

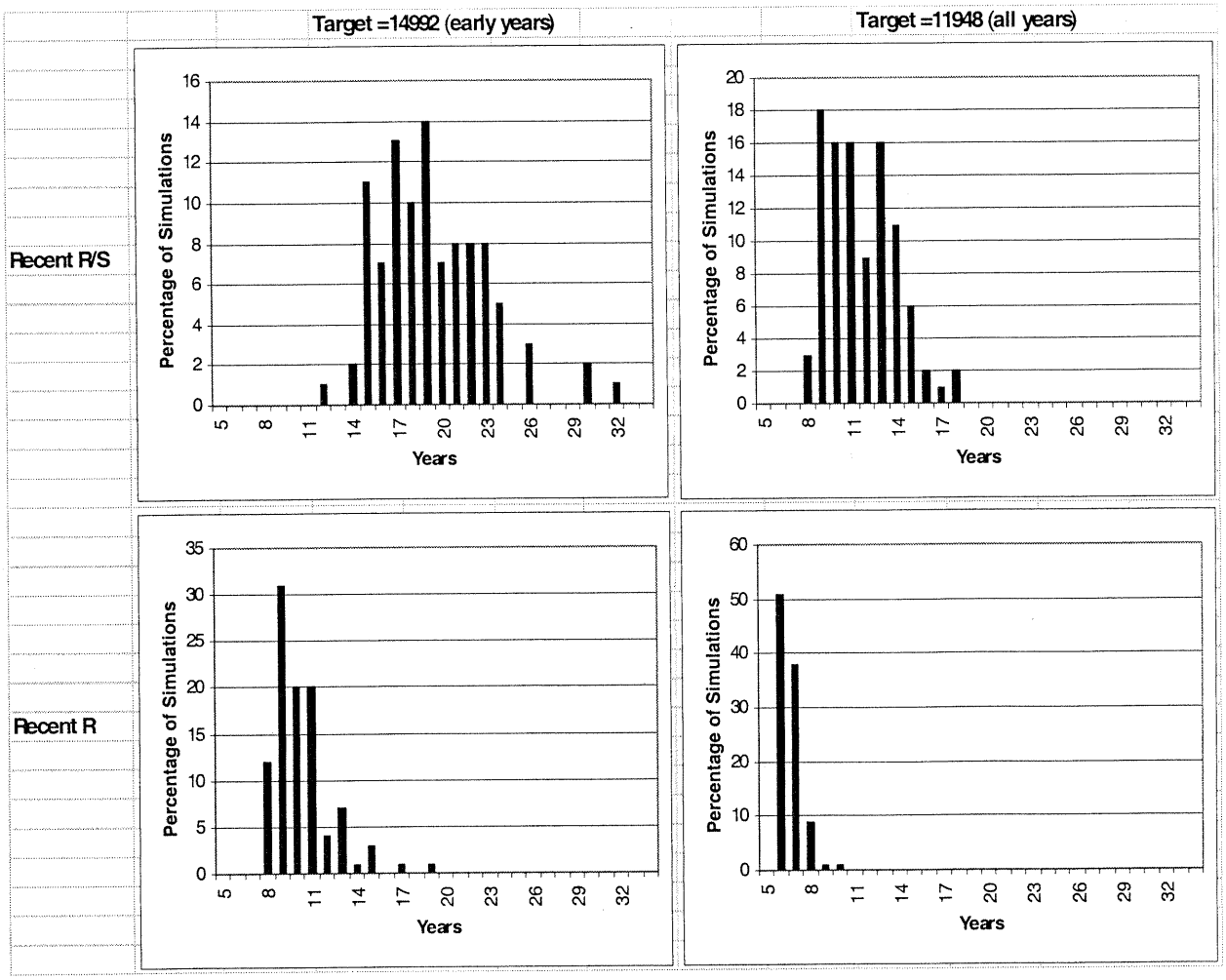

Figure 4. Probability distribution of times to reach rebuilding target in the absence of fishing. "Early years" refer to pre-exploitation recruitments, 1965 to 1979 yearclasses.

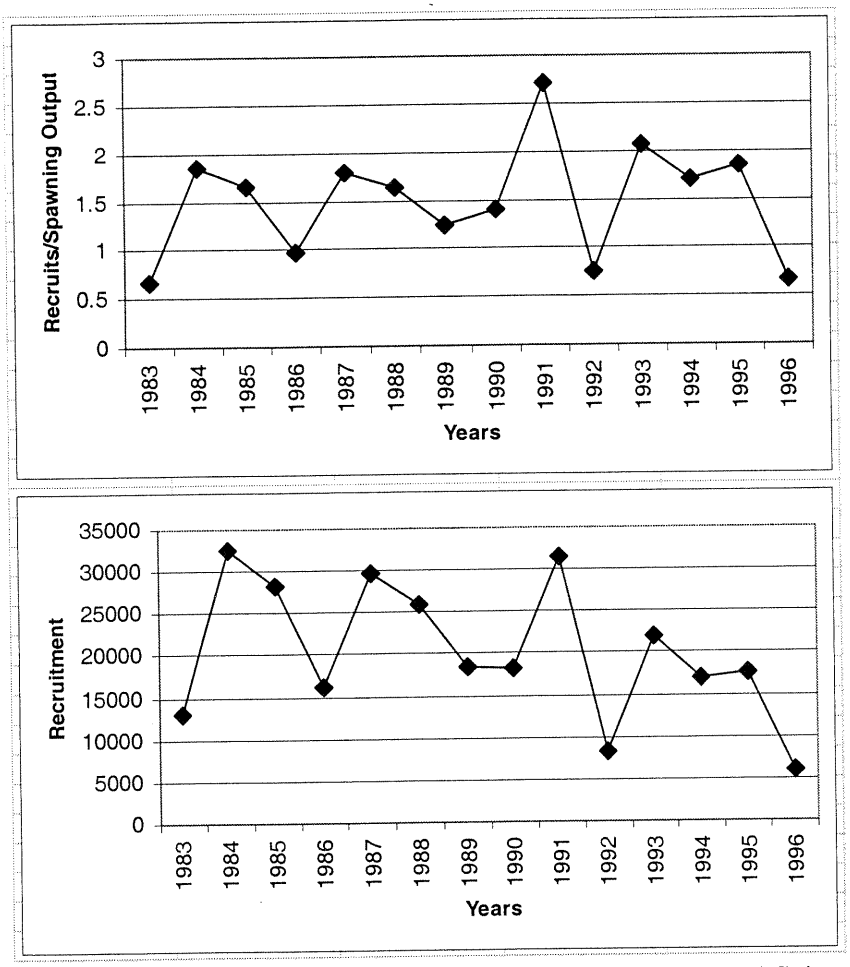

Figure 5. Recent trends in recruitment rates of widow rockfish.

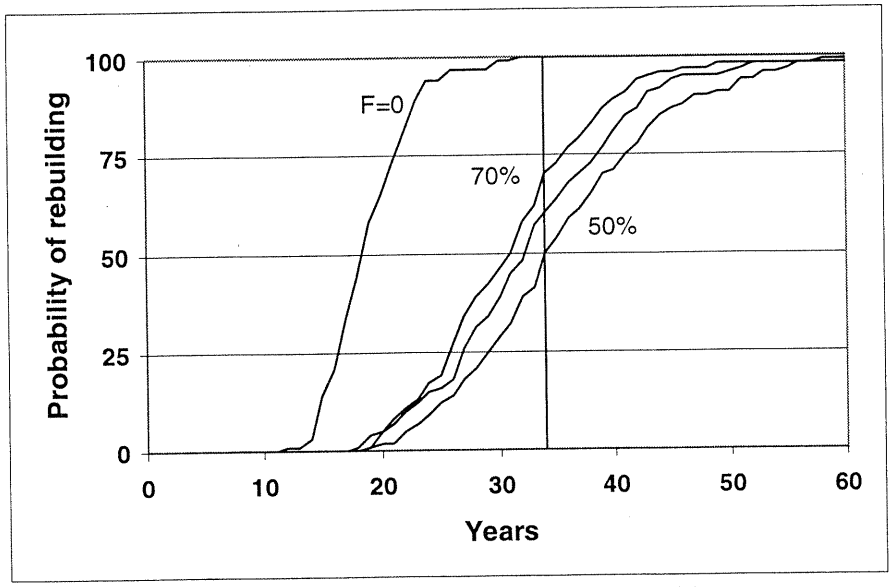

Figure 6. Probability of rebuilding at alternative fishing rates. Vertical line is maximum median rebuilding time, Tmax.

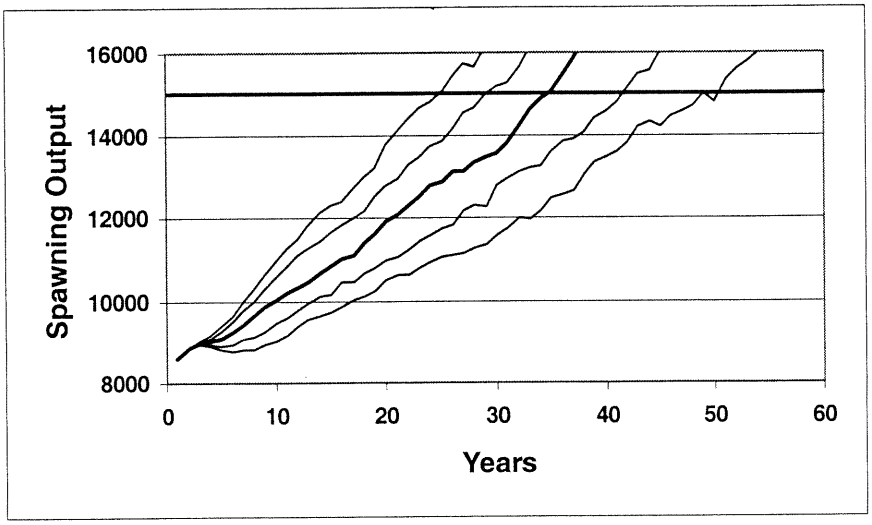

Figure 7. Envelope of rebuilding trajectories for constant fishing rate policy with 50% probability of rebuilding in 34yr. Lines represent 10, 25, 50 (median, dark line), 75 and 90 pecentiles of spawning output at given time.

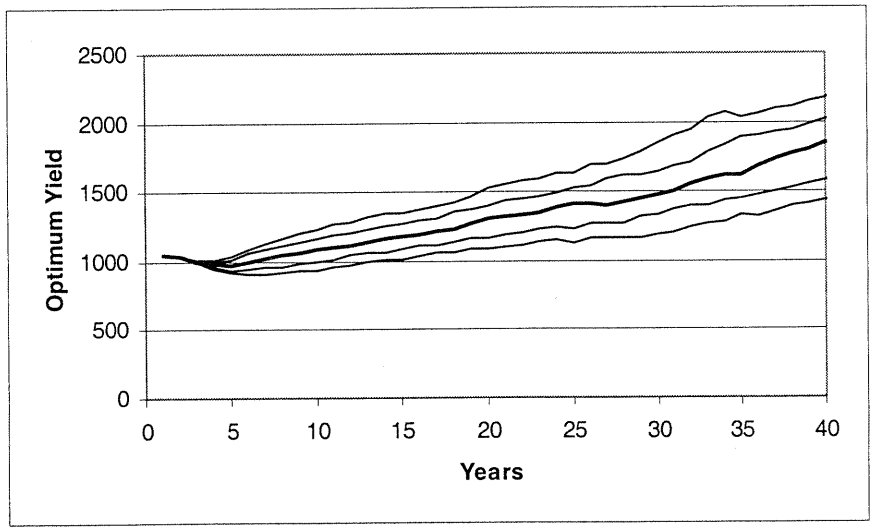

Figure 8. Envelope of yields corresponding to the fishing rate and trajectories in Figure 7.