Rebuilding analysis for widow rockfish in 2005

Xi He[1], Andre Punt[2,] Alec D. MacCall[1], and Stephen Ralston[1]

October 2005

[1]National Marine Fisheries Service
Southwest Fisheries Science Center
Santa Cruz Laboratory
110 Shaffer Road
Santa Cruz, CA 95060

[2]School of Aquatic and Fishery Sciences
Box 355020
University of Washington
Seattle, WA 98195-5020

Introduction

In 1998, the PFMC adopted Amendment 11 of the Groundfish Management Plan, which established a minimum stock size threshold of 25% of unfished spawning potential. Based on the stock assessment in 2000 (Williams et al. 2000), widow rockfish was formally declared to be overfished in 2001, thereby requiring the development of a Rebuilding Plan. The 2003 stock assessment (He et al. 2003b) estimated that the spawning output in 2002 was just below 25% of unfished spawning output. However, in the most recent stock assessment (He et al. 2005), the base model estimated that the population has never been overfished, although one of alternative models did indicate that the population was overfished in early 2000s. 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 Analyses.

Data and Parameters

This rebuilding analysis uses the SSC Default Rebuilding Analysis program as implemented by Punt (2005) (Version 2.8a, April 2005). Historical estimates of spawning output and recruitment are taken from the 2005 assessment by He et al. (2005). Life history parameters and selectivity are based on a simplification of the two-area, two-sex, four-fishery selectivity model used in the assessment (Appendix A). The rebuilding analyses are based on a coastwide population. However, fecundity- and weight-at-age differ between the southern and northern areas. Therefore, spatially-averaged fecundity- and weight-at-age, based on a weighting factor computed from the total catches for two areas from the last seven years, are used in the rebuilding analysis. The age-specific selectivity pattern is calculated by averaging selectivity functions for four fisheries, using weighting factors computed from the total catches by each fishery over the last five years. Fecundity-at-age, weight-at-age and selectivity-at-age are presented in Figures 1 and 2. These functions are very similar to those used in the 2002 and 2003 rebuilding analysis for widow rockfish (MacCall and Punt 2001, He et al. 2003a).

Management Reference Points

B_{MSY}: The rebuilding target is the spawning output that produces MSY, B_{MSY}. B_{MSY} cannot be determined easily, but experience in other fisheries has shown that B_{MSY} is often near 40% of the average initial unfished spawning output (B_0), and this value ($B_{40\%}$) is used here as a proxy for B_{MSY} (see the SSC's Terms of Reference). Values of B_0 are estimated by multiplying mean recruitment by the spawning output-per-recruit at F=0. As in the previous rebuilding analysis, the average recruitment used when computing B_0 was based on the pre-fishery recruitments (the 1958-79 year-classes). The following table shows the current population status from the base model in the stock assessment, and the population status estimated in the 2003 rebuilding analysis.

Estimated parameter	Value (2005)	Value (2003)
Estimated B_0 (millions of eggs)	49,676	43,580
Rebuilding target (millions of eggs)	19,870	17,432
Current spawning output (millions of eggs)	15,444	9,756
Percent of B_t/B_0 (depletion rate)	31.09%	22.39%

Mean generation time: If the stock cannot be rebuilt within ten years, then the maximum time allowed for rebuilding, T_{max}, is the length of time required to rebuild at F=0 (T_{min}) plus one mean generation time. Mean generation time can be estimated from the net maternity function (product of survivorship and fecundity at age), and for widow rockfish is estimated to be 17 years, which is slightly different from the value estimated in the 2003 rebuilding analysis (16 years, He et al. 2003a).

Simulation Model

The simulation model tracks numbers at age, with age 20 being treated as a plus-group. Fecundity-, weight-, and selectivity-at-age are given in Appendix A and plotted in Figures 1 and 2. When computing $T_{\min}$, the population simulations begin with the age-structure at the start of 2001 because 2001 was the year in which widow rockfish was declared to be overfished. The 2004 age-structure was used for estimating the Optimal Yield (OY) for 2006 and beyond. The detailed specifications of the simulation model are given by Punt (2005).

Initial test runs were conducted to determine the number of simulations needed to achieve stable outputs. The test was conducted using the base model from the stock assessment with 500, 1,000, 2,000, 3,000, 5,000, and 10,000 simulations. The results showed that the outputs did not change much with increasing numbers of simulations once the number of simulations reached 2,000. Therefore, all of the model runs in this rebuilding analysis are based on 2,000 simulations.

Twelve simulation scenarios were constructed from a combination of four stock assessment models and three methods of generating future recruitments. Four stock assessment models are: Model T1, Model M015, Model T2, and Model M011 (He et al. 2005). Model T2 is the base model. Selection of these models is based on different values of recruitment steepness, natural mortality, and fishery selectivity. Details on these models are in He et al. (2005). Three methods of generating future recruitment are: (1) future recruitment for all years is generated using the stock-recruitment relationship estimated in the stock assessment; (2) future recruitment for all years is generated by re-sampling historical recruits-per-spawner ratios; and (3) future recruitment from 2005 to 2007 is pre-specified using the juvenile (age 0 fish) survey indices from the NMFS Santa Cruz Laboratory, and future recruitment for all other years is generated by re-sampling historical recruits-per-spawner ratios. Method 3 was used in the 2003 rebuilding analysis, because the juvenile (age-0 fish) survey conducted by the Santa Cruz Laboratory indicated a strong recruitment of age-0 fish in 2002 (Fig. 8 in He et al. 2005). This 2002 year-class is not included in the stock assessment, but could potentially impact estimates of future population size. The 2005 STAR panel pointed out that there is great uncertainty associated with using the juvenile survey data.

The total catch of widow rockfish in 2005 is estimated at 284mt in all simulations, which is the same as the harvest guideline (OY) for 2005.

Rebuilding Projections

The rebuilding projections used $B_{40\%}$ as the rebuilding targets for the models. Table 2 lists the Optimum Yield (OY) for 2006, the constant fishing mortality (*F*, expressed as SPR) from 2006, the probability that the population will be rebuilt by $T_{\max}$ ($P_{\max}$), and median time in years from 2001 until the population will be rebuilt with 50% probability (T_{target}) for nine rebuild strategies and the four assessment models. Results for three methods of generating future recruitments are presented in Table 2a, Table 2b, and Table 2c, respectively. The first five rebuilding strategies apply constant fishing mortality rates from 2004 that correspond to five probabilities of being rebuilt by T_{max} (50%, 60%, 70%, 80%, and 90%, P_{max} = 0.5, 0.6, 0.7, 0.8, and 0.9, respectively). The sixth rebuilt is to set $T_{target} = T_{mid}$, where T_{mid} is the middle year between $T_{\min}$ and $T_{\max}$, and to set the probability of rebuilding by T_{mid} to be 50%. The seventh rebuilding strategy is no fishing ($F = 0$), the eighth is the “40:10” control rule, and the ninth is the ABC rule.

Figure 3 shows time series of the probability of the spawning output exceeding the target for six rebuilding strategies and a scenario of no fishing for the base model. Two other rebuilding strategies (40:10 rule and ABC rule) have zero probability of the spawning output exceeding the target. Also, comparisons of spawning biomass over target between the base assessment model (Model T2) and other assessment models indicates that Model M011 predicts initial increases of spawning biomass and then continuous decline of spawning biomass (Fig. 4). This suggests that it would be inadequate to use Model M011 as an assessment model to predict OY in the near future, although the model estimates the current depletion rate to be 38.49% (Table 15, He et al. 2005).

Table 3 shows Optimum Yields for the next 10 years (2007-2016) under the eight rebuilding strategies for four assessment models. In this table, future recruitments are generated using the stock-recruitment relationship. Table 4 shows the same information but with future recruitments generated by re-sampling recruits-per-spawner ratios in past years. Table 5 is same as Table 4 but with pre-specified 2005-2007 recruitments.

In general, Model M015 predicts the smallest OYs while Model M011 predicts the largest OYs, regardless of how future recruitments are generated. The OY for 2007 predicted by Model T2 (base model) is 1,352mt (Table 3), which is much greater than the OY for 2005 (284mt). This prediction is based on using the stock-assessment relationship for generating future recruitment and the default P_{max} for widow rockfish. Model M015 predicts the least OY for 2006 (538mt) while Model M011 predicts the most OY for 2006 (4503mt) (Table 3). As noted previously, Model M011 will have decreasing spawning biomass trend in the future (Figure 4).

Projections with future recruitments generated by re-sampling recruits-per-spawner ratios have higher OYs than those with future recruitments generated by the stock-recruitment relationship (Tables 3 and 4). This is the case for all four stock assessment models. If future recruitments are generated by re-sampling recruits-per-spawner ratios and with pre-specified 2005-2007 recruitments, projections have even higher OYs than those without pre-specified recruitments (Tables 4 and 5). It is evident that the projections largely depend on how future recruitments are generated. The following analyses are based on using the stock-recruitment relationship, which is believed to be more reasonably estimated in the current assessment than those in the past assessments.

Table 6 shows projected OYs for 2007-2016 from the base assessment model (Model T2) for six rebuilding runs requested for species currently managed under rebuilding plans (Appendix B). These runs have pre-specified probabilities of recovery, recovery times, and different fishing mortality (SPR) rates as in the current (2005) rebuilding plan. If the current SPR is used in the projections (Runs #1, #3, and #5), projected OYs are lower than if the current T_{target} or T_{max} are used (Runs #2 and #4). However, Runs #1, #3, and #5 still have higher OYs (447mt for 2007, for example) than those estimated in the 2003 rebuilding analysis (OY is 289mt for 2006, He et al. 2004a).

A decision table, which is copied from the 2005 assessment (He et al. 2005), is presented in Table 7. States of nature are presented by four assessment models. Management actions include the catches predicted by each of these four models. Future recruitments are generated using the stock-recruitment relationship. It is important to notice again that if management actions use the catches predicted by Model M011, all four models predict that the population will decline and be more depleted in the future than the current level.

References

He, X., A. Punt, A. D. MacCall, and S. Ralston. 2003a. Rebuilding analysis for widow rockfish in 2003. Status of the Pacific coast groundfish fishery through 2003, stock assessment and fishery evaluation, Volume 1. Pacific Fisheries Management Council, August 2003.

He, X., A. D. MacCall, S. V. Ralston, D. E. Pearson, and E.J. Dick. 2003b. Status of the widow rockfish resource in 2003. Status of the Pacific coast grounfish fishery through 2003, stock assessment and fishery evaluation, Volume 1. Pacific Fisheries Management Council, August 2003.

He, X., D.E. Pearson, E.J. Dick, J.C. Field, S. Ralston, and A.D. MacCall. 2005. Status of the widow rockfish resource in 2005. Final document submitted to the Pacific Fisheries Management Council.

Punt, A. 2005. SSC default rebuilding analysis (Version 2.8a, April 2005). University of Washington, Seattle.

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.

Table 1. Specifications of four stock assessment models based on different recruitment steepness, natural mortality and selectivity (He et al. 2005). Probability for each model is assigned by the 2005 STAR Panel. Model T2 is the base model.

Model name	Recruitment steepness	Natural mortality	Selectivity	Probability
Model T1	0.45	0.125	Double logistic / logistic	0.2
Model M015	0.25	0.150	Double logistic	0.1
Model T2 (base model)	0.28	0.125	Double logistic	0.4
Model M011	0.32	0.110	Double logistic	0.3

Table 2. Optimum yield (OY, mt) for 2006, spawner per recruit rate (SPR), probability of recovery by $T_{\max}$ ($P_{\max}$), and the year in which the probability of rebuild is 0.5 (T_{target}) for nine rebuilding strategies. Future recruitments are generated using three methods: Table 2a – using the stock-recruitment relationship; Table 2b – by re-sampling recruits-per-spawner ratios in past years; and Table 2c – by resampling recruits-per-spawner ratios in past years and with pre-specified 2005-2007 recruitments. NA = not applicable.

Table 2a: Future recruitments are generated using the stock-recruitment relationship.

		Rebuilding strategy								
Model		$P_{\max}=50\%$	$P_{\max}=60\%$	$P_{\max}=70\%$	$P_{\max}=80\%$	$P_{\max}=90\%$	T_{mid} & P_{mid}=50%	$F=0$	40:10	ABC
Model T1	OY	2457	2276	2091	1881	1626	2034	0	2569	3861
	SPR	0.633	0.653	0.675	0.701	0.734	0.682	1.0	NA	NA
	$P_{\max}$	49.9	60.0	69.9	80.1	89.9	72.8	100.0	13.2	2.5
	T_{target}	2029	2025	2023	2021	2019	2023	2012	2070	NA
Model M015	OY	687	538	389	201	0.2	545	0	3121	5114
	SPR	0.906	0.926	0.946	0.971	1.0	0.924	1.0	NA	NA
	$P_{\max}$	50.1	69.9	70.0	80.0	88.4	59.5	88.4	0	0
	T_{target}	2048	2042	2037	2032	2028	2042	2028	NA	NA
Model T2	OY	1551	1352	1148	903	609	1328	0	4249	5334
(base model)	SPR	0.812	0.834	0.857	0.886	0.921	0.837	1.0	NA	NA
	$P_{\max}$	50.1	60.0	69.9	79.9	90.0	61.1	98.5	0	0
	T_{target}	2033	2027	2023	2020	2017	2027	2013	NA	NA
Model M011	OY	4415	4388	4378	4375	4375	4413	0	5531	5574
	SPR	0.575	0.577	0.578	0.578	0.578	0.575	1.0	NA	NA
	$P_{\max}$	50.0	59.9	70.6	79.6	90.8	50.4	100.0	1.8	1.6
	T_{target}	2011	2008	2007	2007	2007	2010	2007	NA	NA

Table 2b: Future recruitments are generated by re-sampling recruits-per-spawner ratio in past years.

Model		Rebuilding strategy								
		$P_{\max} = 50\%$	$P_{\max} = 60\%$	$P_{\max} = 70\%$	$P_{\max} = 80\%$	$P_{\max} = 90\%$	T_{mid} & P_{mid}=50%	$F = 0$	40:10	ABC
Model T1	OY	2590	2476	2341	2190	1940	2205	0	2569	3851
	SPR	0.619	0.631	0.646	0.663	0.693	0.661	1.0	NA	NA
	P_{max}	50.1	59.9	70.0	79.9	90.0	78.7	100.0	11.9	0.7
	T_{target}	2030	2028	2026	2023	2021	2024	2012	2054	NA
Model M015	OY	809	682	559	413	231	647	0	3122	5115
	SPR	0.890	0.907	0.923	0.942	0.967	0.911	1.0	NA	NA
	P_{max}	50.0	60.0	70.0	79.9	89.9	62.9	95.7	0.0	0.0
	T_{target}	2045	2040	2036	2033	2029	2039	2026	NA	NA
Model T2	OY	1754	1593	1415	1231	929	1525	0	4298	5335
(base model)	SPR	0.791	0.808	0.827	0.848	0.882	0.815	1.0	NA	NA
	P_{max}	50.1	60.0	69.9	80.0	89.9	63.7	99.8	0	0
	T_{target}	2032	2027	2024	2021	2018	2026	2012	NA	NA
Model M011	OY	4444	4381	4378	4376	4374	4444	0	5531	5573
	SPR	0.573	0.577	0.578	0.578	0.578	0.573	1.0	NA	NA
	P_{max}	50.1	59.5	69.8	80.5	91.6	50.5	100	0.7	0.4
	T_{target}	2011	2008	2007	2007	2007	2010	2007	NA	NA

Table 2c: Future recruitments are generated by re-sampling recruits-per-spawner ratio in past years and with pre-specified 2005-2007 recruitments.

		Rebuilding strategy								
Model		$P_{\max} = 50\%$	$P_{\max} = 60\%$	$P_{\max} = 70\%$	$P_{\max} = 80\%$	$P_{\max} = 90\%$	T_{mid} & P_{mid}=50%	$F = 0$	40:10	ABC
Model T1	OY	2865	2727	2612	2460	2260	2456	0	2572	3865
	SPR	0.590	0.604	0.616	0.633	0.655	0.634	1.0	NA	NA
	$P_{\max}$	50.1	60.1	70.0	80.1	90.0	80.3	100.0	19.1	0.6
	T_{target}	2027	2025	2022	2021	2019	2019	2011	2046	NA
Model M015	OY	1027	903	763	627	402	855	0	3161	5121
	SPR	0.864	0.879	0.896	0.914	0.944	0.885	1.0	NA	NA
	$P_{\max}$	50.1	60.0	69.9	80.1	90.0	63.4	98.6	0	0
	T_{target}	2036	2032	2028	2025	2022	2030	2018	NA	NA
Model T2 (base model)	OY	2190	2049	1905	1738	1549	1967	0	4254	5340
	SPR	0.747	0.761	0.775	0.793	0.813	0.769	1.0	NA	NA
	$P_{\max}$	50.0	59.9	69.9	79.9	90.0	65.9	100.0	0	0
	T_{target}	2026	2021	2018	2015	2013	2020	2011	NA	NA
Model M011	OY	4624	4595	4593	4587	4572	4573	0	5532	5573
	SPR	0.561	0.563	0.563	0.563	0.564	0.564	1.0	NA	NA
	$P_{\max}$	50.0	60.0	69.8	80.2	90.5	85.5	100.0	0	0
	T_{target}	2011	2011	2011	2011	2010	2010	2007	NA	NA

Table 3. Projected Optimal Yields (OY, mt) for 2006-2015 for four alternative assessment models. Model T2 is the base model. Future recruitments are generated using the stock-recruitment relationship.

Model	Year	Pmax=0.5	Pmax=0.6	Pmax=0.7	Pmax=0.8	Pmax=0.9	Pmid=0.5	40-10 Rule	ABC Rule
T1	2007	2458	2277	2091	1881	1626	2034	2569	3862
	2008	2487	2312	2131	1925	1672	2075	2731	3802
	2009	2465	2298	2125	1927	1681	2072	2758	3679
	2010	2434	2275	2109	1917	1679	2058	2733	3562
	2011	2415	2262	2102	1916	1683	2052	2711	3473
	2012	2421	2272	2114	1930	1699	2065	2708	3439
	2013	2450	2302	2145	1961	1730	2096	2752	3452
	2014	2479	2333	2177	1994	1761	2128	2799	3463
	2015	2523	2376	2221	2038	1803	2173	2859	3484
	2016	2550	2405	2251	2067	1834	2202	2912	3484
M015	2007	687	538	389	201	0	546	3121	5114
	2008	709	556	403	209	0	565	3118	4897
	2009	707	556	404	210	0	564	2954	4569
	2010	691	544	396	207	0	552	2719	4224
	2011	675	533	388	203	0	541	2504	3944
	2012	663	524	382	200	0	532	2340	3766
	2013	661	523	382	200	0	530	2246	3666
	2014	660	523	382	200	0	530	2170	3581
	2015	665	527	385	203	0	535	2120	3510
	2016	668	530	388	204	0	538	2070	3411
T2 (base)	2007	1554	1352	1148	903	609	1328	4249	5334
	2008	1588	1385	1180	931	631	1362	4161	5144
	2009	1572	1375	1175	930	633	1353	3899	4842
	2010	1532	1343	1150	913	623	1321	3583	4523
	2011	1493	1311	1125	895	613	1291	3305	4260
	2012	1464	1287	1106	881	605	1267	3102	4087
	2013	1456	1282	1103	880	605	1262	2980	3995
	2014	1449	1277	1099	878	604	1257	2875	3913
	2015	1455	1283	1105	884	609	1263	2805	3851
	2016	1452	1282	1106	885	611	1262	2729	3767
M011	2007	4529	4503	4493	4491	4490	4528	5547	5628
	2008	4465	4440	4431	4429	4428	4463	5321	5471
	2009	4307	4284	4276	4274	4273	4305	4952	5215
	2010	4130	4109	4101	4100	4099	4128	4579	4954
	2011	3983	3964	3957	3956	3955	3982	4279	4742
	2012	3888	3869	3862	3860	3859	3886	4058	4606
	2013	3841	3823	3816	3815	3814	3839	3921	4532
	2014	3781	3764	3757	3756	3755	3780	3781	4444
	2015	3746	3729	3723	3722	3721	3745	3681	4374
	2016	3693	3678	3672	3671	3670	3692	3562	4289

Table 4. Projected Optimal Yields (OY, mt) for 2006-2015 for four alternative assessment models. Model T2 is the base model. Future recruitments are generated by re-sampling recruits-per-spawner ratios in past years.

Model	Year	Pmax=0.5	Pmax=0.6	Pmax=0.7	Pmax=0.8	Pmax=0.9	Pmid=0.5	40-10 Rule	ABC Rule
T1	2007	2590	2477	2341	2190	1939	2205	2569	3862
	2008	2614	2506	2375	2228	1983	2243	2734	3803
	2009	2582	2480	2356	2216	1980	2230	2752	3675
	2010	2514	2418	2301	2170	1946	2183	2680	3512
	2011	2487	2396	2284	2157	1940	2169	2639	3425
	2012	2478	2389	2279	2155	1944	2168	2625	3372
	2013	2506	2419	2310	2187	1975	2200	2652	3384
	2014	2551	2464	2356	2232	2020	2245	2725	3414
	2015	2605	2518	2411	2288	2075	2301	2819	3453
	2016	2654	2568	2461	2338	2126	2350	2901	3473
M015	2007	809	682	559	413	231	647	3122	5115
	2008	835	705	579	428	240	669	3128	4906
	2009	835	706	581	431	243	671	2983	4605
	2010	816	691	570	423	239	657	2758	4260
	2011	801	680	561	417	236	646	2567	4019
	2012	790	671	554	413	233	638	2418	3838
	2013	786	668	552	412	233	636	2313	3743
	2014	787	669	553	413	234	637	2245	3663
	2015	794	676	560	418	237	644	2214	3597
	2016	802	683	565	423	240	650	2173	3505
T2	2007	1754	1593	1415	1231	929	1524	4250	5335
	2008	1789	1629	1451	1265	960	1560	4172	5153
	2009	1778	1622	1448	1266	964	1555	3936	4882
	2010	1730	1582	1415	1239	947	1517	3630	4567
	2011	1698	1555	1393	1222	936	1492	3401	4348
	2012	1671	1531	1373	1207	927	1471	3210	4180
	2013	1660	1523	1367	1201	924	1463	3085	4085
	2014	1657	1521	1367	1203	927	1462	2998	4021
	2015	1668	1532	1377	1213	936	1472	2940	3971
	2016	1677	1543	1389	1225	946	1484	2887	3900
M011	2007	4559	4497	4495	4492	4491	4558	5548	5629
	2008	4499	4442	4440	4438	4436	4499	5336	5481
	2009	4371	4319	4316	4314	4313	4371	5009	5265
	2010	4188	4140	4138	4136	4135	4188	4639	4998
	2011	4093	4047	4045	4043	4043	4092	4411	4851
	2012	4008	3964	3962	3960	3960	4008	4219	4726
	2013	3957	3915	3913	3912	3911	3957	4078	4651
	2014	3926	3886	3884	3883	3882	3926	3964	4589
	2015	3890	3851	3850	3848	3847	3890	3856	4518
	2016	3858	3821	3819	3818	3817	3858	3756	4445

Table 5. Projected Optimal Yields (OY, mt) for 2006-2015 for four alternative assessment models. Model T2 is the base model. Future recruitments are generated by re-sampling recruits-per-spawner ratios in past years and with pre-specified 2005-07 recruitments.

Model	Year	Pmax=0.5	Pmax=0.6	Pmax=0.7	Pmax=0.8	Pmax=0.9	Pmid=0.5	40-10 Rule	ABC Rule
T1	2007	2865	2727	2612	2460	2260	2453	2572	3865
	2008	2903	2770	2659	2512	2316	2504	2779	3841
	2009	2993	2862	2753	2606	2410	2599	3000	3900
	2010	3102	2972	2862	2715	2517	2707	3244	3992
	2011	3165	3036	2928	2782	2585	2774	3424	4028
	2012	3162	3038	2933	2791	2599	2784	3477	3984
	2013	3110	2992	2893	2757	2572	2750	3412	3880
	2014	3110	2996	2898	2765	2584	2759	3399	3852
	2015	3106	2995	2901	2772	2597	2766	3385	3809
	2016	3126	3019	2927	2802	2628	2795	3402	3796
M015	2007	1027	903	763	626	402	855	3126	5121
	2008	1067	940	796	655	422	891	3194	4970
	2009	1128	995	845	696	450	943	3335	4983
	2010	1194	1054	896	740	479	1000	3530	5059
	2011	1233	1090	928	767	498	1035	3644	5038
	2012	1230	1089	928	768	500	1034	3559	4846
	2013	1192	1057	902	747	487	1004	3310	4534
	2014	1166	1034	884	732	478	983	3082	4313
	2015	1143	1015	868	721	471	965	2880	4097
	2016	1133	1007	862	716	469	958	2731	3931
T2	2007	2190	2049	1905	1738	1549	1967	4254	5340
	2008	2239	2099	1955	1789	1598	2018	4237	5207
	2009	2321	2179	2034	1865	1670	2097	4284	5200
	2010	2409	2265	2117	1944	1744	2181	4381	5237
	2011	2452	2308	2159	1986	1784	2225	4404	5196
	2012	2429	2289	2144	1974	1777	2208	4264	5024
	2013	2355	2222	2083	1920	1730	2144	3989	4764
	2014	2305	2176	2042	1884	1700	2101	3769	4581
	2015	2259	2134	2005	1852	1672	2062	3562	4406
	2016	2233	2112	1986	1836	1660	2041	3394	4264
M011	2007	4734	4707	4705	4699	4684	4685	5552	5633
	2008	4697	4671	4669	4663	4650	4651	5397	5526
	2009	4740	4715	4714	4708	4695	4696	5342	5531
	2010	4807	4783	4781	4776	4763	4764	5356	5574
	2011	4809	4786	4785	4779	4767	4768	5317	5546
	2012	4723	4701	4699	4694	4682	4683	5152	5417
	2013	4544	4524	4522	4517	4507	4507	4840	5183
	2014	4439	4420	4418	4414	4404	4405	4615	5036
	2015	4327	4309	4308	4303	4294	4295	4380	4880
	2016	4232	4215	4214	4210	4201	4202	4182	4743

Table 6. Projected Optimal Yields (OY, mt) for 2007-2016 from the base model (Model T2) for nine rebuilding runs with pre-specified probabilities of recovery, recovery times, and different SPR (fishing mortality) rates. Specifications for some runs are in Appendix B. SPR rates and recovery time are either old (estimated in the 2003 rebuilding analysis) or new (estimated in specific runs). Future recruitments are generated using the stock-recruitment relationship.

	Run #1	Run #2	Run #3	Run #4A	Run #4	Run #5	Run #6	Run#6	Run#6 (40:10 rule)
Probability of recovery	0.9625 (estimated)	0.5 (Fixed)	0.9765 (estimated)	0.8 (Fixed)	0.6 (P_0, Fixed)	0.9395 (estimated)	0.6 (P_0, Fixed)	0.8	<0.001
Recovery time	2038 (Old Ttarget)	2038 (Old Ttarget)	2042 (Old Tmax)	2042 (Old Tmax)	2042 (Old Tmax)	2033 (New Tmax)	2033 (New Tmax)	2033 (New Tmax)	N/A
SPR	0.936 (Old)	0.798 (New)	0.936 (Old)	0.855 (New)	0.810 (New)	Old	0.834 (New)	0.886 (New)	N/A
Fishing mortality	0.0093	0.0354	0.0093	0.0243	0.0329	0.0093	0.0283	0.0188	N/A
2007	447	1683	447	1162	1568	447	1352	903	4249
2008	464	1716	464	1194	1601	464	1385	931	4161
2009	466	1696	466	1189	1586	466	1375	930	3899
2010	460	1650	460	1163	1544	460	1343	913	3583
2011	453	1606	453	1138	1505	453	1311	895	3305
2012	447	1575	447	1118	1476	447	1287	881	3102
2013	448	1564	448	1115	1468	448	1282	880	2980
2014	448	1556	448	1111	1460	448	1277	878	2875
2015	452	1561	452	1118	1467	452	1283	884	2805
2016	454	1557	454	1118	1463	454	1282	885	2729

Table 7 (next page). Decision table copied from the 2005 stock assessment (He et al. 2005). States of nature are represented by four alternative models. Management actions include the catches predicted by each of these four alternative models. Future recruitments are generated using the stock-recruitment relationship. It is important to notice that if management actions use the catches predicted by Model 011, all four models predict that the population will decline and be more depleted in the future than the current level. Series in bold font show decreasing population abundance. Also notice that catch for 2006 for Model M011 is not pre-specified because of difficulty in obtaining rebuilding results.

			State of Nature							
			Model T1		Model M015		Model T2 (base)		Model M011	
Management action	Year	Total catch (mt)	Spawning output	Depletion (%)	Spawning output	Depletion (%)	Spawning output	Depletion (%)	Spawning output	Depletion (%)
	2005	285	8992	25.3	12052	25.8	15444	31.1	20351	38.5
	2006	289	9746	27.4	12546	26.8	16018	32.2	21030	39.8
	2007	2277	10655	30.0	13234	28.3	16839	33.9	21149	40.0
	2008	2312	11092	31.2	13477	28.8	17230	34.7	21625	40.9
	2009	2298	11361	31.9	13524	28.9	17407	35.0	21910	41.4
Model T1	2010	2275	11527	32.4	13408	28.7	17421	35.1	22058	41.7
	2011	2262	11648	32.8	13195	28.2	17328	34.9	22135	41.9
	2012	2272	11754	33.0	12933	27.7	17185	34.6	22166	41.9
	2013	2302	11880	33.4	12697	27.2	17016	34.3	22139	41.9
	2014	2333	12030	33.8	12465	26.7	16847	33.9	22111	41.8
	2015	2376	12214	34.3	12292	26.3	16720	33.7	22088	41.8
	2005	285	8992	25.3	12052	25.8	15444	31.1	20351	38.5
	2006	289	9746	27.4	12546	26.8	16018	32.2	21030	39.8
	2007	538	10655	30.0	13234	28.3	16839	33.9	21149	40.0
	2008	556	11459	32.2	13832	29.6	17590	35.4	21989	41.6
	2009	556	12113	34.1	14248	30.5	18150	36.5	22665	42.9
Model M015	2010	544	12663	35.6	14493	31.0	18548	37.3	23213	43.9
	2011	533	13153	37.0	14618	31.3	18824	37.9	23683	44.8
	2012	524	13604	38.3	14668	31.4	19035	38.3	24093	45.6
	2013	523	14058	39.5	14715	31.5	19182	38.6	24427	46.2
	2014	523	14512	40.8	14751	31.6	19331	38.9	24751	46.8
	2015	527	14997	42.2	14844	31.8	19512	39.3	25079	47.4
	2005	285	8992	25.3	12052	25.8	15444	31.1	20351	38.5
	2006	289	9746	27.4	12546	26.8	16016	32.2	21030	39.8
	2007	1352	10655	30.0	13234	28.3	16839	33.9	21149	40.0
	2008	1385	11287	31.7	13666	29.2	17421	35.1	21819	41.3
	2009	1375	11759	33.1	13907	29.7	17801	35.8	22310	42.2
Model T2	2010	1343	12129	34.1	13982	29.9	18017	36.3	22670	42.9
(base)	2011	1311	12449	35.0	13950	29.8	18125	36.5	22955	43.4
	2012	1287	12746	35.8	13864	29.7	18170	36.6	23190	43.9
	2013	1282	13061	36.7	13788	29.5	18184	36.6	23363	44.2
	2014	1277	13382	37.6	13718	29.3	18206	36.6	23530	44.5
	2015	1283	13748	38.7	13700	29.3	18270	36.8	23717	44.9
	2005	285	**8992**	**25.3**	**12052**	**25.8**	**15444**	**31.1**	**20351**	**38.5**
	2006	4388	**9746**	**27.4**	**12546**	**26.8**	**16018**	**32.2**	**21030**	**39.8**
	2007	4503	**10655**	**30.0**	**13234**	**28.3**	**16839**	**33.9**	**21149**	**40.0**
	2008	4440	**10624**	**29.9**	**13025**	**27.9**	**16771**	**33.8**	**21162**	**40.0**
	2009	4285	**10425**	**29.3**	**12624**	**27.0**	**16483**	**33.2**	**20969**	**39.7**
Model M011	2010	4109	**10159**	**28.6**	**12101**	**25.9**	**16058**	**32.3**	**20665**	**39.1**
	2011	3964	**9901**	**27.8**	**11538**	**24.7**	**15577**	**31.4**	**20330**	**38.4**
	2012	3869	**9679**	**27.2**	**10988**	**23.5**	**15102**	**30.4**	**19996**	**37.8**
	2013	3823	**9546**	**26.8**	**10515**	**22.5**	**14661**	**29.5**	**19664**	**37.2**
	2014	3764	**9446**	**26.6**	**10083**	**21.6**	**14242**	**28.7**	**19351**	**36.6**
	2015	3729	**9415**	**26.5**	**9735**	**20.8**	**13914**	**28.0**	**19080**	**36.1**

Figure 1. Fecundity-at-age and weight-at-age by sex for widow rockfish as used in the rebuilding analyses.

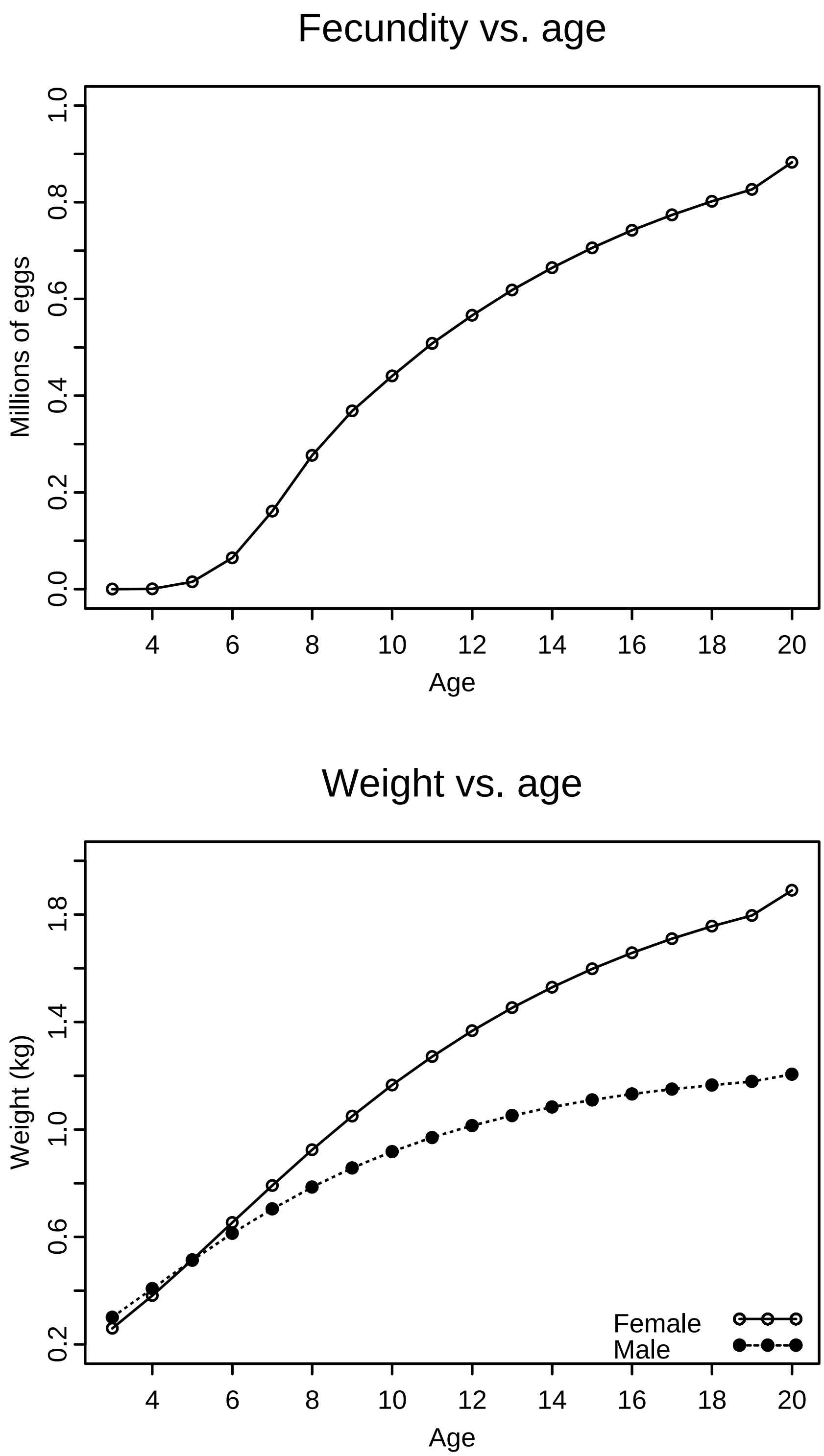


Figure 2. The selectivity pattern for widow rockfish used in the rebuilding analyses.

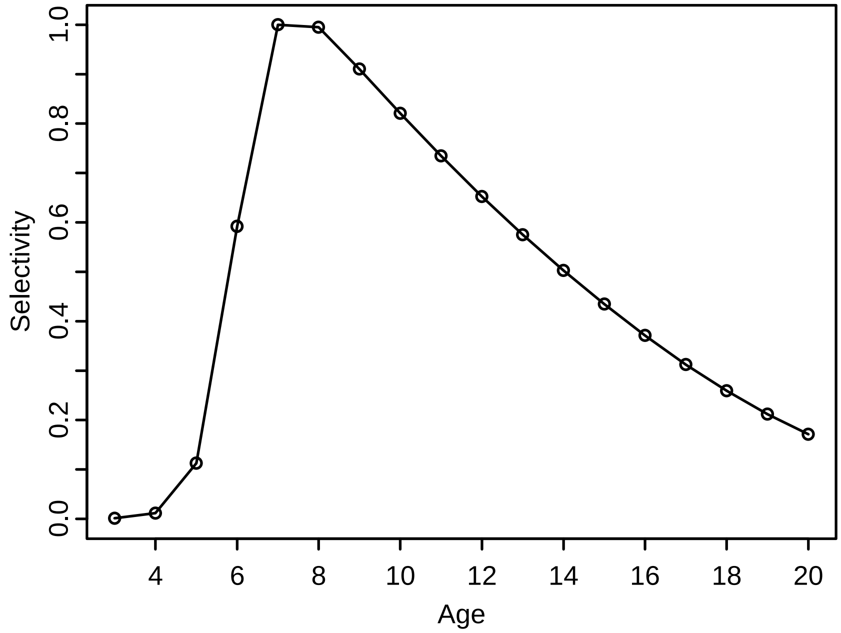
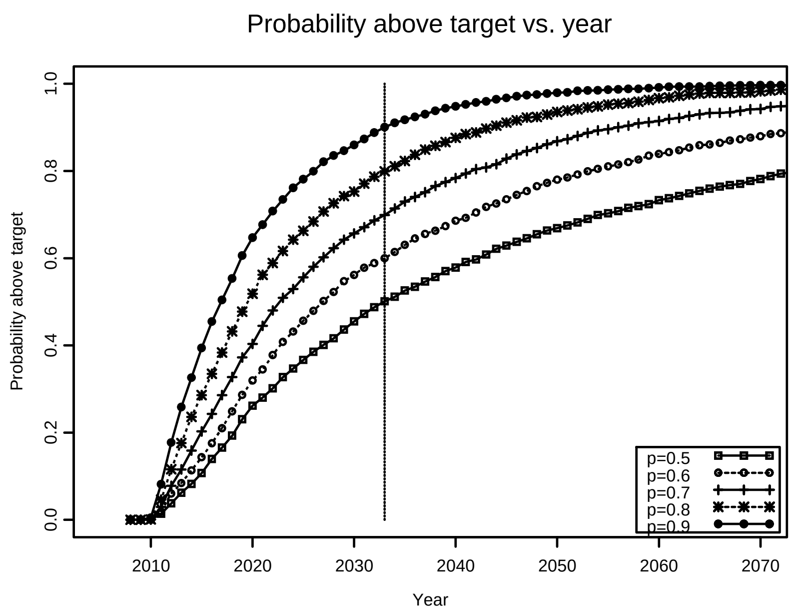


Figure 3. Time-series of the probability of the spawning output exceeding the target ($0.4B_0$) for five rebuilding strategies of $P_{\max} = 0.5 - 0.9$ (upper panel) and two rebuilding strategies of T_{mid} and no fishing (lower panel). The results are the base model (Model T2) with future recruitments generated using the stock-recruitment relationship. The vertical lines are new T_{target}.



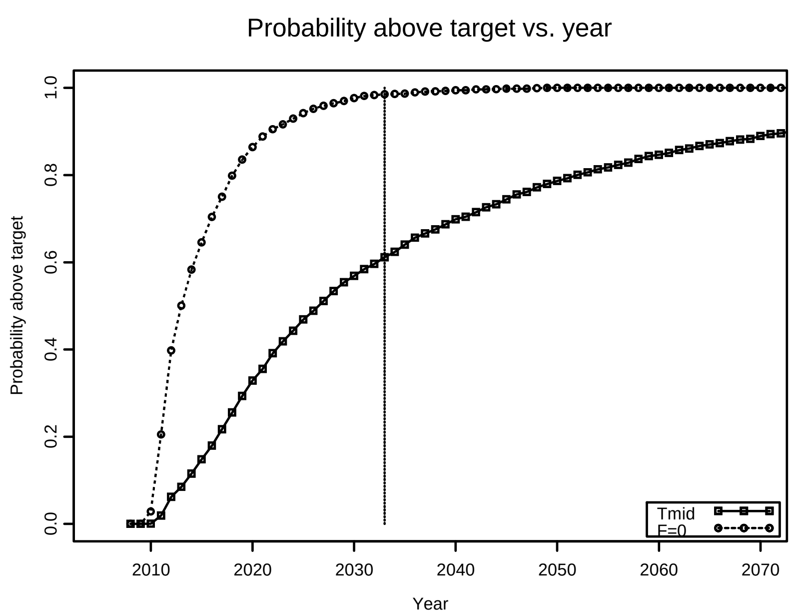
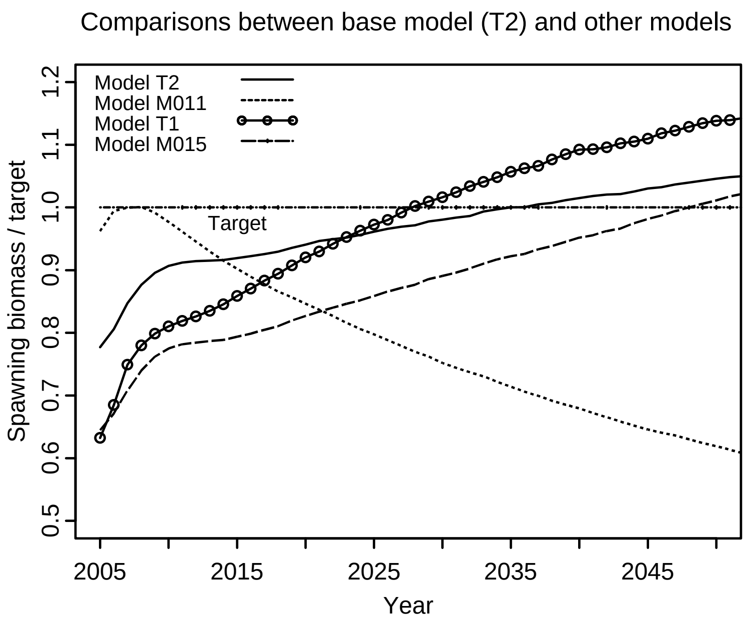


Figure 4. Time series of spawning biomass over target for the base model (T2) and other models. Targets are defined as P_{max} =60%. Future recruitments are generated using the stock-recruitment relationship. Notice that the harvest strategies are different before and after recovery occurs. Also notice that Model M011 predicts an initial increases of spawning biomass and then continuous decline of spawning biomass.



Appendix A. The “rebuild.dat” file used in the rebuilding analysis for Model T2. Model T2 is the stock assessment base model.

```
# Rebuild.dat for 2005 widow rebuiding
Widow (RecruitOverRiding=0, UseXHhPrior=1, PowCoefficientSCLabIndex=?)
# Number of sexes
2
# Age range to consider (minimum age; maximum age)
3 20
# Number of fleets to consider
1
# First year of the projection
2005
# Year declared overfished
2001
# Is the maximum age a plus-group (1=Yes;2=No)
1
# Generate future recruitments using historical recruitments (1), historical recruits/spawner (2), or a stock-recruitment (3)
3
# Constant fishing mortality (1) or constant Catch (2) projections
1
# Fishing mortality based on SPR (1) or actual rate (2)
2
# Pre-specify the year of recovery (or -1) to ignore
-1
# Fecundity-at-age
# A blank comment line - needed for the program to run
 0.0001 0.0002 0.0151 0.0645 0.1612 0.2765 0.3685 0.4409 0.5083 0.5663 0.6184 0.6648 0.7059 0.7422 0.7741 0.8021 0.8266
0.8829
# Age specific information (Females then males), weight and selectivity
# Females
```

0.2595 0.3814 0.5152 0.6538 0.7916 0.9244 1.0495 1.1655 1.2714 1.3673 1.4532 1.5298 1.5977 1.6576 1.7103 1.7566 1.7970 1.8899
0.0011 0.0117 0.1129 0.5920 1.0000 0.9950 0.9105 0.8210 0.7346 0.6525 0.5752 0.5027 0.4346 0.3711 0.3125 0.2592 0.2120 0.1712
Males
0.3001 0.4071 0.5131 0.6131 0.7042 0.7853 0.8562 0.9174 0.9698 1.0142 1.0517 1.0833 1.1097 1.1318 1.1502 1.1656 1.1784 1.2053
0.0011 0.0117 0.1129 0.5920 1.0000 0.9950 0.9105 0.8210 0.7346 0.6525 0.5752 0.5027 0.4346 0.3711 0.3125 0.2592 0.2120 0.1712
Age specific information (Females then males), natural mortality and numbers at age
Females
0.1250 0.1250 0.1250 0.1250 0.1250 0.1250 0.1250 0.1250 0.1250 0.1250 0.1250 0.1250 0.1250 0.1250 0.1250 0.1250 0.1250 0.1250
8821.83 7651.89 9287.03 8870.50 2911.46 1861.43 1470.15 2207.72 2168.79 1535.05 3930.71 2004.23 838.17 640.11 790.19 264.72 505.85 4741.80
Males
0.1250 0.1250 0.1250 0.1250 0.1250 0.1250 0.1250 0.1250 0.1250 0.1250 0.1250 0.1250 0.1250 0.1250 0.1250 0.1250 0.1250 0.1250
8821.83 7651.89 9287.03 8870.50 2911.46 1861.43 1470.15 2207.72 2168.79 1535.05 3930.71 2004.23 838.17 640.11 790.19 264.72 505.85 4741.80
Initial age-structure (for Tmin)
12910.05 4245.58 2742.71 2235.07 3441.90 3375.30 2372.11 6030.39 3054.12 1269.36 964.01 1184.08 394.90 751.57 795.60 639.59 513.07 5027.01
12910.05 4245.58 2742.71 2235.07 3441.90 3375.30 2372.11 6030.39 3054.12 1269.36 964.01 1184.08 394.90 751.57 795.60 639.59 513.07 5027.01
Year for Tmin Age-structure
2001
Number of simulations
2000
Recruitment and Spanwer biomasses
Number of historical assessment years
47
Historical data: Year, Recruitment, Spawner biomass, Used to compute B0, Used to project based
on R, Used to project based on R/S
1958 34509 44904 1 0 0
1959 34837 44906 1 0 0
1960 35136 44922 1 0 0
1961 35165 44996 1 0 0
1962 33910 45168 1 0 0
1963 32743 45437 1 0 0
1964 29179 45759 1 0 0
1965 31198 46084 1 0 0
1966 23707 46351 1 0 0
1967 37326 45676 1 0 0
1968 39174 44743 1 0 0
1969 40118 44157 1 0 0
1970 41811 43994 1 0 0
1971 44367 44042 1 0 0
1972 40465 44391 1 0 0
1973 89102 45063 1 0 0
1974 32175 45835 1 0 0
1975 12357 46972 1 0 0
1976 10109 48588 1 0 0
1977 16332 50426 1 0 0
1978 21602 51386 1 0 0
1979 10252 51001 1 0 0
1980 38903 49123 1 0 0
1981 57581 42492 1 0 0
1982 20937 34716 1 0 0
1983 66061 27663 0 0 0
1984 77951 25244 0 0 0
1985 28033 24086 0 0 0
1986 28601 23757 0 1 1
1987 28770 24357 0 1 1
1988 22501 24756 0 1 1
1989 9962 24891 0 1 1
1990 24254 23705 0 1 1
1991 15480 22428 0 1 1

```
1992     15827     21660 0 1 1
1993     29059     20622 0 1 1
1994     43799     19016 0 1 1
1995     13461     17848 0 1 1
1996     15161     16806 0 1 1
1997     12223     16474 0 1 1
1998      6587     16406 0 1 1
1999      7052     16567 0 1 1
2000      9623     16306 0 1 1
2001     25820     15664 0 1 1
2002     23850     15241 0 1 1
2003     17341     15138 0 1 1
2004     17644     15337 0 1 1
# Number of years with pre-specified catches
2
# Catches for years with pre-specified catches
2005 285
2006 289
# Number of future recruitments to override
3
# Process for overiding (-1 for average otherwise index in data list)
2005 0 0
2006 0 0
2007 0 0
# Which probability to product detailed results for (1=0.5,2=0.6,etc.)
2
# Steepness and sigma-R and auto-correlations
  0.280964  0.500000 0.000000
# Target SPR rate (FMSY Proxy)
0.500000
# Target SPR information: Use (1=Yes) and power
0 20
# Discount rate (for cumulative catch)
0.100000
# Truncate the series when 0.4B0 is reached (1=Yes)
0
# Set F to FMSY once 0.4B0 is reached (1=Yes; 2=Apply 40:10 rule after recovery)
0
# Percentage of FMSY which defines Ftarget
0.900000
# Maximum possible F for projection (-1 to set to FMSY)
2
# Conduct MacCall transition policy (1=Yes)
0
# Defintion of recovery (1=now only;2=now or before)
2
# Results for rec probs by Tmax (1) or 0.5 prob for various Ttargets
1
# Definition of the 40-10 rule
10 40
# Produce the risk-reward plots (1=Yes)
0
# Calculate coefficients of variation (1=Yes)
0
# Number of replicates to use
20
# First Random number seed
-89102
# Conduct projections for multiple starting values (0=No;else yes)
0
# File with multiple parameter vectors
MCMC.PRJ
# Number of parameter vectors
100
# User-specific projection (1=Yes); Output replaced (1->6)
1 7 0 0.5
# Catches and Fs (Year; 1/2 (F or C); value); Final row is -1
2007 1 0.000000
```

```
2010 1 0.000000
2100 1 0.000000
-1 -1 -1
# Split of Fs
2005 1
-1 1
# Time varying weight-at-age (1=Yes;0=No)
0
# File with time series of weight-at-age data
HakWght.Csv

20


4
```

Appendix B: Rebuilding Runs Requested for Species Currently Managed Under Rebuilding Plans

During recent weeks, there has been considerable dialogue regarding the most appropriate measures for evaluating the adequacy of rebuilding progress for species that are currently managed under rebuilding plans. A conference call was held last Friday (including participants from the NW Center, NW Region, Council staff, and the SSC) to discuss the uncertainties that have emerged since the June Council meeting. Following that call, an effort was made to identify a set of rebuilding runs which would allow authors to complete the analytical work that may be required by the Council (and advisors) and NMFS to evaluate rebuilding adequacy later this year. These runs are described in the table below. We are hopeful that there will be no need for any additional runs by authors who complete these six. Authors should be sure to address A) - C) below before proceeding to D).

A. Convert the current F to an SPR (this can be achieved straightforwardly given the biological parameters – reported in the rebuilding analysis).
B. Define how B_0 is to be calculated for the current rebuilding analysis (from the assessment; based on average recruitment over the early years, etc.)
C. Define how future recruitment is to be generated.
D. Do the following analyses. Report, T_{MIN}, T_{MAX}, T_{TARGET}, SPR/F, Probability of recovery by T_{MAX}, probability of recovery by T_{TARGET}.

For runs #1 and 2, the existing T_{TARGET} should be substituted for T_{MAX} in Puntalyzer setup. Run #1 will provide the likelihood of achieving T_{TARGET} with the current SPR, which can then be compared to the 50% likelihood estimated originally. Run #2 provides the SPR that restores a 50% likelihood of rebuilding by T_{TARGET}. Similarly, run #3 estimates the likelihood of rebuilding by the existing T_{MAX} with the current SPR, and run #4 estimates the SPR that would be required to restore a P_0 likelihood of rebuilding in T_{MAX}. Runs #5 and 6 provide comparable outputs relative to the "new" T_{MAX}, as calculated using outputs from 2005 assessments.

Run #	Prob (recovery)	By	Based on
#1 (default)	Estimated	Current T_{TARGET}	Current SPR
#2 (T_{TARGET} with 50% prob)	0.5	Current T_{TARGET}	Estimated SPR
#3 (#1 based on T_{MAX})	Estimated	Current T_{MAX}	Current SPR
#4 (#2 based on T_{MAX})	P_0	Current T_{MAX}	Estimated SPR
#5 (#3 with re-estimated T_{MAX})	Estimated	T_{MAX} (re-estimated)	Current SPR
#6 (#4 with re-estimated T_{MAX})	P_0	T_{MAX} (re-estimated)	Estimated SPR