Rebuilding analysis for widow rockfish in 2003

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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 spawning potential. In 2001, and based on the stock assessment in 2000 (Williams et al. 2000), widow rockfish was declared formally to be overfished, thereby requiring the development of a Rebuilding Plan. The most recent stock assessment (He et al. 2003) estimated that the spawning output in 2002 was just below 25% of unfished spawning output. 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.

The stock has declined since fishing began in the late 1970's (Table 1). The relative decline in total biomass has been somewhat less than that in spawning output (the best measure of stock reproductive potential). Older 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 (2002) population status of widow rockfish relative to pre-fishing years estimated by the base model in the stock assessment (He et al. 2003).

	Age 3+ biomass (mt)	Spawning output (millions of eggs)
Average 1958-79	233,722	39,567
2002	57,480	9,755
Percent	24.59%	24.65%

Data and Parameters

This rebuilding analysis uses the SSC Default Rebuilding Analysis as implemented by Punt (2003) (Version 2.7, July 2003). Historical estimates of spawning output and recruitment are taken from the assessment by He et al. (2003). 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 five 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 rebuilding analysis for widow rockfish (MacCall and Punt 2001).

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 (1.053 million eggs of spawning output-per-recruit). 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, Table 2). Figure 3 shows the simulated frequency distribution for B_0 determined by re-sampling recruitments at random from those for 1958-79. The mean of this distribution was used as the estimate of B_0 in the subsequent analyses. There is a highly significant difference between the pre-fishery (pre-1982) recruitments and the post-fishing-down (post-1982) recruitments (one-tailed t-test, P<0.01). This difference is presumably due to the decline in spawning abundance, but may also be associated with a less favorable climate in the most-recent period. For the scenarios in which future recruitment is determined by re-sampling historical recruits-per-spawner ratios, the re-sampling period was set to 1986-2002; the same period on which the previous rebuilding analysis was based (MacCall and Punt 2001).

Table 2. Rebuilding parameters (units: millions of eggs) for the base model in the stock assessment. The estimated B_0 differs from the value in Table 1 because the fecundity function used in the rebuilding program is for the most recent years; one consequence of this is that the current depletion (B_{2002}/B_0) is lower (22.39%) than that in Table 1 (24.65%)

Rebuilding parameter	Value
Estimated B_0	43,580
Rebuilding target	17,432
Current spawning output (B_{2002})	9,756
Percent of B_{2002}/B_0	22.39%

Mean generation time: If the stock cannot be rebuilt with in 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 16.4 years, which is rounded to an integer value of 16 years.

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 2002 age-structure was used for estimating the Optimal Yield (OY) for 2004 and beyond. The detailed specifications of the simulation model are given by Punt (2003).

Initial test runs were conducted to determine the number of simulations needed to achieve stable outputs. The test was conducted using the Model 8 (described below) with numbers of simulations of 500, 1,000, 2,000, 3,000, 5,000, and 10,000. The results showed that the outputs did not change much with increasing numbers of simulations once the number of simulations reached 3,000. Therefore, all of the model runs in this rebuilding analysis are based on 3,000 simulations.

Twelve simulation scenarios (Models 1-12) were constructed from three factors: (1) whether the recruitments (age 3) for 2003-5 were pre-specified, (2) whether a stock-recruitment relationship or recruits-per-spawner ratios were used to generate future recruitment, and (3) a range for the power coefficient for the midwater juvenile survey index (Table 3):

(1) 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. 2003). This 2002 year-class is not included in the stock assessment, but it could have potential impacts on the future population size. To include the information on this year-class in the projections, the sizes of the recruitments for 2003-5 (i.e. the 2000-2 year-classes) were pre-specified rather than being generated. The equation used to compute the pre-specified recruitments for 2003-5 was:

$$R_i = e^{\frac{1}{p}\log(\frac{I_i}{q}) - a_{\min} M} \quad (1.1)$$

where I_i is survey index for year i, q is catchability, p is a power coefficient for the survey index, $a_{\min}$ is minimum age, and M is the instantaneous rate of natural mortality.

(2) The stock assessment incorporated a Beverton-Holt stock-recruitment relationship. However, the stock assessment also indicated that there is great uncertainty about the stock-recruitment relationship and about the relationship between the juvenile survey index and recruitment for widow rockfish. The previous rebuilding analysis for widow rockfish (MacCall and Punt 2001) generated future recruitment by re-sampling historical recruits-per-spawner ratios. Therefore, both methods for generating future recruitment were used in this rebuilding analysis.

(3) The stock assessment also indicated that the power coefficient is an important parameter in determining the level of recent recruitments, and thus the slope of the stock-recruitment relationship, and when translating the juvenile survey indices into future recruitments. Three values for the power coefficient (2.0, 3.0 and 4.0) are used in this rebuilding analysis to bound the value (3.0) used in the base model in the stock assessment.

An estimate of the total catch of widow rockfish during 2003 needs to be specified. The harvest guideline for widow rockfish set by the Council for 2003 was 832mt. However, the most recent estimate of the total catch for 2002 from the PacFIN database is 263mt, much less than the harvest guideline for 2002 set by the Council (856mt). It is therefore very possible that total catch for 2003 will also be less than the harvest guideline. The most recent estimate of total catch in 2003 by the GMT is 274mt. Therefore, the total catch for 2003 is assumed to be 300mt in this analysis.

Rebuilding Projections

The rebuilding projections used $B_{40\%}$ =17,201, 17,432, and 17,714 as the rebuilding targets for the models that have the power coefficients of 2.0, 3.0, and 4.0, respectively. Table 4 lists the Optimum Yield (OY) for 2004, the constant fishing mortality (*F*) from 2004, 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 12 simulation scenarios. The first five rebuilding strategies apply constant fishing mortality rates from 2004 that correspond to five probabilities of rebuild 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 "rebuilding strategy" 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.

The simulated frequency distribution of $T_{\min}$ for Model 8 is presented in Figure 4. The distribution has a long tail in the right side, a pattern similar to distributions of other models. Figure 5 shows time series of the probability of the spawning output exceeding the target for four rebuilding strategies and a scenario of no fishing for Model 8. Table 5 shows Optimum Yields for the next 10 years under the seven rebuilding strategies for the 12 simulation scenarios. In general, OYs are greater when recruitment is pre-specified, when future recruitment is generated by re-sampling from historical recruits-per-spawner ratios and when the power coefficient is high

(Tables 4 and 5). The high power coefficients are associated with higher steepness values, indicating increased compensations in the stock-recruitment relation at low abundance. Also, the high power coefficients raised the mean level of recruitment in recent years, again suggesting increased compensations at low abundance (Table 3). This result is also supported by the fact that the allowable biological catches (ABC) for 2004 increase as the power coefficients increase (Table 4).

Rebuilding cannot occur if the power coefficient is low (P = 2.0) and future recruitment is generated using the estimated stock-recruitment relationship (Models 4 and 10). The simulation scenario in which recruitment for 2003-5 is pre-specified, future recruitment is generated by re-sampling recruits-per-spawner ratios and the power coefficient is set to 4 (Model 9) has the shortest rebuilding time in the absence of fishing and the highest OYs (Table 4b).

Fishing mortalities from all models ranged from 0 to 0.017, lower than the value of 0.0268 estimated in the previous rebuilding analysis and used for determining the 2002 and 2003 OYs (MacCall and Punt 2001), and much lower than F_{MSY} estimated for widow rockfish (= 0.118). If Model 8 is selected for determining the 2004 OY, the fishing mortality of Model 8 is 0.0093, which is about 1/3 of the fishing mortality estimated from the previous rebuilding analysis and is less than 8% of F_{MSY}.

Four models (Models 2, 5, 8, and 11) are based on the same assumptions as the stock assessment base model. However, even restricting the final decision of an OY for 2004 to these models (because the base model presumably has higher credibility than the other models) still leads to a wide range of possible 2004 OYs. For example, the OYs corresponding to $P_{\max} = 60\%$ range from <1mt (Model 5) to 284mt (Model 8). To assist management decisions, a risk analysis was conducted based on three of these four models (Models 2, 5, and 8); Model 11 was not included in the risk analysis since it is intermediate between Models 2 and 5 (Table 4). Four levels of catch (i.e. OYs from 2004) were examined to each of the three models: 35mt ($P_{\max} = 50\%$, 2004 OY from Model 5), 194mt ($P_{\max} = 60\%$, 2004 OY from Model 2), 284mt ($P_{\max} = 60\%$, 2004 OY from Model 8), and 501mt ($P_{\max} = 60\%$, 2004 OY from Model 9). The highest catch level was included in the risk analysis to assess the implications if the OY is based on a model with a high value for the power coefficient when the "correct" model has P=3. Fishing mortality in 2004 estimated from each of the four levels of catch were applied in future years. That is, all simulations in the risk analysis used constant fishing police. Risks are expressed as changes to $P_{\max}$, T_{target} and P_{100}. P_{100} is an indicator of population sustainability - the probability of the spawning output being above the current spawning output in 100 years.

The analysis shows that the risks are high for catch levels ≥ 194mt if the Model 5 is the "correct" model. The sustainability of the population, as measured by P_{100}, will fall to 27.1% if a catch level of 501mt is applied and Model 5 is 'correct" (Table 6). The analysis also shows that the risks are low if Model 8 is "correct"; at a catch level of 284 mt, $P_{\max} = 60\%$, $T_{target} = 2037$ and $P_{100} = 100\%$. If this model is "correct", the population will be able to sustain with $P_{100} = 100\%$ even if the catch level of 501mt is applied. That is, there is a 100% of probability that spawning outputs will be above the current spawning output in 100 years if the catch is 501mt (Table 6).

Model 8 uses the base model from the stock assessment and generates future recruitment by re-sampling historical recruits-per-spawner ratios – this is how the previous rebuilding analysis (MacCall and Punt 2001) was conducted. Model 8 also pre-specifies the recruitment for 2003-5. As a result, the projections imply that strong 2002 year-class will greatly increase the spawning output once it recruits to the population in 2005. The strong 2002 year-classes of other rockfishes indicates that the current environmental conditions may be favorable for rockfish recruitment, but the assumption that the 2002 widow rockfish year-class will actually be strong when it recruits to the fishery can only be tested in time.

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Table 3. Specifications of the 12 simulation scenarios (models) based on: whether recruitment is pre-specified, how future recruitment is generated, and the value of the power coefficient for the midwater juvenile survey index. The value of steepness (h) is listed when the projections are based on a stock-recruitment relationship. Abbreviation: NA = not applicable.

Model	Recruitment pre-specified?	Stock recruitment relationship used?	Power coefficient for midwater survey	*h*
1	No	No	2.0	NA
2	No	No	3.0	NA
3	No	No	4.0	NA
4	No	Yes	2.0	0.201
5	No	Yes	3.0	0.217
6	No	Yes	4.0	0.237
7	Yes	No	2.0	NA
8	Yes	No	3.0	NA
9	Yes	No	4.0	NA
10	Yes	Yes	2.0	0.201
11	Yes	Yes	3.0	0.217
12	Yes	Yes	4.0	0.237

Table 4. Optimum yield (OY) for 2004 (mt), fishing mortality (F) during rebuild (yr^{-1}), probability of recovery by T_{max} (P_{max}), and the year in which the probability of rebuild is 0.5 (T_{target}) for nine rebuild strategies for various simulation scenarios. T_{max} is T_{target} for $P_{max} = 0.5$. Abbreviations: SR = stock-recruitment relationship is used; P = value of the power coefficient of the midwater juvenile index; NA = not applicable.

(a) Recruitment for 2003-5 is not pre-specified

				Rebuilding strategy								
Model	SR	P		$P_{max} = 50\%$	$P_{max} = 60\%$	$P_{max} = 70\%$	$P_{max} = 80\%$	$P_{max} = 90\%$	T_{mid} & P_{mid}=50%	$F = 0$	40:10	ABC
1	N	2.0	OY	128	72	15	<1	<1	60	0	1088	3076
			F	0.0047	0.0026	0.0005	0.0000	0.0000	0.0022	0.0000	NA	0.1181
			P_{max}	50.0	60.1	70.0	72.6	75.6	62.2	72.6	0.0	0.0
			T_{target}	2072	2066	2061	2060	2061	2066	2061	NA	NA
2	N	3.0	OY	259	194	123	41	<1	149	0	1439	3460
			F	0.0085	0.0064	0.0040	0.0013	0.0000	0.0049	0.0000	NA	0.1183
			P_{max}	50.0	60.1	70.0	79.7	83.8	66.6	83.8	0.0	0.0
			T_{target}	2057	2053	2049	2045	2044	2051	2044	NA	NA
3	N	4.0	OY	426	354	276	183	54.6	251.5	0	1887	3908
			F	0.0124	0.103	0.0080	0.0053	0.0016	0.0073	0.0000	NA	0.1186
			P_{max}	50.0	60.1	70.0	79.9	90.1	72.8	92.9	0.0	0.0
			T_{target}	2045	2042	2039	2036	2033	2039	2032	NA	NA
4	Y	2.0	OY	0	0	0	0	0	0	0	NA	NA
			F	0	0	0	0	0	0	0	NA	NA
			P_{max}	<50%	<50%	<50%	<50%	<50%	<50%	<50%	NA	NA
			T_{target}	>2500	>2500	>2500	>2500	>2500	>2500	>2500	NA	NA
5	Y	3.0	OY	35	<1	<1	<1	<1	13.5	0	1439	3460
			F	0.0012	0.0000	0.0000	0.0000	0.0000	0.0004	0.0000	NA	0.1183
			P_{max}	49.9	55.9	55.9	55.9	55.9	53.4	55.9	0.0	0.0
			T_{target}	2123	2111	2111	2111	2112	2117	2112	NA	NA
6	Y	4.0	OY	185	98	2	<1	<1	105	0	1888	3909
			F	0.0054	0.0028	0.0001	0.0000	0.0000	0.0031	0.0000	NA	0.1186
			P_{max}	50.1	60.0	70.0	70.2	70.2	59.3	70.3	0.0	0.0
			T_{target}	2063	2055	2050	2050	2050	2057	2050	NA	NA

(Table 4 Continued)

(b) Recruitment for 2003-5 is pre-specified

Model	SR	P		$P_{max}=50\%$	$P_{max}=60\%$	$P_{max}=70\%$	$P_{max}=80\%$	$P_{max}=90\%$	T_{mid} & $P_{mid}=50\%$	$F=0$	40:10	ABC
				Rebuilding strategy								
7	N	2.0	OY	248	181	111	30	<1	139	0	1088	3076
			F	0.0092	0.0067	0.0041	0.0011	0.0000	0.0051	0.0000	NA	0.1181
			P_{max}	50.1	60.0	70.0	80.1	82.8	66.2	82.8	0.0	0.0
			T_{target}	2042	2038	2034	2030	2030	2036	2030	NA	NA
8	N	3.0	OY	354	284	212	123	3.7	208	0	1439	3460
			F	0.0117	0.0093	0.0070	0.0040	0.0001	0.0068	0.0000	NA	0.1183
			P_{max}	50.0	60.1	70.0	80.0	90.0	70.5	90.2	0.0	0.0
			T_{target}	2041	2037	2034	2031	2028	2035	2028	NA	NA
9	N	4.0	OY	582	501	419	323	205	385	0	1888	3908
			F	0.0170	0.0146	0.0122	0.0094	0.0060	0.0112	0.0000	NA	0.1186
			P_{max}	49.9	60.0	69.9	79.9	89.9	73.5	97.5	0.0	0.0
			T_{target}	2036	2033	2030	2027	2026	2030	2022	NA	NA
10	Y	2.0	OY	<1	<1	<1	<1	<1	<1	0	1088	3076
			F	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	NA	0.1181
			P_{max}	49.8	49.8	49.8	49.8	49.8	49.8	49.9	0.0	0.0
			T_{target}	2155	2155	2155	2155	2156	2156	2156	NA	NA
11	Y	3.0	OY	67	<1	<1	<1	<1	29.8	0	1439	3460
			F	0.0022	0.0000	0.0000	0.0000	0.0000	0.0010	0.0000	NA	0.1183
			P_{max}	50.5	59.2	59.2	59.2	59.2	55.0	59.2	0.0	0.0
			T_{target}	2070	2058	2058	2058	2059	2064	2059	NA	NA
12	Y	4.0	OY	281	172	55	<1	<1	160	0	1888	3076
			F	0.0082	0.0050	0.0016	0.0000	0.0000	0.0046	0.0000	NA	0.1181
			P_{max}	49.9	60.0	69.9	74.9	74.9	61.4	74.9	0.0	0.0
			T_{target}	2044	2038	2032	2030	2031	2038	2031	NA	NA

Table 5. Projected Optimal Yields (mt, median annual catches) for 2004-13 for seven rebuild strategies and 12 simulation scenarios (models).

(a) For Models 1-3

Year	$P_{\max}=50\%$			$P_{\max}=60\%$			$P_{\max}=70\%$			$P_{\max}=80\%$			$P_{\max}=90\%$			T_{mid} & P_{mid}=50%			40:10 rule		
Model	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
2004	128	259	426	72	194	354	15	123	276	0	41	182	0	0	55	60	149	252	1088	1439	1888
2005	128	260	430	72	195	358	15	124	279	0	41	185	0	0	56	60	150	255	1015	1358	1798
2006	128	263	436	72	197	364	15	125	284	0	42	189	0	0	57	60	152	259	968	1308	1746
2007	130	267	444	73	201	371	15	128	290	0	43	193	0	0	58	61	154	265	943	1287	1721
2008	132	271	448	74	204	374	16	130	293	0	43	195	0	0	59	62	157	268	944	1275	1688
2009	134	272	450	75	205	376	16	131	294	0	44	196	0	0	59	63	158	269	936	1259	1659
2010	135	274	452	76	207	378	16	132	296	0	44	198	0	0	60	63	159	271	936	1250	1636
2011	136	276	455	76	209	381	16	133	299	0	45	200	0	0	60	64	161	273	933	1243	1624
2012	137	278	458	77	210	383	16	134	301	0	45	201	0	0	61	64	162	275	925	1231	1604
2013	138	281	464	78	212	388	16	135	305	0	46	204	0	0	62	65	164	279	918	1218	1589

(b) For Models 4-6

Year	$P_{\max}=50\%$			$P_{\max}=60\%$			$P_{\max}=70\%$			$P_{\max}=80\%$			$P_{\max}=90\%$			T_{mid} & P_{mid}=50%			40:10 rule		
Model	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
2004	0	35	185	0	<1	98	0	<1	2	0	<1	<1	0	0	0	0	14	105	0	1438	1888
2005	0	36	187	0	<1	99	0	<1	2	0	<1	<1	0	0	0	0	14	107	0	1358	1798
2006	0	36	191	0	<1	101	0	<1	2	0	<1	<1	0	0	0	0	14	109	0	1303	1738
2007	0	36	193	0	<1	102	0	<1	2	0	<1	<1	0	0	0	0	14	110	0	1256	1683
2008	0	36	193	0	<1	102	0	<1	2	0	<1	<1	0	0	0	0	14	110	0	1206	1621
2009	0	36	192	0	<1	102	0	<1	2	0	<1	<1	0	0	0	0	14	110	0	1155	1560
2010	0	36	191	0	<1	102	0	<1	2	0	<1	<1	0	0	0	0	14	109	0	1104	1501
2011	0	36	191	0	<1	102	0	<1	2	0	<1	<1	0	0	0	0	14	110	0	1064	1460
2012	0	36	192	0	<1	102	0	<1	2	0	<1	<1	0	0	0	0	14	110	0	1034	1429
2013	0	36	193	0	<1	103	0	<1	2	0	<1	<1	0	0	0	0	14	111	0	995	1385

Table 5 (continued).

(a) For Models 7-9

Year	$P_{\max}=50\%$			$P_{\max}=60\%$			$P_{\max}=70\%$			$P_{\max}=80\%$			$P_{\max}=90\%$			T_{mid} & P_{mid}=50%			40:10 rule		
Model	7	8	9	7	8	9	7	8	9	7	8	9	7	8	9	7	8	9	7	8	9
2004	248	354	583	180	284	501	111	212	418	30	123	323	<1	4	206	139	208	385	1088	1439	1888
2005	247	355	587	180	285	505	111	213	423	30	124	327	<1	4	209	139	209	389	1016	1359	1799
2006	247	359	595	181	289	513	111	216	430	30	126	333	<1	4	213	140	212	396	974	1317	1755
2007	256	373	617	187	300	532	116	225	447	31	131	346	<1	4	222	145	221	412	994	1347	1790
2008	293	410	666	214	330	575	132	247	483	36	144	374	<1	4	240	166	243	445	1246	1558	1991
2009	393	492	761	287	396	657	177	297	552	48	173	428	<1	5	275	222	292	509	2023	2082	2441
2010	469	549	823	343	442	712	212	332	598	57	194	464	<1	6	298	265	326	552	2886	2570	2816
2011	465	543	813	340	438	703	211	329	592	57	192	460	<1	6	296	263	324	546	3064	2624	2808
2012	443	526	791	325	425	685	202	319	578	55	187	449	<1	6	290	252	314	533	2810	2451	2641
2013	422	509	772	310	411	670	192	310	565	52	182	440	<1	6	284	240	304	522	2470	2230	2438

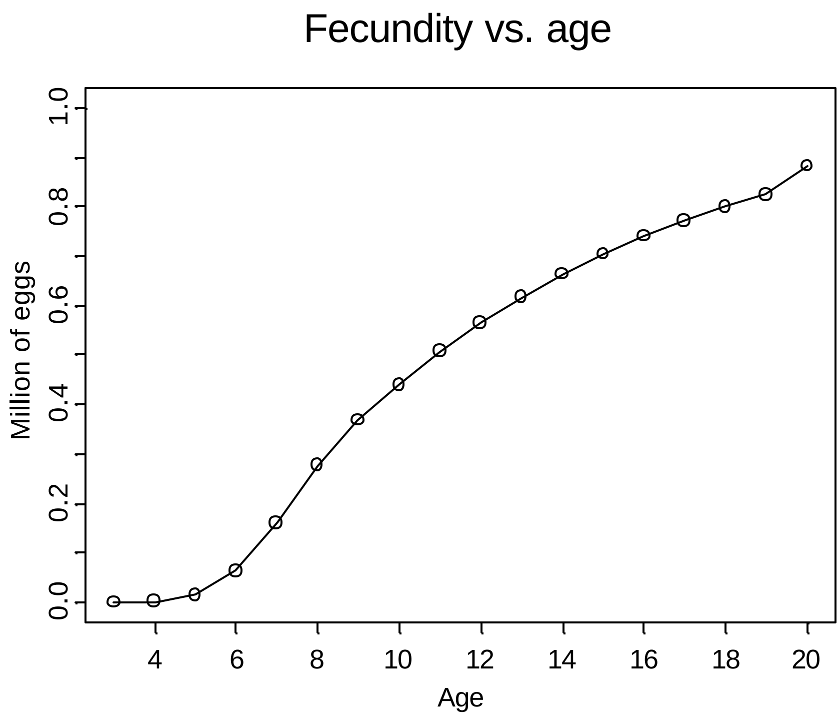
(b) For Models 10-12

Year	$P_{\max}=50\%$			$P_{\max}=60\%$			$P_{\max}=70\%$			$P_{\max}=80\%$			$P_{\max}=90\%$			T_{mid} & P_{mid}=50%			40:10 rule		
Model	10	11	12	10	11	12	10	11	12	10	11	12	10	11	12	10	11	12	10	11	12
2004	<1	67	281	<1	<1	172	<1	<1	55	<1	<1	<1	<1	<1	<1	<1	30	159	1088	1439	1888
2005	<1	68	285	<1	<1	175	<1	<1	56	<1	<1	<1	<1	<1	<1	<1	30	162	1016	1359	1799
2006	<1	69	290	<1	<1	179	<1	<1	57	<1	<1	<1	<1	<1	<1	<1	31	166	974	1317	1755
2007	<1	72	302	<1	<1	186	<1	<1	59	<1	<1	<1	<1	<1	<1	<1	32	173	994	1347	1790
2008	<1	79	327	<1	<1	201	<1	<1	64	<1	<1	<1	<1	<1	<1	<1	35	187	1246	1557	1990
2009	<1	95	373	<1	<1	230	<1	<1	74	<1	<1	<1	<1	<1	<1	<1	42	213	2018	2076	2432
2010	<1	105	402	<1	<1	248	<1	<1	79	<1	<1	<1	<1	<1	<1	<1	47	230	2852	2531	2770
2011	<1	103	395	<1	<1	244	<1	<1	78	<1	<1	<1	<1	<1	<1	<1	46	227	2957	2532	2727
2012	<1	99	383	<1	<1	237	<1	<1	76	<1	<1	<1	<1	<1	<1	<1	44	220	2656	2316	2523
2013	<1	95	371	<1	<1	230	<1	<1	74	<1	<1	<1	<1	<1	<1	<1	43	214	2264	2051	2286

Table 6. Risk analysis of four catch levels for three models (Models 5, 2 and 8 – see Table 3 for definitions). These models use the outputs from the base model in the stock assessment but with assumptions about whether recruitment for 2003-5 should be pre-specified and how future recruitment should be generated. The number in bold-italic typeface indicate the basis for the first three catch levels. Model numbers are same as in Tables 3 and 4. Abbreviations are: RP = recruitment is pre-specified; SR = the stock-recruitment relationship is used to generate future recruitment; P = the value of the power coefficient of the midwater juvenile index; and NA = not applicable. Symbols are: OY = Optimum Yield for 2004; F = fishing mortality; P_{max} = probability (%) to rebuild by T_{max}; T_{target} = year in which the probability of recovery is 0.5; and P_{100} = probability (%) of the spawning output being above the current spawning output in 100 years (year 2103).

Catch level (2004 OY (mt))		Model 5 (RP=N, SR=Y, P=3)	Model 2 (RP=N, SR=N, P=3)	Model 8 (RP=Y, SR=N, P=3)
35	OY	***35***	35	35
	F	***0.0012***	0.00115	0.00114
	P_{max}	***49.9***	80.4	87.8
	T_{target}	***2123***	2045	2028
	P_{100}	***91.2***	100.0	100.0
194	OY	195	***194***	194
	F	0.0064	***0.0064***	0.00634
	P_{max}	26.0	***60.1***	72.2
	T_{target}	NA	***2053***	2033
	P_{100}	75.4	***100.0***	100.0
284	OY	283	282	***284***
	F	0.0093	0.00925	***0.0093***
	P_{max}	14.9	46.7	***60.1***
	T_{target}	NA	2058	***2037***
	P_{100}	61.8	100.0	***100.0***
501	OY	502	499	501
	F	0.0165	0.0164	0.0165
	P_{max}	2.6	18.1	30.9
	T_{target}	NA	2081	2052
	P_{100}	27.1	99.6	100.0

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



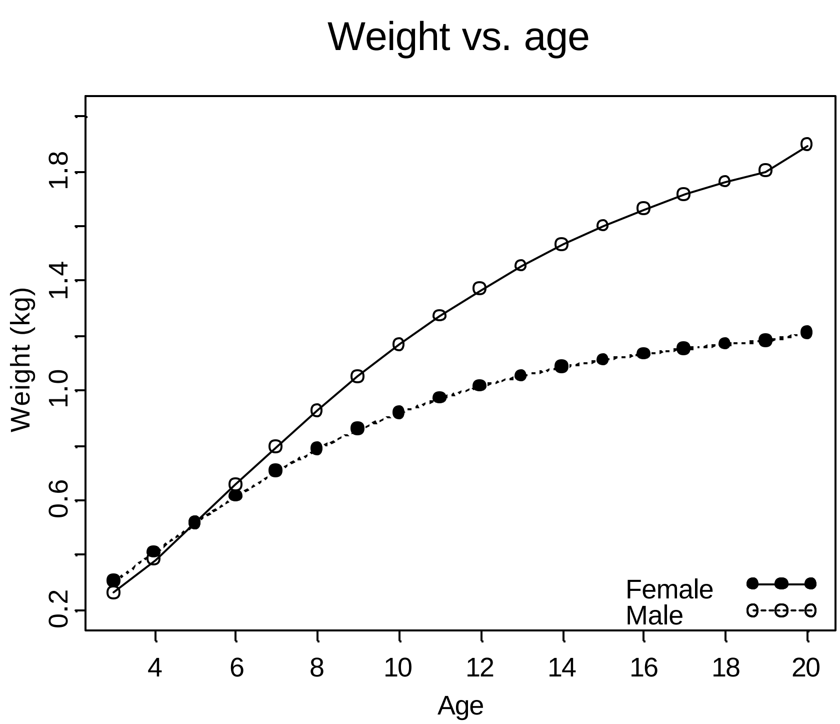


Figure 2. The selectivity pattern for widow rockfish used in the rebuilding analyses.

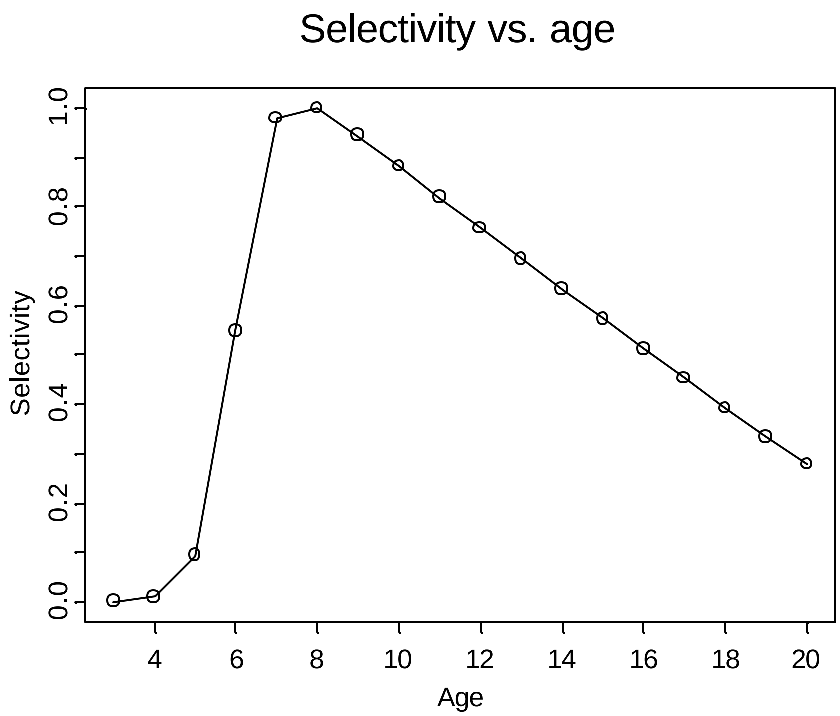


Figure 3. Simulated frequency distribution of unfished spawning output (B_0) from 3,000 simulations in which the sizes of the cohorts in the unfished population are determined by randomly re-sampling pre-fishing recruitments. The vertical line represents the mean B_0 used in the rebuilding analyses.

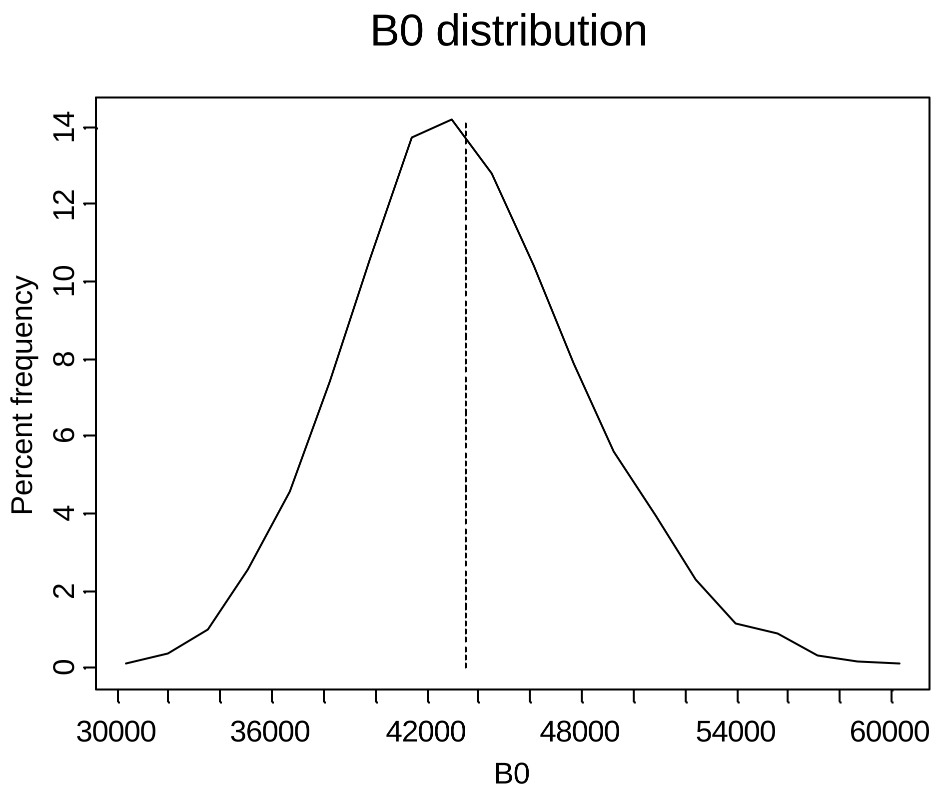


Figure 4. Simulated frequency distribution of the time to recover to 0.4 B_0 from 2001 with fishing (T_{min}), computed from 3,000 simulations based on the specifications of the Model 8. The vertical line represents the value of T_{min} used in the rebuilding analyses.

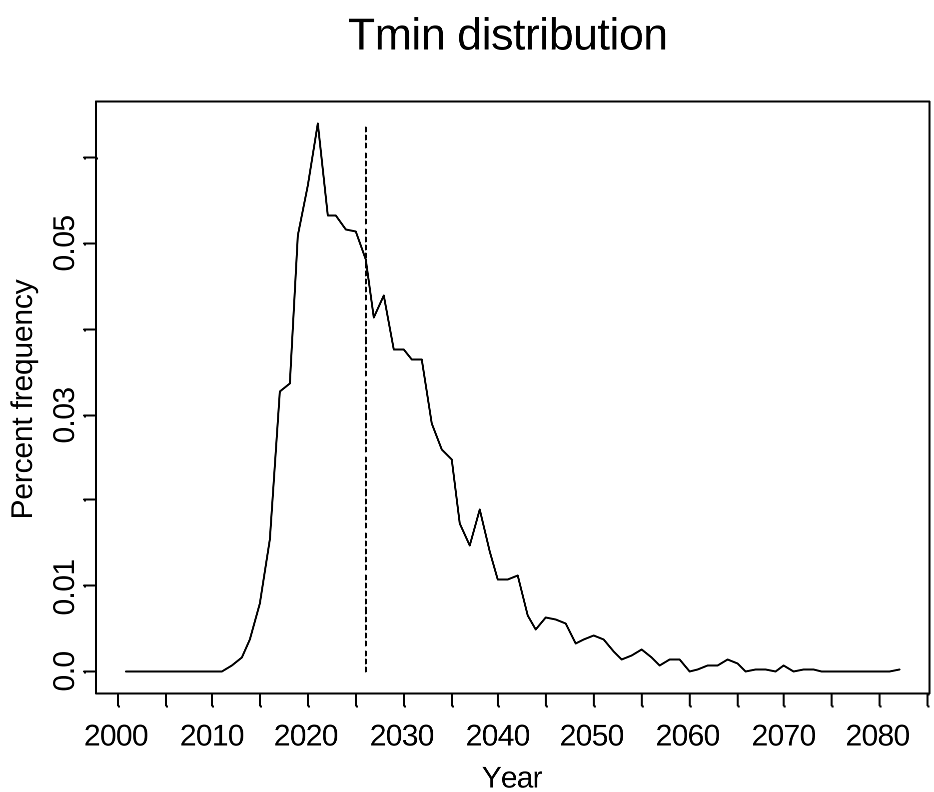
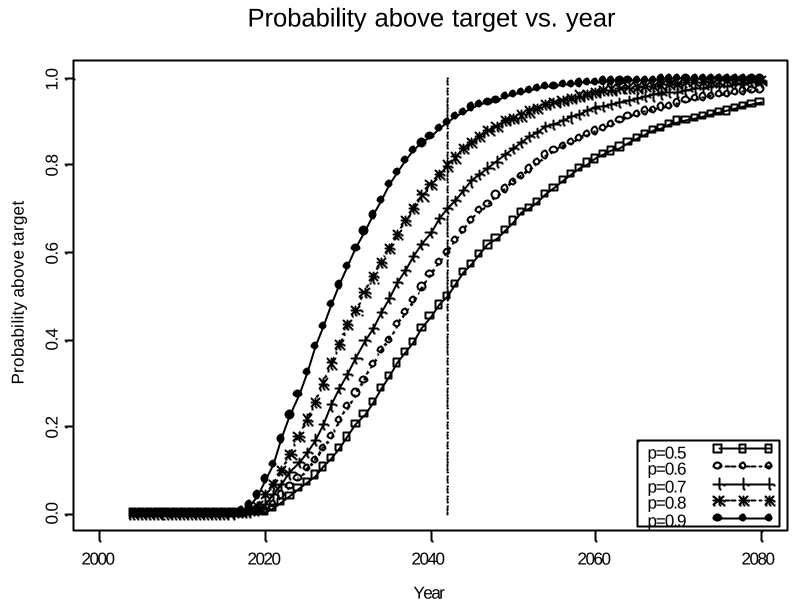
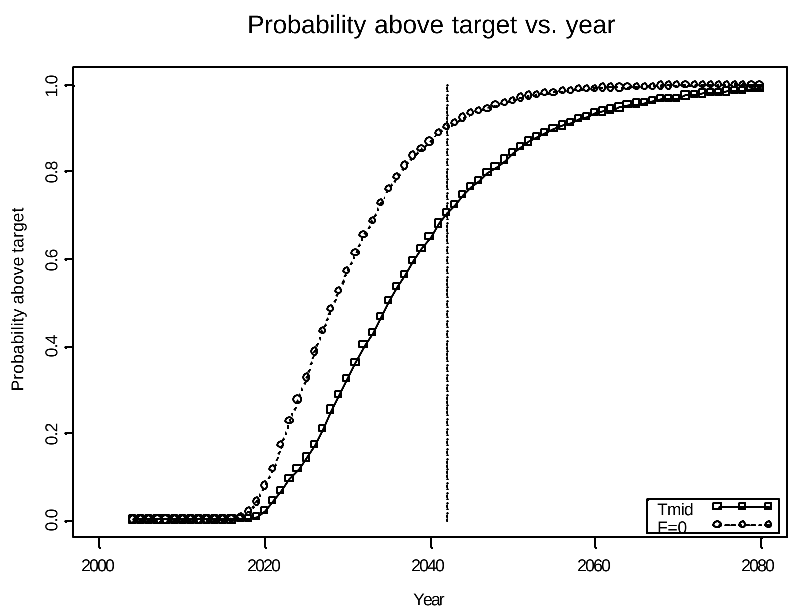


Figure 5. Time-series of the probability of the spawning output exceeding the target ($0.4B_0$) for five rebuilding strategies of $P_{max} = 0.5 - 0.9$ (upper panel) and two rebuilding strategies of T_{mid} and no fishing (lower panel). The results are based on Model 8. The vertical lines are T_{target}.





Appendix A. The "rebuild.dat" file used in the rebuilding analysis for Model 8. Model 8 is the stock assessment base model with pre-specified recruitment for 2003-5 and in which future recruitment is generated by re-sampling historical recruits-per-spawner ratios.

```
# Title
Widow (RO=1 R=2 P=3)
# 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
2003
# 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)
2
# Constant fishing mortality (1) or constant Catch (2) projections
1
# Pre-specify the year of recovery (or -1) to ignore
-1
# Fecundity-at-age
#  3  4  5  6  7  8  9 10
 0.0001 0.0002 0.0146 0.0634 0.1605 0.2757 0.3677 0.4399 0.5071 0.5650 0.6171
0.6635 0.7046 0.7410 0.7730 0.8011 0.8257 0.8824
# Age specific information (Females then males), weight and selectivity
# Females
 0.2623 0.3841 0.5176 0.6558 0.7932 0.9257 1.0507 1.1665 1.2726 1.3685 1.4547
1.5316 1.5998 1.6601 1.7131 1.7597 1.8005 1.8944
 0.0009 0.0097 0.0944 0.5498 0.9806 1.0000 0.9453 0.8830 0.8198 0.7569 0.6948
0.6336 0.5730 0.5128 0.4526 0.3929 0.3345 0.2792
# Males
 0.3031 0.4098 0.5155 0.6151 0.7060 0.7869 0.8578 0.9191 0.9715 1.0161 1.0537
1.0854 1.1120 1.1343 1.1529 1.1684 1.1814 1.2086
 0.0009 0.0097 0.0944 0.5498 0.9806 1.0000 0.9453 0.8830 0.8198 0.7569 0.6948
0.6336 0.5730 0.5128 0.4526 0.3929 0.3345 0.2792
# Age specific information (Females then males), natural mortality and
numbers at age
# Females
 0.1500 0.1500 0.1500 0.1500 0.1500 0.1500 0.1500 0.1500 0.1500 0.1500 0.1500
0.1500 0.1500 0.1500 0.1500 0.1500 0.1500 0.1500
     6274.02     4219.67     4443.77     2428.76     2128.70     2287.86
2868.73     1529.30     3492.11     1528.23      763.42      666.90
753.59      244.06      434.89      433.69      260.16     1900.81
# Males
 0.1500 0.1500 0.1500 0.1500 0.1500 0.1500 0.1500 0.1500 0.1500 0.1500 0.1500
0.1500 0.1500 0.1500 0.1500 0.1500 0.1500 0.1500
     6274.02     4219.67     4443.77     2428.76     2128.70     2287.86
2868.73     1529.30     3492.11     1528.23      763.42      666.90
753.59      244.06      434.89      433.69      260.16     1900.81
```

```
# Initial age-structure (for Tmin)
     4902.82     5165.99     2838.84     2566.73     2845.16     3569.44
1893.83     4302.17     1873.12      931.09      809.53      910.67
293.67      521.16      517.66      309.35      244.81     2000.34
     4902.82     5165.99     2838.84     2566.73     2845.16     3569.44
1893.83     4302.17     1873.12      931.09      809.53      910.67
293.67      521.16      517.66      309.35      244.81     2000.34
# Year for Tmin Age-structure
2001
# Number of simulations
3000
# Recruitment and Spanwer biomasses
# Number of historical assessment years
45
# Historical data: Year, Recruitment, Spawner biomass, Used to compute B0,
Used to project based
# on R, Used to project based on R/S
1958     42425     39568 1 0 0
1959     42862     39569 1 0 0
1960     43310     39589 1 0 0
1961     43450     39675 1 0 0
1962     43484     39870 1 0 0
1963     43588     40171 1 0 0
1964     38812     40532 1 0 0
1965     37029     40920 1 0 0
1966     36109     41294 1 0 0
1967     41850     40763 1 0 0
1968     56748     39987 1 0 0
1969     38332     39553 1 0 0
1970     56976     39558 1 0 0
1971     48694     39775 1 0 0
1972     45931     40223 1 0 0
1973    114065     40903 1 0 0
1974     32197     41586 1 0 0
1975     10281     42616 1 0 0
1976     13405     44140 1 0 0
1977     18353     45821 1 0 0
1978     27513     46409 1 0 0
1979      9198     45497 1 0 0
1980     60680     43132 1 0 0
1981     62387     36181 1 0 0
1982     25945     28394 1 0 0
1983     53363     21674 0 0 0
1984     77180     19954 0 0 0
1985     28235     19304 0 0 0
1986     27537     19015 0 1 1
1987     34969     19188 0 1 1
1988     27526     19056 0 1 1
1989     12418     18741 0 1 1
1990     29889     17297 0 1 1
1991     20008     16076 0 1 1
1992     17124     15525 0 1 1
1993     24993     14779 0 1 1
1994     41204     13536 0 1 1
1995     13379     12701 0 1 1
```

```
1996     18878     11757 0 1 1
1997     11283     11258 0 1 1
1998      8153     10898 0 1 1
1999      7673     10928 0 1 1
2000     12005     10558 0 1 1
2001      9806     10027 0 1 1
2002     12548      9755 0 1 1
# Number of years with pre-specified catches
1
# Catches for years with pre-specified catches
2003 300
# Number of future recruitments to override
3
# Process for overiding (-1 for average otherwise index in data list)
2003 1 13321
2004 1 21225
2005 1 41765
# Which probability to product detailed results for (1=0.5,2=0.6,etc.)
2
# Steepness and sigma-R and auto-correlations
  0.217141  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
# 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 5
# Catches and Fs (Year; 1/2 (F or C); value); Final row is -1
2004 1 0.000000
2005 1 0.000000
2010 1 0.000000
2100 1 0.000000
-1 -1 -1
# Split of Fs
2003 1
-1 1
```