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Cowcod Rebuilding Analysis

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Introduction

The status of cowcod (*Sebastes levis*) in the Southern California Bight was first assessed by Butler et al. (1999), who concluded that spawning biomass in 1998 was 7% of the unfished biomass. The stock was declared overfished in 2000 and the first rebuilding plan was adopted under Amendment 16-3 (PFMC, 2004). The stock was assessed again in 2005 (Piner et al., 2006) and the original rebuilding plan parameters were supplanted by the rebuilding analysis of Piner (2006). Parameters from the 2004 and 2006 rebuilding analyses are provided in Table 1.

This rebuilding analysis is based on the assessment of Dick et al. (2007). The 2007 base model included six major revisions to the prior assessment: 1) a correction to the gear selectivity curve, 2) updated commercial landings estimates, 3) separation of commercial and recreational fisheries, 4) a revised selectivity curve for the recreational fishery and commercial passenger fishing vessel (CPFV) logbook index, 5) a revised model structure for the CPFV logbook index, and 6) a correction to the data used in the length-at-age analysis. The 2007 base model also assumes that the steepness parameter in the Beverton-Holt stock-recruitment relationship is 0.6 (compared to 0.5 in the 2005 assessment). This change is based on a meta-analysis of several rockfish stocks (M. Dorn, pers. comm.). Dick et al. estimated spawning biomass in 2007 as 4.6% of the unfished level, however there was considerable uncertainty in this estimate. The 2007 assessment was modeled using Stock Synthesis II software (Methot, 2005).

In his addendum to the 2007 stock assessment, Dick (2007) describes a correction to the 2002 cowcod biomass estimate from the visual survey, and outlines its effects on the assessment results and the rebuilding analysis. The results in this document reflect the changes associated with this revised biomass estimate.

Simulation Model and Rebuilding Calculations

Estimation of Virgin Biomass (B_0)

The 2007 base model assumes a Beverton-Holt stock-recruitment relationship with steepness fixed at 0.6. Virgin recruitment (R_0) is estimated at 109,942 recruits. Spawning output is assumed to be directly proportional to spawning biomass. For each simulation, virgin biomass (B_0), is defined using the equation:

$$B_0 = 0.5R_0 \sum_{a=a_{mat}}^{a_{last}} \phi_a e^{-\sum_{a'=a_{\min}}^{a-1} M_{a'}}$$

where a_{mat} is the minimum age-at-maturity, a_{last} is 5 times the last age group (to approximate the plus-group), $M_{a'}$ is the natural mortality rate at age a', and ϕ_a is fecundity at age a. Age-specific values for fecundity, weight, and other model inputs are given in Table 2. Spawning biomass in the 2004 and 2005 rebuilding analyses included both males and females. Values reported in the 2007 assessment and rebuilding analysis are for female spawning biomass only.

Simulation of Future Recruitments

In each model run, 1000 simulated trajectories were generated with recruitment determined by a Beverton-Holt stock-recruitment (S-R) relationship. A major axis of uncertainty in the assessment was the assumed value of the steepness parameter in the S-R relationship. During the SSC's review of the assessment, it was decided that the rebuilding analysis would represent uncertainty about steepness by using a discrete distribution of parameter values (Fig. 1). The relative frequency of each value approximates the prior probability distribution from a meta-analysis of multiple rockfish stocks (M. Dorn, pers. comm.). Variability in future recruitment is therefore expressed as a weighted set of twenty-one different states of nature (steepness values), rather than random deviations from an average S-R relationship (i.e. σ_R is fixed at zero).

Mean Generation Time

Mean generation time for cowcod is estimated from the net maternity function, and is 38 years. This is one year shorter than the estimate in the 2005 assessment, due to changes in the assumed growth model.

Description of Model Runs

In a memo dated September 4, 2007, the Pacific Fishery Management Council requested that authors of rebuilding analyses present results for the following model runs (letters match requests in the 9/4/07 memo):

C. *Provide the projected year to rebuild if all fishing mortalities were eliminated beginning in 2009 ($T_{F=0}$).*

D. *Provide the following projections:*

   1. *Projections of yields, median rebuilding times, and rebuilding probabilities at T_{TARGET} and T_{MAX} under the SPR harvest rates specified in rebuilding plans adopted under Amendment 16-4 (see attached Table 4-2 from the FMP depicting the F_{SPR} harvest rates). NOTE: If the estimated mean generation time has changed in the assessment, T_{MAX} needs to be recalculated by adding estimated mean generation time to the T_{MIN} value specified in Table 4-2.*

   2. *Projections of yields, median rebuilding times, SPR harvest rates, and rebuilding probabilities at T_{TARGET} and T_{MAX} under the harvest rates (solved for using new models) which produce the current optimum yield amounts in place for 2007-2008.*

      [Note: The 4 mt coastwide OY for cowcod is based on the convention of doubling the OY for the stock in the SCB (2 mt) (PFMC and NMFS, 2006)]

   3. *Projections of yields and SPR harvest rates (solved for using new models) which rebuild the stock in 50 percent of the runs by the T_{TARGET} specified in Amendment 16-4.*

   4. *Projections of yields, median rebuilding times, SPR harvest rates, and rebuilding probabilities at T_{TARGET} and T_{MAX} under the ABC harvest rate.*

The following runs were also suggested:

Projections with median rebuilding times evenly distributed between $T_{F=0}$ and T_{MAX}. These projections should be determined by projecting the median rebuilding times under the most conservative rebuilding strategy (i.e., $T_{F=0}$) and the most liberal, allowable rebuilding strategy (i.e., T_{MAX}) and then parsing intermediate time intervals in even quartile increments. That is, if $T_{F=0}$ = 10 years and T_{MAX} = 50 years, then the intermediate alternatives would have rebuilding times equal to 20, 30, and 40 years, respectively. Through iteration, determine the SPR harvest rate, 2009 and 2010 OYs, and the probability of rebuilding by T_{MAX} (i.e., P_{MAX}) under each alternative rebuilding schedule. This will allow the Council to explore the tradeoff between economic impacts associated with alternative harvest levels and conservation needs of the stock.

Total removals (bycatch) in 2007 and 2008 are difficult to determine for cowcod in the Southern California Bight. The most recent coast wide estimate from the bycatch scorecard is 1.9 metric tons (Table 3). However, there is very little information to determine how much is caught within the defined stock boundary (south of Point Conception). The non-whiting limited entry trawl fishery accounts for and estimated 1.4 metric tons, but operates north of the assumed stock boundary. Bycatch from the recreational groundfish fishery in California is estimated at 0.1 mt. In this rebuilding analysis, total removals for 2007 and 2008 are assumed to be 0.5 mt, consistent with the 2007 stock assessment.

This rebuilding analysis uses the default SSC rebuilding program (version 2.11, September 2007).

Results

The results of this rebuilding analysis differ significantly from the previous analysis due to the combined effects of changes to the base model's structure (correction and revision of gear selectivity curves, separation of recreational and commercial fisheries, increased steepness) and revisions to data used in the assessment (commercial landings, length-at-age data). A summary of results for runs C and D1-D4 is presented in Tables 4 and 5. These results suggests that if fishing mortality was eliminated beginning in 2009, the median year for rebuilding ($T_{F=0}$) would be 2061 and the revised probability of rebuilding by the current T_{target} (2039) would be 21.6% (Table 4). T_{min} and $T_{F=0}$ were both 2035 in the previous analysis (Table 1). Amendment 16-4 specifies P_{max} (the probability of rebuilding by T_{max}) for cowcod as 90.6%. However, simulations based on the 2007 assessment indicate that fishing at the adopted harvest control rule ($F_{90\%}$) would rebuild by the adopted T_{max} (2074) with a 59.8% probability (Table 4).

The use of the discrete steepness distribution causes some model trajectories to have a "step" pattern (Fig. 2). As a result, proximal years often have the same probability of being above target and different catch streams appear to produce the same probability of rebuilding in a given year (Table 4). The effect is noticeable because this analysis does not consider recruitment variability in forward projections.

The distribution of virgin biomass (B_0) that results from the assumed distribution for steepness is skewed (Fig. 3), with a mean of 2550 mt and mode at 2488 mt. The corresponding values (mean and mode) of B_{MSY} are 1020 mt and 995 mt, respectively. The values reported in the 2007 stock assessment are the modes of these distributions, prior to correcting for the revised 2002 biomass estimate (Dick et al., 2007).

Run C estimates $T_{F=0}$ (2061) using the new model. Run D1 shows that fishing at the adopted harvest control rule ($F_{90\%}$) delays the median rebuilding time by four years relative to the case in which fishing mortality is set to zero (Table 5, Fig. 4). Run D2 fishes at the rate that produces the 2007-2008 OY for cowcod in the SCB (2 mt), and delays the median rebuilding time by eleven years relative to the case in which fishing mortality is set to zero. Run D3 does not apply for cowcod. The probability of rebuilding by the T_{target} specified in Amendment 16-4 (2039) is 21.6% in the absence of fishing. Run D4 fishes at the ABC harvest rate ($F_{50\%}$). Due to the discrete distribution, the probability of being above target biomass remains slightly below 0.5 for the entire simulation. The median spawning biomass trajectory for this run reaches 99% of target biomass in 2201. For this scenario, however, the probability of rebuilding by T_{MAX} is less than 50% (Table 4). Median catch for runs C, D1-D4, is plotted as Fig. 5.

The PFMC also requested projections with median rebuilding times evenly distributed between $T_{F=0}$ and T_{MAX}. Tables 6 and 7 summarize results from this set of runs. Trajectories of the probability that biomass is above target, median spawning biomass relative to target, and median catch are shown in figures 6, 7, and 8, respectively.

Literature cited

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Table 1. Parameters from the two previous rebuilding analyses. Biomass estimates from 2004 and 2006 were reported for males and females combined. The 2007 assessment and rebuilding analysis provide estimates of female spawning biomass only.

	Date of Analysis	
Rebuilding Parameter	**2004**	**2006**
B_0 [mt]	3367	3045
B_{MSY} [mt]	1350	1218
T_{MIN}	2062	2035
T_{MAX}	2099	2074
$T_{F=0}$	2062	2035
P_{MAX}	60%	90.6%
T_{TARGET}	2090	2039
Harvest Control Rule	$F_{78\%}$	$F_{90\%}$

Table 2. Age-specific quantities used in the rebuilding analysis.

	Female				Fleet 1		Fleet 2	
Age	Fecundity	M	Init N	Init N Tmin	Weight	Selectivity	Weight	Selectivity
0	0.00000	0.055	20.873	13.261	0.064	0	0.051	0
1	0.00000	0.055	18.718	11.932	0.169	0	0.130	0.002
2	0.00000	0.055	16.721	10.394	0.370	0.00005	0.256	0.009
3	0.00009	0.055	14.870	9.287	0.627	0.00059	0.392	0.038
4	0.00126	0.055	13.157	9.471	0.843	0.00427	0.513	0.105
5	0.00874	0.055	11.572	9.022	1.006	0.01840	0.626	0.214
6	0.03501	0.055	10.108	9.080	1.137	0.05302	0.737	0.349
7	0.09615	0.055	9.014	8.045	1.255	0.11464	0.852	0.489
8	0.20397	0.055	8.103	7.428	1.366	0.20253	0.975	0.618
9	0.36160	0.055	7.049	6.246	1.478	0.30968	1.109	0.726
10	0.56415	0.055	6.283	5.151	1.594	0.42609	1.256	0.812
11	0.80184	0.055	6.382	4.211	1.717	0.54175	1.416	0.876
12	1.06323	0.055	6.046	4.844	1.849	0.64862	1.590	0.921
13	1.33757	0.055	6.046	5.062	1.992	0.74137	1.777	0.952
14	1.61611	0.055	5.321	6.257	2.147	0.81741	1.975	0.972
15	1.89259	0.055	4.882	6.819	2.315	0.87650	2.184	0.984
16	2.16318	0.055	4.083	6.346	2.495	0.92006	2.400	0.991
17	2.42614	0.055	3.351	4.964	2.688	0.95053	2.622	0.995
18	2.68117	0.055	2.730	4.199	2.890	0.97075	2.848	0.997
19	2.92888	0.055	3.132	3.090	3.102	0.98348	3.075	0.999
20	3.17027	0.055	3.267	2.147	3.319	0.99107	3.303	0.999
21	3.40632	0.055	4.032	1.408	3.539	0.99537	3.530	1
22	3.63780	0.055	4.391	0.847	3.761	0.99768	3.756	1
23	3.86519	0.055	4.084	0.479	3.982	0.99887	3.980	1
24	4.08867	0.055	3.193	0.258	4.201	0.99946	4.200	1
25	4.30823	0.055	2.701	0.133	4.418	0.99974	4.417	1
26	4.52370	0.055	1.987	0.067	4.630	0.99988	4.630	1
27	4.73487	0.055	1.380	0.035	4.839	0.99994	4.839	1
28	4.94148	0.055	0.905	0.018	5.043	0.99997	5.043	1
29	5.14331	0.055	0.545	0.010	5.242	0.99999	5.242	1
30	5.34016	0.055	0.308	0.006	5.437	0.99999	5.437	1
31	5.53186	0.055	0.166	0.004	5.626	1	5.626	1
32	5.71826	0.055	0.085	0.003	5.809	1	5.809	1
33	5.89927	0.055	0.043	0.002	5.988	1	5.988	1
34	6.07482	0.055	0.022	0.002	6.161	1	6.161	1
35	6.24488	0.055	0.012	0.001	6.328	1	6.328	1
36	6.40942	0.055	0.007	0.001	6.490	1	6.490	1
37	6.56846	0.055	0.004	0.001	6.648	1	6.648	1
38	6.72610	0.055	0.003	0.001	6.803	1	6.803	1
39	6.87810	0.055	0.002	0.001	6.952	1	6.952	1
40	7.02454	0.055	0.001	0.001	7.096	1	7.096	1
41	7.16549	0.055	0.001	0.001	7.234	1	7.234	1
42	7.30106	0.055	0.001	0.000	7.367	1	7.367	1
43	7.43136	0.055	0.001	0.000	7.495	1	7.495	1
44	7.55650	0.055	0.001	0.000	7.617	1	7.617	1
45	7.67661	0.055	0.000	0.000	7.735	1	7.735	1
46	7.79183	0.055	0.000	0.000	7.848	1	7.848	1
47	7.90229	0.055	0.000	0.000	7.956	1	7.956	1
48	8.00812	0.055	0.000	0.000	8.059	1	8.059	1
49	8.10948	0.055	0.000	0.000	8.159	1	8.159	1
50	8.20650	0.055	0.000	0.000	8.253	1	8.253	1
51	8.29932	0.055	0.000	0.000	8.344	1	8.344	1
52	8.38810	0.055	0.000	0.000	8.431	1	8.431	1
53	8.47297	0.055	0.000	0.000	8.514	1	8.514	1
54	8.55408	0.055	0.000	0.000	8.593	1	8.593	1
55	8.63157	0.055	0.000	0.000	8.669	1	8.669	1
56	8.70556	0.055	0.000	0.000	8.741	1	8.741	1
57	8.77620	0.055	0.000	0.000	8.810	1	8.810	1
58	8.84362	0.055	0.000	0.000	8.876	1	8.876	1
59	8.90795	0.055	0.000	0.000	8.939	1	8.939	1
60	8.96931	0.055	0.000	0.000	8.999	1	8.999	1
61	9.02782	0.055	0.000	0.000	9.056	1	9.056	1
62	9.08361	0.055	0.000	0.000	9.111	1	9.111	1
63	9.13679	0.055	0.000	0.000	9.162	1	9.162	1
64	9.18747	0.055	0.000	0.000	9.212	1	9.212	1
65	9.23575	0.055	0.000	0.000	9.259	1	9.259	1
66	9.28175	0.055	0.000	0.000	9.304	1	9.304	1
67	9.32556	0.055	0.000	0.000	9.347	1	9.347	1
68	9.36728	0.055	0.000	0.000	9.387	1	9.387	1
69	9.40700	0.055	0.000	0.000	9.426	1	9.426	1
70	9.44481	0.055	0.000	0.000	9.463	1	9.463	1
71	9.48080	0.055	0.000	0.000	9.498	1	9.498	1
72	9.51506	0.055	0.000	0.000	9.532	1	9.532	1
73	9.54765	0.055	0.000	0.000	9.563	1	9.563	1
74	9.57867	0.055	0.000	0.000	9.594	1	9.594	1
75	9.60817	0.055	0.000	0.000	9.622	1	9.622	1
76	9.63624	0.055	0.000	0.000	9.650	1	9.650	1
77	9.66293	0.055	0.000	0.000	9.676	1	9.676	1
78	9.68832	0.055	0.000	0.000	9.701	1	9.701	1
79	9.71247	0.055	0.000	0.000	9.724	1	9.724	1
80	9.73543	0.055	0.000	0.000	9.746	1	9.746	1

Table 3. Recent estimates of cowcod catch.

Year	**Estimated Coastwide Catch [mt]**	**Source**
2004	2.4	Total Mortality Report (Hastie, Sep. '06)
2005	2.0	Total Mortality Report (Hastie, Dec. '06)
2006	2.6	GMT scorecard (Jan. '07)
2007	1.9	GMT scorecard (projected Sep. '07)

Table 4. Summary of requested model runs. The discrete distribution of steepness in the model runs causes the probability of being above target to change in a step-wise fashion (see Figure 2). This also causes the probability of being above target in run D4 to converge to a value just below 50%. Therefore, the median rebuilding year presented for run D4 is the year in which median spawning biomass is 99% of the target biomass. * Results from run D3 are not applicable to cowcod (see text for details).

	Run	**C**	**D1**	**D2**	**D3***	**D4**
	SPR	1	**0.900**	0.790	n/a	**0.5**
	F	**0**	0.0038	0.0088	n/a	0.0295
	Median rebuilding year	2061	2065	2072	n/a	2201
Pr{above target}	by 2035 (old Tmin)	0.159	0.159	0.159	n/a	0.027
	by 2039 (old Ttarget)	0.216	0.216	0.216	n/a	0.062
	by 2060 (new Tmin)	0.467	0.467	0.402	n/a	0.159
	by 2074 (old Tmax)	0.662	0.598	0.533	n/a	0.216
	by 2098 (new Tmax)	0.784	0.724	0.662	n/a	0.338
Median Catch (metric tons)						
	2007	*0.5*	*0.5*	*0.5*	n/a	*0.5*
	2008	*0.5*	*0.5*	*0.5*	n/a	*0.5*
	2009	0	0.9	**2.0**	n/a	6.6
	2010	0	0.9	2.1	n/a	6.9
	2011	0	1.0	2.2	n/a	7.1
	2012	0	1.0	2.3	n/a	7.3
	2013	0	1.1	2.4	n/a	7.5
	2014	0	1.1	2.5	n/a	7.8
	2015	0	1.2	2.7	n/a	8.0
	2016	0	1.2	2.8	n/a	8.3
	2017	0	1.3	2.9	n/a	8.6
	2018	0	1.4	3.1	n/a	8.9

Table 5. Median spawning output relative to the rebuilding target for runs C and D1-D4.

Run	C	D1	D2	D3	D4
SPR	1	0.900	0.790	n/a	0.5
F	0	0.0038	0.0088	n/a	0.0295
Median Spawning Biomass Relative to Target					
2007	0.094	0.094	0.094	n/a	0.094
2008	0.100	0.100	0.100	n/a	0.100
2009	0.106	0.106	0.106	n/a	0.106
2010	0.112	0.112	0.111	n/a	0.109
2011	0.119	0.118	0.117	n/a	0.112
2012	0.125	0.124	0.122	n/a	0.116
2013	0.132	0.131	0.128	n/a	0.119
2014	0.140	0.137	0.134	n/a	0.123
2015	0.147	0.145	0.141	n/a	0.127
2016	0.155	0.152	0.148	n/a	0.131
2017	0.164	0.160	0.155	n/a	0.135
2018	0.173	0.168	0.162	n/a	0.140
2019	0.182	0.177	0.170	n/a	0.144
2020	0.192	0.186	0.178	n/a	0.149
2021	0.202	0.195	0.186	n/a	0.155
2022	0.213	0.205	0.195	n/a	0.160
2023	0.224	0.215	0.204	n/a	0.166
2024	0.236	0.226	0.214	n/a	0.172
2025	0.248	0.237	0.224	n/a	0.178
2026	0.260	0.249	0.234	n/a	0.184
2027	0.274	0.261	0.245	n/a	0.190
2028	0.287	0.273	0.256	n/a	0.196
2029	0.301	0.286	0.267	n/a	0.203
2030	0.316	0.300	0.279	n/a	0.209
2031	0.331	0.313	0.291	n/a	0.216
2032	0.347	0.328	0.304	n/a	0.223
2033	0.364	0.342	0.316	n/a	0.230
2034	0.380	0.358	0.330	n/a	0.237
2035	0.398	0.373	0.343	n/a	0.244
2036	0.416	0.390	0.357	n/a	0.252
2037	0.434	0.406	0.372	n/a	0.259
2038	0.454	0.423	0.386	n/a	0.267
2039	0.473	0.441	0.401	n/a	0.275
2040	0.493	0.459	0.417	n/a	0.282
2041	0.514	0.477	0.433	n/a	0.290
2042	0.535	0.496	0.449	n/a	0.299
2043	0.557	0.515	0.465	n/a	0.307
2044	0.579	0.535	0.482	n/a	0.315
2045	0.601	0.555	0.499	n/a	0.324
2046	0.624	0.575	0.516	n/a	0.332
2047	0.648	0.596	0.534	n/a	0.341
2048	0.672	0.617	0.551	n/a	0.349
2049	0.696	0.638	0.570	n/a	0.358
2050	0.720	0.660	0.588	n/a	0.367
2051	0.745	0.682	0.606	n/a	0.376
2052	0.770	0.704	0.625	n/a	0.385

Run	C	D1	D2	D3	D4
SPR	1	0.900	0.790	n/a	0.5
F	0	0.0038	0.0088	n/a	0.0295
Median Spawning Biomass Relative to Target					
2053	0.796	0.727	0.644	n/a	0.394
2054	0.822	0.749	0.663	n/a	0.403
2055	0.848	0.772	0.683	n/a	0.412
2056	0.874	0.796	0.702	n/a	0.421
2057	0.901	0.819	0.721	n/a	0.430
2058	0.928	0.842	0.741	n/a	0.440
2059	0.955	0.866	0.761	n/a	0.449
2060	0.981	0.889	0.780	n/a	0.458
2061	1.008	0.913	0.800	n/a	0.467
2062	1.036	0.937	0.820	n/a	0.476
2063	1.063	0.960	0.840	n/a	0.486
2064	1.090	0.984	0.860	n/a	0.495
2065	1.117	1.008	0.879	n/a	0.504
2066	1.144	1.031	0.899	n/a	0.513
2067	1.172	1.055	0.919	n/a	0.522
2068	1.199	1.079	0.939	n/a	0.531
2069	1.226	1.102	0.958	n/a	0.540
2070	1.252	1.125	0.977	n/a	0.549
2071	1.279	1.148	0.997	n/a	0.558
2072	1.305	1.171	1.016	n/a	0.567
2073	1.332	1.194	1.035	n/a	0.576
2074	1.358	1.217	1.054	n/a	0.585
2075	1.384	1.239	1.072	n/a	0.594
2076	1.409	1.262	1.091	n/a	0.602
2077	1.435	1.284	1.109	n/a	0.611
2078	1.460	1.305	1.127	n/a	0.619
2079	1.484	1.327	1.145	n/a	0.627
2080	1.509	1.348	1.163	n/a	0.636
2081	1.533	1.369	1.180	n/a	0.644
2082	1.557	1.390	1.197	n/a	0.652
2083	1.580	1.410	1.214	n/a	0.660
2084	1.603	1.430	1.231	n/a	0.668
2085	1.626	1.450	1.247	n/a	0.675
2086	1.648	1.469	1.263	n/a	0.683
2087	1.670	1.488	1.279	n/a	0.691
2088	1.692	1.507	1.295	n/a	0.698
2089	1.714	1.525	1.310	n/a	0.705
2090	1.735	1.543	1.325	n/a	0.712
2091	1.755	1.561	1.340	n/a	0.720
2092	1.775	1.579	1.354	n/a	0.726
2093	1.795	1.596	1.368	n/a	0.733
2094	1.814	1.612	1.382	n/a	0.740
2095	1.833	1.629	1.396	n/a	0.747
2096	1.852	1.645	1.409	n/a	0.753
2097	1.870	1.661	1.422	n/a	0.759
2098	1.888	1.676	1.435	n/a	0.766

Table 6. Projections with median rebuilding times evenly distributed between $T_{F=0}$ and T_{MAX}.
* The median rebuilding year for $T_{F=0}$ is 2060.5, which was rounded to 2061. Therefore, results for a median target year of 2061 are slightly different from Run C (e.g. catch is not exactly zero).
** Due to the discrete distribution, the probability of being above target is less than 50%.

		Median Rebuilding Year				
		2061*	**2070**	**2080**	**2089**	**2098**
	SPR	0.990	0.806	0.697	0.638	0.599
	F	0.0003	0.0080	0.0140	0.0178	0.0207
Pr{above target}	by 2035 (old Tmin)	0.159	0.159	0.107	0.107	0.062
	by 2039 (old Ttarget)	0.216	0.159	0.159	0.107	0.107
	by 2060 (new Tmin)	0.467	0.402	0.338	0.276	0.276
	by 2074 (old Tmax)	0.662	0.533	0.467	0.402	0.402
	by 2098 (new Tmax)	0.784	0.662	0.598	0.533	0.467**
Median Catch (metric tons)						
	2007	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*
	2008	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*
	2009	0.1	1.8	3.2	4.0	4.7
	2010	0.1	1.9	3.3	4.2	4.9
	2011	0.1	2.0	3.5	4.4	5.0
	2012	0.1	2.1	3.6	4.6	5.2
	2013	0.1	2.2	3.8	4.7	5.4
	2014	0.1	2.3	3.9	4.9	5.7
	2015	0.1	2.4	4.1	5.1	5.9
	2016	0.1	2.5	4.3	5.4	6.1
	2017	0.1	2.7	4.5	5.6	6.4
	2018	0.1	2.8	4.7	5.8	6.6

Table 7. Median spawning output relative to the rebuilding target for projections with median rebuilding times evenly distributed between $T_{F=0}$ and T_{MAX}.

Median Rebuilding Year	2061	2070	2080	2089	2098
SPR	0.990	0.806	0.697	0.638	0.599
F	0.0003	0.0080	0.0140	0.0178	0.0207
Year	**Median Spawning Biomass Relative to Target**				
2007	0.094	0.094	0.094	0.094	0.094
2008	0.100	0.100	0.100	0.100	0.100
2009	0.106	0.106	0.106	0.106	0.106
2010	0.112	0.111	0.111	0.110	0.110
2011	0.119	0.117	0.116	0.115	0.114
2012	0.125	0.123	0.121	0.119	0.119
2013	0.132	0.129	0.126	0.124	0.123
2014	0.139	0.135	0.131	0.129	0.128
2015	0.147	0.141	0.137	0.134	0.132
2016	0.155	0.148	0.143	0.140	0.138
2017	0.163	0.155	0.149	0.146	0.143
2018	0.172	0.163	0.156	0.152	0.149
2019	0.182	0.171	0.163	0.158	0.155
2020	0.191	0.179	0.170	0.165	0.161
2021	0.201	0.188	0.178	0.172	0.167
2022	0.212	0.197	0.186	0.179	0.174
2023	0.223	0.206	0.194	0.186	0.181
2024	0.235	0.216	0.202	0.194	0.188
2025	0.247	0.226	0.211	0.202	0.196
2026	0.259	0.237	0.220	0.211	0.204
2027	0.272	0.247	0.230	0.219	0.211
2028	0.286	0.259	0.239	0.228	0.219
2029	0.300	0.270	0.249	0.237	0.228
2030	0.315	0.282	0.260	0.246	0.236
2031	0.330	0.295	0.270	0.255	0.245
2032	0.345	0.307	0.281	0.265	0.254
2033	0.362	0.321	0.292	0.275	0.263
2034	0.378	0.334	0.303	0.285	0.272
2035	0.396	0.348	0.315	0.296	0.282
2036	0.414	0.362	0.327	0.306	0.292
2037	0.432	0.377	0.339	0.317	0.302
2038	0.451	0.392	0.352	0.328	0.312
2039	0.470	0.408	0.365	0.340	0.322
2040	0.490	0.423	0.378	0.351	0.333
2041	0.511	0.439	0.391	0.363	0.344
2042	0.532	0.456	0.405	0.375	0.355
2043	0.553	0.473	0.419	0.388	0.366
2044	0.575	0.490	0.433	0.400	0.377
2045	0.597	0.507	0.447	0.413	0.389
2046	0.620	0.525	0.462	0.425	0.400
2047	0.643	0.543	0.477	0.438	0.412
2048	0.667	0.562	0.492	0.452	0.424
2049	0.691	0.580	0.507	0.465	0.436
2050	0.715	0.599	0.522	0.478	0.448
2051	0.740	0.618	0.538	0.492	0.460
2052	0.765	0.637	0.554	0.506	0.473

Median Rebuilding Year	2061	2070	2080	2089	2098
SPR	0.990	0.806	0.697	0.638	0.599
F	0.0003	0.0080	0.0140	0.0178	0.0207
Year	**Median Spawning Biomass Relative to Target**				
2053	0.790	0.657	0.570	0.519	0.485
2054	0.816	0.677	0.585	0.533	0.498
2055	0.842	0.696	0.602	0.547	0.510
2056	0.868	0.716	0.618	0.562	0.523
2057	0.894	0.736	0.634	0.576	0.536
2058	0.920	0.757	0.650	0.590	0.549
2059	0.947	0.777	0.667	0.604	0.562
2060	0.973	0.797	0.683	0.618	0.574
2061	1.000	0.818	0.700	0.633	0.587
2062	1.027	0.838	0.716	0.647	0.600
2063	1.054	0.858	0.732	0.661	0.613
2064	1.081	0.879	0.749	0.676	0.626
2065	1.108	0.899	0.765	0.690	0.639
2066	1.134	0.919	0.782	0.704	0.651
2067	1.161	0.940	0.798	0.718	0.664
2068	1.188	0.960	0.814	0.732	0.677
2069	1.214	0.980	0.830	0.746	0.690
2070	1.241	1.000	0.847	0.760	0.702
2071	1.267	1.020	0.863	0.774	0.715
2072	1.293	1.040	0.878	0.788	0.727
2073	1.319	1.059	0.894	0.802	0.739
2074	1.345	1.079	0.910	0.815	0.751
2075	1.370	1.098	0.925	0.829	0.763
2076	1.396	1.117	0.941	0.842	0.775
2077	1.421	1.136	0.956	0.855	0.787
2078	1.445	1.154	0.971	0.868	0.799
2079	1.470	1.173	0.985	0.881	0.811
2080	1.494	1.191	1.000	0.894	0.822
2081	1.518	1.209	1.014	0.906	0.833
2082	1.541	1.227	1.029	0.919	0.844
2083	1.564	1.244	1.043	0.931	0.855
2084	1.587	1.261	1.057	0.943	0.866
2085	1.610	1.278	1.070	0.955	0.877
2086	1.632	1.295	1.084	0.966	0.887
2087	1.654	1.311	1.097	0.978	0.898
2088	1.675	1.327	1.110	0.989	0.908
2089	1.696	1.343	1.122	1.000	0.918
2090	1.717	1.358	1.135	1.011	0.928
2091	1.737	1.373	1.147	1.022	0.937
2092	1.757	1.388	1.159	1.032	0.947
2093	1.776	1.403	1.171	1.042	0.956
2094	1.795	1.417	1.182	1.052	0.965
2095	1.814	1.431	1.194	1.062	0.974
2096	1.832	1.445	1.205	1.072	0.983
2097	1.850	1.458	1.216	1.081	0.992
2098	1.868	1.472	1.226	1.091	1.000

Fig. 1. Frequency distribution for twenty-one fixed steepness values used to characterize uncertainty in rebuilding projections. Steepness values are the midpoints of the bins.

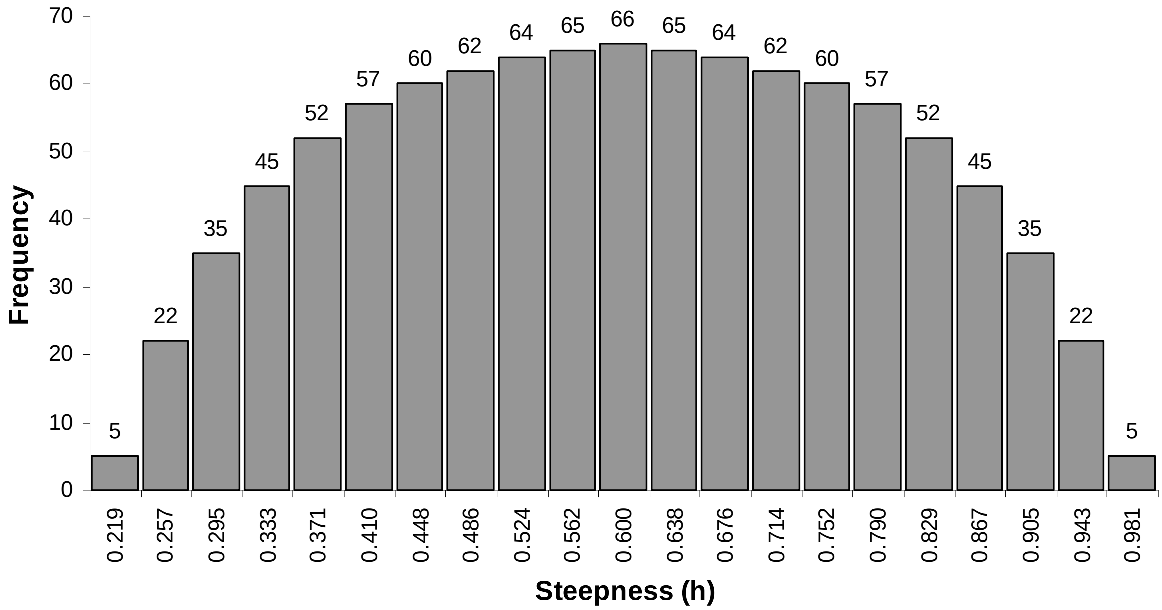


Fig. 2. Projected probability of being above target biomass for runs C and D1-D4. The discrete distribution for steepness causes a step-like characteristic.

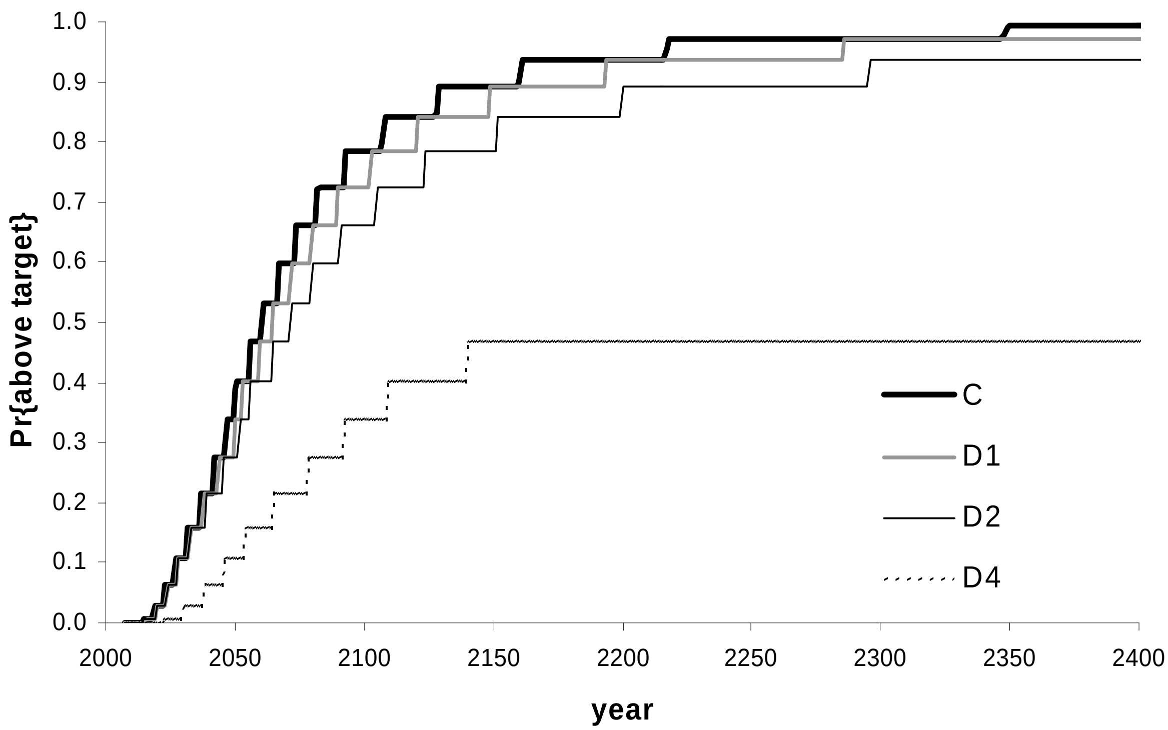


Fig. 3. Assumed frequency distribution of unfished female spawning biomass.

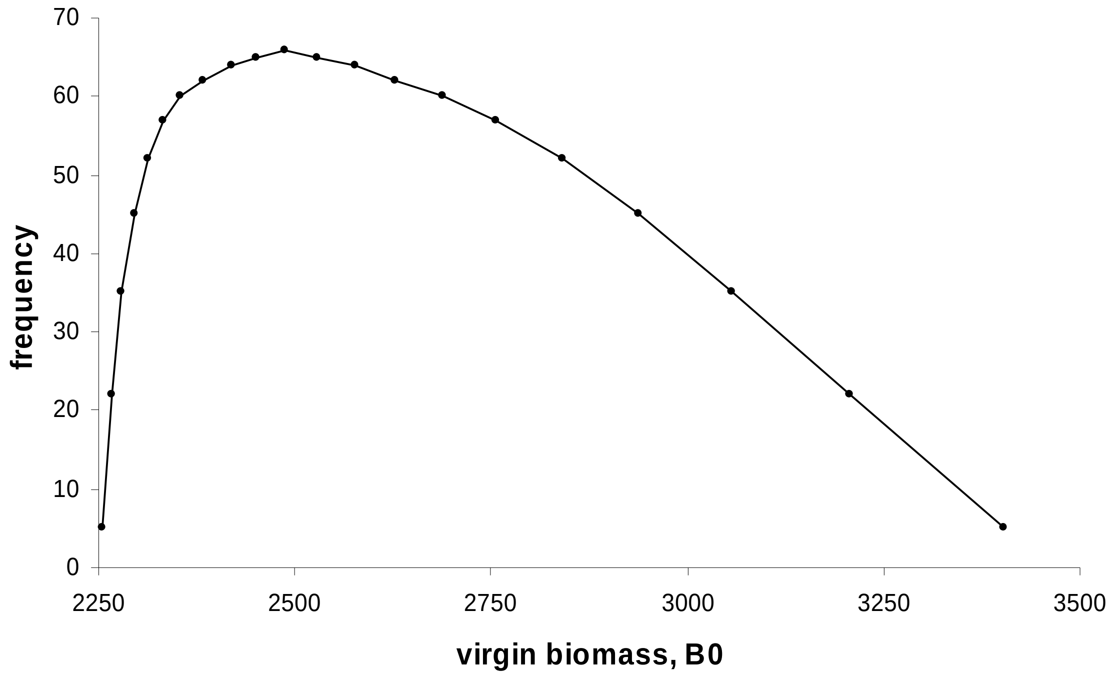


Fig. 4. Projections of median spawning biomass relative to target biomass for runs C and D1-D4.

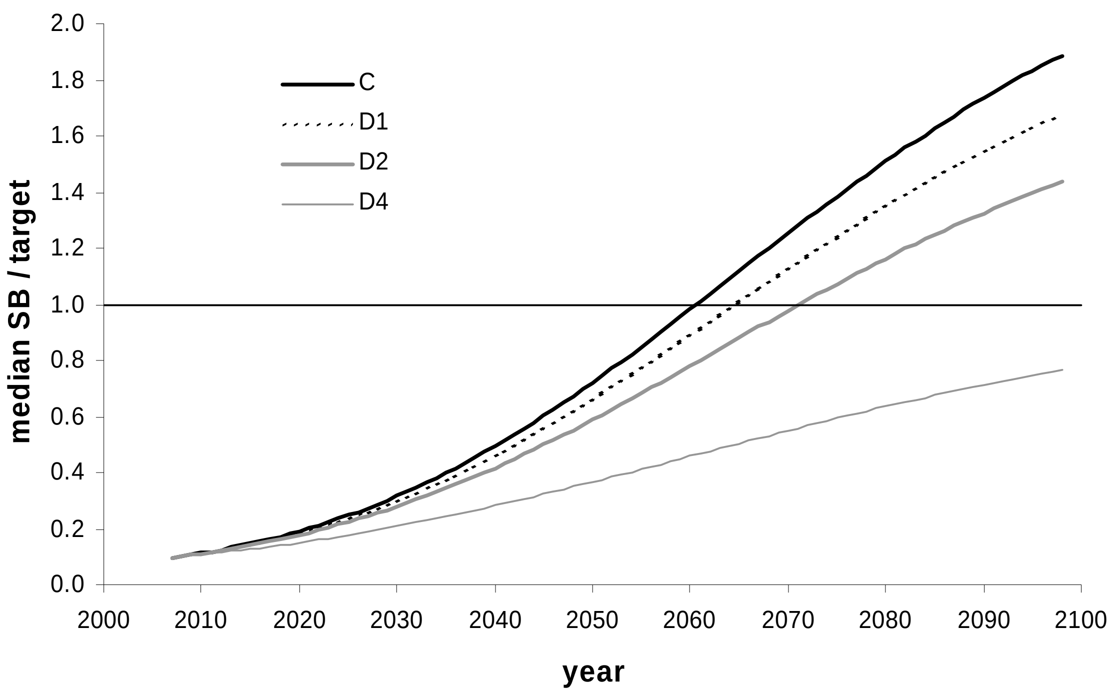


Fig. 5. Projected median catch trajectories for runs D1-D4.

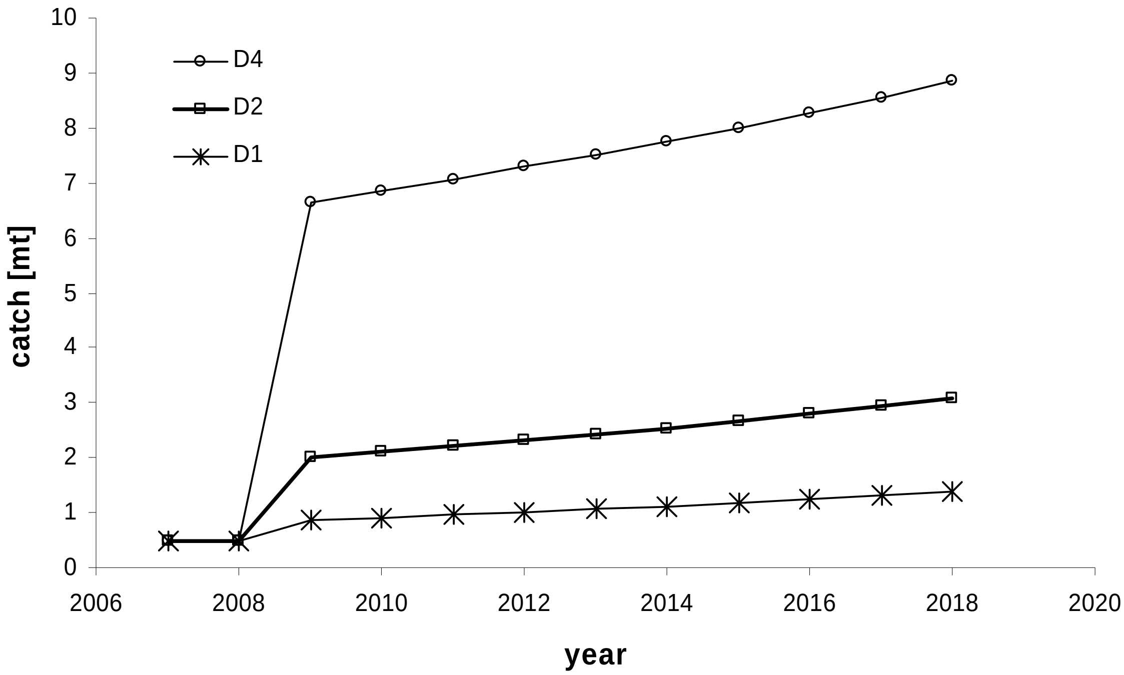


Fig. 6. Projected probability of being above target biomass for projections with median rebuilding times evenly distributed between $T_{F=0}$ and T_{MAX}.

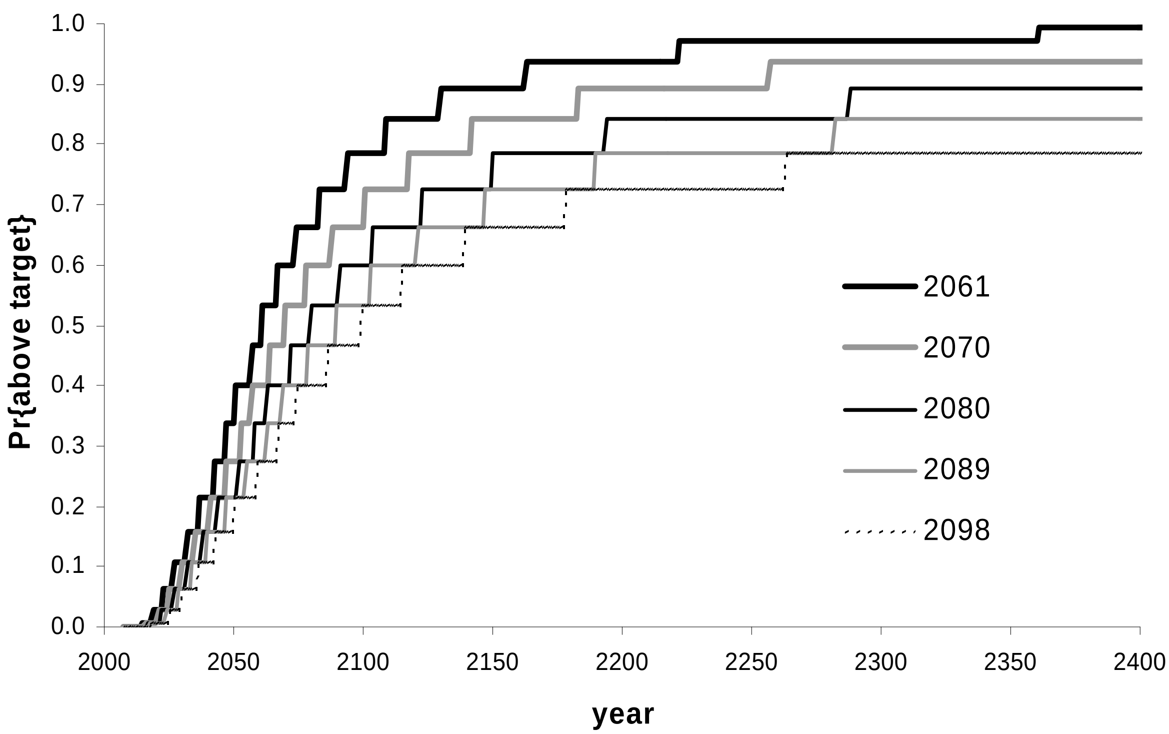


Fig. 7. Projections of median spawning biomass relative to target biomass for runs with median rebuilding times evenly distributed between $T_{F=0}$ and T_{MAX}.

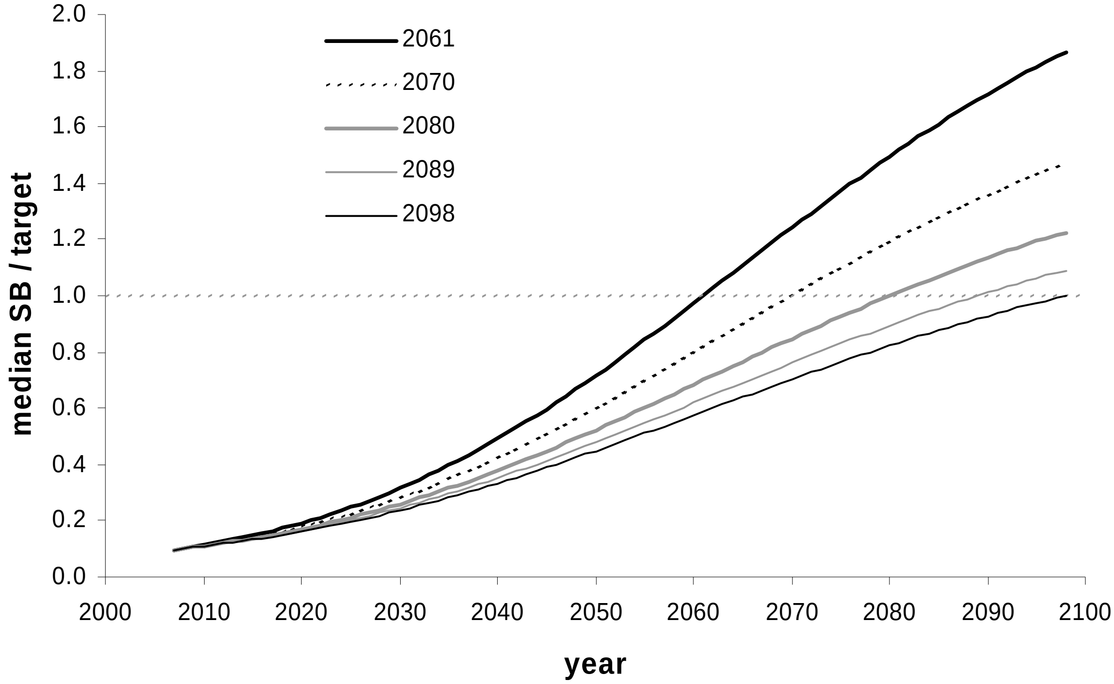
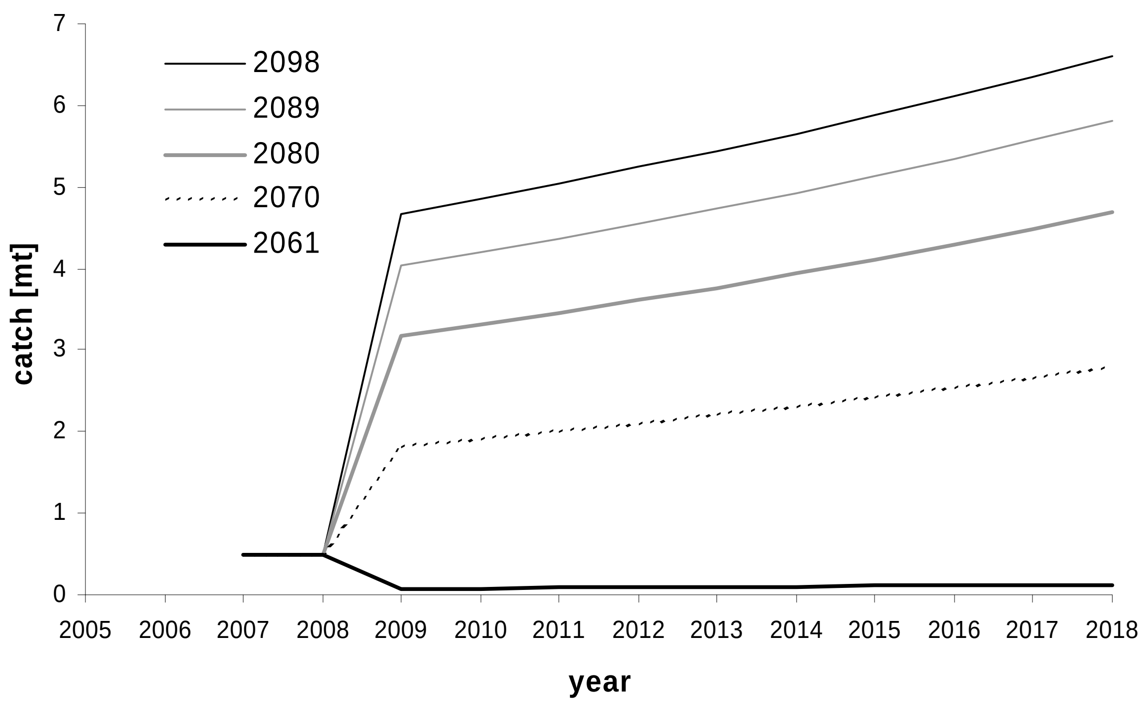


Fig. 8. Projected median catch trajectories for projections with median rebuilding times evenly distributed between $T_{F=0}$ and T_{MAX}. Since the new estimate of $T_{F=0}$ (2061) was rounded up from a fractional year, catches based on a target median rebuilding time for this (rounded) year are reported as slightly above zero.



Rebuild.dat file for run C

```
#Title # Run C, T(F=0)
```

```
moo3_rebuild.dat
# Number of sexes
1
# Age range to consider (minimum age; maximum age)
0 80
# Number of fleets
2
# First year of projection (Yinit)
2007
# First Year of rebuilding period (Ydecl)
2000
# 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)
1
# Pre-specify the year of recovery (or -1) to ignore
-1
# Fecundity-at-age
# 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59
60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 #runnumber: 22
moo3_base.dat moo3_base.ctl 16.5365 4976.24 198.724
 0 1.27093e-007 3.34807e-006 9.01415e-005 0.00126286 0.00873566 0.0350091 0.0961502
0.203967 0.361596 0.564146 0.801836 1.06323 1.33757 1.61611 1.89259 2.16318 2.42614
2.68117 2.92888 3.17027 3.40632 3.6378 3.86519 4.08867 4.30823 4.5237 4.73487 4.94148
5.14331 5.34016 5.53186 5.71826 5.89927 6.07482 6.24488 6.40942 6.56846 6.7261 6.8781
7.02454 7.16549 7.30106 7.43136 7.5565 7.67661 7.79183 7.90229 8.00812 8.10948 8.2065
8.29932 8.3881 8.47297 8.55408 8.63157 8.70556 8.7762 8.84362 8.90795 8.96931 9.02782
9.08361 9.13679 9.18747 9.23575 9.28175 9.32556 9.36728 9.407 9.44481 9.4808 9.51506
9.54765 9.57867 9.60817 9.63624 9.66293 9.68832 9.71247 9.73543 #female fecundity;
weighted by N in year Y_init across morphs and areas
# Age specific selectivity and weight adjusted for discard and discard mortality
 #wt and selex for gender,fleet: 1 1
 0.0635516 0.168778 0.3697 0.627271 0.843211 1.00574 1.13742 1.25451 1.36626 1.47826
1.59429 1.71716 1.84912 1.99194 2.14689 2.31463 2.49513 2.68757 2.89041 3.10154
3.31853 3.53898 3.7607 3.9819 4.2012 4.41761 4.6304 4.83904 5.04316 5.24245 5.43671
5.62575 5.80946 5.98774 6.16055 6.32784 6.48963 6.64799 6.8028 6.95201 7.09569 7.23394
7.36686 7.49457 7.61718 7.73483 7.84764 7.95577 8.05935 8.15852 8.25342 8.34421
8.43102 8.51399 8.59327 8.66899 8.74129 8.81031 8.87617 8.93899 8.99892 9.05605
9.11052 9.16243 9.2119 9.25903 9.30392 9.34667 9.38738 9.42614 9.46303 9.49814 9.53156
9.56335 9.5936 9.62238 9.64975 9.67579 9.70055 9.72409 9.74648
 0 3.85763e-006 5.02165e-005 0.000590347 0.00426779 0.0184032 0.053019 0.114639
0.202529 0.309685 0.426087 0.541752 0.648622 0.74137 0.817414 0.876498 0.920056
0.950529 0.970754 0.98348 0.991073 0.995371 0.997684 0.998874 0.999463 0.999745
0.999878 0.999941 0.999971 0.999985 0.999992 0.999996 0.999998 0.999999 0.999999
0.999999 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1
 #wt and selex for gender,fleet: 1 2
 0.0509934 0.129586 0.256494 0.392248 0.513435 0.625602 0.736515 0.851737 0.975086
1.10922 1.25589 1.41608 1.58992 1.77679 1.97538 2.18386 2.40012 2.62203 2.84759
3.07509 3.30309 3.53045 3.75622 3.97965 4.20011 4.4171 4.63016 4.83893 5.0431 5.24243
5.43669 5.62574 5.80946 5.98774 6.16054 6.32784 6.48963 6.64799 6.8028 6.95201 7.09569
7.23394 7.36686 7.49457 7.61718 7.73483 7.84764 7.95577 8.05935 8.15852 8.25342
8.34421 8.43102 8.51399 8.59327 8.66899 8.74129 8.81031 8.87617 8.93899 8.99892
9.05605 9.11052 9.16243 9.2119 9.25903 9.30392 9.34667 9.38738 9.42614 9.46303 9.49814
9.53156 9.56335 9.5936 9.62238 9.64975 9.67579 9.70055 9.72409 9.74648
 0 0.00161388 0.0088351 0.037502 0.105252 0.21417 0.34888 0.488771 0.617605 0.726343
0.812095 0.875988 0.921252 0.951846 0.971613 0.983838 0.991087 0.995219 0.99749 0.9987
0.999331 0.999654 0.999819 0.999904 0.999947 0.999971 0.999983 0.99999 0.999994
0.999996 0.999998 0.999998 0.999999 0.999999 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
# M and current age-structure in year Yinit: 2007
```

```
 # gender = 1
 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055
0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055
0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055
0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055
0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055
0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055 0.055
 20.8725 18.7177 16.7208 14.8702 13.1566 11.5717 10.1079 9.01391 8.10312 7.04934
6.28335 6.38181 6.04636 6.04576 5.32065 4.88158 4.08261 3.35113 2.73013 3.13227
3.26686 4.03243 4.3909 4.08379 3.19319 2.7009 1.98686 1.38048 0.905292 0.544862
0.308132 0.165958 0.0852645 0.0433505 0.0222229 0.0118263 0.00662999 0.00398906
0.00258374 0.00178995 0.00131948 0.0010184 0.000815456 0.000672306 0.000567825
0.000488118 0.000425903 0.000376046 0.000334929 0.000301046 0.000272505 0.000248303
0.000227066 0.000208253 0.000191258 0.000176002 0.000162309 0.000149712 0.000138242
0.00012779 0.000118272 0.000109622 0.000101736 9.45437e-005 8.80337e-005 8.20475e-005
7.66454e-005 7.16362e-005 6.70124e-005 6.27369e-005 5.88242e-005 5.51909e-005
5.19556e-005 4.90046e-005 4.62738e-005 4.37874e-005 4.15761e-005 3.93556e-005
3.71628e-005 3.5069e-005 0.000465183
# Age-structure at Ydecl= 2000
 13.2608 11.9315 10.3944 9.28739 9.47051 9.02246 9.08043 8.04518 7.42794 6.24644
5.15053 4.21102 4.84421 5.06212 6.25678 6.81911 6.34585 4.96372 4.19937 3.08957
2.14679 1.40788 0.847368 0.47921 0.258102 0.132605 0.0674198 0.0345617 0.0183926
0.0103111 0.00620389 0.0040183 0.00278378 0.00205208 0.00158383 0.00126821 0.00104558
0.000883091 0.000759129 0.00066237 0.000584831 0.000520884 0.000468189 0.000423801
0.000386162 0.000353133 0.000323874 0.000297444 0.000273717 0.000252422 0.00023283
0.000214992 0.000198737 0.000183934 0.000170481 0.000158217 0.000147031 0.000136906
0.000127596 0.000119195 0.000111404 0.000104213 9.75638e-005 9.14787e-005 8.58281e-005
8.07964e-005 7.6207e-005 7.196e-005 6.80931e-005 6.4654e-005 6.12006e-005 5.77902e-005
5.45339e-005 5.14618e-005 4.85115e-005 4.549e-005 4.24727e-005 3.94473e-005 3.64728e-
005 3.36246e-005 0.000425943
# Year for Tmin Age-structure (set to Ydecl by SS2)
2000
# Number of simulations
1000
#  recruitment and biomass
# Number of historical assessment years
109
# Historical data
# year recruitment spawner in B0 in R project in R/S project
1899  1900 1901 1902 1903 1904 1905 1906 1907 1908 1909 1910 1911 1912 1913 1914 1915
1916 1917 1918 1919 1920 1921 1922 1923 1924 1925 1926 1927 1928 1929 1930 1931 1932
1933 1934 1935 1936 1937 1938 1939 1940 1941 1942 1943 1944 1945 1946 1947 1948 1949
1950 1951 1952 1953 1954 1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966
1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000
2001 2002 2003 2004 2005 2006 2007 #years (with first value representing R0)
109.942  109.942 109.942 109.923 109.886 109.83 109.755 109.662 109.551 109.42 109.271
109.102 108.914 108.706 108.478 108.228 107.956 107.662 107.344 106.787 106.274
105.999 105.695 105.446 105.207 104.846 104.309 103.692 102.858 102.178 101.685
101.251 100.648 99.7845 99.2896 99.0108 98.8291 98.7973 99.0277 99.2299 99.4799
99.7021 99.9078 100.067 100.356 100.625 100.956 101.259 101.505 101.7 101.828 101.896
101.933 101.867 101.886 101.924 101.828 101.654 101.361 101.139 100.906 100.737
100.441 100.157 99.9465 99.7048 99.5182 99.1501 98.4735 97.427 96.6073 95.6868 94.8613
94.0572 92.5541 90.7845 88.372 86.0066 82.5588 79.3452 75.9829 70.893 65.9361 60.6571
50.3715 46.592 37.1386 25.9435 16.4862 12.8416 9.42624 10.0745 10.9863 11.9928 12.0758
12.762 11.9293 11.8168 10.9567 11.6036 12.6061 13.2608 14.0668 15.2376 16.3951 17.5381
18.6651 19.776 20.8725 #recruits; first value is R0 (virgin)
4976.24  4976.24 4976.23 4971.13 4960.99 4945.89 4925.92 4901.18 4871.76 4837.77
4799.34 4756.56 4709.56 4658.45 4603.35 4544.37 4481.61 4415.19 4345.2 4226.92 4122.46
4068.26 4009.63 3962.55 3918.17 3852.68 3758.48 3654.62 3521.22 3417.86 3346.07 3284.6
3202.05 3089.34 3027.41 2993.34 2971.45 2967.65 2995.39 3020.07 3051 3078.89 3105.07
3125.54 3163.33 3198.98 3243.87 3285.71 3320.29 3348.2 3366.58 3376.54 3381.82 3372.24
3375.07 3380.57 3366.66 3341.61 3300.04 3269.03 3237 3214.06 3174.43 3137.19 3110.03
3079.24 3055.79 3010.29 2929.28 2810.26 2721.95 2627.54 2546.87 2471.66 2339.32 2195.9
2019.17 1863.9 1664.24 1501.71 1351.65 1155.94 994.367 847.003 614.672 543.371 389.928
243.616 142.128 107.32 76.5805 82.2828 90.4063 99.5164 100.275 106.583 98.9377 97.9125
```

```
90.1405 95.9752 105.144 111.215 118.781 129.958 141.231 152.586 164.008 175.49 187.049
#spbio; first value is S0 (virgin)
1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  # in Bzero
0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1  0 0 0 # in R project
0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1  0 0 0 # in R/S project
# Number of years with pre-specified catches
2
# catches for years with pre-specified catches go next
2007 0.5
2008 0.5
# Number of future recruitments to override
0
# Process for overiding (-1 for average otherwise index in data list)
# Which probability to product detailed results for (1=0.5; 2=0.6; etc.)
7
# Steepness sigma-R Auto-correlation
0.6 0 0
# Target SPR rate (FMSY Proxy); manually change to SPR_MSY if not using SPR_target
0.5
# Target SPR information: Use (1=Yes) and power
0 20
# Discount rate (for cumulative catch)
0.1
# Truncate the series when 0.4B0 is reached (1=Yes)
0
# Set F to FMSY once 0.4B0 is reached (1=Yes)
0
# Percentage of FMSY which defines Ftarget
0.75
# Maximum possible F for projection (-1 to set to FMSY)
-1
# 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 (2)
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
15
# Random number seed
-98765
# Conduct projections for multiple starting values (0=No;else yes)
1
# File with multiple parameter vectors
Dorn_prior_2.ss2
# Number of parameter vectors: value is placeholder only, user needs to change it
1000
# User-specific projection (1=Yes); Output replaced (1->9)
0  5  0  0.1
# Catches and Fs (Year; 1/2/3 (F or C or SPR); value); Final row is -1
2009 1 1
-1 -1 -1
# Split of Fs
2007 1 1
-1  99  99
```

```
# Five pre-specified years (used to define Ttarget for projection type 4)
2009 2010 2011 2012 2013 # placeholder
#year for probability of recovery
2039
# Time varying weight-at-age (1=Yes;0=No)
0
# File with time series of weight-at-age data
none
# Use bisection (0) or linear interpolation (1)
1
# Target Depletion
0.4
# Project with Historical recruitments when computing Tmin (1=Yes)
0
# CV of implementation error
0
```

Addendum to the 2007 Stock Assessment and Rebuilding Analysis for Cowcod, *Sebastes levis*

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Summary

The 2007 cowcod assessment and rebuilding analysis are updated with a revised biomass estimate from the 2002 submersible survey. An error in the calculation of mean size was recently corrected in the survey results, reducing the estimate of cowcod biomass in the survey area from 940 to 524 metric tons. The revised biomass estimate is more consistent with the trend in relative abundance observed in CPFV logbook data, reducing estimated depletion in 2007 to 3.8% of unfished biomass in the base model. Revised models for the low and high alternative states of nature estimate depletion at 3.4% and 16.3%, respectively. Results from the recent rebuilding analysis are only slightly changed, with a median rebuilding year of 2065 under the Amendment 16-4 harvest rate ($F_{90\%}$). The revised estimate of T_{max} is 2098.

Introduction and Background

In the most recent assessment of cowcod, *Sebastes levis*, in the Southern California Bight, Dick et al. (2007) estimate spawning stock biomass in 2007 at approximately 4.6% of the theoretical unfished biomass. The uncertainty in this estimate was characterized by two alternative "low" and "high" models, which estimate 2007 depletion at 4.1% and 27.3%, respectively. In the subsequent rebuilding analysis (Dick and Ralston, 2007) the estimated median time to rebuild (T_{target}) under the current harvest rate ($F_{90\%}$) was delayed by 23 years relative to the T_{target} of 2039 specified in Amendment 16-4 to the Pacific Coast Groundfish Fishery Management Plan (FMP). This change is largely driven by revised estimates of stock productivity, historical commercial landings, and a structural flaw detected in the 2005 assessment (Dick et al., 2007).

One of the data sets included in the 2007 assessment was an estimate of cowcod biomass in 2002 based on a visual transect survey conducted from an occupied submersible (Yoklavich et al., in press). A formal review of this survey was conducted in 2004 with the assistance of the Center for Independent Experts (http://www.rsmas.miami.edu/groups/cie/) and the biomass estimate was included in the last two assessments as a relative index of abundance with an informative prior on the catchability parameter (Piner et al., 2005; Dick et al., 2007). In this way, estimated biomass from the survey area was adjusted to reflect the expected biomass in the entire Southern California Bight.

An error was recently discovered in the visual survey methodology, related to the calculation of mean weight (M. Yoklavich, pers. comm.). During the survey, cowcod at greater distances were easier to detect if they were large. Although the originally reported numbers and densities of cowcod remain unchanged, the total biomass estimate (940 metric tons) was based on estimates of mean weight that did not account for this effect. The survey investigators therefore adjusted their estimates of mean weight to include only cowcod sighted within 2.7 meters of the transect line. Within this distance they found no relationship between fish size and distance. Their revised estimate of cowcod biomass in the survey area is 524 metric tons, 56% of the previous estimate.

Effect on the 2007 Cowcod Stock Assessment

The three models presented in the 2007 cowcod assessment were fit using the revised biomass estimate from the visual survey (Table 1). While changes to unfished biomass are minor (<1%), female spawning biomass in 2007 is estimated at 94 metric tons, compared to 113 mt in the original 2007 assessment. This reduces depletion in 2007 from 4.6% to 3.8% in the base model. The revised range of plausible depletion levels in 2007 is between 3.4% and 16.3%, based on point estimates from the alternative low and high models, respectively.

One of the unresolved issues with the 2007 assessment was a conflict between the CPFV logbook index and the visual survey. The 2002 biomass estimated from the visual survey was considerably higher than the model-predicted biomass, which was influenced by the declining trend in the CPFV index. Therefore, the prior distribution for the visual survey's catchability coefficient (expansion factor) was not consistent with the posterior mode. The revised biomass estimate reduces, but does not eliminate, this discrepancy between the two data sets (Table 1).

Effect on the 2007 Rebuilding Analysis

Table 2 summarizes changes to the results for rebuilding model runs requested by the PMFC. A complete revision of the rebuilding analysis is presented as a separate document.

Literature Cited

Dick, E.J., S. Ralston, and D. Pearson. 2007. Status of cowcod, *Sebastes levis*, in the Southern California Bight. Document submitted to the PFMC, August 22, 2007.

Dick, E.J. and S. Ralston. 2007. Cowcod rebuilding analysis. Document submitted to the PFMC, October 3, 2007.

Piner, K., E. J. Dick, and J. Field. 2006. 2005 Stock Status of Cowcod in the Southern California Bight and Future Prospects. In Volume 1: Status of the Pacific Coast Groundfish Fishery Through 2005, Stock Assessment and Fishery Evaluation: Stock Assessments and Rebuilding Analyses. Portland, OR: Pacific Fishery Management Council.

Yoklavich, M., M. Love, and K. Forney. In press. A fishery-independent assessment of cowcod (*Sebastes levis*) using direct observations from an occupied submersible. Canadian Journal of Fisheries and Aquatic Sciences.

Table 1. Comparison of results from the 2007 cowcod stock assessment, using original (940 mt) and revised (524 mt) estimates of cowcod biomass from the 2002 visual survey.

	Visual survey biomass = 940 mt			**Visual survey biomass = 524 mt**		
	h = 0.4	h = 0.6	h = 0.8	h = 0.4	h = 0.6	h = 0.8
Reference Points	CPFV index & visual survey	CPFV index & visual survey	Visual survey only	CPFV index & visual survey	CPFV index & visual survey	Visual survey only
Unfished female spawning biomass (SB_0)	2785	2494	2496	2777	2488	2389
Unfished summary (age-1+) biomass	5923	5303	5308	5905	5291	5080
40% of SB_0 (proxy for SB_{MSY})	1114	997	998	1111	995	956
Female spawning biomass in 2007	115	113	681	94	94	389
SB in 2007 / unfished SB	4.1%	4.6%	27.3%	3.4%	3.8%	16.3%
Parameter Estimates						
Unfished recruitment (R_0)	123.1	110.2	110.3	122.7	109.9	105.6
Catchability for CPFV logbook index	0.000197	0.000208	n/a	0.000205	0.000216	n/a
Catchability for visual survey	3.06	3.19	0.75	2.22	2.30	0.75
Likelihood components						
Total negative log likelihood	17.22	17.91	n/a	15.90	16.54	n/a
CPFV logbook index	12.28	12.67	n/a	12.92	13.34	n/a
Visual survey	0.99	1.05	n/a	0.64	0.68	n/a
Prior on visual survey	3.95	4.19	n/a	2.35	2.51	n/a

Table 2. Revised summary of requested model runs, based on 2007 cowcod assessment with revised 2002 biomass estimate. Refer to Ralston and Dick (2007) for a description of model runs. Values in bold are fixed. Run D3 does not apply to cowcod because the median time to recovery exceeds the Amendment16-4 value for T_{target} even in the absence of fishing.

	Run	C	D1	D2	D3*	D4
	SPR	1	**0.900**	0.790	n/a	**0.5**
	F	**0**	0.0038	0.0088	n/a	0.0295
	Median rebuilding year	2061	2065	2072	n/a	2201
Pr{above target}	by 2035 (old Tmin)	0.159	0.159	0.159	n/a	0.027
	by 2039 (old Ttarget)	0.216	0.216	0.216	n/a	0.062
	by 2060 (new Tmin)	0.467	0.467	0.402	n/a	0.159
	by 2074 (old Tmax)	0.662	0.598	0.533	n/a	0.216
	by 2098 (new Tmax)	0.784	0.724	0.662	n/a	0.338
Median Catch (metric tons)						
	2007	*0.5*	*0.5*	*0.5*	n/a	*0.5*
	2008	*0.5*	*0.5*	*0.5*	n/a	*0.5*
	2009	0	0.9	**2.0**	n/a	6.6
	2010	0	0.9	2.1	n/a	6.9
	2011	0	1.0	2.2	n/a	7.1
	2012	0	1.0	2.3	n/a	7.3
	2013	0	1.1	2.4	n/a	7.5
	2014	0	1.1	2.5	n/a	7.8
	2015	0	1.2	2.7	n/a	8.0
	2016	0	1.2	2.8	n/a	8.3
	2017	0	1.3	2.9	n/a	8.6
	2018	0	1.4	3.1	n/a	8.9

Literature Cited

Dick, E.J., S. Ralston, and D. Pearson. 2007. Status of cowcod, *Sebastes levis*, in the Southern California Bight. Document submitted to the PFMC, August 22, 2007.

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Piner, K., E. J. Dick, and J. Field. 2006. 2005 Stock Status of Cowcod in the Southern California Bight and Future Prospects. In Volume 1: Status of the Pacific Coast Groundfish Fishery Through 2005, Stock Assessment and Fishery Evaluation: Stock Assessments and Rebuilding Analyses. Portland, OR: Pacific Fishery Management Council.

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