

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

Butler, J. L., L. D. Jacobson and J.T. Barnes. 1999. Stock assessment of cowcod rockfish. In: Pacific Fishery Management Council. 1999. Appendix: Status of the Pacific Coast Groundfish Fishery through 1999 and recommended biological catches for 2000: Stock assessment and fishery evaluation. Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, Oregon, 97201.

Dick, E.J. 2007. Addendum to the 2007 Stock Assessment and Rebuilding Analysis for Cowcod, *Sebastes levis*. Document submitted to the PFMC, October 15, 2007.

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.

Hastie, J. 2006a. Revised Estimated 2004 Discard and Total Catch of Selected Groundfish Species. http://www.nwfsc.noaa.gov/research/divisions/fram/observer/datareport/docs/revised_total_fg_catch_estimation2004.pdf.

Hastie, J. 2006b. Estimated 2005 Discard and Total Catch of Selected Groundfish Species. http://www.nwfsc.noaa.gov/research/divisions/fram/observer/datareport/docs/totalmortality2005_final.pdf

Methot, R. D. 2005. Technical description of the Stock Synthesis II assessment program.

PFMC (Pacific Fishery Management Council) and NMFS (National Marine Fisheries Service). 2006. Proposed Acceptable Biological Catch and Optimum Yield Specifications and Management Measures for the 2007-2008 Pacific Coast Groundfish Fishery, and Amendment 16-4: Rebuilding Plans For Seven Depleted Pacific Coast Groundfish Species; Final Environmental Impact Statement Including Regulatory Impact Review and Initial Regulatory Flexibility Analysis. Pacific Fishery Management Council, Portland, OR. October 2006.

Piner, K. 2006. Cowcod Rebuilding Analysis 2005 Analysis of the Progress towards Rebuilding in the Southern California Bight. 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.

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.

PFMC. 2004. Appendix F to amendment 16-3 to the Pacific coast groundfish fishery management plan. Cowcod draft rebuilding plan. Adopted April 2004. Pacific Fishery Management Council.

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.

Rebuilding Parameter	Date of Analysis	
	2004	2006
B₀ [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.

Age	Female		Init N		Fleet 1		Fleet 2	
	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 T _{min})	0.159	0.159	0.159	n/a	0.027
	by 2039 (old T _{target})	0.216	0.216	0.216	n/a	0.062
	by 2060 (new T _{min})	0.467	0.467	0.402	n/a	0.159
	by 2074 (old T _{max})	0.662	0.598	0.533	n/a	0.216
	by 2098 (new T _{max})	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	Run	C	D1	D2	D3	D4
SPR	1	0.900	0.790	n/a	0.5	SPR	1	0.900	0.790	n/a	0.5
F	0	0.0038	0.0088	n/a	0.0295	F	0	0.0038	0.0088	n/a	0.0295
Median Spawning Biomass Relative to Target						Median Spawning Biomass Relative to Target					
2007	0.094	0.094	0.094	n/a	0.094	2053	0.796	0.727	0.644	n/a	0.394
2008	0.100	0.100	0.100	n/a	0.100	2054	0.822	0.749	0.663	n/a	0.403
2009	0.106	0.106	0.106	n/a	0.106	2055	0.848	0.772	0.683	n/a	0.412
2010	0.112	0.112	0.111	n/a	0.109	2056	0.874	0.796	0.702	n/a	0.421
2011	0.119	0.118	0.117	n/a	0.112	2057	0.901	0.819	0.721	n/a	0.430
2012	0.125	0.124	0.122	n/a	0.116	2058	0.928	0.842	0.741	n/a	0.440
2013	0.132	0.131	0.128	n/a	0.119	2059	0.955	0.866	0.761	n/a	0.449
2014	0.140	0.137	0.134	n/a	0.123	2060	0.981	0.889	0.780	n/a	0.458
2015	0.147	0.145	0.141	n/a	0.127	2061	1.008	0.913	0.800	n/a	0.467
2016	0.155	0.152	0.148	n/a	0.131	2062	1.036	0.937	0.820	n/a	0.476
2017	0.164	0.160	0.155	n/a	0.135	2063	1.063	0.960	0.840	n/a	0.486
2018	0.173	0.168	0.162	n/a	0.140	2064	1.090	0.984	0.860	n/a	0.495
2019	0.182	0.177	0.170	n/a	0.144	2065	1.117	1.008	0.879	n/a	0.504
2020	0.192	0.186	0.178	n/a	0.149	2066	1.144	1.031	0.899	n/a	0.513
2021	0.202	0.195	0.186	n/a	0.155	2067	1.172	1.055	0.919	n/a	0.522
2022	0.213	0.205	0.195	n/a	0.160	2068	1.199	1.079	0.939	n/a	0.531
2023	0.224	0.215	0.204	n/a	0.166	2069	1.226	1.102	0.958	n/a	0.540
2024	0.236	0.226	0.214	n/a	0.172	2070	1.252	1.125	0.977	n/a	0.549
2025	0.248	0.237	0.224	n/a	0.178	2071	1.279	1.148	0.997	n/a	0.558
2026	0.260	0.249	0.234	n/a	0.184	2072	1.305	1.171	1.016	n/a	0.567
2027	0.274	0.261	0.245	n/a	0.190	2073	1.332	1.194	1.035	n/a	0.576
2028	0.287	0.273	0.256	n/a	0.196	2074	1.358	1.217	1.054	n/a	0.585
2029	0.301	0.286	0.267	n/a	0.203	2075	1.384	1.239	1.072	n/a	0.594
2030	0.316	0.300	0.279	n/a	0.209	2076	1.409	1.262	1.091	n/a	0.602
2031	0.331	0.313	0.291	n/a	0.216	2077	1.435	1.284	1.109	n/a	0.611
2032	0.347	0.328	0.304	n/a	0.223	2078	1.460	1.305	1.127	n/a	0.619
2033	0.364	0.342	0.316	n/a	0.230	2079	1.484	1.327	1.145	n/a	0.627
2034	0.380	0.358	0.330	n/a	0.237	2080	1.509	1.348	1.163	n/a	0.636
2035	0.398	0.373	0.343	n/a	0.244	2081	1.533	1.369	1.180	n/a	0.644
2036	0.416	0.390	0.357	n/a	0.252	2082	1.557	1.390	1.197	n/a	0.652
2037	0.434	0.406	0.372	n/a	0.259	2083	1.580	1.410	1.214	n/a	0.660
2038	0.454	0.423	0.386	n/a	0.267	2084	1.603	1.430	1.231	n/a	0.668
2039	0.473	0.441	0.401	n/a	0.275	2085	1.626	1.450	1.247	n/a	0.675
2040	0.493	0.459	0.417	n/a	0.282	2086	1.648	1.469	1.263	n/a	0.683
2041	0.514	0.477	0.433	n/a	0.290	2087	1.670	1.488	1.279	n/a	0.691
2042	0.535	0.496	0.449	n/a	0.299	2088	1.692	1.507	1.295	n/a	0.698
2043	0.557	0.515	0.465	n/a	0.307	2089	1.714	1.525	1.310	n/a	0.705
2044	0.579	0.535	0.482	n/a	0.315	2090	1.735	1.543	1.325	n/a	0.712
2045	0.601	0.555	0.499	n/a	0.324	2091	1.755	1.561	1.340	n/a	0.720
2046	0.624	0.575	0.516	n/a	0.332	2092	1.775	1.579	1.354	n/a	0.726
2047	0.648	0.596	0.534	n/a	0.341	2093	1.795	1.596	1.368	n/a	0.733
2048	0.672	0.617	0.551	n/a	0.349	2094	1.814	1.612	1.382	n/a	0.740
2049	0.696	0.638	0.570	n/a	0.358	2095	1.833	1.629	1.396	n/a	0.747
2050	0.720	0.660	0.588	n/a	0.367	2096	1.852	1.645	1.409	n/a	0.753
2051	0.745	0.682	0.606	n/a	0.376	2097	1.870	1.661	1.422	n/a	0.759
2052	0.770	0.704	0.625	n/a	0.385	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
	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
Pr{above target}	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**
<hr/>						
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						Median Rebuilding					
Year	2061	2070	2080	2089	2098	Year	2061	2070	2080	2089	2098
SPR	0.990	0.806	0.697	0.638	0.599	SPR	0.990	0.806	0.697	0.638	0.599
F	0.0003	0.0080	0.0140	0.0178	0.0207	F	0.0003	0.0080	0.0140	0.0178	0.0207

Year	Median Spawning Biomass Relative to Target					Year	Median Spawning Biomass Relative to Target				
2007	0.094	0.094	0.094	0.094	0.094	2053	0.790	0.657	0.570	0.519	0.485
2008	0.100	0.100	0.100	0.100	0.100	2054	0.816	0.677	0.585	0.533	0.498
2009	0.106	0.106	0.106	0.106	0.106	2055	0.842	0.696	0.602	0.547	0.510
2010	0.112	0.111	0.111	0.110	0.110	2056	0.868	0.716	0.618	0.562	0.523
2011	0.119	0.117	0.116	0.115	0.114	2057	0.894	0.736	0.634	0.576	0.536
2012	0.125	0.123	0.121	0.119	0.119	2058	0.920	0.757	0.650	0.590	0.549
2013	0.132	0.129	0.126	0.124	0.123	2059	0.947	0.777	0.667	0.604	0.562
2014	0.139	0.135	0.131	0.129	0.128	2060	0.973	0.797	0.683	0.618	0.574
2015	0.147	0.141	0.137	0.134	0.132	2061	1.000	0.818	0.700	0.633	0.587
2016	0.155	0.148	0.143	0.140	0.138	2062	1.027	0.838	0.716	0.647	0.600
2017	0.163	0.155	0.149	0.146	0.143	2063	1.054	0.858	0.732	0.661	0.613
2018	0.172	0.163	0.156	0.152	0.149	2064	1.081	0.879	0.749	0.676	0.626
2019	0.182	0.171	0.163	0.158	0.155	2065	1.108	0.899	0.765	0.690	0.639
2020	0.191	0.179	0.170	0.165	0.161	2066	1.134	0.919	0.782	0.704	0.651
2021	0.201	0.188	0.178	0.172	0.167	2067	1.161	0.940	0.798	0.718	0.664
2022	0.212	0.197	0.186	0.179	0.174	2068	1.188	0.960	0.814	0.732	0.677
2023	0.223	0.206	0.194	0.186	0.181	2069	1.214	0.980	0.830	0.746	0.690
2024	0.235	0.216	0.202	0.194	0.188	2070	1.241	1.000	0.847	0.760	0.702
2025	0.247	0.226	0.211	0.202	0.196	2071	1.267	1.020	0.863	0.774	0.715
2026	0.259	0.237	0.220	0.211	0.204	2072	1.293	1.040	0.878	0.788	0.727
2027	0.272	0.247	0.230	0.219	0.211	2073	1.319	1.059	0.894	0.802	0.739
2028	0.286	0.259	0.239	0.228	0.219	2074	1.345	1.079	0.910	0.815	0.751
2029	0.300	0.270	0.249	0.237	0.228	2075	1.370	1.098	0.925	0.829	0.763
2030	0.315	0.282	0.260	0.246	0.236	2076	1.396	1.117	0.941	0.842	0.775
2031	0.330	0.295	0.270	0.255	0.245	2077	1.421	1.136	0.956	0.855	0.787
2032	0.345	0.307	0.281	0.265	0.254	2078	1.445	1.154	0.971	0.868	0.799
2033	0.362	0.321	0.292	0.275	0.263	2079	1.470	1.173	0.985	0.881	0.811
2034	0.378	0.334	0.303	0.285	0.272	2080	1.494	1.191	1.000	0.894	0.822
2035	0.396	0.348	0.315	0.296	0.282	2081	1.518	1.209	1.014	0.906	0.833
2036	0.414	0.362	0.327	0.306	0.292	2082	1.541	1.227	1.029	0.919	0.844
2037	0.432	0.377	0.339	0.317	0.302	2083	1.564	1.244	1.043	0.931	0.855
2038	0.451	0.392	0.352	0.328	0.312	2084	1.587	1.261	1.057	0.943	0.866
2039	0.470	0.408	0.365	0.340	0.322	2085	1.610	1.278	1.070	0.955	0.877
2040	0.490	0.423	0.378	0.351	0.333	2086	1.632	1.295	1.084	0.966	0.887
2041	0.511	0.439	0.391	0.363	0.344	2087	1.654	1.311	1.097	0.978	0.898
2042	0.532	0.456	0.405	0.375	0.355	2088	1.675	1.327	1.110	0.989	0.908
2043	0.553	0.473	0.419	0.388	0.366	2089	1.696	1.343	1.122	1.000	0.918
2044	0.575	0.490	0.433	0.400	0.377	2090	1.717	1.358	1.135	1.011	0.928
2045	0.597	0.507	0.447	0.413	0.389	2091	1.737	1.373	1.147	1.022	0.937
2046	0.620	0.525	0.462	0.425	0.400	2092	1.757	1.388	1.159	1.032	0.947
2047	0.643	0.543	0.477	0.438	0.412	2093	1.776	1.403	1.171	1.042	0.956
2048	0.667	0.562	0.492	0.452	0.424	2094	1.795	1.417	1.182	1.052	0.965
2049	0.691	0.580	0.507	0.465	0.436	2095	1.814	1.431	1.194	1.062	0.974
2050	0.715	0.599	0.522	0.478	0.448	2096	1.832	1.445	1.205	1.072	0.983
2051	0.740	0.618	0.538	0.492	0.460	2097	1.850	1.458	1.216	1.081	0.992
2052	0.765	0.637	0.554	0.506	0.473	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.

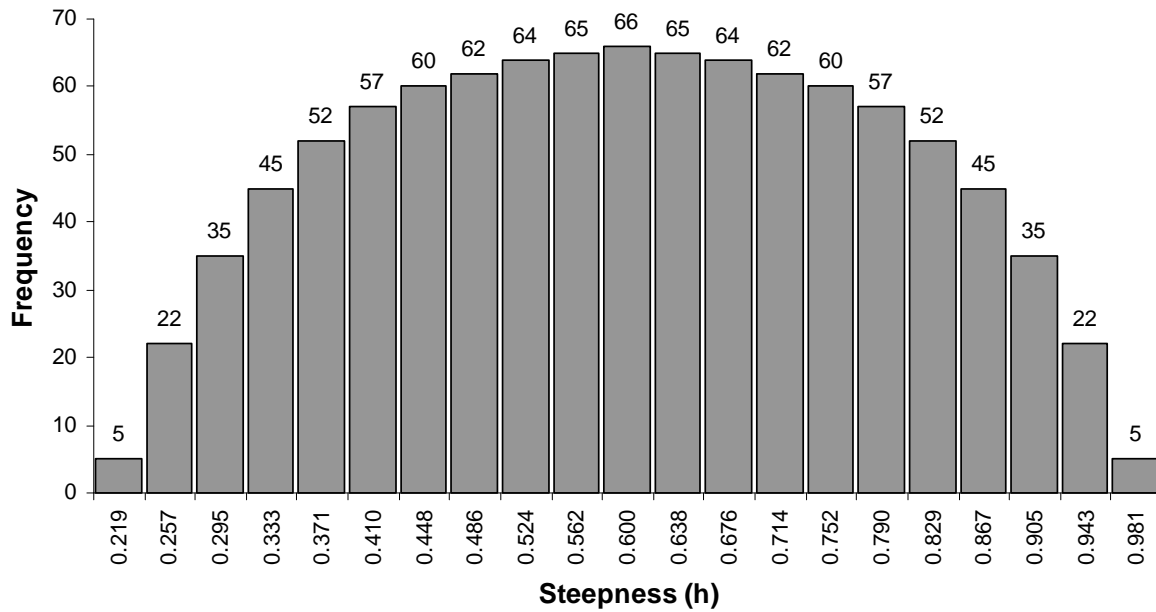


Fig. 2. Projected probability of being above target biomass for runs C and D1-D4. The discrete distribution for steepness causes a step-like characteristic.

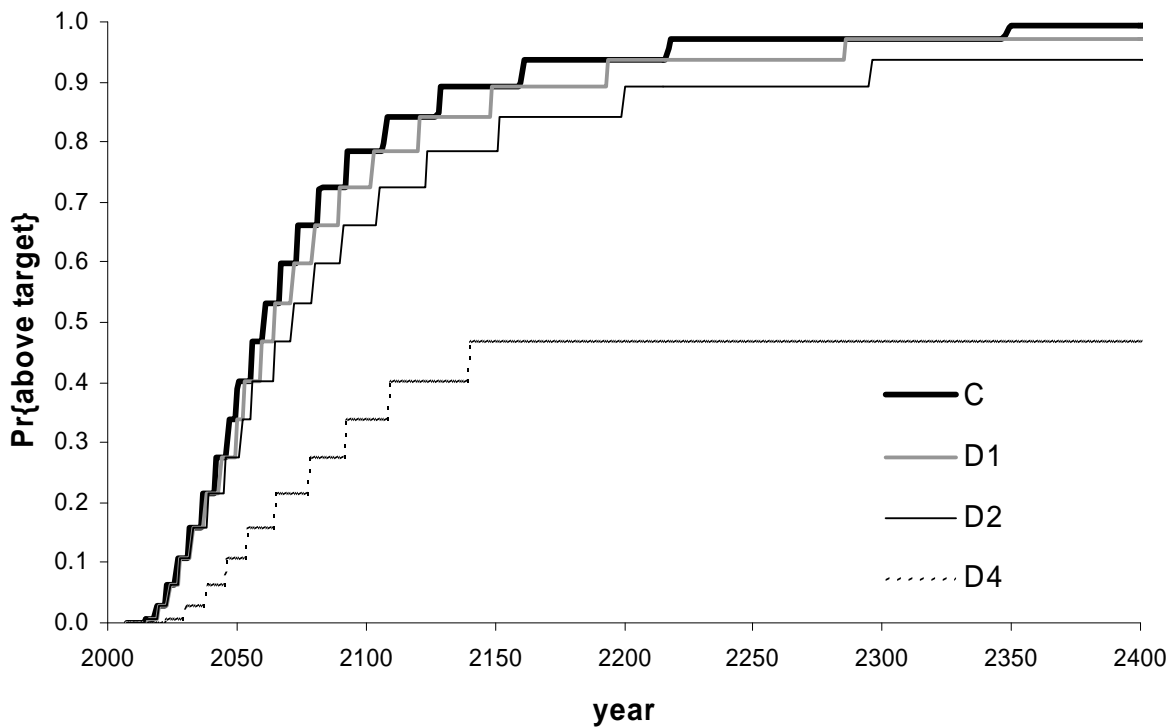


Fig. 3. Assumed frequency distribution of unfished female spawning biomass.

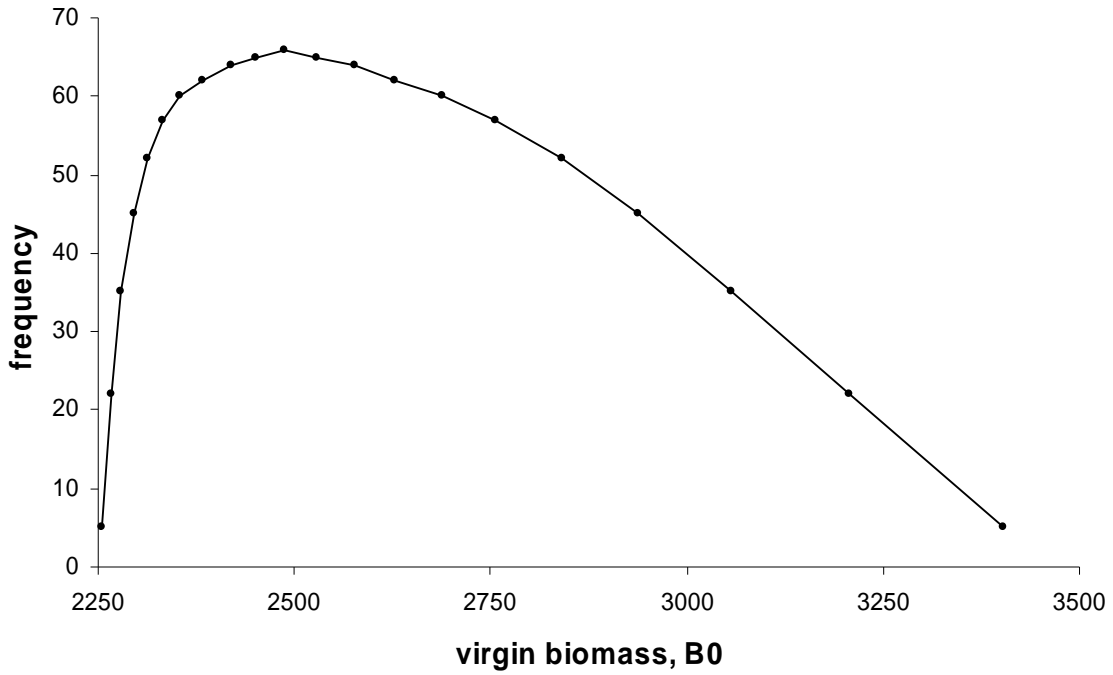


Fig. 4. Projections of median spawning biomass relative to target biomass for runs C and D1-D4.

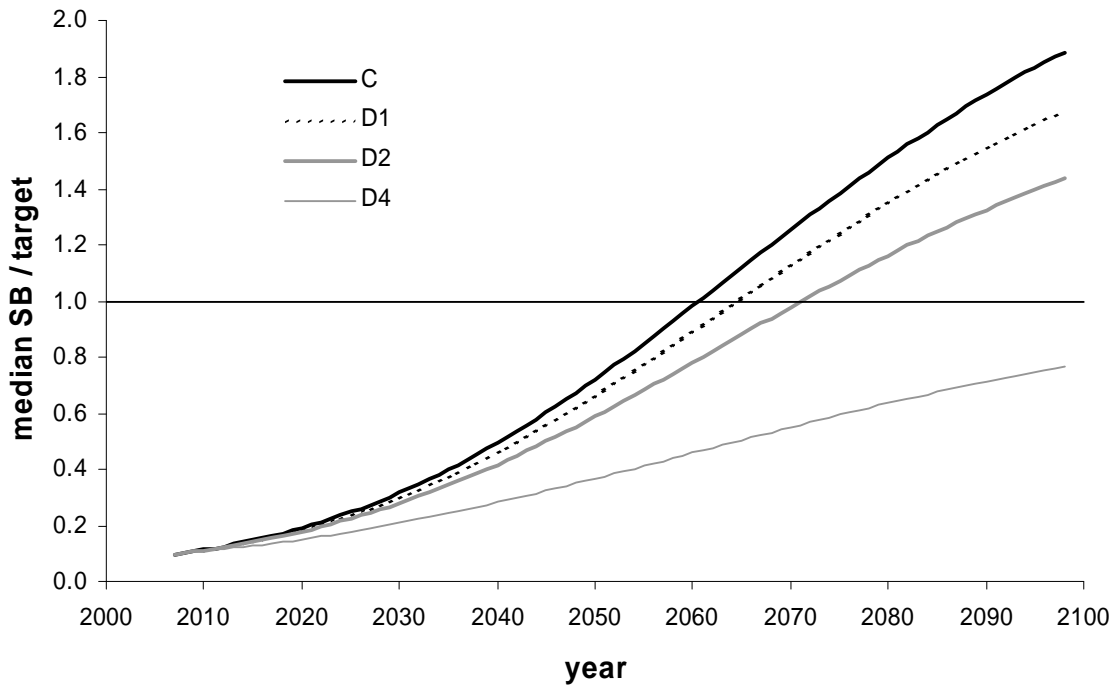


Fig. 5. Projected median catch trajectories for runs D1-D4.

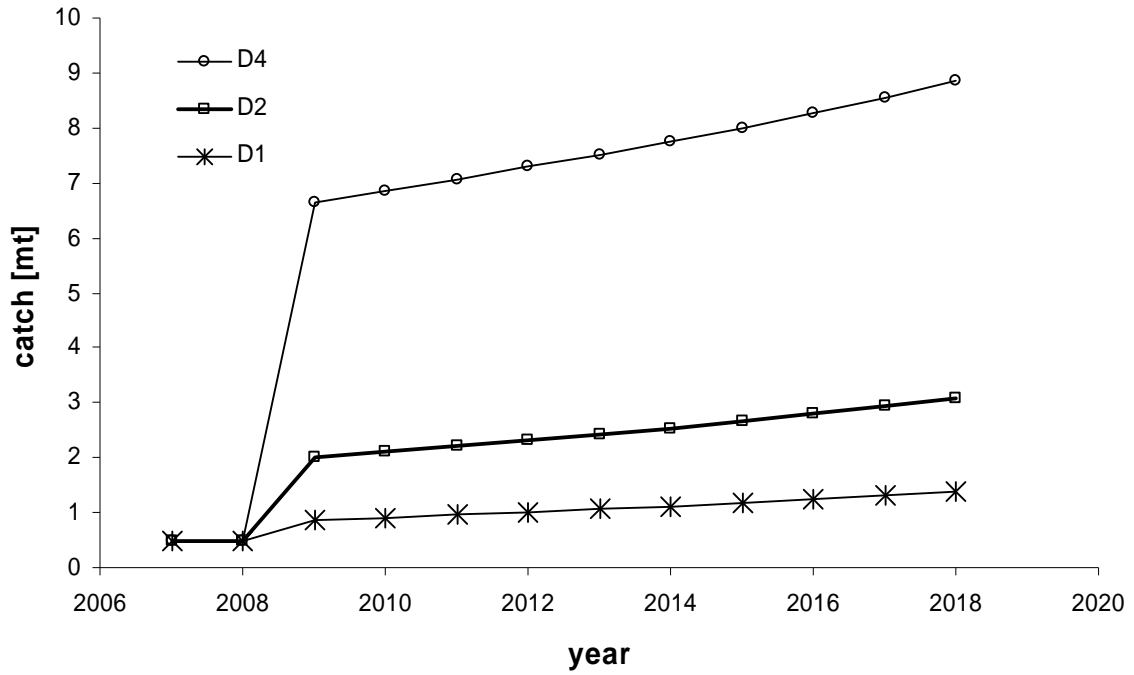


Fig. 6. Projected probability of being above target biomass for projections with median rebuilding times evenly distributed between $T_{F=0}$ and T_{MAX} .

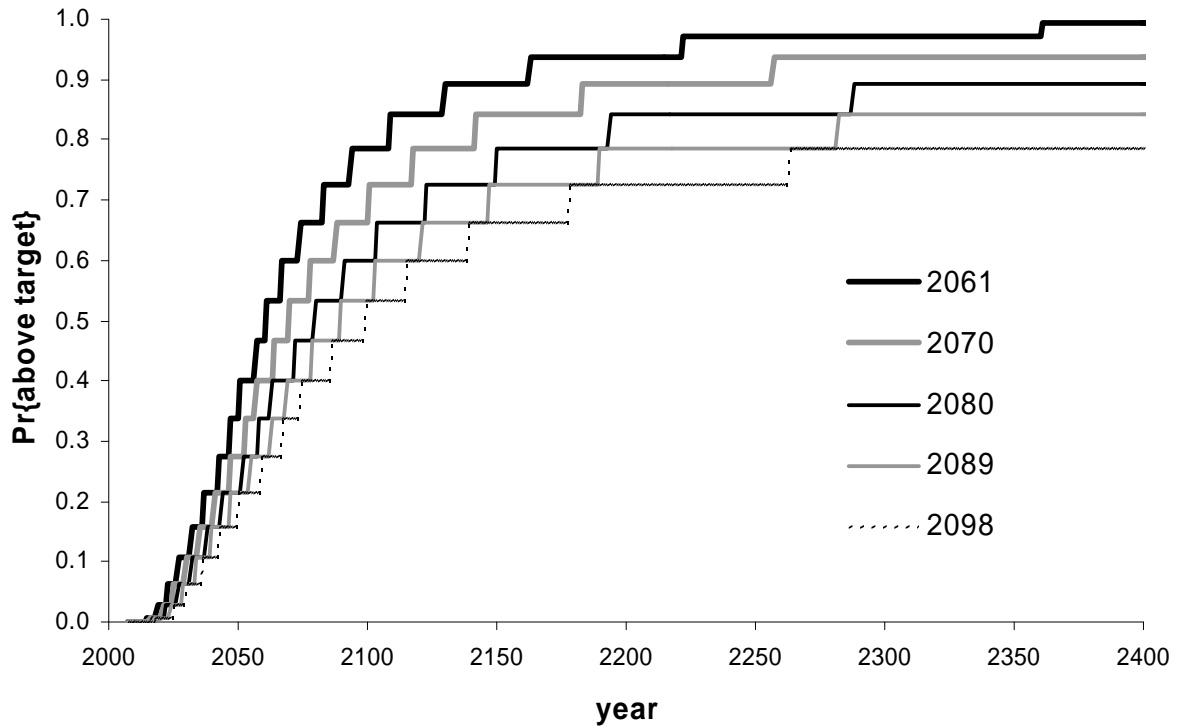


Fig. 7. Projections of median spawning biomass relative to target biomass for runs with median rebuilding times evenly distributed between $T_{F=0}$ and T_{MAX} .

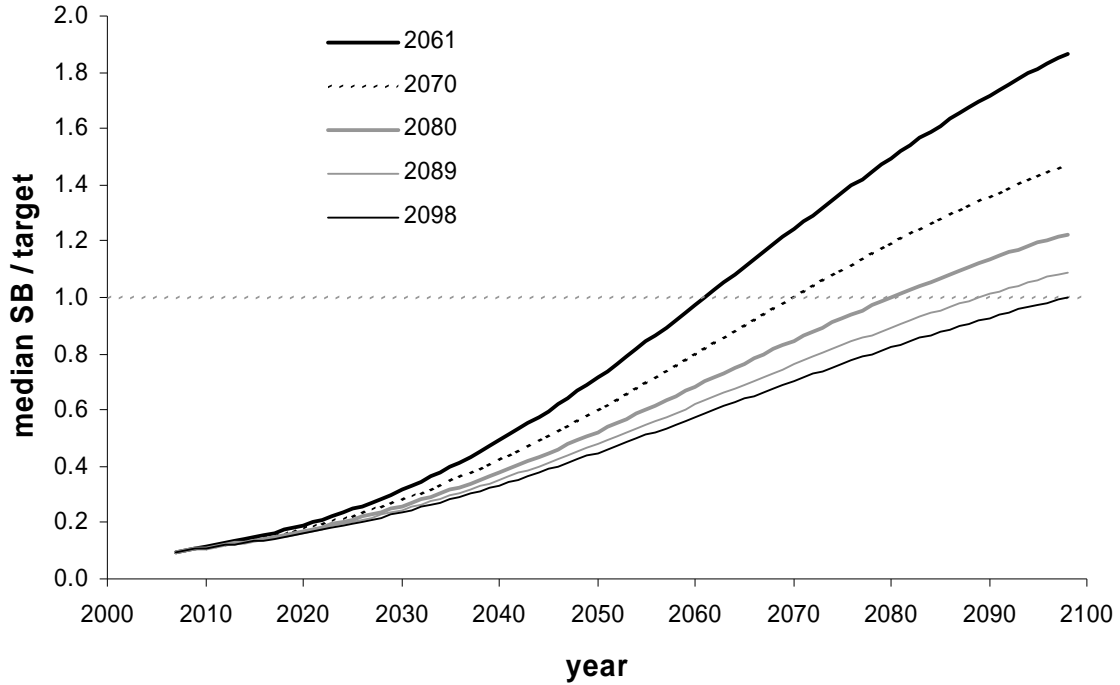
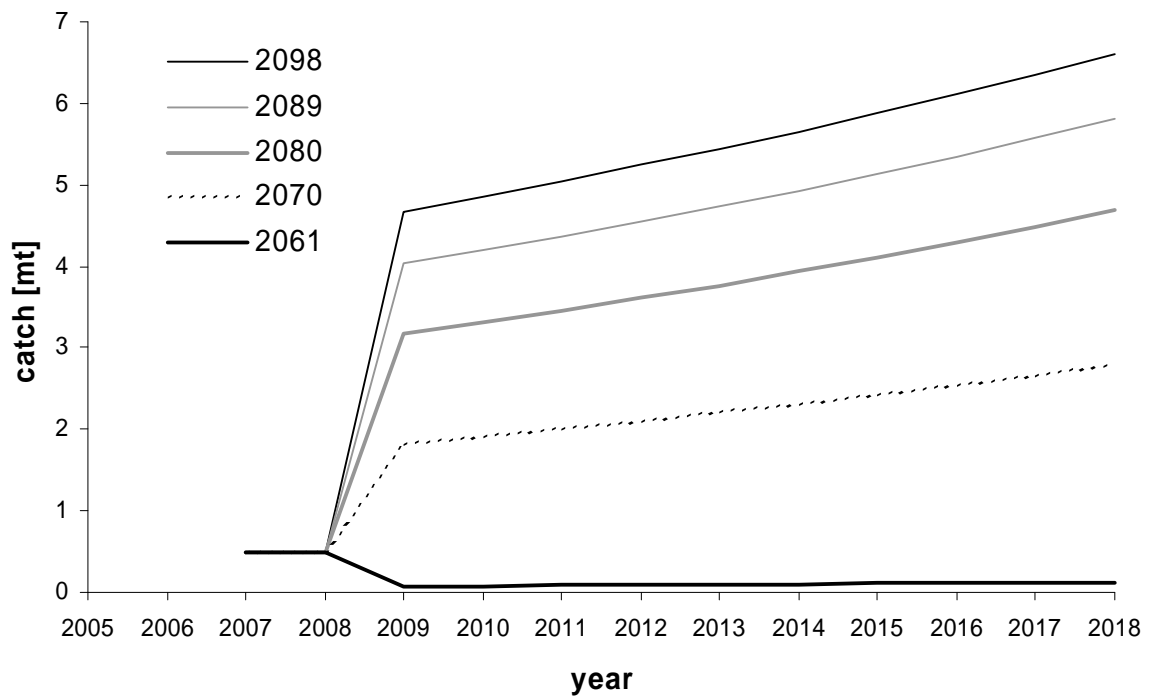


Fig. 8. Projected median catch trajectories for projections with median rebuilding times evenly distributed between $T_{F=0}$ and T_{MAX} . Since the new estimate of $T_{F=0}$ (2061) was rounded up from a fractional year, catches based on a target median rebuilding time for this (rounded) year are reported 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.ct1 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
#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 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
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

```



```
-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
```