Updated Draft (9/30/2021) - Rebuilding analysis for copper rockfish (*Sebastes caurinus*) in U.S. waters off the coast of California south of Point Conception based on the 2021 stock assessment

by
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Summary

This rebuilding analysis is for the stock of copper rockfish (*Sebastes caurinus*) in waters off California, south of Point Conception. The analysis is based on the 2021 stock assessment. The 2021 assessment model estimated the copper rockfish south of Point Conception to be at 18.1 percent of the unexploited equilibrium spawning output at the beginning of 2021. This rebuilding analysis compares the results of applying a suite of potential management actions to the stock for 2023 and beyond.

1 Introduction

The 2021 assessment of copper rockfish south of Point Conception documented that the stock had declined below the Minimum Stock Size Threshold (MSST), 25 percent of unfished spawning output for rockfish stocks, for the first time during the mid-1980s, remained below the MSST until 2011, increased above the MSST briefly between 2011-2016, but had fallen back below the MSST starting in 2017 (Wetzel et al. 2021). Based on the assumed stock productivity combined with the longevity of copper rockfish a range of alternative rebuilding approaches were examined where the stock rebuilt to or above the management target of 40% ranging between 2033 - 2033 based on various SPR harvest rates from 0.55 - 1.

2 Overview of the 2021 stock assessment

The 2021 assessment of copper rockfish assessed the stock as four separate sub-stocks along the U.S. west coast: south of Point Conception in California, north of Point Conception in California, Oregon, and Washington. This was the first assessment of copper rockfish conducted within Stock Synthesis that used catch and length composition data to inform model estimates around stock size and status. The previous assessment of copper rockfish conducted in 2013 was modeled using Extended Depletion-Based Stock Reduction Analysis (XDB-SRA), a delay-difference model, using catch, catch-per-unit-effort data, and prior distributions around biological parameters (Cope et al. 2013). The 2013 assessment estimated the stock at 76 percent of unfished spawning output based on fits to catch-per-unit-effort and updated parameter distribution around biology (i.e., the posterior distributions). During model bridging between the 2013 to the 2021 assessment model, the large downward shift in estimated stock status in the new assessment was identified to be driven by the inclusion of the length data which implied a low relative stock size in recent years (Wetzel et al. 2021).

The stock assessment for the sub-stock south of Point Conception in California assumed two fishing fleets, a commercial and a recreational fleet, along with one survey fleet, the Northwest Fisheries Science Center Hook and Line Survey (NWFSC HKL Survey). The majority of the removals and length composition data within the model arose from the recreational fleet. Total removals of copper rockfish south of Point Conception peaked in the late 1970s and early 1980s, decreased from the late 1980s to mid-2000s but had high annual variability, and then increased in recent years (2013 - 2019). The stock was modeled using Stock Synthesis as a two-sex age-structured model. Area specific length-at-age and fecundity-at-length for copper rockfish south of Point Conception were estimated externally and then fixed within the model. Weight-at-length was estimated externally based upon observations by the NWFSC HKL and West Coast Groundfish Bottom Trawl Survey observations with the values fixed within the assessment model. Natural mortality and steepness were both fixed at the median or mean of the respective priors. The selectivity of both the commercial and recreational fishery were estimated to be domed-shape with the NWFSC HKL Survey selectivity fixed to be asymptotic. The assessment model decision table explore uncertainty around stock size and status using lower and higher $\log(R_0)$ values relative to the base model.

3 Management performance under rebuilding

This is the first rebuilding plan for copper rockfish off the coast of California south of Point Conception.

4 Rebuilding calculations

This rebuilding analysis was conducted using software developed by A. Punt (version 3.12h, August 2021). The steps followed were:

- Define how equilibrium spawning output (SB_0) will be calculated.
- Define how future recruitment will be generated.
- Define the fishery selectivity and allocation to be applied during rebuilding.
- Decide how to include uncertainty in input parameters from the stock assessment in the rebuilding analysis.
- Calculate rebuilding reference points from the most current assessment results
  - Calculate the projected year in which the stock would rebuild with a 50 percent probability if all future fishing mortality was eliminated (T_F=0).
  - Calculate the projected year for a 50 percent probability of rebuilding from the year in which the stock was first declared overfished (T_{MIN}).
  - Calculate the mean generation time.
  - Calculate the maximum allowable rebuilding time (T_{MAX}).
- Identification and analysis of alternative harvest strategies for rebuilding.

4.1 Definition of Equilibrium Spawning Output

The equilibrium spawning output (SB_0) used in this rebuilding analysis is calculated via the stock-recruitment relationship in order to be consistent with assessment model results. This level was estimated to be 233.04 millions of eggs in the base case assessment model, which dictates a rebuilding relative spawning output target ($SB_{40\%}$) of 93.22 millions of eggs (Table 1).

4.2 Generation of future recruitment

The estimated parameters of the stock recruitment relationship (unexploited equilibrium recruitment, $\log(R_0)$, and steepness, h) were used to generate future recruitments in the rebuilding analysis. The 2021 assessment model did not estimate annual recruitment deviations but uncertainty around future recruitments was generated by assuming a recruitment variability of $\sigma_R = 0.60$.

4.3 Population biology, fishery selectivity, and removal allocations

The biological parameters used for the rebuilding projections were based on the values from the Stock Synthesis assessment model. Biological parameters in the assessment were sex-specific and constant across time.

The selectivity used in the rebuilding analysis were obtained from 2021 assessment. Selectivity in the assessment model was constant across time for each fishing fleet. The relative allocation of catch among fleets in this rebuilding analysis was informed using the relative fishing mortality averaged over recent years (2015-2019).

4.4 Inclusion of uncertainty

Uncertainty was included in this rebuilding analysis via 1,200 random simulations of stochastic future recruitment strengths and integration over the three states of nature across stock size, $\log(R_0)$. The base model was given 50 percent of the weight and each alternative state of nature was given 25 percent of the weight.

4.5 Alternate rebuilding strategies analyzed

Assuming that a constant rate of harvest will be applied throughout a rebuilding period, the basis for rebuilding alternatives can be divided into two approaches: 1) strategies based on selection of a constant harvest rate (SPR rate), or 2) strategies based selection of a T_{TARGET} (year for 50 percent probability of recovery). This rebuilding analysis presents the following alternate strategies spread among the approaches based on the selection of a SPR harvest rate or rebuilding by a selected target year:

- Apply a range of SPR values: 0.55, 0.60, 0.65, 0.70, and 0.75
- Eliminate all harvest, F = 0, beginning in the next management cycle, 2023, the same as setting a constant SPR harvest rate of 1.0.
- Apply the Annual Catch Limits (ACL) based on the 40:10 harvest control rule.
- Apply the Acceptable Biological Catch (ABC) with time-varying σ.
- Apply SPR harvest rates that are estimated to lead to a 50 percent probability of recovery by alternative target years: T_{MID}, T_{MAX}, and other years between T_{MIN} and T_{MAX}

All of the above rebuilding strategies were conducted assuming removals of 90.8 mt and 88.9 mt in 2021 and 2022.

The rebuilding strategies were run without capping catches by the ABC in future projection years. In application rebuilding progress would be monitored through updated rebuilding analysis on a regular basis during rebuild that would evaluate the progress of the selected rebuilding strategy and associated SPR harvest rate limiting the probability of the rebuilding harvest exceeding the ABC in reality. An additional analysis was conducted that did limit the future catches by the ABC and is provided in Section **??** for comparison.

5 Results

5.1 Rebuilding reference points

All reference points calculated based on this rebuilding analysis are given in Table 1. The minimum time required for rebuilding, T_{MIN}, with no fishing (F=0) starting in 2023 was estimated to be 10 years, corresponding to the stock being rebuilt by 2033, assuming the default removals for 2021 and 2022. The mean generation time was estimated to be 17 years. The maximum time allowed for rebuilding, T_{MAX} is defined as the T_{MIN} plus the mean generation time for stocks that are unable to rebuild in less than 10 years. The minimum rebuilding time for copper rockfish was 10 years, just falling at the cut-off of 10 years, so T_{MAX} was set to 2033.

5.2 Alternative harvest projections

6 Acknowledgments

Thank you to Andre Punt for quickly updating the rebuilder program to apply time-varying σ for the Acceptable Biological Catch scenarios and thank you for his assistance and guidance on application of the rebuilding program. This document was greatly improved based on feedback and review of Owen Hamel.

7 References

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Wetzel, C. R., Brian J. Langseth, Jason M Cope, and John Budrick. 2021. "The Status of Copper Rockfish (*Sebastes Caurinus*) in U.S. Waters Off the Coast of California South of Point Conception in 2021 Using Catch and Length Data." Pacific Fishery Management Council, Portland, Oregon.

8 Tables

8.1 Rebuilding reference points and summary of alternatives

Table 1: Summary of the rebuilding reference points.

Parameter	2021 Assessment Values
SB0 (millions of eggs)	233.04
SB40% (millions of eggs)	93.22
SB2021 (millions of eggs)	42.28
Year rebuilding begins	2023
Current year	2021
Tmin	2033
Mean generation time (years)	17
Tmax	2033
Ttarget	TBD
SPRtarget	TBD

Table 2: Results of rebuilding alternatives based on selection of an SPR target or year for 50 percent probability of recovery based on the assumed removals for 2021-22. The SPR value for the ABC Rule is lower than 0.50 since this value represents the average SPR value applied across the projection period based on the time-varying buffer.

	SPR= .500	SPR= .600	SPR= .700	SPR= .800	SPR= .900	Yr=Tmid	F=0	40-10 rule	ABC Rule
2021 Assumed Removals (mt)	90.8	90.8	90.8	90.8	90.8	90.8	90.8	90.8	90.8
2022 Assumed Removals (mt)	88.9	88.9	88.9	88.9	88.9	88.9	88.9	88.9	88.9
2023 ACL (mt)	21.68	15.9	11.06	6.9	3.25	2.07	0	8.57	21.68
2024 ACL (mt)	24.06	17.97	12.69	8.02	3.81	2.44	0	11.16	24.06
SPR	0.5	0.6	0.7	0.8	0.9	0.935	1	0.788	0.5
Ttarget	2052	2042	2038	2035	2034	2033	2033	2041	2052
Tmax	2033	2033	2033	2033	2033	2033	2033	2033	2033
Probability of recovery by Tmax	0.012	0.057	0.153	0.31	0.46	0.5	0.58	0.07	0.012

Table 3: Results of rebuilding alternatives based on alternative SPR harvest rates.

	SPR= .900	SPR= .920	SPR= .940	SPR= .950	SPR= .960	Yr=Tmid F=0		40-10 rule	ABC Rule
2021 Assumed Removals (mt)	90.8	90.8	90.8	90.8	90.8	90.8	90.8	90.8	90.8
2022 Assumed Removals (mt)	88.9	88.9	88.9	88.9	88.9	88.9	88.9	88.9	88.9
2023 ACL (mt)	3.25	2.57	1.91	1.58	1.26	2.07	0	8.57	21.68
2024 ACL (mt)	3.82	3.03	2.25	1.86	1.49	2.44	0	11.16	24.06
SPR	0.9	0.92	0.94	0.95	0.96	0.935	1	0.788	0.5
Ttarget	2034	2034	2033	2033	2033	2033	2033	2041	2052
Tmax	2033	2033	2033	2033	2033	2033	2033	2033	2033
Probability of recovery by Tmax	0.464	0.486	0.509	0.52	0.538	0.5	0.578	0.072	0.012

8.2 Rebuilding alternative time series

Table 4: Probability of recovery by year for rebuilding SPR alternatives assuming removals of 90.8 and 88.9 mt in 2021 and 2022, respectively.

Year	SPR= .500	SPR= .600	SPR= .700	SPR= .800	SPR= .900	Yr=Tmid F=0		40-10 rule	ABC Rule
2021	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2022	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2023	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2024	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2025	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2026	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2027	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2028	0.000	0.000	0.001	0.001	0.006	0.006	0.009	0.000	0.000
2029	0.001	0.001	0.006	0.013	0.024	0.031	0.048	0.001	0.001
2030	0.001	0.004	0.016	0.041	0.092	0.122	0.169	0.004	0.001
2031	0.002	0.013	0.043	0.111	0.201	0.242	0.313	0.018	0.002
2032	0.005	0.031	0.092	0.198	0.332	0.368	0.448	0.034	0.005
2033	0.012	0.058	0.152	0.310	0.460	0.500	0.580	0.070	0.012
2034	0.020	0.086	0.232	0.417	0.569	0.625	0.729	0.108	0.020
2035	0.033	0.128	0.315	0.522	0.698	0.757	0.825	0.154	0.033
2036	0.043	0.182	0.398	0.632	0.804	0.848	0.900	0.230	0.043
2037	0.056	0.242	0.492	0.723	0.877	0.912	0.948	0.282	0.056
2038	0.073	0.299	0.571	0.812	0.930	0.949	0.977	0.342	0.073
2039	0.108	0.351	0.665	0.873	0.960	0.978	0.989	0.404	0.108
2040	0.138	0.404	0.738	0.918	0.980	0.988	0.993	0.479	0.138
2041	0.163	0.467	0.792	0.951	0.988	0.992	0.998	0.554	0.163
2042	0.196	0.534	0.847	0.968	0.992	0.998	0.999	0.615	0.196
2043	0.227	0.606	0.881	0.978	0.999	0.999	0.999	0.674	0.227
2044	0.258	0.665	0.908	0.986	0.999	0.999	1.000	0.728	0.258
2045	0.282	0.703	0.931	0.993	0.999	0.999	1.000	0.760	0.282
2046	0.328	0.748	0.948	0.997	0.999	1.000	1.000	0.793	0.328
2047	0.358	0.776	0.962	0.998	1.000	1.000	1.000	0.815	0.358
2048	0.387	0.816	0.975	0.998	1.000	1.000	1.000	0.851	0.387
2049	0.422	0.848	0.982	1.000	1.000	1.000	1.000	0.886	0.422
2050	0.455	0.876	0.984	1.000	1.000	1.000	1.000	0.898	0.455
2051	0.490	0.899	0.987	1.000	1.000	1.000	1.000	0.918	0.490
2052	0.517	0.912	0.992	1.000	1.000	1.000	1.000	0.922	0.517
2053	0.556	0.928	0.993	1.000	1.000	1.000	1.000	0.937	0.556
2054	0.583	0.937	0.995	1.000	1.000	1.000	1.000	0.946	0.583
2055	0.609	0.943	0.996	1.000	1.000	1.000	1.000	0.952	0.609

Table 5: Median catches (mt) by year for rebuilding SPR alternatives assuming removals of 90.8 and 88.9 mt in 2021 and 2022, respectively.

Year	SPR= .500	SPR= .600	SPR= .700	SPR= .800	SPR= .900	Yr=Tmid	F=0	40-10 rule	ABC Rule
2021	90.80	90.80	90.80	90.80	90.80	90.80	90.8	90.80	90.80
2022	88.90	88.90	88.90	88.90	88.90	88.90	88.9	88.90	88.90
2023	21.68	15.90	11.06	6.90	3.25	2.07	0.0	8.57	21.68
2024	24.06	17.97	12.69	8.02	3.81	2.44	0.0	11.16	24.06
2025	26.13	19.82	14.17	9.04	4.35	2.79	0.0	14.05	26.13
2026	27.82	21.40	15.47	9.96	4.82	3.10	0.0	16.78	27.82
2027	28.82	22.37	16.33	10.62	5.19	3.35	0.0	19.33	28.82
2028	29.83	23.35	17.15	11.21	5.51	3.56	0.0	21.46	29.83
2029	30.66	24.20	17.88	11.78	5.81	3.76	0.0	23.02	30.66
2030	31.62	25.26	18.80	12.43	6.16	3.99	0.0	24.81	31.62
2031	32.63	26.11	19.56	13.00	6.47	4.20	0.0	26.37	32.63
2032	33.54	27.10	20.39	13.59	6.78	4.41	0.0	27.51	33.54
2033	34.65	28.09	21.24	14.25	7.14	4.64	0.0	28.97	34.65
2034	35.19	28.73	21.86	14.69	7.38	4.81	0.0	29.88	35.19
2035	36.02	29.55	22.57	15.20	7.66	4.99	0.0	30.89	36.02
2036	36.93	30.31	23.17	15.63	7.88	5.15	0.0	31.82	36.93
2037	37.70	31.15	23.90	16.17	8.18	5.34	0.0	32.97	37.70
2038	38.48	31.82	24.45	16.61	8.42	5.50	0.0	34.18	38.48
2039	39.23	32.62	25.14	17.08	8.67	5.67	0.0	35.83	39.23
2040	39.99	33.33	25.75	17.53	8.89	5.81	0.0	38.35	39.99
2041	40.70	33.95	26.28	17.92	9.12	5.96	0.0	41.11	40.70
2042	41.27	34.59	26.78	18.30	9.32	6.10	0.0	43.41	41.27
2043	41.94	35.19	27.31	18.69	9.53	6.24	0.0	44.71	41.94
2044	42.30	35.53	27.64	18.94	9.68	6.33	0.0	45.94	42.30
2045	42.41	35.70	27.81	19.11	9.78	6.41	0.0	45.82	42.41
2046	42.40	35.85	27.98	19.25	9.85	6.46	0.0	46.05	42.40
2047	43.34	36.58	28.40	19.48	9.95	6.53	0.0	46.23	43.34
2048	43.90	37.06	28.96	19.91	10.19	6.68	0.0	46.56	43.90
2049	44.30	37.41	29.23	20.06	10.28	6.74	0.0	47.01	44.30
2050	44.46	37.60	29.39	20.21	10.35	6.79	0.0	47.36	44.46
2051	44.71	37.86	29.55	20.33	10.43	6.84	0.0	47.46	44.71
2052	44.70	37.83	29.58	20.38	10.46	6.86	0.0	47.00	44.70
2053	44.77	38.00	29.74	20.47	10.52	6.90	0.0	47.02	44.77
2054	44.81	38.00	29.81	20.55	10.57	6.94	0.0	47.25	44.81
2055	45.49	38.56	30.22	20.83	10.70	7.02	0.0	47.53	45.49

Table 6: Median ABCs (mt) by year for rebuilding SPR alternatives assuming removals of 90.8 and 88.9 mt in 2021 and 2022, respectively.

Year	SPR= .500	SPR= .600	SPR= .700	SPR= .800	SPR= .900	Yr=Tmid	F=0	40-10 rule	ABC Rule
2021	23.47	23.47	23.47	23.47	23.47	23.47	23.47	23.47	23.47
2022	21.33	21.33	21.33	21.33	21.33	21.33	21.33	21.33	21.33
2023	18.94	18.94	18.94	18.94	18.94	18.94	18.94	18.94	18.94
2024	20.82	21.19	21.51	21.78	22.01	22.09	22.23	21.67	20.82
2025	22.40	23.15	23.80	24.35	24.85	25.01	25.30	24.07	22.40
2026	23.63	24.76	25.73	26.57	27.33	27.56	27.99	25.98	23.63
2027	24.25	25.66	26.91	28.06	29.07	29.43	30.03	27.06	24.25
2028	24.86	26.51	28.00	29.34	30.61	31.02	31.83	27.96	24.86
2029	25.31	27.24	29.01	30.56	31.98	32.49	33.34	28.82	25.31
2030	25.86	28.15	30.15	31.97	33.67	34.24	35.24	29.47	25.86
2031	26.44	28.91	31.17	33.17	35.08	35.73	36.85	30.35	26.44
2032	26.92	29.65	32.07	34.31	36.43	37.13	38.38	31.23	26.92
2033	27.55	30.43	33.11	35.64	37.98	38.73	40.07	31.81	27.55
2034	27.72	30.84	33.72	36.40	38.92	39.72	41.28	32.13	27.72
2035	28.11	31.43	34.50	37.34	40.02	40.88	42.43	32.64	28.11
2036	28.72	32.16	35.29	38.29	41.06	41.99	43.67	33.27	28.72
2037	29.33	33.09	36.53	39.64	42.63	43.58	45.44	33.94	29.33
2038	29.93	33.77	37.32	40.68	43.85	44.95	46.88	34.58	29.93
2039	30.51	34.60	38.25	41.79	45.13	46.32	48.30	34.92	30.51
2040	31.10	35.30	39.28	42.86	46.29	47.42	49.54	35.36	31.10
2041	31.66	36.00	40.14	43.98	47.50	48.73	50.91	35.84	31.66
2042	32.10	36.69	40.92	44.84	48.55	49.79	52.12	35.97	32.10
2043	32.62	37.33	41.70	45.72	49.66	50.95	53.33	36.45	32.62
2044	32.90	37.70	42.23	46.43	50.41	51.75	54.18	36.52	32.90
2045	32.99	37.90	42.53	46.84	50.95	52.34	54.89	36.54	32.99
2046	32.97	38.02	42.64	47.16	51.43	52.88	55.44	36.54	32.97
2047	33.71	38.81	43.38	47.73	51.93	53.30	55.89	36.77	33.71
2048	34.14	39.35	44.21	48.81	53.20	54.60	57.30	37.16	34.14
2049	34.45	39.70	44.59	49.24	53.60	55.14	57.86	37.26	34.45
2050	34.58	39.92	44.89	49.51	53.93	55.47	58.24	37.30	34.58
2051	34.77	40.13	45.14	49.93	54.57	56.15	59.00	37.14	34.77
2052	34.76	40.13	45.18	50.02	54.61	56.18	59.01	37.10	34.76
2053	34.82	40.33	45.44	50.23	54.98	56.57	59.51	37.12	34.82
2054	34.85	40.33	45.54	50.49	55.24	56.80	59.64	37.11	34.85
2055	35.38	40.91	46.15	51.10	55.82	57.46	60.37	37.25	35.38

Table 7: Median spawning output relative to the 40 percent of unfished spawning output target by year for rebuilding SPR alternatives assuming removals of 90.8 and 88.9 mt in 2021 and 2022, respectively.

Year	SPR= .500	SPR= .600	SPR= .700	SPR= .800	SPR= .900	Yr=Tmid	F=0	40-10 rule	ABC Rule
2021	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
2022	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
2023	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
2024	0.40	0.40	0.41	0.41	0.41	0.41	0.42	0.41	0.40
2025	0.42	0.43	0.44	0.45	0.46	0.46	0.46	0.45	0.42
2026	0.45	0.47	0.48	0.50	0.51	0.52	0.53	0.49	0.45
2027	0.48	0.51	0.53	0.56	0.58	0.58	0.60	0.54	0.48
2028	0.51	0.55	0.58	0.61	0.64	0.65	0.67	0.58	0.51
2029	0.54	0.59	0.63	0.67	0.71	0.72	0.74	0.63	0.54
2030	0.57	0.63	0.68	0.73	0.78	0.79	0.82	0.67	0.57
2031	0.60	0.67	0.73	0.79	0.84	0.86	0.90	0.71	0.60
2032	0.62	0.70	0.78	0.85	0.91	0.93	0.97	0.75	0.62
2033	0.65	0.74	0.82	0.90	0.97	1.00	1.05	0.79	0.65
2034	0.68	0.78	0.87	0.96	1.04	1.07	1.12	0.82	0.68
2035	0.70	0.81	0.91	1.01	1.11	1.14	1.20	0.85	0.70
2036	0.73	0.84	0.96	1.06	1.17	1.20	1.27	0.89	0.73
2037	0.75	0.87	1.00	1.11	1.22	1.26	1.33	0.91	0.75
2038	0.77	0.90	1.03	1.16	1.28	1.32	1.40	0.94	0.77
2039	0.78	0.93	1.07	1.20	1.33	1.38	1.46	0.96	0.78
2040	0.80	0.95	1.10	1.25	1.39	1.44	1.52	0.98	0.80
2041	0.82	0.98	1.14	1.29	1.44	1.49	1.58	1.00	0.82
2042	0.84	1.01	1.18	1.34	1.50	1.55	1.65	1.02	0.84
2043	0.86	1.03	1.21	1.38	1.54	1.60	1.70	1.03	0.86
2044	0.88	1.06	1.24	1.42	1.59	1.65	1.76	1.04	0.88
2045	0.90	1.09	1.28	1.46	1.64	1.70	1.82	1.05	0.90
2046	0.91	1.11	1.31	1.50	1.69	1.75	1.87	1.05	0.91
2047	0.93	1.13	1.33	1.53	1.72	1.79	1.91	1.06	0.93
2048	0.94	1.15	1.35	1.56	1.76	1.83	1.95	1.06	0.94
2049	0.95	1.16	1.37	1.58	1.79	1.86	1.99	1.07	0.95
2050	0.96	1.18	1.39	1.61	1.82	1.89	2.03	1.07	0.96
2051	0.97	1.19	1.41	1.63	1.85	1.92	2.06	1.08	0.97
2052	0.98	1.20	1.43	1.65	1.87	1.94	2.09	1.09	0.98
2053	0.99	1.22	1.45	1.68	1.90	1.98	2.13	1.09	0.99
2054	1.00	1.23	1.47	1.70	1.92	2.00	2.15	1.09	1.00
2055	1.00	1.24	1.48	1.71	1.94	2.02	2.17	1.09	1.00

8.3 Rebuilding alternative time series for high SPR harvest rates

Table 8: The probability of rebuilding for additional SPR harvest rates assuming removals of 90.8 and 88.9 mt in 2021 and 2022, respectively.

Year	SPR= .900	SPR= .920	SPR= .940	SPR= .950	SPR= .960	Yr=Tmid	F=0	40-10 rule	ABC Rule
2021	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2022	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2023	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2024	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2026	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2027	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2028	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00
2029	0.02	0.03	0.03	0.03	0.03	0.03	0.05	0.00	0.00
2030	0.09	0.10	0.12	0.13	0.15	0.12	0.17	0.00	0.00
2031	0.20	0.23	0.25	0.26	0.27	0.25	0.32	0.02	0.00
2032	0.34	0.37	0.39	0.40	0.41	0.38	0.46	0.03	0.01
2033	0.46	0.49	0.51	0.52	0.54	0.50	0.58	0.07	0.01
2034	0.57	0.60	0.63	0.64	0.66	0.62	0.73	0.11	0.02
2035	0.70	0.74	0.76	0.77	0.79	0.76	0.82	0.16	0.03
2036	0.80	0.82	0.85	0.86	0.87	0.85	0.90	0.23	0.04
2037	0.88	0.89	0.91	0.92	0.92	0.91	0.95	0.28	0.05
2038	0.93	0.94	0.95	0.96	0.97	0.95	0.98	0.34	0.07
2039	0.96	0.98	0.98	0.98	0.98	0.98	0.99	0.40	0.11
2040	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.48	0.14
2041	0.99	0.99	0.99	0.99	0.99	0.99	1.00	0.55	0.16
2042	0.99	1.00	1.00	1.00	1.00	1.00	1.00	0.61	0.20
2043	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.67	0.23
2044	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.73	0.26
2045	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.76	0.28
2046	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.79	0.32
2047	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.81	0.35
2048	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.85	0.38
2049	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.88	0.42
2050	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.90	0.45
2051	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.92	0.48
2052	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.92	0.51
2053	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.94	0.55
2054	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.94	0.58
2055	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.60

Table 9: Median catches (mt) by year for additional SPR harvest rates assuming removals of 90.8 and 88.9 mt in 2021 and 2022, respectively.

Year	SPR= .900	SPR= .920	SPR= .940	SPR= .950	SPR= .960	Yr=Tmid	F=0	40-10 rule	ABC Rule
2021	90.80	90.80	90.80	90.80	90.80	90.80	90.8	90.80	90.80
2022	88.90	88.90	88.90	88.90	88.90	88.90	88.9	88.90	88.90
2023	3.25	2.57	1.91	1.58	1.26	2.07	0.0	8.57	21.68
2024	3.82	3.03	2.25	1.86	1.49	2.44	0.0	11.16	24.06
2025	4.35	3.46	2.58	2.14	1.70	2.79	0.0	14.07	26.17
2026	4.84	3.85	2.87	2.38	1.90	3.11	0.0	16.84	27.91
2027	5.21	4.15	3.10	2.57	2.05	3.35	0.0	19.38	28.97
2028	5.55	4.43	3.31	2.74	2.19	3.58	0.0	21.56	29.97
2029	5.82	4.64	3.47	2.89	2.31	3.76	0.0	23.12	30.70
2030	6.15	4.91	3.67	3.05	2.44	3.98	0.0	24.66	31.71
2031	6.47	5.17	3.88	3.23	2.58	4.19	0.0	26.37	32.62
2032	6.78	5.43	4.07	3.39	2.71	4.40	0.0	27.53	33.54
2033	7.14	5.72	4.29	3.57	2.86	4.64	0.0	29.05	34.67
2034	7.40	5.93	4.45	3.71	2.97	4.81	0.0	30.03	35.36
2035	7.68	6.15	4.62	3.85	3.09	5.00	0.0	30.99	36.11
2036	7.88	6.31	4.74	3.95	3.17	5.13	0.0	31.80	36.93
2037	8.16	6.54	4.92	4.10	3.29	5.32	0.0	32.76	37.70
2038	8.40	6.74	5.07	4.22	3.38	5.48	0.0	34.05	38.34
2039	8.65	6.94	5.22	4.35	3.49	5.64	0.0	35.63	39.24
2040	8.90	7.14	5.37	4.48	3.59	5.81	0.0	38.21	40.06
2041	9.12	7.32	5.51	4.59	3.68	5.96	0.0	41.21	40.73
2042	9.32	7.48	5.63	4.69	3.76	6.08	0.0	43.41	41.39
2043	9.51	7.64	5.75	4.80	3.85	6.22	0.0	44.70	41.85
2044	9.65	7.75	5.84	4.87	3.90	6.31	0.0	45.95	42.23
2045	9.79	7.86	5.92	4.94	3.96	6.40	0.0	46.01	42.50
2046	9.87	7.93	5.97	4.98	4.00	6.46	0.0	46.05	42.37
2047	9.95	7.99	6.01	5.02	4.02	6.50	0.0	46.25	43.30
2048	10.19	8.18	6.17	5.14	4.13	6.66	0.0	46.63	43.91
2049	10.27	8.25	6.22	5.19	4.16	6.72	0.0	47.06	44.15
2050	10.34	8.31	6.25	5.22	4.19	6.76	0.0	47.34	44.43
2051	10.43	8.38	6.31	5.26	4.22	6.82	0.0	47.49	44.77
2052	10.50	8.45	6.37	5.31	4.26	6.88	0.0	47.00	44.77
2053	10.55	8.48	6.39	5.34	4.28	6.91	0.0	47.16	44.92
2054	10.61	8.53	6.43	5.36	4.30	6.95	0.0	47.34	45.02
2055	10.72	8.61	6.49	5.42	4.35	7.02	0.0	47.63	45.68

Table 10: Median ABCs (mt) by year for additional SPR harvest rates assuming removals of 90.8 and 88.9 mt in 2021 and 2022, respectively.

Year	SPR= .900	SPR= .920	SPR= .940	SPR= .950	SPR= .960	Yr=Tmid F=0		40-10 rule	ABC Rule
2021	23.47	23.47	23.47	23.47	23.47	23.47	23.47	23.47	23.47
2022	21.33	21.33	21.33	21.33	21.33	21.33	21.33	21.33	21.33
2023	18.94	18.94	18.94	18.94	18.94	18.94	18.94	18.94	18.94
2024	22.02	22.06	22.10	22.13	22.15	22.09	22.23	21.67	20.82
2025	24.89	24.98	25.07	25.12	25.17	25.05	25.34	24.09	22.44
2026	27.41	27.55	27.69	27.76	27.83	27.66	28.11	26.06	23.70
2027	29.22	29.41	29.59	29.68	29.78	29.54	30.15	27.24	24.37
2028	30.95	31.17	31.38	31.49	31.59	31.33	32.03	28.06	24.98
2029	32.07	32.32	32.59	32.71	32.86	32.53	33.43	28.83	25.35
2030	33.62	33.92	34.21	34.35	34.50	34.14	35.08	29.55	25.93
2031	35.09	35.47	35.81	36.00	36.18	35.73	36.87	30.36	26.43
2032	36.45	36.87	37.25	37.44	37.62	37.16	38.39	31.21	26.92
2033	38.01	38.47	38.89	39.09	39.31	38.79	40.09	31.85	27.56
2034	39.03	39.50	39.98	40.21	40.44	39.86	41.36	32.18	27.85
2035	40.09	40.60	41.11	41.37	41.63	40.98	42.60	32.79	28.18
2036	41.02	41.53	42.06	42.32	42.59	41.93	43.67	33.25	28.72
2037	42.53	43.12	43.70	43.99	44.27	43.55	45.37	33.85	29.32
2038	43.70	44.29	44.87	45.17	45.46	44.73	46.65	34.54	29.82
2039	45.08	45.72	46.37	46.69	47.01	46.21	48.22	34.91	30.52
2040	46.31	47.01	47.68	48.01	48.33	47.52	49.62	35.44	31.16
2041	47.56	48.25	48.94	49.28	49.62	48.77	50.97	35.98	31.68
2042	48.56	49.28	49.97	50.31	50.69	49.81	52.12	36.06	32.19
2043	49.58	50.34	51.09	51.46	51.82	50.89	53.29	36.46	32.55
2044	50.32	51.09	51.89	52.29	52.69	51.69	54.15	36.53	32.85
2045	50.95	51.77	52.55	52.96	53.36	52.35	54.89	36.55	33.06
2046	51.50	52.34	53.12	53.51	53.93	52.93	55.47	36.51	32.96
2047	51.88	52.68	53.47	53.87	54.25	53.27	55.80	36.75	33.68
2048	53.17	53.97	54.80	55.23	55.66	54.60	57.28	37.21	34.15
2049	53.54	54.42	55.25	55.68	56.11	55.04	57.82	37.12	34.34
2050	53.87	54.75	55.61	56.03	56.45	55.41	58.15	37.24	34.56
2051	54.57	55.49	56.37	56.81	57.23	56.15	58.96	37.23	34.82
2052	54.78	55.68	56.55	56.97	57.38	56.34	59.10	37.16	34.82
2053	55.09	56.01	56.91	57.36	57.80	56.69	59.60	37.19	34.94
2054	55.35	56.28	57.19	57.62	58.07	56.97	59.85	37.22	35.01
2055	55.95	56.84	57.78	58.24	58.67	57.55	60.47	37.42	35.53

Table 11: Median spawning output relative to the 40 percent of unfished spawning output target by year for additional SPR harvest rates assuming removals of 90.8 and 88.9 mt in 2021 and 2022, respectively.

Year	SPR= .900	SPR= .920	SPR= .940	SPR= .950	SPR= .960	Yr=Tmid	F=0	40-10 rule	ABC Rule
2021	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
2022	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
2023	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
2024	0.41	0.41	0.41	0.41	0.41	0.41	0.42	0.41	0.40
2025	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.45	0.42
2026	0.51	0.52	0.52	0.52	0.52	0.52	0.53	0.49	0.45
2027	0.58	0.58	0.58	0.59	0.59	0.58	0.60	0.54	0.48
2028	0.64	0.65	0.65	0.66	0.66	0.65	0.67	0.58	0.51
2029	0.71	0.72	0.72	0.73	0.73	0.72	0.74	0.63	0.54
2030	0.78	0.79	0.80	0.80	0.81	0.80	0.82	0.67	0.57
2031	0.85	0.86	0.87	0.87	0.88	0.86	0.90	0.72	0.60
2032	0.91	0.93	0.94	0.94	0.95	0.94	0.98	0.75	0.63
2033	0.97	0.99	1.00	1.01	1.02	1.00	1.05	0.79	0.65
2034	1.04	1.06	1.07	1.08	1.09	1.07	1.12	0.82	0.68
2035	1.11	1.13	1.14	1.15	1.16	1.14	1.20	0.86	0.70
2036	1.17	1.19	1.21	1.22	1.23	1.21	1.27	0.89	0.73
2037	1.23	1.25	1.27	1.28	1.29	1.27	1.34	0.92	0.75
2038	1.29	1.31	1.33	1.35	1.36	1.33	1.40	0.94	0.77
2039	1.34	1.36	1.39	1.40	1.42	1.38	1.47	0.97	0.78
2040	1.39	1.42	1.44	1.46	1.47	1.44	1.53	0.98	0.80
2041	1.44	1.46	1.49	1.51	1.52	1.49	1.58	1.00	0.82
2042	1.49	1.52	1.55	1.57	1.58	1.55	1.64	1.02	0.84
2043	1.54	1.57	1.60	1.62	1.64	1.60	1.70	1.03	0.86
2044	1.59	1.62	1.66	1.67	1.69	1.65	1.76	1.04	0.88
2045	1.64	1.67	1.71	1.73	1.74	1.70	1.81	1.05	0.89
2046	1.68	1.72	1.76	1.78	1.79	1.75	1.87	1.05	0.91
2047	1.72	1.76	1.80	1.82	1.83	1.79	1.91	1.06	0.93
2048	1.76	1.80	1.84	1.86	1.88	1.83	1.95	1.06	0.94
2049	1.79	1.83	1.87	1.89	1.91	1.86	2.00	1.07	0.95
2050	1.82	1.86	1.91	1.93	1.95	1.89	2.03	1.07	0.96
2051	1.85	1.89	1.93	1.96	1.98	1.92	2.06	1.08	0.97
2052	1.87	1.91	1.96	1.98	2.00	1.94	2.09	1.08	0.98
2053	1.90	1.95	1.99	2.01	2.03	1.98	2.12	1.09	0.99
2054	1.92	1.97	2.01	2.04	2.06	2.00	2.15	1.09	1.00
2055	1.94	1.99	2.04	2.06	2.08	2.02	2.18	1.09	1.00

9 Figures

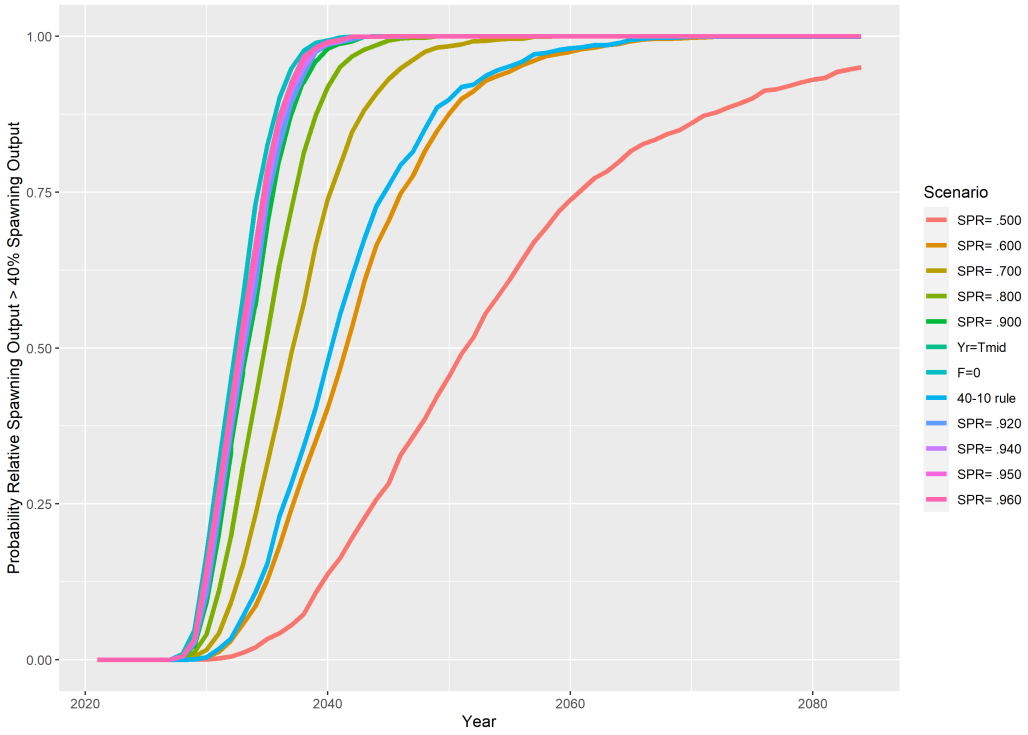

Figure 1: Probability of rebuilding by year for alternative rebuilding strategies.

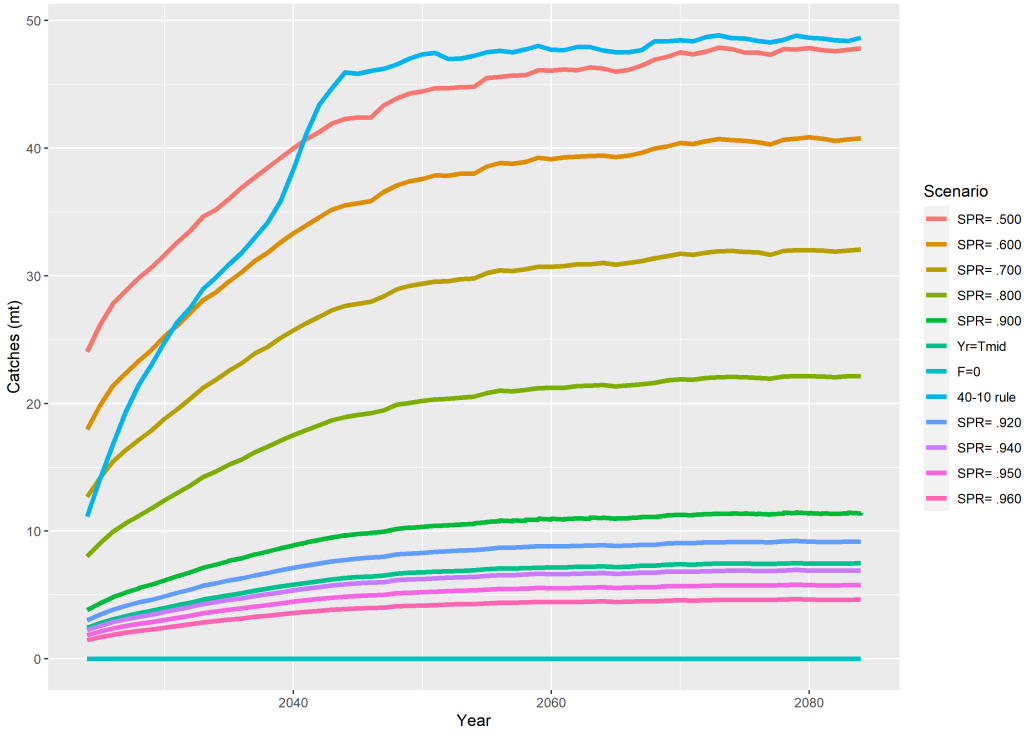

Figure 2: Catches (mt) by year for alternative rebuilding strategies.

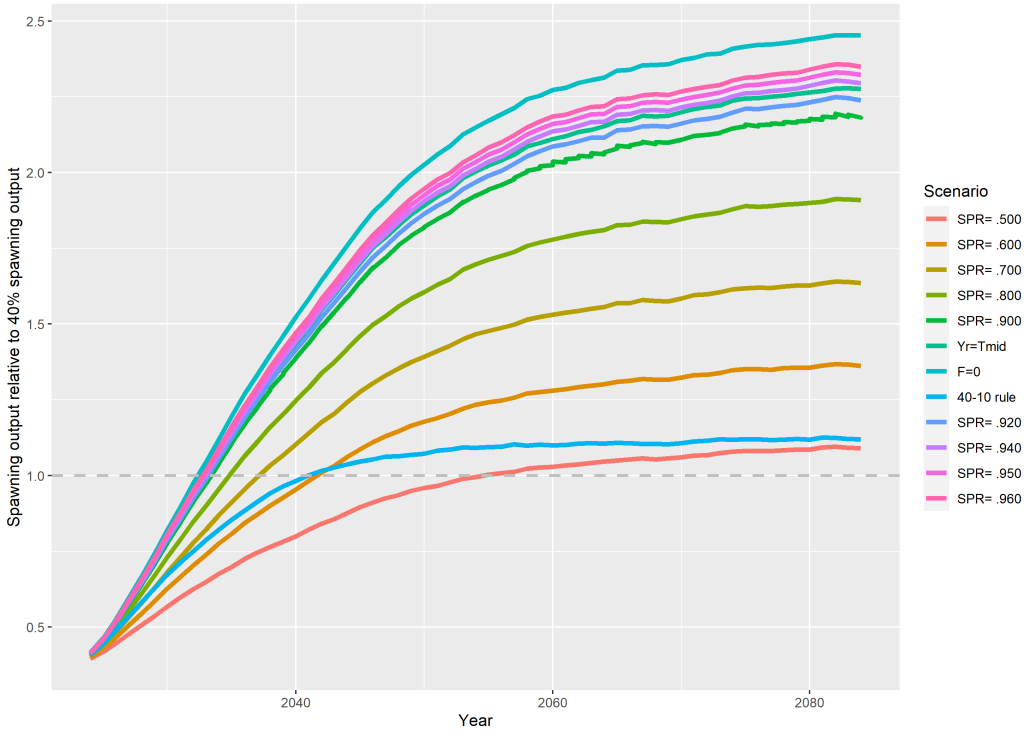

Figure 3: Spawning output relative to the management target of 40 percent of unfished spawning output by year for alternative rebuilding strategies.