Cowcod Rebuilding

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Introduction

The cowcod (*Sebastes levis*) resource is currently considered to be one continuous population that extends from Washington south into Mexico. Fishable biomass is similar to spawning biomass because cowcod are recruited to the fishery near the size of first maturity. While cowcod spawning biomass will always be somewhat less than fishable biomass, for the purposes of the rebuilding analysis they are assumed to be approximately equal. The International North Pacific Fisheries Commission (INPFC) Conception Area portion of the stock was assessed by U. S. scientists in 1999 at which time the spawning biomass was determined to have fallen below 10% of its unfished size (Figure 1). The Pacific Fishery Management Council (PFMC) responded by imposing significant reductions in quotas.

Management Reference Points

B_{msy}: The rebuilding target is the spawning biomass level that produces MSY. Experience from other fisheries has shown the B_{msy} is often near 40% of initial biomass, which is also the biomass target for rebuilding the stock. Butler et al. (1999) estimated initial biomass at 3370 MT with 2840 MT and 3990 MT as lower and upper 95% confidence intervals. The rebuilding target for the Conception Area is then 1350 MT biomass with 1140 and 1600 MT as lower and upper 95% confidence intervals respectively.

Mean Generation Time

If the stock cannot be rebuilt within 10 years, then the maximum time allowed for rebuilding is the length of time required to rebuild at F=0 plus one mean generation time. Mean generation time (Pielou 1977) can be estimated from the net maternity function (product of survivorship and fecundity at age; Figure 2 and Table 2). Parameters used to estimate mean generation time are taken from Butler et al. (1999). Because larger and older cowcod females have high reproductive values, mean generation time is sensitive to maximum age. The oldest cowcod in a sample of 264 fish was 55 y (Butler et al. 1999), but it may not represent maximum age of this species. It is likely that older fish could be found if a larger sample size were available, or if samples were available from the un-exploited population. A plausible range of maximum age of cowcod is from 60-100 years which results in mean generation times of 35-40 years. Since data were not available to narrow this range, we used 75 y as the maximum age for cowcod and estimated mean generation time at 37 y. This long generation time is due in part to the fact that cowcod continue to grow after maturity, and thus older and larger female cowcod have very high reproductive value.

Simulation Model

We modeled cowcod rebuilding using a surplus production model because of the density dependent population growth inherent in the logistic equation (Appendix I). We also tried the delay difference model used in the cowcod stock assessment (Butler et al. 1999), but that model yielded longer rebuilding times (Average time = 145 y). Population simulations began with the 1998 cowcod biomass. Surplus production was modeled using a log-normal distribution fitted to recruitment during 1951-1998 (Butler et al. 1999). Population trajectories with a fixed mean r indicated that minimum time to B_{msy} with no fishing was 61 y.

The time series of recruitment from the stock assessment model is highly correlated with a lag of one year (Figure 3). In order to test whether the auto correlation affected rebuilding time, we incorporated an auto correlation of 0.8 into recruitment to the population. This changed the pattern of biomass trajectories but had no effect on the median time to rebuilding or the probability of success when averaged over 500 replicates.

The maximum time to rebuild to B_{MSY} allowed by the Magnuson-Stevens Fishery Conservation and Management Act is the minimum time (61 y) plus one mean generation time (37 y) or a total of 98 y. Population trajectories with randomly sampled log-normal production were repeated 250 times with different constant values of F to find a fishing rate that provided some catch but resulted in a 60% probability of achieving B_{MSY} within the maximum allowed time.

Initial Conditions

The cowcod stock assessment (Butler et al. 1999) found uncertainty in the 1998 biomass. Upper and lower 95% confidence intervals indicated that the 1998 cowcod biomass could be at 4-11% (126-451 MT) of unfished stock size. In order to capture the uncertainty in current cowcod stock size, population trajectories were initialized at 126, 238 and 451 MT. Mean time to B_{MSY} with no fishing varies, which under different initial conditions, are 42, 62 and 80 y respectively.

Projections

The probability of rebuilding success under alternative fishing rates and three initial conditions are presented in Table 1. If the 1998 population is as low as 4% of the virgin biomass, almost no realistic quota achieves rebuilding. If the 1998 biomass is 7% of virgin biomass, which is the basecase scenario from the assessment, then a quota of 2.4 MT will achieve rebuilding in about 95 y. If the 1998 biomass is 11% of the virgin biomass, then a quota of 4.5 MT will achieve rebuilding in 67 y.

Discussion

The combination of an unproductive stock and extremely low current biomass level compounds the difficulties to rebuild cowcod. Rebuilding yields are very low compared to the large amount of fishing effort that is present in California waters. This provides the opportunity for target yields to be inadvertently exceeded due to inherent imprecision in catch statistics, and unrecorded fishing mortality from discarded bycatch. Calculations show that the long-term consequence of small over harvest could be significant. Unaccounted removals as small as 1-2 tons per year may sufficiently jeopardize the rebuilding plan. Although it will be necessary to closely monitor annual commercial and recreational landings, additional information will be necessary to provide assurance that rebuilding targets are not exceeded. Reliable estimates of discards are a critical element to rebuilding efforts, since discarded cowcod do not survive. Identification of geographic areas where cowcod density is comparatively high may also be of interest to managers seeking ways to assure that cowcod catches do not exceed rebuilding targets.

Future reassessments will demonstrate whether management measures have accomplished intended objectives. However, it is likely that many years will need to pass before it is possible to detect statistically significant change in abundance for an unproductive species such as cowcod.

Rebuilding yields have been calculated for that portion of the stock that is found in the Conception Management Area. The stock ranges much further to the north, and a significant fishery has also occurred in the Monterey Management Area. The Monterey Area was not included in rebuilding calculations because that portion of the stock is data poor, and consequently was outside the area of the stock assessment. However, significant catches have occurred in the Monterey Area over many years, and it is likely that the stock is also overfished in that portion of the range. One possible approach for estimating rebuilding yields for the Monterey Area is to take proportional catch reductions to that which are necessary in the Conception Area.

Literature cited

Butler, J. L., L. D. Jacobson, J. T. Barnes, H. G. Moser, and R. Collins. 1999. Stock assessment of cowcod. In: Pacific Fishery Management Council. 1999. Appendix: Status of the Pacific Coast Groundfish Fishery through 1998 and recommended biological catches for 1999: Stock assessment and fishery evaluation. Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, Oregon, 97201.

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List of Figures

Figure 2. Net maturity function of female cowcod.

Figure 3. Cowcod recruitment biomass and spawning biomass during 1951-1998.

Figure 1. Basecase model results for cowcod spawning biomass with 95% confidence interval.

Figure 2. Net maturnity function for female cowcod.

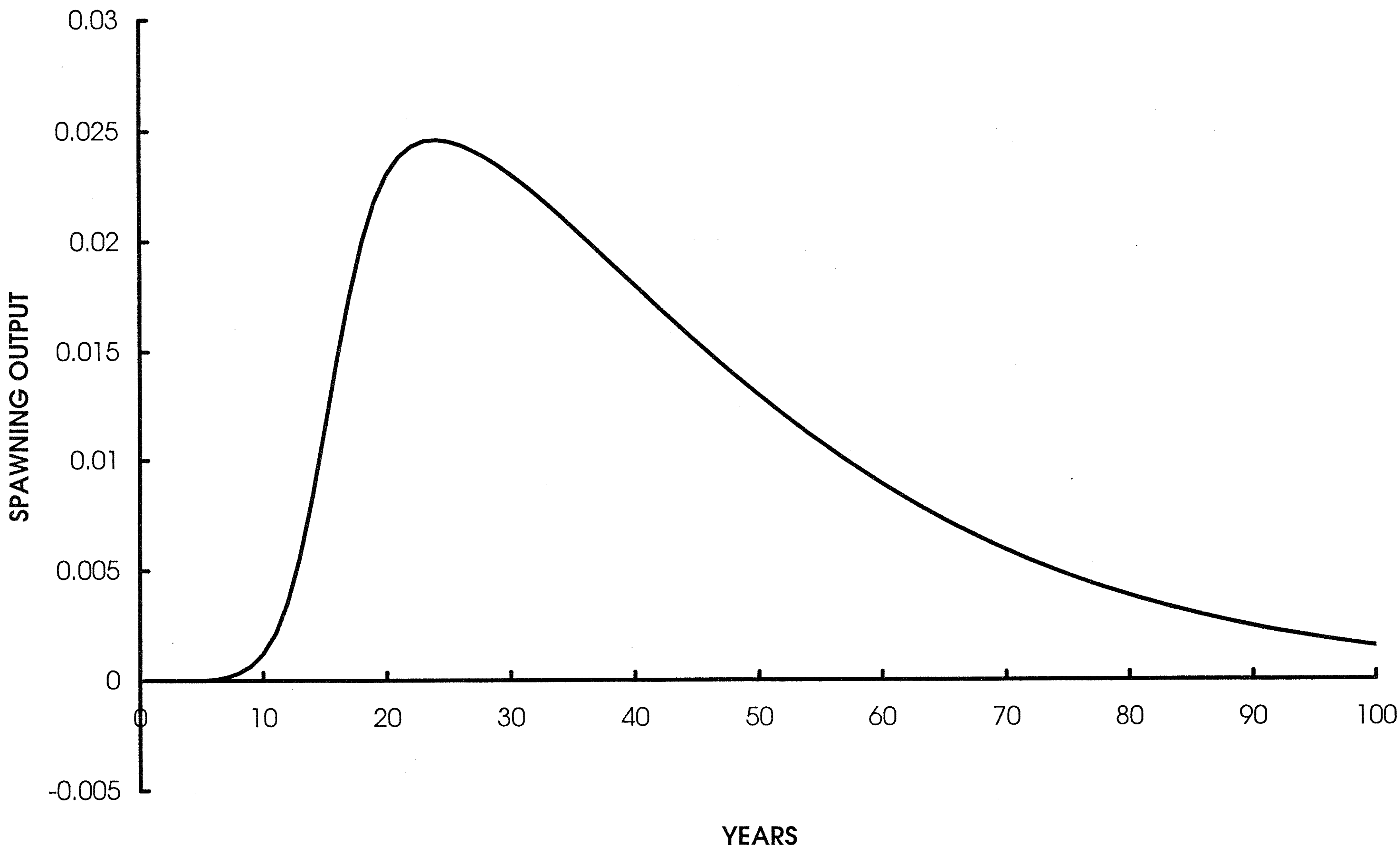

Figure 3. Cowcod recruitment biomass and spawning biomass from 1951-1998.

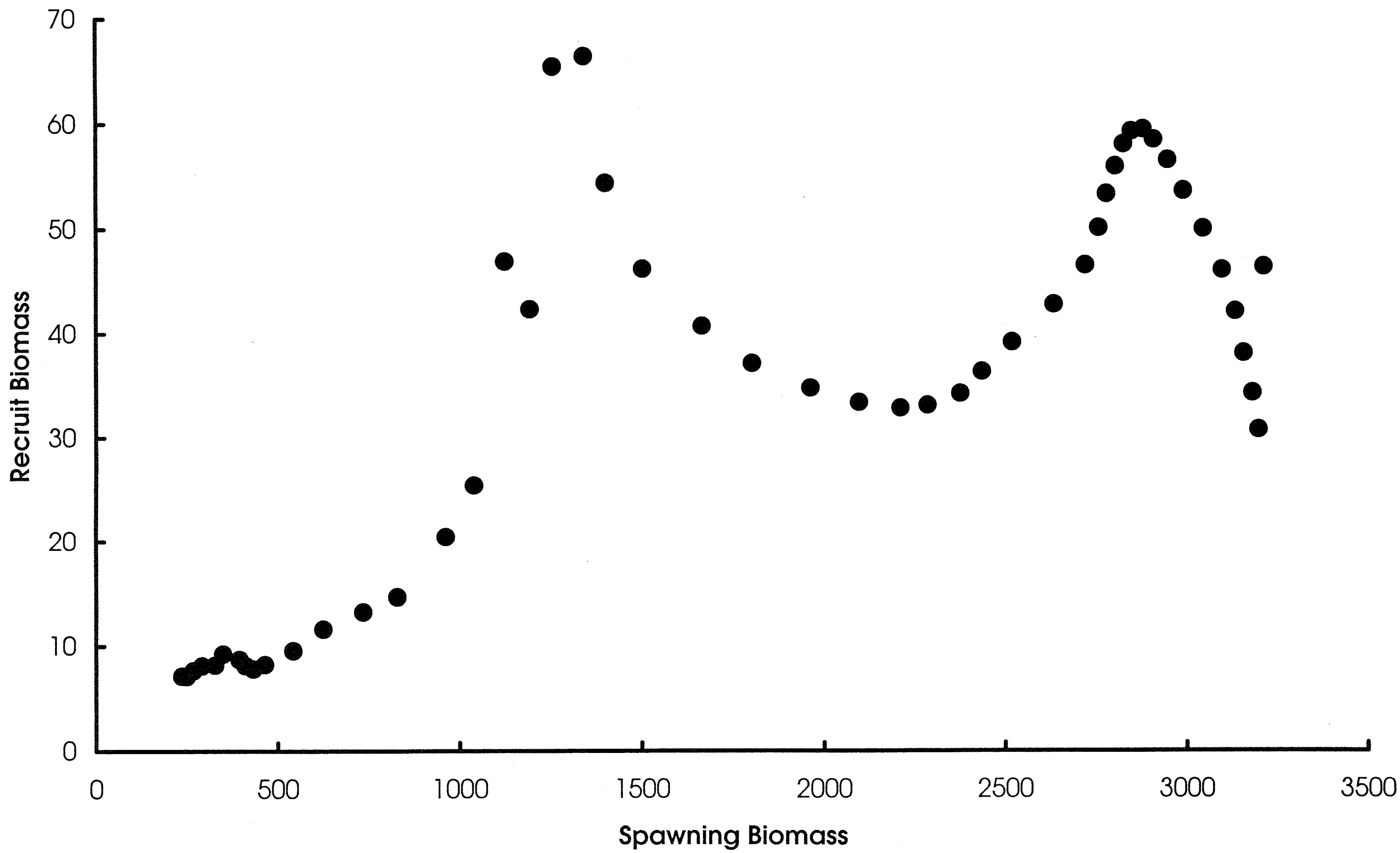

Table 1. Probabilities of cowcod rebuilding under a constant harvest rate, assuming three alternative 1998 biomass levels. **Catch** is the mean annual catch during the first three years of the projection period (1999-2000); **Percent Success** is the percentage of simulations that achieve rebuilding schedule; **Median Time** is median time (y) to reach Bmsy (=0.4*3370 MT). Bold values are base case run.

LOW 1998 BIOMASS (4 % OF VIRGIN BIOMASS)

F	CATCH MT	PERCENT SUCCESS	MEDIAN TIME
0	0	100	81
0.00425	0.55	60	94
0.01	1.3	1	121
0.02	2.5	0	277
0.03	3.7	0	>300
0.04	5	0	>300

MEDIUM 1998 BIOMASS (7 % OF VIRGIN BIOMASS)

F	CATCH	PERCENT SUCCESS	MEDIAN TIME
0	0	100	62
0.009	**2.1**	**60**	**90**
0.01	2.4	55	95
0.02	5	0	227
0.03	7	0	>300
0.04	9	0	>300

HIGH 1998 BIOMASS (11 % OF VIRGIN BIOMASS)

F	CATCH	PERCENT SUCCESS	MEDIAN TIME
0	0	100	42
0.01	4.5	99	67
0.014	6.4	60	92
0.02	9	0	186
0.03	13	0	>300
0.04	16	0	>300

Table 2. Weight at age, Maturity, Reproductive output (M_x) and Survivorship (L_x) of Cowcod (*Sebastes levis*)

Age	Weight	Maturity	M_x	L_x
1	-805.36302	0	0	1
2	-590.69241	0	0	0.94648515
3	-377.30596	0	0	0.89583414
4	-165.196	0	0	0.8478937
5	45.6451091	0	0	0.8025188
6	255.22496	0.01	2.5522496	0.75957212
7	463.551097	0.0189	8.76111573	0.71892373
8	670.631019	0.0308	20.6554354	0.68045064
9	876.472182	0.0497	43.5606675	0.64403642
10	1081.082	0.0794	85.8379105	0.60957091
11	1284.46783	0.1246	160.044691	0.57694981
12	1486.637	0.19	282.461029	0.54607443
13	1687.59678	0.2789	470.670742	0.51685133
14	1887.35442	0.3894	734.93581	0.48919211
15	2085.9171	0.5125	1069.03251	0.46301307
16	2283.29197	0.6341	1447.83544	0.43823499
17	2479.48614	0.7408	1836.80333	0.41478291
18	2674.50666	0.8249	2206.20055	0.39258587
19	2868.36057	0.8859	2541.08063	0.37157669
20	3061.05483	0.9276	2839.43446	0.35169182
21	3252.5964	0.9548	3105.57904	0.33287108
22	3442.99215	0.9721	3346.93267	0.31505754
23	3632.24895	0.9829	3570.13749	0.29819728
24	3820.37361	0.9895	3780.25968	0.2822393
25	4007.3729	0.9936	3981.72571	0.2671353
26	4193.25355	0.9961	4176.89986	0.2528396
27	4378.02226	0.9976	4367.515	0.23930892
28	4561.68567	0.9986	4555.29931	0.22650234
29	4744.25041	0.9991	4739.98058	0.2143811
30	4925.72303	0.9995	4923.26017	0.20290853
31	5106.11008	0.9997	5104.57825	0.19204991
32	5285.41805	0.9998	5284.36097	0.18177239
33	5463.65339	1	5463.65339	0.17204486
34	5640.82252	1	5640.82252	0.16283791
35	5816.93182	1	5816.93182	0.15412366
36	5991.98763	1	5991.98763	0.14587576
37	6165.99624	1	6165.99624	0.13806924
38	6338.96393	1	6338.96393	0.13068048
39	6510.89692	1	6510.89692	0.12368714
40	6681.80141	1	6681.80141	0.11706804
41	6851.68353	1	6851.68353	0.11080316
42	7020.54942	1	7020.54942	0.10487354
43	7188.40514	1	7188.40514	0.09926125
44	7355.25674	1	7355.25674	0.0939493
45	7521.11023	1	7521.11023	0.08892162
46	7685.97158	1	7685.97158	0.08416299

47	7849.84673	1	7849.84673	0.07965902
48	8012.74156	1	8012.74156	0.07539608
49	8174.66196	1	8174.66196	0.07136127
50	8335.61374	1	8335.61374	0.06754238
51	8495.6027	1	8495.6027	0.06392786
52	8654.6346	1	8654.6346	0.06050677
53	8812.71517	1	8812.71517	0.05726876
54	8969.85009	1	8969.85009	0.05420403
55	9126.04503	1	9126.04503	0.05130331
56	9281.3056	1	9281.3056	0.04855782
57	9435.6374	1	9435.6374	0.04595926
58	9589.04598	1	9589.04598	0.04349975
59	9741.53686	1	9741.53686	0.04117187
60	9893.11554	1	9893.11554	0.03896856
61	10043.7875	1	10043.7875	0.03688317
62	10193.5581	1	10193.5581	0.03490937
63	10342.4327	1	10342.4327	0.0330412
64	10490.4168	1	10490.4168	0.03127301
65	10637.5157	1	10637.5157	0.02959944
66	10783.7346	1	10783.7346	0.02801543
67	10929.0788	1	10929.0788	0.02651618
68	11073.5536	1	11073.5536	0.02509717
69	11217.1641	1	11217.1641	0.0237541
70	11359.9155	1	11359.9155	0.02248291
71	11501.813	1	11501.813	0.02127974
72	11642.8616	1	11642.8616	0.02014095
73	11783.0665	1	11783.0665	0.01906311
74	11922.4327	1	11922.4327	0.01804295
75	12060.9652	1	12060.9652	0.01707739
76	12198.6689	1	12198.6689	0.01616349
77	12335.549	1	12335.549	0.01529851
78	12471.6102	1	12471.6102	0.01447981
79	12606.8574	1	12606.8574	0.01370493
80	12741.2957	1	12741.2957	0.01297151
81	12874.9297	1	12874.9297	0.01227734
82	13007.7643	1	13007.7643	0.01162032
83	13139.8043	1	13139.8043	0.01099846
84	13271.0544	1	13271.0544	0.01040988
85	13401.5194	1	13401.5194	0.0098528
86	13531.2039	1	13531.2039	0.00932553
87	13660.1127	1	13660.1127	0.00882647
88	13788.2503	1	13788.2503	0.00835412
89	13915.6214	1	13915.6214	0.00790705
90	14042.2305	1	14042.2305	0.00748391
91	14168.0823	1	14168.0823	0.00708341
92	14293.1812	1	14293.1812	0.00670434
93	14417.5318	1	14417.5318	0.00634556
94	14541.1385	1	14541.1385	0.00600598
95	14664.0058	1	14664.0058	0.00568457
96	14786.1381	1	14786.1381	0.00538036

97	14907.5398	1	14907.5398	0.00509243
98	15028.2152	1	15028.2152	0.00481991
99	15148.1688	1	15148.1688	0.00456197
100	15267.4048	1	15267.4048	0.00431784

Appendix I

Annual surplus production during 1951-1998 was computed by:

$$P_y = B_{y+1} - B_y + C_y \qquad 1)$$

Where B_y was a biomass estimate from the basecase run of the cowcod assessment model (Butler et al. 1999) at the beginning of the year y, K is the population carrying capacity or "virgin biomass," C_y was catch data and r is the slope of the production function at the origin. Production was modeled using the logistic model with process errors:

$$P_y = r B_y \left(1 - \frac{B_y}{K}\right) \qquad 2)$$

Solving for r_y gives:

$$r_y = \frac{P_y K}{B_y \left(K - B_y\right)} \qquad 3)$$

The recruitment parameter r_y was calculated for each year from 1951-1998 and modeled using the lognormal distribution. Then forward projections of biomass were obtained from rearranging Eq (1), giving:

$$B_{y+1} = B_y + P_y - C_y \quad 4)$$

Where P_y was obtained from Eq. (2) using a stochastic lognormal r.