Rebuilding Analysis for Canary Rockfish

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Introduction

The most recent stock assessment for canary rockfish in the northern area (Columbia and U.S. Vancouver INPFC areas) indicated that a long-term decline had continued and that the abundance of the female spawning biomass had fallen below the depleted threshold (Crone et al., 1999). A similar conclusion was reached for the stock in the southern area (Williams et al., 1999). Canary rockfish was determined to be in an "overfished" state on Jan. 1, 2000 which initiated development of a rebuilding plan.

The purpose of this document is to estimate the potential rate of rebuilding of canary rockfish in the northern area. This will involve five steps:
(1) examining the recruitment-spawner information to determine a functional relationship;
(2) determine unfished level of spawning biomass in order to calculate target levels for rebuilding;
(3) determining the generation time, which affects the potential duration or rebuilding;
(4) determining expected levels of recruitment during the rebuilding period;
(5) calculating in rebuilding can occur within 10 years, and if not then calculating the time to rebuild with no fishing mortality;
(6) finally, calculate the degree of reduction in fishing mortality needed to rebuild within a time period equal to one mean generation time plus the time to rebuild with no fishing mortality.

The canary rock fish assessment explored two scenarios regarding natural mortality and fishery selectivity for females. These two scenarios provide alternative explanations for the relative low occurrence of old females compared to the occurrence of old males. Scenario #1 has increasing natural mortality for older females and asymptotic fishery selectivity for both sexes. Scenario #2 has constant natural mortality for both sexes and dome-shaped fishery selectivity to explain the low incidence of old females in the fishery samples. Neither the STAT or STAR in 1999 was able to develop a preference between these two hypotheses, so both are carried forward in this rebuilding analysis.

A modification to the Council's 40-10 harvest policy is proposed here to provide a rebuilding plan which will smoothly transition into a long-term sustainable harvest policy. The 40-10 policy involves a precautionary adjustment to the harvest rate as the spawnign biomass falls below its target level (40% of the unfished spawning biomass level (40% SPB)). This

adjustment is 1.0 at the 40% SPB level and 0.0 at the 10% SPB level. Since a rebuilding plan is basically an adjustment to this level of precaution in order to accelerate rebuilding, we propose to introduce an exponent to the precautionary adjustment. If this exponent (power) is 1.0, then the rebuilding plan is identical to the 40-10 OY policy. As the rebuilding power increases, there is a downward adjustment in catch to accelerate rebuilding.

Scenario #1

Spawner-Recruit Relationship

The synthesis assessment model was rerun with the same data set as used in the1999 assessment. In these new runs, the model was set up to estimate the parameters of a Beverton-Holt spawner-recruit relationship. This relationship was parameterized so that the steepness was defined as the level of recruitment when spawning biomass was at 20% of its unfished level. The level of recruitment variability was set equal to 0.5 on a logarithmic scale. In addition, the reruns of the model correct an error in the female maturity vector used in the 1999 assessment. This error has no impact on the fitting of the model to the data in the 1999 assessment, but did have a small impact on the female spawning biomass levels reported from that assessment.

The estimated S/R steepness is only 0.389 (Figure 1). Hence, canary rockfish are estimated to have a high level of decline in recruitment as spawning biomass is reduced to a low level. The level of recruits per spawner for canary rockfish is barely above the replacement level throughout the time series (Figure 2). As long as similar levels of recruits/spawner occur, any rebuilding will be extremely slow.

Recruitments at the beginning and end of the assessment time series are imprecisely estimated because of the low level of data for those years. At the end of the time series, the sequence of higher recruitment levels for 1996-1998 are reduced in these new runs with the S/R relationship included, but they still represent a much higher level than had occurred in the early 1990s (Figure 1, 2). Because of concern over making projections with these high recruitment levels, the original assessment (Crone et al, 1999) also include projections with lower levels for these 3 recruitments. These lower levels were nearly identical to the levels that correspond to the estimated S/R curve (Figure 1).

Projections of future abundance made in this rebuilding analysis use recruitments through 1999 as reestimated in Table 1 and Figure 1.

Unfished Abundance Level

Three possibilities are the level from the assessment model, the level from the fitted spawner-recruitment curve, and the level calculated from the mean recruitment level in the early years of the time series.

The highest value comes from the initial assessment where a recruitment level of 2856

million age 1 recruits would produce an unfished female spawning biomass of 22239 mtons. In the initial assessment modeling, this initial recruitment level is acted on by a fishing mortality sufficient to produce a catch of 1000 mtons which reduces the initial spawning biomass down to 18838 mtons (Table 1, Figure 1).

The lowest level comes from the intercept between the estimated spawner-recruitment curve and the recruits/spawner replacement line. This level has 1412 million recruits producing a spawning biomass of 10995 mtons. However, because this relationship is fitted to the logarithm of recruitment, a correction when backtransforning to recruitment is necessary. These transformed values are 1600 million recruits producing an unfished spawning biomass of 12459 mtons (Table 1, Figure 1).

An intermediate level comes from taking the early mean recruitment level (1964 million recruits from the 1966 through 1979 yearclasses) which would produce a spawning biomass of 15294 mtons if unfished. This level is taken as the best estimate of unfished spawning biomass.

The rebuilding target is set at 40% of the unfished spawning biomass level, which is 6118 mtons of female spawners. An alternative would be to calculate the level associated with MSY on the basis of the estimated spawner-recruitment curve. MSY is estimated to be approximately 725 mtons which occurs at a spawning biomass of about 5700 mtons if the fishing mortality rate corresponds to a SPR of 63% (Figure 3). Note that because of the low S/R steepness for canary, fishing at an SPR of 65% is expected to produce a spawning biomass level equal to about 40% of the unfished level. The equilibrium catch at F50% to F70% ranges from 689 to 724 mtons, but at F levels of F50% - F60% the stock level would be less than the rebuilding target of 40%.

Generation Time

This is calculated as the mean age of female spawners in an unfished population. It is calculated to be 16.8 years in scenario #1 in which female natural mortality increases as older ages.

Expected Recruitment Level

Figure 3 shows that fishing at a Fspr rate above F65% will not maintain the stock above the B40% level. Thus, the default harvest rate of F50% for rockfish is not expected to keep canary rockfish at a optimum population level because of its extreme lack of resiliency in recruitment. We use a F65% harvest rate as the endpoint for these rebuilding calculations. Note that this achieves nearly as much catch as a F50% policy if the currently estimated S/R function holds in the future. If future recruitments increase more than expected from the S/R curve, then we will be able to actually estimate the F that produces MSY in the future.

The main approach to estimating future recruitment levels is through randomly resampling the historical values of recruits per spawner (Figure 2) and multiplying the selected value by the previous year's spawning biomass to estimate the current year's recruitment of age 1 fish. These R/S values indicate very little ability of the population to compensate for fishing mortality.

Recent R/S values are higher, but these values are driven nearly solely by the highly variable occurrence of young canary rockfish in the 1998 triennial trawl survey.

Most projections will be based upon resampling the R/S from 1987-1997 to include some but not all the recent, imprecisely estimated values. Some projections with alternative time periods were conducted, as well as projections using the spawner-recruitment relationship and some projections using resampling of deviations from the estimated spawner-recruitment relationship.

Rebuilding in the Absence of Fishing

The rate of rebuilding with no fishing mortality depends only upon the level of recruitment that occurs during the rebuilding period. An optimistic scenario would draw recruitments from the estimated spawner-recruitment curve and would be rebuilt in 26 years. A more realistic scenario would draw randomly from recent values of recruits per spawner (using 1987-1997 to avoid the poorly estimated and anomalously high values in 1998 and 1999). This would result in an average rebuilding time of 37 years (based on median of 500 trials). A similar result is obtained by resampling deviations from the spawner-recruitment curve for the same years. However, randomly drawing from the actual 1987-1997 recruitment values would not rebuild in 90% of the trials.

The target rebuilding time is equal to one generation time plus the time to rebuild with zero fishing. The value is 54 years.

Rebuilding

In order to create a rebuilding plan that will smoothly transition into a long-term sustainable harvest policy, we modify the 40-10 OY policy by raising the precautionary adjustment to a power. At a power of 1.0, theannual catch during the rebuilding period would be equal to the value calculated from the 40-10 policy. At higher levels of the power, the catch will be reduced during the rebuilding period and will transition to the 40-10 level when the spawning biomass rebuilds to the target (40%) level.

Rebuilding times were calculated for 500 trials using F65%, the 40-10 policy, resampling of recruits/spawner from 1987-1997, and various levels of the rebuilding power. At a power of 1, the median time to rebuild would be 127 years; well in excess of the 54 year limit (Figure 4). By increasing the power to 10, the time to rebuild is reduced to 55 years which is close to the target. However, during the first several years of the rebuilding period, the catch would need to be zero to match the expectations of the plan. In implementing the rebuilding plan, it may not be feasible to keep the catch below about 100 mtons, thus delaying rebuilding.

Sscenario #2

insert scenario #2 results here

Summary

Both scenarios result in rebuilding targets near 55 years, and both require catch to be near zero for nearly a decade in order to get started on this rebuilding given low current recruitment levels (Figure 9). However, differences between the two scenarios appear when one considers the rate of rebuilding. For scenario #1, the biomass is increasing rapidly as the stock achieves the target level. This is a consequence of the large proportional increase in SPB from current low levels combined with the use of recruits/spawner to generate future recruitment levels. For scenario #2, the mean spawning biomass does not quite achieve the rebuilding target (Figure 9) even though the median time to rebuild is achieved.

This rebuilding scenario is based upon recruitment projections that are realistic based upon the history of canary rockfish. However, these recruitment levels are much lower than typical rockfishes, which tend to have a S/R steepness closer to 0.65, but with substantial variability between species and areas. If the estimated 1996-1998 recruitments of canary rockfish areconfirmed in future assessments and followed by comparable recruitments in future years, then canary rockfish will be returning to a S/R curvature more like that of other rockfishes and will rebuild more quickly than estimated here.

Table 1. Revised time series of canary rockfish abundance in the northern area according to scenario #1 in which fishery selectivity is asymptotic at older ages, and females are estimated to have increasing natural mortality (Crone et al 1999). A spawner-recruitment function is estimated within the updated assessment model. Use of this S/R function in the model also serves to pull imprecisely estimated recruitments at the beginning and end of the time series towards the relationship. In addition, the maturity schedule used to calculate female spawning biomass is corrected.

YR	Total Biomass	Female Spawning Biomass	Age 1 Recruits	Catch
Alternative Calculations of unfished level:				
S/R equil	33544	10995	1412	0
S/R, with bias adjust	38010	12459	1600	0
recent recr mean	46659	15294	1964	0
init. Equilibrium	67848	22239	2856	0
Estimated time series:				
Initial Equilibrium	52725	18838	2856	1000
67	52633	18838	534	2504
68	50784	18252	1061	2802
69	48490	17507	2965	1731
70	47313	17233	2483	1607
71	46237	16980	2556	1427
72	45312	16735	1231	1382
73	44364	16418	1233	4181
74	40360	14831	2308	860
75	40022	14719	1842	1351
76	39105	14393	1688	785
77	38797	14290	2755	1672
78	37518	13773	1375	2326
79	35591	12942	2427	3192
80	32874	11752	3039	3215
81	30292	10641	751	2608
82	28504	9840	1724	4352
83	24894	8330	1318	4277
84	21503	7020	1399	1839
85	20804	6893	1199	2084
86	19822	6711	1395	1848
87	19018	6625	674	2698
88	17179	6073	677	2578
89	15379	5505	942	2820
90	13207	4742	700	2174
91	11669	4213	950	2802
92	9410	3311	714	2433
93	7522	2566	537	1982
94	6072	1974	353	960
95	5681	1840	312	770
96	5474	1806	948	974
97	5019	1663	777	920
98	4613	1502	760	996
99	4129	1290	405	996

Table 2. Revised time series of canary rockfish abundance in the northern area according to scenario #2 in which fishery selectivity is dome-shaped and natural mortality is constant for all ages and both sexes (Crone et al 1999). A spawner-recruitment function is estimated within the updated assessment model. Use of this S/R function in the model also serves to pull imprecisely estimated recruitments at the beginning and end of the time series towards the relationship. In addition, the maturity schedule used to calculate female spawning biomass is corrected.

YR	Total Biomass	Female Spawning Biomass	Age 1 Recruits	Catch
Alternative Calculations of unfished level:				
S/R equil	45243	22881	1395	0
S/R, with bias adjust	51267	25928	1581	0
recent recr mean	61063	30882	1883	0
init. Equilibrium	88702	44860	2735	0
Estimated time series:				
Initial Equilibrium	66955	34070	2735	1000
67	66866	34070	477	2504
68	65002	33501	974	2802
69	62656	32686	2721	1731
70	61392	32331	2393	1607
71	60213	31980	2377	1427
72	59172	31630	1146	1382
73	58104	31201	1177	4181
74	53938	29390	2213	860
75	53404	29092	1752	1351
76	52309	28594	1653	785
77	51850	28348	2730	1672
78	50433	27686	1336	2326
79	48350	26662	2399	3192
80	45436	25191	3012	3215
81	42599	23723	757	2608
82	40520	22544	1738	4352
83	36570	20535	1334	4277
84	32772	18691	1433	1839
85	31646	18082	1246	2084
86	30250	17433	1495	1848
87	29055	16889	773	2698
88	26849	15870	799	2578
89	24703	14845	1172	2820
90	22213	13622	917	2174
91	20387	12659	1270	2802
92	17874	11321	939	2433
93	15760	10164	751	1982
94	14106	9181	511	960
95	13540	8712	493	770
96	13204	8393	1595	974
97	12678	7999	1335	920
98	12264	7614	1340	996
99	11828	7200	785	996

Figure 1. Estimated recruitment and spawner levels for scenario #1.

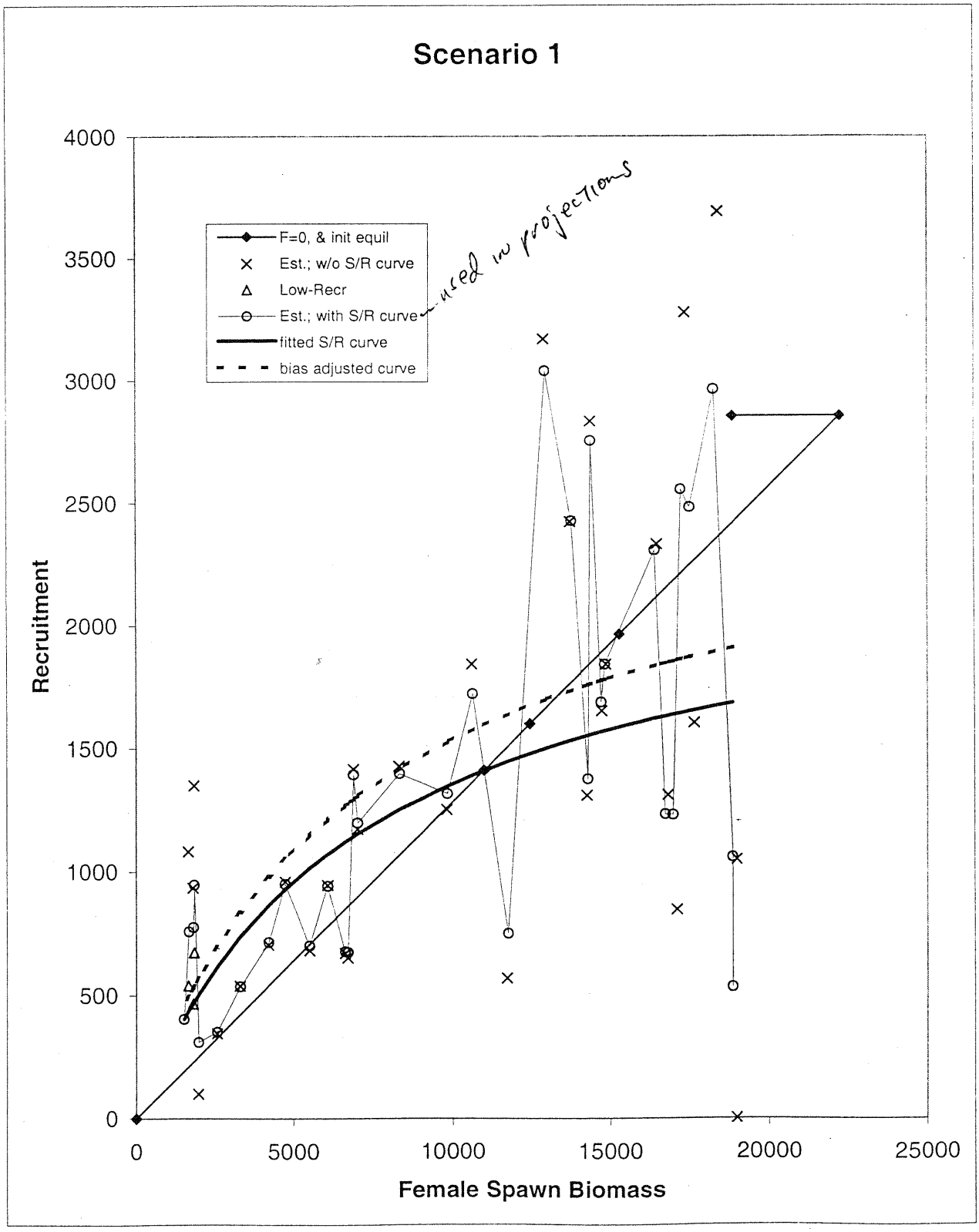


Figure 2. Recruits per Spawner time series for scenario #1

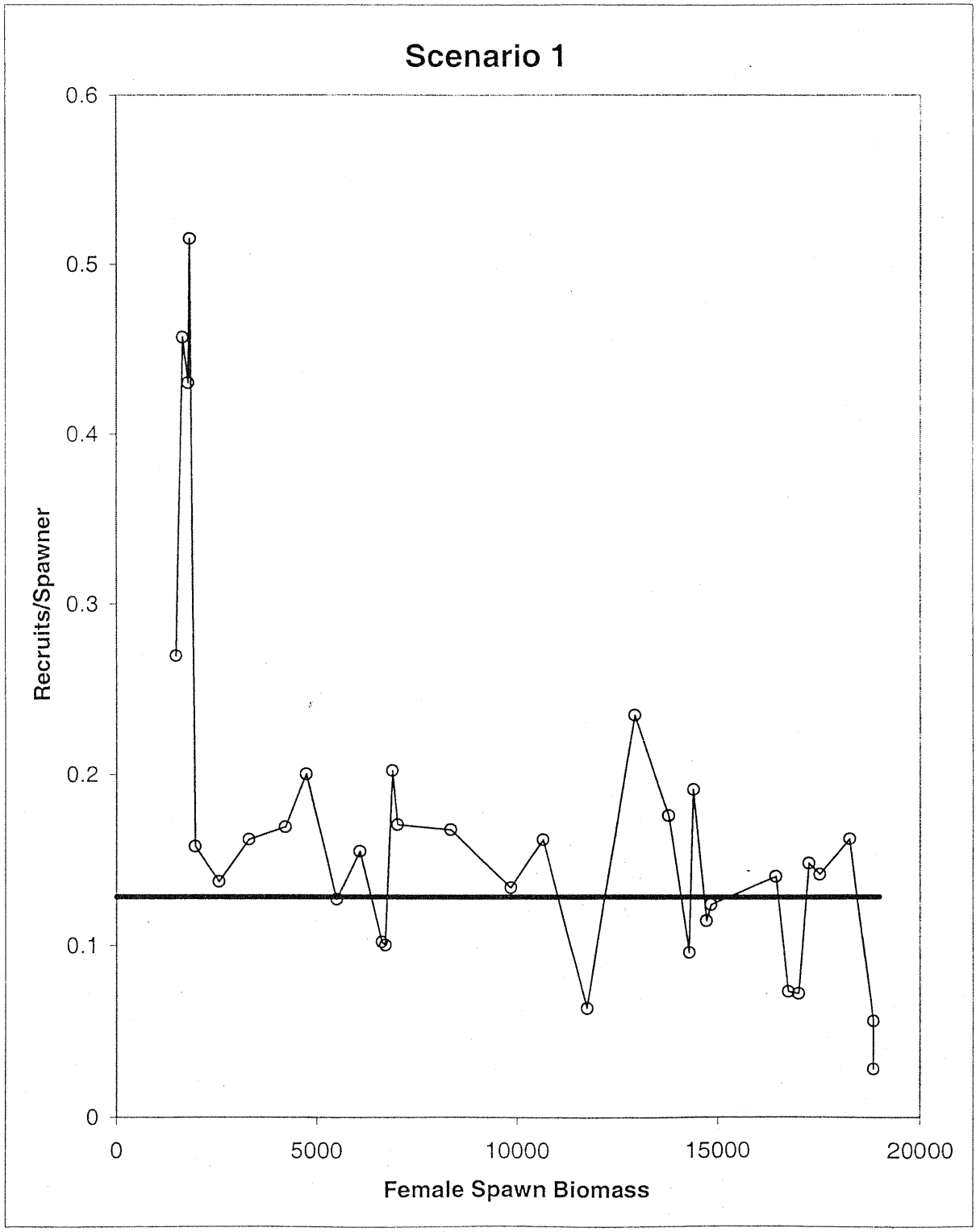


Figure 3. One hundred year projections of catch and spawning biomass assuming future recruitments come from the S/R curve (adjusting for log-transform bias), and catch is according to the 40-10 OY policy. Fspr levels from F50% to F70% are shown.

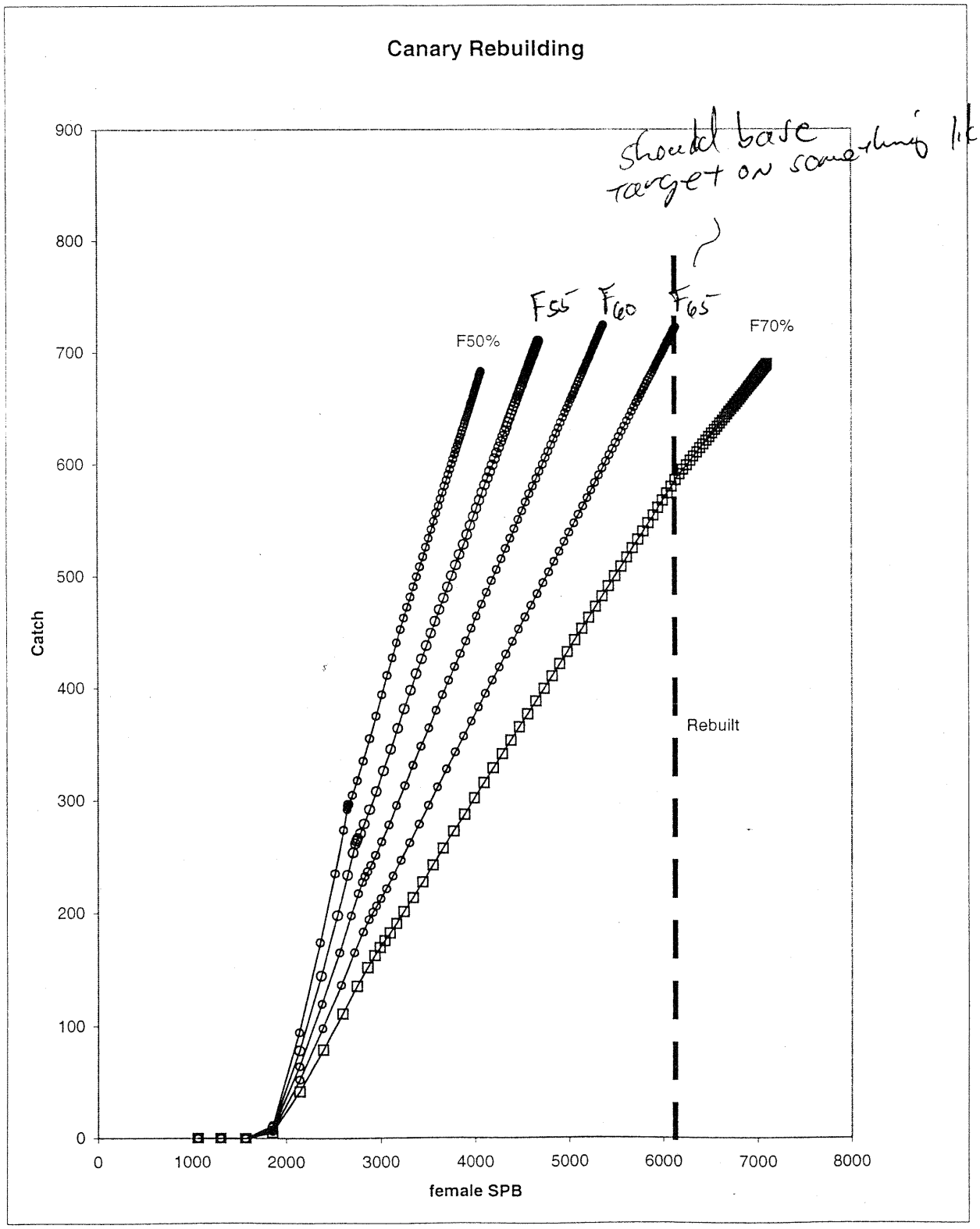


Figure 4. Relationship between time to rebuild in scenario #1 and the power for the rebuilding relationship.

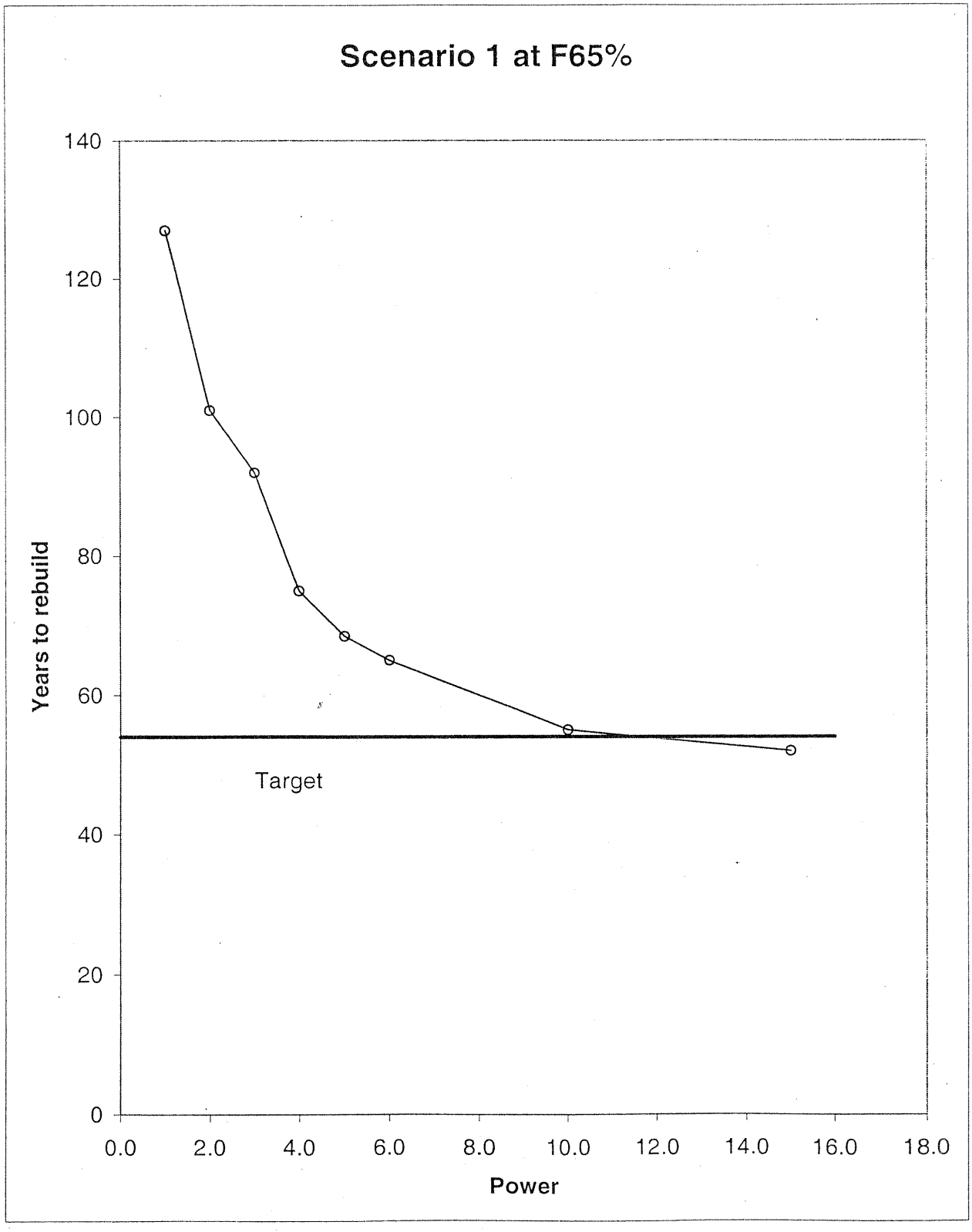


Figure 5. Estimated recruitment and spawner levels for scenario #2.

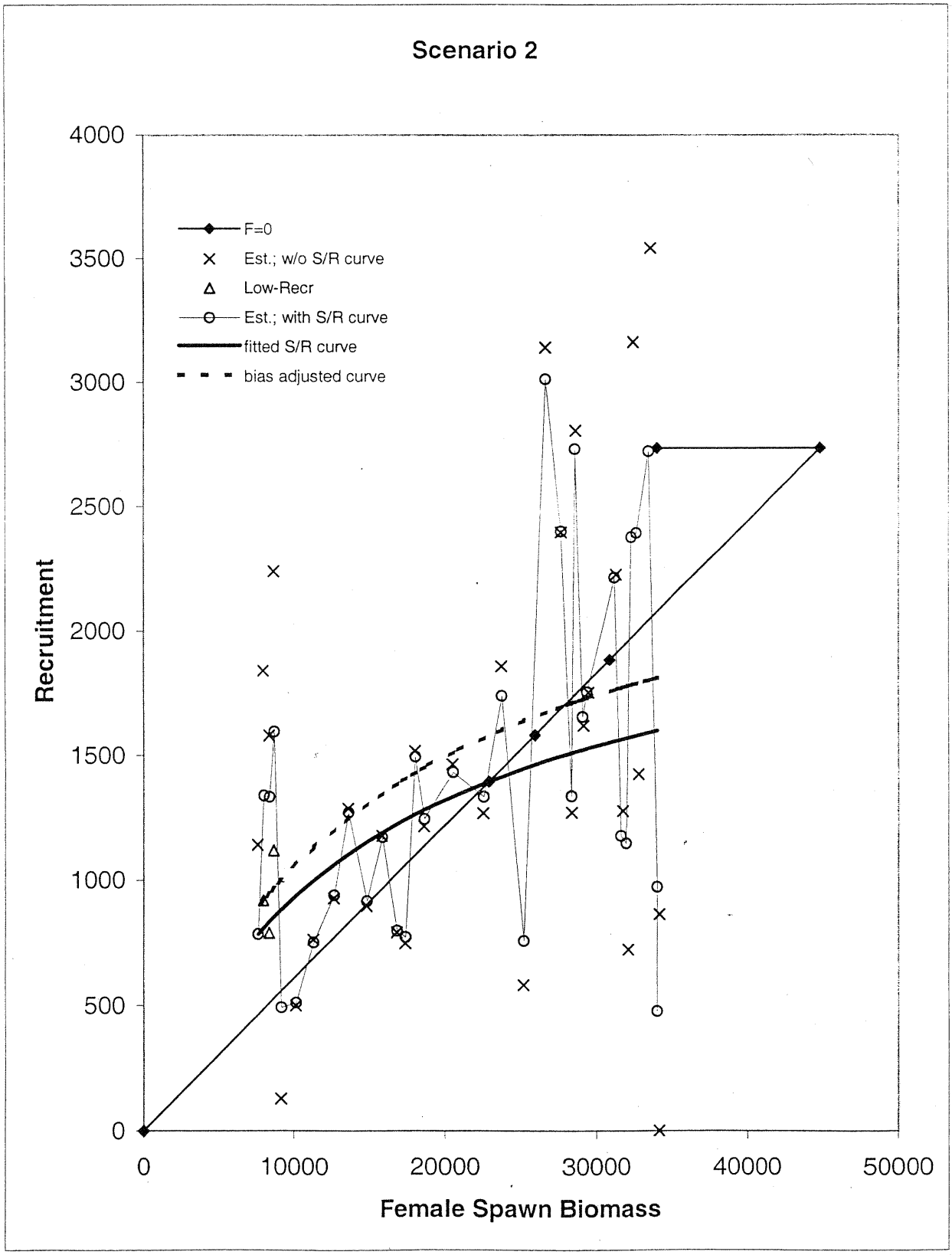


Figure 6. Estimated time series of recruits per spawner for scenario #2.

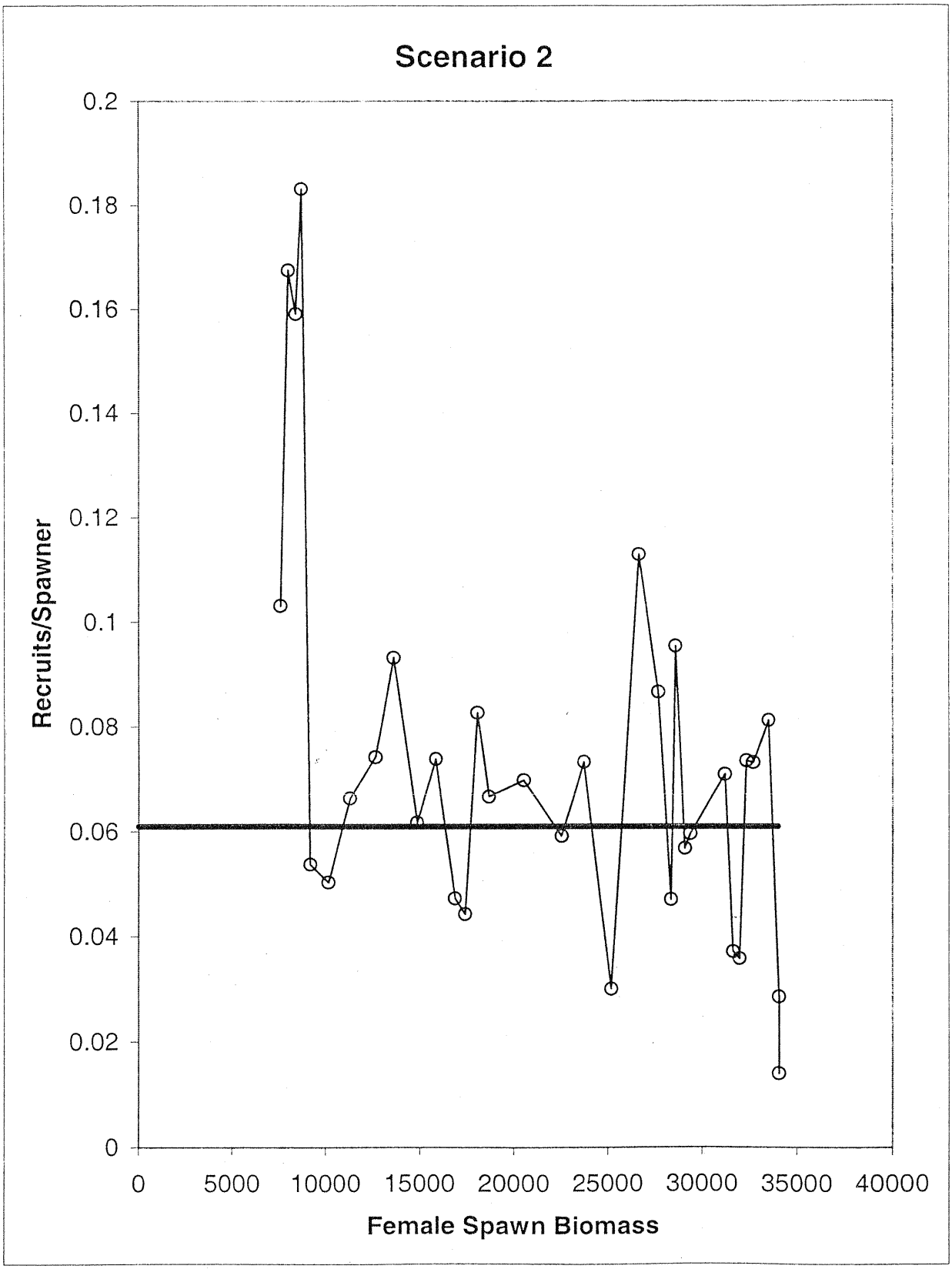
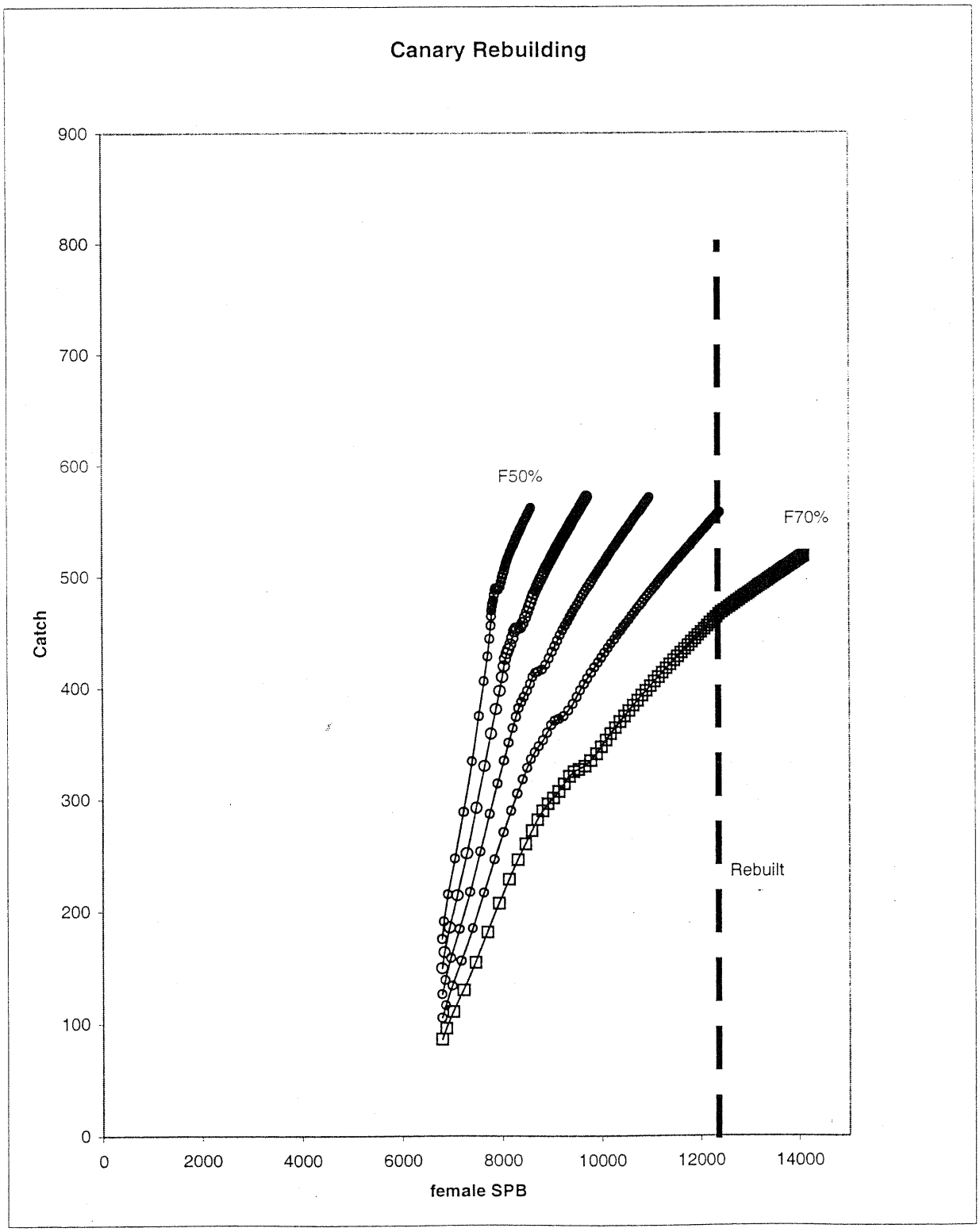


Figure 7. One hundred year projections of catch and spawning biomass assuming future recruitments come from the S/R curve (adjusting for log-transform bias), and catch is according to the 40-10 OY policy. Fspr levels from F50% to F70% are shown.



Fugure 8. Relationship between time to rebuild in scenario #2 and the power for the rebuilding relationship.

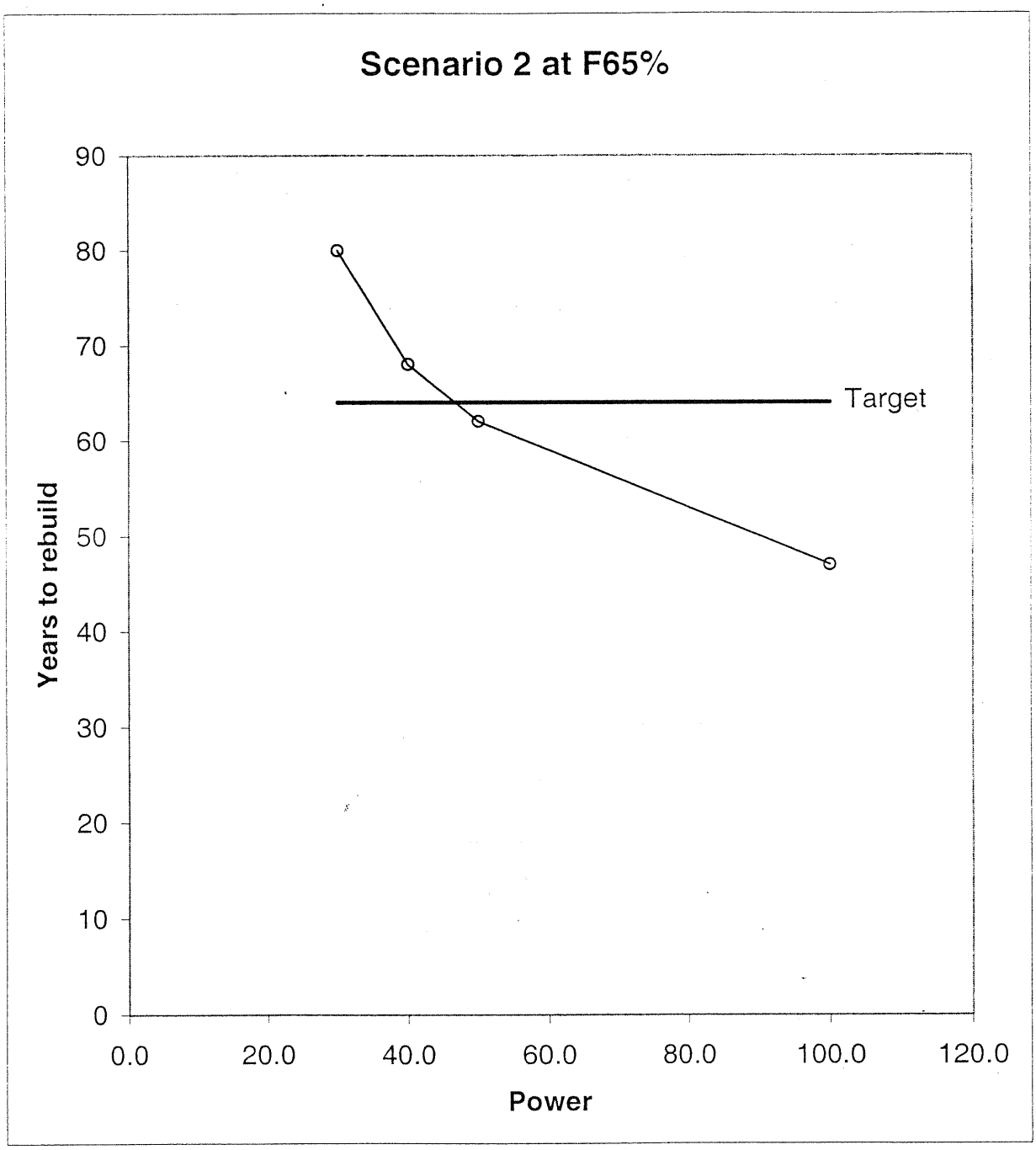


Figure 9. Summary rebuilding calculations for scenarios 1 and 2. Spawning biomass is expressed as a fraction fo the target level to facilitate comparison between the scenarios. Presentation is based upon the mean catch and spawning biomass from 200 simulations.