Revised Rebuilding Analysis for Widow Rockfish

Alec D. MacCall[1] and Andre Punt[2] 5/17/01

1. NMFS Santa Cruz Laboratory
110 Shaffer Rd.
Santa Cruz, CA 95060

email: Alec.MacCall@noaa.gov

2. School of Aquatic and Fishery Sciences
Box 5020
University of Washington
Seattle, WA 98195-5020
email: aepunt@u.washington.edu

Introduction

In 1998, the PFMC adopted Amendment 11 of the Groundfish Management Plan, which established a minimum stock size threshold of 25% of unfished biomass. Based on the most recent abundance estimates (Williams et al. 2000), widow rockfish has been declared formally to be overfished, thereby requiring development of a rebuilding plan. This rebuilding analysis provides information needed to develop the rebuilding plan for widow rockfish, and is in accord with the SSC Terms of Reference for Groundfish Rebuilding Plans.

The 2000 widow rockfish stock assessment included rebuilding projections, but those calculations contained an error and that analysis should be discarded. This rebuilding analysis supersedes the rebuilding analysis in the stock assessment document.

The stock has declined since fishing began in the late 1970's (Table 1). The relative decline in overall biomass has has been somewhat less than that for spawning output (the best measure of stock reproductive potential). Older, larger fish have a higher fecundity per body weight than do young fish. Widow rockfish bear their offspring live as larvae, and spawning output is measured in million fertilized eggs, at a stage prior to parturition of larvae.

Table 1. Current status of widow rockfish relative to pre-fishery years.

	Age 3+ Biomass (mt)	Spawning Output (million eggs)
Avg. 1968-79	197998	33490
1999	60551	8223
percentage	30.6%	24.6%

Data and Parameters

This analysis uses both the SSC Default Rebuilding Analysis developed by Andre Punt and the rebuilding simulation developed by Alec MacCall for previous analyses. Stock and recruitment histories are taken from the assessment by Williams et al. (2000). Life history parameters are a simplification of the two-area, two- sex model, time-varying selectivity model used in the assessment. The model is tuned to the most recent three years of the assessment, and achieves a close match to the characteristics of the original assessment model (Appendix 1).

Management Reference Points

Bmsy: The rebuilding target is the spawning abundance level that produces MSY. This cannot be determined easily, but experience in other fisheries has shown that B_{MSY} is often near 40% of the average initial unfished spawning abundance (B_0), and this value ($B_{40\%}$) is used as a proxy for B_{MSY} (see the SSC's Terms of Reference). Spawning abundance is measured in units of spawning output. Values of B_0 are estimated by dividing mean recruitment by the spawning output per recruit at F=0 (1.057 million eggs of spawning output per thousand recruits). Two estimates of B_0 were developed, based on use of pre-fishery recruitments (1965 to 1979 yearclasses) and all recruitments (Table 2). There is a strong statistical difference between pre-fishery (pre-1982) recruitments and post-fishing-down (post-1982) recruitments, as shown by a t-test (one-tailed, P=0.002). This difference is presumably due to the decline in spawning abundance, but also may be associated with a less favorable climate in the later period.

Table 2. Calculation of B_0 and rebuilding targets of spawning output (million eggs).

Source of recruitments	Pre-exploitation (1965-79)	All years
Mean recruitment	39615	31570
Estimated B_0	41872	33369
Rebuilding target	16749*	13348

* default target

Simulation of an unfished resource by re-sampling recruitments from the respective data sets provides frequency distributions of initial abundance that can be compared with the early abundances estimated in the stock assessment (Figure 1). The range of pre-exploitation biomasses given by the stock assessment is consistent with either frequency distribution, but the values from the assessment are somewhat low given the estimated sizes of pre-exploitation recruitments. Several explanations can be considered. Foreign fishing for whiting during the 1960s and 1970s probably had an incidental take (perhaps several hundred tons annually) of widow rockfish, so population biomasses estimated for the early (pre-exploitation) years of the assessment may not truly reflect pre-exploitation conditions. Low frequency climate variability could also have generated somewhat lower recruitment levels prior to 1965. Also, the initial conditions and earliest years of recruitments in the assessment model are prone to model mis-specification and may be less reliable than values estimated for later years.

The relationship between current stock status and the rebuilding target is shown relative to the historical stock-recruitment relationship in Figure 2. The rebuilding target of 16749 is similar to the stock status at the end of the 1980's, and tended to produce somewhat higher recruitments than have been seen recently.

Mean generation time: If the stock cannot be rebuilt in ten years, then the maximum time allowed for rebuilding is the length of time required to rebuild at F=0 plus one generation time. Mean generation time can be estimated from the net maternity function (product of survivorship and fecundity at age, Figure 3), and for widow rockfish is estimated to be 16.4 years, which is rounded to an integer value of 16 years.

Simulation Model

The simulation model tracks abundances at age, with an accumulator at age 20+. Values of weights at age, selectivity and fecundity are given in Appendix 1. Population simulations begin with the 1999 age composition estimated by the stock assessment (age 3 and older). Recruitments for birth years 1997 and 1998 are treated differently from later years. The 1997 value (recruited at age 3 in 2000) is based on the average value of the source data (recruits or recruits-per-spawning output). The 1998 value corresponds to an El Niño year, and is treated as equivalent to the corresponding value from 1992, another recent El Niño year. Subsequent recruitments or recruits per spawning output values are generated in two alternative ways. In the "R" simulations, recruitment values themselves are drawn randomly from those estimated for the spawning years 1983 to 1996. In the "R/S" method, recruitments are generated by a random draw of one of the historical values of R/S from the same years, which is multiplied by current spawning output (S) to obtain the following year's recruitment. One hundred simulations were conducted for each management scenario, using the same sets of random numbers across alternative model formulations in order to maximize comparability.

Tmax (Time to Rebuild at F=0): Four sets of simulations were run following the logical classification in the SSC's Terms of Reference, corresponding to the two alternative $B_{40\%}$ rebuilding targets in Table 2 and use of the "R" vs. "R/S" simulation approaches. Results are summarized in Table 3.

Table 3. Median rebuilding times for the case of F=0 (* indicates default case).

	$B_{40\%}$ =16749 (early years)	$B_{40\%}$ =13348 (all years)
Recent R/S	median T = 22yr*	median T = 14yr
Recent R	median T = 12yr	median T = 7yr

The "S/R" simulations have much longer rebuilding times than the "R" simulations. This is due to the effect of the currently low biomass, which results in much smaller recruitments in the initial years of rebuilding. The recent history of R/S has been stable, whereas recruitments themselves have been declining (Figure 4). The tendency for R to decline in more recent years (and at lower spawning abundances) is reason to reject the right-hand and lower cases in Table 3. Based on a median time of 22 years to rebuild, the maximum allowable median time to rebuild (Tmax) is 38 years.

Rebuilding Projections

Constant rate policies

Rebuilding projections used $B_{40\%}$ =16749 as the rebuilding target, and the "R/S" simulation method. Three constant fishing rate policies are presented, corresponding to 50%, 60%, 70% and 80% probabilities of reaching the rebuilding target in 38 years (Figure 5, Table 4). Increasing the rebuilding probability is equivalent to setting a slightly earlier median time to rebuild. The envelope of rebuilding trajectories is shown in Figure 6 for spawning output, and optimum yields. One half of the results fall between the 25 and 75 percentile lines, and 90

percent of the results fall between the 5 and 95 percentile lines. The highest fishing rate allowable has a 50% probability of success within the time limit.

Table 4. Alternative constant rate rebuilding policies.

Fishing rate	0.0288	0.0268	0.0243	0.0227	0
OY_{2002} (mt)	921	856	777	726	0
Prob. rebuild by Tmax (38yr)	50%	60%	70%	80%	100%
Median time to rebuild (yr)	38	37	35	34	22

Transition policies

The constant rate policies maintain a low harvest rate until rebuilding is achieved, and then abruptly increase the harvest rate to Fmsy. Transition policies allow an increase in harvest rate as the stock rebuilds, so that the final change to Fmsy is relatively small. Two important principles apply to transition policies. The first is that, in order to achieve rebuilding within the required time limit, any transitional increase in harvest rate at higher abundances must be balanced by a reduction in harvest rate earlier in the rebuilding process. The second principle is that if the transition harvest rate is too close to Fmsy as the rebuilding target is approached, further average population growth rate tends to cease, hindering final completion of rebuilding except as a random effect.

A “segmented” transition policy is considered here (Figure 7). The transition policy consists of an initial “setaside” fraction of the potential catch that is not taken in order to speed rebuilding. When abundance reaches a “transition abundance,” harvest rate rises with further increases in abundance to a maximum rate that is 90% of Fmsy, where estimated Fmsy=0.06. Two sets of policies are presented, corresponding to 50% and 70% probabilities of rebuilding within the time limit of 38 years (Table 5). The constant harvest rate policy is equivalent to a fraction set aside of zero. The “median years to transition” indicates how soon the fraction set aside would begin to pay off in increased harvest rates. Small amounts of fraction set aside do not result in sufficient rebuilding to have the median years to transition be much sooner than the corresponding value under the constant harvest rate policy. Envelopes of rebuilding trajectories for an example transition policy are shown and are compared with the median trajectory of the corresponding constant harvest rate policy in Figure 8.

Table 5. Performance of alternative transition policies.

	50% probability			70% probability		
FRACsetaside	Btrans	OY_{2002} (mt)	median years to transition	Btrans	OY_{2002} (mt)	median years to transition
0.0	0.40	920	38	0.40	777	35
0.2	0.37	737	31	0.39	623	31
0.3	0.36	646	26	0.38	546	28
0.4	0.32	554	19	0.36	468	23
0.5	0.28	462	13	0.33	391	19

Long-term outlook

The stock-recruitment data used in this analysis indicate that the rebuilt resource will be able to sustain an annual harvest of about 3300mt at a harvest rate of approximately F=0.06, near an SPR of 70%. This estimate is not very reliable, but will improve as we track stock productivity during rebuilding. Nonetheless, current information indicates that the resource is incapable of sustaining F50% at recent biomass levels and under recent environmental conditions. The resource would decline further at that fishing rate. It is widely suspected that the weak recruitments during the 1990's have been associated with unusually warm environmental conditions and low plankton abundances. Present understanding of environmental influences is severely limited, and the reliability of climate forecasts for the next few decades is insufficient to allow an environmentally-tuned rebuilding plan. However, if future decades are more favorable than the past decade for widow rockfish reproduction, higher productivity will result both in an earlier transition to normal harvest levels, and in higher sustainable yields once the stock is rebuilt.

References

Williams, E. H., A. D. MacCall, S. V. Ralston, and D. E. Pearson. 2000. Status of the widow rockfish resource in Y2K. In: Appendix to Status of the Pacific coast groundfish fishery through 2000 and recommended acceptable biological catches for 2001. Stock assessment and fishery evaluation. Pacific Fishery Management Council. 2130 SW Fifth Avenue, Suite 224, Portland, OR, 97201.

Appendix: Data used in rebuilding analysis (REBUILD.DAT file)

```
# Number of sexes
2
# Age range to consider (minimum age; maximum age)
3 20
# Is the maximum age a plus-group (1=Yes;2=No)
1
# Generate using historical recruitments (1) or historical Recuits/Spawner (2)
2
# Fecundity by age
#  3  4  5  6  7  8  9 10
5.71571E-05,0.000192238,0.014959075,0.06416152,0.161188109,0.276595084,0.36866541,0.4
41150816,0.508537268,0.566615354,0.618765039,0.665202145,0.706388539,0.74275911,0.774
748748,0.802838386,0.827408957,0.883903028
# Age specific information (Females then males), M, weight, selectivity and numbers
# Females
  0.150000 0.150000 0.150000 0.150000 0.150000 0.150000 0.150000 0.150000 0.150000
0.150000 0.150000 0.150000 0.150000 0.150000 0.150000 0.150000 0.150000 0.150000
0.260608092 0.382403028 0.516070194 0.654578339 0.792170662 0.924895027 1.049946766
1.165864012 1.271881655 1.367769472 1.453797243 1.530488701 1.598486647 1.658533881
1.711419248 1.757704614 1.798297893 1.89163453
0.000593893 0.005686670 0.054780300 0.362629000 0.846479000 0.998077000 0.963625000
0.904980000 0.847668000 0.793880000 0.743284000 0.695263000 0.649123000 0.604100000
0.559340000 0.513919000 0.466977000 0.41801300
  2958.5 7588.5 6246.5 6863.0 2061.5 5577.5 2272.0 1669.5 1646 1334.5 542.5 675 517 141 171
386.5 239 935
# Males
  0.150000 0.150000 0.150000 0.150000 0.150000 0.150000 0.150000 0.150000 0.150000
0.150000 0.150000 0.150000 0.150000 0.150000 0.150000 0.150000 0.150000 0.150000
0.303357216 0.410118829 0.515691806 0.615331188 0.706167139 0.787117388 0.857984578
0.919248338 0.971690941 1.016243337 1.053962138 1.085701311 1.112314822 1.134579656
1.153172796 1.168719902 1.181646637 1.20887895
0.000590021 0.005633680 0.054211900 0.359841000 0.844941000 0.998171000 0.962820000
0.902934000 0.844470000 0.789659000 0.738174000 0.689400000 0.642654000 0.597194000
0.552196000 0.506774000 0.460107000 0.41171100
  2958.5 7588.5 6246.5 6863.0 2061.5 5577.5 2272.0 1669.5 1646 1334.5 542.5 675 517 141 171
386.5 239 935
# Number of simulations
1000
# Recruitment and Spanwer biomasses
# Number of years
32
```

```
# Year, Recruitment, Spawner biomass, Used to compute B0, Used to project based
# on R, Used to project based on R/S
1968  29603 30662 1 0 0
1969  39748 30664 1 0 0
1970  37990 30668 1 0 0
1971  47532 30716 1 0 0
1972  39929 30910 1 0 0
1973 112579 31371 1 0 0
1974  42955 32096 1 0 0
1975  20667 33298 1 0 0
1976  11070 35254 1 0 0
1977  23596 37731 1 0 0
1978  39407 39189 1 0 0
1979  02219 39316 1 0 0
1980  73666 38032 1 0 0
1981  48325 32253 1 0 0
1982  24940 25329 1 0 0
1983  47876 19457 0 0 0
1984  62307 17592 0 0 0
1985  21667 17055 0 0 0
1986  13094 16665 0 1 1
1987  32540 16481 0 1 1
1988  28129 15782 0 1 1
1989  16110 14978 0 1 1
1990  29622 13019 0 1 1
1991  25813 11553 0 1 1
1992  18452 11079 0 1 1
1993  18265 10632 0 1 1
1994  31413 09860 0 1 1
1995   8327 09533 0 1 1
1996  21956 08985 0 1 1
1997  16901 08664 0 1 1
1998  17637 08261 0 1 1
1999   5917 08223 0 1 1
# Number of years with pre-specified catches
3
# catches for years with pre-specified catches
1999 4363
2000 4033
2001 2300
# Number of future recruitments to override
2
# Process for overiding (-1 for average otherwise index in data list)
2000 -1
2001 28
# Which probability to product detailed results for (1=0.5,2=0.6,etc.)
2
```

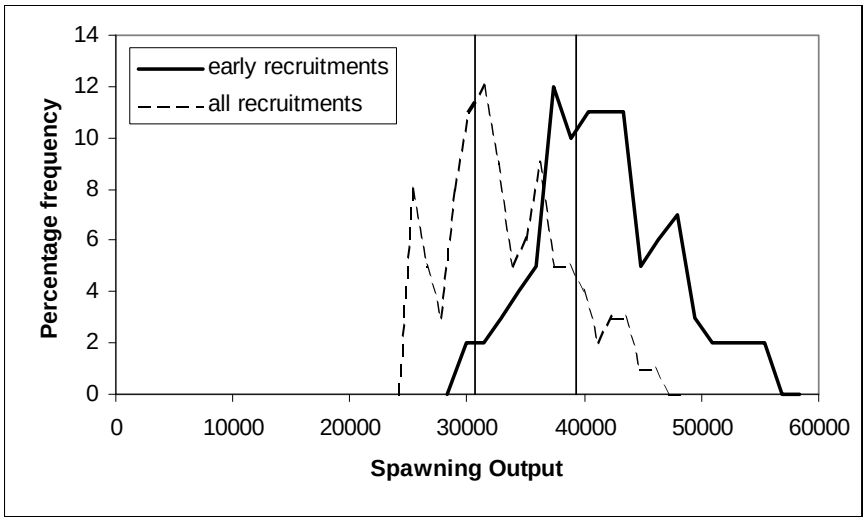

Figure 1. Simulated frequency distributions of unfished spawning output based on either pre-fishery recruitments or all recruitments. Vertical lines represent the range of pre-fishery spawning abundances estimated by the stock assessment.

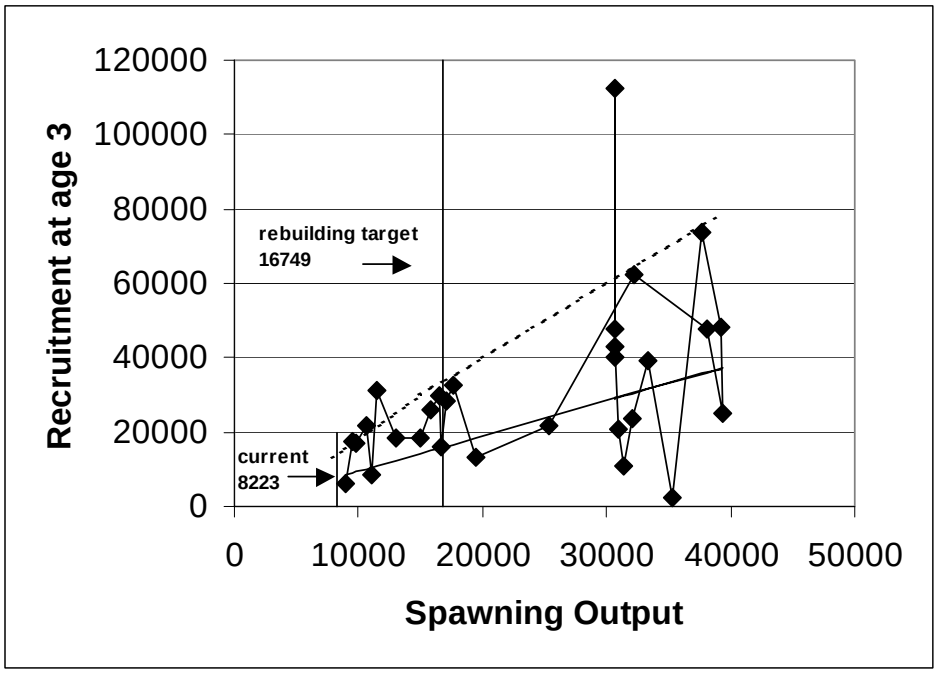

Figure 2. Historical stock-recruitment relationship for widow rockfish, showing relationship of rebuilding target ($B_{40\%}$) to current spawning abundance. Solid diagonal line is replacement level of recruitment at F=0; dashed diagonal line is replacement level of recruitment under $F_{50\%}$ policy with 40-10 adjustment.

Figure 3. Net maternity function for widow rockfish.

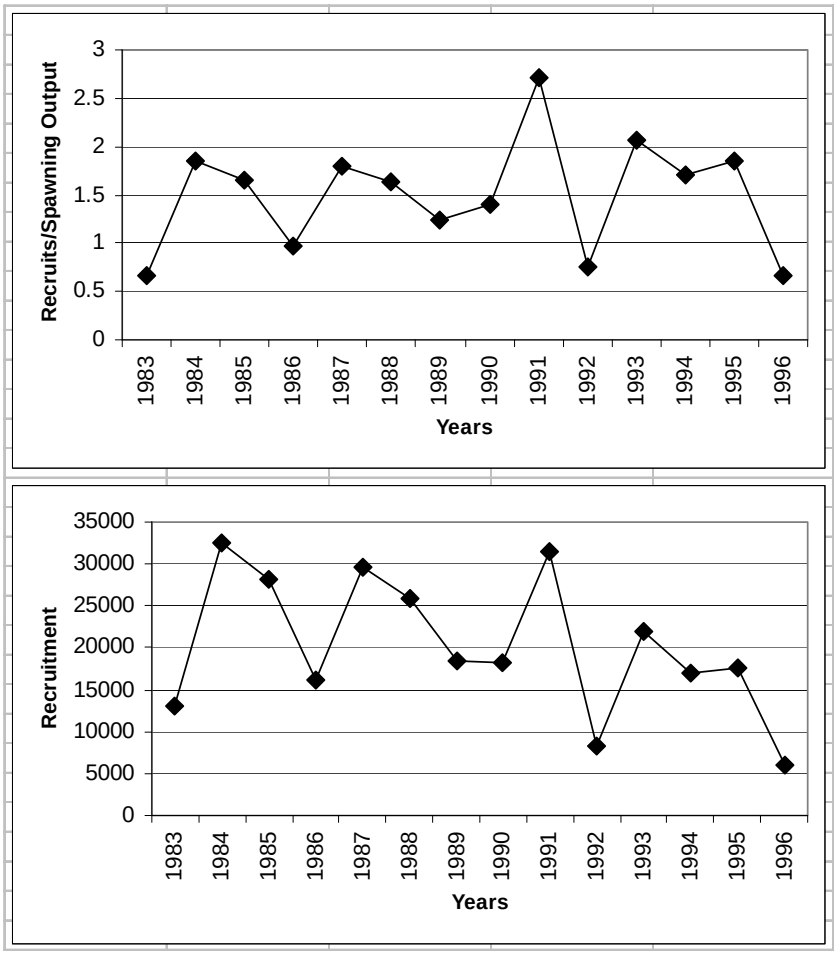

Figure 4. Recent trends in recruitment rates of widow rockfish.

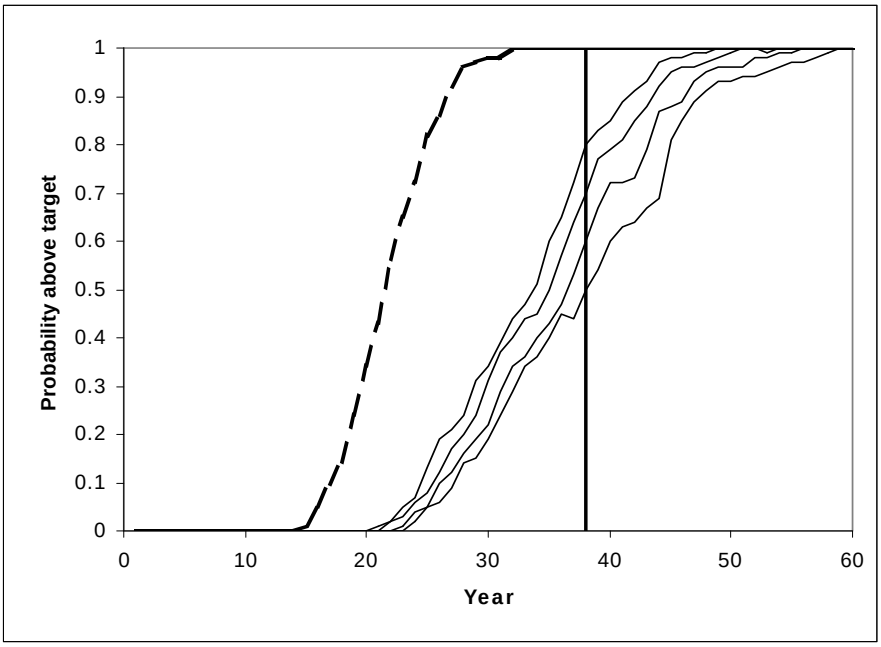

Figure 5. Probability of rebuilding at alternative constant harvest rates. Dashed line is F=0, thin solid lines are 80%, 70%, 60% and 50% from top to bottom. Vertical line is maximum median rebuilding time, Tmax=38 years.

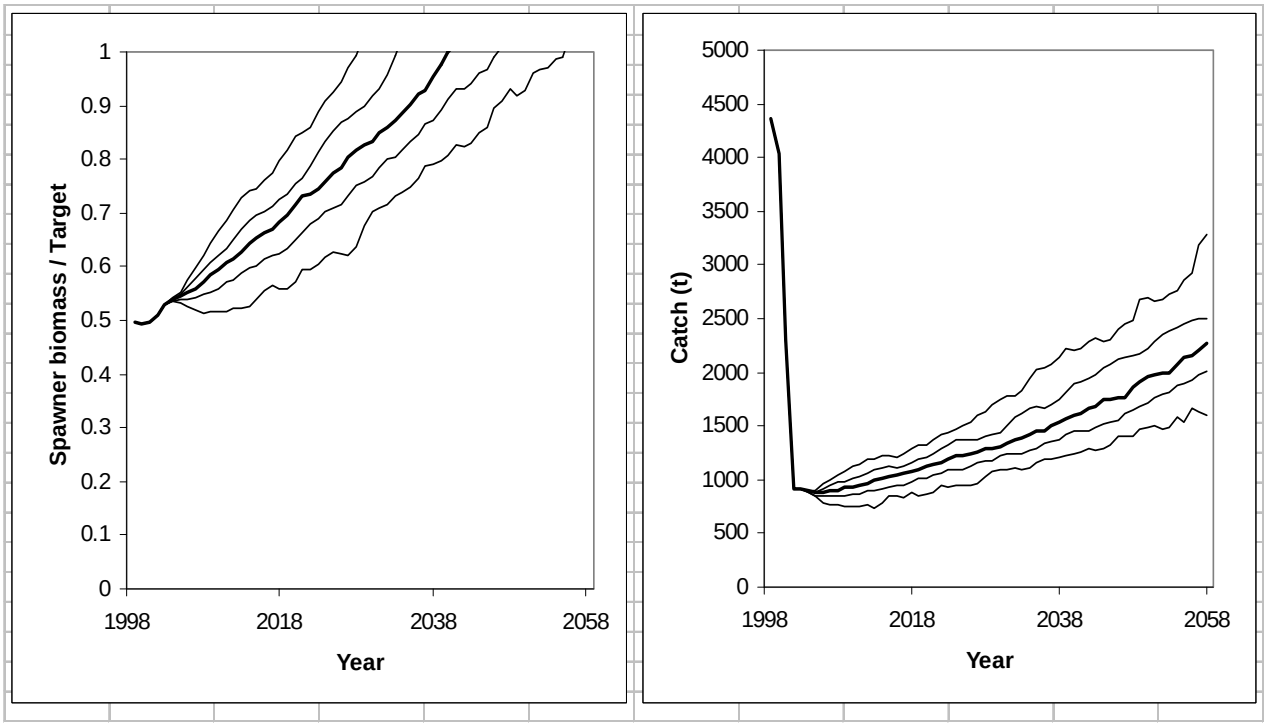

Figure 6. Envelopes of rebuilding trajectories for spawning output (left) and OY (right) under a constant harvest rate policy with 50% probability of rebuilding by Tmax=38 years. Lines are 5, 25, 50 (median, dark line), 75 and 95 percentiles of values in the given year.

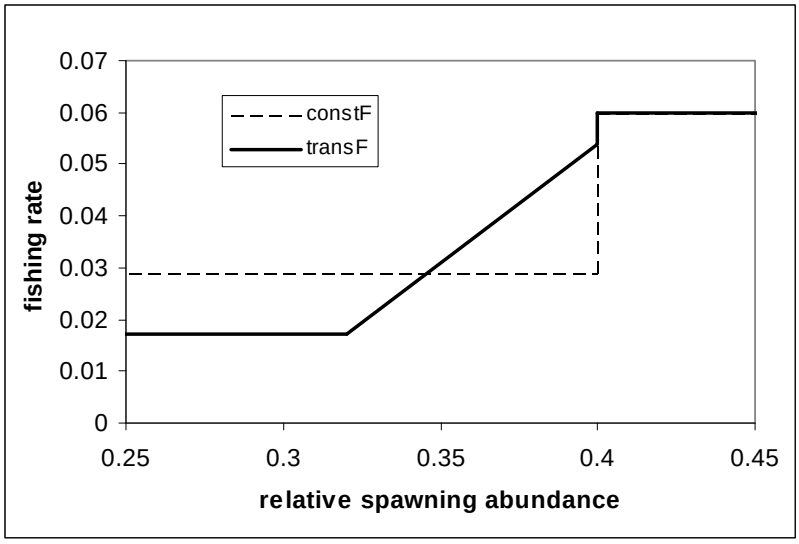

Figure 7. Comparison of fishing rates under constant harvest rate policy and segmented transition harvest rate policy

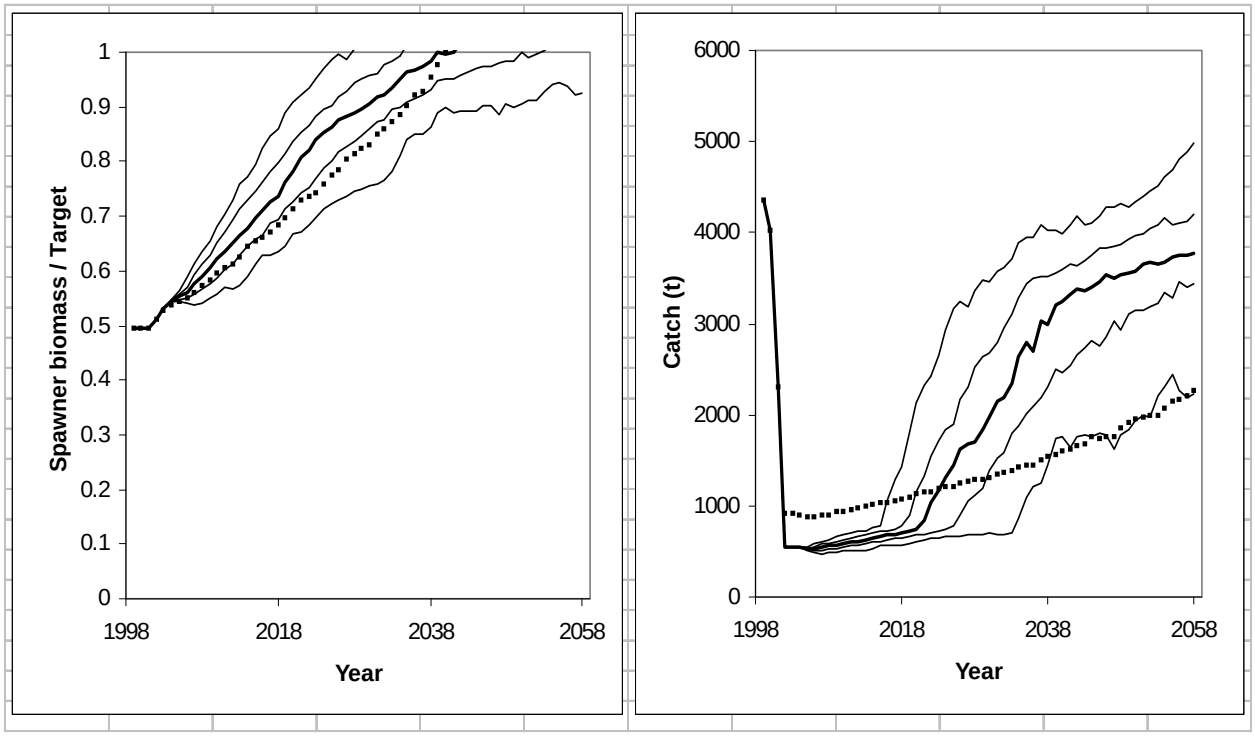

Figure 8. Envelopes of rebuilding trajectories for spawning output (left) and OY (right) under a segmented transition policy (probability=50%, FRACsetaside=0.4, Btrans=0.32). Lines are 5, 25, 50 (median, dark line), 75 and 95 percentiles. Dotted line is median from corresponding constant harvest rate policy.