**Rebuilding Update for Pacific Ocean Perch**

*October 6, 2005*

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# 1. Introduction

The Pacific Fishery Management Council (PFMC) adopted Amendment 11 to its Groundfish Management Plan in 1998. This amendment established a definition for an overfished stock of 25% of the unfished spawning biomass ($0.25B_0$). NMFS determined that a rebuilding plan was required for Pacific ocean perch (*Sebastes alutus*) in March 1999 based on the most recent stock assessment at that time (Ianelli and Zimmerman, 1998). The PFMC began developing a rebuilding plan for Pacific ocean perch (based upon a rebuilding analysis; August 1999; A. MacCall, pers. comm.) and submitted this plan to NMFS in February 2000. However, NMFS deferred adoption of the plan until the stock assessment was updated and reviewed, which was later that year (Ianelli *et al.*, 2000). Punt (2002) conducted a rebuilding analysis for Pacific ocean perch based on the stock assessment conducted by Ianelli *et al*. (2000) that was consistent with the Terms of Reference for rebuilding analyses developed by the PFMC SSC (SSC, 2001; revised in 2005).

A new stock assessment for Pacific ocean perch stock was conducted in 2003 (Hamel *et al*., 2003), and updated in 2005 (Hamel, 2005). This assessment, similar to that of Ianelli *et al*. (2000), involved fitting an age-structured population dynamics model to catch, catch-rate, length-frequency, age-composition, and survey data. Ianelli *et al*. (2000), Hamel *et al*. (2003), and Hamel (2005) present results based on maximum likelihood and Bayesian estimation frameworks. A rebuilding analysis was conducted by Punt (2002), based upon the estimates corresponding to the maximum of the posterior density function (the MPD estimates) from Model 1c of Ianelli *et al*. (2000) because the STAR panel that evaluated the 2000 Pacific Ocean perch stock assessment selected this model variant as the "best assessment" (PFMC, 2000). In contrast, the STAR panel that evaluated the 2003 assessment of Pacific ocean perch endorsed both the MPD estimates and the distributions for the model outputs that arose from the application of the MCMC algorithm to sample equally likely parameter vectors from the posterior distribution (PFMC, 2003). Punt et al. (2003) conducted a rebuilding analysis with runs based upon both the MPD estimates and the MCMC outputs. The council adopted a rebuilding plan based upon the results of the MCMC analysis (sampling from the full Bayesian posterior). For this update to the previous rebuilding analysis for Pacific ocean perch, selections are taken to be the same as those on which the rebuilding analysis conducted by Punt et al. (2005) was based. Analyses using the MPD estimates are conducted for comparison.

# 2. Specifications

## 2.1 Selection of $B_0$

It is common to define $B_0$ in terms of the recruitment in the first years of the assessment period. However, this rebuilding analysis and those of Punt (2002) and Punt et al. (2003) determines $B_0$ from the fitted stock-recruitment relationship because this seems inherently more consistent with the assumptions underlying the original stock assessment. The MPD estimate of $B_0$ is 37,838 units of spawning output[1] while the posterior median and 90% intervals for $B_0$ are 35,371 and (28,022; 44,866). These values for $B_0$ are slightly lower than those on which the previous rebuilding analysis was based (MPD: 39,198, posterior: 37,230 (29,035; 47,393)). The MPD estimate of the depletion of the spawning output at the start of 2005 is 0.234 (2003: 0.254) while the posterior median and 90% intervals are 0.276 (0.198; 0.371) (2003: 0.277 (0.201; 0.384)).

## 2.2 Generation of future recruitment

Recruitment in the assessment and projection models for Pacific ocean perch relate to the abundance of animals aged 3 years. The assessment of Pacific ocean perch by Hamel *et al*. (2003) and its update

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[1] Spawning output is defined in terms of mt of mature females.

(Hamel, 2005) both include the assumption that, *apriori*, recruitment is related to spawning output according to a Beverton-Holt stock-recruitment relationship. The rebuilding analysis conducted by Punt et al. (2003) included three approaches: basing the projections on resampling historical recruitments or from those for the years 1965-2001, basing the projections on resampling historical recruits per spawner for those same years, or assuming a Beverton-Holt spawner recruit relationship. The first approach was chosen by the council for the final rebuilding plan.

Figure 1 plots the MPD estimates of recruitment and recruits / spawning output from the assessments conducted by Hamel *et al*. (2003) and Hamel (2005). The rationale for generating future recruitment by sampling historical recruitment for rebuilding analysis conducted by Punt (2002) was that 1965-1998 was a period of relative stability in recruitment. In contrast to recruitment, recruits / spawning output showed an increasing trend over time. The situation is now slightly more complicated because there is no longer an obvious increasing trend in recruits / spawning output with time for either the 2003 or 2005 assessments, nor are the recruitments completely stable. In keeping with the previous decision, resampling historical recruitment (now from the years 1965-2003) is used exclusively for the analyses in this document. Hamel (2005) estimated steepness for Pacific ocean perch to be 0.55.
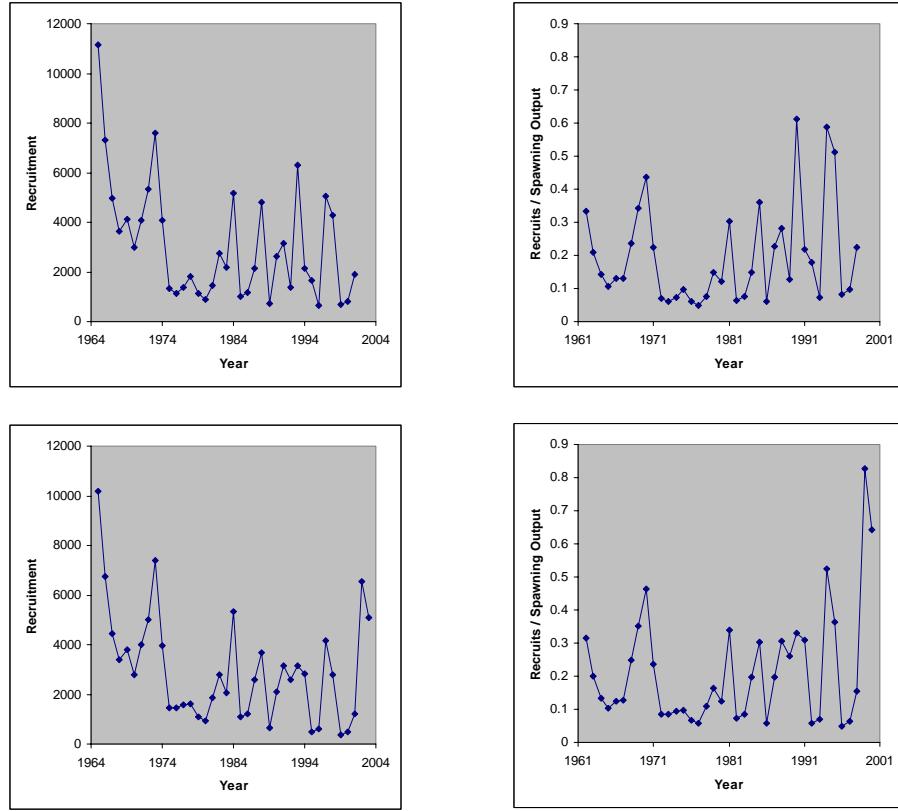


**Figure 1**: Recruitment and recruits per spawner for assessments of Pacific ocean perch conducted in 2003 and 2005 (upper and lower panels respectively).

*2.3 Mean generation time*
The mean generation time is defined as the mean age weighted by net spawning output (see Figure 2 for a plot of net spawning output *versus* age based on the MPD estimates). The best estimate of the mean generation time for the full posterior is 28 years, and for the MPD it is 29 years. These are unchanged from the 2003 rebuilding analysis.

**Net Spawning Output**
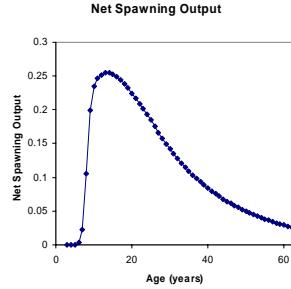
**Figure 2**: MPD relationship between net spawning output and age for Pacific Ocean perch.

*2.4 The harvest strategies*

Table 1 summarizes those options considered in the analyses of this paper. These include calculating the probability of rebuilding by $T_{target}$ and $T_{max}$ from the last rebuilding analysis or by a recalculated $T_{max}$ assuming the same rebuild SPR as in the previous analysis (cases 1, 3, and 5). The rebuild SPR of 0.696 was calculated from the rebuild fishing mortality of 0.0257 computed by Punt et al. (2003) and other biological parameters from the 2003. Cases 2, 4, and 6 involve recalculating the SPR given a 50% probability of rebuilding by $T_{target}$ or a 70% probability of rebuilding by $T_{max}$. Case 7 estimates the probability of rebuilding by the previous $T_{max}$ given that the catch series adopted by the council following the 2003 rebuilding analysis is continued. Case 8 uses the median catch series from case 4. These 8 cases are also explored using the MPD results for comparison.

**Table 1**: Harvest strategy options considered in this document.

| Case | Future recruitment | $T_{max}$ | $SPR_{rebuild}$ | $P_{max}$ |
|------|--------------------|-----------|-----------------|-----------|
| 1 | Recruits | 2026 | 0.696 | Re-estimated |
| 2 | Recruits | 2026 | Re-estimated | 0.5 |
| 3 | Recruits | 2042 | 0.696 | Re-estimated |
| 4 | Recruits | 2042 | Re-estimated | 0.7 |
| 5 | Recruits | Re-estimated | 0.696 | Re-estimated |
| 6 | Recruits | Re-estimated | Re-estimated | 0.7 |
| 7 | Recruits | 2042 | 2003 catch series | Re-estimated |
| 8 | Recruits | 2042 | Case 4 catch series | Re-estimated |

*2.5 Other specifications*

The calculations of this document were performed using Version 2.8 of the rebuilding software developed by Punt (2005) and the results are based on 1,000 Monte Carlo replicates (analyses based on the MPD estimates) and 3,000 Monte Carlo replicates (analyses based on 1,000 random samples from the full Bayesian posterior distribution). The selection of 1,000 replicates is based on the evaluation of Monte Carlo precision conducted by Punt (2002). The analyses based on full posterior distribution involve 3 simulations for each of 1,000 samples for the posterior.

The definition of "recovery by year *y*" in this analysis is that the spawning output reaches $0.4B_0$ by year *y* (even if it subsequently drops below this level due to recruitment variability). Appendix 1 lists the MPD estimates for the biological and technological parameters and the age-structure of the population at the start of 2000 / 2005, while Appendix 2 lists the MPD time-series of recruitment and

spawning output.  The input to the rebuilding program for cases 3 and 4 is given as Appendix 3. The catch for 2005 and 2006 were set to 447 mt (the Council-selected *OYs* for 2005-2006).

## 3. Results

### 3.1 Time-to-recovery

Figure 3 shows the distribution for the number of years beyond the year 2000 that it would have taken to recover to $0.4B_0$ had there been no harvest since 2000. Results are shown for analyses based on the MPD estimates (left panel) and the full Bayesian posterior (right panel). As expected, the distribution based on the full Bayesian posterior has a much longer tail than that based on the MPD estimates. The median time to recover to 0.4 $B_0$ in the absence of catches with 50% probability is termed $T_{min}$. The values for $T_{min}$ (15 and 19 years respectively for the full Bayesian and MPD results) are greater than the value of $T_{min}$ from the previous rebuilding analysis (14 and 17 years respectively). If $T_{max}$ is determined using the new information on the depletion level and the age-structure of the population in 2000, it changes only slightly from 2042 to 2043 if the calculations are based on the full Bayesian estimates but increases to 2048 if the calculations are based on the MPD results.
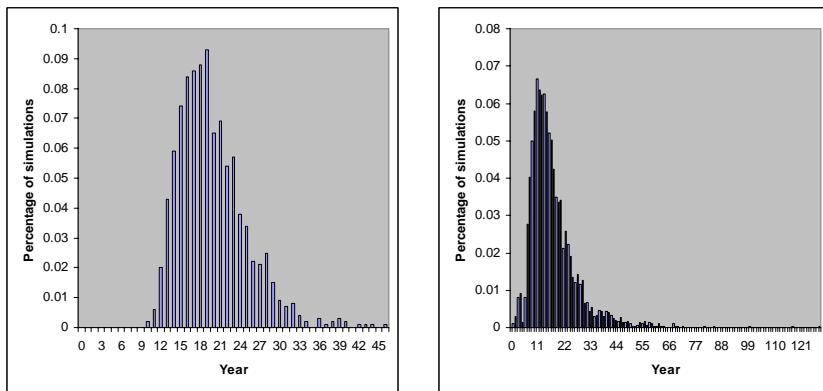


**Figure 3**: Time to recover to $0.4B_0$ in the absence of catches from 2000 on for the base-case analysis. The results based on the MPD estimates are shown in the left panel and those based on full Bayesian posterior in the right panel.

### 3.2 OYs and fishing mortalities

Table 2 gives summary statistics from the 2003 rebuilding plan and the current analysis for full posterior and MPD results. Tables 3 and 4 list some key output statistics for six rebuild strategies (probabilities of recovery in the maximum allowable rebuild period of 0.5, 0.7, the 40-10 rule, the ABC rule, the strategy of setting SPR from 2007 equal to 0.696, and going forward with the chosen strategy from the previous rebuilding analysis). Table 3 lists results based on the full Bayesian posterior. Results are shown for each of the analysis options outlined in Table 1. Table 4 lists results based on the MPD estimates.

**Table 2**:  Summary statistics.

| Case | 2003 | Bayesian | MPD |
|---|---|---|---|
| Year in which rebuilding commenced | 2000 | 2000 | 2000 |
| Present year | 2003 | 2005 | 2005 |
| Tmin | 14 years | 15 years | 19 years |
| Mean generation time | 28 years | 28 years | 29 years |
| Tmax | 2042 | 2043 | 2048 |

**Table 3**: Five management-related quantities for various rebuild strategies for the projections based on the full posterior distribution.

| Scenario / Quantity | *Rebuild Strategy* | | | | |
| --- | --- | --- | --- | --- | --- |
| | $P_{max}$=0.5 | Defined | $P_{max}$=0.7 | 40-10 rule | ABC rule |
| **2003 Rebuilding analysis ($T_{max}$=2042)** | | | | | |
| Fishing mortality rate | | | 0.0257 | | |
| SPR | | | 0.696 | | 0.500 |
| $OY_{2004}$ (mt) | | | 443.6 | 612.6 | 979.9 |
| $P_{max}$ | | | 70.1 | 38.9 | 27.9 |
| $T_{target}$ | | | 2026.4 | N/A | N/A |
| **Cases 1/2 ($T_{max}$=2026)** | | | | | |
| Fishing mortality rate | 0.0304 | | | | |
| SPR | 0.633 | 0.696 | | | 0.500 |
| $OY_{2007}$ (mt) | 521.7 | 397.0 | | 514.5 | 900.0 |
| $P_{max}$ | 50.0 | 59.7 | | 34.2 | 26.7 |
| $T_{target}$ | 2026.0 | 2021.4 | | N/A | N/A |
| **Cases 3/4 ($T_{max}$=2042)** | | | | | |
| Fishing mortality rate | | | 0.0290 | | |
| SPR | | 0.696 | 0.644 | | 0.500 |
| $OY_{2007}$ (mt) | | 397.0 | 498.1 | 514.5 | 900.0 |
| $P_{max}$ | | 78.2 | 70.0 | 48.5 | 38.0 |
| $T_{target}$ | | 2021.4 | 2025.0 | N/A | N/A |
| **Cases 5/6 ($T_{max}$=2043)** | | | | | |
| Fishing mortality rate | | | 0.0295 | | |
| SPR | | 0.696 | 0.640 | | 0.500 |
| $OY_{2007}$ (mt) | | 397.0 | 505.9 | 514.5 | 900.0 |
| $P_{max}$ | | 78.9 | 70.0 | 49.0 | 38.6 |
| $T_{target}$ | | 2021.4 | 2025.4 | N/A | N/A |
| **Cases 7/8 ($T_{max}$=2042)** | | | | | |
| Fishing mortality rate | | | | | |
| SPR | | N/A | N/A | | |
| $OY_{2007}$ (mt) | | 449.0 | 498.0 | | |
| $P_{max}$ | | 74.3 | 68.2 | | |
| $T_{target}$ | | 2021.3 | 2024.8 | | |

## 4. Selection of a preferred variant

The Council interim choice for $P_{max}$ is 70%. The 2007 OYs in Tables 3 and 4, based upon either this $P_{max}$ or the previous SPR, range from 356 to 506 mt. Table 5 shows 10 year projections for the 6 requested runs (Cases 1-6). The 2007 OY from the previous adopted rebuilding plan is 449 mt, within the range of the current estimates. Appendix 4 lists the annual catches (2007+) for five of the harvest strategies in Tables 3 and 4, for cases 3, 4, and 7, including the Pmax = 0.7, the 2003 catch series, SPR = 0.696, the 40-10 rule and the ABC rule. Appendix 5 lists the annual median spawning output for those five rebuilding strategies. Appendix 6 lists the annual median spawning output relative to $B_{40}$ for the five rebuilding strategies. Appendix 7 lists the annual median ABC for the five rebuilding strategies.

**Table 4**: Five management-related quantities for various rebuild strategies for the projections based on the MPD estimates

| Scenario / Quantity | Rebuild Strategy | | | | |
|---|---|---|---|---|---|
| | $P_{max}$=0.5 | Defined | $P_{max}$=0.7 | 40-10 rule | ABC rule |
| **2003 Rebuilding analysis ($T_{max}$=2042)** | | | | | |
| Fishing mortality rate | | | 0.0218 | | |
| SPR | | | 0.0731 | | 0.500 |
| $OY_{2004}$ (mt) | | | 334.7 | 449.3 | 840.5 |
| $P_{max}$ | | | 69.9 | 12.2 | 2.0 |
| $T_{target}$ | | | 2031.6 | N/A | N/A |
| **Cases 1/2 ($T_{max}$=2026)** | | | | | |
| Fishing mortality rate | 0.0149 | | | | |
| SPR | 0.783 | 0.696 | | | 0.500 |
| $OY_{2007}$ (mt) | 230.2 | 356.4 | | 449.3 | 840.5 |
| $P_{max}$ | 50.0 | 27.9 | | 4.4 | 0.7 |
| $T_{target}$ | 2026.0 | 2032.6 | | N/A | N/A |
| **Cases 3/4 ($T_{max}$=2042)** | | | | | |
| Fishing mortality rate | | | 0.0231 | | |
| SPR | | 0.696 | 0.696 | | 0.500 |
| $OY_{2007}$ (mt) | | 356.4 | 356.5 | 449.3 | 840.5 |
| $P_{max}$ | | 70.1 | 70.0 | 14.2 | 4.5 |
| $T_{target}$ | | 2032.6 | 2032.6 | N/A | N/A |
| **Cases 5/6 ($T_{max}$=2048)** | | | | | |
| Fishing mortality rate | | | 0.0256 | | |
| SPR | | 0.696 | 0.673 | | 0.500 |
| $OY_{2007}$ (mt) | | 356.4 | 394.2 | 449.3 | 840.5 |
| $P_{max}$ | | 78.1 | 70.0 | 17.9 | 6.0 |
| $T_{target}$ | | 2032.6 | 2035.6 | N/A | N/A |
| **Case 7 ($T_{max}$=2042)** | | | | | |
| Fishing mortality rate | | | | | |
| SPR | | N/A | N/A | | |
| $OY_{2007}$ (mt) | | 449.0 | 357.0 | | |
| $P_{max}$ | | 57.6 | 67.9 | | |
| $T_{target}$ | | 2037.5 | 2032.3 | | |

Figures 5 and 6 contrast the time-trajectory of the probability of recovery and of catch for 5 rebuild strategies, with $T_{max}$ = 2042: Probability of recovery equals 0.7, the 2003 rebuilding plan catch series, zero catch, the 40-10 rule and the ABC rule. Figure 5 shows the results based upon the full Bayesian posterior, and Figure 6 shows the results based upon the MPD figures.

Table 5: Ten year catch/OY projections for the six requested runs.

| Year | Run 1 | Run 2 | Run 3 | Run 4 | Run 5 | Run 6 |
|---|---|---|---|---|---|---|
| P | 0.597 | 0.5 | 0.782 | 0.7 | 0.789 | 0.7 |
| SPR | 0.696 | 0.633 | 0.696 | 0.644 | 0.696 | 0.640 |
| F | 0.0231 | 0.0304 | 0.0231 | 0.0290 | 0.0231 | 0.0295 |
| $T_{max}$ | | | **2042** | **2042** | **2043** | **2043** |
| $T_{target}$ | **2026** | **2026** | 2021 | 2025 | 2021 | 2025 |
| 2007 | 397 | 522 | 397 | 498 | 397 | 506 |
| 2008 | 412 | 538 | 412 | 514 | 412 | 522 |
| 2009 | 431 | 561 | 431 | 536 | 431 | 544 |
| 2010 | 455 | 588 | 455 | 564 | 455 | 572 |
| 2011 | 473 | 609 | 473 | 583 | 473 | 591 |
| 2012 | 482 | 617 | 482 | 592 | 482 | 600 |
| 2013 | 488 | 621 | 488 | 597 | 488 | 605 |
| 2014 | 498 | 633 | 498 | 608 | 498 | 616 |
| 2015 | 508 | 643 | 508 | 618 | 508 | 626 |
| 2016 | 519 | 655 | 519 | 630 | 519 | 638 |
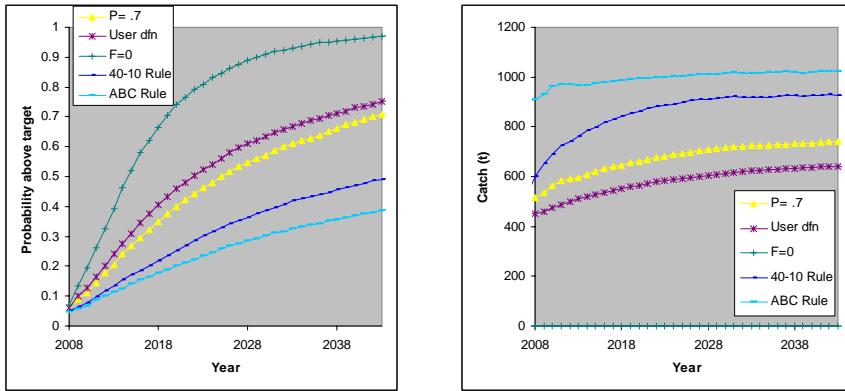


**Figure 5**: Time trajectories of the probability of recovery and catch for five rebuild strategies by $T_{max}$ = 2042 based upon the full Bayesian posterior.
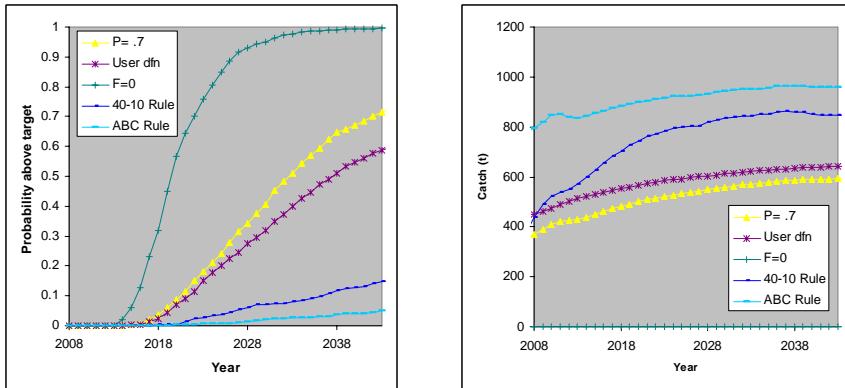


**Figure 6**: Time trajectories of the probability of recovery and catch for five rebuild strategies by $T_{max}$ = 2042 based upon the MPD results.

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**Appendix 1** : Biological and technological parameters used for the rebuilding analyses based on the MPD estimates.

| Age | Fecundity | Weight (kg) | Selectivity | Natural mortality | $N$ (2000) | $N$ (2005) |
|---|---|---|---|---|---|---|
| 3 | 0.000 | 0.169 | 0.001 | 0.0514 | 490 | 1385 |
| 4 | 0.000 | 0.241 | 0.003 | 0.0514 | 353 | 1316 |
| 5 | 0.000 | 0.317 | 0.012 | 0.0514 | 2511 | 4595 |
| 6 | 0.004 | 0.396 | 0.048 | 0.0514 | 3578 | 5608 |
| 7 | 0.028 | 0.474 | 0.163 | 0.0514 | 479 | 981 |
| 8 | 0.137 | 0.550 | 0.383 | 0.0514 | 384 | 378 |
| 9 | 0.274 | 0.622 | 0.598 | 0.0514 | 2028 | 271 |
| 10 | 0.339 | 0.690 | 0.810 | 0.0514 | 2071 | 1917 |
| 11 | 0.375 | 0.752 | 1.000 | 0.0514 | 1554 | 2703 |
| 12 | 0.404 | 0.809 | 0.992 | 0.0514 | 1697 | 357 |
| 13 | 0.431 | 0.861 | 0.933 | 0.0514 | 1006 | 283 |
| 14 | 0.454 | 0.908 | 0.860 | 0.0514 | 269 | 1480 |
| 15 | 0.475 | 0.950 | 0.860 | 0.0514 | 1360 | 1503 |
| 16 | 0.494 | 0.987 | 0.860 | 0.0514 | 842 | 1127 |
| 17 | 0.510 | 1.021 | 0.860 | 0.0514 | 344 | 1233 |
| 18 | 0.525 | 1.050 | 0.860 | 0.0514 | 270 | 733 |
| 19 | 0.538 | 1.076 | 0.860 | 0.0514 | 1143 | 196 |
| 20 | 0.550 | 1.099 | 0.860 | 0.0514 | 386 | 992 |
| 21 | 0.560 | 1.119 | 0.860 | 0.0514 | 464 | 614 |
| 22 | 0.569 | 1.137 | 0.860 | 0.0514 | 268 | 251 |
| 23 | 0.576 | 1.153 | 0.860 | 0.0514 | 118 | 197 |
| 24 | 0.583 | 1.166 | 0.860 | 0.0514 | 122 | 834 |
| 25+ | 0.589 | 1.178 | 0.860 | 0.0514 | 3405 | 3475 |

**Appendix 2** : MPD historical series of spawning output and recruitment.

| Year | Recruitment (age 3) | Spawning output |
|---|---|---|
| 1956 | 3701 | 33537 |
| 1957 | 46180 | 32332 |
| 1958 | 4026 | 31204 |
| 1959 | 18498 | 30754 |
| 1960 | 8784 | 30435 |
| 1961 | 4151 | 30558 |
| 1962 | 3554 | 32282 |
| 1963 | 4872 | 33901 |
| 1964 | 14223 | 33527 |
| 1965 | 10177 | 33191 |
| 1966 | 6753 | 30670 |
| 1967 | 4433 | 21919 |
| 1968 | 3381 | 16088 |
| 1969 | 3795 | 14210 |
| 1970 | 2783 | 15892 |
| 1971 | 3984 | 16714 |
| 1972 | 4994 | 17089 |
| 1973 | 7387 | 17255 |
| 1974 | 3967 | 16928 |
| 1975 | 1468 | 16669 |
| 1976 | 1460 | 16736 |
| 1977 | 1586 | 16708 |
| 1978 | 1636 | 17112 |
| 1979 | 1108 | 16983 |
| 1980 | 938 | 16470 |
| 1981 | 1855 | 15632 |
| 1982 | 2803 | 14828 |
| 1983 | 2046 | 14243 |
| 1984 | 5319 | 13121 |
| 1985 | 1096 | 12094 |
| 1986 | 1215 | 11228 |
| 1987 | 2593 | 10597 |
| 1988 | 3660 | 10254 |
| 1989 | 635 | 9921 |
| 1990 | 2100 | 9527 |
| 1991 | 3152 | 9139 |
| 1992 | 2583 | 8592 |
| 1993 | 3133 | 8365 |
| 1994 | 2837 | 7970 |
| 1995 | 501 | 7652 |
| 1996 | 591 | 7578 |
| 1997 | 4178 | 7607 |
| 1998 | 2784 | 7763 |
| 1999 | 372 | 7902 |
| 2000 | 490 | 7925 |
| 2001 | 1206 | 8012 |
| 2002 | 6543 | 8222 |
| 2003 | 5093 | 8640 |
| 2004 | 1385 | 8846 |
| 2005 | 1385 | 8846 |

**Appendix 3** : The input file for the base-case rebuilding analysis

```
#Title
POP Re2005
# Number of sexes
1
# Age range to consider (minimum age; maximum age)
3 25
# Number of fleets
1
# First year of projection
2005
# Year declared overfished
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)
1
# 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
35
# Fecundity-at-age
# 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
3.84E-06 4.03E-05 0.000392248 0.003560962 0.028260766 0.1374925 0.273954602 0.338584679 0.375081501 0.404469053 0.430553194
0.453991276 0.4749965 0.493739 0.510395 0.52515 0.53818 0.549655 0.559745 0.568595 0.576345 0.58313 0.589055
# Age specific information (Females then males) weight  selectivity
0.169105 0.240603 0.317273 0.395966 0.474162 0.54997 0.62206 0.689572 0.752022 0.80921 0.861146 0.907988 0.949993 0.987478 1.02079 1.0503
1.07636 1.09931 1.11949 1.13719 1.15269 1.16626 1.17811
```

| | | | | | |
|---|---|---|---|---|---|
| 0.000903593 | 0.003300729 | 0.012388376 | 0.047593441 | 0.163229009 | 0.382540283 |
| 0.598099334 | 0.809628096 | 1 | 0.991963314 | 0.932527674 | 0.860131135 | 0.860131135 |
| 0.860131135 | 0.860131135 | 0.860131135 | 0.860131135 | 0.860131135 | 0.860131135 |
| 0.860131135 | 0.860131135 | 0.860131135 | 0.860131135 |

```
# M and current age-structure
0.0513825 0.0513825 0.0513825 0.0513825 0.0513825 0.0513825 0.0513825 0.0513825 0.0513825 0.0513825 0.0513825 0.0513825 0.0513825
         0.0513825 0.0513825 0.0513825 0.0513825 0.0513825 0.0513825 0.0513825 0.0513825 0.0513825 0.0513825
```

| 1385.26 | 1315.86 | 4595.37 | 5607.68 | 981.432 | 378.161 | 271.302 | 1916.72 | 2703.19 | 357.442 | 282.7 | 1480.32 | 1503.2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1126.99 | 1233.43 | 733.158 | 195.904 | 991.757 | 614.288 | 250.854 | 197.062 | 833.566 | 3475.15 |

```
# Age-structure at declaration
```

| | 490.092 | 353.044 | 2511.34 | 3578.08 | 479.42 | 383.831 | 2028.39 | 2071.01 | 1553.79 | 1696.58 | 1006.08 | 268.582 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1359.69 | 842.181 | 343.918 | 270.169 | 1142.81 | 385.819 | 464.475 | 268.23 | 118.46 | 122.402 | 3405 |

```
# Year for Tmin Age-structure
2000
# Number of simulations
3000
#  recruitment and biomass
# Number of historical assessment years
51
# Historical data
# year recruitment spawner in B0 in R project in R/S project
```

| year | recruitment | spawner | in B0 | in R project | in R/S project |
|---|---|---|---|---|---|
| 1955 | 4917.35 | 37837.7 | 1 | 0 | 0 |
| 1956 | 3701.21 | 33536.7 | 0 | 0 | 0 |
| 1957 | 46180.4 | 32331.7 | 0 | 0 | 0 |
| 1958 | 4025.69 | 31204 | 0 | 0 | 0 |
| 1959 | 18497.7 | 30753.6 | 0 | 0 | 1 |
| 1960 | 8784.3 | 30435.3 | 0 | 0 | 1 |
| 1961 | 4150.88 | 30557.9 | 0 | 0 | 1 |
| 1962 | 3553.65 | 32281.5 | 0 | 0 | 1 |
| 1963 | 4871.81 | 33900.7 | 0 | 0 | 1 |
| 1964 | 14222.6 | 33527.1 | 0 | 0 | 1 |
| 1965 | 10177 | 33191.1 | 0 | 1 | 1 |
| 1966 | 6752.62 | 30670.1 | 0 | 1 | 1 |
| 1967 | 4433.1 | 21918.6 | 0 | 1 | 1 |
| 1968 | 3381.03 | 16087.5 | 0 | 1 | 1 |
| 1969 | 3795.42 | 14209.6 | 0 | 1 | 1 |
| 1970 | 2783.04 | 15892.2 | 0 | 1 | 1 |
| 1971 | 3984.48 | 16713.8 | 0 | 1 | 1 |
| 1972 | 4994.01 | 17089 | 0 | 1 | 1 |
| 1973 | 7386.61 | 17255.1 | 0 | 1 | 1 |
| 1974 | 3966.51 | 16928.4 | 0 | 1 | 1 |

| 1975 | 1467.6 | 16669.2 | 0 | 1 | 1 |
| 1976 | 1459.93 | 16735.7 | 0 | 1 | 1 |
| 1977 | 1585.72 | 16707.5 | 0 | 1 | 1 |
| 1978 | 1636.11 | 17112.3 | 0 | 1 | 1 |
| 1979 | 1107.56 | 16982.5 | 0 | 1 | 1 |
| 1980 | 937.97 | 16469.5 | 0 | 1 | 1 |
| 1981 | 1854.81 | 15631.7 | 0 | 1 | 1 |
| 1982 | 2802.99 | 14828.1 | 0 | 1 | 1 |
| 1983 | 2046.46 | 14242.8 | 0 | 1 | 1 |
| 1984 | 5318.98 | 13120.6 | 0 | 1 | 1 |
| 1985 | 1096.11 | 12093.5 | 0 | 1 | 1 |
| 1986 | 1214.67 | 11228 | 0 | 1 | 1 |
| 1987 | 2592.61 | 10596.6 | 0 | 1 | 1 |
| 1988 | 3660.31 | 10253.9 | 0 | 1 | 1 |
| 1989 | 634.96 | 9920.8 | 0 | 1 | 1 |
| 1990 | 2100.48 | 9527.23 | 0 | 1 | 1 |
| 1991 | 3152.13 | 9138.56 | 0 | 1 | 1 |
| 1992 | 2582.58 | 8591.56 | 0 | 1 | 1 |
| 1993 | 3132.81 | 8365.16 | 0 | 1 | 1 |
| 1994 | 2836.94 | 7969.99 | 0 | 1 | 1 |
| 1995 | 501.47 | 7652.18 | 0 | 1 | 1 |
| 1996 | 590.583 | 7577.77 | 0 | 1 | 1 |
| 1997 | 4177.68 | 7607.47 | 0 | 1 | 1 |
| 1998 | 2783.69 | 7762.58 | 0 | 1 | 1 |
| 1999 | 371.673 | 7901.71 | 0 | 1 | 1 |
| 2000 | 490.092 | 7925.14 | 0 | 1 | 1 |
| 2001 | 1206.17 | 8012.21 | 0 | 1 | 1 |
| 2002 | 6543.38 | 8221.56 | 0 | 1 | 1 |
| 2003 | 5092.95 | 8639.65 | 0 | 1 | 1 |
| 2004 | 1385.26 | 8846.15 | 0 | 0 | 0 |
| 2005 | 1385.26 | 8845.86 | 0 | 0 | 0 |

# Number of years with pre-specified catches
2
# catches for years with pre-specified catches
2005    447
2006    447
# Number of future recruitments to override
0
# Process for overriding (-1 for average otherwise index in data list)
# Which probability to product detailed results for (1=0.5; 2=0.6; etc.)
3
# Steepness sigma-R Auto-correlation
0.550651  1        0
# Target SPR rate (FMSY Proxy)
0.5
# Target SPR information: Use (1=Yes) and power
0       20
# Discount rate (for cumulative catch)
0.1
# Truncate the series when 0.4B0 is reached (1=Yes)
0
# Set F to FMSY once 0.4B0 is reached (1=Yes)
0
# Percentage of FMSY which defines Ftarget
0.9
# Maximum possible F for projection (-1 to set to FMSY)
-1
# Conduct MacCall transition policy (1=Yes)
0
# Definition of recovery (1=now only;2=now or before)
2
# Results for rec probs by Tmax (1) or 0.5 prob for various Ttargets (2)
1
"# Definition of the ""40-10"" rule"
10       40
# Produce the risk-reward plots (1=Yes)
0
# Calculate coefficients of variation (1=Yes)
0
# Number of replicates to use
10
# Random number seed

-99004
# Conduct projections for multiple starting values (0=No;else yes)
1
# File with multiple parameter vectors
mcmcreb.dat
# Number of parameter vectors
1000
# User-specific projection (1=Yes); Output replaced (1->9)
1          5          0          0.1
# Catches and Fs (Year; 1/2/3 (F or C or SPR); value); Final row is -1
2007      3          0.696
-1          -1          -1
# Split of Fs
2005      1
-1          1
# Time varying weight-at-age (1=Yes;0=No)
0
# File with time series of weight-at-age data
HakWght.Csv

**Appendix 4** : Median annual catches (mt) for five rebuilding strategies.

(a) Projections based on the full posterior estimates; Future recruitment = recruits

| Year | Prob=0.7 | 2003 Prj | SPR=0.696 | 40-10 rule | ABC rule |
|---|---|---|---|---|---|
| 2007 | 498 | 449 | 397 | 514 | 900 |
| 2008 | 514 | 450 | 412 | 599 | 911 |
| 2009 | 536 | 460 | 431 | 654 | 931 |
| 2010 | 564 | 474 | 455 | 689 | 961 |
| 2011 | 583 | 488 | 473 | 724 | 970 |
| 2012 | 592 | 500 | 482 | 741 | 972 |
| 2013 | 597 | 512 | 488 | 762 | 967 |
| 2014 | 608 | 521 | 498 | 784 | 967 |
| 2015 | 618 | 529 | 508 | 797 | 973 |
| 2016 | 630 | 537 | 519 | 817 | 977 |
| 2017 | 638 | 544 | 528 | 828 | 981 |
| 2018 | 645 | 553 | 535 | 841 | 986 |
| 2019 | 655 | 559 | 545 | 855 | 990 |
| 2020 | 661 | 565 | 551 | 861 | 994 |
| 2021 | 668 | 572 | 558 | 873 | 995 |
| 2022 | 678 | 578 | 566 | 880 | 998 |
| 2023 | 682 | 584 | 572 | 886 | 999 |
| 2024 | 688 | 588 | 578 | 892 | 1001 |
| 2025 | 693 | 591 | 583 | 899 | 1005 |
| 2026 | 698 | 596 | 588 | 904 | 1007 |
| 2027 | 704 | 601 | 593 | 911 | 1012 |
| 2028 | 709 | 604 | 599 | 911 | 1010 |
| 2029 | 712 | 607 | 603 | 915 | 1013 |
| 2030 | 715 | 613 | 607 | 918 | 1014 |
| 2031 | 719 | 616 | 609 | 920 | 1017 |
| 2032 | 720 | 619 | 612 | 918 | 1017 |
| 2033 | 724 | 624 | 615 | 918 | 1017 |
| 2034 | 724 | 626 | 616 | 919 | 1015 |
| 2035 | 726 | 628 | 619 | 919 | 1020 |
| 2036 | 728 | 630 | 621 | 922 | 1020 |
| 2037 | 730 | 632 | 623 | 926 | 1023 |
| 2038 | 733 | 634 | 625 | 925 | 1019 |
| 2039 | 733 | 637 | 626 | 922 | 1016 |
| 2040 | 734 | 637 | 627 | 928 | 1017 |
| 2041 | 737 | 639 | 630 | 925 | 1022 |
| 2042 | 740 | 641 | 632 | 931 | 1021 |
| 2043 | 742 | 642 | 633 | 927 | 1022 |
| 2044 | 741 | 642 | 634 | 926 | 1024 |
| 2045 | 741 | 644 | 634 | 929 | 1019 |
| 2046 | 745 | 644 | 638 | 929 | 1025 |
| 2047 | 746 | 647 | 639 | 928 | 1026 |
| 2048 | 747 | 646 | 641 | 921 | 1022 |
| 2049 | 746 | 647 | 640 | 926 | 1022 |
| 2050 | 746 | 649 | 640 | 926 | 1023 |

(b) Projections based on the MPD estimates; Future recruitment = recruits

| Year | Prob=0.7 | 2003 Prj | SPR=0.696 | 40-10 rule | ABC rule |
|---|---|---|---|---|---|
| 2007 | 357 | 449 | 356 | 370 | 780 |
| 2008 | 370 | 450 | 370 | 437 | 793 |
| 2009 | 390 | 460 | 390 | 490 | 818 |
| 2010 | 411 | 474 | 411 | 521 | 846 |
| 2011 | 422 | 488 | 422 | 537 | 851 |
| 2012 | 425 | 500 | 425 | 550 | 841 |
| 2013 | 429 | 512 | 429 | 569 | 835 |
| 2014 | 439 | 521 | 439 | 599 | 842 |
| 2015 | 450 | 529 | 450 | 626 | 853 |
| 2016 | 461 | 537 | 461 | 653 | 864 |
| 2017 | 472 | 544 | 472 | 680 | 874 |
| 2018 | 483 | 553 | 482 | 702 | 884 |
| 2019 | 491 | 559 | 491 | 727 | 893 |
| 2020 | 501 | 565 | 501 | 743 | 898 |
| 2021 | 508 | 572 | 508 | 761 | 903 |
| 2022 | 514 | 578 | 514 | 771 | 912 |
| 2023 | 522 | 584 | 522 | 784 | 915 |
| 2024 | 528 | 588 | 527 | 793 | 922 |
| 2025 | 534 | 591 | 534 | 798 | 922 |
| 2026 | 538 | 596 | 538 | 801 | 923 |
| 2027 | 542 | 601 | 542 | 804 | 928 |
| 2028 | 549 | 604 | 549 | 817 | 933 |
| 2029 | 554 | 607 | 554 | 825 | 938 |
| 2030 | 558 | 613 | 557 | 834 | 944 |
| 2031 | 562 | 616 | 562 | 840 | 948 |
| 2032 | 569 | 619 | 568 | 842 | 951 |
| 2033 | 571 | 624 | 571 | 843 | 950 |
| 2034 | 574 | 626 | 574 | 850 | 952 |
| 2035 | 577 | 628 | 577 | 853 | 956 |
| 2036 | 582 | 630 | 582 | 858 | 963 |
| 2037 | 586 | 632 | 585 | 863 | 962 |
| 2038 | 588 | 634 | 588 | 860 | 963 |
| 2039 | 590 | 637 | 590 | 858 | 962 |
| 2040 | 589 | 637 | 589 | 851 | 959 |
| 2041 | 590 | 639 | 590 | 847 | 960 |
| 2042 | 591 | 641 | 590 | 849 | 958 |
| 2043 | 593 | 642 | 592 | 847 | 958 |
| 2044 | 594 | 642 | 594 | 849 | 959 |
| 2045 | 595 | 644 | 595 | 853 | 960 |
| 2046 | 598 | 644 | 598 | 858 | 961 |
| 2047 | 600 | 647 | 600 | 851 | 962 |
| 2048 | 599 | 646 | 599 | 854 | 965 |
| 2049 | 603 | 647 | 602 | 852 | 965 |
| 2050 | 603 | 649 | 603 | 852 | 963 |

**Appendix 5** : Time trajectories of median spawning output for five rebuilding strategies.

(a) Projections based on the full posterior estimates; Future recruitment = recruits

| Year | Prob=0.7 | 2003 Prj | SPR=0.696 | 40-10 rule | ABC rule |
|------|----------|----------|-----------|------------|----------|
| 2007 | 9775 | 9775 | 9775 | 9775 | 9775 |
| 2008 | 10469 | 10500 | 10518 | 10444 | 10258 |
| 2009 | 10892 | 10934 | 10989 | 10830 | 10490 |
| 2010 | 11092 | 11183 | 11244 | 10931 | 10489 |
| 2011 | 11328 | 11460 | 11528 | 11119 | 10533 |
| 2012 | 11581 | 11755 | 11832 | 11255 | 10598 |
| 2013 | 11776 | 12010 | 12078 | 11382 | 10637 |
| 2014 | 12003 | 12276 | 12366 | 11505 | 10678 |
| 2015 | 12226 | 12544 | 12620 | 11630 | 10714 |
| 2016 | 12413 | 12786 | 12857 | 11692 | 10757 |
| 2017 | 12571 | 12956 | 13051 | 11853 | 10815 |
| 2018 | 12747 | 13139 | 13258 | 11919 | 10884 |
| 2019 | 12912 | 13358 | 13474 | 12025 | 10982 |
| 2020 | 13109 | 13580 | 13706 | 12095 | 10988 |
| 2021 | 13210 | 13749 | 13841 | 12158 | 11019 |
| 2022 | 13332 | 13900 | 14004 | 12204 | 11074 |
| 2023 | 13436 | 14054 | 14159 | 12275 | 11127 |
| 2024 | 13553 | 14215 | 14274 | 12311 | 11155 |
| 2025 | 13676 | 14347 | 14430 | 12364 | 11207 |
| 2026 | 13797 | 14453 | 14590 | 12386 | 11212 |
| 2027 | 13906 | 14585 | 14729 | 12424 | 11232 |
| 2028 | 13984 | 14727 | 14839 | 12453 | 11258 |
| 2029 | 14030 | 14829 | 14901 | 12424 | 11253 |
| 2030 | 14060 | 14921 | 14946 | 12453 | 11234 |
| 2031 | 14136 | 15008 | 15034 | 12447 | 11233 |
| 2032 | 14210 | 15097 | 15117 | 12475 | 11249 |
| 2033 | 14279 | 15147 | 15208 | 12503 | 11263 |
| 2034 | 14305 | 15196 | 15266 | 12536 | 11314 |
| 2035 | 14319 | 15247 | 15319 | 12544 | 11340 |
| 2036 | 14385 | 15297 | 15355 | 12512 | 11360 |
| 2037 | 14415 | 15372 | 15410 | 12536 | 11350 |
| 2038 | 14458 | 15425 | 15462 | 12550 | 11342 |
| 2039 | 14529 | 15450 | 15561 | 12575 | 11373 |
| 2040 | 14551 | 15488 | 15591 | 12569 | 11383 |
| 2041 | 14568 | 15545 | 15611 | 12542 | 11373 |
| 2042 | 14587 | 15595 | 15657 | 12496 | 11341 |
| 2043 | 14593 | 15636 | 15676 | 12512 | 11362 |
| 2044 | 14604 | 15667 | 15696 | 12515 | 11378 |
| 2045 | 14604 | 15684 | 15689 | 12512 | 11357 |
| 2046 | 14637 | 15710 | 15726 | 12520 | 11386 |
| 2047 | 14650 | 15663 | 15739 | 12539 | 11417 |
| 2048 | 14703 | 15770 | 15800 | 12553 | 11394 |
| 2049 | 14672 | 15789 | 15780 | 12541 | 11387 |
| 2050 | 14691 | 15773 | 15806 | 12551 | 11391 |

(b) Projections based on the MPD estimates; Future recruitment = recruits

| Year | Prob=0.7 | 2003 Prj | SPR=0.696 | 40-10 rule | ABC rule |
|------|----------|----------|-----------|------------|----------|
| 2007 | 9147 | 9147 | 9147 | 9147 | 9147 |
| 2008 | 9881 | 9835 | 9881 | 9874 | 9671 |
| 2009 | 10344 | 10259 | 10344 | 10304 | 9923 |
| 2010 | 10481 | 10362 | 10482 | 10391 | 9851 |
| 2011 | 10593 | 10444 | 10594 | 10449 | 9756 |
| 2012 | 10806 | 10627 | 10807 | 10606 | 9769 |
| 2013 | 11080 | 10868 | 11080 | 10823 | 9862 |
| 2014 | 11376 | 11131 | 11376 | 11049 | 9974 |
| 2015 | 11626 | 11347 | 11627 | 11228 | 10068 |
| 2016 | 11878 | 11562 | 11879 | 11417 | 10162 |
| 2017 | 12152 | 11811 | 12153 | 11587 | 10269 |
| 2018 | 12415 | 12030 | 12416 | 11767 | 10394 |
| 2019 | 12671 | 12270 | 12672 | 11914 | 10507 |
| 2020 | 12912 | 12487 | 12913 | 12026 | 10579 |
| 2021 | 13084 | 12675 | 13085 | 12139 | 10637 |
| 2022 | 13252 | 12828 | 13254 | 12188 | 10715 |
| 2023 | 13432 | 12985 | 13434 | 12272 | 10727 |
| 2024 | 13599 | 13161 | 13600 | 12346 | 10819 |
| 2025 | 13773 | 13284 | 13775 | 12385 | 10867 |
| 2026 | 13865 | 13398 | 13867 | 12391 | 10875 |
| 2027 | 13988 | 13504 | 13990 | 12407 | 10919 |
| 2028 | 14135 | 13657 | 14137 | 12505 | 10964 |
| 2029 | 14289 | 13796 | 14291 | 12551 | 11036 |
| 2030 | 14427 | 13912 | 14429 | 12608 | 11097 |
| 2031 | 14529 | 14038 | 14530 | 12625 | 11155 |
| 2032 | 14655 | 14102 | 14657 | 12644 | 11168 |
| 2033 | 14727 | 14212 | 14728 | 12665 | 11180 |
| 2034 | 14829 | 14340 | 14831 | 12705 | 11235 |
| 2035 | 14943 | 14438 | 14945 | 12731 | 11303 |
| 2036 | 15029 | 14484 | 15031 | 12770 | 11328 |
| 2037 | 15100 | 14587 | 15102 | 12784 | 11316 |
| 2038 | 15169 | 14648 | 15171 | 12754 | 11338 |
| 2039 | 15182 | 14662 | 15184 | 12732 | 11305 |
| 2040 | 15177 | 14676 | 15179 | 12704 | 11315 |
| 2041 | 15271 | 14704 | 15274 | 12681 | 11282 |
| 2042 | 15290 | 14755 | 15292 | 12706 | 11272 |
| 2043 | 15305 | 14744 | 15307 | 12683 | 11312 |
| 2044 | 15363 | 14818 | 15365 | 12698 | 11319 |
| 2045 | 15367 | 14825 | 15369 | 12718 | 11330 |
| 2046 | 15445 | 14881 | 15447 | 12724 | 11354 |
| 2047 | 15498 | 14941 | 15501 | 12712 | 11305 |
| 2048 | 15449 | 14960 | 15451 | 12729 | 11309 |
| 2049 | 15523 | 14944 | 15526 | 12713 | 11365 |
| 2050 | 15530 | 15034 | 15532 | 12731 | 11317 |

**Appendix 6** : Time trajectories of median spawning output relative to target for five rebuilding strategies.

(a) Projections based on the full posterior estimates; Future recruitment = recruits

| Year | Prob=0.7 | 2003 Prj | SPR=0.696 | 40-10 rule | ABC rule |
|---|---|---|---|---|---|
| 2007 | 0.69 | 0.69 | 0.69 | 0.69 | 0.69 |
| 2008 | 0.75 | 0.75 | 0.75 | 0.75 | 0.73 |
| 2009 | 0.78 | 0.78 | 0.78 | 0.77 | 0.75 |
| 2010 | 0.79 | 0.80 | 0.80 | 0.78 | 0.75 |
| 2011 | 0.80 | 0.81 | 0.82 | 0.79 | 0.75 |
| 2012 | 0.82 | 0.83 | 0.84 | 0.80 | 0.75 |
| 2013 | 0.84 | 0.85 | 0.86 | 0.81 | 0.75 |
| 2014 | 0.85 | 0.87 | 0.88 | 0.82 | 0.76 |
| 2015 | 0.86 | 0.89 | 0.89 | 0.83 | 0.77 |
| 2016 | 0.88 | 0.90 | 0.91 | 0.83 | 0.77 |
| 2017 | 0.89 | 0.92 | 0.93 | 0.84 | 0.77 |
| 2018 | 0.90 | 0.93 | 0.94 | 0.84 | 0.77 |
| 2019 | 0.92 | 0.94 | 0.96 | 0.85 | 0.78 |
| 2020 | 0.93 | 0.96 | 0.97 | 0.85 | 0.78 |
| 2021 | 0.93 | 0.97 | 0.97 | 0.86 | 0.78 |
| 2022 | 0.94 | 0.98 | 0.99 | 0.86 | 0.78 |
| 2023 | 0.95 | 0.99 | 1.00 | 0.86 | 0.78 |
| 2024 | 0.96 | 1.00 | 1.01 | 0.86 | 0.78 |
| 2025 | 0.97 | 1.01 | 1.02 | 0.86 | 0.79 |
| 2026 | 0.97 | 1.02 | 1.03 | 0.87 | 0.79 |
| 2027 | 0.98 | 1.03 | 1.04 | 0.87 | 0.79 |
| 2028 | 0.99 | 1.04 | 1.04 | 0.87 | 0.79 |
| 2029 | 0.99 | 1.04 | 1.05 | 0.87 | 0.79 |
| 2030 | 1.00 | 1.05 | 1.06 | 0.87 | 0.79 |
| 2031 | 1.00 | 1.06 | 1.06 | 0.87 | 0.80 |
| 2032 | 1.01 | 1.06 | 1.07 | 0.87 | 0.80 |
| 2033 | 1.01 | 1.07 | 1.08 | 0.87 | 0.79 |
| 2034 | 1.01 | 1.07 | 1.08 | 0.87 | 0.79 |
| 2035 | 1.01 | 1.07 | 1.08 | 0.87 | 0.80 |
| 2036 | 1.01 | 1.08 | 1.08 | 0.88 | 0.80 |
| 2037 | 1.01 | 1.08 | 1.09 | 0.87 | 0.80 |
| 2038 | 1.02 | 1.08 | 1.09 | 0.87 | 0.80 |
| 2039 | 1.02 | 1.08 | 1.09 | 0.88 | 0.80 |
| 2040 | 1.03 | 1.09 | 1.10 | 0.88 | 0.81 |
| 2041 | 1.03 | 1.09 | 1.10 | 0.88 | 0.81 |
| 2042 | 1.03 | 1.10 | 1.11 | 0.88 | 0.80 |
| 2043 | 1.03 | 1.10 | 1.11 | 0.88 | 0.80 |
| 2044 | 1.04 | 1.10 | 1.11 | 0.88 | 0.80 |
| 2045 | 1.04 | 1.10 | 1.11 | 0.88 | 0.80 |
| 2046 | 1.04 | 1.10 | 1.12 | 0.88 | 0.80 |
| 2047 | 1.04 | 1.10 | 1.12 | 0.87 | 0.80 |
| 2048 | 1.04 | 1.11 | 1.12 | 0.87 | 0.80 |
| 2049 | 1.04 | 1.11 | 1.11 | 0.87 | 0.80 |
| 2050 | 1.04 | 1.11 | 1.12 | 0.87 | 0.80 |

(b) Projections based on the MPD estimates; Future recruitment = recruits

| Year | Prob=0.7 | 2003 Prj | SPR=0.696 | 40-10 rule | ABC rule |
|------|----------|----------|-----------|------------|----------|
| 2007 | 0.61 | 0.61 | 0.61 | 0.61 | 0.61 |
| 2008 | 0.65 | 0.65 | 0.65 | 0.65 | 0.64 |
| 2009 | 0.69 | 0.68 | 0.69 | 0.68 | 0.66 |
| 2010 | 0.69 | 0.69 | 0.69 | 0.69 | 0.65 |
| 2011 | 0.70 | 0.69 | 0.70 | 0.69 | 0.65 |
| 2012 | 0.72 | 0.70 | 0.72 | 0.70 | 0.65 |
| 2013 | 0.73 | 0.72 | 0.73 | 0.72 | 0.65 |
| 2014 | 0.75 | 0.74 | 0.75 | 0.73 | 0.66 |
| 2015 | 0.77 | 0.75 | 0.77 | 0.74 | 0.67 |
| 2016 | 0.79 | 0.77 | 0.79 | 0.76 | 0.67 |
| 2017 | 0.81 | 0.78 | 0.81 | 0.77 | 0.68 |
| 2018 | 0.82 | 0.80 | 0.82 | 0.78 | 0.69 |
| 2019 | 0.84 | 0.81 | 0.84 | 0.79 | 0.70 |
| 2020 | 0.86 | 0.83 | 0.86 | 0.80 | 0.70 |
| 2021 | 0.87 | 0.84 | 0.87 | 0.80 | 0.70 |
| 2022 | 0.88 | 0.85 | 0.88 | 0.81 | 0.71 |
| 2023 | 0.89 | 0.86 | 0.89 | 0.81 | 0.71 |
| 2024 | 0.90 | 0.87 | 0.90 | 0.82 | 0.72 |
| 2025 | 0.91 | 0.88 | 0.91 | 0.82 | 0.72 |
| 2026 | 0.92 | 0.89 | 0.92 | 0.82 | 0.72 |
| 2027 | 0.93 | 0.89 | 0.93 | 0.82 | 0.72 |
| 2028 | 0.94 | 0.90 | 0.94 | 0.83 | 0.73 |
| 2029 | 0.95 | 0.91 | 0.95 | 0.83 | 0.73 |
| 2030 | 0.96 | 0.92 | 0.96 | 0.84 | 0.74 |
| 2031 | 0.96 | 0.93 | 0.96 | 0.84 | 0.74 |
| 2032 | 0.97 | 0.93 | 0.97 | 0.84 | 0.74 |
| 2033 | 0.98 | 0.94 | 0.98 | 0.84 | 0.74 |
| 2034 | 0.98 | 0.95 | 0.98 | 0.84 | 0.74 |
| 2035 | 0.99 | 0.96 | 0.99 | 0.84 | 0.75 |
| 2036 | 1.00 | 0.96 | 1.00 | 0.85 | 0.75 |
| 2037 | 1.00 | 0.97 | 1.00 | 0.85 | 0.75 |
| 2038 | 1.01 | 0.97 | 1.01 | 0.85 | 0.75 |
| 2039 | 1.01 | 0.97 | 1.01 | 0.84 | 0.75 |
| 2040 | 1.01 | 0.97 | 1.01 | 0.84 | 0.75 |
| 2041 | 1.01 | 0.97 | 1.01 | 0.84 | 0.75 |
| 2042 | 1.01 | 0.98 | 1.01 | 0.84 | 0.75 |
| 2043 | 1.01 | 0.98 | 1.01 | 0.84 | 0.75 |
| 2044 | 1.02 | 0.98 | 1.02 | 0.84 | 0.75 |
| 2045 | 1.02 | 0.98 | 1.02 | 0.84 | 0.75 |
| 2046 | 1.02 | 0.99 | 1.02 | 0.84 | 0.75 |
| 2047 | 1.03 | 0.99 | 1.03 | 0.84 | 0.75 |
| 2048 | 1.02 | 0.99 | 1.02 | 0.84 | 0.75 |
| 2049 | 1.03 | 0.99 | 1.03 | 0.84 | 0.75 |
| 2050 | 1.03 | 1.00 | 1.03 | 0.84 | 0.75 |

**Appendix 7** : Time trajectories of ABC for five rebuilding strategies.

(a) Projections based on the full posterior estimates; Future recruitment = recruits

| Year | Prob=0.7 | 2003 Prj | SPR=0.696 | 40-10 rule | ABC rule |
|------|----------|----------|-----------|------------|----------|
| 2007 | 900 | 900 | 900 | 900 | 900 |
| 2008 | 930 | 932 | 935 | 927 | 911 |
| 2009 | 970 | 976 | 980 | 965 | 931 |
| 2010 | 1017 | 1026 | 1031 | 1006 | 961 |
| 2011 | 1043 | 1059 | 1063 | 1025 | 970 |
| 2012 | 1063 | 1082 | 1087 | 1040 | 972 |
| 2013 | 1075 | 1096 | 1103 | 1042 | 967 |
| 2014 | 1089 | 1112 | 1121 | 1054 | 967 |
| 2015 | 1112 | 1137 | 1150 | 1068 | 973 |
| 2016 | 1128 | 1157 | 1167 | 1076 | 977 |
| 2017 | 1141 | 1173 | 1187 | 1085 | 981 |
| 2018 | 1159 | 1195 | 1206 | 1093 | 986 |
| 2019 | 1178 | 1217 | 1230 | 1100 | 990 |
| 2020 | 1191 | 1232 | 1245 | 1107 | 994 |
| 2021 | 1204 | 1249 | 1262 | 1110 | 995 |
| 2022 | 1215 | 1262 | 1276 | 1114 | 998 |
| 2023 | 1225 | 1274 | 1291 | 1119 | 999 |
| 2024 | 1235 | 1288 | 1304 | 1121 | 1001 |
| 2025 | 1244 | 1302 | 1315 | 1124 | 1005 |
| 2026 | 1252 | 1314 | 1326 | 1128 | 1007 |
| 2027 | 1261 | 1321 | 1336 | 1129 | 1012 |
| 2028 | 1271 | 1333 | 1349 | 1131 | 1010 |
| 2029 | 1273 | 1344 | 1353 | 1134 | 1013 |
| 2030 | 1276 | 1353 | 1359 | 1138 | 1014 |
| 2031 | 1285 | 1359 | 1368 | 1133 | 1017 |
| 2032 | 1286 | 1365 | 1370 | 1132 | 1017 |
| 2033 | 1292 | 1371 | 1377 | 1134 | 1017 |
| 2034 | 1297 | 1376 | 1384 | 1138 | 1015 |
| 2035 | 1301 | 1382 | 1390 | 1140 | 1020 |
| 2036 | 1307 | 1383 | 1398 | 1141 | 1020 |
| 2037 | 1311 | 1389 | 1401 | 1137 | 1023 |
| 2038 | 1314 | 1396 | 1409 | 1137 | 1019 |
| 2039 | 1313 | 1401 | 1408 | 1135 | 1016 |
| 2040 | 1318 | 1403 | 1413 | 1139 | 1017 |
| 2041 | 1320 | 1406 | 1416 | 1141 | 1022 |
| 2042 | 1324 | 1411 | 1420 | 1141 | 1021 |
| 2043 | 1329 | 1412 | 1427 | 1142 | 1022 |
| 2044 | 1332 | 1414 | 1429 | 1140 | 1024 |
| 2045 | 1335 | 1417 | 1435 | 1142 | 1019 |
| 2046 | 1339 | 1420 | 1438 | 1142 | 1025 |
| 2047 | 1338 | 1425 | 1442 | 1140 | 1026 |
| 2048 | 1335 | 1428 | 1439 | 1135 | 1022 |
| 2049 | 1333 | 1425 | 1438 | 1132 | 1022 |
| 2050 | 1334 | 1426 | 1438 | 1131 | 1023 |

(b) Projections based on the MPD estimates; Future recruitment = recruits

| Year | Prob=0.7 | 2003 Prj | SPR=0.696 | 40-10 rule | ABC rule |
|---|---|---|---|---|---|
| 2007 | 780 | 780 | 780 | 780 | 780 |
| 2008 | 811 | 807 | 811 | 810 | 793 |
| 2009 | 853 | 846 | 853 | 850 | 818 |
| 2010 | 900 | 889 | 900 | 892 | 846 |
| 2011 | 924 | 911 | 924 | 911 | 851 |
| 2012 | 930 | 914 | 930 | 912 | 841 |
| 2013 | 939 | 921 | 939 | 916 | 835 |
| 2014 | 960 | 939 | 960 | 932 | 842 |
| 2015 | 985 | 961 | 985 | 951 | 853 |
| 2016 | 1010 | 983 | 1010 | 970 | 864 |
| 2017 | 1032 | 1003 | 1032 | 984 | 874 |
| 2018 | 1056 | 1024 | 1056 | 999 | 884 |
| 2019 | 1075 | 1042 | 1075 | 1011 | 893 |
| 2020 | 1097 | 1060 | 1097 | 1020 | 898 |
| 2021 | 1111 | 1077 | 1112 | 1029 | 903 |
| 2022 | 1126 | 1089 | 1126 | 1036 | 912 |
| 2023 | 1142 | 1104 | 1142 | 1042 | 915 |
| 2024 | 1154 | 1117 | 1154 | 1047 | 922 |
| 2025 | 1168 | 1126 | 1168 | 1049 | 922 |
| 2026 | 1178 | 1137 | 1178 | 1051 | 923 |
| 2027 | 1187 | 1145 | 1187 | 1056 | 928 |
| 2028 | 1201 | 1160 | 1201 | 1058 | 933 |
| 2029 | 1212 | 1166 | 1213 | 1064 | 938 |
| 2030 | 1221 | 1178 | 1221 | 1071 | 944 |
| 2031 | 1231 | 1186 | 1231 | 1072 | 948 |
| 2032 | 1245 | 1195 | 1245 | 1074 | 951 |
| 2033 | 1249 | 1203 | 1249 | 1075 | 950 |
| 2034 | 1256 | 1213 | 1256 | 1078 | 952 |
| 2035 | 1263 | 1221 | 1264 | 1082 | 956 |
| 2036 | 1274 | 1227 | 1274 | 1082 | 963 |
| 2037 | 1281 | 1235 | 1281 | 1083 | 962 |
| 2038 | 1286 | 1244 | 1286 | 1082 | 963 |
| 2039 | 1291 | 1248 | 1291 | 1081 | 962 |
| 2040 | 1289 | 1248 | 1290 | 1079 | 959 |
| 2041 | 1291 | 1245 | 1291 | 1078 | 960 |
| 2042 | 1292 | 1248 | 1292 | 1079 | 958 |
| 2043 | 1296 | 1251 | 1296 | 1076 | 958 |
| 2044 | 1300 | 1254 | 1300 | 1077 | 959 |
| 2045 | 1302 | 1254 | 1302 | 1078 | 960 |
| 2046 | 1309 | 1263 | 1309 | 1079 | 961 |
| 2047 | 1313 | 1268 | 1313 | 1079 | 962 |
| 2048 | 1311 | 1269 | 1311 | 1080 | 965 |
| 2049 | 1318 | 1272 | 1319 | 1078 | 965 |
| 2050 | 1319 | 1275 | 1319 | 1079 | 963 |