Rebuilding Update for Pacific Ocean Perch

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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 a*l. (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

[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.

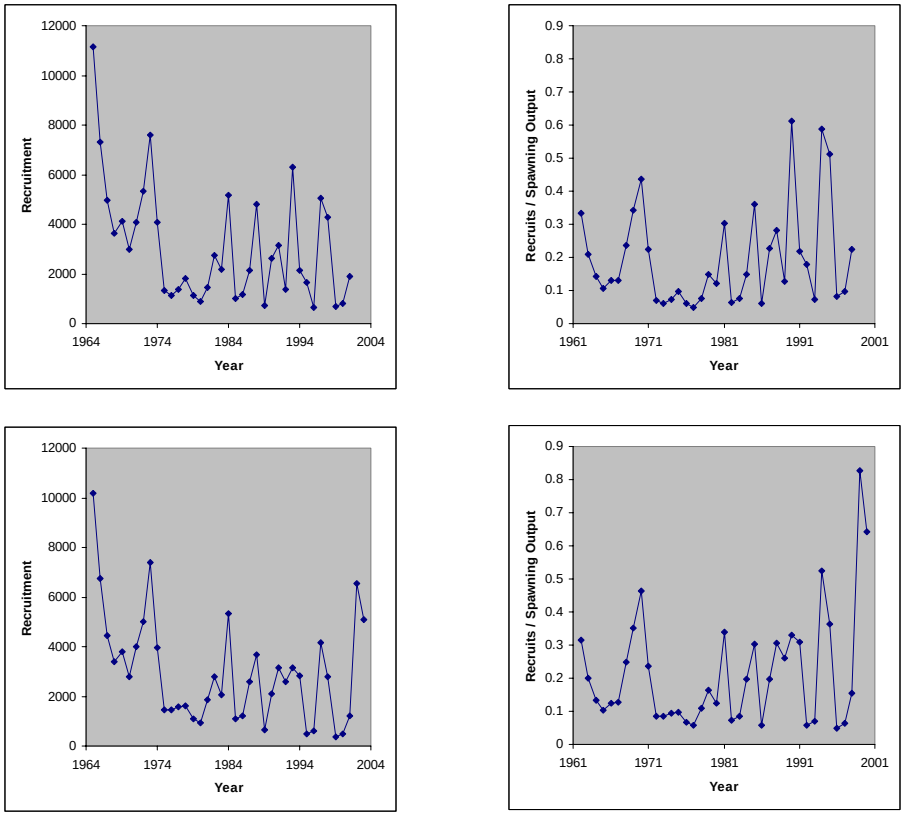

Figure 1: Recruitment and recruits per spawner for assessments of Pacific ocean perch conducted in 2003 and 2005 (upper and lower panels respectively).

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.

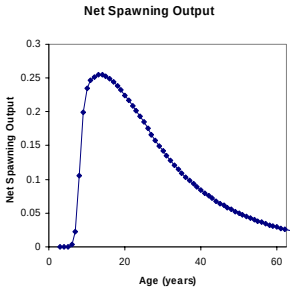

Figure 2: MPD relationship between net spawning output and age for Pacific Ocean perch.

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.

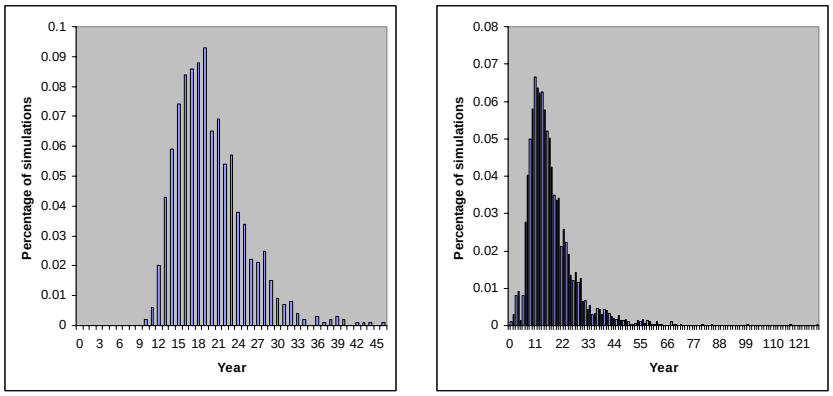

Figure 3: Time to recover to $0.4B_0$ in the absence of catches from 2000 on for the base-case analysis. The results based on the MPD estimates are shown in the left panel and those based on full Bayesian posterior in the right panel.

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

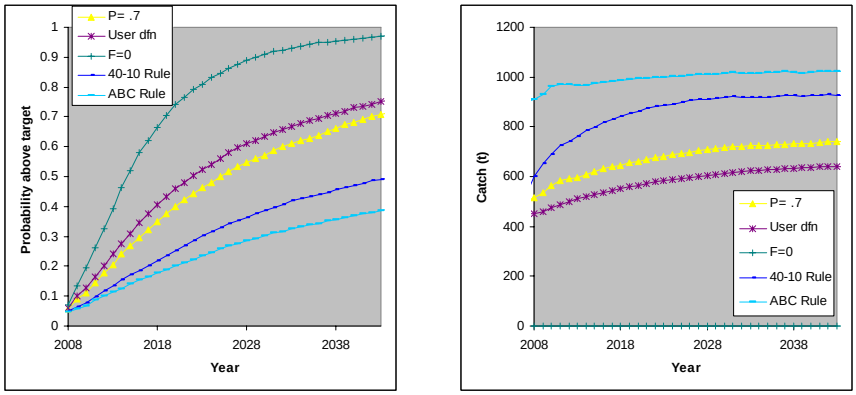

Figure 5: Time trajectories of the probability of recovery and catch for five rebuild strategies by T_{max} = 2042 based upon the full Bayesian posterior.

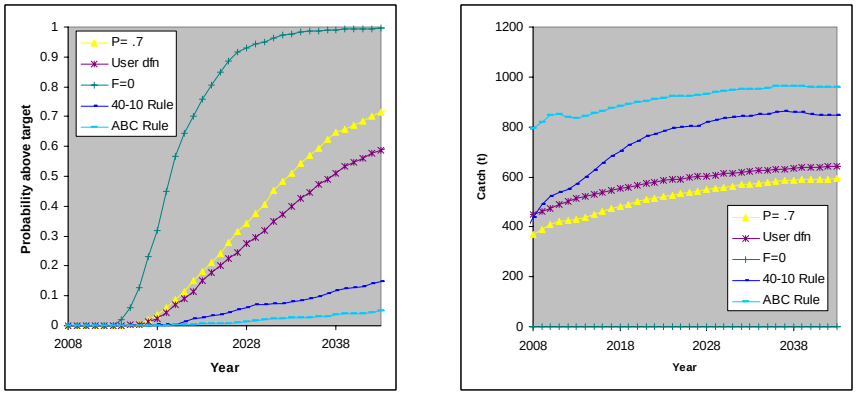

Figure 6: Time trajectories of the probability of recovery and catch for five rebuild strategies by T_{max} = 2042 based upon the MPD results.

References

Hamel, O.S. 2005. Status and future prospects for the Pacific Ocean Perch resource in waters off Washington and Oregon as assessed in 2005.

Hamel, O.S., Stewart, I.J. and A.E. Punt. 2003. Status and future prospects for the Pacific Ocean Perch resource in waters off Washington and Oregon as assessed in 2003. In: Appendix to "Status of the Pacific coast groundfish fishery through 2003 and recommended Acceptable Biological Catches for 2004". Stock Assessment and Fishery Evaluation. Pacific Fishery Management Council, Portland, OR.

Ianelli, J.N., Wilkins, M. and S. Harley. 2000. Status and future prospects for the Pacific Ocean Perch resource in waters off Washington and Oregon as assessed in 2000. 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, Portland, OR.

Ianelli, J.N. and M. Zimmerman. 1998. Status and future prospects for the Pacific Ocean perch resource in waters off Washington and Oregon as assessed in 1998. In: "Status of the Pacific coast groundfish fishery through 1998 and recommended Acceptable Biological Catches for 1999". Stock Assessment and Fishery Evaluation. Pacific Fishery Management Council, Portland, OR.

Pacific Fishery Management Council. 2000. Pacific Ocean Perch STAR Panel Report. In "Status of the Pacific Coast Groundfish Fishery Through 2000 and Recommended Biological Catches for 2001: Stock Assessment and Fishery Evaluation". (Document prepared for the Council and its advisory entities) Pacific Fishery Management Council, Portland, OR.

Pacific Fishery Management Council. 2003. Pacific Ocean Perch STAR Panel Report.

Punt, A.E., O.S. Hamel and I.J. Stewart. Rebuilding Analysis for Pacific Ocean Perch for 2003. In: Appendix to "Status of the Pacific coast groundfish fishery through 2003 and recommended Acceptable Biological Catches for 2004". Stock Assessment and Fishery Evaluation. Pacific Fishery Management Council, Portland, OR.

Punt, A.E. 2002. Revised Rebuilding Analysis for Pacific Ocean Perch (July 2002). Pacific Fishery Management Council, 7700 Ambassador Place NE, Suite 200, Portland, OR.

Punt, A.E. 2005. SSC default rebuilding analysis. Technical specifications and user manual. Ver. 2.8.

Scientific and Statistical Committee (SSC). 2001. SSC terms of reference for groundfish rebuilding analysis. Pacific Fishery Management Council, Portland, Oregon.

Scientific and Statistical Committee (SSC). 2005. SSC terms of reference for groundfish rebuilding analysis. Revised version. Pacific Fishery Management Council, Portland, Oregon.

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
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