PERFORMANCE OF A REVISED MANAGEMENT PROCEDURE FOR SABLEFISH IN BRITISH COLUMBIA

Context

Fisheries and Oceans Canada (DFO) and the British Columbia (BC) Sablefish (*Anoplopoma fimbria*) fishing industry collaborate on a management strategy evaluation (MSE) process intended to develop and implement a transparent and sustainable harvest strategy. Sustainability of harvest strategies is determined by simulation testing alternative management procedures against operating models that represent a range of hypotheses about uncertain Sablefish stock dynamics. Performance of management procedures used in these tests is measured against pre-agreed conservation and catch objectives for the stock and fishery.

An incremental revision to the current Sablefish management procedure was identified during a September 2013 review of fishery objectives, when industry stakeholders proposed a minimum catch limit. Specifically, the suggested revision imposes a total allowable catch (TAC) “floor” on the harvest control rule component of the current management procedure. This proposed revision requires simulation testing to quantify the expected change in conservation and catch performance of the overall fishery harvest strategy. Fisheries Management Branch subsequently requested that Science Branch provide information and advice for January 2014 on these effects. Existing fishery objectives are used to determine whether performance changes are acceptable.

The objectives of this Science Response are to:

1. Revise the harvest control rule component of the existing Sablefish management procedure to include a minimum TAC floor set at the 2013/14 TAC of 1,992 metric tonnes;
2. Complete simulations that apply the revised management procedure to the same observed and simulated data documented by Cox et al. (2011) and compare with their results; and
3. Apply the revised management procedure to commercial landings and survey data updated to 2013 to produce a catch recommendation for the 2014/15 fishery.

This Science Response Report results from the January 2014 Science Response Process for the Performance of a revised management procedure for the British Columbia Sablefish fishery.

Background

Sablefish are caught in directed fisheries by the longline trap and hook K licence category sector and the T licence category trawl sector, and are also intercepted by the non-directed groundfish longline hook fisheries primarily targeting Pacific Halibut (*Hippoglossus stenolepis*), rockfishes (*Sebastes* sp.), and Lingcod (*Ophiodon elongatus*). Individual Sablefish smaller than 55 cm fork length are released by regulation in all fisheries. The BC Integrated Groundfish Fishery (DFO 2013) operates on a February 21 to February 20 fishing year with allowances for carryover of quota overage and underage. The TAC for the 2013/14 fishing year was set at 1,992 metric tonnes (t) as per direct calculation from the existing management procedure (Cox et al. 2011).

Measurable and quantitative fishery objectives guide the MSE process for the BC Sablefish fishery. Objectives are developed via consultations between fishery managers, scientists, and industry stakeholders, and are specifically chosen to be consistent with the DFO Fishery

Decision-Making Framework Incorporating the Precautionary Approach (DMF). Objectives have been revised in each phase of the MSE process (Cox et al. 2009, Cox et al. 2011, Cox et al. 2013) to reflect both industry concerns and DFO updates to Canadian fisheries policy. Upon completing the most recent scientific analysis and review in 2010, a management procedure (MP) was chosen and implemented that met the following objectives in simulation tests:

1. Maintain spawning stock biomass above the limit reference point LRP = $0.4B^{MSY}$, where B^{MSY} is the spawning biomass at maximum sustainable yield (MSY), in 95% of years measured over two Sablefish generations (36 years);
2. When in the Cautious Zone, limit the probability of decline over the next 10 years from very low (5%) at the LRP to moderate (50%) at the target reference point. At intermediate stock status levels, define the tolerance for decline by linearly interpolating between these probabilities;
3. Maintain the spawning biomass above (a) B^{MSY} , or (b) $0.8B^{MSY}$ when rebuilding from the Cautious zone, in 50% of the years measured over two Sablefish generations; and
4. Maximize the average annual catch over 10 years subject to meeting Objectives 1-3.

The MP meeting these objectives applies a surplus production stock assessment model to total Sablefish landings from all BC fisheries and catch per unit effort (CPUE) indices from the commercial trap fishery (1979-2009), standardized trap survey (1991-2009), and stratified random trap survey (2003-present). The assessment model estimates current exploitable biomass ($\hat{B}_T$), the exploitation rate and biomass at maximum sustainable yield ($\hat{U}^{MSY}$, $\hat{B}^{MSY}$, respectively), and the exploitable biomass forecast for the coming year ($\hat{B}_{T+1}$). These estimates are used in a harvest control rule that linearly reduces the target exploitation rate from a maximum $\hat{U}^{MSY}$ when the exploitable biomass forecast falls below an upper operational control point ($B_{upper} = 0.6\hat{B}^{MSY}$) to 0 at the lower operational control point ($B_{lower} = 0.4\hat{B}^{MSY}$). This procedure is termed U60-40 (Cox et al. 2011 used the term StRSHiTune46 for the same procedure) to reflect the choice of these operational control points.

Performance of the U60-40 management procedure in simulation tests showed that Objectives 1-2 could be met with a high degree of certainty. Meeting Objective 3a was not possible to the required certainty, mainly because of the recent stock status of Sablefish combined with constraints on population growth imposed by their generation time. Therefore, Objective 3b was introduced to replace the B^{MSY} reference point with $0.8B^{MSY}$ when stocks are rebuilding from the Cautious zone. This point coincides with the provisional Upper Stock Reference (USR) point defining the boundary separating the Cautious and Healthy Zones of the DMF. The U60-40 procedure met this revised objective, and Objective 3 (given above) now reflects these adjustments.

Analysis and Response

Data

Simulation testing of the revised MP is based on the same data inputs and sequence of random errors used in Cox et al. (2011). These data included total Sablefish landings from all BC fisheries (1965-2009) and catch per unit effort (CPUE) indices from the commercial trap fishery (1979-2009), standardized trap survey (1991-2009), and stratified random trap survey (2003-2009) (Table 1). All CPUE indices are expressed in units of Sablefish kg/trap.

In contrast to the simulation testing of the revised MP using data available to Cox et al. (2011), quota recommendations for the years since 2010, as well as for the 2014/15 fishing year, are based on landings updated to the end of each calendar year. Relative abundance indices

derived from commercial trap fishery CPUE and the standardized trap survey are included in the procedure up to 2009; however, the only abundance index used after 2009 is the stratified random trap survey catch rate series, which is updated every year. Minor differences between the landings and abundance indices in this paper and Cox et al. (2011) are attributed to post-fishery adjustments to final calendar year landings and because of corrections applied during quality assurance auditing.

Methods

A closed-loop feedback simulation approach was used to evaluate revised management procedure performance against a Sablefish operating model representing alternative hypotheses about population dynamics, at-sea release mortality rates, individual growth rate, and recruitment autocorrelation. The operating model is structured by age and also by growth group, where the latter dimension is used in accounting for size-based discarding, size-selection at sea, and potential regulatory changes aimed at reducing these activities. Details of the eight alternative operating models and conditioning on historical data are given in Cox et al. (2011, see Appendix D) and are not repeated in this document. In this analysis, we used six of the original eight scenarios for evaluating revised MP performance relative to the existing U60-40 procedure.

Following the scenario naming convention of Cox et al. (2011), the six scenarios include the baseline operating model (S1:Baseline), which estimates the natural mortality rate given an informative *N* (0.08, 0.005) prior. Secondary scenarios serve as tests of sensitivity and potential robustness of candidate MPs to a fixed natural mortality rate of M =0.08/yr (S2:FixedM) and moderate recruitment autocorrelation (S5:S1+AR and S6:S2+AR). Scenarios S5 and S6 are identical to S1 and S2, respectively, except that recruitment autocorrelation is fixed at γ=0.4 for projection years 2011 – 2046. Scenarios "S7:S1-Mean" and "S8:S1-10th" address parameter uncertainty by using posterior means of operating model parameters (S7) and the particular parameter set representing the 10^{th} percentile of the posterior distribution for maximum sustainable yield. The latter operating model is a robustness test reflecting the case in which Sablefish productivity is grossly over-estimated.

The harvest control rule component of the U60-40 MP was modified to include a minimum TAC floor, $Q_{\min}$, by setting the total catch of legal fish recommended by the MP to the maximum of either $Q_{\min}$ or the product of the target harvest rate and exploitable biomass forecast (equation H3 of Table 2).

The following algorithm was used to simulate MP performance against each operating model scenario (revisions to include TAC floor indicated in bold font):

1. Define a management procedure based on (*i*) data types, (*ii*) assessment method, (*iii*) harvest control rule, and (*iv*) sub-legal regulation;
2. Initialize a pre-conditioned operating model scenario for the period (1965 – 2010) based on historical data;
3. Project the operating model population and fishery one time step into the future and apply the following:
   a. Generate the data (1.*i*) available for stock assessment;
   b. Apply the production model (1.*ii*) to the data to estimate quantities required by the control rule;
   c. Apply the harvest control rule (1.*iii*) to generate a catch limit;

   d. Set the catch limit to the maximum of the output from the control rule (3.c) or the TAC Floor;
   e. Update the operating model population given the fishing mortality rate generated by the final catch limit and sub-legal regulation (1.*iv*), new recruitment, and natural mortality;
   f. Repeat Steps 3a-3**e** until the projection period ends.

4. Calculate quantitative performance statistics for the simulation replicate.

Repeat Steps 2-4 for 100 replicates, each of which applies a new sequence of random errors.

Table 1. Total Sablefish landings from all BC fisheries and catch per unit effort (CPUE) indices from the commercial trap fishery (1979-2009), standardized trap survey (1991-2009), and stratified random trap survey (2003-2013). Landings for 2013 are estimated based on end of year data and trips in progress.

Year	Total Landings (t)	Nominal Trap Fishery CPUE (kg/trap)	Std. Trap Survey CPUE (kg/trap)	Stratified Random Survey CPUE (kg/trap)
1965	547			
1966	907			
1967	1646			
1968	2914			
1969	5074			
1970	5554			
1971	3523			
1972	5906			
1973	3986			
1974	4777			
1975	7407			
1976	7077			
1977	4796			
1978	3873			
1979	4381	17.661		
1980	4311	15.312		
1981	3830	15.056		
1982	4027	16.973		
1983	4336	16.819		
1984	3827	13.059		
1985	4193	17.687		
1986	4448	15.602		
1987	4630	16.160		
1988	5399	24.736		
1989	5324	25.695		
1990	4905	19.222	20.017	
1991	5112	24.600	19.336	
1992	5008	24.363	25.569	
1993	5110	20.380	36.509	
1994	5002	18.397	15.571	
1995	4184	15.020	13.665	
1996	3469	14.087	11.258	
1997	4142	12.956	7.721	
1998	4592	13.020	12.037	
1999	4714	13.426	7.720	
2000	3836	12.667	8.912	
2001	3615	10.082	3.016	
2002	3010	9.899	8.206	
2003	2355	19.222	27.590	28.364
2004	2989	14.009	26.415	24.941
2005	4662	11.615	19.432	23.725
2006	4583	10.034	17.382	28.924
2007	3418	9.705	10.348	20.474
2008	3106	10.042	10.662	26.238
2009	2522	10.090	7.087	18.329
2010	2296			21.380
2011	2069			19.799
2012	2208			15.205
2013	*1925*			19.729

Table 2. Revised harvest control rule component of the Sablefish management procedure. Parameters of the rule (H1) are derived from the TAC floor ($Q_{\min}$), and surplus production stock assessment model estimates of the optimal harvest rate U^{MSY}, biomass producing maximum potential yield B^{MSY}, and multipliers (0.4,0.6) of B^{MSY} that define the bounds B_{lower} and B_{upper}, respectively. These parameters determine a precautionary target harvest rate, U_{T+1} (H2) that is applied to the exploitable biomass forecast, $\hat{B}_{T+1}$, to determine a recommended total quota Q_{T+1} of legal-size fish subject to the minimum TAC floor, $Q_{\min}$ (H3).

H1 $$\Psi = \left(\hat{U}^{MSY}, \hat{B}_{lower}, \hat{B}_{upper}, \hat{B}_{T+1}, Q_{\min}\right)$$

H2 $$U_{T+1} = \begin{cases} 0 & \hat{B}_{T+1} < \hat{B}_{lower} \\ \hat{U}^{MSY}\left(\dfrac{\hat{B}_{T+1} - \hat{B}_{lower}}{\hat{B}_{upper} - \hat{B}_{lower}}\right) & \hat{B}_{lower} \le \hat{B}_{T+1} < \hat{B}_{upper} \\ \hat{U}^{MSY} & \hat{B}_{T+1} \ge \hat{B}_{upper} \end{cases}$$

H3 $$Q_{T+1} = \max\left(Q_{\min}, U_{T+1}\hat{B}_{T+1}\right)$$

Results

Simulation testing the revised MP

Conservation performance of the revised (U60-40+Floor) and existing MPs (U60-40) was similar across operating model scenarios (Table 3, Figure 1, Figure 2). Both U60-40+Floor and the U60-40 procedures maintained simulated Sablefish biomass above the LRP under all operating model scenarios as specified under Objective 1.

Both procedures failed Objective 2 in two of the six scenarios. In the first scenario, recruitment autocorrelation (S6), the number of simulated Sablefish population trajectories that declined over 10 years for the U60-40+Floor procedure was 33 of 100 replicates (0.33). This probability exceeded the criterion for acceptable future decline under Objective 2 of 24 of 100 replicates (0.33>0.24). This result is only slightly worse than the U60-40 procedure, which also failed to achieve Objective 2 in 31 of 100 replicates (0.31>0.24) under this scenario. In the second, worst-case scenario (S8), U60-40+Floor and U60-40 procedures both failed Objective 2 with probabilities of future biomass decline of 0.46 and 0.45, respectively, as compared to an acceptable probability of decline of 0.21 over 10 years.

Both the revised and existing MPs failed to maintain the stock at, or above, a target reference point of B^{MSY} at least 50% of the time (Objective 3a) under all but scenarios S1: Baseline and S5: S1+AR. Rather than a reflection of poor MP performance, this result is more a reflection of (*i*) Sablefish stock status as of 2010 and (*ii*) population growth limited by a relatively long generation time of approximately 18 years. As discussed above, and originally in Cox et al. (2011), even with perfect information about stock biomass and the optimal harvest rate (Perfect U60-40, Table 3), the stock would not grow fast enough to meet Objective 3a under most

scenarios. A new criterion (Objective 3b) established the Cautious-Healthy zone boundary (80% of B^{MSY}) as an alternative rebuilding target (Cox et al. 2011). The revised and existing MPs met Objective 3b with greater than 50% probability in three (S1, S5, S7) out of six scenarios and with greater than 36% probability in two others (S2, S6). Only Perfect U60-40 met Objective 3b under the worst-case scenario (S8) (Table 3).

Table 3. Performance summary for three management procedures tested against six operating model scenarios. Objectives that are satisfied by a procedure are indicated by (●). A procedure meets Objective 1 if the stock remains above the LRP in 95% of years, on average, over two generations. Objective 2 is met if the proportion of declining stock trajectories is less than P(decline) over the first 10 projection years. Objective 3a is met if spawning biomass is greater than B^{MSY} in 50% of years over 2 generations, and Objective 3b is met if spawning biomass is greater than $0.8B^{MSY}$ in 50% of years over 2 generations. Values under Objective 4 are median average catches (000s t) in the first 10 years of the projections. Values of performance measures are provided where a procedure fails under Objectives 2 or 3ab. "Min C" is median of minimum legal catch, over the first 10 projection years, AAV is the average absolute annual variation in catch, and D_{2011} and C_{2011} are the average spawning biomass depletion and average projected legal catch for 2011.

	Objective								
Scenario Management procedure	1	2	3a	3b	4	Min *C*	*AAV*	D_{2011}	C_{2011}
S1: Baseline									
Perfect U60-40	●	●	0.40	0.83	2.50	2.21	4.25	0.18	2.22
U60-40	●	●	●	0.88	2.37	1.97	7.18	0.18	2.06
U60-40+Floor	●	●	●	0.87	2.38	1.98	6.51	0.18	2.11
S2: FixedM									
Perfect U60-40	●	●	0.16	0.50	2.14	1.96	4.74	0.24	1.97
U60-40	●	●	0.12	0.42	2.37	2.10	6.36	0.24	2.17
U60-40+Floor	●	●	0.12	0.40	2.37	2.10	5.70	0.24	2.18
S5: S1+AR									
Perfect U60-40	●	●	0.38	0.73	2.48	2.19	4.91	0.18	2.22
U60-40	●	●	●	0.81	2.36	1.91	8.13	0.18	2.06
U60-40+Floor	●	●	●	0.78	2.38	1.98	6.55	0.18	2.11
S6: S2+AR									
Perfect U60-40	●	●	0.19	0.43	2.11	1.94	5.26	0.24	1.97
U60-40	●	0.31>0.24	0.17	0.40	2.36	2.07	6.74	0.24	2.17
U60-40+Floor	●	0.33>0.24	0.16	0.36	2.38	2.07	5.74	0.24	2.18
S7: S1-Posterior Mean									
Perfect U60-40	●	●	0.28	0.70	2.15	1.88	5.41	0.19	1.91
U60-40	●	●	0.28	0.65	2.27	1.90	7.70	0.19	2.06
U60-40+Floor	●	●	0.27	0.62	2.28	1.98	6.30	0.19	2.11
S8: S1-10th									
Perfect U60-40	●	●	0.17	0.52	1.65	1.48	8.17	0.20	1.48
U60-40	●	0.45>0.21	0.02	0.15	2.23	1.92	7.03	0.20	2.13
U60-40+Floor	●	0.46>0.21	0.01	0.11	2.24	1.98	5.44	0.20	2.15

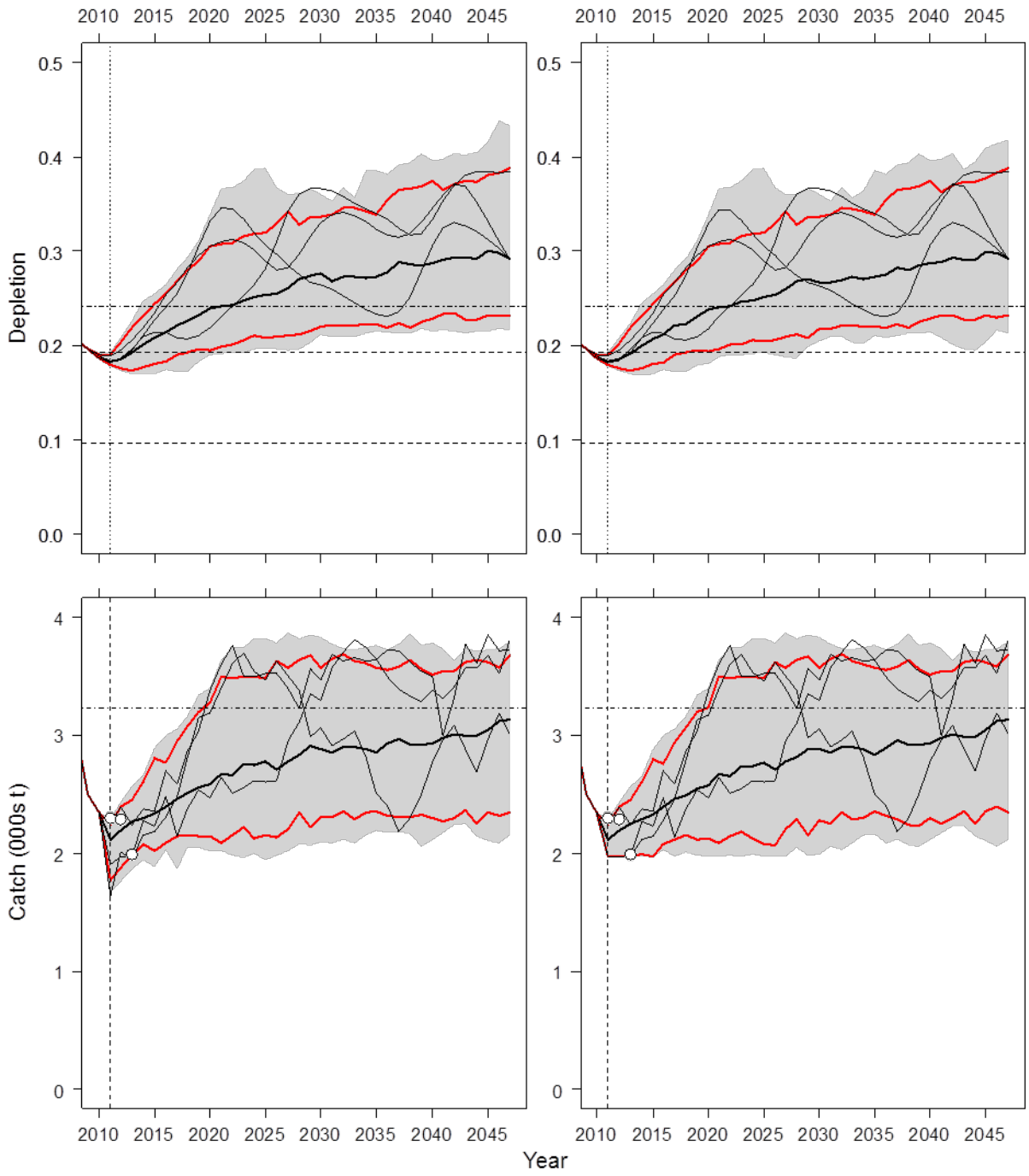

Figure 1. Projected distributions of spawning biomass depletion (upper panels) and total fishery landings (lower panels) for the U60-40 (left panels) and U60-40+Floor (right panels) MPs applied to the S1:Baseline scenario. Thick black lines indicate the median trajectories, red lines give upper 90th and lower 10th percentiles, and the shaded region covers the central 90% of trajectories. Thin black lines give three individual trajectories selected at random (although the biomass and catch lines correspond). The horizontal dashed lines (top to bottom) indicate depletion at B^{MSY}, $0.8B^{MSY}$, and $0.4B^{MSY}$ (spawning biomass) and the operating model MSY *(catch). Realized TACs for the 2011/12 through 2013/14 fishing years are shown in the lower panels (white circles).*

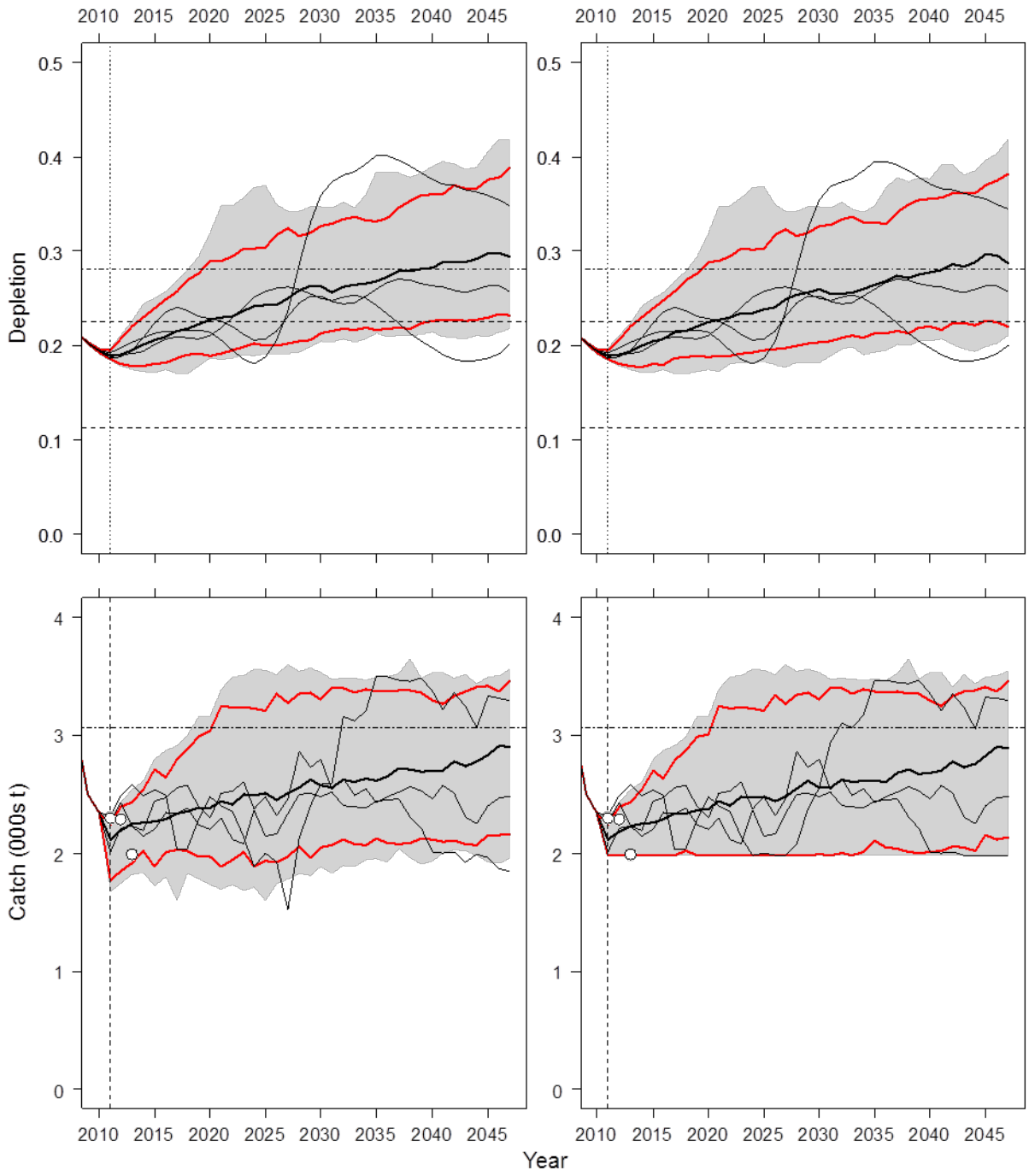

Figure 2. Projected distributions of spawning biomass depletion (upper panels) and total fishery landings (lower panels) for the U60-40 (left panels) and U60-40+Floor (right panels) MPs applied to the S7: S1-Posterior Mean. Thick black lines indicate the median trajectories, red lines give upper 90th and lower 10th percentiles, and the shaded region covers the central 90% of trajectories. Thin black lines give three individual trajectories selected at random (although the biomass and catch lines correspond). The horizontal dashed lines (top to bottom) indicate depletion at B^{MSY}, $0.8B^{MSY}$, and $0.4B^{MSY}$ (spawning biomass) and the operating model MSY *(catch). Realized TACs for the 2011/12 through 2013/14 fishing years are shown in the lower panels (white circles).*

Potential harvest recommendation for the 2014/15 fishing year

Applying the existing U60-40+Floor procedure to updated landings and survey indices for 2013 results in a preliminary 2014 harvest recommendation for legal-sized Sablefish of 2,129 t (Figure 3), which is 6.5% above the proposed TAC floor.

The harvest recommendation above is subject to the assumptions and procedures used to estimate 1,925 t in legal-size Sablefish landings for the 2013 calendar year, which is the time frame necessary for the U60-40+Floor landings data. Landings for 2013 of 1,754 t were obtained from the DFO catch database as of January 6, 2014. This value did not include 26.5 t of landings resulting from the 2013 StRS survey and an estimated 144 t of legal-size Sablefish caught on fishing trips that began in 2013 that will land product in the 2014 calendar year.

Conclusions

Stock assessment for B.C. Sablefish involves an ongoing management strategy evaluation process in which stakeholders and fishery managers develop fishery objectives that are consistent with the DMF. Fishery objectives are defined using (a) limit and upper stock reference points of $0.4B^{MSY}$ and $0.8B^{MSY}$, respectively, that delimit the DMF Critical, Cautious and Healthy stock zones, and (b) a target reference point of B^{MSY}, or $0.8B^{MSY}$ while rebuilding the stock within the Cautious Zone. Because all of these reference points are uncertain, candidate management procedures are simulation-tested against alternative operating model scenarios that are each consistent with historical data. Management procedures that provide acceptable performance against the objectives are considered suitable to provide annual harvest advice.

In 2013, fishing industry stakeholders proposed a TAC floor of 1,992 t, because lower quotas may increase economic risks. The existing U60-40 MP was revised to implement this TAC floor and simulation analyses were conducted to determine whether a new U60-40+Floor procedure would continue to meet agreed conservation objectives.

The proposed U60-40+Floor MP provides conservation performance that is comparable to the existing U60-40 procedure. The U60-40+Floor did not violate conservation Objective 1 under any operating model scenario, including the case where actual Sablefish production is much lower than currently estimated. There is a slightly higher probability of a stock decline (conservation Objective 2) over the years 2011-2020, but only under the most pessimistic operating model scenarios. The U60-40+Floor procedure promoted Sablefish population growth similar to the U60-40 procedure under all scenarios, with a high probability of growth to the Healthy zone under most scenarios. As expected, the U60-40+Floor procedure provided slightly higher and more stable annual catches than the existing U60-40 procedure, because all future TACs were constrained from being less than the proposed 1,992 t floor. Applying the U60-40+Floor procedure to updated landings and biomass index data resulted in a harvest recommendation of 2,129 t, which was above the proposed TAC floor.

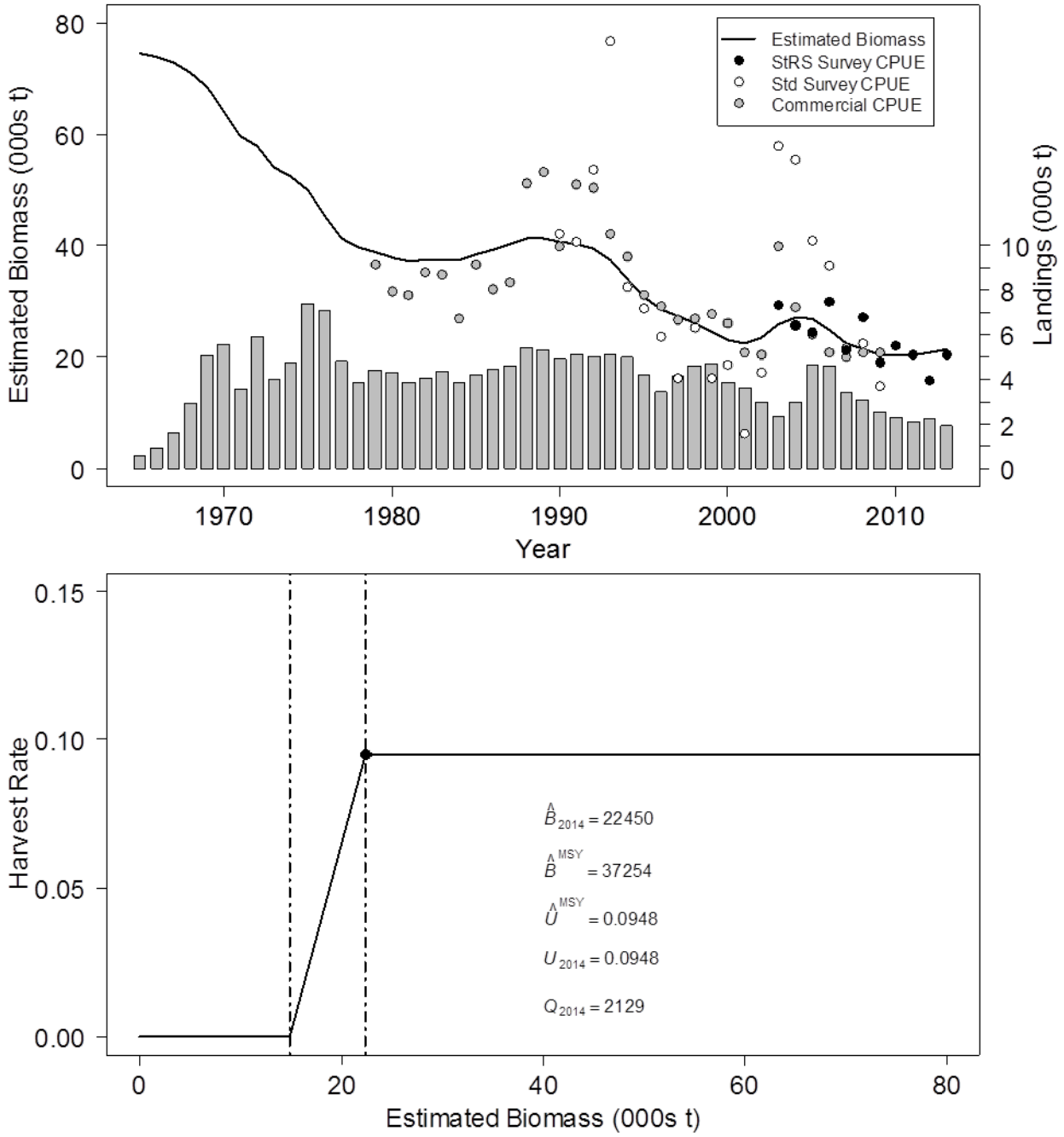

Figure 3. Estimated exploitable biomass (upper panel) from surplus production model fit to CPUE indices from the commercial trap fishery (Commercial, 1979-2009), standardized trap survey (Std Survey, 1991-2009), and stratified random trap survey (StRS Survey, 2003-2013). Annual landings (metric tonnes) are shown as vertical bars. The harvest control rule (lower panel) shows the estimated 2014 exploitable biomass, $\hat{B}_T$, and estimated spawning biomass at MSY, $\hat{B}^{MSY}$ *in metric tonnes. Also shown is the estimated harvest rate at* MSY, $\hat{U}^{MSY}$. *As the predicted biomass was approximately located at the upper control bound of the harvest control rule, no precautionary adjustment to the harvest rate was required to produce the potential legal harvest in metric tonnes, Q_{2014}.*

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Sources of information

This Science Response results from the Science Response Process of January 2014 on the Performance of a revised management procedure for Sablefish in British Columbia. Additional publications from this process will be posted on the Fisheries and Oceans Canada Science Advisory Schedule as they become available.

Cox, S.P. and Kronlund, A.R. 2008. Practical stakeholder-driven harvest policies for groundfish in British Columbia, Canada. Fish. Res. 94(3): 224-237.

Cox, S.P., Kronlund, A.R., Lacko, L. 2011. Management procedures for the multi-gear sablefish (Anoplopoma fimbria) fishery in British Columbia, Canada. Can. Sci. Advis. Sec. Res. Doc. 2011/063. viii + 45 p.

DFO. 2013. Pacific Region Integrated Fisheries Management Plan: Groundfish. Effective February 21, 2013, Version 1.1. Fisheries and Oceans Canada.

DFO. 2011. Management procedures for the multi-gear sablefish (*Anoplopoma fimbria*) fishery in British Columbia, Canada. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2011/025.

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