INITIAL ANALYSES RELATED TO EVALUATING PARAMETER VALUE CHOICES FOR PACIFIC SARDINE
ADDITIONAL SENSITIVITY ANALYSES

Felipe Hurtado-Ferro and André E. Punt
School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA 98195-5020

SENSITIVITY ANALYSES

Multiple fleets

For this sensitivity test, the OFL and HG were computed based on a value for DISTRIBUTION of 0.87, the catch by Canada was computed using the Pacific Northwest selectivity pattern and a fully-selected fishing mortality of $0.1y^{-1}$, and the catch by Mexico was computed using the MexCal selectivity pattern and a fully-selected fishing mortality of $0.2yr^{-1}$, i.e. the fully-selected fishing mortality for the whole fishery was computed as:

$$C_y = \sum_{a=0}^{x} \frac{w_{y,a+1/2} S_{y,a} F_y}{Z_{y,a}} N_{y,a} (1 - e^{-Z_{y,a}}) \quad \text{(S.1)}$$

where $Z_{y,a} = M + S_{y,a} F_y + S_a^{\text{MexCal}} 0.2 + S_a^{\text{PNW}} 0.1$.

Table S.1 shows the values for the performance measures for a subset of harvest policy variants, while the results of the sensitivity tests in the trade-off space are shown in Figure S.1. Note that the catch-related quantities reported in Table S.1 refer only to the US fishery, and do not include catches for Mexico and Canada. Under this sensitivity scenario, it was not uncommon for the stock to collapse, so an additional performance measure was added to Table S.1 showing the percentage of the runs where the stock collapsed.

Time varying selectivity

For this sensitivity test, the age-specific selectivity pattern was given by:

$$S_{y,a} = J_y S_{y,a}^{\text{MexCal}} + (1 - J_y) S_a^{\text{PNW}} \quad \text{(S.2a)}$$

where $J_y = \max(0, \min(1, a + bV_y))$ and a and b were selected so that $J_{1985} = 0$ and $J_{2011} / (1 - J_{2011})$ matches the ratio of the fully-selected Fs for the MexCal area to the PNW. The selectivity-at-age for the MexCal fleet is:

$$S_{y,a}^{\text{MexCal}} = L_y S_a^{\text{MexCal-1}} + (1 - L_y) S_a^{\text{MexCal-2}} \quad \text{(S.2b)}$$

where $L_y = \max(0, \min(1, c + dV_y))$ and c and d are selected so that $L_{1996} = 1$ and $L_{2006} = 0$. $S_a^{\text{MexCal-1}}$ is the F-weighted selectivity-at-age (between seasons) for the MexCal area for 1993-1999 and $S_a^{\text{MexCal-2}}$ is the F-weighted selectivity-at-age (between seasons) for the MexCal area for 2000-2011 (see Table A.5 of the original report).

Table S.2 shows the values for the performance measures for a subset of harvest policy variants, while the results of the sensitivity tests in the trade-off space are shown in Figure S.2.

Time-varying weight-at-age

The weight-at-age for year *y* is:

$$w_{y,a} = Q_y w_a^{1981–1993} + (1 - Q_y) w_a^{2000–2011} \quad \text{(S.3)}$$

where $Q_y = \max(0, \min(1, e + fV_y))$ and *e* and *f* were selected so that $Q_{1987} = 1$ and $Q_{2006} = 0$. The weight-at-age used when computing 1+ biomass for use in the HCR was set to the average weight-at-age.

Table S.3 shows the values for the performance measures for a subset of harvest policy variants, while the results of the sensitivity tests in the trade-off space are shown in Figure S.3.

Hyper-stability in biomass estimates

Hyper-stability in biomass estimates was specified modifying the way $\hat{B}_y^{1+}$ is estimated in the model. In the base model, $\hat{B}_y^{1+} = B_y^{1+} e^{\psi}; \psi \sim N(0, \sigma_B)$, which was modified as

$$\hat{B}_y^{1+} = q_y B_y^{1+} e^{\psi}; \psi \sim N(0, \sigma_B) \quad \text{(S.4a)}$$

$$q_y = \max\left(g\left(B_y^{1+}\right)^{-0.5}, 1\right), \quad \text{(S.4b)}$$

where *g* is a scaling parameter set at 620, 500, 400, 320 and 210, so that biomass is being overestimated at below 400 000t, 250 000t, 150 000t, 100 000t and 50 000t respectively (Figure S.4).

Table S.4 shows the values for the performance measures for harvest policy variant J. Harvest policy variant J is robust to hyper-stability in biomass estimates under the hyper-stability parameterizations explored.

Table S.1. Results of applying a subset of the harvest control variants to the *multiple fleets* sensitivity scenario. The variants where the performance measure is within 5% of the best value are shaded in green and those for which the performance measure is within 5% of the poorest value are shaded in red. Note that all catch-related quantities refer only to the US fishery, and do not include catches for Mexico and Canada

	A	**L**	**OFL**	**HG-J**	**HG-V3**	**HG-V4**	**Alt4**
Symbol	1	3	5	6	9	10	14
FRACTION (%)	20	E_{MSY}	45	5-15*	5-E_{MSY} *	5-E_{MSY} *	E_{MSY}†
CUTOFF	50	0	0.33·B_0	150	0.20·B_0	0.33·B_0	50
MAXCAT	400			200			-
Performance Measure							
Mean catch	91.7	84.8	232.5	74.2	104.0	84.5	92.2
SD catch	93.1	107.4	285.5	59.9	129.9	62.3	117.1
Mean B1+	443.8	72.9	656.5	791.0	821.9	920.7	613.5
SD B1+	618.9	292.3	566.8	735.6	683.8	760.9	637.4
Mean SSB	289.0	47.2	421.7	549.4	563.8	654.0	405.9
SD SSB	431.3	194.4	335.2	547.3	473.6	570.4	433.3
%B1+>400	36.04	6.06	63.04	65.85	72.22	76.62	52.97
%No catch	29.31	86.59	56.56	16.32	28.64	42.27	14.34
%Catch<50	61.76	93.44	65.65	55.10	59.52	65.34	55.58
Median catch	57.6	47.9	145.1	56.7	63.1	70.6	53.5
Median B1+	216.7	0.0	525.0	593.0	657.9	744.1	434.3
Median SSB	139.2	0.0	356.0	403.2	453.4	524.3	287.8
Mean pop age	1.70	0.31	2.10	2.24	2.28	2.38	2.03
Mean Catch Age	1.10	0.20	1.37	1.46	1.49	1.55	1.32
Mean Yrs No Catch	9.62	387.20	4.34	3.37	3.50	4.05	5.29
%HCR min	NA	NA	NA	11.80	11.80	11.80	NA
%HCR max	NA	NA	NA	52.78	42.74	42.74	NA
Mean Yrs HCRmin	NA	NA	NA	2.67	2.67	2.67	NA
Mean Yrs HCRmax	NA	NA	NA	7.59	6.10	6.10	NA
% runs collapses	42	100	8	6	3	2	17

† – Combination of FRACTION and CUTOFF, under 0 MAXCATCH, that leads to the largest mean catch (with zero catch years included), subject to the maximum exploitation rate not being larger than E_{MSY}.

Table S.2. Results of applying a subset of the harvest control variants to the *time varying selectivity* sensitivity scenario. The variants where the performance measure is within 5% of the best value are shaded in green and those for which the performance measure is within 5% of the poorest value are shaded in red.

	A	L	OFL	HG-J	HG-V3	HG-V4	Alt4
Symbol	1	3	5	6	9	10	14
FRACTION (%)	20	E_{MSY}	45	5-15*	5-E_{MSY} *	5-E_{MSY} *	E_{MSY}†
CUTOFF	50	0	0.33·B_0	150	0.20·B_0	0.33·B_0	50
MAXCAT	400			200			-
Performance Measure							
Mean catch	174.4	182.5	305.7	115.7	154.1	108.4	173.2
SD catch	121.4	168.5	333.6	69.9	172.9	73.5	172.6
Mean B1+	1044.4	1014.2	998.8	1342.9	1291.2	1419.4	1185.7
SD B1+	861.9	800.5	642.7	882.9	764.7	867.9	766.0
Mean SSB	769.0	738.0	699.2	1053.6	989.9	1128.1	887.8
SD SSB	709.2	622.6	431.6	761.7	606.8	748.0	603.5
%B1+>400	80.24	79.34	92.24	96.94	98.00	98.66	94.76
%No catch	0.17	0.00	29.29	2.37	5.83	14.74	2.17
%Catch<50	15.12	14.46	39.26	27.04	34.09	41.58	22.99
Median catch	143.1	136.5	207.3	112.9	101.4	99.5	125.2
Median B1+	829.5	828.9	841.2	1130.3	1119.3	1218.4	1007.2
Median SSB	584.4	586.4	599.1	859.9	849.0	945.7	744.1
Mean pop age	2.28	2.24	2.25	2.71	2.64	2.85	2.48
Mean Catch Age	2.68	2.64	2.70	3.25	3.18	3.43	2.97
Mean Yrs No Catch	1.21	1.00	2.00	1.67	1.60	1.85	1.74
%HCR min	NA	NA	NA	11.93	11.93	11.93	NA
%HCR max	NA	NA	NA	52.26	42.19	42.19	NA
Mean Yrs HCRmin	NA	NA	NA	2.64	2.64	2.64	NA
Mean Yrs HCRmax	NA	NA	NA	7.47	6.01	6.01	NA

† – Combination of FRACTION and CUTOFF, under 0 MAXCATCH, that leads to the largest mean catch (with zero catch years included), subject to the maximum exploitation rate not being larger than E_{MSY}.

Table S.3. Results of applying a subset of the harvest control variants to the *time varying weight-at-age* sensitivity scenario. The variants where the performance measure is within 5% of the best value are shaded in green and those for which the performance measure is within 5% of the poorest value are shaded in red.

	A	L	OFL	HG-J	HG-V3	HG-V4	Alt4
Symbol	1	3	5	6	9	10	14
FRACTION (%)	20	E_{MSY}	45	5-15*	5-E_{MSY} *	5-E_{MSY} *	E_{MSY}†
CUTOFF	50	0	0.33·B_0	150	0.20·B_0	0.33·B_0	50
MAXCAT	400			200			-
Performance Measure							
Mean catch	151.8	154.4	301.3	111.0	149.3	107.2	161.2
SD catch	123.3	166.3	357.1	70.9	175.3	73.8	172.5
Mean B1+	912.2	576.5	916.7	1285.5	1237.5	1392.6	1089.5
SD B1+	875.8	780.4	644.1	912.2	781.4	894.1	784.0
Mean SSB	642.4	399.5	613.5	978.8	917.2	1078.6	782.8
SD SSB	680.5	559.6	383.6	753.1	579.0	738.3	575.0
%B1+>400	68.11	43.93	86.86	94.83	97.03	98.35	89.78
%No catch	0.95	32.85	36.11	2.66	7.05	16.34	2.28
%Catch<50	25.68	51.01	46.06	30.24	37.03	43.42	27.30
Median catch	113.4	104.8	193.1	104.0	94.4	97.2	110.4
Median B1+	662.1	289.9	754.1	1051.0	1050.4	1174.0	894.0
Median SSB	448.7	198.4	527.6	779.1	778.9	892.9	641.4
Mean pop age	2.46	1.62	2.42	2.81	2.74	2.92	2.60
Mean Catch Age	1.59	1.05	1.56	1.84	1.78	1.91	1.68
Mean Yrs No Catch	1.41	531.48	2.27	1.66	1.63	1.89	1.74
%HCR min	NA	NA	NA	11.93	11.93	11.93	NA
%HCR max	NA	NA	NA	52.26	42.19	42.19	NA
Mean Yrs HCRmin	NA	NA	NA	2.64	2.64	2.64	NA
Mean Yrs HCRmax	NA	NA	NA	7.47	6.01	6.01	NA

† – Combination of FRACTION and CUTOFF, under 0 MAXCATCH, that leads to the largest mean catch (with zero catch years included), subject to the maximum exploitation rate not being larger than E_{MSY}.

Table S.4. Results of applying harvest control option J to five variants of the sensitivity test for hyper-stability in biomass estimates.

	***g* = 210**	***g* = 320**	***g* = 400**	***g* = 500**	***g* = 620**
Performance Measure					
Mean catch	110.79	110.79	110.78	110.73	110.50
SD catch	70.57	70.57	70.57	70.59	70.61
Mean B1+	1268.84	1268.84	1268.84	1268.74	1267.35
SD B1+	894.12	894.12	894.12	894.16	894.72
Mean SSB	985.86	985.86	985.85	985.78	984.63
SD SSB	765.36	765.36	765.36	765.39	765.79
%B1+>400	94.63	94.63	94.63	94.61	94.44
%No catch	2.73	2.73	2.73	2.68	2.48
%Catch<50	30.05	30.05	30.05	30.06	30.09
Median catch	104.24	104.24	104.23	104.15	103.65
Median B1+	1045.41	1045.41	1045.41	1045.38	1044.52
Median SSB	786.22	786.22	786.20	786.16	785.47
Mean pop age	2.81	2.81	2.81	2.81	2.81
Mean Catch Age	1.83	1.83	1.83	1.83	1.83
MeanYrs No Catch	1.67	1.67	1.67	1.65	1.65
%HCR min	11.80	11.80	11.80	11.80	11.80
%HCR max	52.78	52.78	52.78	52.78	52.78
Mean Yrs HCRmin	2.67	2.67	2.67	2.67	2.67
Mean Yrs HCRmax	7.59	7.59	7.59	7.59	7.59

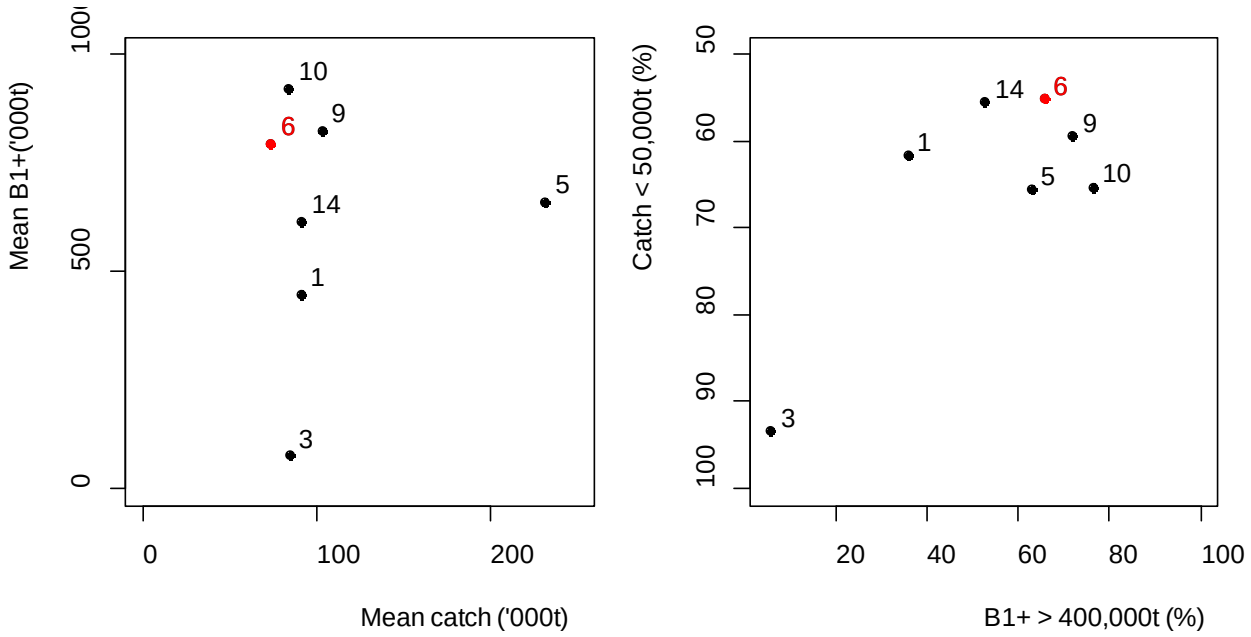

Figure S.1. Trade-offs plots (mean annual catch when the catch is non-zero vs 1+ biomass [left]; and the probability of a catch < 50,000t vs. the probability of 1+ biomass exceeding 400,000t [right]) for the *multiple fleets* sensitivity scenario. The numbers denote the values used to refer to the harvest control rule options in Table S.1.

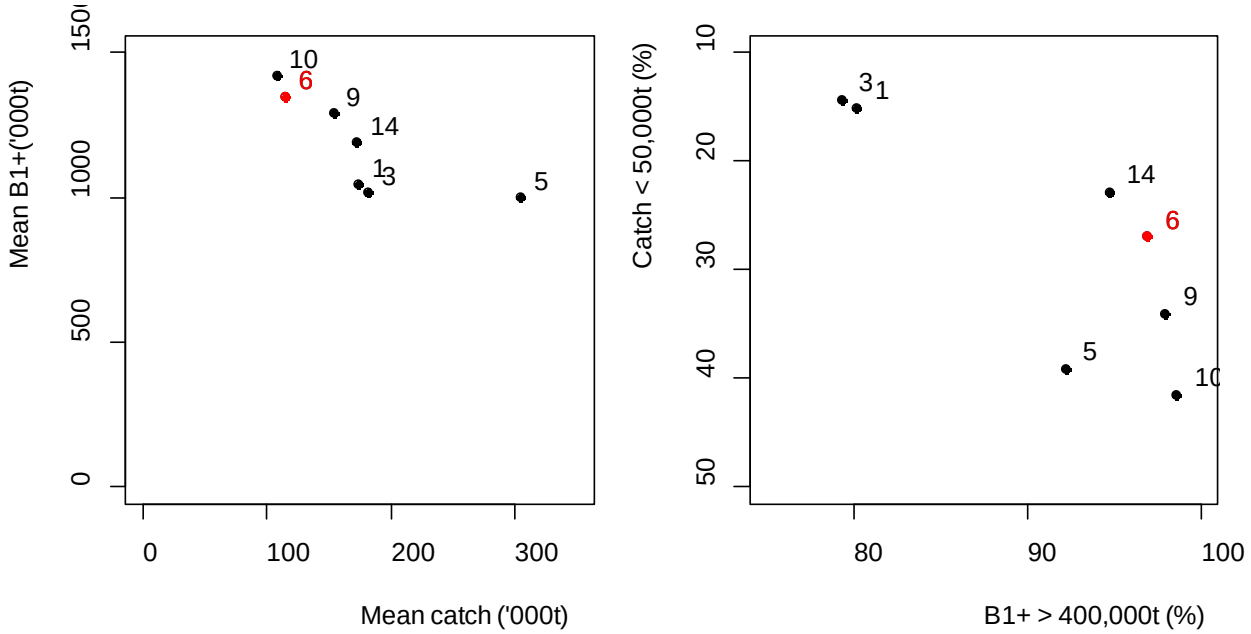

Figure S.2. Trade-offs plots (mean annual catch when the catch is non-zero vs 1+ biomass [left]; and the probability of a catch < 50,000t vs. the probability of 1+ biomass exceeding 400,000t [right]) for the *time varying selectivity* sensitivity scenario. The numbers denote the values used to refer to the harvest control rule options in Table S.2.

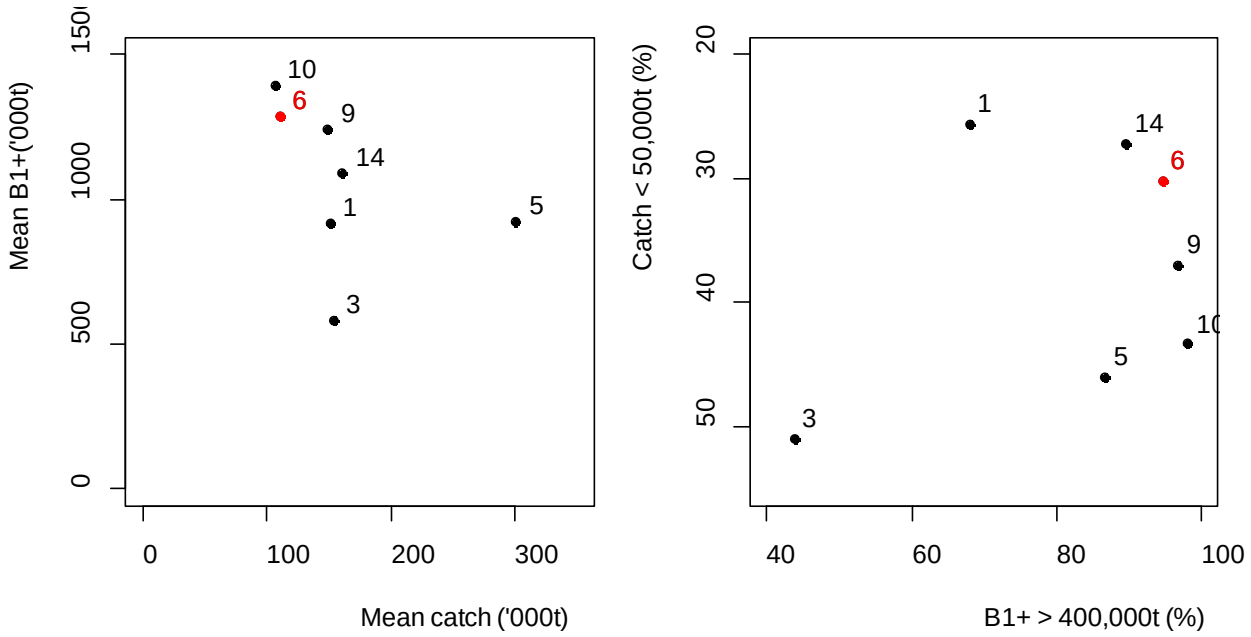

Figure S.3. Trade-offs plots (mean annual catch when the catch is non-zero vs 1+ biomass [left]; and the probability of a catch < 50,000t vs. the probability of 1+ biomass exceeding 400,000t [right]) for the *time varying weight-at-age* sensitivity scenario. The numbers denote the values used to refer to the harvest control rule options in Table S.3.

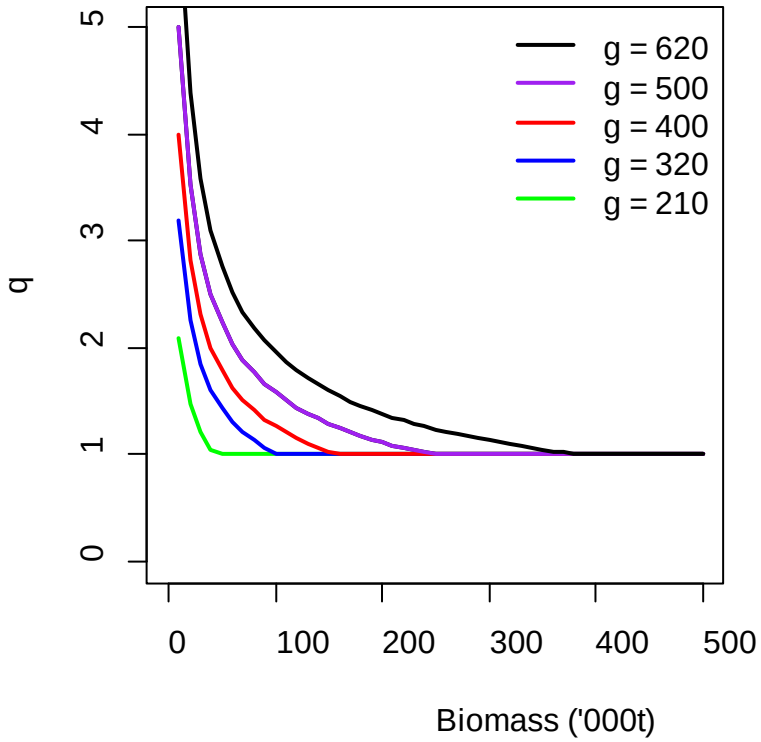

Figure S.4. Values of *q* for the hyper-stability sensitivity scenario for a range of values of *g*.