Is OMP-18 robust to alternative assumptions about anchovy dynamics?

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The anchovy control parameter in OMP-18 is finalised given a revised baseline Operating Model (OM) and robustness to alternative OMs is tested. OMP-18 is robust to many of the alternative OMs tested. However, in five cases the risk to the anchovy resource under OMP-18 is notably higher than that assumed to be acceptable when tuning the Harvest Control Rule. These cases include i) should the stock-recruit relationship be better represented by a Hockey-Stick or ii) Ricker curve, than the Beverton Holt curve assumed when tuning OMP-18, iii) should natural mortality be lower than that assumed for the baseline OM, iv) should commercial selectivity not decrease for larger fish and v) if the egg survey estimates of abundance were over-estimates of spawner biomass instead of the absolute estimate assumed when tuning OMP-18.

Introduction

The development of OMP-18 has thus far been based on a single anchovy Operating Model (OM) (e.g. de Moor 2018b). Alternative anchovy OMs were previously defined and available (de Moor 2016), but time constraints restricted the full testing of OMP-18 under alternative anchovy OMs. This document provides a retuning of the anchovy control parameter in OMP-18 given a revised baseline OM and tests the robustness of this OMP to alternative anchovy OMs which make alternative assumptions about factors affecting anchovy dynamics.

Methods

The anchovy OM used to develop OMP-18 thus far used priors on carrying capacity, K, and steepness of the Beverton Holt stock recruitment curve, h, that were not accurate. Correct values for K and h were calculated after resampling from the Markov Chain Monte Carlo chain as a means to begin OMP-18 testing while new chains were run under the assumption that the original chains would be sufficiently ball-park. However, given the focus on sardine during the development of OMP-18 the corrected anchovy baseline MCMC chains – though available – were never used. This oversight has now been corrected.

Following the same procedure as before (de Moor 2018a,c), the acceptable level of risk for anchovy was determined by running OMP-14 under the revised baseline OM. This results in the acceptable maximum level for anchovy risk[1] being 0.089, and the corresponding anchovy control parameter in OMP-18 which satisfies the risk level is 1.16[2].

Robustness to OMP-18 was tested under the following alternative anchovy OMs (see de Moor 2016 for further details about these choices):

A_{BH} - Beverton Holt stock-recruitment curve, with uniform priors on steepness and carrying capacity.
$\bar{M}_j^A = \bar{M}_{ad}^A = 1.2$. **Baseline OM.**

A_{2BH} - Two Beverton Holt stock-recruitment curves, with uniform priors on steepness and carrying capacity, one estimated using data from 1984 to 1999 and the other from 2000 to 2015.

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[1] The probability that the anchovy spawner biomass is below the 1996 level over the projection period.

[2] The acceptable maximum level of anchovy risk using the previous anchovy OM was 0.134 and the anchovy control parameter that satisfied that risk level was 1.313

A_R - Ricker stock-recruitment curve, with uniform priors on steepness and carrying capacity.

A_{HS} - Hockey stick stock-recruitment curve, with uniform priors on the log of the maximum recruitment and on the ratio of the spawning biomass at the inflection point to carrying capacity.

A_{M1} $\bar{M}_j^A = \bar{M}_{ad}^A = 0.9$- (for comparison with the base case assessment of 2007)

A_{M2} - $\bar{M}_j^A = 1.5$ and $\bar{M}_{ad}^A = 1.2$ (alternative $\bar{M}_j^A$, similar to A_{BH} in terms of value of the negative log joint posterior mode)

A_{Mad} - Annually varying adult natural mortality, i.e. random effects model with $\sigma_{ad} \sim U(0.2, 0.5)$, and $\rho \sim U(0,1)$.

A_{Mj} - Annually varying juvenile natural mortality, i.e. random effects model with $\sigma_j \sim U(0.2, 0.5)$, and $\rho \sim U(0,1)$.

A_{M2000+} - Natural mortality assumed to have increased at the turn of the century; i.e. $\bar{M}_j^A = \bar{M}_{ad}^A = 0.9$year^{-1} prior to 2000 and $\bar{M}_j^A = \bar{M}_{ad}^A = 1.2$ year^{-1} from 2000 onwards. The Beverton-Holt stock recruitment relationship was estimated to correspond to the years 2000 onwards, with no stock-recruitment relationship assumed prior to 2000.

A_{sur} - Survey selectivity below 7cm was estimated to be a constant, and uniform (1) selectivity was assumed for lengths ≥7cm.

A_{com} - Commercial selectivity was not estimated to decrease at higher lengths, i.e. $\delta_q = 0$.

A_{com2} - Commercial selectivity was modelled using a double-logistic curve.

A_{kegg1} - Negatively biased egg surveys, i.e., $k_g^A = 0.75$.

A_{kegg2} - Positively biased egg surveys, i.e., $k_g^A = 1.25$.

A_{lamR} - Fix the additional variance (over and above the survey sampling CV) associated with the recruit survey, $(\lambda_r^A)^2$=0.

A_{lamN} - Estimate the additional variance (over and above the survey sampling CV) associated with the November survey, with the associated prior for $(\lambda_N^A)^2 \sim U(0,100)$.

A_{lamN2} - Fix the additional variance (over and above the survey sampling CV) associated with the November survey, $(\lambda_N^A)^2 = 0.02$

Table 1 defines the parameters used in this document. All results are run using a sardine control parameter of $\beta = 0.124$ (de Moor 2019).

Results and Discussion

Table 2 compares the posterior distributions for some key model parameters between the alternative anchovy OMs. Table 3 gives the anchovy performance statistics when running OMP-18 under the alternative OMs. There is little difference in the sardine performance statistics between these alternative anchovy OMs (results not shown), except for the sardine bycatch.

Robustness of an OMP to alternative OMs is generally considered at the level of a "tick test" with a check to see if anything is particularly concerning. From a resource perspective it would be concerning if the risk were substantially higher under an alternative OM.

The risk to the anchovy resource under A_{2BH} is less than that under A_{BH}, with higher projected biomasses and average catches. This is logical given the more productive resource estimated using spawner biomass and recruitment values between 2000 and 2015 than over the full historical period of 1984-2015.

The risk to the anchovy resource is 25-45% higher under A_{Ricker} and A_{HS} with a higher chance of the biomass falling below the Critical Biomass threshold.

Should natural mortality be lower than that assumed when tuning OMP-18 (A_{M1}) – these lower values being those assumed during OMP-08 development – there would be little impact on the anchovy catches, but the risk to the resource would be ~20% higher than under A_{BH}. There is little change to the performance statistics if juvenile natural mortality is higher than that assumed when tuning OMP-18 (A_{M2}) or if adult natural mortality is assumed to fluctuate annually about a median value (A_{Mad}). Given the high proportion of recruits in the anchovy population, and in the anchovy catch, if juvenile natural mortality is assumed to fluctuate annually about a median value (A_{Mj}), the range of the biomass performance statistics are wider, with substantially higher medians. Given the dependence of the anchovy catch on recruits, it is logical that the MAV_A is also higher under A_{Mj} than under A_{BH}. However, risk to the resource would be lower.

If natural mortality prior to 2000 was lower than that assumed when tuning OMP-18, with the Beverton Holt stock recruitment relationship fitted to 2000-2015 only (A_{M2000+}), then the risk to the anchovy resource is less than that under A_{BH}, but not as low as A_{2BH}.

Risk to the anchovy resource would be 5% higher if survey selectivity were assumed to be constant for larger fish and a lower constant for smaller fish (A_{sur}). If commercial selectivity was not assumed to decrease at larger lengths, the risk to the resource will be 15% higher than that to which OMP-18 was tuned under the baseline OM. There is little impact on the performance statistics if the shape of the commercial selectivity curve was double logistic.

The baseline OM assumes the historical egg survey provided an absolute estimate of spawner biomass. If, instead, the egg survey provided an under- or over-estimate of spawner biomass, the absolute biomass statistics are logically higher (A_{kegg1}) or lower (A_{kegg2}) although the average catches only differ from the baseline by 1%. The difference in risk to the resource is 11-13% (higher risk under A_{kegg2}).

If there is no additional variance in the recruit survey (A_{lamR}), the risk to the resource would be lower and the average catch higher. There is little impact on the performance statistics if additional variance in the November survey is estimated (A_{lamN}) or fixed >0 (A_{lamN2}).

In all cases there is no impact on the median of the simulated catches or the median of the median simulated catches. This is because the Harvest Control Rule frequently sets the anchovy TAC at the maximum value of 350 000t.

In summary, therefore, the alternative OMs of A_{HS}, A_R, A_{M1}, A_{com} and A_{kegg2} pose some concern under OMP-18 and it is recommended that when updated assessments of the anchovy resource are run, the likelihood of these alternatives providing a better fit to the data (presumably, therefore, a closer match to reality) be closely monitored.

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Table 1. Model parameters, variables and performance statistics referred to in this document.

Parameter/ Variable	Description
B_y^A	Model predicted total biomass at the beginning of November in year y, associated with the November survey
$B_y^{sp,A}$	Model predicted spawning biomass at the beginning of November in year y
$B_{min}^{sp,A}$	The minimum anchovy spawner biomass during the projection period
$Risk_A$	The probability that the anchovy spawner biomass falls below the 1996 level during the projection period
M_a^A	Rate of natural mortality of age a
$\bar{M}_j^A$	Median juvenile rate of natural mortality
$\bar{M}_{ad}^A$	Median rate of natural mortality for 1+ anchovy
σ_j	Standard deviation in the annual residuals about juvenile natural mortality
σ_{ad}	Standard deviation in the annual residuals about natural mortality for ages 1+
ρ	Annual autocorrelation coefficient
h^A	Steepness associated with the stock-recruitment curve
K^A	Carrying capacity
a^A	Maximum median recruitment in the Hockey Stick stock-recruitment curve or stock-recruitment curve parameter related to h^A and K^A, for Beverton Holt and Ricker curves
b^A	Biomass above which median recruitment is constant and independent of spawning biomass in the Hockey Stock stock-recruitment curve or stock-recruitment curve parameter related to h^A and K^A, for Beverton Holt and Ricker curves
$(\sigma_r^A)^2$	Variance in the residuals (lognormal deviation) about the stock recruitment curve
k_N^A	Multiplicative bias associated with the November acoustic survey
k_g^A	Multiplicative bias associated with the November egg survey
k_r^A	Multiplicative bias associated with the recruit survey
$(\lambda_N^A)^2$	Additional variance, over and above $\left(\sigma_{y,N}^A\right)^2$, associated with the November survey
$(\lambda_r^A)^2$	Additional variance, over and above $\left(\sigma_{y,r}^A\right)^2$, associated with the recruit survey
C^A	The anchovy catch during the projection period
Med C^A	The median anchovy catch during the projection period
MAV^A	Median annual variation in anchovy catch
B_{crit}^A	The critical biomass threshold which is used as part of the anchovy Harvest Control Rule, and therefore in terms of survey estimated biomass

Table 2. The posterior median and 95% probability intervals for key parameters and outputs. All robustness tests are defined in the main text and all parameters are defined in Table 1. Fixed values are given in **bold**. Numbers are reported in billions and biomass in thousands of tons.

	A_{BH}	A_{2BH}	A_{R}	A_{HS}	A_{M1}	A_{M2}	A_{Mad}	A_{Mj}	A_{M2000+}
$\bar{M}_j^A$	**1.2**	**1.2**	**1.2**	**1.2**	**0.9**	**1.5**	**1.2**	**1.1-1.3**	**0.9; 1.2**
$\bar{M}_{ad}^A$	**1.2**	**1.2**	**1.2**	**1.2**	**0.9**	**1.2**	**1.0-1.7**	**1.2**	**0.9; 1.2**
σ_j	-	-	-	-	-	-	-	0.10	-
σ_{ad}	-	-	-	-	-	-	0.20	-	-
ρ	-	-	-	-	-	-	0.40	0.08	-
k_N^A	0.63 [0.5,0.79]	0.63 [0.50,0.79]	0.63 [0.49,0.79]	0.64 [0.50,0.79]	0.61 [0.47,0.75]	0.62 [0.50,0.78]	0.64 [0.50,0.80]	0.63 [0.50,0.79]	0.59 [0.47,0.74]
k_r^A	0.53 [0.39,0.69]	0.52 [0.38,0.68]	0.52 [0.39,0.68]	0.53 [0.40,0.68]	0.59 [0.46,0.73]	0.46 [0.35,0.60]	0.51 [0.38,0.66]	0.52 [0.38,0.69]	0.54 [0.41,0.69]
k_g^A	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
$(\lambda_N^A)^2$	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
$(\lambda_r^A)^2$	0.23 [0.11,0.48]	0.23 [0.11,0.48]	0.22 [0.11,0.46]	0.23 [0.11,0.49]	0.30 [0.15,0.64]	0.23 [0.11,0.49]	0.19 [0.08,0.44]	0.22 [0.10,0.43]	0.26 [0.13,0.60]
a^A	1181 [534,7740]	9671 [404,146616] 1149 [675,2832]	0.62 [0.41,1.18]	726 [467,1244]	665 [355,4135]	1659 [775,21550]	1416 [598,8770]	20220 [931,510058]	1295 [741,12710]
b^A	1089 [37,14747]	15759 [35,350572] 377 [9,3880]	0.0002 [0.0000,0.0005]	1127 [106,2667]	801 [27,12510]	1255 [65,37250]	1532 [52,19625]	42989 [554,1202431]	475 [12,26140]
K^A	1826 [982,4314]	7337 [831,9902] 2385 [1417,3886]	2220 [855,6735]	1807 [1148,3106]	1745 [911,3484]	1825 [872,4932]	1989 [997,4253]	8166 [1632,9941]	2362 [1241,6109]
h^A	0.41 [0.22,0.91]	0.27 [0.20,0.91] 0.64 [0.27,0.98]	0.28 [0.21,0.48]	-	0.44 [0.22,0.93]	0.37 [0.21,0.86]	0.37 [0.22,0.89]	0.23 [0.20,0.52]	0.60 [0.22,0.98]
σ_r^A	0.84 [0.63,1.13]	1.02 [0.68,1.58] 0.71 [0.46,1.18]	0.84 [0.64,1.13]	0.84 [0.64,1.18]	0.90 [0.67,1.25]	0.84 [0.62,1.19]	0.84 [0.63,1.15]	0.86 [0.64,1.17]	0.77 [0.51,1.29]
B_{2015}^A	3375 [2363,4776]	3441 [2417,4873]	3394 [2418,4801]	3322 [2415,4636]	3630 [2670,5110]	3356 [2349,4775]	3354 [2296,4827]	3427 [2451,4890]	3545 [2476,4927]
$B_{2015}^{sp,A}$	2026 [1445,2841]	2063 [1481,2855]	2025 [1474,2773]	1979 [1482,2734]	2175 [1634,3004]	2026 [1465,2786]	2000 [1373,2905]	2051 [1493,2825]	2033 [1458,2792]

Table 2 (continued).

	A_{BH}	A_{sur}	A_{com}	A_{com2}	A_{kegg1}	A_{kegg2}	A_{lamR}	A_{lamN}	A_{lamN2}
$\bar{M}_j^A$	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**
$\bar{M}_{ad}^A$	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**
σ_j	-	-	-	-	-	-	-	-	-
σ_{ad}	-	-	-	-	-	-	-	-	-
ρ	-	-	-	-	-	-	-	-	-
k_N^A	0.63 [0.5,0.79]	0.63 [0.50,0.81]	0.45 [0.35,0.58]	0.63 [0.49,0.79]	0.50 [0.39,0.63]	0.75 [0.59,0.95]	0.57 [0.45,0.70]	0.63 [0.50,0.80]	0.61 [0.48,0.77]
k_r^A	0.53 [0.39,0.69]	0.53 [0.40,0.70]	0.29 [0.20,0.40]	0.52 [0.38,0.69]	0.42 [0.32,0.56]	0.61 [0.45,0.80]	0.44 [0.35,0.54]	0.52 [0.39,0.69]	0.51 [0.39,0.67]
k_g^A	**1.00**	**1.00**	**1.00**	**1.00**	**0.75**	**1.25**	**1.00**	**1.00**	**1.00**
$(\lambda_N^A)^2$	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	0.00	**0.02**
$(\lambda_r^A)^2$	0.23 [0.11,0.48]	0.23 [0.12,0.49]	0.26 [0.12,0.53]	0.24 [0.11,0.48]	0.24 [0.12,0.49]	0.23 [0.11,0.49]	**0.00**	0.23 [0.12,0.46]	0.20 [0.09,0.43]
a^A	1181 [534,7740]	1147 [553,5705]	2011 [922,12799]	1181 [570,7425]	2346 [757,179296]	1034 [512,6614]	3180 [957,55326]	1144 [554,8110]	1287 [564,11284]
b^A	1089 [37,14747]	1116 [36,11908]	805 [36,10182]	1084 [36,16838]	3493 [151,459088]	916 [34,14101]	5519 [594,137183]	1062 [58,16412]	1292 [50,24443]
K^A	1826 [982,4314]	1817 [984,3788]	1222 [587,3081]	1754 [815,3433]	2702 [1237,9886]	1570 [907,3527]	2702 [1186,7977]	1778 [953,3837]	1849 [985,4954]
h^A	0.41 [0.22,0.91]	0.40 [0.22,0.92]	0.38 [0.22,0.89]	0.40 [0.21,0.91]	0.30 [0.20,0.80]	0.41 [0.22,0.93]	0.27 [0.21,0.52]	0.40 [0.22,0.87]	0.38 [0.22,0.89]
σ_r^A	0.84 [0.63,1.13]	0.83 [0.62,1.16]	0.84 [0.63,1.15]	0.84 [0.63,1.12]	0.85 [0.63,1.17]	0.83 [0.62,1.13]	0.69 [0.53,0.93]	0.83 [0.63,1.12]	0.81 [0.61,1.13]
B_{2015}^A	3375 [2363,4776]	3344 [2361,4758]	4761 [3286,6937]	3386 [2340,4771]	4236 [2974,5994]	2814 [1964,4000]	4676 [3592,6293]	3354 [2388,4894]	3576 [2393,5356]
$B_{2015}^{sp,A}$	2026 [1445,2841]	2027 [1452,2811]	1864 [1307,2580]	2018 [1424,2808]	2566 [1826,3521]	1671 [1193,2348]	2744 [2106,3611]	2010 [1466,2868]	2138 [1465,3087]

Table 3. Key anchovy summary performance statistics for OMP-18, with $\beta = 0.124$ and $\alpha = 1.16$. Where appropriate, medians are provided, and for some statistics the means are provided additionally and shown in **bold**. All biomasses are given in thousands of tons.

Performance Statistics		No Catch	A_{BH} (CMP#)	A_{2BH}	A_R	A_{HS}	A_{M1}	A_{M2}	A_{Mad}	A_{Mj}	A_{M2000+}
Risk	$Risk_A$ [3]	0.018	0.089[4]	0.020	0.112	0.129	0.109	0.087	0.090	0.074	0.037
Biomass	$B_{2036}^{sp,A}$	**3384** 2341 [600,9493]	**2669** 1613 [219,8309]	**2989** 2333 [569,7664]	**3805** 1785 [123,12584]	**1879** 1331 [94,5187]	**2714** 1580 [214,8631]	**3750** 1618 [199,10070]	**2893** 1734 [177,9220]	**17144** 6267 [126,67596]	**4276** 2371 [472,10262]
	$B_{2036}^{sp,A}/B_{2015}^{sp,A}$	1.6 [0.4,6.6]	1.1 [0.2,5.9]	1.5 [0.4,4.9]	1.2 [0.1,8.9]	0.9 0.1,3.8]	1.0 [0.1,5.2]	1.1 [0.1,7.3]	1.2 [0.1,6.2]	4.3 [0.1,48.8]	1.6 [0.3,7.5]
	$B_{2036}^{sp,A}/B_{1996}^{sp,A}$	4.9 [1.3,20.7]	3.4 [0.5,17.3]	5.0 [1.3,17.3]	3.9 [0.3,29.0]	2.9 [0.2,12.5]	3.0 [0.4,16.3]	3.4 [0.4,22.8]	3.7 [0.4,22.2]	14.4 [0.3,166.3]	4.4 [0.9,20.0]
	$B_{2036}^{sp,A}/K^A$	1.2 [0.3,4.5]	0.9 [0.1,3.7]	1.0 [0.3,3.1]	0.8 [0.1,4.1]	0.7 [0.1,2.9]	0.9 [0.1,4.1]	0.9 [0.1,4.5]	0.8 [0.1,4.1]	1.0 [0.0,8.9]	1.0 [0.3,3.3]
	$B_{min}^{sp,A}$	920 [318,2564]	543 [115,2165]	1004 [271,2207]	610 [71,2805]	480 [65,1486]	564 [128,2144]	569 [117,2466]	583 [101,2272]	1660 [83,4030]	1005 [220,2369]
	$B_{min}^{sp,A}/B_{1996}^{sp,A}$	2.03 [0.66,5.57]	1.17 [0.24,4.56]	2.19 [0.60,4.91]	1.38 [0.17,6.29]	1.05 [0.14,3.42]	1.07 [0.23,4.10]	1.21 [0.25,5.47]	1.29 [0.20,5.26]	3.84 [0.17,9.48]	1.82 [0.40,4.47]
	$B_{min}^{sp,A}/K^A$	0.51 [0.19,1.06]	0.30 [0.07,0.84]	0.42 [0.14,0.76]	0.27 [0.04,0.87]	0.27 [0.04,0.69]	0.33 [0.09,0.97]	0.32 [0.07,0.88]	0.30 [0.05,0.90]	0.26 [0.01,0.63]	0.43 [0.11,0.76]
Catch	C^A	**11** 0 [0,217]	**311** 350 [148,350]	**329** 350 [217,350]	**303** 350 [55,350]	**298** 350 [33,350]	**308** 350 [130,350]	**311** 350 [149,350]	**310** 350 [134,350]	**316** 350 [128,350]	**327** 350 [217,350]
	Med C^A	0 [0,0]	350 [258,350]	350 [349,350]	350 [193,350]	350 [198,350]	350 [249,350]	350 [261,350]	350 [254,350]	350 [223,350]	350 [338,350]
	MAV^A	-	0.0 [0.00,0.28]	0.0 [0.00,0.11]	0.0 [0.00,0.36]	0.0 [0.00,0.37]	0.0 [0.00,0.30]	0.0 [0.00,0.29]	0.0 [0.00,0.30]	0.0 [0.00,0.36]	0.0 [0.00,0.15]
Critical Biomass	$p(B_y^{Aobs} < B_{crit}^A, B_y < B_{crit}^A/k_N^A)$	-	0.07	0.02	0.09	0.11	0.07	0.07	0.07	0.06	0.02
	$p(B_y^{Aobs} < B_{crit}^A, B_y \geq B_{crit}^A/k_N^A)$	-	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00
	$p(B_y^{Aobs} \geq B_{crit}^A, B_y < B_{crit}^A/k_N^A)$	-	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00
	$p(B_y^{Aobs} \geq B_{crit}^A, B_y \geq B_{crit}^A/k_N^A)$	-	0.91	0.98	0.89	0.87	0.91	0.91	0.91	0.93	0.97
	Avg # years $B_y^{Aobs} < B_{crit}^A$ consecutively		2.3	1.9	3.0	3.0	2.4	2.3	2.4	3.4	2.08
Ecosystem	P(Bsar+Banch) < historical min	0.01	0.07	0.02	0.09	0.11	0.07	0.07	0.08	0.06	0.02

[3] The lowest historical spawner biomass for A_{M2} and A_{M2000+} was 1995, not 1996, but 1996 is still used as the threshold year in these robustness tests as the spawner biomass in 1996 was only 5 and 6% more, respectively, than 1995.

[4] The acceptable maximum level of anchovy risk using the previous anchovy OM was 0.134 and the anchovy control parameter that satisfied that risk level was 1.313, but lower average catches were predicted under this previous OM.

Table 3 (continued).

Performance Statistics		No Catch	A_{BH} (CMP#)	A_{sur}	A_{com}	A_{com2}	A_{kegg1}	A_{kegg2}	A_{lamR}	A_{lamN}	A_{lamN2}
Risk	$Risk_A$ [5]	0.018	0.089	**0.093**	0.102	0.091	0.079	0.101	0.065	0.09	0.096
Biomass	$B_{2036}^{sp,A}$	**3384** 2341 [600,9493]	**2669** 1613 [219,8309]	**3007** 1608 [186,7589]	**1952** 1209 [189,6334]	**2485** 1533 [194,7596]	**10767** 2883 [225,39645]	**2184** 1304 [142,6969]	**5161** 2263 [244,16924]	**2565** 1479 [194,7526]	**2863** 1585 [162,9122]
	$B_{2036}^{sp,A}/B_{2015}^{sp,A}$	1.6 [0.4,6.6]	1.1 [0.2,5.9]	1.1 [0.1,5.3]	1.0 [0.2,5.1]	1.1 [0.1,5.5]	1.6 [0.1,21.2]	1.1 [0.1,6.3]	1.2 [0.1,9.3]	1.0 [0.1,5.4]	1.0 [0.1,5.7]
	$B_{2036}^{sp,A}/B_{1996}^{sp,A}$	4.9 [1.3,20.7]	3.4 [0.5,17.3]	3.4 [0.4,17.5]	2.8 [0.5,14.5]	3.2 [0.4,16.4]	4.7 [0.4,67.3]	3.3 [0.4,19.3]	3.9 [0.4,30.9]	3.3 [0.5,17.0]	3.3 [0.4,18.2]
	$B_{2036}^{sp,A}/K^A$	1.2 [0.3,4.5]	0.9 [0.1,3.7]	0.8 [0.1,3.6]	1.0 [0.2,4.3]	0.9 [0.1,4.1]	1.0 [0.1,6.4]	0.8 [0.1,3.5]	0.8 [0.1,4.3]	0.9 [0.1,3.8]	0.8 [0.1,3.8]
	$B_{min}^{sp,A}$	920 [318,2564]	543 [115,2165]	527 [116,1882]	471 [111,1509]	539 [113,1743]	931 [143,4433]	443 [84,1580]	1039 [168,4982]	529 [119,1897]	578 [99,2254]
	$B_{min}^{sp,A}/B_{1996}^{sp,A}$	2.03 [0.66,5.57]	1.17 [0.24,4.56]	1.11 [0.26,4.24]	1.04 [0.28,3.43]	1.16 [0.25,3.65]	1.54 [0.23,7.93]	1.18 [0.22,4.62]	1.80 [0.28,8.45]	1.12 [0.27,4.22]	1.16 [0.21,4.67]
	$B_{min}^{sp,A}/K^A$	0.51 [0.19,1.06]	0.30 [0.07,0.84]	0.29 [0.07,0.86]	0.38 [0.11,1.04]	0.30 [0.07,0.92]	0.32 [0.04,0.88]	0.27 [0.06,0.77]	0.38 [0.06,1.06]	0.29 [0.07,0.83]	0.31 [0.06,0.88]
Catch	C^A	**11** 0 [0,217]	**311** 350 [148,350]	**310** 350 [143,350]	**312** 350 [171,350]	**310** 350 [151,350]	**314** 350 [156,350]	**307** 350 [110,350]	**319** 350 [201,350]	**310** 350 [145,350]	**309** 350 [127,350]
	Med C^A	0 [0,0]	350 [258,350]	350 [267,350]	350 [270,350]	350 [268,350]	350 [252,350]	350 [239,350]	350 [267,350]	350 [267,350]	350 [253,350]
	MAV^A	-	0.0 [0.00,0.28]	0.0 [0.00,0.26]	0.0 [0.00,0.27]	0.0 [0.00,0.27]	0.0 [0.00,0.29]	0.0 [0.00,0.36]	0.0 [0.00,0.20]	0.0 [0.00,0.26]	0.0 [0.00,0.32]
Critical Biomass	$p\left(B_y^{Aobs} < B_{crit}^A, B_y < B_{crit}^A/k_N^A\right)$	-	0.07	**0.07**	0.06	0.07	0.06	0.08	0.04	0.07	0.07
	$p\left(B_y^{Aobs} < B_{crit}^A, B_y \geq B_{crit}^A/k_N^A\right)$	-	0.01	**0.01**	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	$p\left(B_y^{Aobs} \geq B_{crit}^A, B_y < B_{crit}^A/k_N^A\right)$	-	0.01	**0.01**	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	$p\left(B_y^{Aobs} \geq B_{crit}^A, B_y \geq B_{crit}^A/k_N^A\right)$	-	0.91	**0.91**	0.92	0.91	0.92	0.90	0.94	0.91	0.90
	Avg # years $B_y^{Aobs} < B_{crit}^A$ consecutively		2.3	**2.2**	2.1	2.2	2.5	2.5	2.2	2.2	2.3
Ecosystem	P(Bsar+Banch) < historical min	0.01	0.07	0.08	0.04	0.07	0.05	0.10	0.04	0.07	0.07

[5] The lowest historical spawner biomass for A_{com} was 1995, not 1996, but 1996 is still used as the threshold year in this robustness test as the spawner biomass in 1996 was only 1% more than 1995.