Performance review of simple management procedures: Supplemental Appendix A

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Appendix A: Reference methods

DCAC

In circumstances where the information available is insufficient to derive a catch-limit from stock assessment Depletion Corrected Average Catch has been applied (DCAC, MacCall 2009). DCAC attempts to calculate average catch accounting for the removal of "windfall harvest" of less productive biomass that may have occurred as the stock became depleted. DCAC requires inputs for M, F_{MSY}/M (or c), B_{MSY}/B_0 (stock biomass at MSY relative to unfished, B_{peak}) and B_{cur}/B_0 (current stock depletion, D). A number of samples are drawn from the following distributions:

App.A.1a) $$M_{DCAC} \sim \text{lognormal}(\mu=M, SD=0.5)$$

App.A.1b) $$c_{DCAC} \sim \text{lognormal}(\mu=c, SD=0.2)$$

App.A.1c) $$D_{DCAC} \sim \text{lognormal}(\mu=D, SD=0.2)$$

where, in keeping with MacCall's (2009) approach, the SDs for M and c are set to 0.5 and 0.2, respectively.. MacCall (2009) states that "unlike the other parameters, the precision of [depletion D] is entirely dependent on the data and method used in its estimation, and there is no clear value of precision that can serve as a default". Subsequently, Dick and MacCall (2011) assume a default distribution with a CV of 0.25. We adopt a beta distribution for depletion:

App.A.2a) $$D_{DCAC} \sim \text{beta}(\mu=D_{obs}, CV = 0.25) \text{ where } D_{obs} < 0.5$$

App.A.2b) $$1\text{-}D_{DCAC} \sim \text{beta}(\mu=1\text{-}D_{obs}, CV = 0.25) \text{ where } D_{obs} > 0.5$$

For each sample of these parameters, sustainable yield (SY) is calculated by:

App.A.3)

$$SY_{DCAC} = \frac{\sum C_{obs}}{n + (1 - D_{DCAC})/(Bpeak_{DCAC} c_{DCAC} M_{DCAC})} = \frac{\sum C_{obs}}{n + (1 - D_{DCAC})/(0.4 c_{DCAC} M_{DCAC})}$$

where the C_{obs} are annual historical catches and n is the number of years of historical catches.

This stochastic approach produces numerous samples of the derived sustainable yield (*SY*) of which a percentile (typically the median) is used as the TAC.

F_{MSY}/M ratio 'Fratio'

It has been suggested that ratios of F_{MSY}/M (c) may be robust to broad life-history types and fisheries exploitation scenarios. Gulland (1971) proposed a simple method of setting maximum sustainable yield $MSY = 0.5M \cdot B_0$, in doing so assuming that B_{MSY}/B_0 =0.5 and F_{MSY}/M = 1. Subsequent publications have revised this F_{MSY} recommendation downwards. The Fratio MP is simulated by generating imperfect knowledge regarding *M*, current absolute biomass and the ratio of F_{MSY}/M.

Delay-difference stock assessment (DD)

The performance of a delay-difference model (Deriso, 1980; Schnute, 1985) fitted to catch and effort data is evaluated to provide a reference for the performance of the other MPs. The delay-difference model requires additional auxiliary (independent) information regarding the form of the stock-recruit function, the fraction mature at age, somatic growth, *M*, and the selectivity-at-age curve. The delay-difference stock assessment method provides estimates of B_{cur} and F_{MSY} and therefore direct estimates of an appropriate catch limit.

The delay-difference model is fitted to annual total catch and effort data. The model is parameterized according to: maximum sustainable yield, MSY_{DD} and harvest rate at maximum sustainable yield, $Umsy_{DD}$. The catchability coefficient scaling effort to fishing mortality rate is also estimated. The growth parameters α and ρ of the Ford-Brody growth model ($W_{a+1}=\alpha+\rho W_a$) are approximated from the known weight at age *W*, for each simulation:

App.A.4) $$\alpha = W_\infty(1-\rho); \qquad \rho = \frac{W_{V_{obs}+2} - W_\infty}{W_{V_{obs}+1} - W_\infty}$$

where W_∞ is the maximum weight of an individual. Selectivity at age is assumed to follow the maturity schedule and AM_{obs} is the observed age at 50% maturity selectivity determined from the ascending limb of the selectivity curve ω (Eqn. App.A.12). Since bias in the age at 50% maturity may strongly affect the delay-difference model, AM_{obs} is simulated subject to imperfect knowledge (Table App.C.1). Survival rate at maximum sustainable yield is given by $Smsy = \exp(-M_{obs})(1-Umsy_{DD})$ so that the number of spawners per recruit, SPR is given by:

App.A.5) $$SPR = \frac{(\alpha \cdot Smsy)/(1-Smsy) + W_{AM_{obs}}}{1-\rho \cdot Smsy}$$

The Beverton-Holt parameter α_{rec}, the maximum recruits per spawner as spawner biomass approaches zero, is calculated:

App.A.6) $$\alpha_{rec} = 1/\left((1-Umsy_{DD})^2 (SPR + Umsy_{DD} \cdot \Delta_{SPR})\right)$$

The derivative of yield with respect to harvest rate Δ_{SPR}, evaluated at $Umsy_{DD}$ is given by:

App.A.7) $$\Delta_{SPR} = -S_0 \frac{p}{1-\rho \cdot Smsy} \frac{SPR+1}{1-\rho \cdot Smsy} \frac{\alpha}{(1-Smsy)} + \frac{Smsy \cdot \alpha}{(1-Smsy)^2}$$

where S_0 is unfished survival rate $S_0 = \exp(-M)$. The Beverton-Holt parameter β_{rec} is calculated as:

App.A.8) $$\beta_{rec} = \frac{Umsy_{DD} \cdot (\alpha_{rec} \cdot SPR - 1/(1-Umsy_{DD}))}{MSY_{DD}}$$

Unfished recruitment R_0 is allocated to recruitments up to and including the age at recruitment to the fishery Am_{obs} and is given by:

App.A.9) $$R_0 = \frac{\alpha_{rec} \cdot SPR_0 - 1}{\beta_{rec} \cdot SPR_0}$$

where unfished spawners per recruit SPR_0 is calculated using Eqn. App.A.5 when S_{msy} is replaced by S_0. It follows that initial biomass B_1 is given by: $B_1 = R_0 \cdot SPR_0$ and initial numbers N_1 is given by $N_1 = R_0 / (1 - S_0)$. From this initialization, biomass dynamics are calculated by:

App.A.10) $$B_{y+1} = S_y\left(\alpha \cdot N_y + \rho \cdot B_y\right) + W_V \cdot R_{y+1} \quad ; \quad N_{y+1} = S_y \cdot N_y + R_{y+1}$$

where $S_y = \exp(-E_y q_{DD} - M)$ is the survival rate in year y, N represents stock numbers, B is the biomass, W_k is the weight of an individual at the age at 50% selectivity k, M is the natural mortality rate (assumed to be known exactly), q_{DD} is the estimated catchability, E_y is the observed fishing effort during year y, and R_y represents the number of recruits during year y:

App.A.11) $$R_{y+k} = \frac{\alpha_{rec}\left(B_y - C_y\right)}{1 + \beta_{rec}\left(B_y - C_y\right)}$$

where catches C, are given by: $C_y = B_y\left(1 - \exp\left(-q_{DD} E_y\right)\right)$.

The model is fitted to observed (simulated) catches by minimizing a global objective O that is calculated by the sum of the negative log likelihood of the catches (excluding constant terms):

App.A.12) $$O = \sum_y \left[\frac{\log(2\pi)}{2} + \log(\sigma_c) + \frac{\left(\log\left(C_y^{obs}\right) - \log\left(C_y\right)\right)^2}{2{\sigma_c}^2} \right]$$

where σ_c is the assumed standard deviation (in log space) of the observation error.

Appendix B. Operating model

Simulating stock dynamics

A standard age-structured, spatial model identical to that of Carruthers *et al*. (2014) was used to simulate population and fishery dynamics. Ranges of parameters and variables allowed variation among simulations for a given stock (*e.g*., natural mortality rate *M*, slope in recent fishing effort, targeting). All parameters that vary as random variables across simulations are denoted with a tilde (*e.g.* $\tilde{\sigma}$). The probability distributions from which these parameters are sampled are detailed in Table App.B.1. Hence, each parameter or variable denoted with a tilde represents a sample from a distribution specific to each stock. This convention alleviates the need for a simulation and stock subscript for every parameter or variable described below. For example, the symbol $\tilde{\sigma}$ represents $\tilde{\sigma}_{s,i} \sim f(\theta_s)$ which is the sample of the parameter $\tilde{\sigma}$ corresponding with the i^{th} simulation for stock *s*, drawn from a distribution function *f*(), which has stock specific parameters θ_s.

The numbers of individuals recruited to the first age group $N_{y,a=1,r}$ in each year *y*, and area *r* is calculated using a Beverton-Holt stock-recruitment relationship with log-normal recruitment deviations:

App. B.1)
$$N_{y,a=1,r} = \exp\left(P_{y,r} - \frac{\tilde{\sigma}_{proc}^{\ 2}}{2}\right)\frac{0.8R_0\tilde{h}\,SSB_{y,r}}{0.2SSB_0(1-\tilde{h}) + (\tilde{h}-0.2)SSB_{y,r}}$$

where *h* is the steepness parameter, R_0 is the mean recruitment given unfished conditions, $SSB_{y,r}$ is spawning stock biomass in the previous year and SSB_0 is the mean spawning stock biomass under unfished conditions. The process error term *P*, is an autocorrelated random variable:

App.B.2)
$$P_{y,r} = \varsigma \cdot P_{y-1,r} + \phi_{y,r} \cdot \sqrt{1-\varsigma^2}\ , \quad \phi_{y,r} \sim \text{normal}(0, \tilde{\sigma}_{proc})$$

where ς controls the level of autocorrelation in recruitment deviations and ϕ is a normally distributed random variable with mean zero and standard deviation $\tilde{\sigma}_{proc}$.

The spawning stock biomass *SSB*, is given by:

App.B.3) $$SSB_{y,r} = \sum_{a=1}^{n_a} m_a W_a N_{y,a,r}$$

where m_a is the maturity-at-age *a*, and the maximum age n_a is specific to each stock. Maturity-at-age is assumed to follow a logistic relationship with age; the slope of the transition from immature to mature is determined by the precision parameter σ_A, and the inflection point $\tilde{A}_m$ that is the age where 50% of individuals are mature (sampled form a random uniform distribution):

App.B.4) $$m_a = \frac{1}{1 + \exp\left(\left(\tilde{A}_m - a\right) / \sigma_A\right)}$$

Numbers at age are converted to biomass using the von Bertalanffy growth equation:

App.B.5) $$L_a = \tilde{L}_{\inf}\left(1 - e^{-\tilde{\kappa}(a - t_0)}\right)$$

where L_a is the length of an individual of age *a*, the asymptotic length is L_{inf}, and κ is the slope at the theoretical age at zero length t_0. Simulated L_{inf} and κ are sampled independently and assumed to be time-varying with mean percentage slope α_{Linf} and α_κ (Table App.B.1.). Parameters α_{Linf} and α_κ were sampled independently from uniform distributions between -0.25 and 0.25 percent per year to investigate whether small temporal changes in growth could affect MP performance. Inter-annual variability in L_{inf} and κ were simulated from log-normal distributions with mean 1, and standard deviations sd_{Linf} and sd_K.

Weight at age W_a is assumed to be related to length by:

App.B.6) $$W_a = \beta L_a^{\alpha}$$

For ages greater than 1, fishing mortality is assumed to occur before natural mortality and the numbers-at-age are calculated by:

App.B.7) $$N_{y,a,r} = \left(N_{y-1,a-1,r} - C_{y-1,a-1,r}\right)\exp\left(-\tilde{M}\right)$$

Similarly to L_{inf} and κ, inter-annual variability in natural mortality rate was generated by sampling from a lognormal distribution with mean 1 and standard deviation sd_M. The underlying trend (per cent per year) in natural mortality was sampled from a random uniform distribution (Table App.B.1.). No "plus group" is modelled; instead the maximum age is set sufficiently high that survival to the maximum age is less than 1% under unfished conditions.

Movement and spatial targeting dynamics were not the focus of this simulation evaluation. The generic two-area model of the simulation framework was parameterized to mimic a fully diffuse stock that was not subject to spatial targeting.

Simulating fishery dynamics

The selectivity at age ω_a, was calculated using a double normal curve with age at maximum selectivity m_{sel}, an ascending limb standard deviation of σ_{sel1} and a descending limb standard deviation σ_{sel2}. These standard deviations were determined for each simulation by numerically solving for two user-specified quantities that are more intuitive: (1) the minimum age at 5% maximum selectivity $\tilde{a}_{0.05}$, and (2) the selectivity of the oldest age class $\tilde{\omega}_{old}$. To sample a wide range of selectivity dynamics $\tilde{a}_{0.05}$ was sampled from a uniform distribution between 20% and 50% age at maturity. Additionally $\tilde{\omega}_{old}$ could range from a 0-100%, representing dome-shaped selectivity curve where older fish are not fished to a 'flatted – topped' selectivity where older fish are fished at the same rate as younger fish.

The ascending limb age selectivity A_a (before normalization to a maximum value of 1) is given by:

App.B.8) $$A_a = \frac{1}{\sqrt{2\pi\tilde{\sigma}_{sel1}^{2}}}\exp\left(-\frac{(a-m_{sel})^2}{\tilde{\sigma}_{sel1}^{2}}\right)$$

The descending limb selectivity D_a is given by:

App.B.9) $$D_a = \frac{1}{\sqrt{2\pi\tilde{\sigma}_{sel2}^{2}}}\exp\left(-\frac{(a-m_{sel})^2}{\tilde{\sigma}_{sel2}^{2}}\right)$$

The selectivity at age is given by:

App.B.10) $$\omega_a = \begin{cases} A_a/\max(A_j) & j \le m_{sel} \\ D_a/\max(D_j) & j > m_{sel} \end{cases}$$

Catch in numbers is calculated by:

App.B.11) $$C_{y,a,r} = N_{y,a,r}\left(1-\exp\left(-\omega_a p_{y,r} F_{y,a}\right)\right)$$

where F is the instantaneous fishing mortality rate.

Observed catch is calculated by multiplying simulated catch in numbers-at-age by weight-at-age and adding observation error:

App.B.12) $$C_y^{obs} = \exp\left(\varepsilon_{y,a,r} - \frac{\tilde{\sigma}_{obs}^{\ 2}}{2}\right)\sum_a\sum_r C_{y,a,r} W_a \ , \quad \varepsilon_{y,a,r} \sim \text{dnorm}(0, \tilde{\sigma}_{obs})$$

The error term ε, is drawn from a standard normal distribution whose standard deviation σ_{obs} is sampled at random in each simulation:

Fishing mortality rate F, was assumed to be proportional to effort according to the constant $\tilde{q}$ which was determined by numerical optimizing for sampled current depletion D (Table App.B.1. below).

App.B.13) $$F_y = \tilde{q} E_y$$

Total effort is not related to biomass levels, and in historical and future projections can remain high even at very low biomass levels. The maximum instantaneous fishing mortality rate is limited to 90% to prevent the simulation of large declines in stock biomass in any year due to TAC recommendations that are occasionally very high.

Log-normal variability in effort is added to a general effort trend V:

App.B.14) $$E_y = \exp\left(\varphi_y - \frac{\tilde{\sigma}_{eff}^{\ 2}}{2}\right) V_y \ , \qquad \varphi_y \sim \text{dnorm}(0, \tilde{\sigma}_{eff})$$

where the effort variability term φ_y is randomly sampled from a standard normal distribution that has a standard deviation, $\tilde{\sigma}_{eff}$ drawn at random for each simulation from a uniform distribution ranging from 0.1 to 0.4.

A range of effort variability is sampled to assess how the degree of auto-correlation affected the performance of stock status classification methods. The general trend in effort is determined by a linear model of change in effort over time with slope a_E, and intercept of 0.5:

App.B.15) $$\frac{dV_y}{dy} = a_E y + 0.5$$

This functional form allows effort to increase, decrease or remain unchanged over time. This effort model is constrained by sampling positive values for initial changes in effort (effort is increasing at the start of the time series). The final annual change in effort $\tilde{\Delta}_E$, was sampled from a uniform distribution between -1 and 1 to simulate a range of final effort trajectories including strongly decreasing and increasing effort:

App.B.16) $$\tilde{\Delta}_E = \frac{dV_{final}}{dy}$$

For any simulated effort time series, the slope a_E, can then be calculated from the total number of years in the time series n_y, and the sampled intercept of 0.5:

App.B.17) $$a_E = (\tilde{\Delta}_E - 0.5)/n_y$$

Simulated effort time series that included negative values were discarded. All of the stocks experienced the same effort dynamics.

In any given year, spatial fishing effort is assumed to be proportional to the distribution of the vulnerable biomass in the previous year, modified by a targeting parameter λ, that controls how strongly fishing effort will be distributed in relation to vulnerable biomass. The fraction of fishing effort P, allocated to each region r, in a given year y, is calculated:

App.B.18) $$p_{y,r} = \left(\sum_a \omega_a W_a N_{y,a,r}\right)^{\lambda} \Big/ \sum_r \left(\sum_a \omega_a W_a N_{y,a,r}\right)^{\lambda}$$

The values for p sum to 1 in any year so they can be used to distribute total effort E_y across areas in each year such that mean F among areas is the same as total annual F. Fishing is distributed evenly regardless of the vulnerable biomass in the previous year when the targeting parameter λ is zero. Spatial fishing will be distributed in favour of areas of high vulnerable biomass when λ is positive and distributed away from such areas when λ is negative. For all stocks a range of the targeting parameter was sampled from a random uniform distribution between -0.5 and 1 to evaluate the impact on MPs of the distribution of fishing relative to the population.

Parameterization of stock dynamics

Given the availability of full stock assessments with which to characterize their stock dynamics, we chose Pacific herring (DFO, 2012), Atlantic bluefin tuna (ICCAT, 2012), and canary rockfish (Wallace and Cope, 2011) as case-studies that span a range of longevity. The values of input parameters and the sources of these inputs are detailed in Table App.B.1.

Table App.B.1. Summary of the variables/parameters that define each of the stock simulations, including values and/or the range over which they are sampled. The values for simulations were taken from recent stock assessments for Pacific herring (DFO, 2012), eastern Atlantic bluefin tuna (ICCAT, 2012) and canary rockfish (Wallace and Cope, 2011). Where two values are provided, variables are sampled from a uniform distribution with the lower and upper bounds listed.

Name		Pacific herring		Eastern Atlantic bluefin tuna		Canary rockfish	
Maximum age	n_a	10		32		64	
Steepness	h	0.4	0.6	0.6	0.9	0.35	0.7
Mean natural mortality rate	μ_M	0.28	0.38	0.12	0.16	0.04	0.08
Interannual variability in natural mortality rate	sd_M	0	0.1	0	0.1	0	0.05
Gradient in natural mortality rate (per cent y^{-1})	α_M	-0.5	0.5	-0.5	0.5	-0.5	0.5
Theoretical age at length zero	$t0$	-0.025		-0.97		-0.04	
Mean maximum length	μ_{Linf}	25	29	315	325	62	68
Interannual variability in maximum length	sd_{Linf}	0	0.025	0	0.025	0	0.025
Gradient in maximum length (per cent y^{-1})	α_{Linf}	-0.25	0.25	-0.25	0.25	-0.25	0.25
Mean von Bertalanffy growth coefficient	μ_K	0.43	0.53	0.08	0.1	0.122	0.128
Interannual variability in the growth coefficient κ	sd_K	0	0.025	0	0.025	0	0.025
Gradient in the growth coefficient κ (per cent y^{-1})	α_K	-0.25	0.25	-0.25	0.25	-0.25	0.25
Weight-length parameter a ($W=aL^b$)	α_{WL}	4.50E-06		1.96E-05		1.55E-05	
Weight-length parameter b ($W=aL^b$)	b_{WL}	3.127		3.009		3.03	
Stock depletion, biomass relative to unfished	D	0.025	0.6	0.025	0.6	0.025	0.6
Age at 50% maturity	A_m	1.7	2.3	3.5	5	6.5	9.5
Spatial targetting parameter	λ	0.5	1	0.5	1	0.5	1
Log-normal recruitment variation	σ_R	0.2	0.4	0.1	0.3	0.2	0.5

Appendix C: Simulating imperfect information

Table App.C.1. Summary of the bias /error parameters and related distributions that control the accuracy and precision of knowledge of the simulated system that is subsequently used by the data-limited methods and harvest control rules. The log-normal distribution described in the table below where ~lognormal(μ,σ) is the exponent of the normal distribution with mean μ and standard deviation σ, parameters: $\text{dnorm}\left(-0.5\log\left(1+\sigma^2/\mu^2\right),\sqrt{\log\left(1+\sigma^2/\mu^2\right)}\right)$.

Variable	**Symbol**	**Related functions**
The standard deviation of the log-normally distributed bias in natural mortality rate M (μ_M varies among simulations)	Υ_M	$M_{obs} = M \times \mu_M$ $\mu_M \sim lognormal(\mu=1,\Upsilon_M)$
The standard deviation of the log-normally distributed bias in von Bertalanffy growth rate parameter K (μ_K varies among simulations)	Υ_K	$K_{obs} = K \times \mu_K$ $\mu_K \sim lognormal(\mu=1,\Upsilon_K)$
The standard deviation of the log-normally distributed bias in biomass at maximum sustainble yield B_{MSY} (μ_{Bmsy} varies among simulations)	Υ_{Bmsy}	$Bmsy_{obs} = Bmsy \times \mu_{Bmsy}$ $\mu_{Bmsy} \sim lognormal(\mu=1,\Upsilon_{Bmsy})$
The standard deviation of the log-normally distributed bias in biomass at maximum sustainable yield relative to unfished Bpeak (B_{MSY}/B_0, μ_{Bpeak} varies among simulations)	Υ_{Bpeak}	$Bpeak_{obs} = Bpeak \times \mu_{Bpeak}$ $\mu_{Bpeak} \sim lognormal(\mu=1,\Upsilon_{Bpeak})$
The standard deviation of the log-normally distributed bias in the ratio of maximum sustainable fishing mortality rate to natural mortality rate $FMSY\_M$ (μ_{FMSY_M} varies among simulations)	Υ_{FMSY_M}	$FMSY\_M_{obs} = FMSY\_M \times \mu_{FMSY\_M}$ $\mu_{FMSY\_M} \sim lognormal(\mu=1,\Upsilon_{FMSY\_M})$
The standard deviation of the log-normally distributed bias in MSY(μ_{MSY} varies among simulations)	Υ_{MSY}	$MSY_{obs} = MSY \times \mu_{MSY}$ $\mu_{MSY} \sim lognormal(\mu=1,\Upsilon_{MSY})$
The standard deviation of the log-normally distributed bias in the age at first maturity Am (μ_{Am} varies among simulations)	Υ_{Am}	$Am_{obs} = Am \times \mu_{Am}$ $\mu_{Am} \sim lognormal(\mu=1,\Upsilon_{Am})$
Uniformly distributed observation error in recruitment (R_{obs}, varies among years and simulations, σ_{Robs} varies among simulations)	σ_{Robs}	$Robs=lognormal(\mu=R, \sigma_{Robs})$ $\sigma_{Robs} \sim U(L_{Robs}, U_{Robs})$
The standard deviation of the log-normally distributed bias in the current level of stock depletion D (B/B_0; D_{obs} and j_D vary among projected years and simulations; μ_D and σ_D vary among simulations)	Υ_D	$D_{obs} = D \times j_D$ $j_D \sim lognormal(\mu_D,\sigma_D)$ $\mu_D \sim lognormal(\mu=1,\Upsilon_D)$
Uniformly distributed observation error in current stock depletion μ_D for projected years	σ_D	$\sigma_D \sim U(L_D,U_D)$
The standard deviation of the log-normally distributed bias in catches C (C_{obs} and Υ_C vary among projected years and simulations; μ_C and σ_C vary among simulations)	Υ_C	$C_{obs} = C \times \Upsilon C$ $\Upsilon_C \sim lognormal(\mu_C,\sigma_C)$ $\mu_C \sim lognormal(\mu=1,\Upsilon_C)$
Uniformly distributed observation error in catches	σC	$\sigma_C \sim U(L_C,U_C)$
Standard deviation in log-normal error in the relative abundance index for projected years (I and Υ_I vary among years and simulations, σ_I varies among simulations)	σ_I	$I=B^{\beta}$ x Υ_I $\Upsilon_I \sim lognormal(1, \sigma_I)$ $\sigma_I \sim U(L_I,U_I)$
The beta parameter controlling hyperstability / hyperdepletion in the abundance index(β varies among simulations)	β	$LN(\beta) \sim U(LN(\beta_{min}),LN(\beta_{max}))$
Loguniform bias in current biomass (B_{obs} and j_B vary among years and simulations, μ_B and σ_B vary among simulations)	min_B max_B	$B_{obs} = B \times j_B$ $j_B \sim lognormal(\mu_B,\sigma_B)$ $log(\mu_B) \sim U(min_B,max_B)$
The maximum standard deviation for log-normal error in current biomass for projected years	σ_B	$\sigma_{Bcur} \sim U(L_B,U_B)$