Evaluating methods for setting catch limits in data-limited fisheries: Supplemental Appendix

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Appendix A: The Operating model

A.1 Simulating stock dynamics

An age-structured, spatial model was used to simulate population and fishery dynamics. A range of parameters and variables are allowed to vary among simulations for a given stock (*e.g.*, M, gradient 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.A.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 $f()$, from the 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.A.1)
$$N_{y+1,a=1,r} = \exp\left(P_{y,a,r} - \frac{\tilde{\sigma}_{proc}^{\ 2}}{2}\right)\frac{0.8R_0\tilde{h}\,SSB_{y,r}}{0.2SSB_0(1-\tilde{h}) + (\tilde{h}-0.2)SSB_{y,r}}$$

where h is the steepness parameter, R_0 is the recruitment given unfished conditions, $SSB_{y,r}$ is spawning stock biomass in the previous year and SSB_0 is the spawning stock biomass under unfished conditions. The process error term P, was randomly sampled from a standard normal distribution that has a standard deviation, σ_{proc}:

App.A.2)
$$P_{y,a,r} \sim N(0, \tilde{\sigma}_{proc})$$

The spawning stock biomass, SSB, is given by:

App.A.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, where 50% of individuals are mature at $\widetilde{A}_m$:

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

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

App.A.5) $$L_a = L_{\inf}\left(1 - e^{-K(a-t_0)}\right)$$

where L_a is the length of an individual of age a, the asymptotic length is L_{inf}, and K is the slope at the theoretical age at zero length t_0.

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

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

where $\widetilde{M}$ is the rate of natural mortality. No "plus group" is modelled, and instead the maximum age is set sufficiently high that survival to the maximum age is less than 1% under unfished conditions.

Movement is assumed to be constant over time and age of individuals, and to occur instantaneously at the end of each year. For example, for individuals of age *a,* moving from area *r,* to area *k* for any year *y*:

App.A.8) $$N_{y,a,k}^{after} = \sum_{r} N_{y,a,r}^{before} \psi_{r,k}$$

where ψ is the probability of an individual moving from area *r*, to area *k* (Equation App.A.27).

A.2 Simulating fishery dynamics

The vulnerability 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% vulnerability $\tilde{\omega}_{0.05}$, and (2) the vulnerability of the oldest age class $\tilde{\omega}_{old}$.

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

App.A.9) $$A_a = \frac{1}{\sqrt{2\pi\tilde{\sigma}_{sel1}^{2}}} \exp\left(- \frac{(a - m_{sel})^2}{\tilde{\sigma}_{sel1}^{2}} \right)$$

The descending limb vulnerability D_a is given by:

App.A.10) $$D_a = \frac{1}{\sqrt{2\pi\tilde{\sigma}_{sel2}^{2}}} \exp\left(- \frac{(a - m_{sel})^2}{\tilde{\sigma}_{sel2}^{2}} \right)$$

The vulnerability at age is given by:

App.A11) $$\omega_a = \begin{cases} A_a / \max(A) & a \le m_{sel} \\ D_a / \max(D) & a > m_{sel} \end{cases}$$

Refuges from fishing is simulated here by a regional availability variable *R* that is 1 for at least one area:

AppA.12)
$$\begin{aligned} R_r &= 1 & r = 1 \\ R_r &\sim dbern\left(1-\left(\tilde{p}_R \frac{n_r}{n_r - 1}\right)\right) & r > 1 \end{aligned}$$

where *R* is the regional availability of the stock to fishing, p_R is the Bernoulli probability of failure ("failure to fish successfully" or "probability of a refuge", Table App.A.1.) pre-specified for each stock.

Since biomass may not be distributed evenly in space, refuges may also be expressed in terms of the fraction of biomass not available to fishing (under unfished conditions):

App.A.13)
$$ref = \frac{\sum_a \sum_r N_{1,a,r} W_a R_r}{\sum_a \sum_r N_{1,a,r} W_a}$$

Catch in numbers is calculated by:

App.A.14)
$$C_{y,a,r} = N_{y,a,r}\left(1 - \exp\left(-\omega_a p_{y,r} R_r F_{y,a}\right)\right)$$

where *F* is the fishing mortality rate.

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

App.A.15)
$$C_y^{obs} = \exp\left(\varepsilon_{y,a,r} - \frac{\tilde{\sigma}_{obs}^{\;2}}{2}\right)\sum_a \sum_r C_{y,a,r} W_a$$

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

App.A.16) $$\varepsilon_{y,a} \sim N(0, \tilde{\sigma}_{obs})$$

Fishing mortality rate *F,* may increase relative to effort (*E*) over the historical period according to catchability *q* modified by a percentage increase in fishing efficiency each year $\tilde{\Delta}_q$:

AppA.17) $$F_y = \tilde{q} E_y \left(1 + \tilde{\Delta}_q / 100\right)^{y-1}$$

Total effort was not related to biomass levels and in historical and future projections could remain high even at very low biomass levels. The maximum fraction of the population that could be caught in any given year was restricted to a maximum of 90% to prevent the simulation of single year stock collapses from ABC recommendations that are occasionally very high.

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

AppA.18) $$E_y = \exp\left(\varphi_y - \frac{\tilde{\sigma}_{eff}^{\;2}}{2}\right) V_y$$

The effort variability term φ_y was randomly sampled from a standard normal distribution that has a standard deviation, σ_{eff} drawn at random for each simulation:

App.A.19) $$\varphi_y \sim N(0, \tilde{\sigma}_{eff})$$

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

App.A.20) $$\frac{dV_y}{dy} = a_E y + \tilde{b}_E$$

This functional form allows effort to increase, decrease or remain flat over time. This effort model was constrained by sampling positive $\tilde{b}_E$ values (effort was increasing at the start of the time series). the final annual change in effort $\tilde{\Delta}_E$, is specified by the user to control the sampling of increasing, neutral and decreasing final effort trajectories:

App.A.21) $$\tilde{\Delta}_E = \frac{dV_{final}}{dy}$$

For any simulated effort time series, the slope could then be calculated from the total number of years in the time series n_y, and the sampled intercept $\tilde{b}_E$:

App.A.22) $$a_E = \left(\tilde{\Delta}_E - \tilde{b}_E\right)/ n_y$$

Effort time series with negative values were discarded. All of the stocks had the same underlying variability in temporal 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:

App.A.23) $$p_{y,r} = \left(\sum_a \omega_a W_a N_{y,a,r} \right)^{\lambda_y} \Big/ \sum_r \left(\sum_a \omega_a W_a N_{y,a,r} \right)^{\lambda_y}$$

The values for p average 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. In order to simulate increases or decreases in targeting, the targeting parameter follows a linear change over time with intercept 0, and final targeting level $\tilde{\lambda}_{cur}$ in the last historical year of the simulation n_y:

App.A.24) $$\lambda_y = \frac{y}{n_y} \tilde{\lambda}_{cur}$$

Targeting was assumed to remain constant over projected years at the same level as the final year of the historical period.

A.3 Initializing the population dynamics model and simulating movement

The initial biomass in each area is initialized according to an equilibrium assumption regarding age and spatial structure:

App.A.25) $$N_{y=1,a,r} = R_0 \left(e^{-\tilde{M}} \right)^{a-1} d_r$$

where d_r is the initial spatial distribution proportion, and the d_r sum to 1 over r. Note that the age structure is assumed to be the same across areas. The initial distribution vector of the stock over areas, $d=[d_1,\ldots,d_n]$, is the stationary distribution satisfying the condition:

App.A.26) $$d = \psi d$$

where d is the positive eigenvector of the movement probability matrix ψ, corresponding to the first eigenvalue (this can also be determined numerically by repeatedly multiplying an initial distribution for d by ψ). The probability ψ of moving from area r, to area k, is derived from a series of gravity terms g:

App.A.27) $$\psi_{r,k} = \frac{\exp(g_{r,k})}{\sum_k \exp(g_{r,k})}$$

These g terms are sampled at random from a uniform distribution defined by a maximum range parameter $\tilde{g}_{\max}$ where an additional residency parameter v, is added to the terms on the positive diagonal to decrease stock mixing (the probability of biomass remaining in the same area):

App.A.28) $$g_{r,k} \sim \begin{cases} U\left(-\frac{\tilde{g}_{\max}}{2}, \frac{\tilde{g}_{\max}}{2}\right) & a \neq k \\ U\left(-\frac{\tilde{g}_{\max}}{2} + \tilde{v}, \frac{\tilde{g}_{\max}}{2} + \tilde{v}\right) & a = k \end{cases}$$

The spatial distribution of the stock is uniform when $\tilde{g}_{\max}$ is zero and becomes increasingly heterogeneous with increasing $\tilde{g}_{\max}$.

A.4 Assigning life-history characteristics to each case study

Due to the availability of full stock assessments with which to characterize their stock dynamics, we chose Atlantic mackerel, Atlantic butterfish, red snapper, red porgy, petrale sole and canary rockfish as case-studies. The values of input parameters and the sources of these inputs are detailed in Error! Reference source not found. and illustrated in Error! Reference source not found..

A.5 Simulating imperfect knowledge

The distributions for imperfect information (Table 3) were chosen based on expert judgement and according to distributions applied in other settings. For example a coefficient of variation of 0.5 was selected for M

based on the recommendation of MacCall (2009): “for data-poor stocks there appears to be no justification for assuming a CV<0.5 unless additional information exists to improve the estimate”. The von Bertalanffy growth rate *K* was assumed to be known relatively precisely and assigned a CV of 20% to reflect the availability of data for growth for many species or taxonomic groups. Length of first capture was assigned a CV of 50% to reflect the difficulty in determining an appropriate value from patchy length-composition data that might be available for data-limited stocks. As in MacCall (2009) and Dick and MacCall (2010) a CV of 0.2 was specified for F_{MSY}/M and B_{MSY}/B_0 (they specify a mean and standard deviation for *Bpeak* for flatfish of respectively 0.25 and 0.05). Finally, we simulated bias with a CV of 1 to reflect large uncertainty in stock depletion or current stock size in a data-limited situation. Inter-annual error in these estimates was sampled from a lognormal distribution with a CV fixed over all projected years for each simulation. This CV was sampled from uniform distribution between 0 and 2 (*e.g*. a value of 0.58 for the CV is sampled from which error in current biomass would be generated for all projected years of a given simulation). This is analogous to the simulation of effort in which a certain amount of inter-annual variation was applied to all of the historical effort for a given simulation.

Table App.A.1. Summary of the variables/parameters that define each of the stock simulations, including values and/or the range over which they are sampled. Some variables/parameters are sampled from a uniform distribution with upper and lower bounds that are specified: U(min, max).

			Mackerel		Butterfish		Snapper		Porgy		Sole		Rockfish	
Symbol	**Description**		**Value**	**Reference**	**Value**	**Reference**	**Value**	**Ref.**	**Value**	**Ref.**	**Value**	**Ref.**	**Value**	**Reference**
n_{proj}	The largest of either 30 years or two generation times		30		30		30		30		30		50	
n_a	The maximum number of simulated ages		18	SAW 2006	6	SAW 2009	45		16		21		64	
M	The annual instantaneous rate of natural mortality	min	0.1	Deroba 2010	0.7	Murawski and Waring 1979	0.05		0.2		0.13		0.04	
		max	0.3		0.9		0.12		0.25		0.22		0.08	
h	The mean fraction of unfished recruitment at 20% of unfished biomass (D = 0.2)	min	0.25	Deroba 2010; SAW 2006	0.3		0.5		0.31		0.6		0.345	
		max	0.7		0.8		0.8		0.51		0.9		0.72	
L_{inf}	The maximum length of individuals (sex aggregated) in centimeters		40.7	Froese and Pauly 2012	24	SAW 2009	90.2		52.77		51.37		65.72554	Wallace and Cope 2011
K	The gradient of the growth curve at age t_0		0.268		0.20327		0.245		0.1985		0.17		0.125	
t_0	The theoretical quantity allowing an age-axis translation of the growth curve. Usually negative to allow positive length at age zero.		-2.17		-3.02		-0.03		-1.02		-1.62		-0.04	
a	The slope of the length (mm) to weight (kg) relationship.		6.0E-06	SAW 2006	1.6E-05	Froese and Pauly 2012	1.0E-06		1.1E-05		2.1E-06		1.6E-05	
b	The exponent of the length (mm) to weight (kg) relationship.		3.154		3.1		3.076		3.076		3.473703		3.03	
A_m	The inflection point of the age-at-maturity curve (age at 50% maturity)	min	2.2	Gregoire et al. 2003; Bigelow and Schroeder 2002	0.6		1.5		1		4		6.5	
		max	2.8		1.4		2.5		3		6		8.5	
σ_A	The slope parameter of the sigmoidal age-at-maturity curve a.		0.5		0.25		0.5	SEDAR 2010	1	SEDAR 2012	0.5	Haltuch et al. 2011	0.75	
m_{sel}	The age at maximum vulnerability	min	2.5	Deroba 2010	1	SAW 2009	2		3		4		6	Stewart 2007
		max	3.5		3		3		6		8		10	
$\omega_{0.05}$	The minimum age for which the ascending limb vulnerability is 0.05	min	0.5		0.5		1		1.5		1		3	
		max	0.75		0.7		1.5		2		2		5	
ω_{old}	The vulnerabilitiy of the descending limb for the oldest age class	min	0.9998		0.9998		0.5		0.9998		0.9998		0.5	
		max	0.9999		0.9999		1		0.9999		0.9999		1	
λ_{cur}	Targetting parameter in the final year of the time series	min	5.0E-01		0.0E+00		5.0E-01		5.0E-01		0.0E+00		0.0E+00	
		max	1.5		1		1		1		0.5		0.5	
Δ_q	The annual percentage increase in catchability	min	0.97		0.97		0.97		0.97		0.97		0.97	
		max	1.03		1.03		1.03		1.03		1.03		1.03	
p_R	The probability that an area is unavailable to fishing	min	0	Deroba 2010; SAW 2006	0		0		0		0		0	
		max	0.000001		0.000001		0.1		0.000001		0.000001		0.000001	

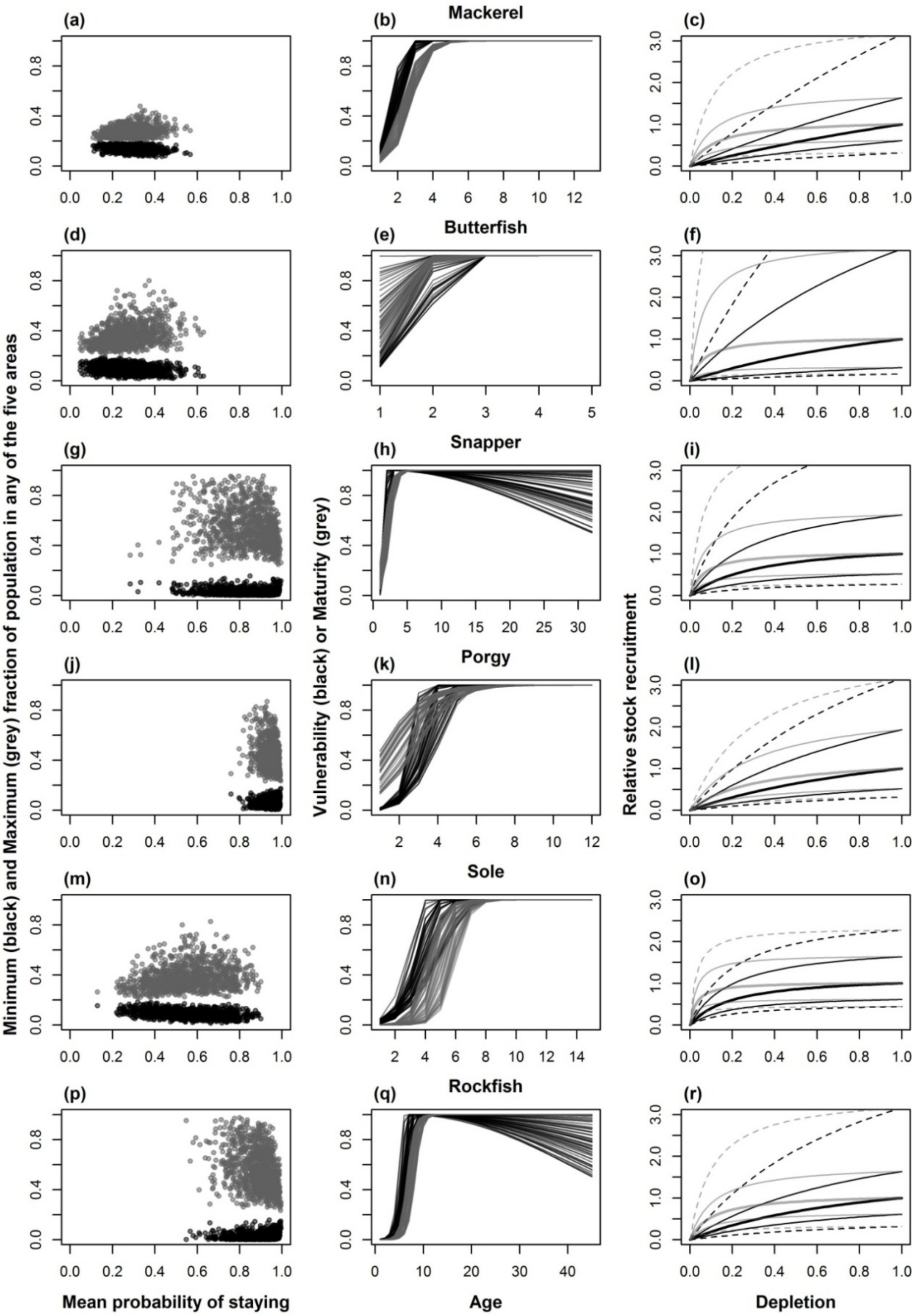

Figure App.A.1. Variation among population and fishery simulations. The left column of panels illustrates the properties of 1,000 simulations of the movement model. Points plotted in grey/black are the maximum/minimum fraction of the unfished population found in one of the five simulated areas, plotted against the mean probability that an individual will stay in a given area. Fifty example simulations of vulnerability-at-age and maturity-at-age are plotted in the middle column of panels. The simulated stock recruitment relationship is illustrated the right column of panels. Recruitment (y axis) is scaled to a fraction of average unfished recruitment. The bold grey and black lines represent the deterministic stock-recruitment curve that corresponds with the highest and lowest bounds specified for the steepness parameter. These are bracketed by solid and dotted lines that represent the 90% probability intervals of recruitment deviations corresponding to the minimum and maximum specified rate of inter-annual recruitment variability.

Appendix B: Implementing data-limited methods

B.1 Management methods M4-M9: Pacific Fishery Management Council static DB-SRA and DCAC

Depletion-Based Stock Reduction Analysis (DB-SRA) has been suggested by the PFMC for stocks classified Category 3. The OFL distribution is determined using stochastic Depletion Based-Stock Reduction Analysis (DB-SRA) assuming simulated imperfect knowledge (Appendix A.5.) and the prior conventions adopted by Dick and MacCall (2011). Distributions are required by DB-SRA for four parameters: M, F_{MSY}/M (or c), B_{MSY}/B_0 (or $Bpeak$) and current depletion (B_{cur}/B_0 or D). Each of these variables is distributed around a mean value μ, that is the 'observed' value after simulating imperfect knowledge. The variability in the DB-SRA Monte Carlo samples of each of these variables is expressed here as the standard deviation σ or coefficient of variability, CV (σ/μ) are set to the values of Dick and MacCall (2011).

App.B.1a) $M_{DBSRA} \sim \text{dlnorm}(\mu{=}M_{obs}, \sigma{=}0.4)$

App.B.1b) $c_{DBSRA} \sim \text{dlnorm}(\mu{=}c_{obs}, \sigma{=}0.2)$

App.B.1c) $Bpeak_{DBSRA} \sim \text{dbeta}(\mu{=}Bpeak_{obs}, \sigma{=}0.05)\text{I}(0.05,0.95)$

Dick and MacCall (2011) sample depletion from a beta distribution with a standard deviation of 0.1 and a mean of 0.4, and therefore a coefficient of variation of 0.25. We chose to define the distribution in terms of the CV since it provides a better approximation to knowledge regarding depletion at low depletion levels. At mean depletion levels greater than 50% it was not clear how to maintain the same coefficient of variation whilst keeping similar properties to the assumed distribution of depletion where the mean was less than 50%.

We chose to use a distribution that is symmetrical in properties around 50% depletion, and hence sample depletion in DB-SRA from two distributions:

29) $D_{DBSRA} \sim \text{dbeta}(\mu{=}D_{obs}, CV = 0.25)$ where $D_{obs} < 0.5$

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

Numerical optimization (the "optimize" function in the base package of the statistical environment R v2.15 64bit) was used to solve for a value of unfished biomasses $B0_{DBSRA}$ that lead to the sampled levels of depletion D_{DBSRA} , given the historical catches, and the sampled values for M_{DBSRA}, c_{DBSRA} and $Bpeak_{DBSRA}$ (for details see Dick and MacCall 2011). It follows that for each sample an estimate of the OFL is calculated:

App.B.3) $$OFL_{DBSRA} = \left(\frac{c_{DBSRA}}{c_{DBSRA}+1}\right)\cdot\left(1-e^{-M_{DBSRA}(1+c_{DBSRA})}\right)\cdot B0_{DBSRA}\cdot Bpeak_{DBSRA}$$

An ABC can then be computed from the OFL vector produced according to the $P*$ percentile rule.

The PFMC applied a particular version of DB-SRA (Dick and MacCall, 2010) that is identical to the above but assumes fixed distributions for the parameters: c (F_{MSY}/M), $Bpeak$ (B_{MSY}/B_0) and depletion D ($Bcur/B_0$):

App.B.4a) $c_{DBSRA} \sim \text{dlnorm}(\mu{=}0.8, \sigma = 0.2)$ (for non-flatfish species)

App.B.4b) $Bpeak_{DBSRA} \sim \text{dlnorm}(\mu{=}0.4, \sigma = 0.05)I(0.05,0.95)$

App.B.4c) $D_{DBSRA} \sim \text{dbeta}(\mu{=}0.4, \sigma = 0.1)$ ($\mu{=}0.25$ for flatfish species)

where the mean μ, and standard deviation σ, are those corresponding to the transformed distribution.

The PFMC uses a P^* (probability of overfishing) approach to convert an OFL recommendation from DB-SRA into an ABC. However, rather than using the distribution of the OFL derived from the stochastic output of DB-SRA the PFMC uses the median OFL estimate and then superimposes an OFL distribution around this median value (with a standard deviation, sigma). DB-SRA is considered a Category (data-poor) 3 stock which leads to an assumed assessment standard deviation of (sigma) of 1.44 and a P^* is assumed, corresponding to a particular scalar multiplier (these are described in App.B.1). Sensitivity is explored to assuming the sigma used for PFMC Category (data-moderate) 2 stocks. The P^*s for PFMC Category 2 and 3 stocks are respectively 40% and 45%. These lead to scalar multipliers of 83.3% and 83.4%. We condense these into a single management scenario (M5) with a scalar multiplier of 83.35%. It follows that three different scalar multipliers are considered: 69.4%, 83.35% and 91.3%.

In circumstances where the information available is insufficient to derive an OFL from stock assessment or DB-SRA, the NMFS advocates the use of Depletion Corrected Average Catch (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. Similarly to DB-SRA, DCAC requires inputs for M, F_{MSY}/M (or c), B_{MSY}/B_0 (or D) and B_{cur}/B_0 (or B_{peak}). All of these quantities are sampled from probability distributions, with the exception of *Bpeak* which is assumed to be 40% (MacCall 2009). A number of samples are drawn for M, D and c from the following distributions:

App.B.5a) $$M_{DCAC} \sim \text{dlnorm}(\mu = M_{obs}, CV = 0.5)$$

App.B.5b) $$c_{DBSRA} \sim \text{dlnorm}(\mu = c_{obs}, \sigma = 0.2)$$

where, in keeping with MacCall's (2009) approach, the CV for M is set to 0.5 and the standard deviation of the log-normally distributed c is set assumed to be 0.2. MacCall (2009) state 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) assumes a default distribution with a CV of 0.25. we adopt the same beta distribution for depletion to remain consistent with the assumptions made in simulating DB-SRA (detailed above in management scenario M1), i.e.:

App.B.6a) $$D_{DBSRA} \sim \text{dbeta}(\mu = D_{obs}, CV = 0.25) \text{ where } D_{obs} < 0.5$$

App.B.6b) $$1\text{-}D_{DBSRA} \sim \text{dbeta}(\mu = 1\text{-}D_{obs}, CV = 0.25) \text{ where } D_{obs} > 0.5$$

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

App.B.7) $$YS_{DCAC} = \frac{\sum C_{obs}}{n + (1 - D_{DCAC})/(Bpeak_{DCAC}c_{DCAC}M_{DCAC})} = \frac{\sum C_{obs}}{n + (1 - D_{DCAC})/(0.4c_{DCAC}M_{DCAC})}$$

where 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 (YS) that may be interpreted as either an OFL or ABC. It should be noted that there is no coherent theoretical basis supporting the assumption that average catches (whether they are adjusted for depletion or not) are representative of an OFL or ABC.

Depletion Corrected Average Catch (DCAC) has been suggested by the PFMC for stocks classified as Category 3. Dick and MacCall (2010) used DCAC for eight stocks that did not have sufficiently reliable catch histories to conduct DB-SRA. They assumed the same fixed distributions for the central parameters: *c Bpeak* and *D*. By specifying distributions for all four input parameters, Dick and MacCall (2010) extended the approach of MacCall (2009). The central equation remains the same (Eqn. App.B.7), and similarly to DB-SRA management scenarios M4-M6, the PFMC superimposes a *P** distribution over the median DCAC value. As before, there are three multipliers (0.694, 0.833 and 0.913) to convert the DCAC median value to an ABC.

B.2 Alternative approaches A1 and A2: depletion adjusted catch scalar

The SAFMC recommends the use of the Only Reliable Catch Stocks (Berkson et al., 2011) approach to determining the OFL for stocks designated level 4. It is not straightforward to reproduce the subjective scoring system of the ORCS approach that is used to determine depletion. Instead imperfect information about depletion was simulated directly from true depletion and then used in the same control rule as described in the ORCS report. The factor is determined by current biomass B_{cur}:

App.B.8)
$$ORCS\ \ factor = \begin{cases} 2 & 0.65B_0 < B_{cur} \\ 1 & 0.2\,B_0 < B_{cur} < 0.65B_0 \\ 0.5 & B_{cur} < 0.2B_0 \end{cases}$$

The OFL is calculated by multiplying this factor by the interquartile mean catch (the average of the values that are greater than the 25th percentile and lower than the 75th percentile).

App.B.9)
$$OFL = ORCS\ factor \times interquartile\ mean\ catches$$

The OFL is then modified again to form the ABC according to a scalar factor (*e.g.* Restrepo et al., 1998). For alternative methods 11, 12 and 13 the ABC is 75%, 90% and 100% of the OFL, respectively.

B.3 Alternative approaches A3-A6: Applying P* rules directly to DB-SRA and DCAC "OFL" distributions

Rather than summarize the outputs of DB-SRA and DCAC as a single median OFL recommendation over which a distribution is superimposed (requiring a user defined 'sigma' value), four methods that make direct use of the DB-SRA and DCAC outputs of methods M4-M9 are tested. The distributions of the "OFL" produced by these methods are then subjected to a pair of $P*$ rules: $P*$ = 25% and $P*$ = 50%. These probabilities are approximated by taking the *P** percentile of the vector of OFL values produced by both DB-SRA and DCAC.

B.4 Alternative Scenarios A7 and A8: Determination of F_{MSY} by life history analysis

It is challenging to reliably predict the historical biomass and depletion trend of a population even in the most data-rich stock assessment settings. The approach of Beddington and Kirkwood (2005) for example, uses coarse fishery and demographic characteristics to determine the rate at which a population may be sustainably exploited. The central equation of Beddington and Kirkwood (2005) is:

App.B.10) $$Fmsy_{LH} = \frac{0.6K_{obs}}{0.67 - Lc_{obs}}$$

where Lc_{obs} is the observed length at first capture and K_{obs} is the observed von Bertalanffy growth coefficient (the maximum growth rate of individuals).

The information requirements for this method are not nearly as high as the other methods described above. In most assessment settings *K* and *Lc* are likely to be better characterized than *D*, *M* and *Fmsy*/*M*. However, an estimate of *Bcur* is required to convert the estimate of F_{MSY} to an OFL. *Bcur* s may be determined by expert judgement, by a current population survey or by combining current observed catches $Ccur_{obs}$ with a short-term tagging experiment to quantify current exploitation rate *Fcur*:

App.B.11) $$Bcur_{obs}\left(1-e^{-F_{MSY}}\right) = \frac{Ccur_{obs}}{1-e^{-Fcur}}\left(1-e^{-F_{MSY}}\right) = OFL$$

The Beddington and Kirkwood (2005) method provides a single point estimate of the OFL. Similarly to the PFMC management scenarios (M4-M9) we derive scalar multipliers from two *P** levels by superimposing a distribution for the OFL over this point estimate. Based on an arbitrary sigma value of 0.5 we identify two scalars of 1 and 0.745 corresponding to *P** values of 50% and 25% of a log-normal distribution respectively.

B.5 Alternative approaches A9-A12: F_{MSY}/M *ratio methods*

It has been proposed 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. While Quinn and Deriso (1999) also identify a F_{MSY} /*M* ratio of 1, Thompson (1993) recommended a lower ratio of 0.8 and Walters and Martell (2002) a ratio of 0.5. The F_{MSY}/M ratio methods are simulated by generating imperfect knowledge regarding *M* (M_{obs}). Two ratios

($F_{MSY}/M = 0.5$, $F_{MSY}/M = 0.8$) and two scalar multipliers (sigma 0.5, $P*$ 25%, scalar = 0.745; sigma 0.5, $P*$ 50%, scalar = 1) were evaluated, essentially multiplying M_{obs} by four scalar multipliers.

B.6 Reference Approaches R1-R2: Delay-difference stock assessment

The performance of a delay-difference model (Deriso 1980, Schnute 1985, Hilborn and Walters 1992) fitted to catch and effort data (Cortés 2002, Cox *et al*. 2002) is evaluated to provide a reference for the performance of data-limited OFL. The delay difference model requires additional auxiliary (independent) information regarding the form of the stock-recruit function, the fraction mature at age, body growth, M, and the vulnerability-at-age curve. The delay-difference stock assessment method provides estimates of B_{curr} and F_{MSY} and therefore direct estimates of the OFL. In this simulation evaluation, the delay-difference assessment included perfect information of all quantities except vulnerability and historical catches. This was intended to represent relatively good performance for a stock assessment method that assumes that historical fishing effort is proportional to fishing mortality rate. Note however that the delay-difference model applied here assumes that recruitment is deterministic unlike data-rich stock assessments that typically attempt to estimate recruitment deviations.

Two time series of simulated data are used by the delay-difference model: spatially- and age- aggregated catch and the aggregate effort data from the simulation model. The delay-difference model is initialized with the following management parameters leading: 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.B.12) $$\alpha = W_{\infty}(1-\rho); \qquad \rho = \frac{W_{V_{obs}+2} - W_{\infty}}{W_{V_{obs}+1} - W_{\infty}}$$

where W_{∞} is the maximum weight of an individual and V_{obs} is the observed age at 50% vulnerability determined from the ascending limb of the vulnerability curve ω (Eqn. App.A.11). Since bias in the age at 50% vulnerability may strongly affect the delay-difference model V_{obs} is simulated subject to imperfect knowledge (**Error! Reference source not found.** 3). Survival rate at maximum sustainable yield is given by $Smsy = \exp(-M_{obs})(1 - Umsy_{DD})$ so the number of spawners per recruit, *SPR* is given by:

App.B.13) $$SPR = \frac{(\alpha\, Smsy)/(1 - Smsy) + W_{V_{obs}}}{1 - \rho\, Smsy}$$

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

App.B.14) $$\alpha_{rec} = 1/\left((1 - Umsy_{DD})^2 (SPR + Umsy_{DD}\Delta_{SPR})\right)$$

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

App.B.15) $$\Delta_{SPR} = -S_0 \frac{p}{1 - \rho Smsy} \frac{SPR + 1}{1 - \rho Smsy} \frac{\alpha}{(1 - Smsy)} + \frac{Smsy\alpha}{(1 - Smsy)^2}$$

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

App.B.16) $$\beta_{rec} = \frac{Umsy_{DD}(\alpha_{rec} SPR - 1/(1 - Umsy_{DD}))}{MSY_{DD}}$$

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

App.B.17) $$R_{1,2 \ldots V_{obs}} = R_0 = \frac{\alpha_{rec} SPR_0 - 1}{\beta_{rec} SPR_0}$$

where unfished spawners per recruit SPR_0 is calculated using Equation App.B.13 when S_{msy} replaced by S_0 :

It follows that initial biomass B_1 is given by: $B_1 = R_0 SPR_0$ and initial numbers N_1 is given by $N_1 = R_0 / (1 - S_0)$. From this initialization, biomass dynamics were calculated by:

App.B.18) $$B_{y+1} = S_y\left(\alpha N_y + \rho B_y\right) + W_V R_{y+1}; \;\; N_{y+1} = S_y N_y + R_{y+1}$$

where $S_y = \exp(-E_y q_{DD} - M)$ is the survival rate in year y, N represents stock numbers, B is the stock biomass, W_k is the weight of an individual at the age at 50% vulnerability 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.B.19) $$R_{y+k} = \frac{\alpha_{rec}\left(B_y - C_y\right)}{1 + \beta_{rec}\left(B_y - C_y\right)}$$

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:

App.B.20) $$O = \sum_y \left[\frac{\log(2\pi)}{2} + \log(\sigma_c) + \frac{\left(\log\left(C_y^{obs}\right) - \log\left(C_y\right)\right)^2}{2{\sigma_c}^2}\right]$$

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

Direct estimates of the OFL can be obtained since the delay-difference model provides direct estimates of current biomass *Bcur* in the latest year in addition to $Umsy_{DD}$, Similarly to alternative methods A7-A12, the OFL recommendation is modified by two scalar multipliers derived from a *P** ABC control rule assuming a sigma of 0.5 and two *P** levels of 25% and 50% (scalar values of 75% and 100%, respectively).

B.7 Reference approaches R3-R4: Current conditions

Two additional management methods are explored: (1) where the ABC is kept constant at the most recent historical catch level (R3) and (2) where fishing effort remains constant at the most recent historical level (R4). For reference case R4, constant effort can be simulated by assuming the same fishing mortality rate in the last historical year (no future catchability increases):

App.B.17) $$ABC_y = \sum_a \sum_r C_{y,a,r} W_a$$

where it is assumed that fishing will continue to be distributed dynamically by $p_{y,r}$ according to the targeting parameter in the final year λ_{ny} and the projected vulnerable biomass (*i.e.* Eqn.App.A.23)

Table App.B.1. The scalar multipliers (multiplied by median OFL from DB-SRA to obtain ABC) resulting from different *P** and sigma values.

PFMC category	**Sigma**	***P****	**Scalar multiplier**	**Applies to management scenario:**
2	0.72	40%	83.3%	M5, M8
2	0.72	45%	91.3%	M6, M9
3	1.44	40%	69.4%	M4, M7
3	1.44	45%	83.4%	M5, M8

Appendix C: Additional results

Table App.C.1. Overfishing, stock status and yield performance metrics for simulations starting above 150% of B_{MSY}. All of the numbers represent a percentage. The probability of overfishing 'P_{OF}' is the fraction of projected years for which fishing mortality rate exceeds F_{MSY}. 'B/B_{MSY}' is the mean biomass divided by biomass at maximum sustainable yield. 'Yield' is the mean relative yield over the last five years of the projection (the yield of a simulation over the last five years of the projection divided by that of the F_{ref} policy). Dark grey shading reflects poor scores (P_{OF} greater than 50%, B/B_{MSY} less than 50%, Yield less than 25%). Light grey shading reflects intermediate scores (P_{OF} greater than 25%, B/B_{MSY} less than 100%, Yield less than 50%).

Type	Code	Name	Mackerel			Butterfish			Snapper			Porgy			Sole			Rockfish		
			P_{OF}	B/B_{MSY}	Yield	P_{OF}	B/B_{MSY}	Yield	P_{OF}	B/B_{MSY}	Yield	P_{OF}	B/B_{MSY}	Yield	P_{OF}	B/B_{MSY}	Yield	P_{OF}	B/B_{MSY}	Yield
Catch-Based (Static)	M1	Median Catch - 3 Years	9	188	59	37	124	59	7	221	75	13	192	66	5	194	60	10	196	61
	M2	Median Catch - 10 Years	6	187	66	31	132	71	5	219	83	10	191	76	2	192	67	8	195	68
	M3	3rd Highest Catch	12	173	74	51	106	68	12	202	91	18	172	80	7	177	77	14	182	74
Depletion-Based (Static)	M4	DB-SRA (Depletion Fixed @ 40%B0) - 69.4% scalar	0	219	33	21	148	66	0	281	18	0	229	44	0	225	33	0	249	10
	M5	DB-SRA (Depletion Fixed @ 40%B0) - 83.4% scalar	0	213	40	29	136	69	0	278	22	1	220	54	0	218	41	0	247	12
	M6	DB-SRA (Depletion Fixed @ 40%B0) - 91.3% scalar	1	209	45	34	130	70	0	276	24	2	215	60	0	214	45	0	246	13
	M7	DCAC (Depletion Fixed @ 40%B0) - 69.4% scalar	0	222	28	10	162	66	0	282	16	0	234	38	0	229	28	0	250	9
	M8	DCAC (Depletion Fixed @ 40%B0) - 83.4% scalar	0	217	35	17	152	74	0	279	20	0	227	47	0	223	35	0	248	11
	M9	DCAC (Fixed Depletion @ 40%B0) - 91.3% scalar	0	214	40	21	146	78	0	277	22	0	222	53	0	220	40	0	247	12
Catch-Based (Dynamic)	A1	Depletion Adjusted Catch Scalar - 75% scalar	19	171	62	22	144	69	14	212	74	18	182	68	20	171	64	16	187	56
	A2	Depletion Adjusted Catch Scalar - 100% scalar	27	152	64	30	133	72	20	192	81	25	163	71	28	151	68	22	171	63
Depletion-Based	A3	DB-SRA (Depletion Adjusted) - 25% P*	25	138	50	29	134	53	12	217	75	23	151	62	34	136	52	9	204	48
	A4	DB-SRA (Depletion Adjusted) - 50% P*	36	120	48	34	127	58	20	184	90	32	136	61	43	121	51	15	169	59
	A5	DCAC (Depletion Adjusted) - 25% P*	0	202	54	25	140	82	0	257	47	1	214	62	0	203	57	0	228	35
	A6	DCAC (Depletion Adjusted) - 50% P*	1	198	58	26	138	82	0	252	53	1	209	67	0	199	61	0	224	39
Abundance-Based (Dynamic)	A7	Life History Analysis - 75% scalar	44	115	63	10	164	52	46	127	81	28	158	74	26	152	69	46	117	71
	A8	Life History Analysis - 100% scalar	52	99	56	14	156	59	53	109	72	36	140	72	35	134	68	54	99	63
	A9	FMSY/M (Low) - 75% scalar	12	184	57	16	155	59	6	238	61	12	196	64	10	194	56	10	200	58
	A10	FMSY/M (Low) - 100% scalar	18	170	62	22	145	65	9	225	69	18	180	69	15	180	62	15	187	65

Table App. C.2. Projected biomass for simulations starting below 50% B_{MSY}. All of the numbers represent a percentage. The probability of biomass increasing 'P_{inc}' is the fraction of projected simulations for which average biomass in the last three years of the projection is larger than average biomass for the last three years of the historical simulation. 'B_{end}' is the mean biomass over the final three years of the projection divided by B_{MSY} average over all simulations. The probability of ending below 50% B_{MSY} '$P_{<50}$' is the fraction of runs for which the mean biomass of the last three projected years is below 50% B_{MSY}. Similarly, $P_{<10}$ is the fraction of runs ending below 10% B_{MSY}. Dark grey shading reflects poor scores (P_{inc} less than 25%, B_{end} less than 50%, $P_{<50}$ greater than 50%, $P_{<10}$ greater than 25%). Light grey shading reflects intermediate scores (P_{inc} less than 50%, B_{end} less than 100%, $P_{<50}$ greater than 25%, $P_{<10}$ greater than 10%).

Type	Code	Name	Mackerel				Butterfish				Snapper				Porgy				Sole				Rockfish			
			P_{inc}	B_{end}	$P_{<50}$	$P_{<10}$	P_{inc}	B_{end}	$P_{<50}$	$P_{<10}$	P_{inc}	B_{end}	$P_{<50}$	$P_{<10}$	P_{inc}	B_{end}	$P_{<50}$	$P_{<10}$	P_{inc}	B_{end}	$P_{<50}$	$P_{<10}$	P_{inc}	B_{end}	$P_{<50}$	$P_{<10}$
Catch-Based (Static)	M1	Median Catch - 3 Years	25	28	81	73	74	119	28	19	29	40	75	68	38	55	66	59	30	44	71	68	13	11	91	82
	M2	Median Catch - 10 Years	13	14	89	84	65	101	38	27	12	16	89	85	23	30	80	74	13	17	88	85	6	5	96	91
	M3	3rd Highest Catch	7	7	95	92	50	76	52	40	5	6	96	94	11	15	90	87	5	6	95	95	2	2	99	95
Depletion-Based (Static)	M4	DB-SRA (Depletion Fixed @ 40%B0) - 69.4% scalar	32	46	70	64	58	86	47	31	82	172	19	18	42	68	60	55	55	99	46	45	76	73	40	22
	M5	DB-SRA (Depletion Fixed @ 40%B0) - 83.4% scalar	23	33	79	74	53	78	52	36	76	152	26	23	30	47	71	67	42	74	58	57	71	66	45	26
	M6	DB-SRA (Depletion Fixed @ 40%B0) - 91.3% scalar	20	27	82	78	51	73	54	38	72	142	30	27	25	38	76	72	36	63	64	62	68	63	47	29
	M7	DCAC (Depletion Fixed @ 40%B0) - 69.4% scalar	38	56	65	59	52	80	49	41	84	178	17	16	51	84	51	46	63	118	37	36	78	75	38	20
	M8	DCAC (Depletion Fixed @ 40%B0) - 83.4% scalar	29	41	74	68	45	69	56	45	79	159	23	20	38	60	64	58	51	90	49	48	73	68	43	24
	M9	DCAC (Fixed Depletion @ 40%B0) - 91.3% scalar	24	34	79	73	42	63	60	48	76	149	27	23	32	48	69	65	44	77	56	54	70	65	45	27
Catch-Based (Dynamic)	A1	Depletion Adjusted Catch Scalar - 75% scalar	45	54	63	51	67	98	37	21	66	102	38	31	64	87	44	30	58	89	45	39	48	36	69	44
	A2	Depletion Adjusted Catch Scalar - 100% scalar	34	41	72	62	59	85	45	27	55	80	50	42	52	68	55	41	47	69	56	50	34	26	78	57
Depletion-Based (Dynamic)	A3	DB-SRA (Depletion Adjusted) - 25% P*	84	97	36	14	81	117	26	7	88	187	15	7	83	126	25	9	72	129	32	24	95	94	23	4
	A4	DB-SRA (Depletion Adjusted) - 50% P*	80	85	42	20	76	107	31	11	81	159	24	14	77	111	31	13	67	114	38	29	89	84	30	8
	A5	DCAC (Depletion Adjusted) - 25% P*	30	33	75	65	41	59	62	48	74	124	29	24	40	55	63	56	33	47	67	64	56	42	61	37
	A6	DCAC (Depletion Adjusted) - 50% P*	18	20	85	77	39	57	63	50	60	90	43	37	26	35	76	69	23	28	79	75	38	29	74	51
Abundance-Based (Dynamic)	A7	Life History Analysis - 75% scalar	48	49	67	47	83	119	24	10	63	82	48	26	77	104	34	14	84	128	22	12	63	45	63	26
	A8	Life History Analysis - 100% scalar	38	38	73	57	79	109	29	12	52	65	59	38	69	87	44	22	75	107	31	20	52	37	71	37
	A9	FMSY/M (Low) - 75% scalar	82	95	39	17	78	108	29	13	98	196	5	1	92	143	17	5	97	176	6	2	96	84	30	4
	A10	FMSY/M (Low) - 100% scalar	75	84	45	23	72	98	35	17	96	181	8	2	86	128	23	8	93	160	11	4	92	77	34	6
	A11	FMSY/M (Hi) - 75% scalar	71	78	48	27	71	96	37	18	95	171	10	2	83	120	26	11	91	150	13	7	90	73	37	7
	A12	FMSY/M (Hi) - 100% scalar	63	67	55	34	66	86	41	22	91	152	15	5	77	104	34	17	85	131	20	12	84	66	44	12
Stock Assessment	R1	Delay-Difference - 75% scalar	87	109	31	12	77	118	30	14	98	245	2	1	88	153	18	7	90	142	13	5	99	100	18	2
	R2	Delay-Difference - 100% scalar	79	98	39	18	75	117	31	15	97	238	4	2	81	138	28	13	75	113	31	16	98	96	21	2
Status Quo (Static)	R3	Current Catch	25	28	81	73	70	112	33	23	28	40	75	69	37	54	66	60	30	44	71	68	13	11	91	82
	R4	Current Effort	16	15	91	68	45	50	63	35	14	17	93	53	23	21	87	50	12	15	93	61	10	12	94	66

Table App.C.3. As for Table App.C.2., except the simulations start between 50% and 100% of B_{MSY}.

Type	Code	Name	Mackerel				Butterfish				Snapper				Porgy				Sole				Rockfish			
			P_{inc}	B_{end}	$P_{<50}$	$P_{<10}$	P_{inc}	B_{end}	$P_{<50}$	$P_{<10}$	P_{inc}	B_{end}	$P_{<50}$	$P_{<10}$	P_{inc}	B_{end}	$P_{<50}$	$P_{<10}$	P_{inc}	B_{end}	$P_{<50}$	$P_{<10}$	P_{inc}	B_{end}	$P_{<50}$	$P_{<10}$
Catch-Based (Static)	M1	Median Catch - 3 Years	46	77	47	38	64	136	18	9	42	78	50	40	52	94	44	36	47	79	47	41	28	48	60	41
	M2	Median Catch - 10 Years	39	64	53	43	59	121	25	12	31	56	61	49	44	78	50	41	40	63	52	43	17	35	70	47
	M3	3rd Highest Catch	23	40	69	61	46	94	39	21	17	31	76	66	25	46	69	62	17	29	77	70	9	21	83	65
Depletion-Based (Static)	M4	DB-SRA (Depletion Fixed @ 40%B0) - 69.4% scalar	90	161	7	3	57	121	26	13	99	251	0	0	88	172	10	6	98	202	1	1	99	162	0	0
	M5	DB-SRA (Depletion Fixed @ 40%B0) - 83.4% scalar	81	140	14	9	51	107	32	17	97	238	2	1	75	143	20	15	93	179	6	4	98	156	1	0
	M6	DB-SRA (Depletion Fixed @ 40%B0) - 91.3% scalar	73	126	20	13	48	100	37	19	96	230	3	2	67	126	28	21	87	164	10	7	96	153	2	0
	M7	DCAC (Depletion Fixed @ 40%B0) - 69.4% scalar	94	173	4	1	65	137	18	9	99	256	0	0	94	191	5	2	100	216	0	0	99	164	0	0
	M8	DCAC (Depletion Fixed @ 40%B0) - 83.4% scalar	88	156	8	4	58	122	25	13	98	244	0	0	86	166	11	7	99	198	1	1	99	159	1	0
	M9	DCAC (Fixed Depletion @ 40%B0) - 91.3% scalar	83	145	11	7	54	114	29	16	98	237	1	0	79	150	16	11	96	186	2	2	98	156	1	0
Catch-Based (Dynamic)	A1	Depletion Adjusted Catch Scalar - 75% scalar	60	104	32	22	61	128	21	7	67	136	27	18	66	126	27	17	64	117	30	24	54	82	36	18
	A2	Depletion Adjusted Catch Scalar - 100% scalar	48	82	44	34	56	116	27	11	56	109	37	30	55	102	39	27	50	90	44	37	43	66	47	28
Depletion-Based (Dynamic)	A3	DB-SRA (Depletion Adjusted) - 25% P*	61	115	34	22	62	131	22	6	77	197	17	8	64	136	29	13	54	116	42	33	85	147	10	3
	A4	DB-SRA (Depletion Adjusted) - 50% P*	54	99	41	31	58	123	26	7	66	164	28	18	57	118	37	19	48	100	48	41	71	123	23	10
	A5	DCAC (Depletion Adjusted) - 25% P*	84	132	11	5	51	106	32	17	95	199	3	1	81	146	14	8	91	149	6	3	91	124	4	0
	A6	DCAC (Depletion Adjusted) - 50% P*	75	116	17	9	49	104	34	18	90	177	5	2	72	125	22	15	85	130	11	6	83	109	8	1
Abundance-Based (Dynamic)	A7	Life History Analysis - 75% scalar	45	82	46	31	70	148	12	2	45	91	44	22	66	128	26	9	74	139	18	9	46	73	41	17
	A8	Life History Analysis - 100% scalar	36	66	57	41	66	140	15	4	35	72	54	32	57	108	35	16	62	116	29	16	35	59	53	27
	A9	FMSY/M (Low) - 75% scalar	82	151	12	5	66	138	16	4	94	222	2	1	84	174	10	3	92	190	5	2	90	141	5	1
	A10	FMSY/M (Low) - 100% scalar	74	135	19	9	62	128	21	6	90	204	4	1	77	155	16	5	86	173	9	4	85	130	9	2
	A11	FMSY/M (Hi) - 75% scalar	70	127	23	11	60	126	21	7	88	193	6	1	73	146	20	7	83	163	12	6	81	123	11	3
	A12	FMSY/M (Hi) - 100% scalar	60	109	31	17	56	115	26	9	81	172	11	2	65	126	28	13	74	142	20	10	72	110	17	5
Stock Assessment	R1	Delay-Difference - 75% scalar	66	121	28	22	62	132	26	11	89	238	8	5	70	153	25	16	58	100	35	28	90	143	7	5
	R2	Delay-Difference - 100% scalar	53	101	40	32	61	130	28	12	85	225	12	8	62	138	32	22	40	74	52	43	84	131	12	8
Status Quo (Static)	R3	Current Catch	46	77	47	38	55	114	29	15	42	78	50	40	51	93	45	38	47	79	47	41	28	48	60	41
	R4	Current Effort	38	69	40	8	49	98	31	8	32	68	41	3	40	73	39	6	34	69	36	4	24	58	50	4

Table App.C.4.. As for Table App.C.2., except the simulations start between 100% and 150% of B_{MSY}.

Type	Code	Name	Mackerel				Butterfish				Snapper				Porgy				Sole				Rockfish			
			P_{inc}	B_{end}	$P_{<50}$	$P_{<10}$	P_{inc}	B_{end}	$P_{<50}$	$P_{<10}$	P_{inc}	B_{end}	$P_{<50}$	$P_{<10}$	P_{inc}	B_{end}	$P_{<50}$	$P_{<10}$	P_{inc}	B_{end}	$P_{<50}$	$P_{<10}$	P_{inc}	d	$P_{<50}$	$P_{<10}$
Catch-Based (Static)	M1	Median Catch - 3 Years	55	129	21	16	49	134	17	9	46	120	29	21	55	131	28	20	56	128	20	15	39	106	22	11
	M2	Median Catch - 10 Years	52	125	19	12	43	123	23	10	43	109	27	18	51	124	27	18	55	125	13	8	31	100	21	8
	M3	3rd Highest Catch	36	94	35	26	31	96	34	18	26	76	46	35	36	90	43	33	29	85	35	25	19	77	36	18
Depletion-Based (Static)	M4	DB-SRA (Depletion Fixed @ 40%B0) - 69.4% scalar	93	201	0	0	45	130	19	9	98	270	0	0	90	207	1	0	99	220	0	0	99	206	0	0
	M5	DB-SRA (Depletion Fixed @ 40%B0) - 83.4% scalar	88	189	1	1	38	115	26	13	98	262	0	0	81	188	4	2	97	206	0	0	98	202	0	0
	M6	DB-SRA (Depletion Fixed @ 40%B0) - 91.3% scalar	83	180	2	1	34	108	30	14	97	257	0	0	76	175	7	3	93	197	0	0	98	200	0	0
	M7	DCAC (Depletion Fixed @ 40%B0) - 69.4% scalar	95	208	0	0	52	145	12	6	98	274	0	0	94	219	0	0	100	228	0	0	100	207	0	0
	M8	DCAC (Depletion Fixed @ 40%B0) - 83.4% scalar	92	198	0	0	45	132	17	9	98	266	0	0	89	203	1	0	99	217	0	0	99	204	0	0
	M9	DCAC (Fixed Depletion @ 40%B0) - 91.3% scalar	89	191	1	0	42	124	21	11	98	261	0	0	84	193	2	1	99	210	0	0	99	202	0	0
Catch-Based (Dynamic)	A1	Depletion Adjusted Catch Scalar - 75% scalar	55	131	21	14	46	132	18	4	61	155	17	11	59	145	21	10	61	141	20	13	47	114	21	8
	A2	Depletion Adjusted Catch Scalar - 100% scalar	43	106	33	24	39	117	24	9	49	130	25	18	48	119	30	19	48	114	31	25	36	94	30	17
Depletion-Based (Dynamic)	A3	DB-SRA (Depletion Adjusted) - 25% P*	47	116	38	27	46	133	20	4	71	200	14	8	50	134	31	14	45	112	45	38	75	167	9	2
	A4	DB-SRA (Depletion Adjusted) - 50% P*	38	94	49	39	43	125	24	6	57	163	25	16	43	115	39	22	39	95	52	46	59	136	23	9
	A5	DCAC (Depletion Adjusted) - 25% P*	84	174	1	0	38	116	24	12	94	223	0	0	80	182	3	1	93	180	0	0	90	169	0	0
	A6	DCAC (Depletion Adjusted) - 50% P*	79	166	2	0	37	114	24	13	92	210	0	0	75	170	4	2	89	171	0	0	85	159	0	0
Abundance-Based (Dynamic)	A7	Life History Analysis - 75% scalar	33	89	44	29	56	151	9	2	31	93	40	22	52	133	23	9	56	137	21	11	30	86	39	16
	A8	Life History Analysis - 100% scalar	26	71	54	39	52	141	12	2	23	74	52	31	42	112	33	15	46	115	31	19	23	69	50	26
	A9	FMSY/M (Low) - 75% scalar	71	165	10	4	51	139	14	3	85	224	3	1	73	178	9	3	80	189	6	3	80	167	3	1
	A10	FMSY/M (Low) - 100% scalar	62	148	16	8	45	129	18	5	78	207	5	1	66	159	14	6	71	171	10	5	71	154	6	1
	A11	FMSY/M (Hi) - 75% scalar	58	139	20	10	44	127	19	5	74	196	6	2	60	150	18	7	67	161	13	7	66	146	9	1
	A12	FMSY/M (Hi) - 100% scalar	48	120	28	16	41	116	24	8	67	175	11	4	50	130	25	12	58	141	21	11	56	130	14	3
Stock Assessment	R1	Delay-Difference - 75% scalar	54	125	32	29	46	125	25	10	74	213	16	12	62	155	26	21	51	108	36	34	73	151	17	13
	R2	Delay-Difference - 100% scalar	44	107	40	36	45	121	30	13	69	199	20	14	54	139	31	25	35	84	45	43	64	133	25	18
Status Quo (Static)	R3	Current Catch	55	129	21	16	34	107	31	15	46	120	29	21	55	130	28	21	56	128	20	15	39	106	22	11
	R4	Current Effort	52	132	6	0	38	112	22	5	42	123	7	0	49	130	8	0	50	129	2	0	38	117	6	0

Table App.C.5. Projected biomass for simulations starting above 150% of B_{MSY}. All of the numbers represent a percentage. The probability of biomass increasing 'P_{inc}' is the fraction of projected years for which average biomass in the last three years of the projection is larger than average biomass for the last three years of the historical simulation. 'B_{end}' is the mean biomass over the final three years of the projection divided by B_{MSY}. The probability of ending below 50% B_{MSY} '$P_{<50}$' is the fraction of runs for which the mean biomass of the last three projected years is below 50% B_{MSY}. Similarly, $P_{<10}$ is the fraction of runs ending below 10% B_{MSY}. Dark grey shading reflects poor scores (P_{inc} less than 25%, B_{end} less than 50%, $P_{<50}$ greater than 50%, $P_{<10}$ greater than 25%). Light grey shading reflects intermediate scores (P_{inc} less than 50%, B_{end} less than 100%, $P_{<50}$ greater than 25%, $P_{<10}$ greater than 10%). Note that since simulations start above B_{MSY} low P_{inc} scores are not necessarily undesirable.

Type	Code	Name	Mackerel				Butterfish				Snapper				Porgy				Sole				Rockfish			
			P_{inc}	B_{end}	$P_{<50}$	$P_{<10}$	P_{inc}	B_{end}	$P_{<50}$	$P_{<10}$	P_{inc}	B_{end}	$P_{<50}$	$P_{<10}$	P_{inc}	B_{end}	$P_{<50}$	$P_{<10}$	P_{inc}	B_{end}	$P_{<50}$	$P_{<10}$	P_{inc}	B_{end}	$P_{<50}$	$P_{<10}$
Catch-Based	M1	Median Catch - 3 Years	46	179	8	6	22	120	25	14	50	218	6	4	42	178	13	8	55	191	5	3	44	194	3	1
(Static)	M2	Median Catch - 10 Years	43	179	4	3	19	112	28	14	46	213	4	2	38	177	9	5	50	189	1	0	39	193	1	0
	M3	3rd Highest Catch	30	157	11	7	13	82	44	23	32	185	10	7	27	148	19	12	33	165	5	3	28	178	4	1
Depletion-	M4	DB-SRA (Depletion Fixed @ 40%B0) - 69.4% scalar	73	227	0	0	23	128	22	9	94	318	0	0	66	236	0	0	85	237	0	0	93	257	0	0
Based (Static)	M5	DB-SRA (Depletion Fixed @ 40%B0) - 83.4% scalar	67	219	0	0	19	111	30	13	92	313	0	0	60	223	1	0	79	227	0	0	93	255	0	0
	M6	DB-SRA (Depletion Fixed @ 40%B0) - 91.3% scalar	64	213	0	0	17	102	34	16	91	309	0	0	55	215	1	1	76	221	0	0	92	254	0	0
	M7	DCAC (Depletion Fixed @ 40%B0) - 69.4% scalar	76	232	0	0	28	147	12	4	94	320	0	0	70	244	0	0	89	243	0	0	94	258	0	0
	M8	DCAC (Depletion Fixed @ 40%B0) - 83.4% scalar	71	224	0	0	23	132	18	7	93	315	0	0	65	233	0	0	85	235	0	0	93	256	0	0
	M9	DCAC (Fixed Depletion @ 40%B0) - 91.3% scalar	68	220	0	0	22	123	22	9	92	312	0	0	61	226	0	0	81	229	0	0	93	255	0	0
Catch-Based	A1	Depletion Adjusted Catch Scalar - 75% scalar	38	161	12	6	23	128	18	5	48	209	8	4	39	172	12	5	42	163	12	7	41	183	6	2
(Dynamic)	A2	Depletion Adjusted Catch Scalar - 100% scalar	29	136	21	14	19	116	26	8	37	181	14	8	30	146	20	11	30	136	22	15	30	164	11	4
Depletion-	A3	DB-SRA (Depletion Adjusted) - 25% P*	34	127	34	23	23	126	22	6	55	221	13	7	32	140	29	13	34	116	44	37	60	205	6	2
Based	A4	DB-SRA (Depletion Adjusted) - 50% P*	26	101	47	37	21	116	26	9	40	174	26	17	25	117	39	22	27	94	54	49	42	163	19	7
	A5	DCAC (Depletion Adjusted) - 25% P*	57	203	0	0	19	114	26	11	81	278	0	0	55	214	0	0	65	206	0	0	79	232	0	0
	A6	DCAC (Depletion Adjusted) - 50% P*	53	198	0	0	18	112	27	12	78	270	0	0	51	207	1	0	60	201	0	0	75	227	0	0
Abundance-	A7	Life History Analysis - 75% scalar	17	95	41	26	29	154	9	1	15	100	42	21	29	144	20	7	34	142	18	9	14	103	33	14
Based	A8	Life History Analysis - 100% scalar	13	76	52	37	27	145	12	3	11	79	53	31	23	122	30	13	26	120	29	17	10	83	45	23
(Dynamic)	A9	FMSY/M (Low) - 75% scalar	47	180	7	3	27	143	13	3	64	249	2	0	46	192	6	2	58	195	4	2	52	199	2	0
	A10	FMSY/M (Low) - 100% scalar	38	163	12	5	25	133	18	5	55	229	4	1	39	173	11	4	50	177	8	4	44	183	5	1
	A11	FMSY/M (Hi) - 75% scalar	34	153	15	7	24	131	20	5	51	217	6	1	36	163	14	5	45	167	11	5	40	174	7	2
	A12	FMSY/M (Hi) - 100% scalar	28	133	23	13	21	120	24	8	42	193	10	3	29	142	23	8	36	147	19	11	32	156	12	4
Stock	R1	Delay-Difference - 75% scalar	42	153	26	24	24	121	31	14	59	224	19	15	43	164	26	22	47	158	22	21	54	170	23	19
Assessment	R2	Delay-Difference - 100% scalar	34	132	34	31	23	117	34	16	53	206	24	18	37	146	32	26	34	132	30	29	45	149	31	26
Status Quo	R3	Current Catch	46	179	8	6	11	77	50	26	50	218	6	4	42	178	13	9	55	191	5	3	44	194	3	1
(Static)	R4	Current Effort	45	189	1	0	19	118	21	4	48	223	0	0	40	191	1	0	53	194	0	0	43	200	0	0

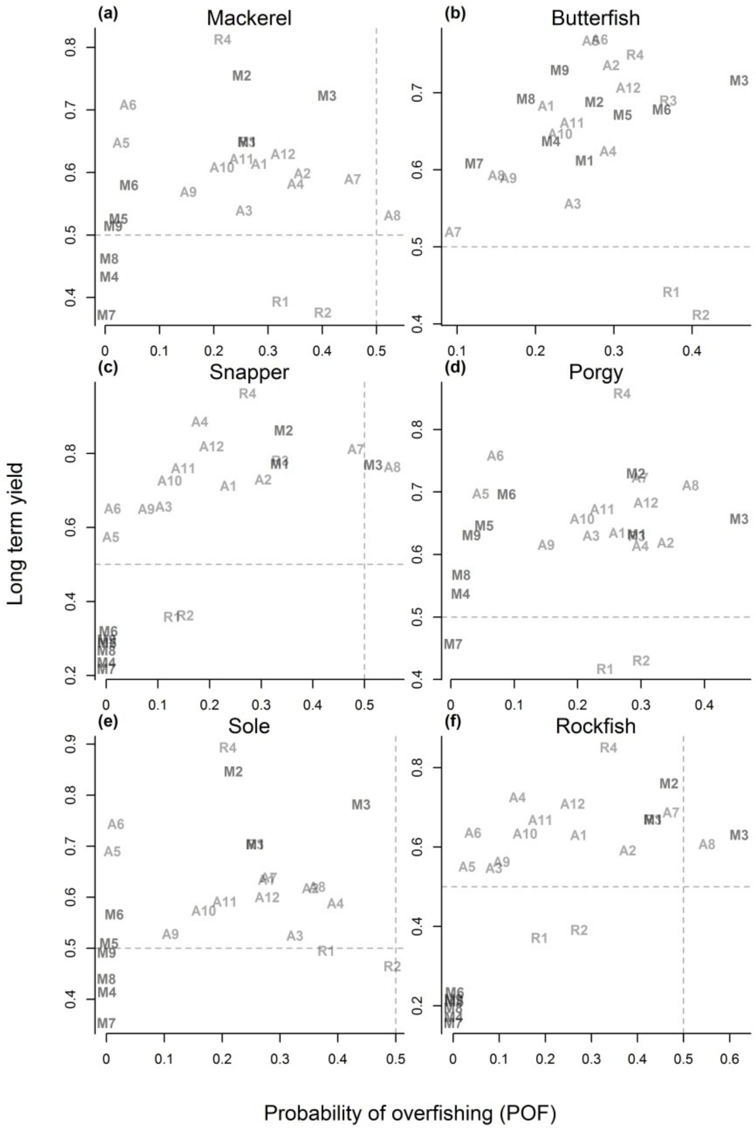

Figure App.C.1. The trade-off between of long term yield (yield over last 5 projected years divided by that of the F_{ref} strategy) and the probability of overfishing (fraction of projected years for which fishing mortality rate exceeded F_{MSY}) for projections starting between 100% and 150% B_{MSY}.

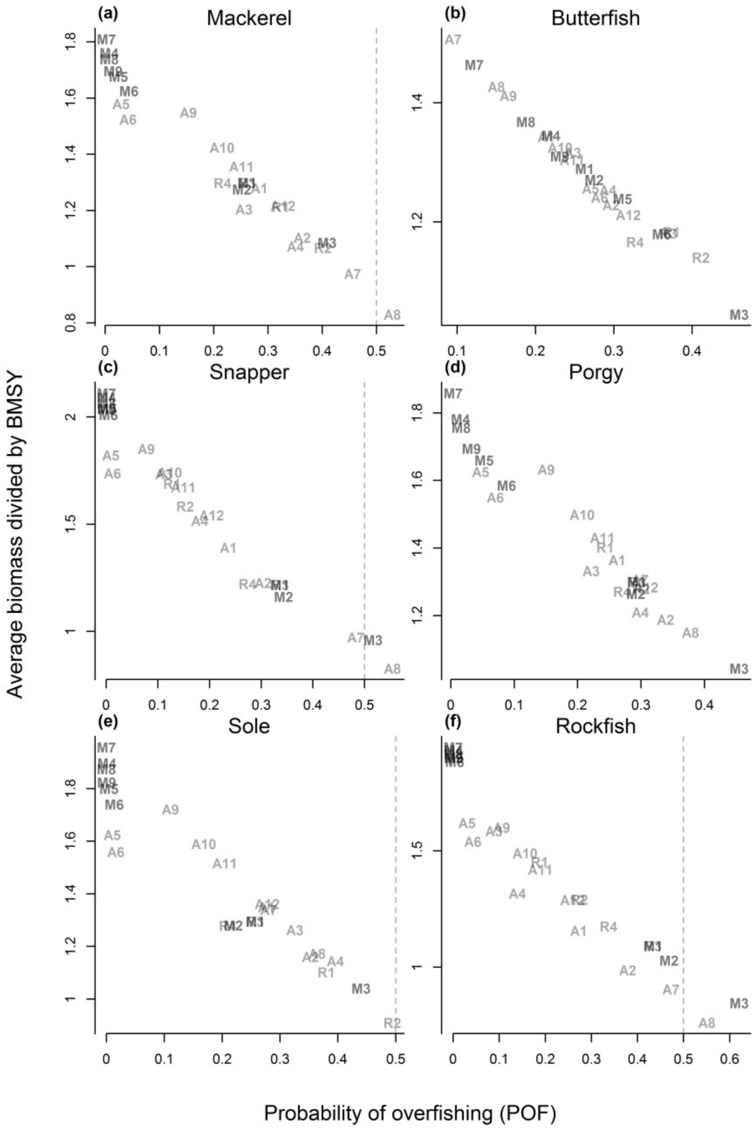

Figure App.C.7. The trade-off between average stock depletion (projected biomass divided by B_{MSY}) and the probability of overfishing (fraction of projected years for which fishing mortality rate exceeded F_{MSY}) for projections starting between 100% and 150% B_{MSY}.

Table App.C.6.. The sensitivity in the probability of overfishing to imperfect knowledge. The variables are CV in observation error (Obs err), bias in depletion (Dep bias), CV in depletion error (Dep CV), bias in the ratio of F_{MSY}/M (FMSY/M), bias in the ratio of B_{MSY} relative to unfished (BMSY/B0), bias in natural mortality rate (M), bias in the age at 50% maturity (50% Mat), bias in the current biomass (B bias), CV of error in current biomass (B CV), bias in the von Bertalanffy growth coefficient K (Von B K) and bias in the length at first recapture (L 1[st] Cap). All numbers are the standard deviation in probability of overfishing across ten divisions of each variable (10 percentile ranges). Sensitivity scores over 10 are shaded light grey, scores over 20 are shaded dark grey.

			Mackerel											Butterfish										
Type	Code	Methods	Obs err	Dep bias	Dep CV	FMSY/M	BMSY/B0	M	50% Mat	B bias	B CV	Von B K	L 1st Cap	Obs err	Dep bias	Dep CV	FMSY/M	BMSY/B0	M	50% Mat	B bias	B CV	Von B K	L 1st Cap
Catch-Based (Static)	M1	Median Catch - 3 Years	1											1										
	M2	Median Catch - 10 Years	1											1										
	M3	3rd Highest Catch	1											1										
Depletion-Based (Static)	M4	DB-SRA (Depletion Fixed @ 40%B0) - 69.4% scalar	1			1	1	7	1					1			1	1	5	2				
	M5	DB-SRA (Depletion Fixed @ 40%B0) - 83.4% scalar	1			1	1	9	1					1			1	1	5	1				
	M6	DB-SRA (Depletion Fixed @ 40%B0) - 91.3% scalar	1			1	1	10	1					1			1	1	5	2				
	M7	DCAC (Depletion Fixed @ 40%B0) - 69.4% scalar	1			1	1	5	1					1			1	1	2	2				
	M8	DCAC (Depletion Fixed @ 40%B0) - 83.4% scalar	1			1	1	7	1					0			1	0	3	2				
	M9	DCAC (Fixed Depletion @ 40%B0) - 91.3% scalar	1			1	1	8	1					0			1	1	3	2				
Catch-Based (Dynamic)	A1	Depletion Adjusted Catch Scalar - 75% scalar	1	8	3									1	6	2								
	A2	Depletion Adjusted Catch Scalar - 100% scalar	1	8	3									1	6	1								
Depletion-Based (Dynamic)	A3	DB-SRA (Depletion Adjusted) - 25% P*	1	19	3	2	2	8	0					0	22	3	2	3	3	1				
	A4	DB-SRA (Depletion Adjusted) - 50% P*	1	25	4	2	3	8	0					0	24	4	3	3	3	1				
	A5	DCAC (Depletion Adjusted) - 25% P*	1	5	1	4	3	7						1	2	1	2	1	3					
	A6	DCAC (Depletion Adjusted) - 50% P*	1	4	1	3	3	6						1	1	1	2	1	2					
Abundance-Based (Dynamic)	A7	Life History Analysis - 75% scalar								33	7	6	1								18	1	4	0
	A8	Life History Analysis - 100% scalar								33	8	5	1								22	1	4	0
	A9	FMSY/M (Low) - 75% scalar						10		21	0								9		23	1		
	A10	FMSY/M (Low) - 100% scalar						11		25	1								10		26	2		
	A11	FMSY/M (Hi) - 75% scalar						11		27	2								9		27	2		
	A12	FMSY/M (Hi) - 100% scalar						12		30	3								10		30	4		
Stock Assessment	R1	Delay-Difference - 75% scalar	1											1										
	R2	Delay-Difference - 100% scalar	1											1										

			Snapper											Porgy										
Type	Code	Methods	Obs err	Dep bias	Dep CV	FMSY/M	BMSY/B0	M	50% Mat	B bias	B CV	Von B K	L 1st Cap	Obs err	Dep bias	Dep CV	FMSY/M	BMSY/B0	M	50% Mat	B bias	B CV	Von B K	L 1st Cap
Catch-Based (Static)	M1	Median Catch - 3 Years	1											1										
	M2	Median Catch - 10 Years	1											1										
	M3	3rd Highest Catch	2											1										
Depletion-Based (Static)	M4	DB-SRA (Depletion Fixed @ 40%B0) - 69.4% scalar	0			0	0	4	0					1			0	1	8	1				
	M5	DB-SRA (Depletion Fixed @ 40%B0) - 83.4% scalar	0			0	0	5	0					1			0	0	11	1				
	M6	DB-SRA (Depletion Fixed @ 40%B0) - 91.3% scalar	0			0	0	6	0					1			1	1	12	1				
	M7	DCAC (Depletion Fixed @ 40%B0) - 69.4% scalar	0			0	0	3	0					1			0	0	5	1				
	M8	DCAC (Depletion Fixed @ 40%B0) - 83.4% scalar	0			1	0	4	0					1			0	0	7	1				
	M9	DCAC (Fixed Depletion @ 40%B0) - 91.3% scalar	0			0	0	5	0					1			0	0	9	1				
Catch-Based (Dynamic)	A1	Depletion Adjusted Catch Scalar - 75% scalar	1	8	2									1	9	2								
	A2	Depletion Adjusted Catch Scalar - 100% scalar	1	8	2									1	8	3								
Depletion-Based (Dynamic)	A3	DB-SRA (Depletion Adjusted) - 25% P*	1	11	2	1	1	5	0					0	21	3	2	2	8	1				
	A4	DB-SRA (Depletion Adjusted) - 50% P*	1	17	4	2	1	7	1					0	27	3	2	3	8	1				
	A5	DCAC (Depletion Adjusted) - 25% P*	0	2	0	2	2	4						1	5	0	4	3	7					
	A6	DCAC (Depletion Adjusted) - 50% P*	0	3	0	3	2	5						1	5	1	3	3	6					
Abundance-Based (Dynamic)	A7	Life History Analysis - 75% scalar								34	8	6	0								32	3	6	1
	A8	Life History Analysis - 100% scalar								33	9	5	1								35	5	6	1
	A9	FMSY/M (Low) - 75% scalar						6		9	1								9		20	1		
	A10	FMSY/M (Low) - 100% scalar						8		14	1								11		25	1		
	A11	FMSY/M (Hi) - 75% scalar						9		17	1								12		27	2		
	A12	FMSY/M (Hi) - 100% scalar						11		22	1								13		31	3		
Stock Assessment	R1	Delay-Difference - 75% scalar	1											1										
	R2	Delay-Difference - 100% scalar	1											1										

			Sole											Rockfish										
Type	Code	Methods	Obs err	Dep bias	Dep CV	FMSY/M	BMSY/B0	M	50% Mat	B bias	B CV	Von B K	L 1st Cap	Obs err	Dep bias	Dep CV	FMSY/M	BMSY/B0	M	50% Mat	B bias	B CV	Von B K	L 1st Cap
Catch-Based (Static)	M1	Median Catch - 3 Years	1											1										
	M2	Median Catch - 10 Years	1											1										
	M3	3rd Highest Catch	1											1										
Depletion-Based (Static)	M4	DB-SRA (Depletion Fixed @ 40%B0) - 69.4% scalar	1			1	0	7	1					1			0	1	6	1				
	M5	DB-SRA (Depletion Fixed @ 40%B0) - 83.4% scalar	1			1	1	10	1					1			0	1	8	1				
	M6	DB-SRA (Depletion Fixed @ 40%B0) - 91.3% scalar	1			1	1	12	1					1			0	1	9	1				
	M7	DCAC (Depletion Fixed @ 40%B0) - 69.4% scalar	1			1	0	5	0					1			0	1	5	1				
	M8	DCAC (Depletion Fixed @ 40%B0) - 83.4% scalar	1			1	1	7	1					1			0	1	7	1				
	M9	DCAC (Fixed Depletion @ 40%B0) - 91.3% scalar	1			1	1	8	1					1			0	1	7	1				
Catch-Based (Dynamic)	A1	Depletion Adjusted Catch Scalar - 75% scalar	1	10	3									1	6	2								
	A2	Depletion Adjusted Catch Scalar - 100% scalar	1	9	3									2	5	2								
Depletion-Based (Dynamic)	A3	DB-SRA (Depletion Adjusted) - 25% P*	0	25	5	1	3	8	1					0	8	2	1	0	3	0				
	A4	DB-SRA (Depletion Adjusted) - 50% P*	1	28	6	1	2	6	1					0	12	3	2	0	6	0				
	A5	DCAC (Depletion Adjusted) - 25% P*	1	4	0	2	2	6						1	6	1	3	4	7					
	A6	DCAC (Depletion Adjusted) - 50% P*	1	4	1	2	2	6						1	7	1	3	4	8					
Abundance-Based (Dynamic)	A7	Life History Analysis - 75% scalar								31	2	6	1								35	7	5	1
	A8	Life History Analysis - 100% scalar								34	4	6	1								34	9	5	1
	A9	FMSY/M (Low) - 75% scalar						8		15	1								8		15	1		
	A10	FMSY/M (Low) - 100% scalar						10		21	1								10		20	1		
	A11	FMSY/M (Hi) - 75% scalar						11		24	1								11		23	1		
	A12	FMSY/M (Hi) - 100% scalar						13		29	2								12		28	2		
Stock Assessment	R1	Delay-Difference - 75% scalar	1											1										
	R2	Delay-Difference - 100% scalar	1											1										

Table App.C.7. The sensitivity in probability of overfishing to variation in life-history and fishery characteristics. The variables are CV in inter-annual recruitment deviations ‘Proc err’, the CV in inter-annual variability in effort ‘Eff CV’, the final effort gradient controlling whether effort declines or increases in the most recent 25 year ‘Eff gradient’, the spatial targeting parameter ‘Targeting’, the annual percentage increase in fishing efficiency ‘F gain’, the steepness of the Beverton-Holt stock recruitment curve ‘Steepness’, the von Bertalanffy growth coefficient K ‘Von B K’, the stock viscosity parameter ‘Viscosity’ and the difference in years between the age at 50% vulnerability and the age at 50% maturity ‘50%V-50%M’. All numbers are standard deviations in probability of overfishing across ten divisions of each variable (10 percentile ranges). Sensitivity scores over 10 are shaded light grey, scores over 20 are shaded dark grey.

			Mackerel									Butterfish								
Type	Code	Methods	Proc err	Eff CV	Eff gradient	Targeting	F gain	Steepness	Von B K	Viscosity	50%V - 50%M	Proc err	Eff CV	Eff gradient	Targeting	F gain	Steepness	Von B K	Viscosity	50%V - 50%M
Catch-Based (Static)	M1	Median Catch - 3 Years	1	1	19	2	28	14	1	2	1	4	1	8	1	9	16	1	1	5
	M2	Median Catch - 10 Years	1	1	18	2	31	16	1	2	2	4	1	8	1	11	16	1	1	6
	M3	3rd Highest Catch	1	1	18	2	31	14	1	2	1	3	1	8	0	14	13	1	1	6
Depletion-Based (Static)	M4	DB-SRA (Depletion Fixed @ 40%B0) - 69.4% scalar	2	1	5	1	21	21	1	1	2	6	1	3	1	15	12	2	2	9
	M5	DB-SRA (Depletion Fixed @ 40%B0) - 83.4% scalar	2	1	5	1	23	22	1	2	2	5	1	3	1	16	10	2	2	9
	M6	DB-SRA (Depletion Fixed @ 40%B0) - 91.3% scalar	2	1	6	1	24	22	1	2	2	5	1	2	1	16	8	2	2	9
	M7	DCAC (Depletion Fixed @ 40%B0) - 69.4% scalar	1	1	4	1	20	21	1	1	2	9	1	3	1	12	24	1	2	9
	M8	DCAC (Depletion Fixed @ 40%B0) - 83.4% scalar	2	1	5	1	22	22	1	1	2	9	1	3	1	13	23	1	2	9
	M9	DCAC (Fixed Depletion @ 40%B0) - 91.3% scalar	2	1	5	1	23	22	1	2	2	9	1	3	1	13	22	1	2	9
Catch-Based (Dynamic)	A1	Depletion Adjusted Catch Scalar - 75% scalar	1	2	2	1	14	13	1	1	2	4	1	1	1	8	13	1	1	5
	A2	Depletion Adjusted Catch Scalar - 100% scalar	1	1	2	1	14	13	1	1	2	3	1	1	1	8	13	1	1	5
Depletion-Based (Dynamic)	A3	DB-SRA (Depletion Adjusted) - 25% P*	1	1	0	1	1	4	1	0	1	1	2	1	1	6	2	2	1	3
	A4	DB-SRA (Depletion Adjusted) - 50% P*	1	1	0	1	1	5	1	0	1	2	1	1	1	7	2	2	1	3
	A5	DCAC (Depletion Adjusted) - 25% P*	2	1	5	1	26	17	0	1	2	9	1	3	1	14	20	1	2	#
	A6	DCAC (Depletion Adjusted) - 50% P*	2	1	6	1	28	19	1	1	2	9	1	3	1	14	20	1	2	#
Abundance-Based (Dynamic)	A7	Life History Analysis - 75% scalar	0	1	0	1	1	10	1	1	1	4	0	1	1	2	10	1	1	2
	A8	Life History Analysis - 100% scalar	1	1	0	1	1	9	1	1	1	4	0	1	2	3	11	2	1	2
	A9	FMSY/M (Low) - 75% scalar	1	1	0	1	2	10	0	1	1	4	1	1	2	2	11	1	1	1
	A10	FMSY/M (Low) - 100% scalar	1	1	0	1	2	11	0	0	1	4	1	1	2	3	11	1	1	1
	A11	FMSY/M (Hi) - 75% scalar	1	1	0	1	2	11	0	1	1	5	1	1	2	3	12	1	1	1
	A12	FMSY/M (Hi) - 100% scalar	1	1	0	1	1	11	1	1	1	4	1	1	2	3	12	1	2	1
Stock Assessment	R1	Delay-Difference - 75% scalar	0	1	4	0	14	8	1	0	1	3	2	2	1	9	6	2	1	3
	R2	Delay-Difference - 100% scalar	2	1	4	0	17	8	1	0	1	4	2	1	1	8	7	1	1	3

			Snapper									Porgy								
Type	Code	Methods	Proc err	Eff CV	Eff gradient	Targeting	F gain	Steepness	Von B K	Viscosity	50%V - 50%M	Proc err	Eff CV	Eff gradient	Targeting	F gain	Steepness	Von B K	Viscosity	50%V - 50%M
Catch-Based (Static)	M1	Median Catch - 3 Years	1	1	17	2	27	4	1	1	2	1	2	17	1	25	8	1	0	4
	M2	Median Catch - 10 Years	1	1	17	1	31	4	2	1	2	1	3	17	1	29	9	1	1	4
	M3	3rd Highest Catch	2	2	18	1	32	4	2	1	2	1	1	17	2	30	7	1	0	4
Depletion-Based (Static)	M4	DB-SRA (Depletion Fixed @ 40%B0) - 69.4% scalar	1	0	2	0	7	3	1	0	1	2	1	5	1	20	11	1	1	6
	M5	DB-SRA (Depletion Fixed @ 40%B0) - 83.4% scalar	1	0	3	0	8	3	1	0	1	3	1	6	1	23	12	0	1	6
	M6	DB-SRA (Depletion Fixed @ 40%B0) - 91.3% scalar	1	1	3	1	9	3	1	0	1	3	1	7	1	24	12	0	1	6
	M7	DCAC (Depletion Fixed @ 40%B0) - 69.4% scalar	1	0	2	0	6	2	1	0	1	2	1	4	1	17	10	1	1	5
	M8	DCAC (Depletion Fixed @ 40%B0) - 83.4% scalar	1	0	2	0	8	3	1	0	1	2	1	5	1	20	11	1	1	6
	M9	DCAC (Fixed Depletion @ 40%B0) - 91.3% scalar	1	0	3	1	8	3	1	0	1	2	1	5	1	22	12	1	1	6
Catch-Based (Dynamic)	A1	Depletion Adjusted Catch Scalar - 75% scalar	1	1	2	1	9	3	0	0	1	2	1	2	0	9	6	1	1	3
	A2	Depletion Adjusted Catch Scalar - 100% scalar	1	1	2	1	11	4	1	1	1	2	2	2	0	10	7	0	1	3
Depletion-Based (Dynamic)	A3	DB-SRA (Depletion Adjusted) - 25% P*	0	0	1	0	1	1	0	1	0	1	0	1	1	1	2	0	1	2
	A4	DB-SRA (Depletion Adjusted) - 50% P*	1	1	1	1	2	1	1	1	1	1	0	1	1	1	2	1	1	2
	A5	DCAC (Depletion Adjusted) - 25% P*	1	0	3	0	11	3	1	0	1	3	2	5	1	22	9	1	1	5
	A6	DCAC (Depletion Adjusted) - 50% P*	1	1	4	1	15	4	1	1	1	3	2	6	1	25	10	0	0	5
Abundance-Based (Dynamic)	A7	Life History Analysis - 75% scalar	1	1	1	1	1	4	1	1	1	1	1	1	1	1	6	2	1	3
	A8	Life History Analysis - 100% scalar	1	1	1	1	1	4	1	1	1	1	1	1	1	1	6	2	1	3
	A9	FMSY/M (Low) - 75% scalar	0	0	0	0	0	2	0	0	1	1	1	0	1	1	4	1	1	2
	A10	FMSY/M (Low) - 100% scalar	1	0	1	0	0	2	0	1	1	1	1	1	1	1	5	1	1	3
	A11	FMSY/M (Hi) - 75% scalar	1	0	0	1	0	3	1	1	1	1	1	1	1	1	5	1	1	3
	A12	FMSY/M (Hi) - 100% scalar	1	0	1	1	1	3	1	1	1	1	1	1	1	1	5	1	1	3
Stock Assessment	R1	Delay-Difference - 75% scalar	1	0	5	1	4	1	0	0	1	1	1	4	1	12	2	0	0	2
	R2	Delay-Difference - 100% scalar	1	0	5	1	5	1	1	0	1	1	1	4	1	13	2	1	0	2

			Sole									Rockfish								
Type	Code	Methods	Proc err	Eff CV	Eff gradient	Targeting	F gain	Steepness	Von B K	Viscosity	50%V - 50%M	Proc err	Eff CV	Eff gradient	Targeting	F gain	Steepness	Von B K	Viscosity	50%V - 50%M
Catch-Based (Static)	M1	Median Catch - 3 Years	1	1	18	1	28	5	1	1	3	1	1	20	2	29	7	1	0	3
	M2	Median Catch - 10 Years	1	1	19	1	33	6	1	1	4	1	2	17	3	30	7	1	1	2
	M3	3rd Highest Catch	1	3	19	1	33	5	1	1	3	1	2	16	3	28	6	1	1	2
Depletion-Based (Static)	M4	DB-SRA (Depletion Fixed @ 40%B0) - 69.4% scalar	1	0	5	1	18	7	1	1	6	0	0	2	1	10	5	1	1	2
	M5	DB-SRA (Depletion Fixed @ 40%B0) - 83.4% scalar	1	0	6	1	21	8	1	1	6	0	0	2	1	11	5	1	1	2
	M6	DB-SRA (Depletion Fixed @ 40%B0) - 91.3% scalar	1	0	6	1	23	8	1	1	6	0	0	2	2	12	6	1	1	2
	M7	DCAC (Depletion Fixed @ 40%B0) - 69.4% scalar	1	0	4	1	15	6	1	1	5	0	0	2	1	9	5	1	1	2
	M8	DCAC (Depletion Fixed @ 40%B0) - 83.4% scalar	1	0	5	1	18	7	1	1	6	0	0	2	2	11	5	1	1	2
	M9	DCAC (Fixed Depletion @ 40%B0) - 91.3% scalar	1	0	5	1	20	7	1	1	6	0	0	2	2	12	6	1	1	2
Catch-Based (Dynamic)	A1	Depletion Adjusted Catch Scalar - 75% scalar	1	1	2	1	10	4	1	1	4	1	1	2	1	13	6	1	1	3
	A2	Depletion Adjusted Catch Scalar - 100% scalar	1	1	2	1	11	4	1	1	4	1	2	2	2	14	6	1	1	3
Depletion-Based (Dynamic)	A3	DB-SRA (Depletion Adjusted) - 25% P*	1	1	2	1	3	1	1	1	1	0	0	1	1	1	2	0	0	0
	A4	DB-SRA (Depletion Adjusted) - 50% P*	1	1	2	2	4	1	0	1	1	1	0	1	1	1	3	0	1	1
	A5	DCAC (Depletion Adjusted) - 25% P*	1	0	6	1	25	7	0	1	6	1	1	3	1	18	5	1	1	3
	A6	DCAC (Depletion Adjusted) - 50% P*	0	0	7	0	28	8	0	1	6	1	1	3	1	22	6	1	1	3
Abundance-Based (Dynamic)	A7	Life History Analysis - 75% scalar	0	1	1	1	0	4	2	1	2	0	1	1	1	1	6	2	1	3
	A8	Life History Analysis - 100% scalar	1	1	1	1	1	4	1	1	2	0	1	1	1	1	5	2	1	3
	A9	FMSY/M (Low) - 75% scalar	0	1	0	0	1	2	1	0	1	1	0	1	1	1	3	1	1	1
	A10	FMSY/M (Low) - 100% scalar	0	1	0	1	1	3	1	0	1	1	0	1	1	1	4	1	1	1
	A11	FMSY/M (Hi) - 75% scalar	0	1	0	1	1	3	1	0	2	1	0	1	1	1	5	1	1	2
	A12	FMSY/M (Hi) - 100% scalar	1	1	0	1	1	4	1	0	2	1	0	1	1	1	6	1	1	2
Stock Assessment	R1	Delay-Difference - 75% scalar	1	0	8	1	19	5	1	1	5	1	1	5	3	4	4	1	1	2
	R2	Delay-Difference - 100% scalar	1	1	7	1	23	4	1	0	3	1	1	5	4	7	5	1	1	2

Appendix D. The effect of mis-specification of inputs on performance of data-limited methods

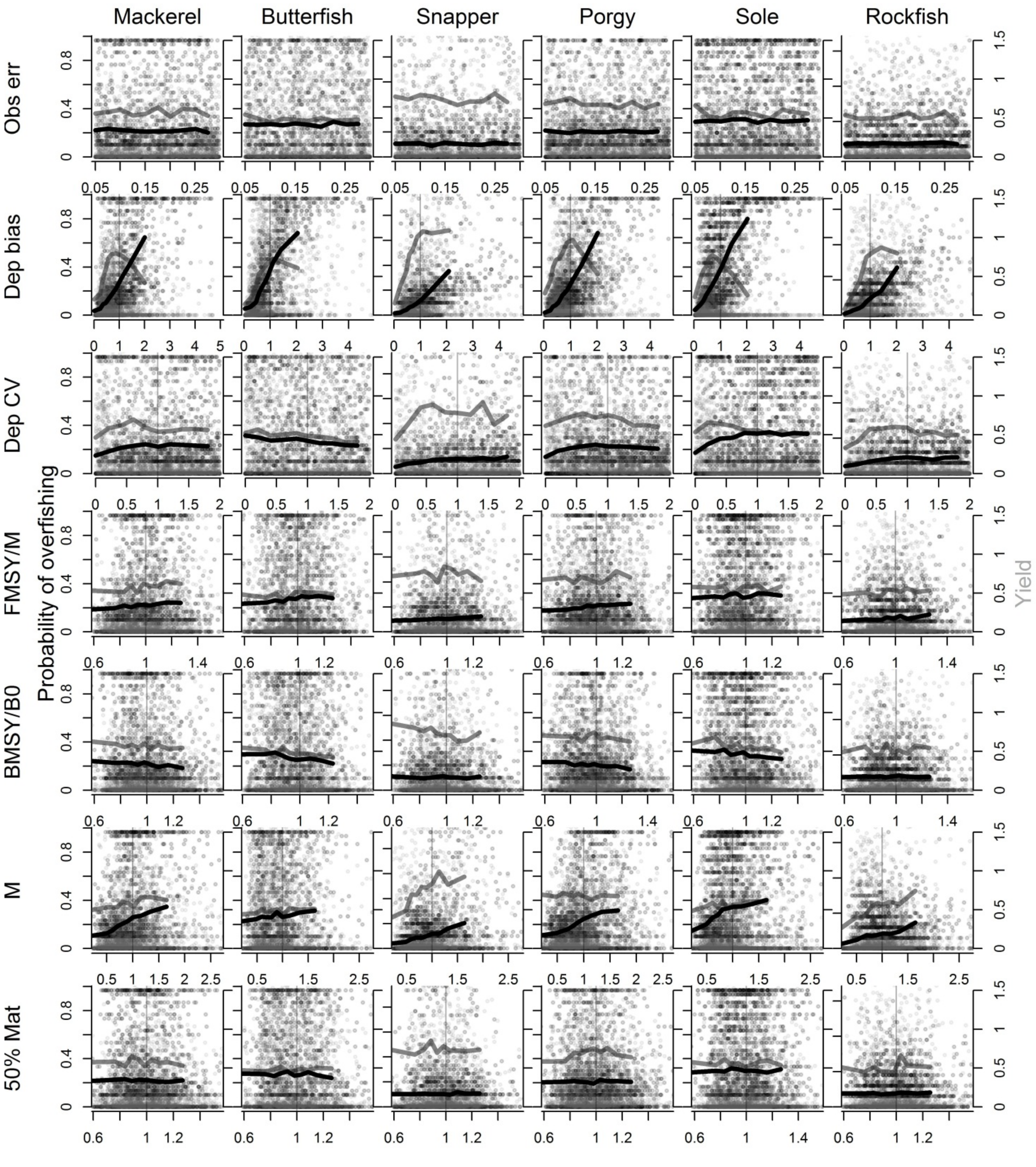

Figure App.D1. The performance of the DB-SRA method A3. The variables are CV in observation error (Obs err), bias in depletion (Dep bias), CV in depletion error (Dep CV), bias in the ratio of F_{MSY}/M (FMSY/M), bias in the ratio of B_{MSY} relative to unfished (BMSY/B0), bias in natural mortality rate (M) and bias in the age at 50% maturity (50% Mat). Each panel contains 2000 points representing simulation results for the yield (grey) and probability of overfishing metrics (black). The x-axis is the variable labelled on each row of panels. The mean trend in both yield and overfishing metrics are superimposed as a solid line and is calculated from all simulations.

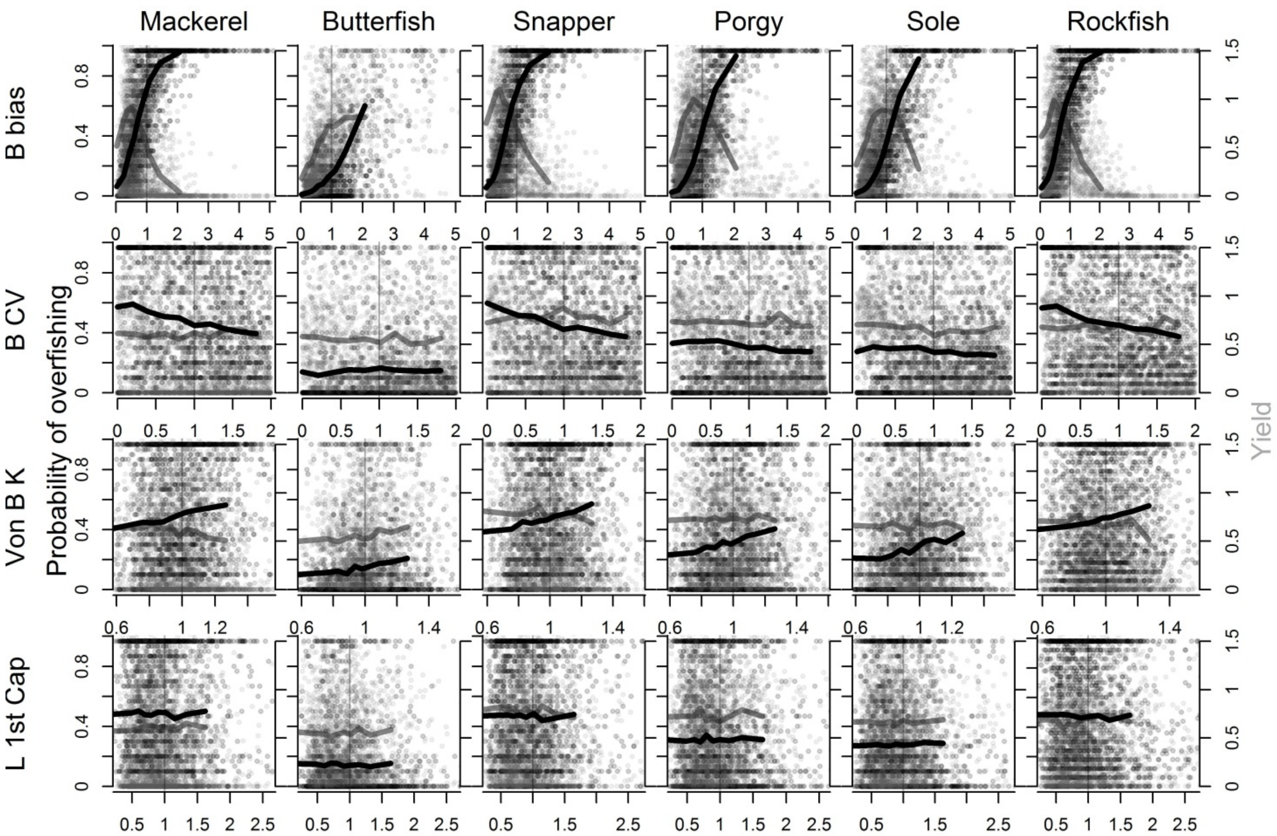

Figure App.D.2. The performance of the life-history method A7, across the sampled range of variables that control imperfect information. The variables are bias in the current biomass (B bias), CV of current biomass error (B CV), bias in the von Bertalanffy growth parameter K (Von B K) and bias in the length at first recapture (L 1st Cap). Each panel contains 2000 points representing simulation results for the yield (grey) and probability of overfishing metrics (black). The x-axis is the variable labelled on each row of panels. The mean trend in both yield and overfishing metrics are superimposed as a solid line and is calculated from all simulations.

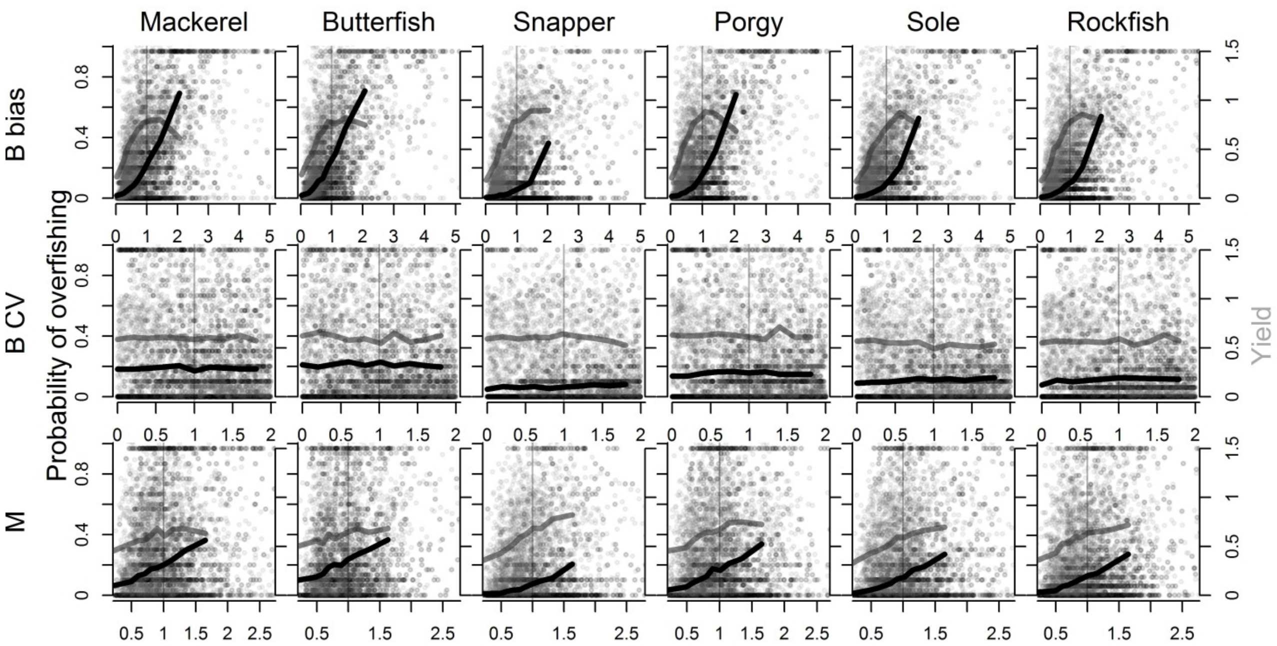

Figure App.D.3. The performance of the F_{MSY} to M ratio method A9, across the sampled range of variables that control imperfect information. The variables are bias in the current biomass (B bias), CV of current biomass error (B CV) and bias in the natural mortality rate (M). Each panel contains 2000 points representing simulation results for the yield (grey) and probability of overfishing metrics (black). The x-axis is the variable labelled on each row of panels. The mean trend in both yield and overfishing metrics are superimposed as a solid line and is calculated from all simulations.

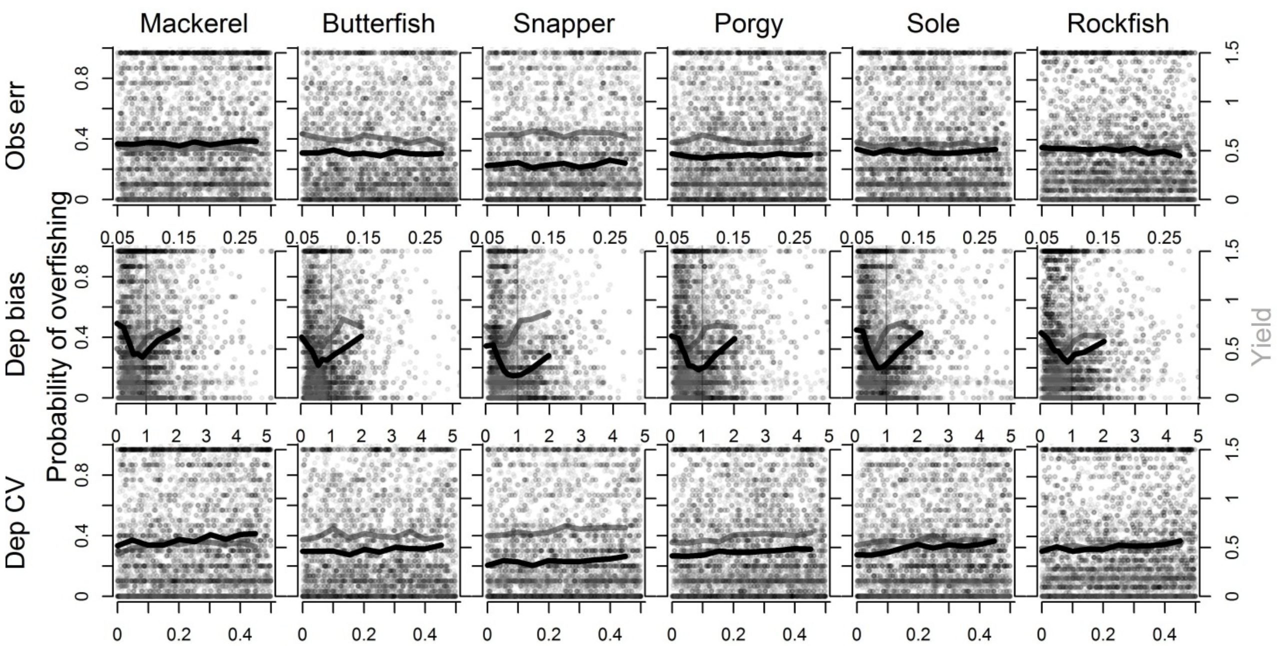

Figure App.D.4. The performance of the depletion adjusted catch scalar method A1 across the sampled range of variables that control imperfect information. The variables are CV in observation error (Obs err), bias in ORCS depletion (Dep bias), CV in ORCS depletion error (Dep CV). Each panel contains 2000 points representing simulation results for the yield (grey) and probability of overfishing metrics (black). The x-axis is the variable labelled on each row of panels. The mean trend in both yield and overfishing metrics are superimposed as a solid line and is calculated from all simulations.

Appendix E. Results of the spatially aggregated simulations

Table App.E.1. Results of the spatially-aggregated simulation model. Overfishing, stock status and yield performance metrics for simulations starting below 50% of B_{MSY}. All of the numbers represent a percentage. The probability of overfishing 'P_{OF}' is the fraction of projected years for which fishing mortality rate exceeds F_{MSY}. 'B/B_{MSY}' is the mean biomass divided by biomass at maximum sustainable yield. 'Yield' is the mean relative yield over the last five years of the projection (the yield of a simulation over the last five years of the projection divided by that of the F_{ref} policy). Dark grey shading reflects poor scores (P_{OF} greater than 50%, B/B_{MSY} less than 25%, Yield less than 25%). Light grey shading reflects intermediate scores (P_{OF} greater than 25%, B/B_{MSY} less than 50%, Yield less than 50%). %).

Type	Code	Name	Mackerel			Butterfish			Snapper			Porgy			Sole			Rockfish		
			P_{OF}	B/B_{MSY}	Yield	P_{OF}	B/B_{MSY}	Yield	P_{OF}	B/B_{MSY}	Yield	P_{OF}	B/B_{MSY}	Yield	P_{OF}	B/B_{MSY}	Yield	P_{OF}	B/B_{MSY}	Yield
Catch-Based (Static)	M1	Median Catch - 3 Years	83	23	18	29	109	110	82	28	21	68	47	28	81	31	16	88	17	10
	M2	Median Catch - 10 Years	89	16	14	41	94	51	93	14	10	81	32	24	90	18	10	95	9	7
	M3	3rd Highest Catch	93	10	7	57	73	48	95	9	4	89	19	11	93	11	5	97	5	2
Depletion-Based (Static)	M4	DB-SRA (Depletion Fixed @ 40%B0) - 69.4% scalar	74	34	23	49	81	42	17	106	24	63	51	30	57	63	23	28	74	25
	M5	DB-SRA (Depletion Fixed @ 40%B0) - 83.4% scalar	80	27	20	55	73	43	24	97	26	73	39	24	67	49	20	34	68	24
	M6	DB-SRA (Depletion Fixed @ 40%B0) - 91.3% scalar	82	24	17	58	70	44	28	92	27	78	33	21	71	43	18	37	65	24
	M7	DCAC (Depletion Fixed @ 40%B0) - 69.4% scalar	69	40	24	52	79	60	14	110	23	56	61	32	48	75	26	25	76	24
	M8	DCAC (Depletion Fixed @ 40%B0) - 83.4% scalar	77	32	22	59	69	54	20	102	27	67	47	27	61	58	22	31	70	25
	M9	DCAC (Fixed Depletion @ 40%B0) - 91.3% scalar	79	28	20	63	64	52	25	96	30	73	40	24	66	50	21	35	67	26
Catch-Based (Dynamic)	A1	Depletion Adjusted Catch Scalar - 75% scalar	60	39	42	36	94	84	33	76	54	41	66	55	47	65	43	58	38	40
	A2	Depletion Adjusted Catch Scalar - 100% scalar	70	31	35	43	86	93	43	64	62	52	55	52	58	52	41	72	28	30
Depletion-Based (Dynamic)	A3	DB-SRA (Depletion Adjusted) - 25% P*	14	67	65	22	107	43	10	115	89	18	92	88	23	96	74	6	88	71
	A4	DB-SRA (Depletion Adjusted) - 50% P*	23	60	75	29	100	48	17	105	109	25	83	87	32	85	83	11	79	101
	A5	DCAC (Depletion Adjusted) - 25% P*	78	27	31	65	61	54	54	61	47	75	38	32	80	31	22	70	36	38
	A6	DCAC (Depletion Adjusted) - 50% P*	87	19	20	67	59	53	67	46	40	84	28	22	89	21	17	82	25	30
Abundance-Based (Dynamic)	A7	Life History Analysis - 75% scalar	57	37	53	19	114	58	46	62	68	39	73	68	26	93	68	49	45	88
	A8	Life History Analysis - 100% scalar	63	31	45	25	106	62	52	53	63	47	63	63	36	81	68	56	38	81
	A9	FMSY/M (Low) - 75% scalar	27	65	61	25	106	63	6	120	49	21	95	58	12	119	55	13	81	66
	A10	FMSY/M (Low) - 100% scalar	34	59	62	31	99	66	10	113	58	28	86	62	17	109	60	20	75	75
	A11	FMSY/M (Hi) - 75% scalar	37	55	62	33	97	66	14	109	62	31	82	63	20	104	62	24	71	80
	A12	FMSY/M (Hi) - 100% scalar	44	48	59	40	88	66	20	100	68	39	72	63	28	93	64	30	64	88
Stock Assessment	R1	Delay-Difference - 75% scalar	22	72	38	28	97	40	8	133	22	23	97	53	27	100	85	8	90	39
	R2	Delay-Difference - 100% scalar	30	65	36	29	95	35	11	126	23	30	90	48	46	82	82	16	86	39
Status Quo (Static)	R3	Current Catch	83	23	18	31	106	112	82	28	21	69	46	27	81	31	16	88	17	10
	R4	Current Effort	93	16	30	71	60	64	96	23	50	91	29	48	95	18	26	95	17	32

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