Table 1. Base-case operating model (OM1) parameters for the anchovy and sardine mixed stock model.

Symbol	Value	Description
Indices		
S	anc; sar	Index for species: anchovy; sardine
t	.25, 0.5, 0.75, 1, 1.5,…,$T_1 - 1$	Quarterly time steps (e.g., a year divided in 4 quarters) until time step before when the management procedure (MP) starts
T_1		Time step when the MP starts (i.e., 2023)
T_2		End year for the MP
y	1990,..,2022	Annual time step from starting year end year in operating model (i.e., $T_1 - 1$)
t_x	0.25	Time step
q	1, 2, 3, 4	Indicator for quarter (e.g., 2023.1,…, 2023.4)
l^s	3,…, 21.5; 3,…, 19.5	Length bins (mm)
g	1, 2, and 3	Index for biomass survey during 1st and 2nd quarter and fishery
Parameters		
$\hat{R}_0^s$	39.03; 38.01	Unfished recruitment (quarterly)
SSB_0^s	1260.9; 457.13	Unfished (quarterly) spawning stock biomass
$\hat{F}_{init}^s$	0; 0.23	Initial fishing mortality
$\hat{l}_0^s$	3.24; 3.25	Mean length at recruitment
$\hat{\sigma}_{l_0}^s$	0.056; 0.057	Standard deviation (SD) for mean length at recruitment
M^s	0.22; 0.25	Instantaneous natural mortality (quarterly)
$\hat{\kappa}^s$	5.00; 1.6	Compensation ratio
$\widehat{\omega}_y^s$		Estimated annual recruitment deviations at year y
$\widehat{\omega}_q^s$		Estimated quarterly effect for recruitment deviations
$\hat{l}_{50}^{s,g}$	10.9, 10.15, 11.31; 5.06, 7.34, 8.91	Length-at-50% vulnerability (mm)
$\hat{l}_{shp}^{s,g}$	14.61, 13.71, 13.03; 8, 9.4, 10.39	Shape parameter for length-at-vulnerability (mm)
$\hat{Q}^{s,g}$	0.58, 1.03; 1.26, 0.89	Catchability coefficient
$\hat{\tau}_I^{s,g}$	0.66, 0.37; 0.52, 0.44	Estimated standard deviation for survey indices
H_{slp}		Slope of the HCR
B_{min}		Minimum biomass for HCR

b^{hcr}	0.6	HCR parameter for the risk averse utility function
L_{∞}^{s}	20.8; 18.1	Mean asymptotic length (mm)
K^{s}	0.113; 0.125	Brody growth parameter (mm year^{-1})
σ_{G}^{s}	0.1; 0.2	Standard deviation (SD) for individual growth
Data		
σ_{R}^{s}	0.4; 0.3	SD of the recruitment variation
σ_{g}^{s}	0.1, 0.1; 0.1, 0.1	Standard deviation SD for survey biomass indices
m^{s}		Maturity proportion at length
w^{s}		Weight at length (g)
$I_{t}^{s,g}$		Acoustic biomass index during 1st and 2nd quarter
Y_{t}^{s}		Observed catch biomass (t)
$C_{t,l}^{s,g}$		Observed catch at length
$\boldsymbol{I}$		Identity matrix
$\boldsymbol{T}^{s}$		Transition matrix
K_{w}	0.7	Kalman weight
F_{max}	0.95	Maximum fishing mortality rate
w_{k}^{s}	8; 8	Weight at recruitment (g)
$\bar{h}^{s}$	0.9; 0.9	Prior mean for steepness
$\sigma_{\bar{h}}^{s}$	0.25; 0.25	Prior standard deviation of steepness
$\bar{Q}^{s,g}$	1, 1; 1, 1	Prior mean for *Q*
$\sigma_{\bar{Q}}^{s,g}$	0.1, 0.1; 0.1, 0.1	Prior standard deviation for *Q*
σ_{Y}^{s}	0.01; 0.01	Standard deviation for catch biomass
ρ^{g}	0.6, 0.6; 0.6,0.6	Autocorrelation parameter for simulated survey indices
$n_{c}^{s,g}$	50, 50, 2.5; 50, 50, 2.5	Effective sample size for multinomial likelihoods
u^{max}	0.6	Maximum harvest rate for the smooth function
$n_{\in g}^{s}$	22, 17; 23, 18	Number of year with length composition
dev	0.05	Parameter for the Smooth function
Derived variables		
$\hat{h}^{s}$	0.56; 0.29	Steepness
φ^{s}		Proportion of recruitment at length
$\boldsymbol{S}_{0}^{s}$		Diagonal matrix with initial survival
S^{s}		Survival at length after fishing

		and natural mortality
ϕ_0^s		Unfished equilibrium spawning biomass per recruit
α^s		Beverton–Holt recruitment
β^s		Beverton–Holt recruitment
F_t^s		Fishing mortality rate
$\widehat{\omega}_t^s$		Estimated recruitment deviates in time t
$\overline{\omega}_t^s$		Average recruitment deviates in time t
TAC_t^s		TAC for species s
$\hat{b}_t^{tot}$		Total simulated stock assessment biomass
ε_t^g		AR(1) errors for simulated survey indices

Table 2. Description of the operating model for the anchovy and sardine mixed stock model.

Description	Equations
(A1) Initial abundance	$R_{init}^{s} = n_0^s \hat{R}_0^s t_x$
(A2) Unfished numbers per recruit	$n_0^s = \varphi^s (\boldsymbol{I} - \boldsymbol{T}^s \boldsymbol{S}_0^s)^{-1}$ $\varphi^s = N \sim \left(\hat{l}_0^s, \left(\hat{\sigma}_{l_0}^s\right)^2\right)$ $\underset{l=t}{\boldsymbol{S}_0^s} = e^{-M^S - F_{init}^S v_l^{s,g_3}}, l \neq t \rightarrow 0$
(A3) Abundance population dynamics	$N_t^s = \begin{cases} R_{init}^s & t = 1 \\ \boldsymbol{T}^s S^s N_{t-1}^s + \varphi^s R_{t-4}^s & t > 1 \end{cases}$
(A4) Recruitment and stock-recruit parameters	$R_t^s = \dfrac{\alpha^s SB_t^s}{1 + \beta^s SB_t^s} e_t^{\widehat{\omega}_t^s - 0.5(\sigma_R^s)^2}$ $\alpha^s = \hat{\kappa}^s / \phi_0^s$ $\beta^s = (\hat{\kappa}^s - 1)/(SSB_0^s)$ $\widehat{\omega}_t^s = \widehat{\omega}_y^s + \widehat{\omega}_q^s$
(A5) Unfished spawning stock biomass	$SSB_0^s = \hat{R}_0^s \phi_0^s$ $\phi_0^s = \sum_l^L n_0^s m^s w^s$
(A6) Spawning stock biomass	$SB_t^s = \sum_l^L N_t^s m^s w^s$
(A7) Vulnerable biomass	$VB_t^{s,g} = \sum_l^L N_t^s v_l^{s,g} w^s$
(A8) Vulnerability at length	$v_l^{s,g} = 1/\left(1 + e^{-[l - \hat{l}_{50}^{s,g}]/\{[\hat{l}_{shp}^{s,g} - \hat{l}_{50}^{s,g}]/log(19)\}}\right)$
(A9) Simulated survey biomass indices ($t \geq T_1$)	$I_t^{\prime\prime s,g} = \hat{Q}^{s,g} VB_t^{s,g} e^{[\varepsilon_t^g \hat{\tau}^{s,g} - 0.5(\hat{\tau}^{s,g})^2]}$ $\varepsilon_t^{\prime g} \sim N(0,1)$ $\varepsilon_t^g = \varepsilon_{t-1}^g \rho^g + \varepsilon_t^{\prime g}$
(A10) Simulated stock biomass from a delay-difference model (DDM) population dynamic model ($t \geq T_1$)	$b_{DD_t}^s = e^{-M^s}\left(VB_{t-1}^{s,g_3} e^{-F_{t-1}^S}\right) + w_k^s \hat{R}_0^s e^{\overline{\omega}_t^s - 0.5(\sigma_R^S)^2}$ $\overline{\omega}_t^s = \dfrac{1}{3} \sum \omega_{t-4}^s + \omega_{t-8}^s + \omega_{t-12}^s$
(A11) Simulated stock assessment biomass (shortcut) ($t \geq T_1$)	$\hat{b}_t^s = \begin{cases} I_t^{\prime\prime s,g_1} K_w + (1 - K_w) b_{DD_t}^s, & q = 1 \\ I_t^{\prime\prime s,g_2} K_w + (1 - K_w) b_{DD_t}^s, & q = 2,3,4 \end{cases}$ $\hat{b}_t^{tot} = \hat{b}_t^{anc} + \hat{b}_t^{sar}$ $0 < K_w < 1$

(A12) Harvest control rule and TAC that includes recruitment and spawning closures ($t \geq T_1$)	$TAC_t = \begin{cases} max\left(0, H_{slp}\left[\hat{b}_t^{tot} - B_{min}\right]\right) {}^1\!/_3 & q = 1 \\ max\left(0, H_{slp}\left[\hat{b}_t^{tot} - B_{min}\right]\right) & q = 2 \\ max\left(0, H_{slp}\left[\hat{b}_t^{tot} - B_{min}\right]\right) {}^1\!/_3 & q = 3 \\ max\left(0, H_{slp}\left[\hat{b}_t^{tot} - B_{min}\right]\right) {}^2\!/_3 & q = 4 \end{cases}$ $TAC_t^s = \begin{cases} \hat{b}_t^{s,g_1}/\hat{b}_t^{tot} TAC_t \ , & q = 1 \\ \hat{b}_t^{s,g_2}/\hat{b}_t^{tot} TAC_t \ , & q = 2,3,4 \end{cases}$
(A13) Fishing mortality ($t \geq T_1$)	$u_t^s = TAC_t^s / VB_t^{s,g_3}$ $F_t^s = min\left(F_{max}, u_t^s / e^{-M^s/2}\right)$
(A14) Actual catch biomass ($t \geq T_1$)	$actC_t^s = \left(1 - e^{-F_t^s}\right) Vb_t^{s,g_3} e^{-M^s/2}$ $actC_t^{tot} = actC_t^{anc} + actC_t^{sar}$
(A15) Utility functions ($t \geq T_1$)	$U_{neutral} = \sum_t^{T_2} actC_t^{tot}$ $U_{averse} = \sum_t^{T_2} (actC_t^{tot} actC_t^{tot})^{b^{hcr}}$

Table 3. Description of the size-structured statistical model for anchovy and sardine.

Operating model	
(A17) Parameter estimated	$\Theta^s = \begin{pmatrix} \hat{R}_0^s, \hat{\kappa}^s, \hat{F}_{init}^S, \{\hat{\omega}_q^s\}_{q=1}^4, \{\hat{\omega}_y^s\}_{y=1}^{T_1-1}, \{\hat{l}_{50}^{s,g}\}_{g=1,2,3}, \\ \{\hat{l}_{shp}^{s,g}\}_{g=1,2,3}, \{\hat{Q}^{s,g}\}_{g=1,2}, \{\hat{\tau}_I^{s,g}\}_{g=1,2} \end{pmatrix}$
(A18) Fishing and total mortality	$u_t^s = Y_t^s / \sum_l^L N_t w^s m^s e^{-M^s/2}$ $tmp = ln(e^{u^{max}/dev} + 1) - dev \ln(e^{-(u_t^s - u^{max})/dev} + 1)$ $F_t^s = -ln(1 - tmp)$ $Ftot_t^s = F_t^s v_l^{s,g_3}$ $Z_t^s = Ftot_t^s + M^s$
(A19) Predicted catch at length for the fishery	$C_{t,l}^{\prime s,g_3} = N_{t,l}^s Ftot_{t,l}^s (1 - e^{-Z_l^s}) / Z_l^s$ $C_{t,l}^{\prime\prime s,g_3} = C_{t,l}^{\prime s,g_3} / \sum_l^L C_{t,l}^{\prime s,g_3}$
(A20) Predicted catch at length for surveys	$C_{t,l}^{\prime s,g} = N_{t,l}^s v_l^{s,g}$ $\quad g = 1,2$ $C_{t,l}^{\prime\prime s,g} = C_{t,l}^{\prime s,g} / \sum_l^L C_{t,l}^{\prime s,g}$
(A21) Observed catch at length proportions for survey indices	$C_{t,l}^{s,g} = C_{t,l}^{s,g} / \sum_l^L C_{t,l}^{s,g}$ $\quad g = 1,2$
(A22) Predicted catch biomass	$Y_t^{\prime s} = \sum_l^L C_{t,l}^{\prime s,g_3} w_l^s$
(A23) Predicted biomass for survey indices	$I_t^{\prime s,g} = \hat{Q}^{s,g} \sum_l^L VB_{t,l}^{s,g}$
(A24) Residuals for catch biomass	$\eta_t^s = ln(Y_t^s) - ln(Y_t^{\prime s})$
(A25) Residuals for biomass survey indices	$\xi_t^{s,g} = ln(I_t^{s,g}) - ln(I_t^{\prime s,g})$ $\quad g = 1,2$
(A26) Standard deviation for survey indices	$\hat{\tau}_I^{s,g} = \sqrt{\frac{1}{n_{\in g}^s - 2} \sum_{t \in g} \xi_t^{s,g}}$ $\quad g = 1,2$
(A27) Catchability coefficient for survey indices	$z_t^{s,g} = ln(I_t^{s,g} / VB_t^{s,g})$ $\quad g = 1,2$ $lnQ^{s,g} = \frac{1}{n_{\in g}^s} \sum_{t \in g} z_t^{s,g}$ $\hat{Q}^{s,g} = e^{lnQ^{s,g}}$
(A28) Log-likelihood for catch at length compositions	$\mathcal{L}_c^{s,g} = n_c^{s,g} \sum_t^{T_1-1} \sum_l^L C_{t,l}^{s,g} ln(C_{t,l}^{\prime\prime s,g})$ $\quad g = 1,2,3$
(A29) Log-likelihood for survey indices	$\mathcal{L}_I^{s,g} = \frac{\sum_t^{T_1-1} (\xi_t^{s,g})^2}{2(\sigma_I^{s,g})^2}$ $\quad g = 1,2$

(A30) Log-likelihood for catch biomass	$\mathcal{L}_Y^s = \dfrac{\sum_t^{T_1-1}(\eta_t^s)^2}{2(\sigma_Y^s)^2}$
(A31) Prior for recruitment deviates	$p_\omega^s = \dfrac{\sum_y^{T_1-1}\sum_q \left(\widehat{\omega}_q^s\right)^2 + \left(\widehat{\omega}_y^s\right)^2}{2(\sigma_R^s)^2}$
(A32) Prior for catchability coefficient	$p_Q^s = \dfrac{\left(\hat{Q}^{s,g} - \bar{Q}^{s,g}\right)^2}{2\left(\sigma_{\bar{Q}}^{s,g}\right)^2} \qquad g = 1,2$
(A33) Prior for steepness	$p_h^s = \dfrac{\left(\hat{h}^s - \bar{h}^s\right)^2}{2\left(\sigma_{\bar{h}}^s\right)^2}$ $\hat{h}^s = \hat{\kappa}^s/(4 + \hat{\kappa}^s)$
(A34) Objective function	$Obj(\Theta^s) = \mathcal{L}_Y^s + \mathcal{L}_c^{s,g} + \mathcal{L}_I^{s,g} + p_\omega^s + p_Q^s + p_h^s \quad g = 1,2$

Table A1. Parameters of the operating models (OM1-OM6) for anchovy (A) and sardine (S).

Parameter	A_OM1	S_OM1	A_OM2	S_OM2	A_OM3	S_OM3	A_OM4	S_OM4	A_OM5	S_OM5	A_OM6	S_OM6
SSB_0	1260.8	457.1	1151.4	1330.1	1401.3	1497.2	1534.3	467.8	1455.0	464.5	810.1	879.5
R_0	39.0	38.0	35.6	50.3	43.2	54.4	47.3	38.5	44.8	26.0	38.8	49.4
κ	5.00	1.60	9.68	9.00	8.46	8.94	4.48	1.20	4.54	1.40	2.91	1.68
l_0	3.24	3.25	3.20	3.25	3.25	3.51	3.22	3.46	3.25	5.46	3.22	3.48
σ_{lo}	0.05	0.06	0.14	0.07	0.05	0.51	0.14	0.48	0.01	2.62	0.14	0.49
F_{init}	0.00	0.23	0.00	0.00	0.00	0.00	0.00	0.22	0.00	0.22	**0.10**	**0.10**
$l_{50}^{g=3}$	11.31	8.91	11.30	8.77	10.91	8.56	10.93	8.63	10.62	7.95	10.61	8.45
$l_{shp}^{g=3}$	13.03	10.39	13.01	10.23	12.66	10.00	12.69	10.48	12.26	9.56	12.23	10.03
$l_{50}^{g=1}$	10.88	5.08	10.90	5.09	11.05	5.00	11.04	5.14	11.32	0.00	11.32	5.16
$l_{shp}^{g=1}$	14.61	*8.00*	14.64	*8.00*	14.99	*8.00*	14.98	*8.00*	15.42	*8.00*	15.42	*8.00*
$l_{50}^{g=2}$	10.15	7.34	10.16	7.37	9.99	7.47	9.98	7.33	10.06	7.40	10.06	7.44
$l_{shp}^{g=2}$	13.71	9.43	13.74	9.48	13.57	9.57	13.56	9.39	13.69	9.85	13.69	9.55
$Q^{g=1}$	0.59	1.26	0.59	1.36	0.50	1.27	0.50	0.69	0.58	1.07	0.59	1.01
$Q^{g=2}$	1.03	0.89	1.03	0.98	0.88	0.89	0.88	0.45	0.99	0.72	0.99	0.71
$\tau_I^{g=1}$	0.66	0.52	0.66	0.53	0.56	0.47	0.56	0.47	0.57	0.43	0.57	0.48
$\tau_I^{g=2}$	0.37	0.44	0.37	0.44	0.33	0.43	0.33	0.46	0.32	0.45	0.32	0.44
h	0.56	0.29	0.71	0.69	0.68	0.69	0.53	0.23	0.53	0.26	0.42	0.30
F_{MSY}	0.23	0.16	0.38	0.29	0.30	0.27	0.19	0.11	0.18	0.13	0.18	0.11
MSY	66.7	103.6	76.3	106.1	87.5	117.0	75.1	173.7	70.5	132.0	72.3	84.2
SSB_{MSY}	452.1	716.1	355.2	411.5	450.3	472.7	561.34	1686.7	528.2	1038.3	540.2	804.6
R_{MSY}	28.7	49.1	28.9	40.3	34.6	43.8	34.1	97.4	32.3	43.1	33.1	46.8
M	0.88	1.00	0.88	1.00	0.88	1.00	0.88	1.00	0.88	1.00	0.88	1.00
σ_R	0.40	0.30	0.40	0.30	0.40	0.30	0.40	0.30	0.40	0.30	0.40	0.30
σ_G	0.10	0.20	0.10	0.20	0.10	0.20	0.10	0.20	0.10	0.20	0.10	0.20
K	0.11	0.12	0.11	0.12	0.11	0.12	0.11	0.12	0.11	0.12	0.11	0.12
L_∞	20.80	18.10	20.80	18.10	20.80	18.10	20.80	18.10	20.80	18.10	20.80	18.10
$\sigma_I^{g=1}$	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
$\sigma_I^{g=2}$	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
σ_Y	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
$n_c^{g=1}$	50.0	50.0	50.0	50.0	**16.6**	**16.6**	**16.6**	**16.6**	**16.6**	**16.6**	**16.6**	**16.6**
$n_c^{g=2}$	50.0	50.0	50.0	50.0	**16.6**	**16.6**	**16.6**	**16.6**	**16.6**	**16.6**	**16.6**	**16.6**
$n_c^{g=3}$	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
$\bar{h}$	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
$\sigma_{\bar{h}}$	0.25	0.25	**0.05**	**0.05**	**0.05**	**0.05**	0.25	0.25	0.25	0.25	0.25	0.25
$\bar{Q}^{g=1}$	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
$\sigma_{\bar{Q}}^{g=1}$	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	**0.05**	**0.05**	**0.05**	**0.05**
$\bar{Q}^{g=2}$	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
$\sigma_{\bar{Q}}^{g=2}$	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	**0.05**	**0.05**	**0.05**	**0.05**
$Obj(\Theta)$	42669	38195	42682	38226	15370	13846	15353	13773	15385	13786	15386	13822
$\mathcal{L}_Y$	57	73	57	70	37	58	36	38	38	44	38	48
$\mathcal{L}_I^{g=1}$	479	313	482	321	343	253	343	257	351	214	351	268
$\mathcal{L}_I^{g=2}$	115	171	114	172	93	166	93	190	89	181	89	177
$\mathcal{L}_C^{g=3}$	1025	933	1025	933	1030	939	1029	928	1041	945	1041	936
$\mathcal{L}_C^{g=1}$	20424	18848	20426	18849	6873	6329	6872	6332	6873	6344	6873	6329
$\mathcal{L}_C^{g=2}$	20412	17601	20407	17585	6856	5878	6858	5904	6856	5903	6856	5887