Online supplementary material:

Implementing the precautionary approach into fisheries management: Biomass reference points and uncertainty buffers

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Supplementary Section A: Methodology

This section includes all equations governing the population dynamics in the operating model and more information about the parameterisation of the three example stocks, as well as the assumptions of the simulation study and the assessment model.

Operating model

We used an age-structured operating model with (sub-)annual time steps to simulate the population dynamics. The equations governing the population dynamics are presented in the following. Growth in length is modelled by means of the von Bertalanffy growth function (von Bertalanffy & von Bertalanffy, 1938):

$$L_a = L_\infty(1 - \exp(-k(a - a_0))) \tag{A1}$$

where L_∞ is the asymptotic length in cm, k is the growth rate in yr^{-1}, and a_0 is the age at length = 0cm. Weight at age is calculated by the power law:

$$w_a = aL_a^b \tag{A2}$$

with the two parameters a in g/cm and unit-less b. Mortality at length is calculated by means of the length-based empirical formula by Gislason et al., 2010:

$$M_L = \exp(0.55 - 1.61\ln(L_a) + 1.44\ln(L_\infty) + \ln(k)) \tag{A3}$$

where M_L for $L \in [0, 10]$ is equal to $\exp(0.55 - 1.61\ln(10) + 1.44\ln(L_\infty) + \ln(k))$, accounting for the low sample size of fish under 10cm in Gislason's meta study (Gislason et al., 2010). Maturity at length is modelled by the logistic function:

$$m_L = \frac{1}{1 + \exp(-\ln(19)\frac{L - L_{m50}}{L_{m95} - L_{m50}})} \tag{A4}$$

where L_{m50} and L_{m95} correspond to the length in cm where 50% and 95% of the individuals, respectively, are mature. Equally, selectivity at length is modelled by:

$$\zeta_L = \frac{1}{1 + \exp(-\ln(19)\frac{L - L_{s50}}{L_{s95} - L_{s50}})} \tag{A5}$$

where L_{s50} and L_{s95} correspond to the lengths in cm at which the probability of capture is 50% and 95%, respectively. Accounting for fish growth within a year, these length-based processes (length, weight, natural mortality, maturity, and selectivity) were converted into age-based processes by season by means of a stochastic seasonal age-length key. The key defines the proportion of fish of a certain length contributing to the different age groups per season (Rudd & Thorson, 2018):

$$p_{l,a,s} = \begin{cases} \phi(\frac{l-L_{a,s}}{L_{a,s}CV_L}) & \text{for } l = 1 \\ \phi(\frac{l-L_{a,s}}{L_{a,s}CV_L}) - \phi(\frac{l-1-L_{a,s}}{L_{a,s}CV_L}) & \text{for } 1 < l < L \\ 1 - \phi(\frac{l-1-L_{a,s}}{L_{a,s}CV_L}) & \text{for } l = L \end{cases} \tag{A6}$$

where $L_{a,s}$ is the length at age a in season s, $l \in [1, L]$ are the mid lengths of the defined length bins, and CV_L is the coefficient of variation per length. The population dynamics are governed by:

$$N_{a,y,s} = \begin{cases} R_y & \text{for } a = 0, y \geq 1, s = 1 \\ N_{a-1,y,s} \exp(-M_{a-1,y,s} - F_y \zeta_{a-1,s}) & \text{for } 0 < a < A, y = 1, s = 1 \\ \frac{N_{a-1,y,s} \exp(-M_{a-1,y,s} - F_y \zeta_{a-1,s})}{1 - \exp(-M_{a-1,y,s} - F_y \zeta_{a-1,s})} & \text{for } a = A, y = 1, s = 1 \\ N_{a,y-1,s} \exp(-M_{a,y,s-1} - F_{y,s-1} \zeta_{a-1,s-1}) & \text{for } a < A, y \geq 1, 1 < s \leq S \\ N_{a-1,y-1,S} \exp(-M_{a-1,y-1,S} - F_{y-1,S} \zeta_{a-1,S}) & \text{for } 0 < a < A, y > 1, s = 1 \\ (N_{a-1,y,s-1} + N_{a,y,s-1}) \exp(-M_{a-1,y,s-1} - F_{y,s-1} \zeta_{a-1,s-1}) & \text{for } a = A, y > 1, s = 1 \end{cases} \tag{A7}$$

where R_y are the number of recruits based on the Beverton-Holt stock recruitment relationship (Beverton & Holt, 1957) parameterised with the steepness parameter h:

$$R_y = \frac{4hR_0 SSB_{y,s-1}}{SSB_0(1-h) + SSB_{y,s-1}(5h-1)} * \exp(\tau_y^R) \tag{A8}$$

where SSB_0 is the unfished spawning stock biomass:

$$SSB_0 = \sum_{a=0}^{A} R_0 \exp(-\sum_{a=0}^{a} M_a) w_a m_a \tag{A9}$$

and τ_y^R are auto-correlated recruitment deviations (Thorson et al., 2014):

$$\tau_y^R = \begin{cases} \epsilon_y^R & \text{for } y = 1 \\ \rho \tau_{y-1}^R + \sqrt(1-\rho^2) \epsilon_y^R & \text{for } y > 1 \end{cases} \tag{A10}$$

where $\epsilon_{Ry} \sim N(-\frac{\sigma_R^2}{2}, \sigma_\mathrm{R}{}^2)$ are biased-corrected recruitment deviations. The catch in numbers by age, year and season is calculated by:

$$C_{a,y,s} = \frac{F_y \zeta_{a,s}}{(M + F_y \zeta_{a,s})} N_{a,y,s} \left(1 - \exp(-M - F_y \zeta_{a,s})\right)) \tag{A11}$$

Annual catch in weight S^w is defined by:

$$\mathrm{C}_y^w = \sum_{a=0}^{A} C_{a,y,s} w_{a,s} \tag{A12}$$

Total stock biomass B is defined by:

$$\mathrm{B}_y = \sum_{a=0}^{A} N_{a,y,s} w_{a,s} \tag{A13}$$

Spawning stock biomass is defined by:

$$\text{SSB}_t = \sum_{a=0}^{A} N_{a,y,s} w_{a,s} m_{a,s} \tag{A14}$$

Annual catch observations are calculated with:

$$\text{Cobs}_y = \text{C}_y^w \epsilon_y^C \tag{A15}$$

where $\epsilon_C \sim \text{Lognormal}(0, \sigma_C^2)$ is the catch observation noise. Survey observations can be computed independent of seasons by:

$$I_t = q \sum_{a=0}^{A} \exp(\ln(N_{a,y,s}) - (M_{a,s} + F_y \zeta_{a,s})\delta_t) w_{a,s} \zeta_{a,s} * \epsilon_y^I \tag{A16}$$

where t defines any time point independent of seasons, δ_t is the time period from the closest season to the time point t, q is the catchability coefficient, and $\epsilon_I \sim \text{Lognormal}(0, \sigma_I^2)$ describes the survey observation noise.

Table A1: Parameter values for the anchovy, haddock, and Greenland halibut representing species with fast-growing, intermediate and slow-growing life history parameters. Growth parameters (L_∞, K) correspond to the von Bertalanffy growth equation (von Bertalanffy & von Bertalanffy, 1938). Steepness (h) corresponds to the Beverton-Holt stock-recruitment relationship (Mace & Doonan, 1988). Selectivity and maturity parameters correspond to a logistic function (Equations A4 and A5). The references for the biological parameters of each stock are given in Table A2. Missing parameter values were not needed as the processes by age were defined directly (see text).

		Stocks		
Parameter	**Description**	**Anchovy**	**Haddock**	**Halibut**
a_{max}	Maximum age [yr]	4	8	27
L_∞	Asymptotic length [cm]	18.69		120
K	Growth rate [1/yr]	0.89		0.073
a_0	Age at length=0 [yr]	-0.02		-0.1
a	Length-weight scaling factor [g/cm^b]	$4.8e^{-3}$		$3.33e^{-3}$
b	Length-weight exponent	3.134		3.249
h	Steepness	0.75/0.9	0.75/0.9	0.75/0.9
L_{m50}	Length at 50% maturity [cm]			71.2
L_{m95}	Length at 95% maturity [cm]			81.2
L_{s50}	Length at 50% selectivity [cm]			51
L_{s95}	Length at 95% selectivity [cm]			58.23
σ_R	Standard deviation of the recruitment deviations	0.766	0.748	0.636
ρ_R	Coeffcient of auto-correlated recruitment deviations	0.435	0.404	0.437

For anchovy and haddock, most life-history information was parameterised by defining the processes at age directly. The parameterisation was based mainly on ICES (2020) and in correspondence with the stock experts (Andres Uriarte and Sonia Sanchez) for anchovy and on ICES (2019) for

Table A2: References for life history parameter values for the anchovy, haddock, and Greenland halibut.

		Stocks		
Parameter	**Description**	**Anchovy**	**Haddock**	**Greenland halibut**
a_{max}	Maximum age [yr]	ICES, 2020	ICES, 2019	Froese and Pauly, 2021
L_{∞}	Asymptotic length [cm]	ICES, 2020		Jardim et al., 2015
K	Growth rate [1/yr]	ICES, 2020		Jardim et al., 2015
a_0	Age at length=0 [yr]	ICES, 2020		Jardim et al., 2015
a	Length-weight scalar [g/cm]	ICES, 2020		Jardim et al., 2015
b	Length-weight exponent	ICES, 2020		Jardim et al., 2015
L_{m50}	Length at 50% maturity [cm]			Rickman et al., 2000
L_{m95}	Length at 95% maturity [cm]			Rickman et al., 2000
L_{s50}	Length at 50% selectivity [cm]			ICES, 2013
L_{s95}	Length at 95% selectivity [cm]			ICES, 2013[1]
σ_R	SD of the recruitment deviations	Thorson et al., 2014	Thorson et al., 2014	Thorson et al., 2014
ρ_R	Coeffcient of auto-correlated recruitment deviations	Thorson et al., 2014	Thorson et al., 2014	Thorson et al., 2014

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[1] L_{s95} for Greenland halibut was not given directly, but inferred from the graph depicting probability of capture vs length in (ICES, 2013).

haddock. For Greenland halibut, maturity at age, weight at age, and gear selectivity at age were transferred from the respective processes by length assuming a stochastic age-length key as described by Rudd and Thorson (2018) with a bin size of 1 cm and a coefficient of variation of 10% (Table A5). Average recruitment (no stock-recruitment relationship) was assumed for anchovy and haddock. For Greenland halibut, the reparameterised Beverton and Holt stock-recruitment relationship was assumed, where steepness represents the fraction of unfished recruitment that results when the spawning biomass is reduced to 20% of the unfished level (Beverton & Holt, 1957; Mace & Doonan, 1988). Recruitment at virgin biomass (R_0) of $1e5$, $1e6$, and $1e3$ and an age of recruitment to the population of zero was assumed for anchovy, haddock, and Greenland halibut. Spawning was assumed to occur at the beginning of each year for haddock and Greenland halibut and in the beginning of the second season for anchovy.

Table A3: Life-history parameters by age for anchovy: Natural mortality (M), maturity (Mat), gear selectivity (Sel), and weight (W). Values seperated by a forward slash '/' represent values per season.

	M	Mat	Sel	W
0	0.6/0.6	0/0	0.001/0.1	0.37/5.16
1	0.4/0.4	1/1	1/1	13.68/22.45
2	0.6/0.6	1/1	1/1	29.73/35.15
3	0.6/0.6	1/1	1/1	38.96/41.54
4	0.6/0.6	1/1	1/1	43.26/44.38

Table A4: Life-history parameters by age for haddock: Natural mortality (M), maturity (Mat), gear selectivity (Sel), and weight (W). Values seperated by a forward slash '/' represent values per season.

	M	Mat	Sel	W
0	1.09	0	0.01	0.06
1	0.72	0.04	0.17	0.18
2	0.57	0.91	0.48	0.37
3	0.48	0.97	0.54	0.69
4	0.44	0.98	0.58	1.12
5	0.41	1	0.64	1.22
6	0.4	1	0.72	1.83
7	0.38	1	1	2.01
8	0.36	1	1	2.21

Table A5: Life-history parameters by age for halibut: Natural mortality (M), maturity (Mat), gear selectivity (Sel), and weight (W). Values seperated by a forward slash '/' represent values per season.

	M	Mat	Sel	W
0	0.1	0	0	0.68
1	0.1	0	0	14.66
2	0.1	0	0	63.26
3	0.1	0	0	162.45
4	0.1	0	0	321.85
5	0.1	0	0.04	545.63
6	0.1	0	0.21	833.77
7	0.1	0.01	0.51	1183.14
8	0.1	0.03	0.76	1588.55
9	0.1	0.1	0.9	2043.5
10	0.1	0.23	0.96	2540.76
11	0.1	0.38	0.98	3072.89
12	0.1	0.54	0.99	3632.53
13	0.1	0.67	1	4212.66
14	0.1	0.78	1	4806.75
15	0.1	0.85	1	5408.84
16	0.1	0.9	1	6013.6
17	0.1	0.93	1	6616.35
18	0.1	0.95	1	7213.02
19	0.1	0.97	1	7800.18
20	0.1	0.98	1	8374.94
21	0.1	0.98	1	8934.94
22	0.1	0.99	1	9478.28
23	0.1	0.99	1	10003.49
24	0.1	0.99	1	10509.49
25	0.1	0.99	1	10995.51
26	0.1	1	1	11461.07
27	0.1	1	1	11905.93

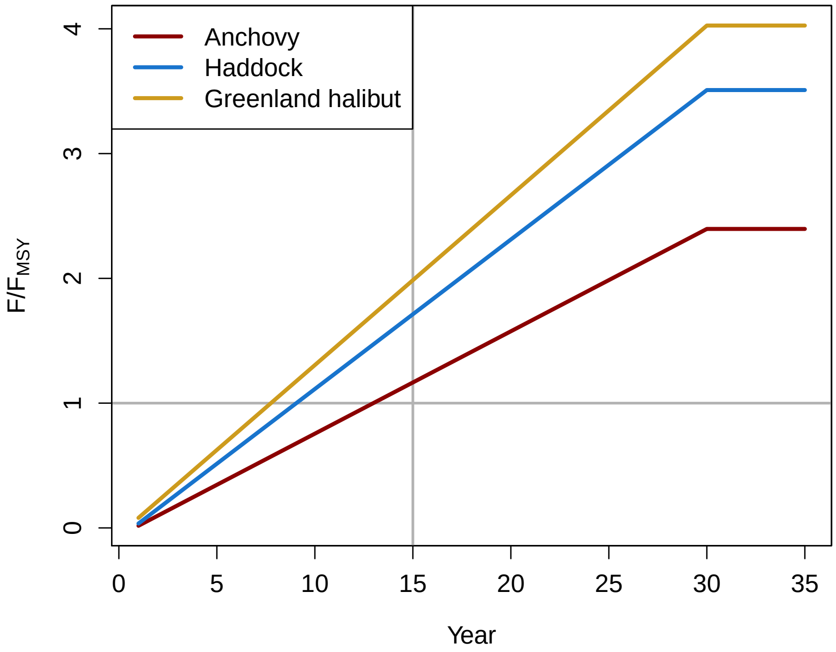

Figure A1: Relative fishing mortality rate (F/F_{MSY}) during the 35 historical years for the three species. The grey vertical line indicates where the time series was cut for the scenario with time series of 20yr, i.e. the historical period for this scenario spans from year 16 to year 35.

We estimated stochastic reference points for each stock based on optimising long-term surplus production over a range of fishing mortality rates assuming process uncertainty and defined the biomass limit reference point B_{lim} as 50% of B_{MSY}.

We estimated stochastic production curves for each stock based on the long-term surplus production over a wide range of fishing mortality rates and assuming process uncertainty (σ_R and $sigma_F$).

The Total Allowable Catch (TAC) resulting from the assessment model in combination with the HCR was removed from the population given that enough biomass was available (the upper limit of the search space for the fishing mortality rate was set to 100yr^{-1} for all anchovy and haddock and 10yr^{-1} for Greenland halibut). The catchability of both simulated surveys was set to 0.05.

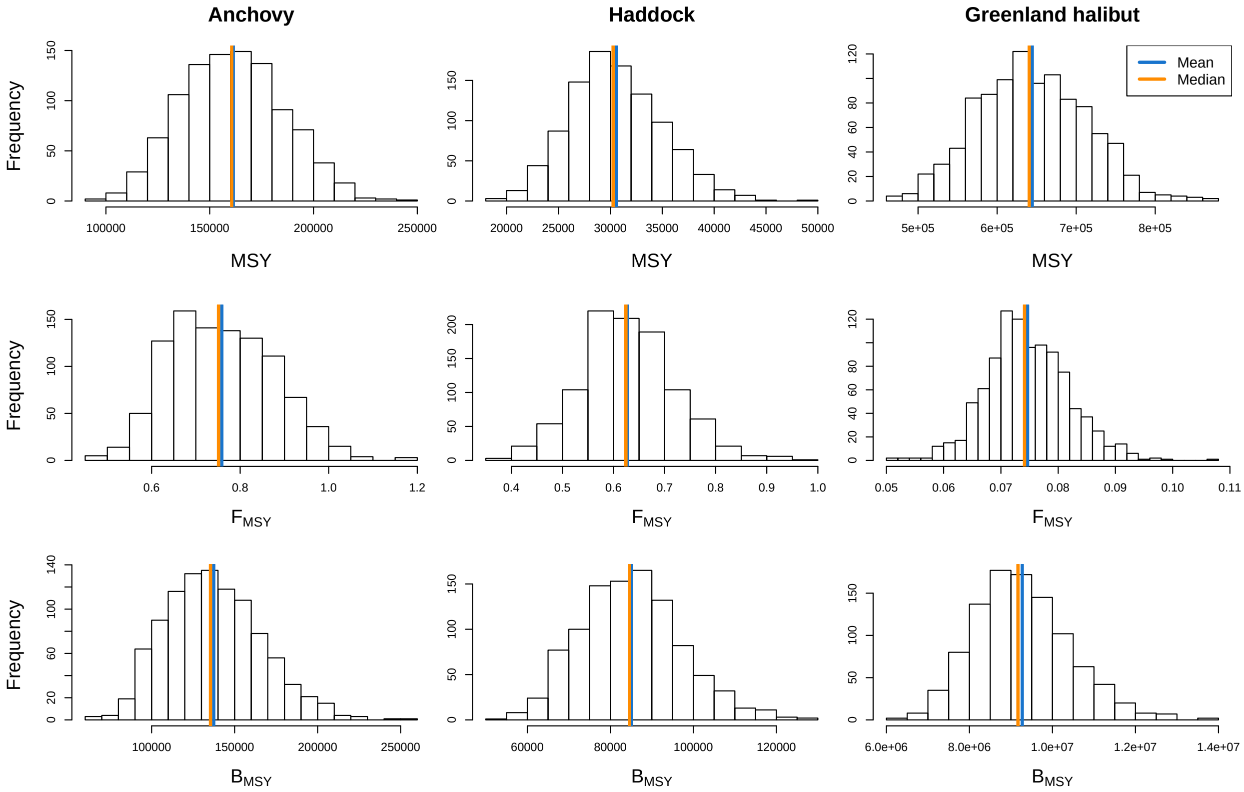

Figure A2: Posterior distributions of the simulated reference points (MSY, F_{MSY}, B_{MSY}) for all species. The two vertical lines represent the mean (blue) and median (orange).

Assessment model

Table A6: Equations of the Stochastic surplus Production model in Continuous Time (SPiCT). For a description of the parameters, please refer to Table A3; for more information, please refer to Pedersen and Berg, 2017.

No	Equation	Description
1	$dB_t = \left(\gamma\, m \frac{B_t}{K} - \gamma\, m \left[\frac{B_t}{K}\right]^n F_t\, B_t\right) dt + \sigma_B\, B_t\, dW_t$	Biomass process
2	$F_t = S_t\, G_t \exp(H_{j(t)})$	Fishing mortality (F) process
3	$d\log(G_t) = \sigma_F\, dV_t$	Diffusion component of the F process
4	$S_t = \exp(D_{s(t)})$	Seasonal component of the F process
5	$I_t = q\, B_t \cdot e^{\nu_t}$	Abudance index observations
6	$C_t = \int_t^{t+\Delta} F_s\, B_s\, ds \cdot e^{\varepsilon_t}$	Catch observations

Table A7: Description of the model parameters of the Stochastic surplus Production model in Continuous Time (SPiCT). The number of estimated parameters in this study adds up to 9 including the 8 parameters in the table plus an additional catchability coefficient for the second abundance index. For more information, please refer to Pedersen and Berg, 2017.

Parameter	**Description**	**Estimated?**
K	Carrying capacity	Yes
m	Productivity parameter (= MSY)	Yes
n	Shape parameter of the production curve	Yes
γ	Gamma $\gamma = n^{n/(n-1)}/(n-1)$	No
W_t	Brownian motion of the biomass process	No
σ_B	Standard deviation of biomass process noise	Yes
V_t	Brownian motion of the fishing mortality (F) process	No
σ_F	Standard deviation of F process noise	Yes
$D_{s(t)}$	Cyclic B-spline with a period of 1 year	No
$s(t)$	Mapping from t to the proportion of the current year that has passed	No
q	Catchability for each abundance index	Yes
ν_t	Index observation errors $\nu_t \sim N(0, \sigma_I^2)$	No
σ_I	Standard deviation of the index observation error	Yes
Δ_t	Time interval length of catch observations (typically a year or quarter of a year)	No
ε_t	Catch observation errors $\varepsilon_t \sim N(0, \sigma_C^2)$	No
σ_C	Standard deviation of the catch observation error	Yes

The default model configuration of SPiCT includes three vague priors on the shape parameter of the production curve $log(n) \sim$ N(2,2)\$ and on two hyper parameters $log(\alpha) \sim N(1,2)$ and \$log(β) $\sim$ N(1,2). The prior on $log(n)$ corresponds to the symmetrical surplus production model (Schaefer, 1954). The hyper parameters are the ratios of the standard deviations (SD) of the observation to process noise terms: $log(\alpha) = log(\sigma_I) - log(\sigma_B)$ and $log(\beta) = log(\sigma_F) - log(\sigma_C)$ (c.f. Table A6 and A7). The priors correspond to equal SDs of the observation and process noise terms for the catches and indices respectively (Pedersen & Berg, 2017).

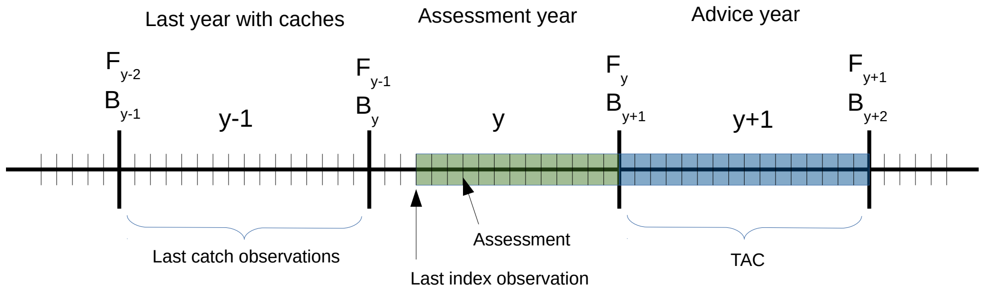

Figure A3: A timeline defining the 'continuous' time quantities of SPiCT in relation to the discrete time of assessment and advice years in fisheries management. The small vertical bars represent the time steps of the Forward Euler scheme (in this graph: 16 time steps per year). The green area depicts the projection period between the last observation (here: index observation) and the start of the management period. The blue area depicts the period for which the TAC is going to be calculated

Supplementary Section B: Complementary results

This section includes complementary results to each of the sub-chapters of the results chapter of the main manuscript.

Biomass reference points and uncertainty buffers

Table B1: Performance metrics per HCR for Anchovy.

HCR	Rel. yield	Risk	AAV	B/Bmsy	F/Fmsy
Median	0.801	0.321	0.639	0.678	0.901
$f^{\mathrm{C}} = 0.45$	0.801	0.272	0.594	0.817	0.765
$f^{\mathrm{C}} = 0.35$	0.784	0.211	0.524	1.132	0.673
$f^{\mathrm{C}} = 0.25$	0.74	0.155	0.489	1.417	0.586
$f^{\mathrm{C}} = 0.15$	0.656	0.12	0.471	1.752	0.466
$f^{\mathrm{C}} = 0.05$	0.499	0.082	0.467	2.239	0.306
$f^{\mathrm{C}} = 0.01$	0.335	0.062	0.472	2.656	0.185
$f^{\mathrm{B,F}} = 0.45$	0.798	0.276	0.595	0.806	0.791
$f^{\mathrm{B,F}} = 0.35$	0.778	0.216	0.525	1.125	0.69
$f^{\mathrm{B,F}} = 0.25$	0.727	0.157	0.492	1.402	0.587
$f^{\mathrm{B,F}} = 0.15$	0.648	0.112	0.472	1.721	0.475
$f^{\mathrm{C,B,F}} = 0.45$	0.794	0.238	0.556	0.963	0.756
$f^{\mathrm{C,B,F}} = 0.35$	0.714	0.138	0.481	1.52	0.554
$f^{\mathrm{C,B,F}} = 0.25$	0.567	0.088	0.467	2.038	0.369
$\mathrm{B_T} = 0.5$	0.89	0.233	0.685	0.725	0.872
$\mathrm{B_T} = 1$	0.881	0.182	0.688	0.926	0.856
$\mathrm{B_T} = 2$	0.768	0.112	0.674	1.363	0.706
$\mathrm{B_T} = 3$	0.631	0.078	0.661	1.773	0.508
$\mathrm{B_T} = 4$	0.526	0.068	0.649	2.024	0.406
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 0.5$	0.711	0.204	0.87	1.185	0.663
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 1$	0.729	0.168	0.839	1.252	0.681
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 2$	0.655	0.108	0.808	1.65	0.591
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 3$	0.534	0.076	0.781	1.964	0.449
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 4$	0.443	0.067	0.767	2.14	0.354
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 1$	0.606	0.145	0.99	1.516	0.553
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 2$	0.562	0.096	0.933	1.794	0.518
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 3$	0.465	0.072	0.882	2.067	0.41
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 4$	0.383	0.062	0.847	2.282	0.325
$\mathrm{B_L} = 0.2, \mathrm{B_T} = 0.8$	0.8	0.194	0.794	0.942	0.779
$\mathrm{B_L} = 0.1, \mathrm{B_T} = 0.9$	0.844	0.186	0.737	0.907	0.806
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5$	0.594	0.172	0.994	1.441	0.488
$\mathrm{B_L} = 1, \mathrm{B_T} = 1$	0.402	0.114	1.125	2.085	0.138

Table B2: Performance metrics per HCR for Haddock.

HCR	Rel. yield	Risk	AAV	B/Bmsy	F/Fmsy
Median	0.994	0.182	0.298	0.69	1.141
$f^{\mathrm{C}} = 0.45$	0.982	0.168	0.292	0.743	1.062
$f^{\mathrm{C}} = 0.35$	0.952	0.144	0.278	0.831	0.924
$f^{\mathrm{C}} = 0.25$	0.907	0.128	0.266	0.929	0.791
$f^{\mathrm{C}} = 0.15$	0.836	0.105	0.257	1.055	0.652
$f^{\mathrm{C}} = 0.05$	0.691	0.086	0.251	1.263	0.456
$f^{\mathrm{C}} = 0.01$	0.517	0.072	0.254	1.49	0.293
$f^{\mathrm{B,F}} = 0.45$	0.984	0.164	0.289	0.743	1.059
$f^{\mathrm{B,F}} = 0.35$	0.952	0.13	0.276	0.85	0.899
$f^{\mathrm{B,F}} = 0.25$	0.897	0.113	0.266	0.998	0.769
$f^{\mathrm{B,F}} = 0.15$	0.81	0.094	0.263	1.148	0.605
$f^{\mathrm{C,B,F}} = 0.45$	0.971	0.151	0.281	0.793	0.987
$f^{\mathrm{C,B,F}} = 0.35$	0.884	0.106	0.262	1.013	0.74
$f^{\mathrm{C,B,F}} = 0.25$	0.741	0.084	0.258	1.249	0.516
$\mathrm{B_T} = 0.5$	1.016	0.109	0.394	0.812	1.01
$\mathrm{B_T} = 1$	0.958	0.082	0.417	0.929	0.9
$\mathrm{B_T} = 2$	0.78	0.073	0.393	1.172	0.631
$\mathrm{B_T} = 3$	0.643	0.068	0.375	1.342	0.486
$\mathrm{B_T} = 4$	0.545	0.066	0.369	1.448	0.394
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 0.5$	1.024	0.092	0.485	0.839	1.062
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 1$	0.957	0.078	0.537	0.96	0.908
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 2$	0.74	0.068	0.474	1.21	0.612
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 3$	0.589	0.064	0.441	1.397	0.457
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 4$	0.491	0.062	0.427	1.513	0.368
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 1$	0.95	0.076	0.648	0.969	0.96
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 2$	0.706	0.067	0.56	1.238	0.608
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 3$	0.552	0.063	0.508	1.433	0.435
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 4$	0.452	0.061	0.486	1.563	0.345
$\mathrm{B_L} = 0.2, \mathrm{B_T} = 0.8$	0.997	0.086	0.489	0.893	0.964
$\mathrm{B_L} = 0.1, \mathrm{B_T} = 0.9$	0.979	0.083	0.447	0.911	0.941
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5$	0.999	0.087	0.578	0.895	1.105
$\mathrm{B_L} = 1, \mathrm{B_T} = 1$	0.722	0.072	0.883	1.188	0.82

Table B3: Performance metrics per HCR for Greenland halibut.

HCR	Rel. yield	Risk	AAV	B/Bmsy	F/Fmsy
Median	1.037	0.098	0.124	0.551	1.168
$f^{\mathrm{C}} = 0.45$	1.025	0.087	0.121	0.582	1.117
$f^{\mathrm{C}} = 0.35$	0.996	0.067	0.115	0.646	1.012
$f^{\mathrm{C}} = 0.25$	0.956	0.058	0.109	0.719	0.898
$f^{\mathrm{C}} = 0.15$	0.891	0.05	0.103	0.813	0.773
$f^{\mathrm{C}} = 0.05$	0.763	0.041	0.098	0.971	0.585
$f^{\mathrm{C}} = 0.01$	0.602	0.037	0.097	1.141	0.412
$f^{\mathrm{B,F}} = 0.45$	1.024	0.079	0.123	0.589	1.103
$f^{\mathrm{B,F}} = 0.35$	0.984	0.06	0.12	0.669	0.968
$f^{\mathrm{B,F}} = 0.25$	0.926	0.05	0.116	0.76	0.841
$f^{\mathrm{B,F}} = 0.15$	0.842	0.043	0.114	0.877	0.699
$f^{\mathrm{C,B,F}} = 0.45$	1.009	0.073	0.119	0.621	1.046
$f^{\mathrm{C,B,F}} = 0.35$	0.919	0.049	0.112	0.767	0.827
$f^{\mathrm{C,B,F}} = 0.25$	0.789	0.04	0.107	0.939	0.632
$\mathrm{B_T} = 0.5$	1.059	0.056	0.132	0.613	1.151
$\mathrm{B_T} = 1$	0.998	0.04	0.127	0.739	1.04
$\mathrm{B_T} = 2$	0.785	0.035	0.108	0.981	0.703
$\mathrm{B_T} = 3$	0.64	0.034	0.103	1.126	0.523
$\mathrm{B_T} = 4$	0.539	0.033	0.101	1.211	0.421
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 0.5$	1.083	0.046	0.147	0.623	1.17
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 1$	1.018	0.037	0.145	0.752	1.069
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 2$	0.751	0.036	0.117	1.026	0.691
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 3$	0.59	0.035	0.112	1.169	0.502
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 4$	0.488	0.034	0.112	1.264	0.397
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 1$	1.041	0.038	0.172	0.737	1.136
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 2$	0.727	0.035	0.129	1.045	0.695
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 3$	0.554	0.034	0.124	1.2	0.489
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 4$	0.449	0.034	0.124	1.303	0.378
$\mathrm{B_L} = 0.2, \mathrm{B_T} = 0.8$	1.051	0.041	0.142	0.694	1.119
$\mathrm{B_L} = 0.1, \mathrm{B_T} = 0.9$	1.023	0.041	0.135	0.716	1.083
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5$	1.114	0.045	0.161	0.619	1.242
$\mathrm{B_L} = 1, \mathrm{B_T} = 1$	1.006	0.036	0.343	0.774	1.273

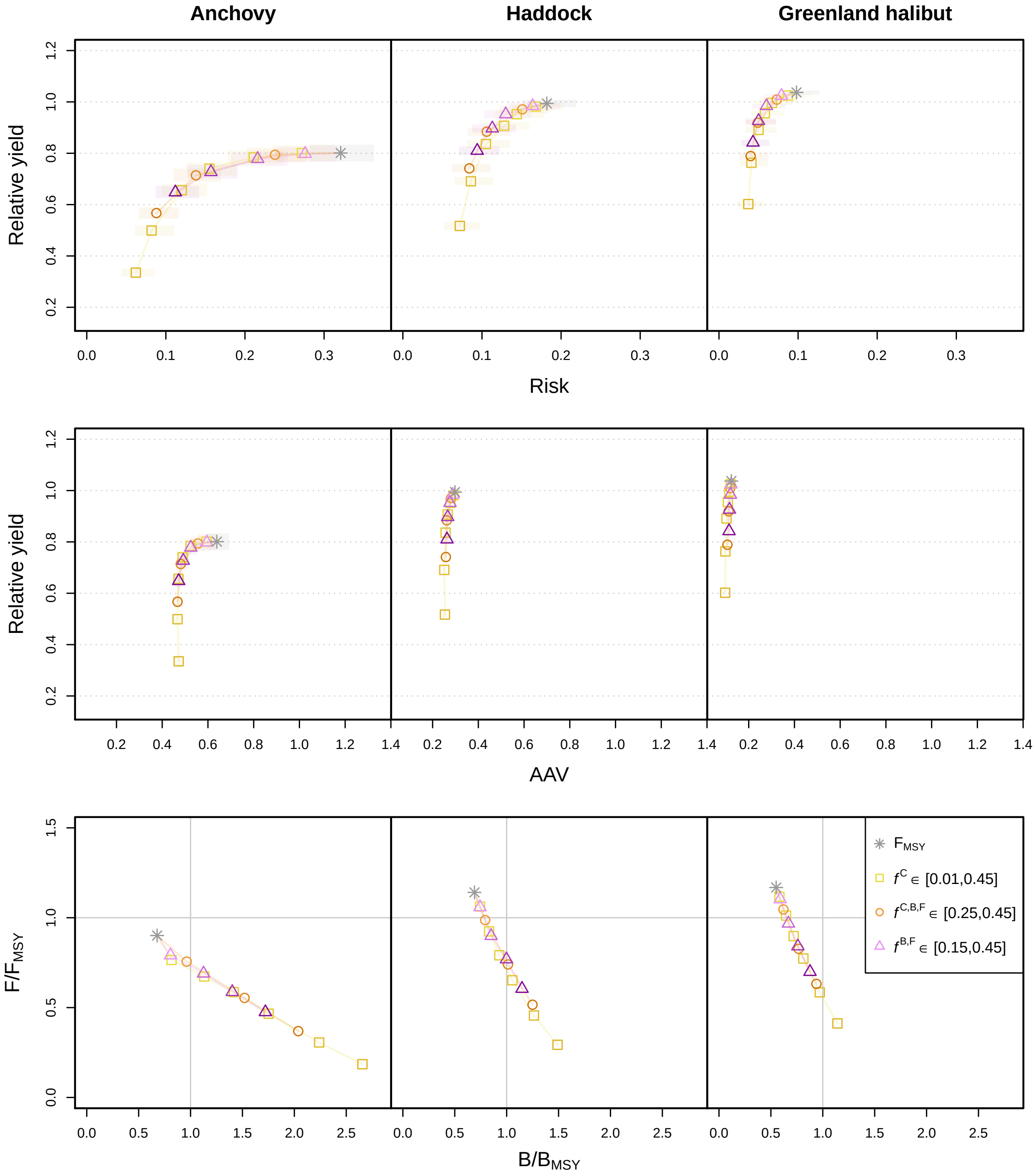

Figure B1: Trade-off graphs of risk and relative yield (upper row) and absolute interannual variability in yield (AAV) and relative yield (middle row) as well as Kobe plots (B/B_{MSY} vs F/F_{MSY}; lower row) for anchovy, haddock, and Greenland halibut (columns). Starting from the grey star symbol (fishing at F/F_{MSY}), the lines connect following HCRs with increasing uncertainty buffers (decreasing fractile): $f^{\mathrm{C}} = \{0.45, 0.35, 0.25, 0.15, 0.05, 0.01\}$ (yellow circles); and following HCRs with increasing biomass thresholds (and limits): $B_{\mathrm{T}} = \{0.5, 1, 2, 3, 4\}$ (orange squares); $B_{\mathrm{L}} = 0.3, B_{\mathrm{T}} = \{0.5, 1, 2, 3, 4\}$ (purple triangles); $B_{\mathrm{L}} = 0.5, B_{\mathrm{T}} = \{1, 2, 3, 4\}$ (blue triangles); $B_{\mathrm{L}} = \{0.5, 1\}, B_{\mathrm{T}} = \{0.5, 1\}$ (green diamonds). The open grey triangles show the additional rules $B_{\mathrm{L}} = 0.2, B_{\mathrm{T}} = 0.8$ and $B_{\mathrm{L}} = 0.1, B_{\mathrm{T}} = 0.9$. The shaded areas around the symbols in the upper and middle row represent the 95% confidence intervals of the respective metrics.

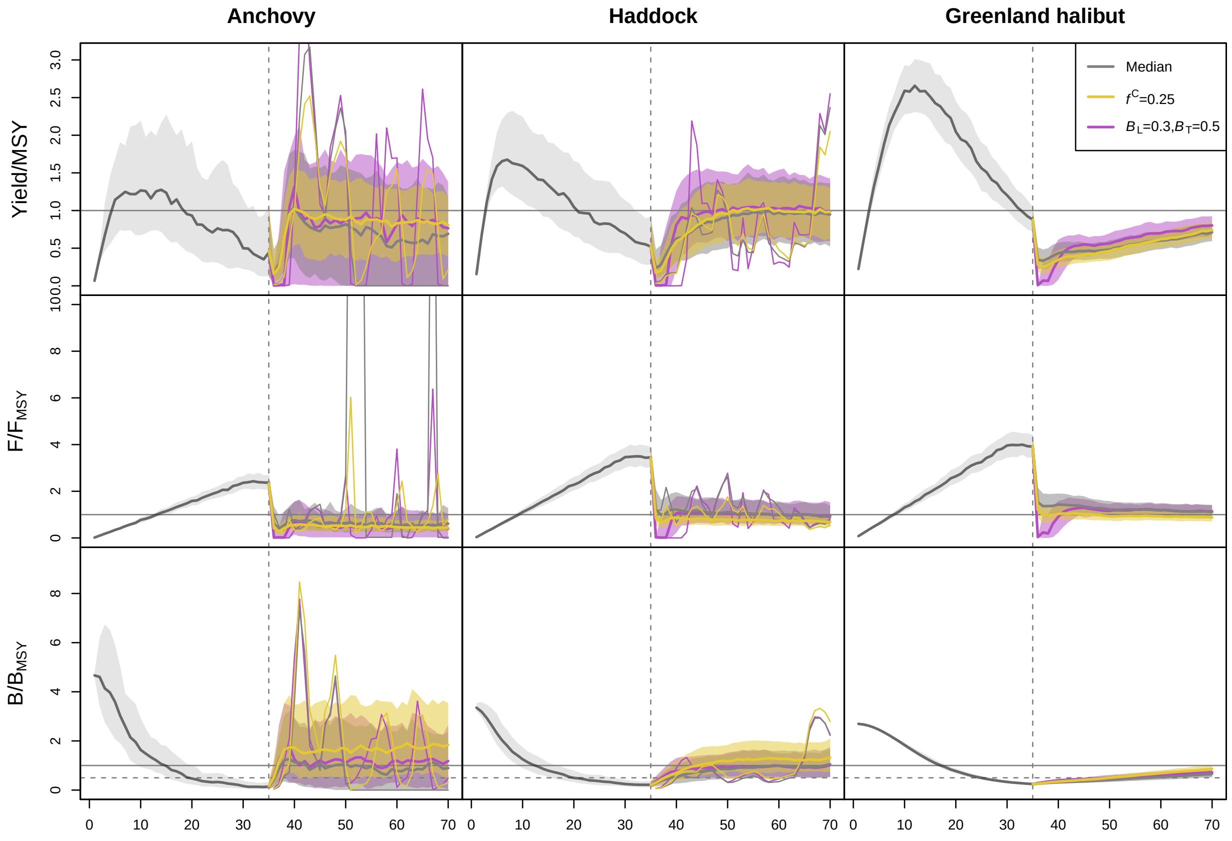

Figure B2: Trajectories of median yield (upper row), fishing mortality (middle row) and biomass (bottom row) relative to reference points for the three stocks anchovy, haddock, and Greenland halibut and selected HCRs. Shaded areas include 60% of the distribution over converged replicates. Dashed vertical lines represent start of management (year 35) and dashed horizontal line in bottom row represents B_{lim} ($0.5B_{\text{MSY}}$).

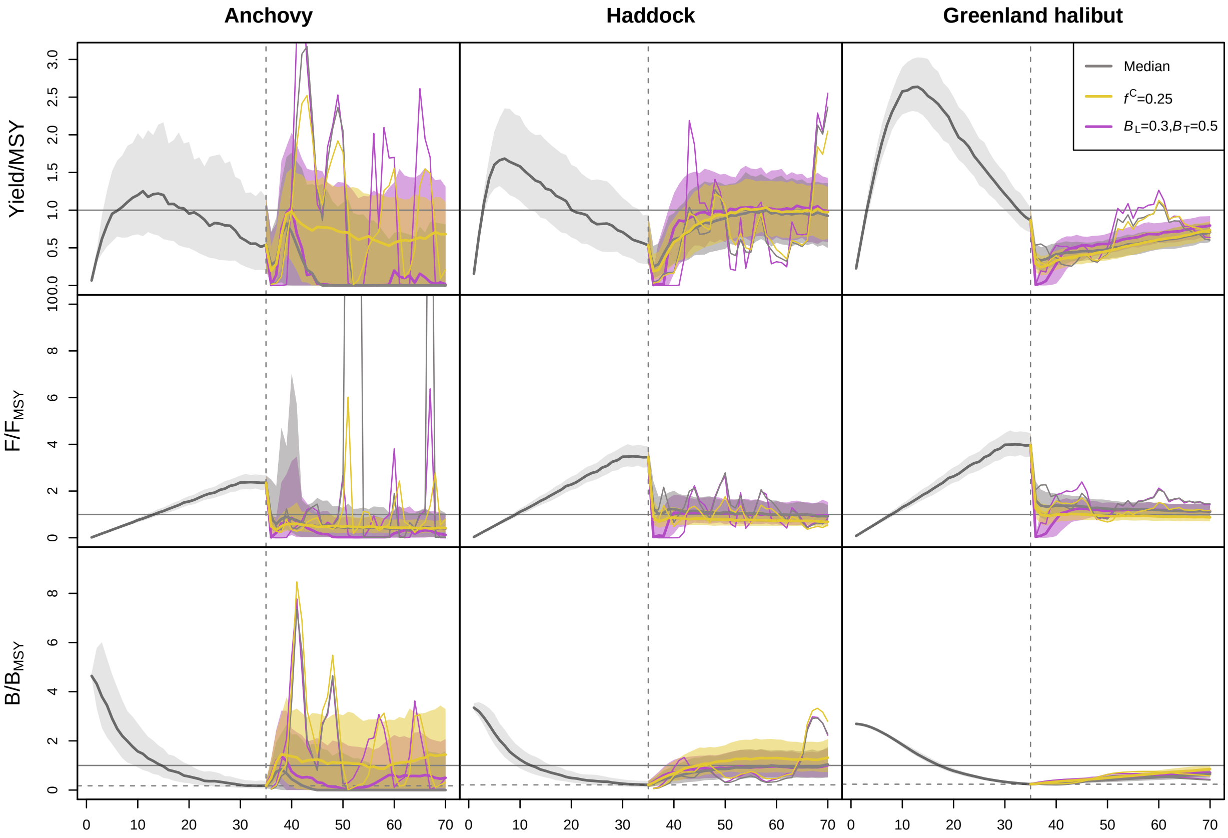

Figure B3: Trajectories of median yield (upper row), fishing mortality (middle row) and biomass (bottom row) relative to reference points for the three stocks anchovy, haddock, and Greenland halibut and selected HCRs. Shaded areas include 60% of the distribution over all (converged + non-converged) replicates. Dashed vertical lines represent start of management (year 35) and dashed horizontal line in bottom row represents B_{lim} ($0.5B_{\text{MSY}}$).

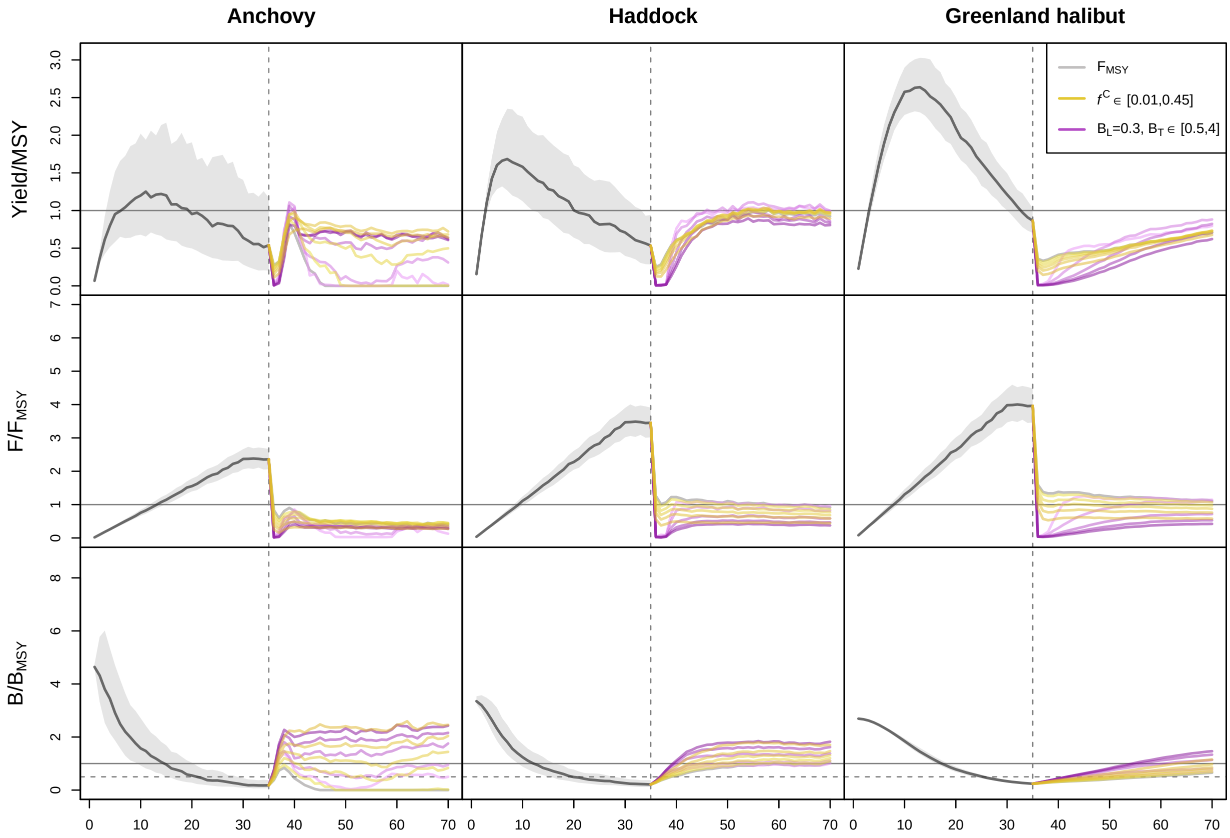

Figure B4: Trajectories of median yield (upper row), fishing mortality (middle row) and biomass (bottom row) relative to reference points for the three stocks anchovy, haddock, and Greenland halibut and selected HCRs. All (converged + non-converged) replicates are considered. Dashed vertical lines represent start of management (year 35) and dashed horizontal line in bottom row represents B_{lim} ($0.5B_{\text{MSY}}$).

Scientific uncertainty

Table B4: Percentage of converged assessments for selected HCRs during stock-specific periods of 4, 8, and 27 years after start of the managment for anchovy, haddock, and Greenland halibut respectively.

Species	HCR	Baseline	Low proc noise	High proc noise	Low obs noise	High obs noise
Anchovy	Median	95	95	91	98	88
Anchovy	$f^{\mathrm{C}} = 0.45$	96	95	92	98	88
Anchovy	$f^{\mathrm{C}} = 0.35$	97	97	92	99	89
Anchovy	$f^{\mathrm{C}} = 0.25$	98	97	94	99	91
Anchovy	$f^{\mathrm{C}} = 0.15$	98	98	94	99	93
Anchovy	$f^{\mathrm{C}} = 0.05$	98	98	94	99	93
Anchovy	$f^{\mathrm{C}} = 0.01$	98	98	94	99	94
Anchovy	$\mathrm{B_T} = 0.5$	96	95	92	98	89
Anchovy	$\mathrm{B_T} = 1$	97	97	92	98	90
Anchovy	$\mathrm{B_T} = 2$	98	98	93	99	92
Anchovy	$\mathrm{B_T} = 3$	98	98	93	99	93
Anchovy	$\mathrm{B_T} = 4$	98	98	93	99	93
Anchovy	$\mathrm{B_L} = 0.3, \mathrm{B_T} = 0.5$	96	95	92	98	90
Anchovy	$\mathrm{B_L} = 0.3, \mathrm{B_T} = 1$	97	97	92	98	91
Anchovy	$\mathrm{B_L} = 0.3, \mathrm{B_T} = 2$	98	97	92	99	92
Anchovy	$\mathrm{B_L} = 0.3, \mathrm{B_T} = 3$	98	98	92	99	93
Anchovy	$\mathrm{B_L} = 0.3, \mathrm{B_T} = 4$	98	98	92	99	93
Anchovy	$\mathrm{B_L} = 0.5, \mathrm{B_T} = 1$	97	97	92	98	91
Anchovy	$\mathrm{B_L} = 0.5, \mathrm{B_T} = 2$	97	97	92	99	92
Anchovy	$\mathrm{B_L} = 0.5, \mathrm{B_T} = 3$	97	98	92	99	93
Anchovy	$\mathrm{B_L} = 0.5, \mathrm{B_T} = 4$	98	98	92	99	94
Anchovy	$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5$	96	96	92	98	90
Anchovy	$\mathrm{B_L} = 1, \mathrm{B_T} = 1$	97	97	92	98	92
Haddock	Median	98	96	95	99	92
Haddock	$f^{\mathrm{C}} = 0.45$	98	96	95	99	92
Haddock	$f^{\mathrm{C}} = 0.35$	98	96	95	99	93
Haddock	$f^{\mathrm{C}} = 0.25$	98	97	95	99	93
Haddock	$f^{\mathrm{C}} = 0.15$	98	97	95	99	93
Haddock	$f^{\mathrm{C}} = 0.05$	98	96	95	99	93
Haddock	$f^{\mathrm{C}} = 0.01$	98	96	95	99	93
Haddock	$\mathrm{B_T} = 0.5$	97	96	95	99	93
Haddock	$\mathrm{B_T} = 1$	97	96	95	99	92
Haddock	$\mathrm{B_T} = 2$	97	96	95	99	92
Haddock	$\mathrm{B_T} = 3$	97	96	95	99	93
Haddock	$\mathrm{B_T} = 4$	97	96	95	99	93
Haddock	$\mathrm{B_L} = 0.3, \mathrm{B_T} = 0.5$	97	96	95	99	92
Haddock	$\mathrm{B_L} = 0.3, \mathrm{B_T} = 1$	97	96	95	99	92
Haddock	$\mathrm{B_L} = 0.3, \mathrm{B_T} = 2$	97	96	94	99	92
Haddock	$\mathrm{B_L} = 0.3, \mathrm{B_T} = 3$	97	96	95	99	92
Haddock	$\mathrm{B_L} = 0.3, \mathrm{B_T} = 4$	97	96	95	99	92
Haddock	$\mathrm{B_L} = 0.5, \mathrm{B_T} = 1$	97	96	94	99	92
Haddock	$\mathrm{B_L} = 0.5, \mathrm{B_T} = 2$	97	96	95	99	92
Haddock	$\mathrm{B_L} = 0.5, \mathrm{B_T} = 3$	97	96	95	99	93
Haddock	$\mathrm{B_L} = 0.5, \mathrm{B_T} = 4$	97	96	95	99	92
Haddock	$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5$	97	96	94	99	92
Haddock	$\mathrm{B_L} = 1, \mathrm{B_T} = 1$	97	96	94	99	92
Greenland halibut	Median	98	98	97	99	94
Greenland halibut	$f^{\mathrm{C}} = 0.45$	98	98	97	99	94
Greenland halibut	$f^{\mathrm{C}} = 0.35$	98	98	98	99	95
Greenland halibut	$f^{\mathrm{C}} = 0.25$	98	98	97	99	95
Greenland halibut	$f^{\mathrm{C}} = 0.15$	98	98	98	99	95
Greenland halibut	$f^{\mathrm{C}} = 0.05$	98	98	98	99	95
Greenland halibut	$f^{\mathrm{C}} = 0.01$	98	98	97	99	95
Greenland halibut	$\mathrm{B_T} = 0.5$	97	98	97	99	94
Greenland halibut	$\mathrm{B_T} = 1$	97	98	97	99	94
Greenland halibut	$\mathrm{B_T} = 2$	97	97	97	99	94
Greenland halibut	$\mathrm{B_T} = 3$	97	97	97	99	94
Greenland halibut	$\mathrm{B_T} = 4$	97	97	97	99	94
Greenland halibut	$\mathrm{B_L} = 0.3, \mathrm{B_T} = 0.5$	97	97	97	99	93
Greenland halibut	$\mathrm{B_L} = 0.3, \mathrm{B_T} = 1$	97	97	97	99	93
Greenland halibut	$\mathrm{B_L} = 0.3, \mathrm{B_T} = 2$	97	97	97	99	93
Greenland halibut	$\mathrm{B_L} = 0.3, \mathrm{B_T} = 3$	97	97	97	99	93
Greenland halibut	$\mathrm{B_L} = 0.3, \mathrm{B_T} = 4$	97	97	97	99	93
Greenland halibut	$\mathrm{B_L} = 0.5, \mathrm{B_T} = 1$	97	97	97	99	93
Greenland halibut	$\mathrm{B_L} = 0.5, \mathrm{B_T} = 2$	97	97	97	99	93
Greenland halibut	$\mathrm{B_L} = 0.5, \mathrm{B_T} = 3$	97	97	97	99	93
Greenland halibut	$\mathrm{B_L} = 0.5, \mathrm{B_T} = 4$	97	97	97	99	93
Greenland halibut	$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5$	97	97	97	99	93
Greenland halibut	$\mathrm{B_L} = 1, \mathrm{B_T} = 1$	97	97	97	99	93

Table B5: Median standard deviation of predicted catch (C_{y+1}), B/B_{MSY} and F/F_{MSY} estimated with SPiCT calculated for all (converged + non-converged) replicates for fishing at F_{MSY} HCR over stock-specific periods of 4, 8, and 27 years after start of the management for anchovy, haddock, and Greenland halibut, respectively.

Species	Quantity	Baseline	Low proc noise	High proc noise	Low obs noise	High obs noise
Anchovy	C_{y+1}	0.58	0.42	0.74	0.51	0.69
Anchovy	B/B_{MSY}	0.9	0.57	1.27	0.74	1.175
Anchovy	F/F_{MSY}	0.61	0.52	0.69	0.51	0.79
Haddock	C_{y+1}	0.43	0.39	0.49	0.38	0.55
Haddock	B/B_{MSY}	0.61	0.44	0.77	0.47	0.87
Haddock	F/F_{MSY}	0.53	0.5	0.56	0.43	0.72
Greenland halibut	C_{y+1}	0.38	0.38	0.38	0.31	0.52
Greenland halibut	B/B_{MSY}	0.45	0.43	0.47	0.36	0.7
Greenland halibut	F/F_{MSY}	0.5	0.48	0.51	0.39	0.72

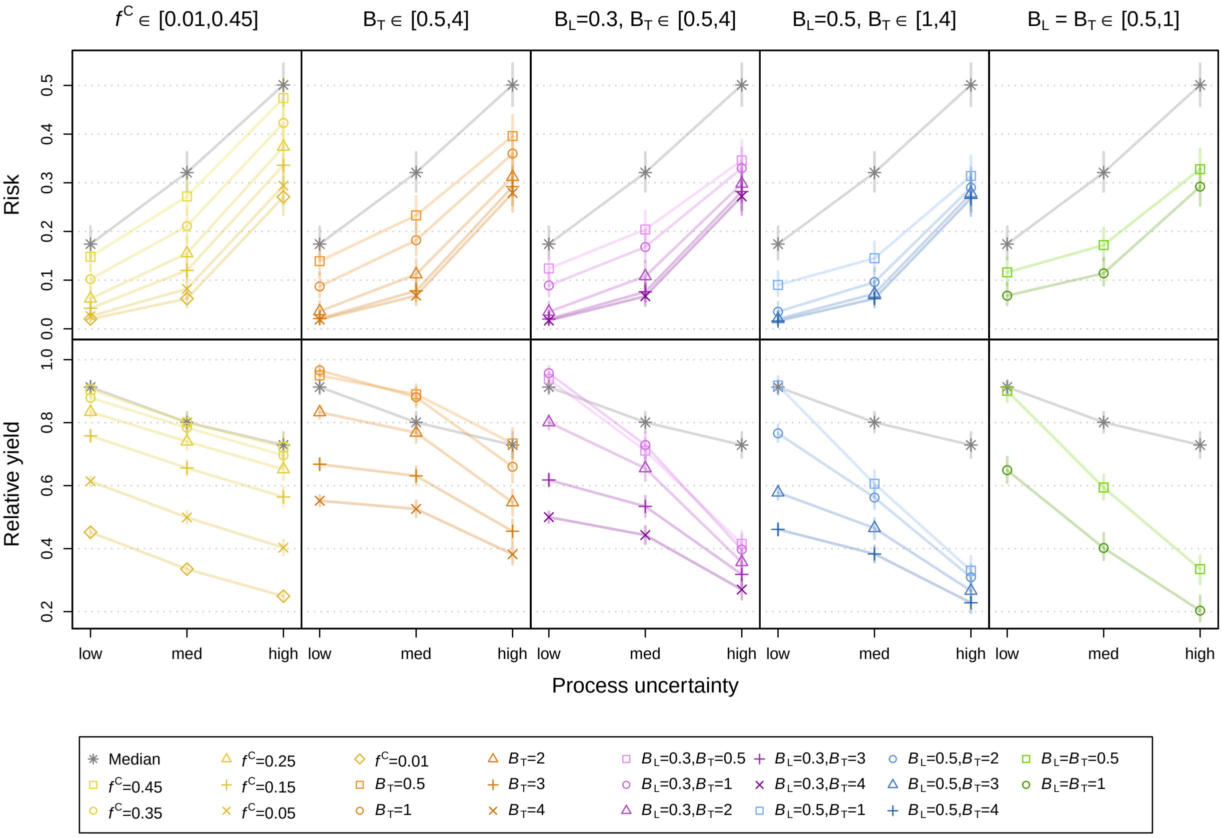

Figure B5: Risk (upper row) and relative yield (lower row) for three scenarios with three **process uncertainty** levels for **anchovy** and various HCRs (colours) sorted by HCR type (columns). Low and high process noise levels assume a recruitment deviations of 50% and 150% of the default stock-specific levels (med), respectively. Vertical lines represent the 95% confidence intervals.

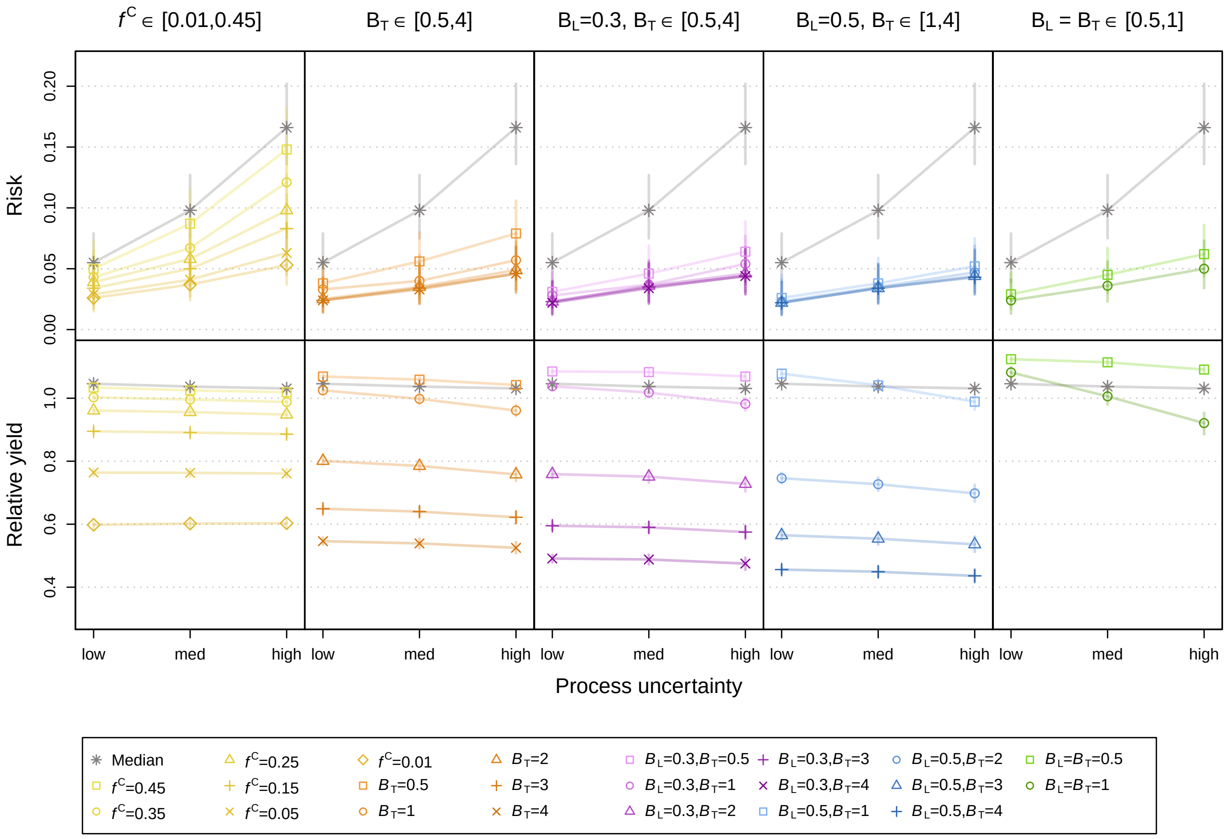

Figure B6: Risk (upper row) and relative yield (lower row) for three scenarios with three **process uncertainty** levels for **Greenland halibut** and various HCRs (colours) sorted by HCR type (columns). Low and high process noise levels assume a recruitment deviations of 50% and 150% of the default stock-specific levels (med), respectively. Vertical lines represent the 95% confidence intervals.

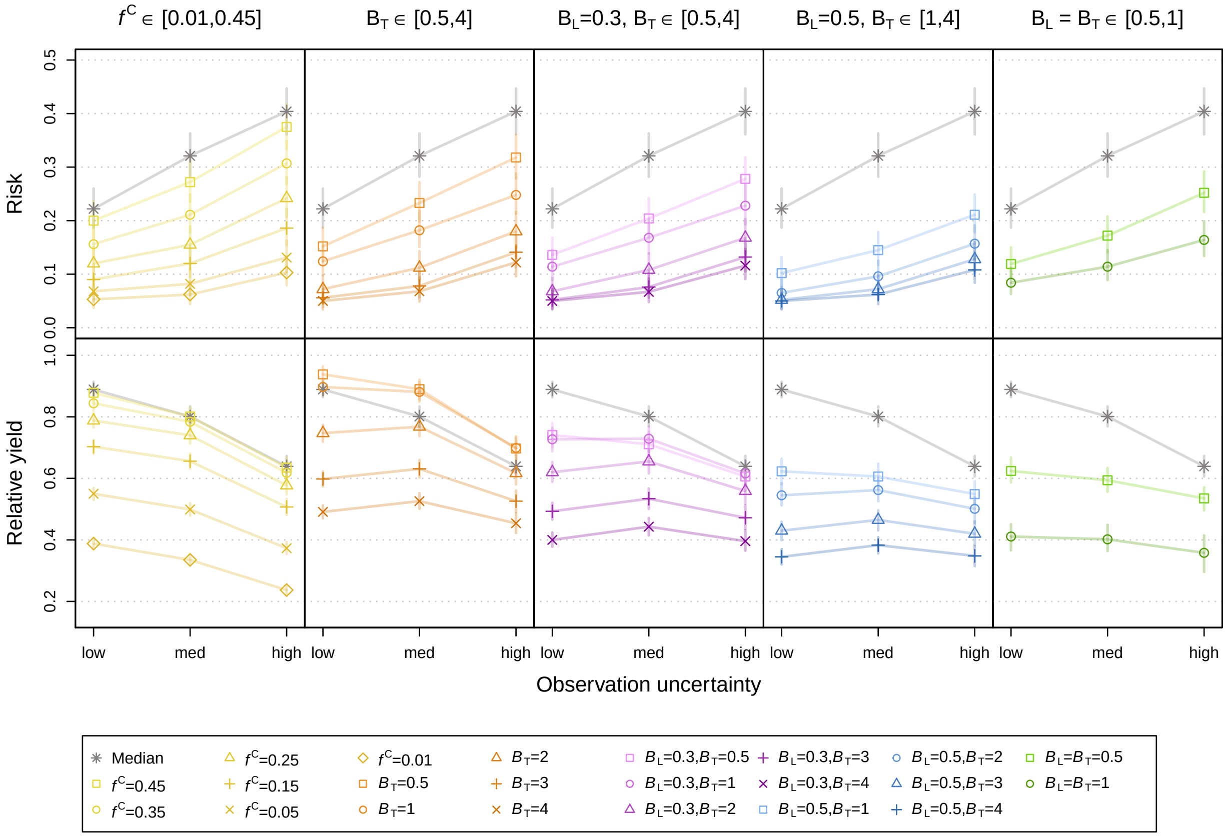

Figure B7: Risk (upper row) and relative yield (lower row) for three scenarios with three **observation uncertainty** for **anchovy** and various HCRs (colours) sorted by HCR type (columns). Low, med, and high observation noise levels assume a SD of $0.15, 0.3, 0.6$, respectively. Vertical lines represent the 95% confidence intervals.

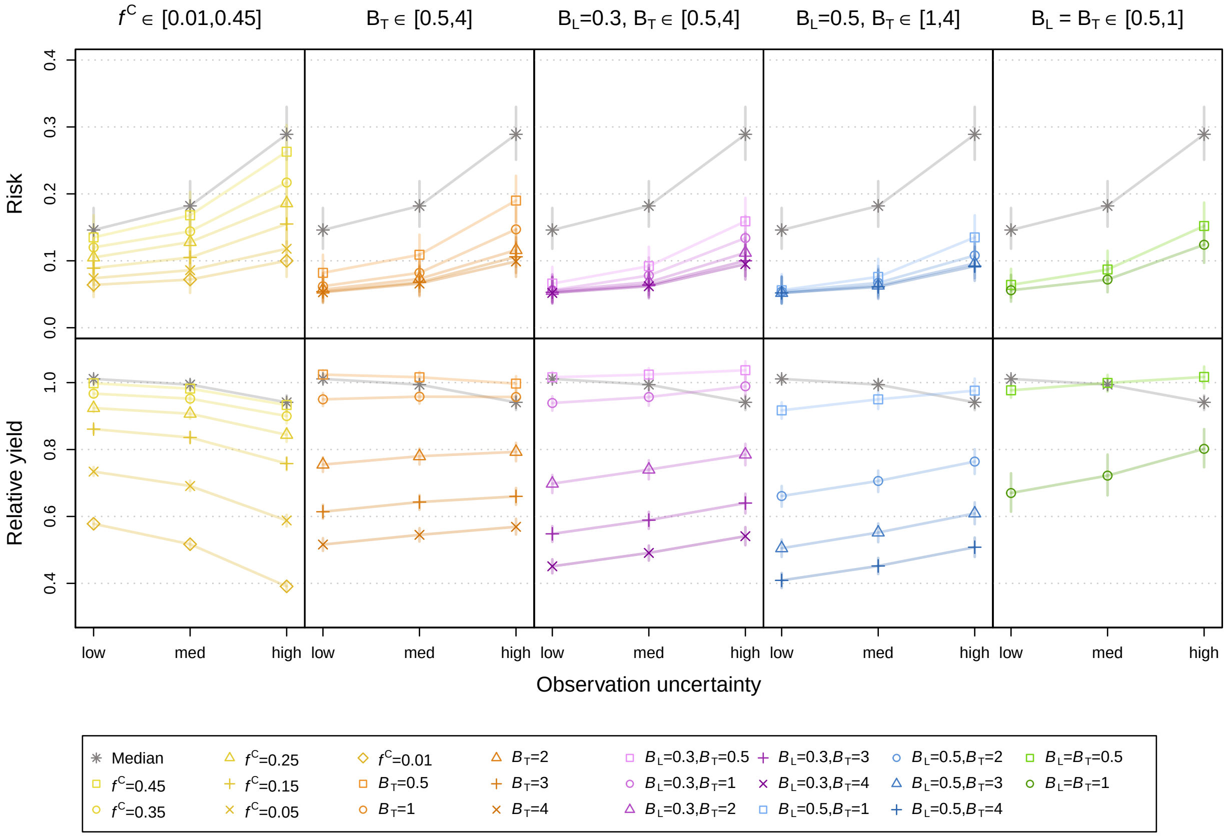

Figure B8: Risk (upper row) and relative yield (lower row) for three scenarios with three **observation uncertainty** for **haddock** and various HCRs (colours) sorted by HCR type (columns). Low, med, and high observation noise levels assume a SD of $0.15, 0.3, 0.6$, respectively. Vertical lines represent the 95% confidence intervals.

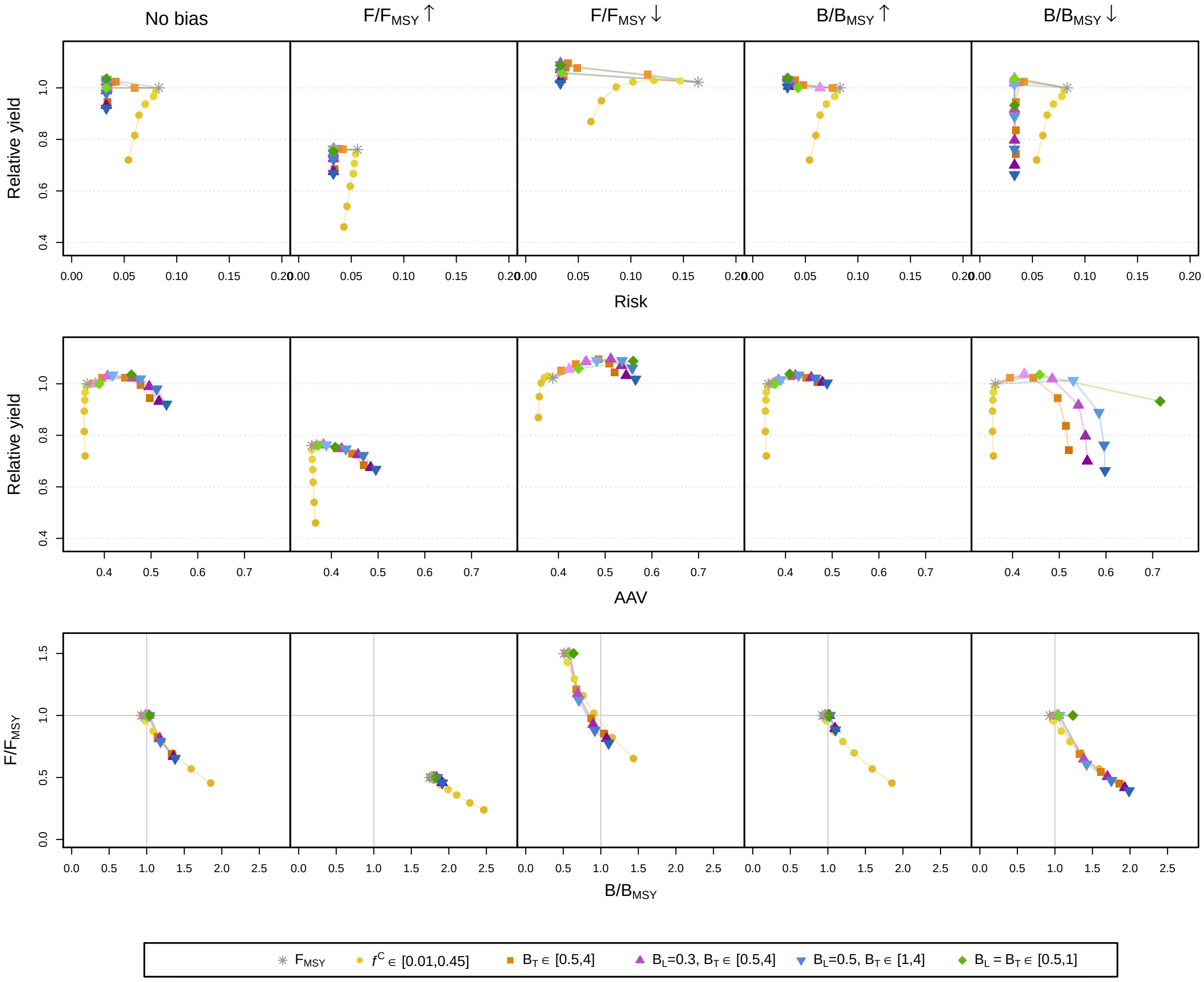

Figure B9: Trade-off graphs of risk and relative yield (upper row) and absolute interannual variability in yield (AAV) and relative yield (middle row) as well as Kobe plots (B/B_{MSY} vs F/F_{MSY}; lower row) of **simulated assessments** for **anchovy** and various biases (columns). Up and down arrows imply +50% and −50% bias in respective quantities.Starting from the grey star symbol (fishing at F/F_{MSY}), the lines connect following HCRs with increasing uncertainty buffers (decreasing fractile): $f^{\mathrm{C}} = \{0.45, 0.35, 0.25, 0.15, 0.05, 0.01\}$ (yellow circles); and following HCRs with increasing biomass thresholds (and limits): $B_{\mathrm{T}} = \{0.5, 1, 2, 3, 4\}$ (orange squares); $B_{\mathrm{L}} = 0.3, B_{\mathrm{T}} = \{0.5, 1, 2, 3, 4\}$ (purple triangles); $B_{\mathrm{L}} = 0.5, B_{\mathrm{T}} = \{1, 2, 3, 4\}$ (blue triangles); $B_{\mathrm{L}} = \{0.5, 1\}, B_{\mathrm{T}} = \{0.5, 1\}$ (green diamonds). The open grey triangles show the additional rules $B_{\mathrm{L}} = 0.2, B_{\mathrm{T}} = 0.8$ and $B_{\mathrm{L}} = 0.1, B_{\mathrm{T}} = 0.9$. The shaded areas around the symbols in the upper and middle row represent the 95% confidence intervals of the respective metrics.

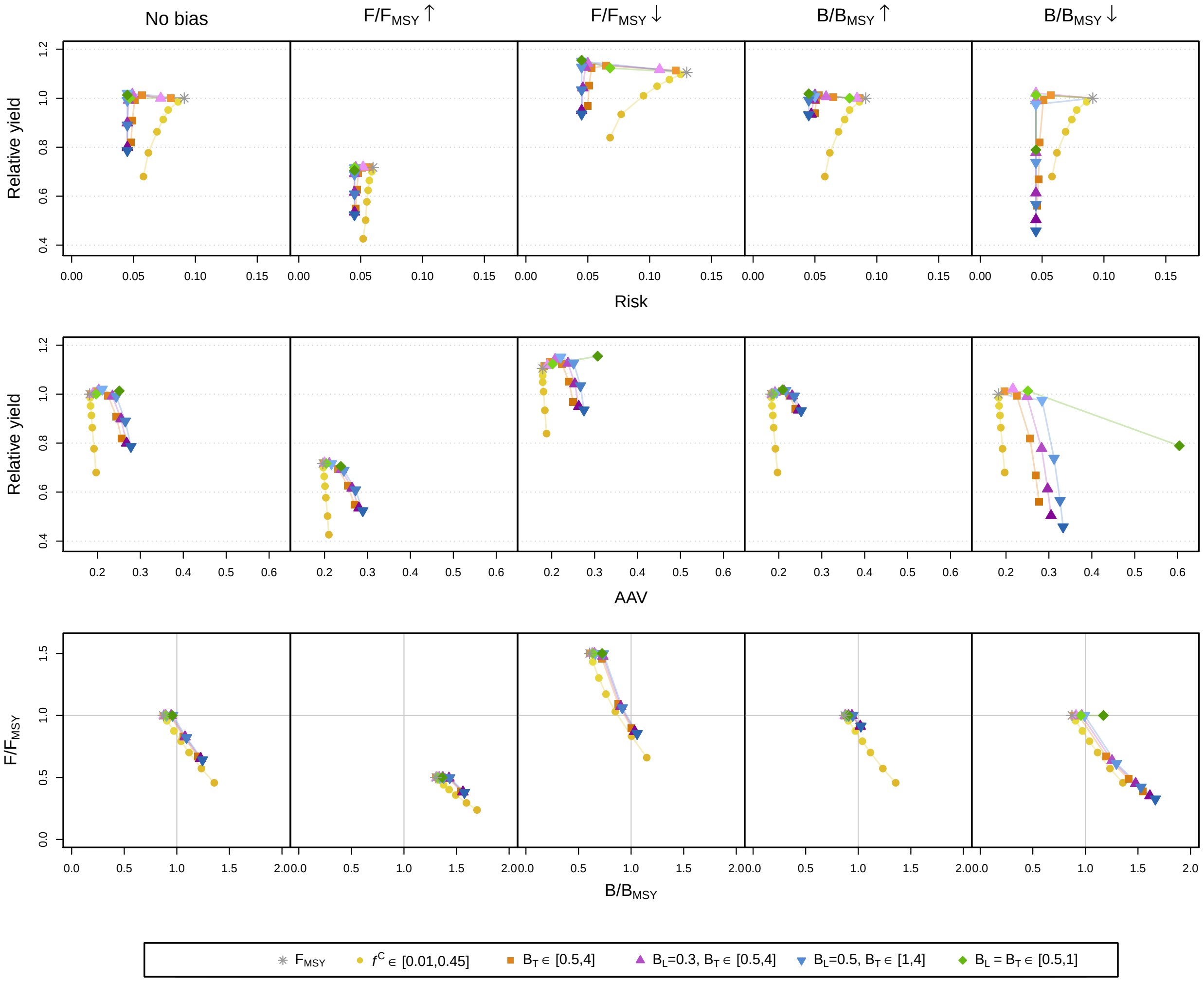

Figure B10: Trade-off graphs of risk and relative yield (upper row) and absolute interannual variability in yield (AAV) and relative yield (middle row) as well as Kobe plots (B/B_{MSY} vs F/F_{MSY}; lower row) of **simulated assessments** for **haddock** and various biases (columns). Up and down arrows imply $+50\%$ and -50% bias in respective quantities.Starting from the grey star symbol (fishing at F/F_{MSY}), the lines connect following HCRs with increasing uncertainty buffers (decreasing fractile): $f^{\mathrm{C}} = \{0.45, 0.35, 0.25, 0.15, 0.05, 0.01\}$ (yellow circles); and following HCRs with increasing biomass thresholds (and limits): $B_{\mathrm{T}} = \{0.5, 1, 2, 3, 4\}$ (orange squares); $B_{\mathrm{L}} = 0.3, B_{\mathrm{T}} = \{0.5, 1, 2, 3, 4\}$ (purple triangles); $B_{\mathrm{L}} = 0.5, B_{\mathrm{T}} = \{1, 2, 3, 4\}$ (blue triangles); $B_{\mathrm{L}} = \{0.5, 1\}, B_{\mathrm{T}} = \{0.5, 1\}$ (green diamonds). The open grey triangles show the additional rules $B_{\mathrm{L}} = 0.2, B_{\mathrm{T}} = 0.8$ and $B_{\mathrm{L}} = 0.1, B_{\mathrm{T}} = 0.9$. The shaded areas around the symbols in the upper and middle row represent the 95% confidence intervals of the respective metrics.

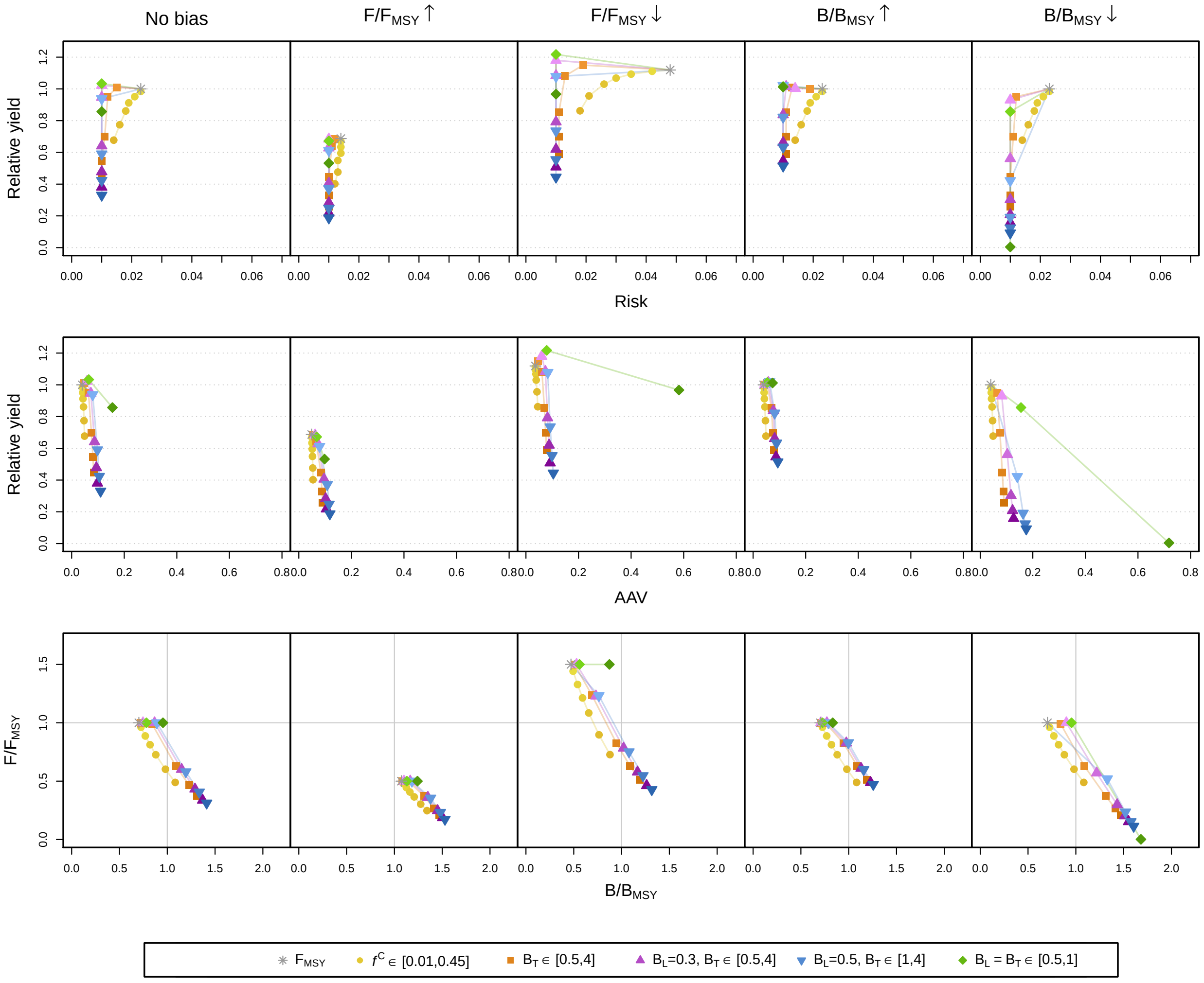

Figure B11: Trade-off graphs of risk and relative yield (upper row) and absolute interannual variability in yield (AAV) and relative yield (middle row) as well as Kobe plots (B/B_{MSY} vs F/F_{MSY}; lower row) of **simulated assessments** for **Greenland halibut** and various biases (columns). Up and down arrows imply +50% and −50% bias in respective quantities.Starting from the grey star symbol (fishing at F/F_{MSY}), the lines connect following HCRs with increasing uncertainty buffers (decreasing fractile): $f^{\mathrm{C}} = \{0.45, 0.35, 0.25, 0.15, 0.05, 0.01\}$ (yellow circles); and following HCRs with increasing biomass thresholds (and limits): $B_{\mathrm{T}} = \{0.5, 1, 2, 3, 4\}$ (orange squares); $B_{\mathrm{L}} = 0.3, B_{\mathrm{T}} = \{0.5, 1, 2, 3, 4\}$ (purple triangles); $B_{\mathrm{L}} = 0.5, B_{\mathrm{T}} = \{1, 2, 3, 4\}$ (blue triangles); $B_{\mathrm{L}} = \{0.5, 1\}, B_{\mathrm{T}} = \{0.5, 1\}$ (green diamonds). The open grey triangles show the additional rules $B_{\mathrm{L}} = 0.2, B_{\mathrm{T}} = 0.8$ and $B_{\mathrm{L}} = 0.1, B_{\mathrm{T}} = 0.9$. The shaded areas around the symbols in the upper and middle row represent the 95% confidence intervals of the respective metrics.

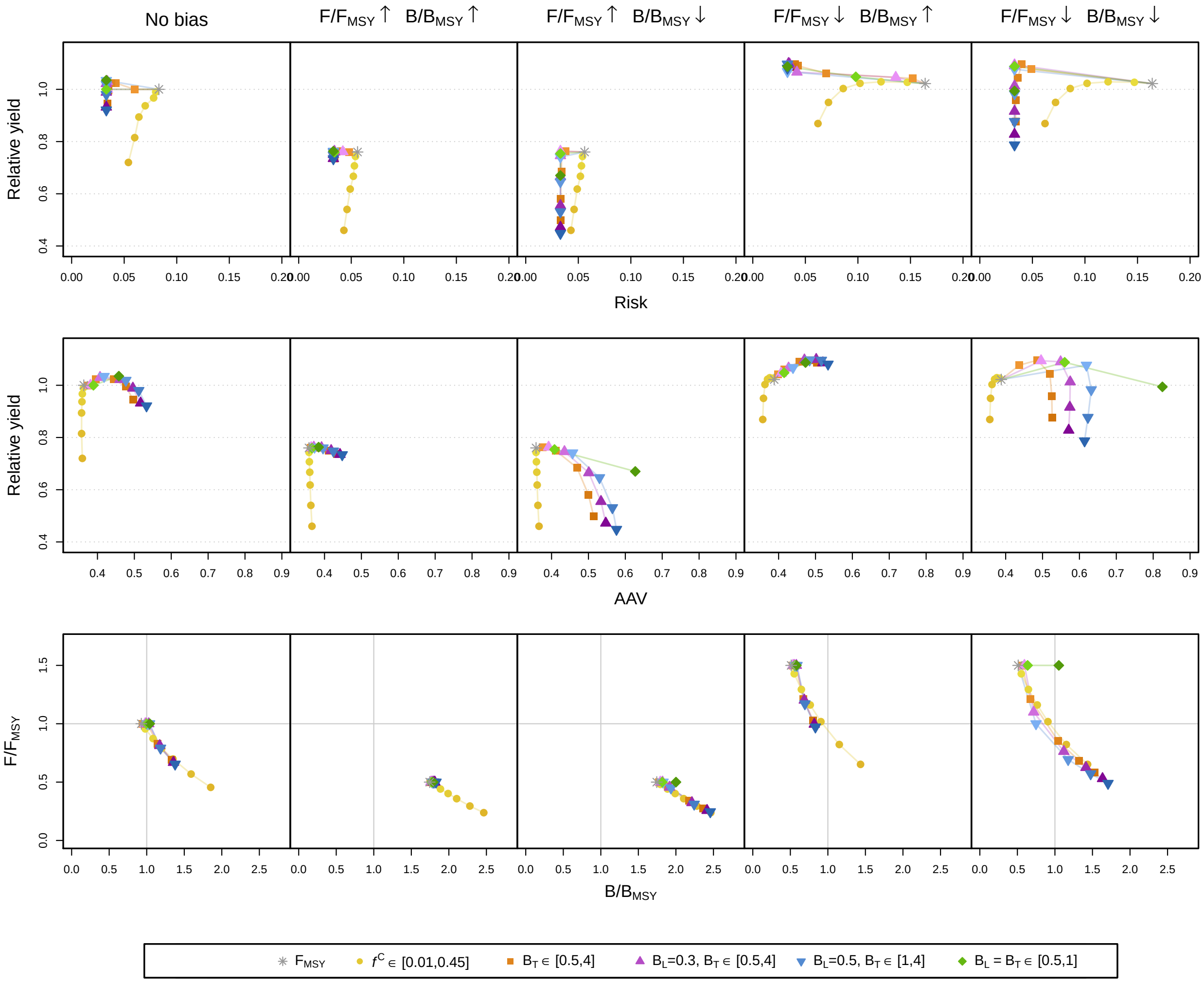

Figure B12: Trade-off graphs of risk and relative yield (upper row) and absolute interannual variability in yield (AAV) and relative yield (middle row) as well as Kobe plots (B/B_{MSY} vs F/F_{MSY}; lower row) of **simulated assessments** for **anchovy** and various biases (columns). Up and down arrows imply +50% and −50% bias in respective quantities.Starting from the grey star symbol (fishing at F/F_{MSY}), the lines connect following HCRs with increasing uncertainty buffers (decreasing fractile): $f^{\mathrm{C}} = \{0.45, 0.35, 0.25, 0.15, 0.05, 0.01\}$ (yellow circles); and following HCRs with increasing biomass thresholds (and limits): $B_{\mathrm{T}} = \{0.5, 1, 2, 3, 4\}$ (orange squares); $B_{\mathrm{L}} = 0.3, B_{\mathrm{T}} = \{0.5, 1, 2, 3, 4\}$ (purple triangles); $B_{\mathrm{L}} = 0.5, B_{\mathrm{T}} = \{1, 2, 3, 4\}$ (blue triangles); $B_{\mathrm{L}} = \{0.5, 1\}, B_{\mathrm{T}} = \{0.5, 1\}$ (green diamonds). The open grey triangles show the additional rules $B_{\mathrm{L}} = 0.2, B_{\mathrm{T}} = 0.8$ and $B_{\mathrm{L}} = 0.1, B_{\mathrm{T}} = 0.9$. The shaded areas around the symbols in the upper and middle row represent the 95% confidence intervals of the respective metrics.

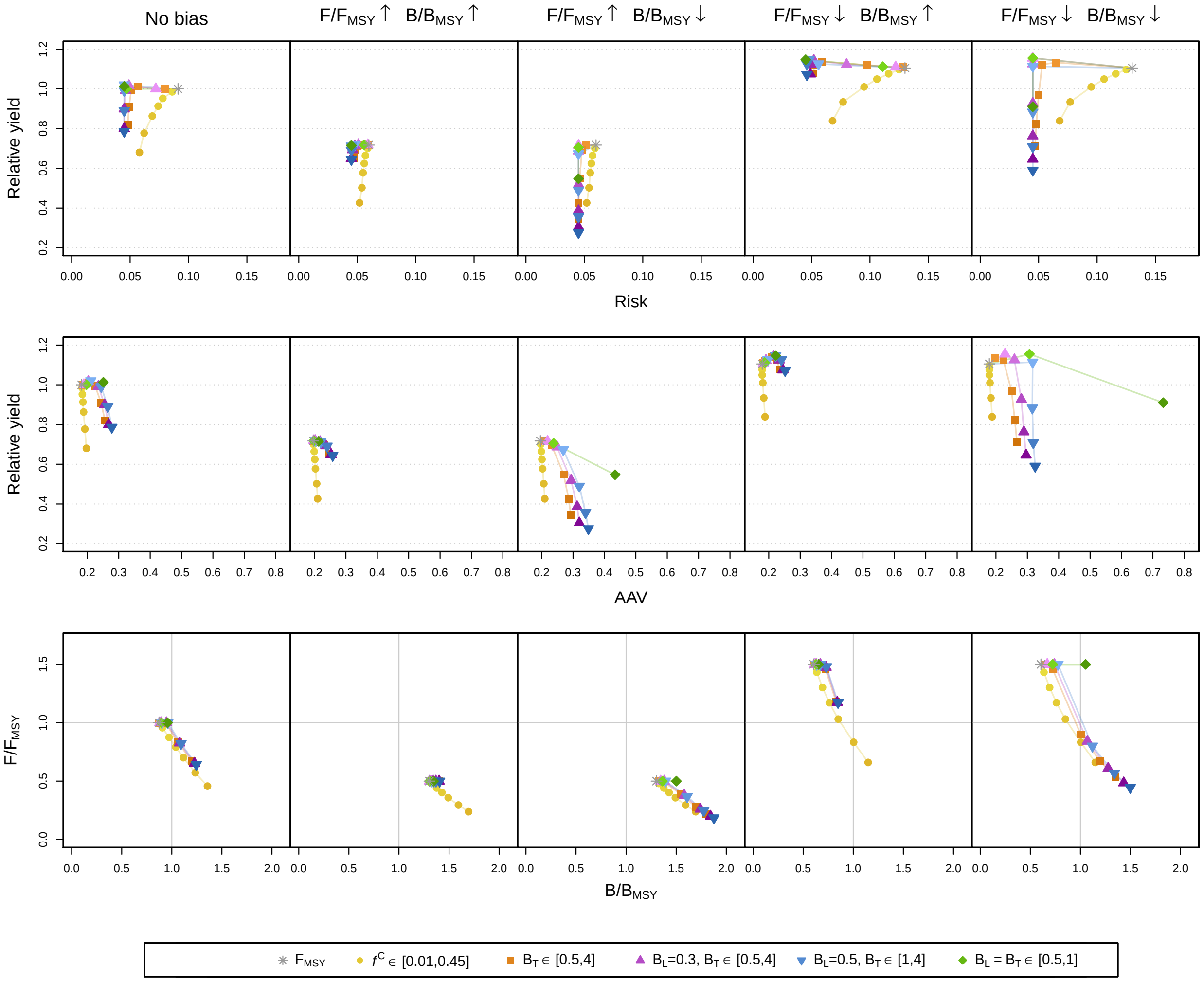

Figure B13: Trade-off graphs of risk and relative yield (upper row) and absolute interannual variability in yield (AAV) and relative yield (middle row) as well as Kobe plots (B/B_{MSY} vs F/F_{MSY}; lower row) of **simulated assessments** for **haddock** and various biases (columns). Up and down arrows imply +50% and −50% bias in respective quantities.Starting from the grey star symbol (fishing at F/F_{MSY}), the lines connect following HCRs with increasing uncertainty buffers (decreasing fractile): $f^{\mathrm{C}} = \{0.45, 0.35, 0.25, 0.15, 0.05, 0.01\}$ (yellow circles); and following HCRs with increasing biomass thresholds (and limits): $B_{\mathrm{T}} = \{0.5, 1, 2, 3, 4\}$ (orange squares); $B_{\mathrm{L}} = 0.3, B_{\mathrm{T}} = \{0.5, 1, 2, 3, 4\}$ (purple triangles); $B_{\mathrm{L}} = 0.5, B_{\mathrm{T}} = \{1, 2, 3, 4\}$ (blue triangles); $B_{\mathrm{L}} = \{0.5, 1\}, B_{\mathrm{T}} = \{0.5, 1\}$ (green diamonds). The open grey triangles show the additional rules $B_{\mathrm{L}} = 0.2, B_{\mathrm{T}} = 0.8$ and $B_{\mathrm{L}} = 0.1, B_{\mathrm{T}} = 0.9$. The shaded areas around the symbols in the upper and middle row represent the 95% confidence intervals of the respective metrics.

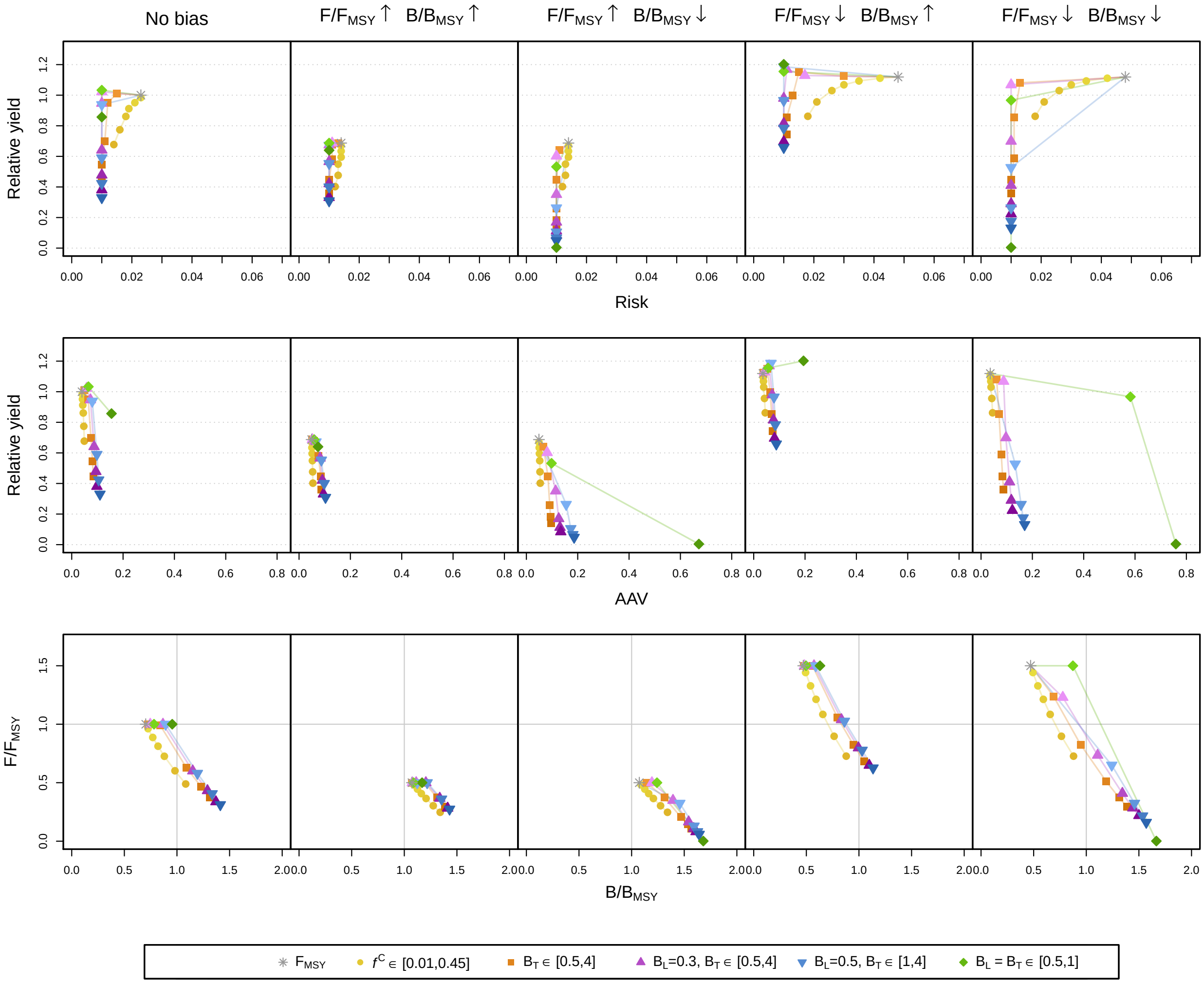

Figure B14: Trade-off graphs of risk and relative yield (upper row) and absolute interannual variability in yield (AAV) and relative yield (middle row) as well as Kobe plots (B/B_{MSY} vs F/F_{MSY}; lower row) of **simulated assessments** for **Greenland halibut** and various biases (columns). Up and down arrows imply +50% and −50% bias in respective quantities.Starting from the grey star symbol (fishing at F/F_{MSY}), the lines connect following HCRs with increasing uncertainty buffers (decreasing fractile): $f^{\mathrm{C}} = \{0.45, 0.35, 0.25, 0.15, 0.05, 0.01\}$ (yellow circles); and following HCRs with increasing biomass thresholds (and limits): $B_{\mathrm{T}} = \{0.5, 1, 2, 3, 4\}$ (orange squares); $B_{\mathrm{L}} = 0.3, B_{\mathrm{T}} = \{0.5, 1, 2, 3, 4\}$ (purple triangles); $B_{\mathrm{L}} = 0.5, B_{\mathrm{T}} = \{1, 2, 3, 4\}$ (blue triangles); $B_{\mathrm{L}} = \{0.5, 1\}, B_{\mathrm{T}} = \{0.5, 1\}$ (green diamonds). The open grey triangles show the additional rules $B_{\mathrm{L}} = 0.2, B_{\mathrm{T}} = 0.8$ and $B_{\mathrm{L}} = 0.1, B_{\mathrm{T}} = 0.9$. The shaded areas around the symbols in the upper and middle row represent the 95% confidence intervals of the respective metrics.

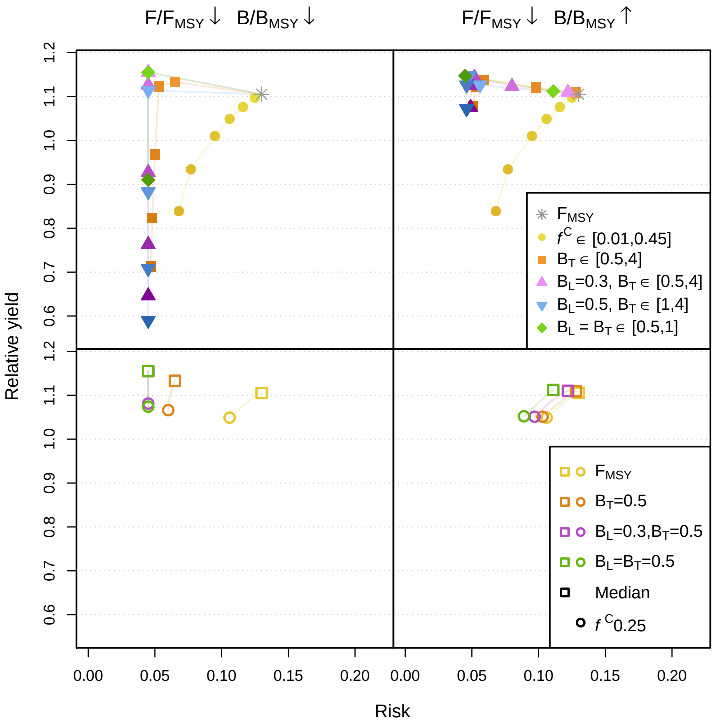

Figure B15: Trade-off between risk and relative yield for simulated assessments and underestimated F/F_{MSY} and B/B_{MSY} (left column) and underestimated F/F_{MSY} and overestimated B/B_{MSY} (right column) for **haddock**. Upper row shows HCRs with biomass reference points and uncertainty buffers, lower row shows combined HCRs for the two scenarios.

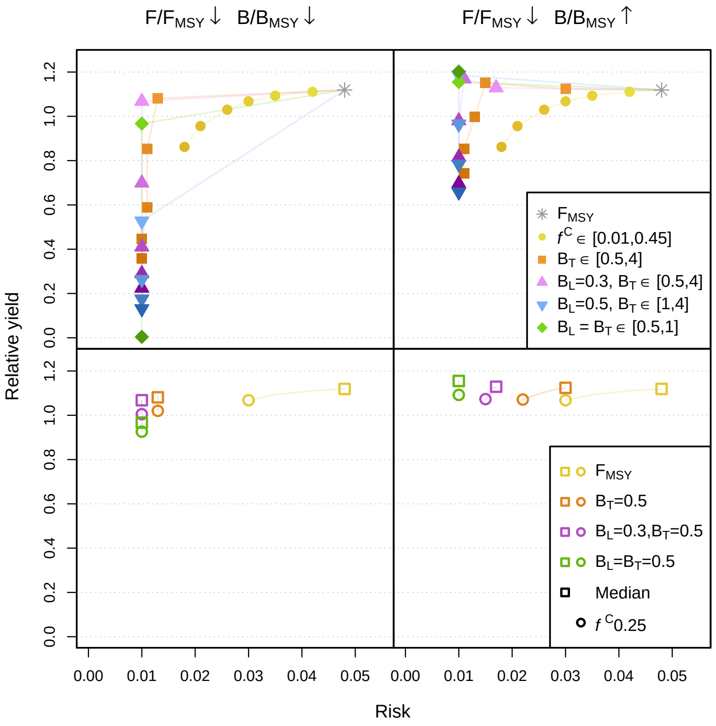

Figure B16: Trade-off between risk and relative yield for simulated assessments and underestimated F/F_{MSY} and B/B_{MSY} (left column) and underestimated F/F_{MSY} and overestimated B/B_{MSY} (right column) for **Greenland halibut**. Upper row shows HCRs with biomass reference points and uncertainty buffers, lower row shows combined HCRs for the two scenarios.

Combining biomass reference points and uncertainty buffers

Table B6: Performance metrics per HCR for Anchovy.

HCR	Rel. yield	Risk	AAV	B/Bmsy	F/Fmsy
$\mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.45$	0.866	0.196	0.655	0.896	0.789
$\mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.35$	0.809	0.153	0.599	1.242	0.692
$\mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.25$	0.731	0.118	0.56	1.529	0.569
$\mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.15$	0.618	0.093	0.537	1.889	0.415
$\mathrm{B_T} = 0.5, f^{\mathrm{B,F}} = 0.45$	0.869	0.19	0.657	0.904	0.796
$\mathrm{B_T} = 0.5, f^{\mathrm{B,F}} = 0.35$	0.813	0.138	0.611	1.288	0.717
$\mathrm{B_T} = 0.5, f^{\mathrm{B,F}} = 0.25$	0.72	0.092	0.586	1.611	0.583
$\mathrm{B_T} = 0.5, f^{\mathrm{B,F}} = 0.15$	0.576	0.068	0.588	2.021	0.419
$\mathrm{B_T} = 0.5, f^{\mathrm{C,B,F}} = 0.45$	0.843	0.166	0.63	1.042	0.772
$\mathrm{B_T} = 0.5, f^{\mathrm{C,B,F}} = 0.35$	0.694	0.094	0.564	1.666	0.524
$\mathrm{B_T} = 0.5, f^{\mathrm{C,B,F}} = 0.25$	0.487	0.063	0.561	2.246	0.316
$\mathrm{B_T} = 1, f^{\mathrm{C}} = 0.45$	0.849	0.154	0.668	1.08	0.801
$\mathrm{B_T} = 1, f^{\mathrm{C}} = 0.35$	0.775	0.12	0.631	1.397	0.66
$\mathrm{B_T} = 1, f^{\mathrm{C}} = 0.25$	0.683	0.098	0.6	1.689	0.544
$\mathrm{B_T} = 1, f^{\mathrm{C}} = 0.15$	0.561	0.085	0.585	2.003	0.394
$\mathrm{B_T} = 1, f^{\mathrm{C,B,F}} = 0.45$	0.811	0.129	0.652	1.265	0.748
$\mathrm{B_T} = 1, f^{\mathrm{C,B,F}} = 0.35$	0.623	0.072	0.613	1.866	0.478
$\mathrm{B_T} = 1, f^{\mathrm{C,B,F}} = 0.25$	0.409	0.054	0.622	2.389	0.281
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.45$	0.581	0.15	0.991	1.595	0.486
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.35$	0.546	0.116	0.88	1.816	0.473
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.25$	0.491	0.09	0.782	2.042	0.403
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{B,F}} = 0.45$	0.562	0.141	0.992	1.648	0.482
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{B,F}} = 0.35$	0.499	0.102	0.989	1.931	0.437
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{B,F}} = 0.25$	0.393	0.073	0.99	2.24	0.341
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{C,B,F}} = 0.45$	0.554	0.126	0.988	1.787	0.48
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{C,B,F}} = 0.35$	0.417	0.073	0.904	2.209	0.349
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{C,B,F}} = 0.25$	0.244	0.054	0.97	2.677	0.187
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.45$	0.702	0.144	0.81	1.41	0.614
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.35$	0.642	0.111	0.766	1.645	0.517
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.25$	0.561	0.09	0.741	1.93	0.44
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.15$	0.453	0.075	0.726	2.208	0.328
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 1, f^{\mathrm{C,B,F}} = 0.45$	0.665	0.12	0.789	1.585	0.564
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 1, f^{\mathrm{C,B,F}} = 0.35$	0.483	0.062	0.762	2.117	0.396
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 1, f^{\mathrm{C,B,F}} = 0.25$	0.291	0.051	0.775	2.606	0.217
$\mathrm{B_L} = 0.1, \mathrm{B_T} = 0.9, f^{\mathrm{C}} = 0.45$	0.816	0.158	0.709	1.074	0.742
$\mathrm{B_L} = 0.1, \mathrm{B_T} = 0.9, f^{\mathrm{C}} = 0.35$	0.747	0.12	0.658	1.406	0.637
$\mathrm{B_L} = 0.1, \mathrm{B_T} = 0.9, f^{\mathrm{C}} = 0.15$	0.659	0.098	0.621	1.704	0.518
$\mathrm{B_L} = 0.1, \mathrm{B_T} = 0.9, f^{\mathrm{C}} = 0.15$	0.541	0.084	0.603	2.03	0.376
$\mathrm{B_L} = 0.2, \mathrm{B_T} = 0.8, f^{\mathrm{C,B,F}} = 0.45$	0.735	0.133	0.752	1.384	0.646
$\mathrm{B_L} = 0.2, \mathrm{B_T} = 0.8, f^{\mathrm{C,B,F}} = 0.35$	0.551	0.074	0.72	1.988	0.425
$\mathrm{B_L} = 0.2, \mathrm{B_T} = 0.8, f^{\mathrm{C,B,F}} = 0.25$	0.352	0.052	0.726	2.482	0.243
$\mathrm{B_L} = 0.2, \mathrm{B_T} = 0.8, f^{\mathrm{C}} = 0.45$	0.774	0.162	0.762	1.148	0.698
$\mathrm{B_L} = 0.2, \mathrm{B_T} = 0.8, f^{\mathrm{C}} = 0.35$	0.711	0.12	0.721	1.465	0.61
$\mathrm{B_L} = 0.2, \mathrm{B_T} = 0.8, f^{\mathrm{C}} = 0.25$	0.623	0.097	0.68	1.778	0.487
$\mathrm{B_L} = 0.2, \mathrm{B_T} = 0.8, f^{\mathrm{C}} = 0.15$	0.51	0.08	0.653	2.096	0.36
$\mathrm{B_L} = 0.1, \mathrm{B_T} = 0.9, f^{\mathrm{C,B,F}} = 0.45$	0.782	0.132	0.691	1.287	0.699
$\mathrm{B_L} = 0.1, \mathrm{B_T} = 0.9, f^{\mathrm{C,B,F}} = 0.35$	0.595	0.075	0.645	1.901	0.454
$\mathrm{B_L} = 0.1, \mathrm{B_T} = 0.9, f^{\mathrm{C,B,F}} = 0.15$	0.382	0.053	0.662	2.418	0.261

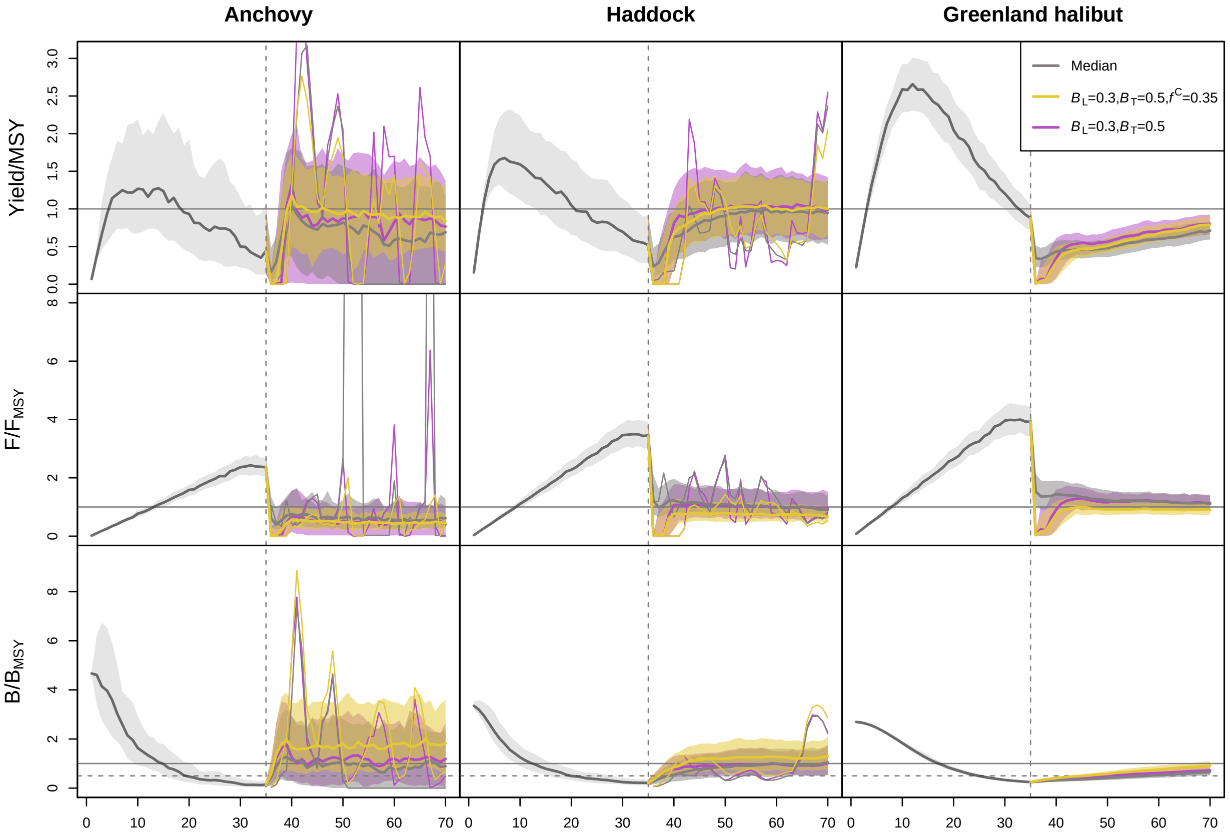

Figure B17: Trajectories of median yield (upper row), fishing mortality (middle row) and biomass (bottom row) relative to reference points for the three stocks anchovy, haddock, and Greenland halibut and selected HCRs. Shaded areas include 60% of the distribution over converged replicates. Dashed vertical lines represent start of management (year 35) and dashed horizontal line in bottom row represents B_{lim} ($0.5B_{\text{MSY}}$).

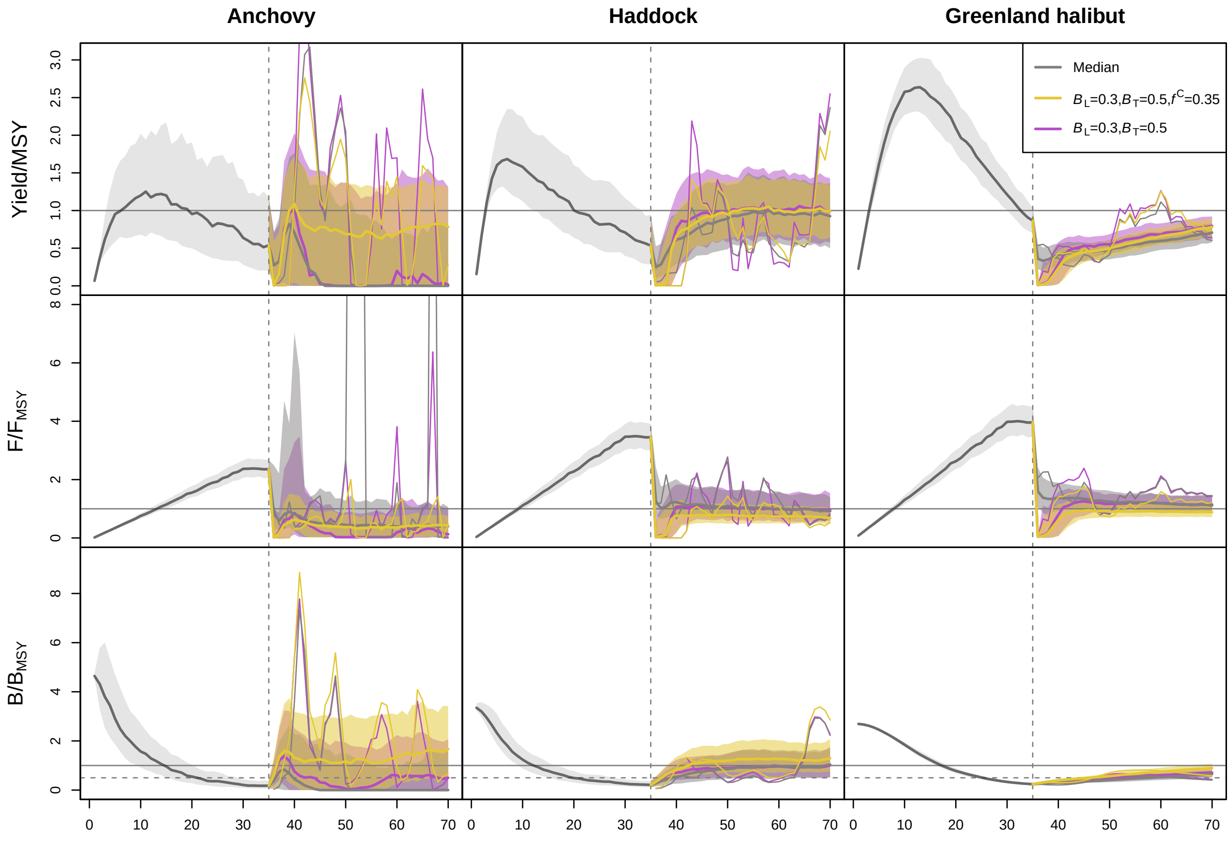

Figure B18: Trajectories of median yield (upper row), fishing mortality (middle row) and biomass (bottom row) relative to reference points for the three stocks anchovy, haddock, and Greenland halibut and selected HCRs. Shaded areas include 60% of the distribution over all (converged + non-converged) replicates. Dashed vertical lines represent start of management (year 35) and dashed horizontal line in bottom row represents B_{lim} ($0.5B_{\text{MSY}}$).

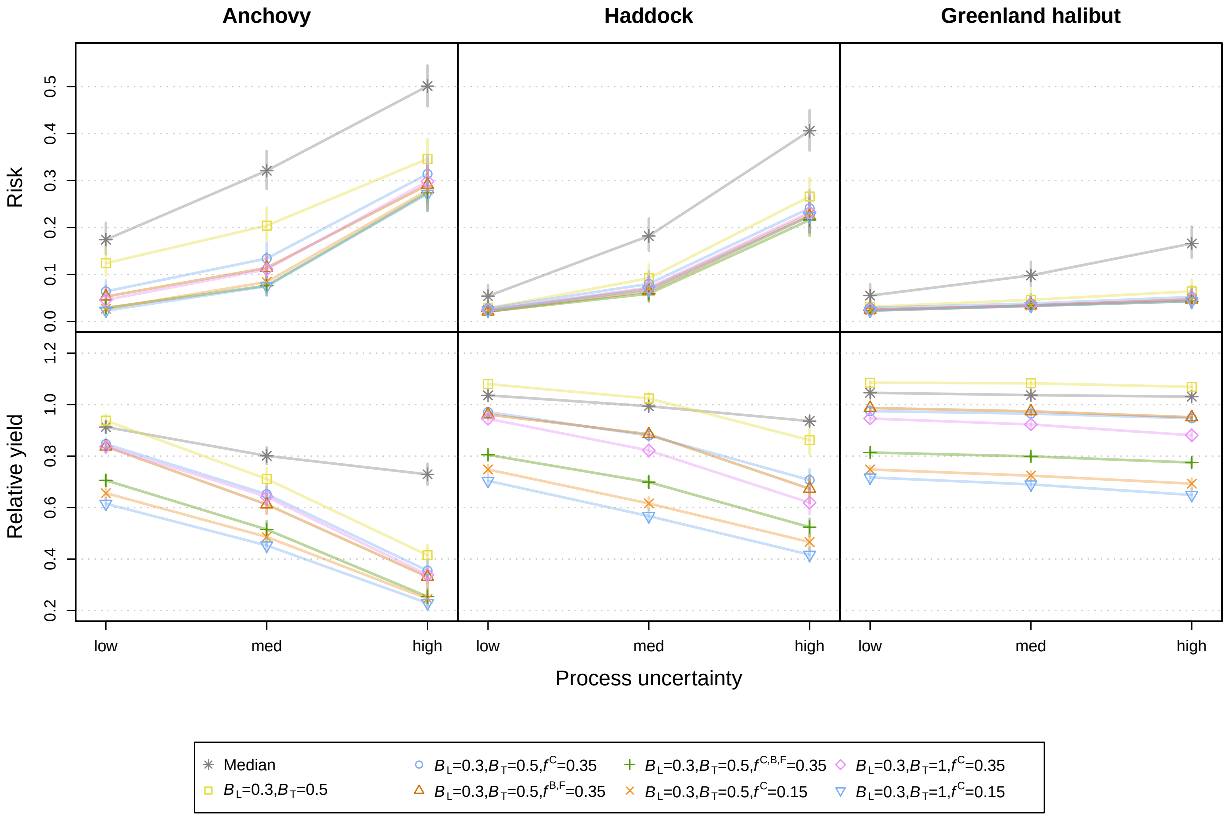

Figure B19: Risk (upper row) and relative yield (lower row) for the three stocks (columns) and various HCRs (colours). Low and high process noise levels assume a recruitment deviations of 50% and 150% of the default stock-specific levels (med), respectively. Vertical lines represent the 95% confidence intervals.

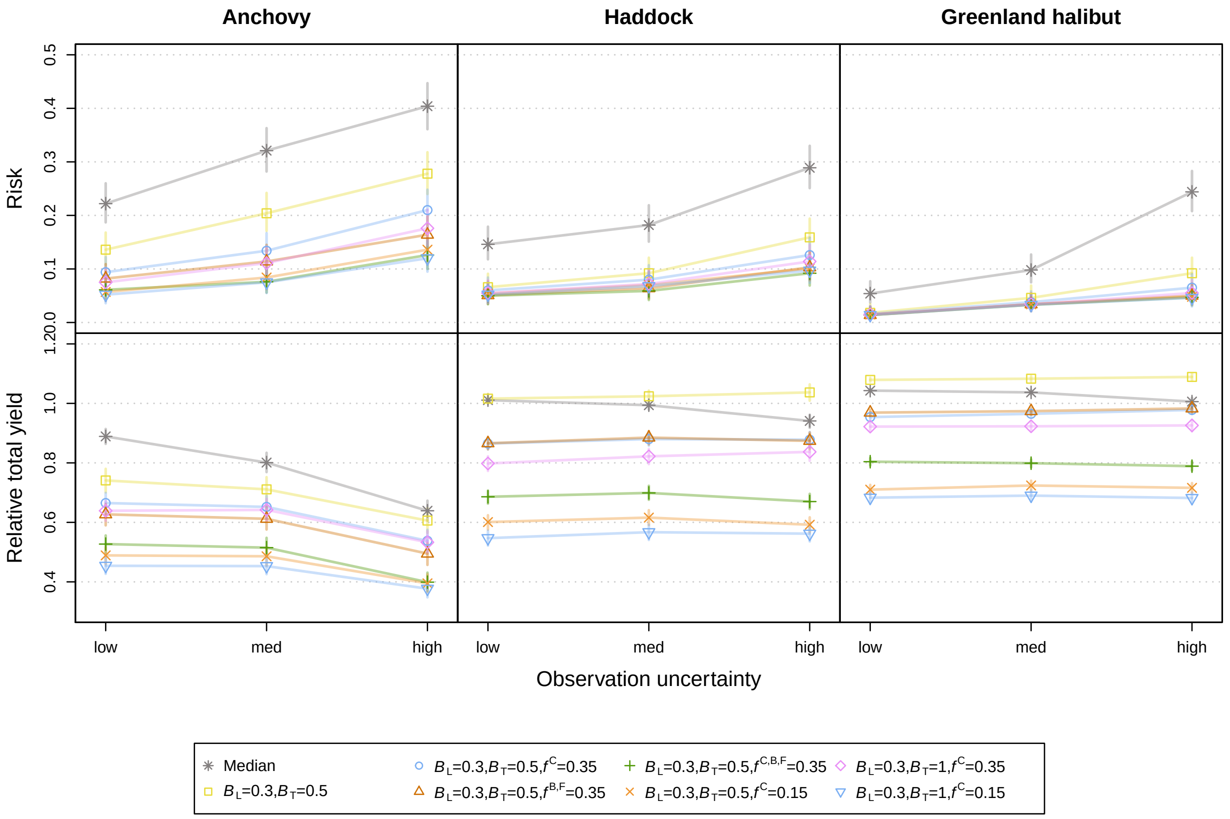

Figure B20: Risk (upper row) and relative yield (lower row) for the three stocks (columns) and various HCRs (colours). Low, med, and high observation noise levels assume a SD of $0.15, 0.3, 0.6$, respectively. Vertical lines represent the 95% confidence intervals.

Table B7: Performance metrics per HCR for Haddock.

HCR	Rel. yield	Risk	AAV	B/Bmsy	F/Fmsy
$\mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.45$	0.998	0.103	0.376	0.854	0.97
$\mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.35$	0.948	0.096	0.344	0.936	0.843
$\mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.25$	0.879	0.087	0.319	1.033	0.722
$\mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.15$	0.778	0.078	0.3	1.169	0.567
$\mathrm{B_T} = 0.5, f^{\mathrm{B,F}} = 0.45$	0.998	0.1	0.376	0.868	0.967
$\mathrm{B_T} = 0.5, f^{\mathrm{B,F}} = 0.35$	0.943	0.077	0.353	0.987	0.827
$\mathrm{B_T} = 0.5, f^{\mathrm{B,F}} = 0.25$	0.854	0.064	0.338	1.118	0.685
$\mathrm{B_T} = 0.5, f^{\mathrm{B,F}} = 0.15$	0.718	0.06	0.326	1.304	0.519
$\mathrm{B_T} = 0.5, f^{\mathrm{C,B,F}} = 0.45$	0.975	0.096	0.36	0.908	0.906
$\mathrm{B_T} = 0.5, f^{\mathrm{C,B,F}} = 0.35$	0.84	0.067	0.32	1.117	0.663
$\mathrm{B_T} = 0.5, f^{\mathrm{C,B,F}} = 0.25$	0.633	0.06	0.305	1.386	0.418
$\mathrm{B_T} = 1, f^{\mathrm{C}} = 0.45$	0.935	0.081	0.405	0.964	0.853
$\mathrm{B_T} = 1, f^{\mathrm{C}} = 0.35$	0.881	0.077	0.382	1.05	0.768
$\mathrm{B_T} = 1, f^{\mathrm{C}} = 0.25$	0.805	0.074	0.36	1.136	0.653
$\mathrm{B_T} = 1, f^{\mathrm{C}} = 0.15$	0.7	0.07	0.338	1.257	0.515
$\mathrm{B_T} = 1, f^{\mathrm{C,B,F}} = 0.45$	0.905	0.074	0.393	1.022	0.798
$\mathrm{B_T} = 1, f^{\mathrm{C,B,F}} = 0.35$	0.749	0.062	0.361	1.246	0.601
$\mathrm{B_T} = 1, f^{\mathrm{C,B,F}} = 0.25$	0.537	0.059	0.345	1.51	0.368
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.45$	0.942	0.083	0.519	0.971	0.975
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.35$	0.814	0.076	0.45	1.139	0.743
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.25$	0.682	0.07	0.397	1.296	0.537
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{B,F}} = 0.45$	0.959	0.074	0.525	0.974	1.021
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{B,F}} = 0.35$	0.824	0.063	0.469	1.149	0.786
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{B,F}} = 0.25$	0.655	0.057	0.463	1.355	0.558
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{C,B,F}} = 0.45$	0.892	0.069	0.476	1.055	0.887
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{C,B,F}} = 0.35$	0.618	0.059	0.409	1.369	0.478
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{C,B,F}} = 0.25$	0.359	0.058	0.424	1.681	0.226
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.45$	0.917	0.076	0.502	1.007	0.85
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.35$	0.822	0.072	0.447	1.117	0.718
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.25$	0.706	0.069	0.4	1.267	0.547
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.15$	0.567	0.068	0.367	1.413	0.381
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 1, f^{\mathrm{C,B,F}} = 0.45$	0.871	0.068	0.471	1.067	0.779
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 1, f^{\mathrm{C,B,F}} = 0.35$	0.637	0.059	0.405	1.353	0.484
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 1, f^{\mathrm{C,B,F}} = 0.25$	0.388	0.058	0.396	1.633	0.237
$\mathrm{B_L} = 0.1, \mathrm{B_T} = 0.9, f^{\mathrm{C}} = 0.45$	0.951	0.08	0.429	0.957	0.887
$\mathrm{B_L} = 0.1, \mathrm{B_T} = 0.9, f^{\mathrm{C}} = 0.35$	0.882	0.076	0.393	1.046	0.759
$\mathrm{B_L} = 0.1, \mathrm{B_T} = 0.9, f^{\mathrm{C}} = 0.15$	0.791	0.073	0.362	1.159	0.632
$\mathrm{B_L} = 0.1, \mathrm{B_T} = 0.9, f^{\mathrm{C}} = 0.15$	0.671	0.069	0.338	1.289	0.486
$\mathrm{B_L} = 0.2, \mathrm{B_T} = 0.8, f^{\mathrm{C,B,F}} = 0.45$	0.921	0.071	0.435	1.003	0.829
$\mathrm{B_L} = 0.2, \mathrm{B_T} = 0.8, f^{\mathrm{C,B,F}} = 0.35$	0.704	0.06	0.371	1.289	0.536
$\mathrm{B_L} = 0.2, \mathrm{B_T} = 0.8, f^{\mathrm{C,B,F}} = 0.25$	0.452	0.058	0.356	1.582	0.277
$\mathrm{B_L} = 0.2, \mathrm{B_T} = 0.8, f^{\mathrm{C}} = 0.45$	0.962	0.08	0.458	0.949	0.893
$\mathrm{B_L} = 0.2, \mathrm{B_T} = 0.8, f^{\mathrm{C}} = 0.35$	0.877	0.074	0.406	1.053	0.759
$\mathrm{B_L} = 0.2, \mathrm{B_T} = 0.8, f^{\mathrm{C}} = 0.25$	0.768	0.071	0.366	1.188	0.596
$\mathrm{B_L} = 0.2, \mathrm{B_T} = 0.8, f^{\mathrm{C}} = 0.15$	0.634	0.068	0.338	1.323	0.436
$\mathrm{B_L} = 0.1, \mathrm{B_T} = 0.9, f^{\mathrm{C,B,F}} = 0.45$	0.914	0.072	0.413	1.014	0.818
$\mathrm{B_L} = 0.1, \mathrm{B_T} = 0.9, f^{\mathrm{C,B,F}} = 0.35$	0.729	0.061	0.366	1.258	0.572
$\mathrm{B_L} = 0.1, \mathrm{B_T} = 0.9, f^{\mathrm{C,B,F}} = 0.15$	0.495	0.058	0.351	1.547	0.318

Table B8: Performance metrics per HCR for Greenland halibut.

HCR	Rel. yield	Risk	AAV	B/Bmsy	F/Fmsy
$\mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.45$	1.042	0.05	0.126	0.638	1.091
$\mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.35$	1	0.044	0.117	0.707	0.975
$\mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.25$	0.944	0.041	0.109	0.782	0.858
$\mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.15$	0.861	0.038	0.101	0.88	0.721
$\mathrm{B_T} = 0.5, f^{\mathrm{B,F}} = 0.45$	1.042	0.043	0.13	0.65	1.094
$\mathrm{B_T} = 0.5, f^{\mathrm{B,F}} = 0.35$	0.988	0.037	0.125	0.737	0.946
$\mathrm{B_T} = 0.5, f^{\mathrm{B,F}} = 0.25$	0.906	0.033	0.118	0.845	0.805
$\mathrm{B_T} = 0.5, f^{\mathrm{B,F}} = 0.15$	0.782	0.032	0.113	0.988	0.642
$\mathrm{B_T} = 0.5, f^{\mathrm{C,B,F}} = 0.45$	1.02	0.042	0.124	0.684	1.024
$\mathrm{B_T} = 0.5, f^{\mathrm{C,B,F}} = 0.35$	0.894	0.035	0.112	0.851	0.786
$\mathrm{B_T} = 0.5, f^{\mathrm{C,B,F}} = 0.25$	0.706	0.032	0.104	1.056	0.547
$\mathrm{B_T} = 1, f^{\mathrm{C}} = 0.45$	0.982	0.04	0.124	0.76	1.012
$\mathrm{B_T} = 1, f^{\mathrm{C}} = 0.35$	0.944	0.037	0.117	0.807	0.946
$\mathrm{B_T} = 1, f^{\mathrm{C}} = 0.25$	0.888	0.037	0.108	0.872	0.834
$\mathrm{B_T} = 1, f^{\mathrm{C}} = 0.15$	0.799	0.034	0.1	0.964	0.691
$\mathrm{B_T} = 1, f^{\mathrm{C,B,F}} = 0.45$	0.956	0.037	0.123	0.795	0.961
$\mathrm{B_T} = 1, f^{\mathrm{C,B,F}} = 0.35$	0.819	0.032	0.113	0.958	0.748
$\mathrm{B_T} = 1, f^{\mathrm{C,B,F}} = 0.25$	0.619	0.031	0.107	1.143	0.501
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.45$	1.062	0.044	0.138	0.683	1.099
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.35$	0.948	0.036	0.117	0.818	0.882
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.25$	0.807	0.036	0.107	0.965	0.673
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{B,F}} = 0.45$	1.073	0.04	0.142	0.681	1.124
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{B,F}} = 0.35$	0.973	0.034	0.121	0.802	0.928
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{B,F}} = 0.25$	0.834	0.032	0.111	0.948	0.733
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{C,B,F}} = 0.45$	1.02	0.036	0.125	0.74	1.01
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{C,B,F}} = 0.35$	0.768	0.032	0.106	1.015	0.631
$\mathrm{B_L} = 0.5, \mathrm{B_T} = 0.5, f^{\mathrm{C,B,F}} = 0.25$	0.498	0.031	0.105	1.269	0.357
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.45$	0.993	0.038	0.137	0.78	1.029
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.35$	0.923	0.034	0.12	0.855	0.905
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.25$	0.822	0.035	0.106	0.949	0.743
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 0.5, f^{\mathrm{C}} = 0.15$	0.69	0.033	0.099	1.077	0.56
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 1, f^{\mathrm{C,B,F}} = 0.45$	0.96	0.035	0.13	0.817	0.974
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 1, f^{\mathrm{C,B,F}} = 0.35$	0.753	0.032	0.109	1.029	0.676
$\mathrm{B_L} = 0.3, \mathrm{B_T} = 1, f^{\mathrm{C,B,F}} = 0.25$	0.506	0.031	0.107	1.249	0.394
$\mathrm{B_L} = 0.1, \mathrm{B_T} = 0.9, f^{\mathrm{C}} = 0.45$	1.006	0.04	0.129	0.74	1.046
$\mathrm{B_L} = 0.1, \mathrm{B_T} = 0.9, f^{\mathrm{C}} = 0.35$	0.959	0.037	0.117	0.794	0.946
$\mathrm{B_L} = 0.1, \mathrm{B_T} = 0.9, f^{\mathrm{C}} = 0.15$	0.89	0.036	0.107	0.871	0.813
$\mathrm{B_L} = 0.1, \mathrm{B_T} = 0.9, f^{\mathrm{C}} = 0.15$	0.787	0.034	0.098	0.973	0.658
$\mathrm{B_L} = 0.2, \mathrm{B_T} = 0.8, f^{\mathrm{C,B,F}} = 0.45$	0.996	0.036	0.126	0.767	0.997
$\mathrm{B_L} = 0.2, \mathrm{B_T} = 0.8, f^{\mathrm{C,B,F}} = 0.35$	0.805	0.031	0.105	0.961	0.696
$\mathrm{B_L} = 0.2, \mathrm{B_T} = 0.8, f^{\mathrm{C,B,F}} = 0.25$	0.559	0.03	0.101	1.202	0.419
$\mathrm{B_L} = 0.2, \mathrm{B_T} = 0.8, f^{\mathrm{C}} = 0.45$	1.027	0.04	0.132	0.724	1.07
$\mathrm{B_L} = 0.2, \mathrm{B_T} = 0.8, f^{\mathrm{C}} = 0.35$	0.961	0.037	0.115	0.795	0.917
$\mathrm{B_L} = 0.2, \mathrm{B_T} = 0.8, f^{\mathrm{C}} = 0.25$	0.874	0.035	0.103	0.886	0.776
$\mathrm{B_L} = 0.2, \mathrm{B_T} = 0.8, f^{\mathrm{C}} = 0.15$	0.755	0.034	0.095	1.012	0.616
$\mathrm{B_L} = 0.1, \mathrm{B_T} = 0.9, f^{\mathrm{C,B,F}} = 0.45$	0.979	0.037	0.126	0.782	0.985
$\mathrm{B_L} = 0.1, \mathrm{B_T} = 0.9, f^{\mathrm{C,B,F}} = 0.35$	0.82	0.032	0.11	0.957	0.735
$\mathrm{B_L} = 0.1, \mathrm{B_T} = 0.9, f^{\mathrm{C,B,F}} = 0.15$	0.597	0.03	0.103	1.158	0.472

Sensitivity results

Table B9: Percentage of converged assessments for selected HCRs during stock-specific periods of 4, 8, and 27 years after start of the managment for anchovy, haddock, and Greenland halibut respectively and the sensitivity scenarios.

Species	HCR	Baseline	dt=1/8	F_y	TAC_{y-1}	Impl. SD=0.15	Schaefer	No priors	20 yr	Effort
Anchovy	Median	95	92	94	92	96	90	81	58	72
Anchovy	$B_L = 0.3, B_T = 0.5$	96	95	96	94	97	90	71	60	67
Anchovy	$B_L = 0.3, B_T = 0.5, f^C = 0.35$	97	97	97	95	97	91	71	61	67
Haddock	Median	98	96	98	96	98	93	60	73	64
Haddock	$B_L = 0.3, B_T = 0.5$	97	96	97	96	98	92	46	71	59
Haddock	$B_L = 0.3, B_T = 0.5, f^C = 0.35$	97	96	97	96	98	92	45	71	60
Greenland halibut	Median	98	98	98	97	98	97	23	85	24
Greenland halibut	$B_L = 0.3, B_T = 0.5$	97	97	97	95	97	94	19	83	22
Greenland halibut	$B_L = 0.3, B_T = 0.5, f^C = 0.35$	97	97	97	96	97	95	20	85	22

Table B10: Median bias [%] in B/B_{MSY} and F/F_{MSY} for fishing at F_{MSY} over stock-specific periods of 4, 8, and 27 years after start of the management for anchovy, haddock, and Greenland halibut, respectively and the sensitivity scenarios.

Quantity	Species	Baseline	dt=1/8	F_y	TAC_{y-1}	Impl. SD=0.15	Schaefer	No priors	20 yr	Effort
B/B_{MSY}	Anchovy	-34	-32	-28	-27	-34	-36	-36	-47	-35
B/B_{MSY}	Haddock	-26	-29	-21	-21	-28	-27	-23	28	-24
B/B_{MSY}	Greenland halibut	10	7	13	13	7	22	-24	98	-20
F/F_{MSY}	Anchovy	19	20	18	19	25	23	22	16	0
F/F_{MSY}	Haddock	-6	-4	-5	-5	-6	-4	-13	-39	-16
F/F_{MSY}	Greenland halibut	-17	-15	-16	-16	-16	-22	-37	-42	-41

Table B11: Median standard deviation of predicted catch (C_{y+1}), B/B_{MSY} and F/F_{MSY} estimated with SPiCT calculated for all (converged + non-converged) replicates for fishing at F_{MSY} HCR over stock-specific periods of 4, 8, and 27 years after start of the management for anchovy, haddock, and Greenland halibut, respectively and the sensitivity scenarios.

Species	Quantity	Baseline	dt=1/8	F_y	TAC_{y-1}	Impl. SD=0.15	Schaefer	No priors	20 yr	Effort
Anchovy	C_{y+1}	0.58	0.57	0.79	0.77	0.58	0.59	0.6	0.61	0.71
Anchovy	B/B_{MSY}	0.9	0.89	1.1	1.08	0.9	0.96	0.99	2.02	1.28
Anchovy	F/F_{MSY}	0.61	0.59	0.79	0.78	0.61	0.65	0.66	0.97	0.6
Haddock	C_{y+1}	0.43	0.43	0.54	0.54	0.44	0.44	0.47	0.43	0.52
Haddock	B/B_{MSY}	0.61	0.61	0.77	0.77	0.6	0.66	0.69	1.16	0.83
Haddock	F/F_{MSY}	0.53	0.52	0.67	0.67	0.53	0.56	0.58	0.78	0.56
Greenland halibut	C_{y+1}	0.38	0.38	0.49	0.48	0.38	0.38	0.62	0.37	0.46
Greenland halibut	B/B_{MSY}	0.45	0.45	0.48	0.48	0.45	0.8	0.91	0.81	0.72
Greenland halibut	F/F_{MSY}	0.5	0.49	0.61	0.61	0.5	0.71	0.8	0.68	0.51

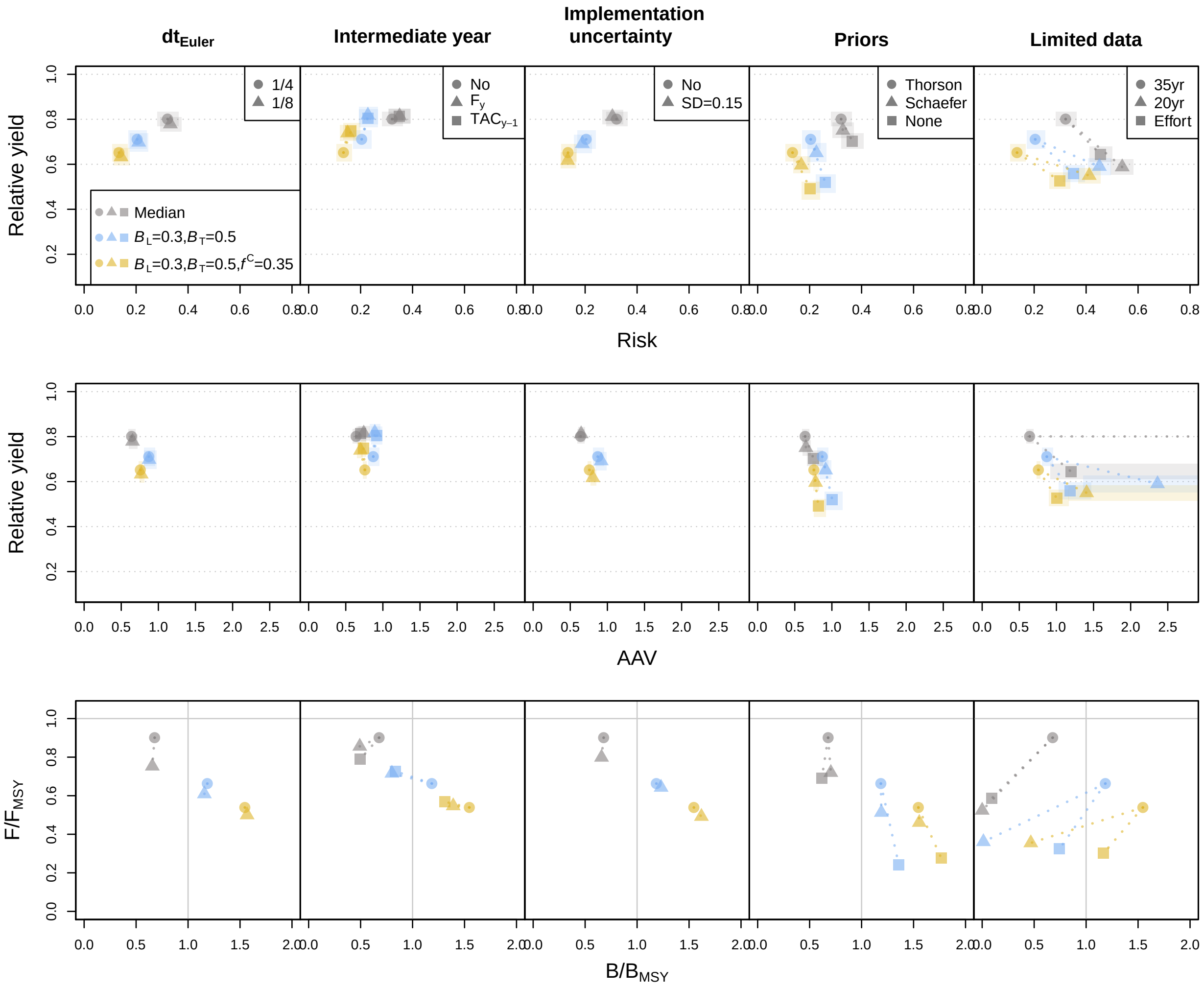

Figure B21: Trade-off graphs of risk and relative yield (upper row) and absolute interannual variability in yield (AAV) and relative yield (middle row) as well as Kobe plots (B/B_{MSY} vs F/F_{MSY}; lower row) for the **sensitivity scenarios** (columns) and **anchovy**. The colours represent three different HCRs, while the shape of the symbols refer to scenarios with various assumptions defined in the legend in the upper right corner for each column. The shaded areas around the symbols in the upper and middle row represent the 95% confidence intervals of the respective metrics.

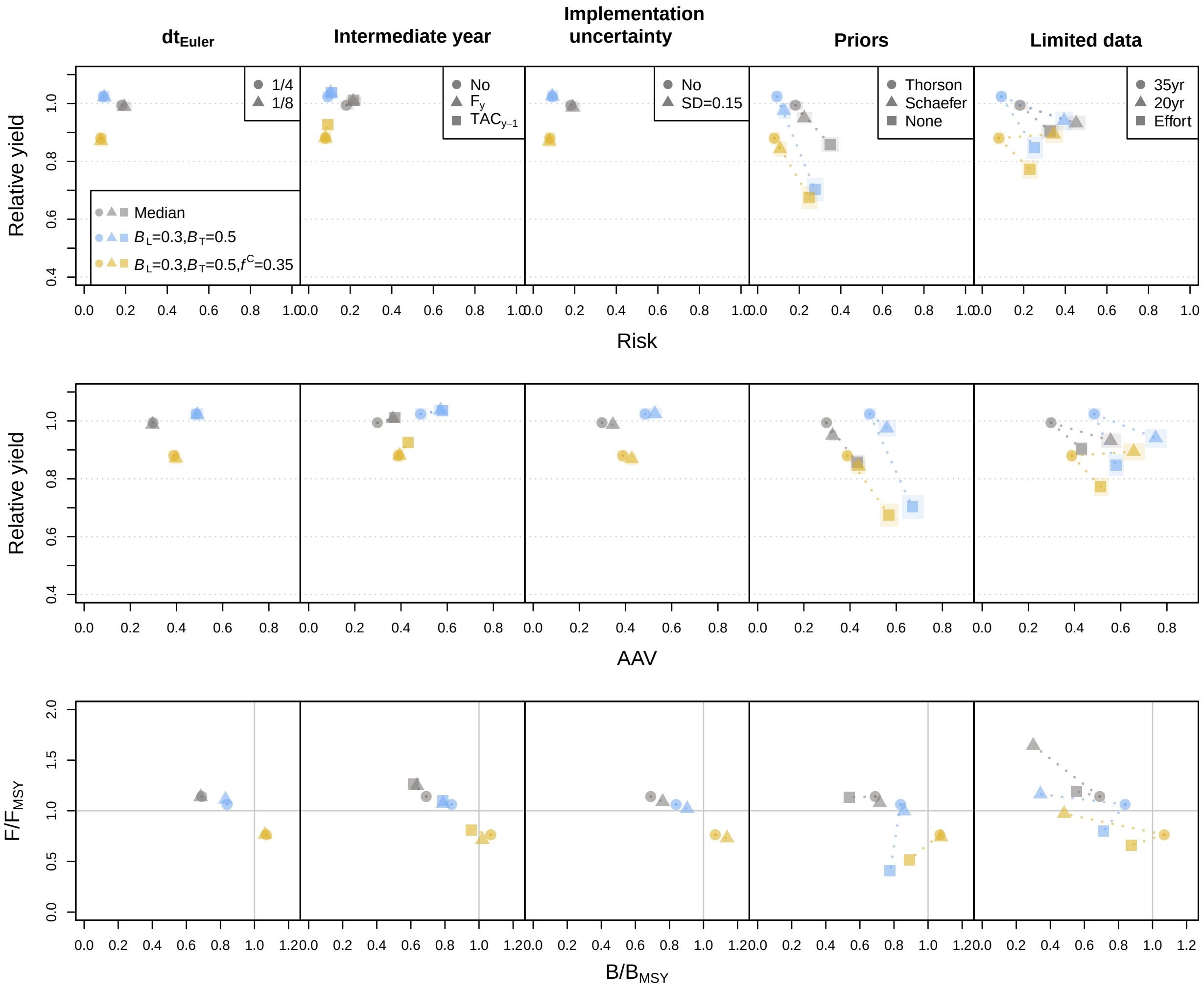

Figure B22: Trade-off graphs of risk and relative yield (upper row) and absolute interannual variability in yield (AAV) and relative yield (middle row) as well as Kobe plots (B/B_{MSY} vs F/F_{MSY}; lower row) for the **sensitivity scenarios** (columns) and **haddock**. The colours represent three different HCRs, while the shape of the symbols refer to scenarios with various assumptions defined in the legend in the upper right corner for each column. The shaded areas around the symbols in the upper and middle row represent the 95% confidence intervals of the respective metrics.

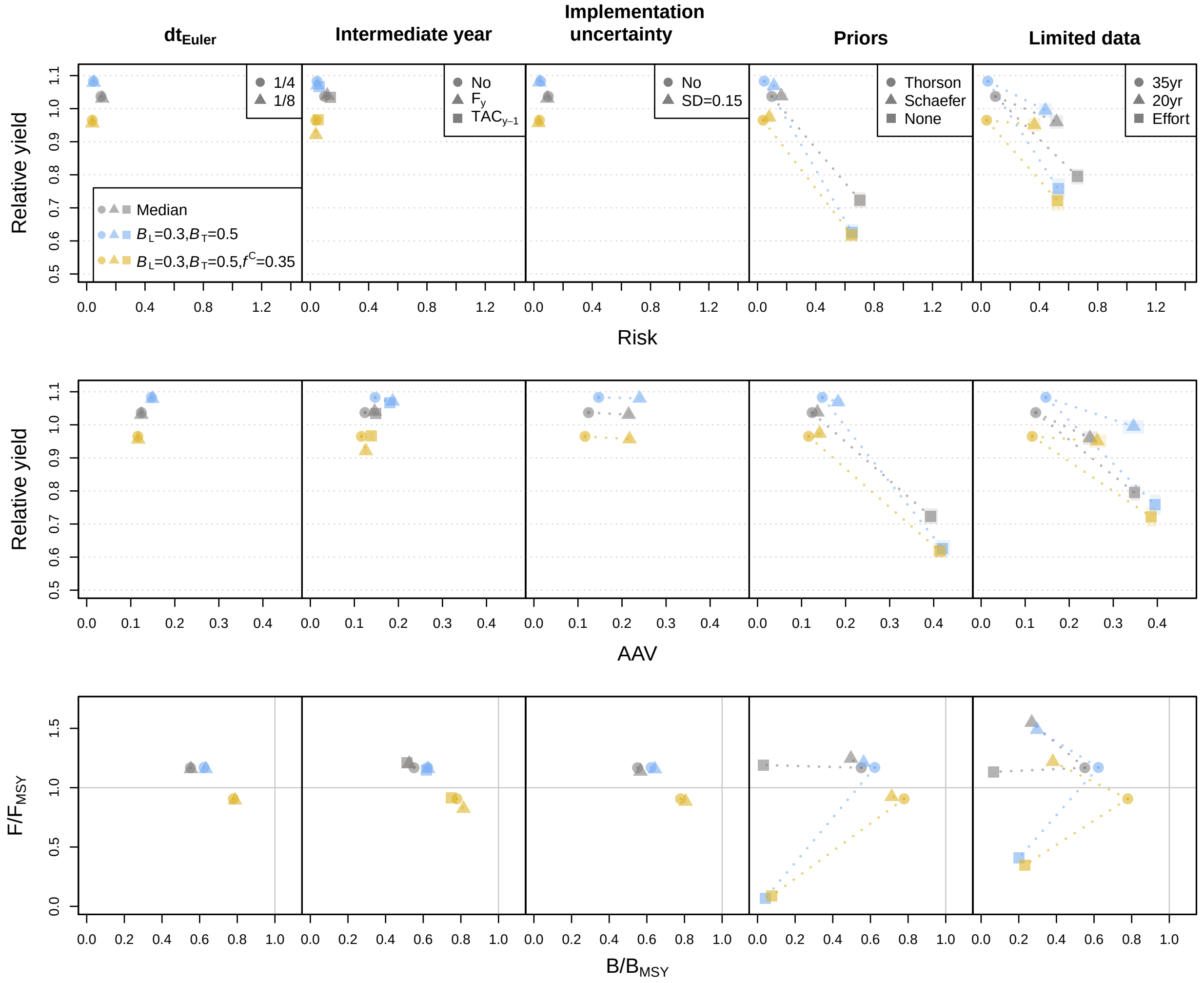

Figure B23: Trade-off graphs of risk and relative yield (upper row) and absolute interannual variability in yield (AAV) and relative yield (middle row) as well as Kobe plots (B/B_{MSY} vs F/F_{MSY}; lower row) for the **sensitivity scenarios** (columns) and **Greenland halibut**. The colours represent three different HCRs, while the shape of the symbols refer to scenarios with various assumptions defined in the legend in the upper right corner for each column. The shaded areas around the symbols in the upper and middle row represent the 95% confidence intervals of the respective metrics.

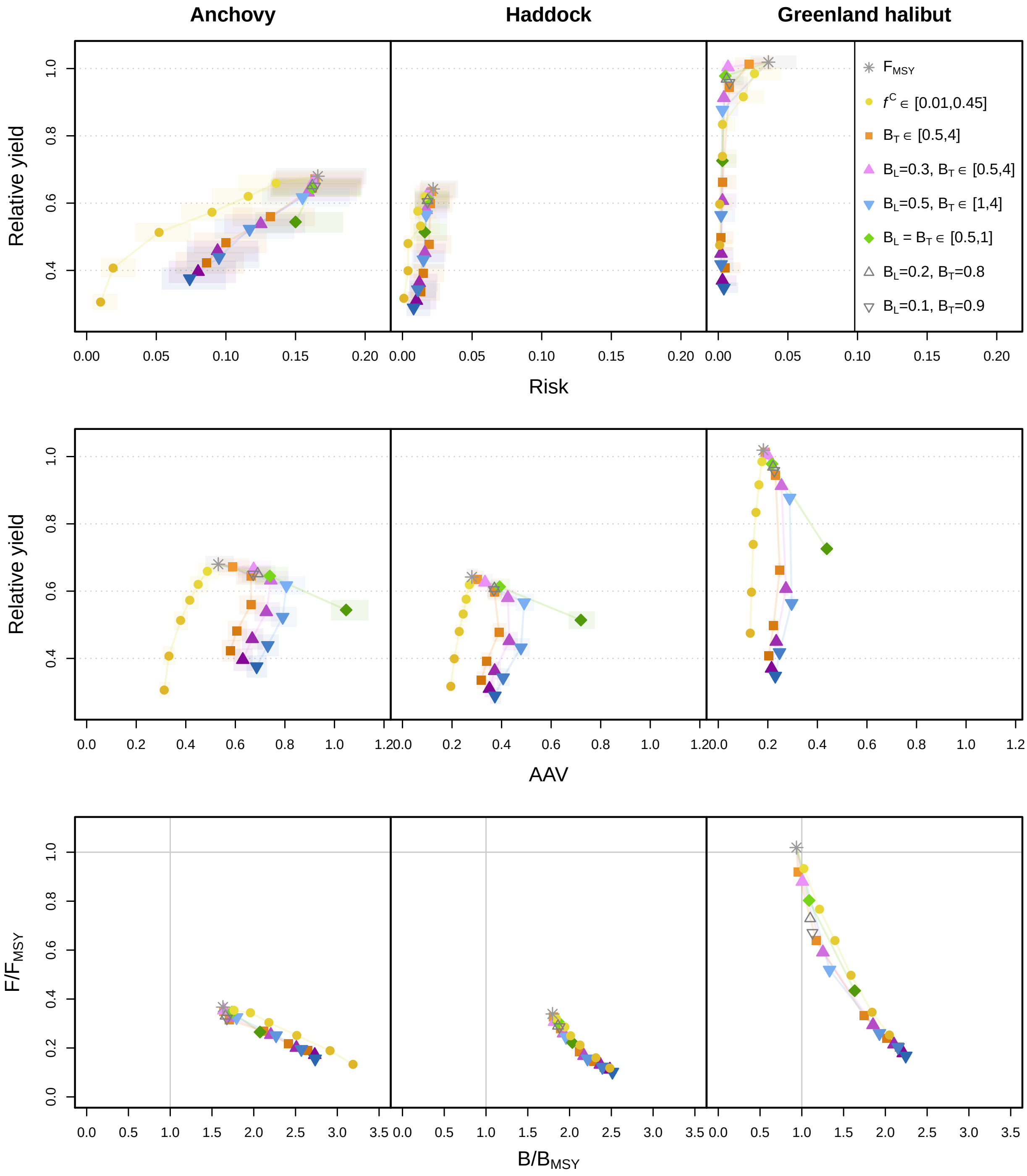

Figure B24: Trade-off graphs of risk and relative yield (upper row) and absolute interannual variability in yield (AAV) and relative yield (middle row) as well as Kobe plots (B/B_{MSY} vs F/F_{MSY}; lower row) for anchovy, haddock, and Greenland halibut (columns) and under-exploited conditions. Starting from the grey star symbol (fishing at F/F_{MSY}), the lines connect following HCRs with increasing uncertainty buffers (decreasing fractile): $f^{\mathrm{C}} = \{0.45, 0.35, 0.25, 0.15, 0.05, 0.01\}$ (yellow circles); and following HCRs with increasing biomass thresholds (and limits): $B_{\mathrm{T}} = \{0.5, 1, 2, 3, 4\}$ (orange squares); $B_{\mathrm{L}} = 0.3, B_{\mathrm{T}} = \{0.5, 1, 2, 3, 4\}$ (purple triangles); $B_{\mathrm{L}} = 0.5, B_{\mathrm{T}} = \{1, 2, 3, 4\}$ (blue triangles); $B_{\mathrm{L}} = \{0.5, 1\}, B_{\mathrm{T}} = \{0.5, 1\}$ (green diamonds). The open grey triangles show the additional rules $B_{\mathrm{L}} = 0.2, B_{\mathrm{T}} = 0.8$ and $B_{\mathrm{L}} = 0.1, B_{\mathrm{T}} = 0.9$. The shaded areas around the symbols in the upper and middle row represent the 95% confidence intervals of the respective metrics.

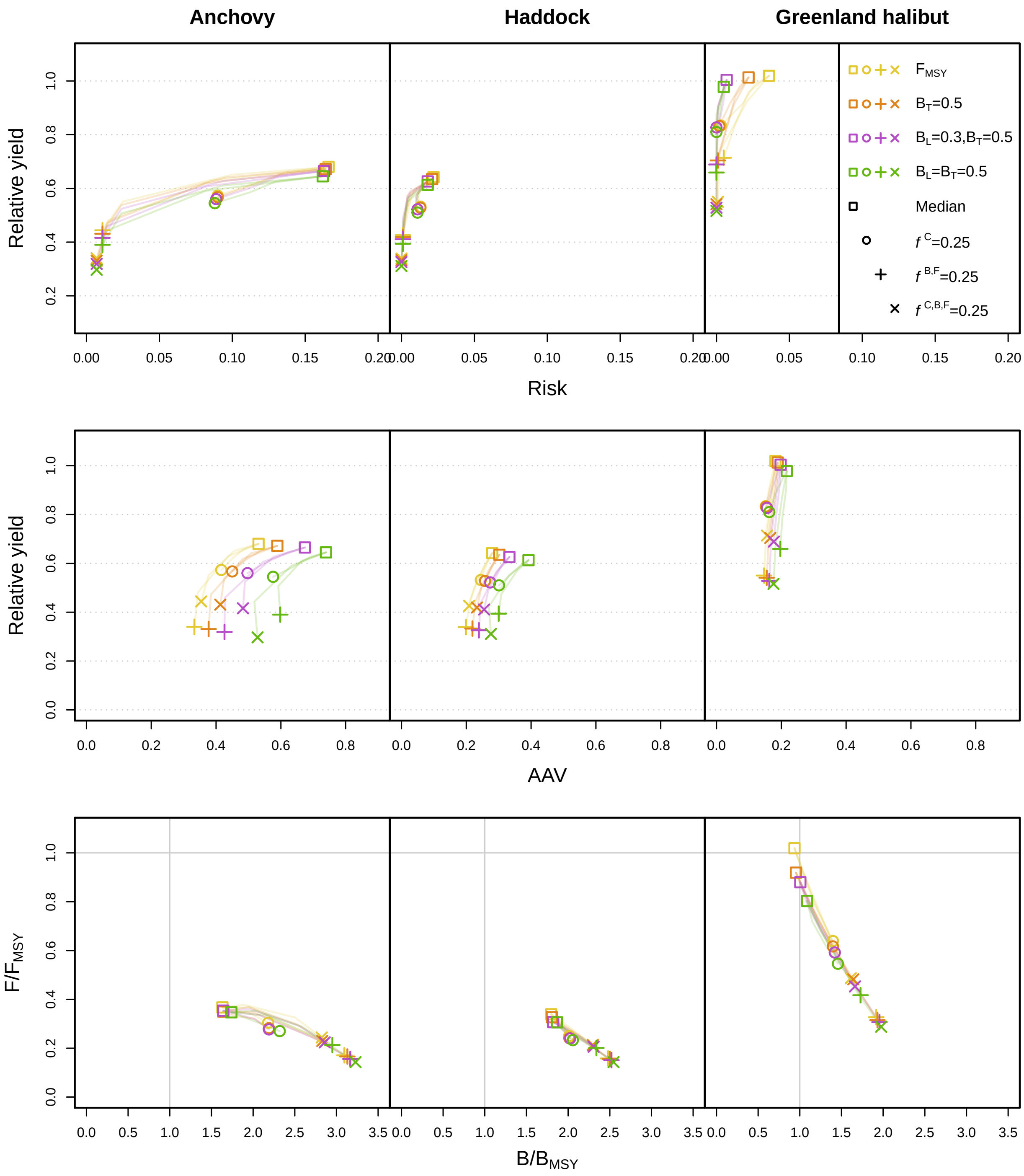

Figure B25: Trade-off between risk and relative yield (upper row) and absolute interannual variability in yield (AAV) and relative yield (middle row) as well as Kobe plots (B/B_{MSY} vs F/F_{MSY}; lower row) for anchovy, haddock, and Greenland halibut (columns) and under-exploited conditions. Colours represent included HCR types: F_{MSY}, $B_{\mathrm{T}} = 0.5$, $B_{\mathrm{L}} = 0.3, B_{\mathrm{T}} = 0.5$, $B_{\mathrm{L}} = B_{\mathrm{T}} = 0.5$. Symbols represent median (star symbol) of each HCR type as well as in combination with three fractile types: $f^{\mathrm{C}} = 0.25$ (circles), $f^{\mathrm{B,F}} = 0.25$ (plus symbol), and $f^{\mathrm{C,B,F}} = 0.25$ (x symbol). Lines connect median, $0.45, 0.35, and 0.25$ fractile for each HCR type.

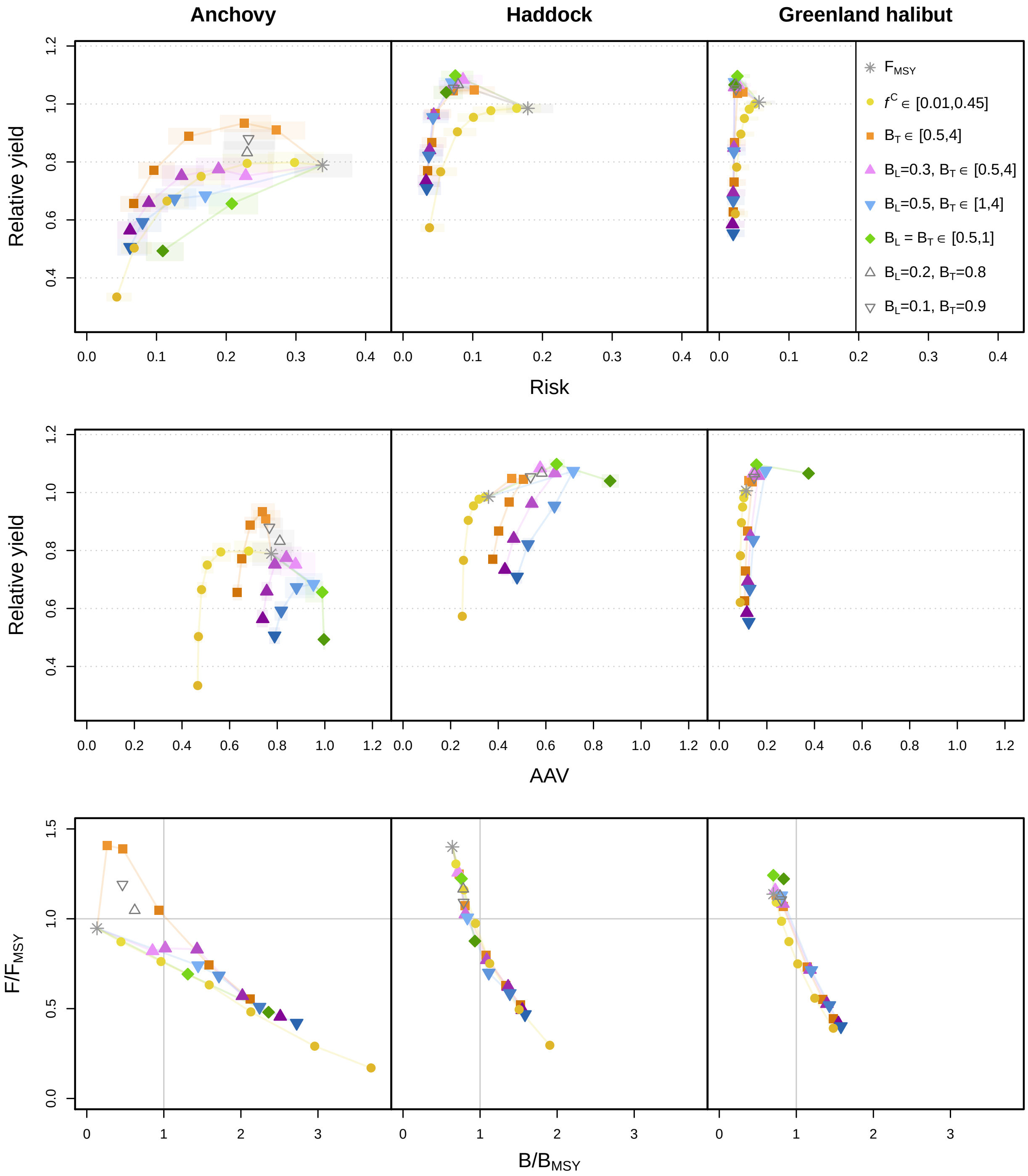

Figure B26: Trade-off graphs of risk and relative yield (upper row) and absolute interannual variability in yield (AAV) and relative yield (middle row) as well as Kobe plots (B/B_{MSY} vs F/F_{MSY}; lower row) for anchovy, haddock, and Greenland halibut (columns) and the alternative steepness parameterisation (h=0.9). Starting from the grey star symbol (fishing at F/F_{MSY}), the lines connect following HCRs with increasing uncertainty buffers (decreasing fractile): $f^{\mathrm{C}} = \{0.45, 0.35, 0.25, 0.15, 0.05, 0.01\}$ (yellow circles); and following HCRs with increasing biomass thresholds (and limits): $B_{\mathrm{T}} = \{0.5, 1, 2, 3, 4\}$ (orange squares); $B_{\mathrm{L}} = 0.3, B_{\mathrm{T}} = \{0.5, 1, 2, 3, 4\}$ (purple triangles); $B_{\mathrm{L}} = 0.5, B_{\mathrm{T}} = \{1, 2, 3, 4\}$ (blue triangles); $B_{\mathrm{L}} = \{0.5, 1\}, B_{\mathrm{T}} = \{0.5, 1\}$ (green diamonds). The open grey triangles show the additional rules $B_{\mathrm{L}} = 0.2, B_{\mathrm{T}} = 0.8$ and $B_{\mathrm{L}} = 0.1, B_{\mathrm{T}} = 0.9$. The shaded areas around the symbols in the upper and middle row represent the 95% confidence intervals of the respective metrics.

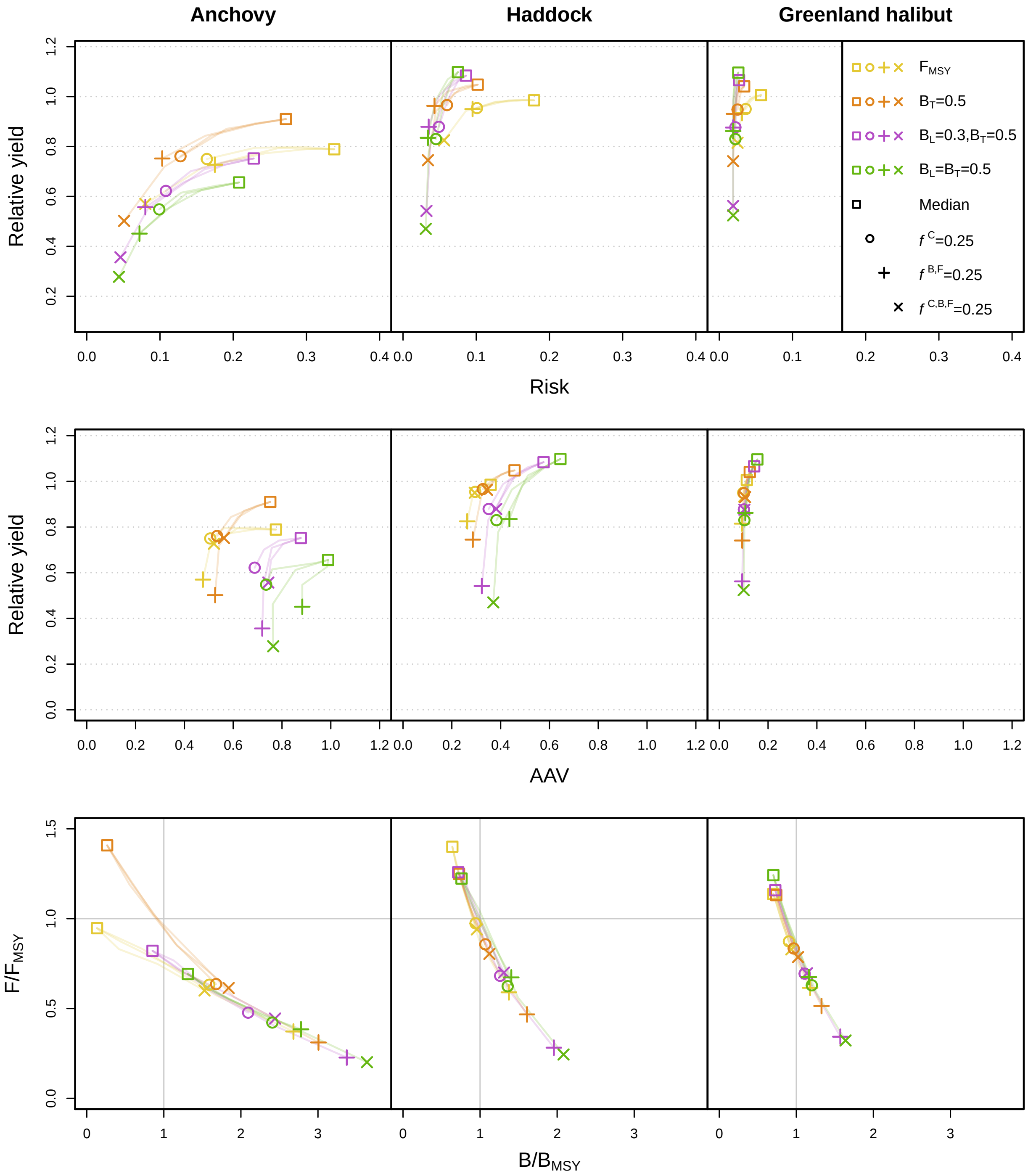

Figure B27: Trade-off between risk and relative yield (upper row) and absolute interannual variability in yield (AAV) and relative yield (middle row) as well as Kobe plots (B/B_{MSY} vs F/F_{MSY}; lower row) for anchovy, haddock, and Greenland halibut (columns) and the alternative steepness parameterisation (h=0.9). Colours represent included HCR types: F_{MSY}, $B_{\mathrm{T}} = 0.5$, $B_{\mathrm{L}} = 0.3, B_{\mathrm{T}} = 0.5$, $B_{\mathrm{L}} = B_{\mathrm{T}} = 0.5$. Symbols represent median (star symbol) of each HCR type as well as in combination with three fractile types: $f^{\mathrm{C}} = 0.25$ (circles), $f^{\mathrm{B,F}} = 0.25$ (plus symbol), and $f^{\mathrm{C,B,F}} = 0.25$ (x symbol). Lines connect median, $0.45, 0.35, and 0.25$ fractile for each HCR type.

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