Results of the Pacific Bluefin Tuna Management Strategy Evaluation

ISC Pacific Bluefin Tuna Working Group

Presented by Desiree Tommasi

Outline

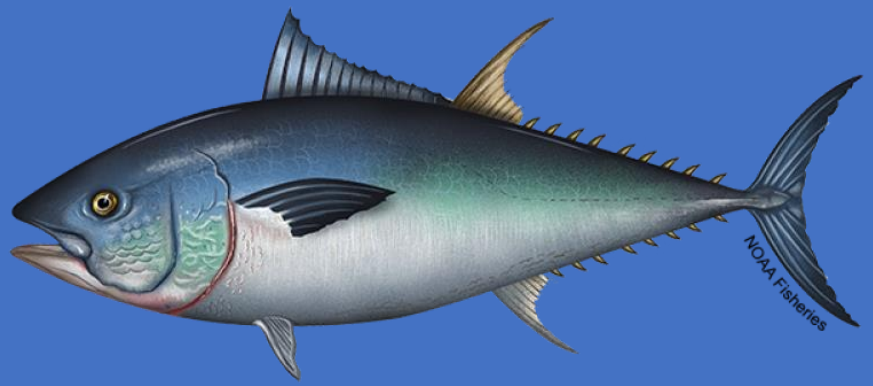
- Overview of Pacific bluefin tuna (PBF) management strategy evaluation (MSE)
- PBF MSE Results

Goal of Pacific Bluefin Tuna Management Strategy Evaluation (MSE)

Help inform development of a long-term management procedure for PBF now that the stock has rebuilt to the second rebuilding target of 20%$SSB_{F=0}$

What the Pacific Bluefin Tuna MSE does

Examines performance of candidate management procedures for PBF relative to the set of management objectives agreed-upon with stakeholders given uncertainty using a closed loop computer simulation

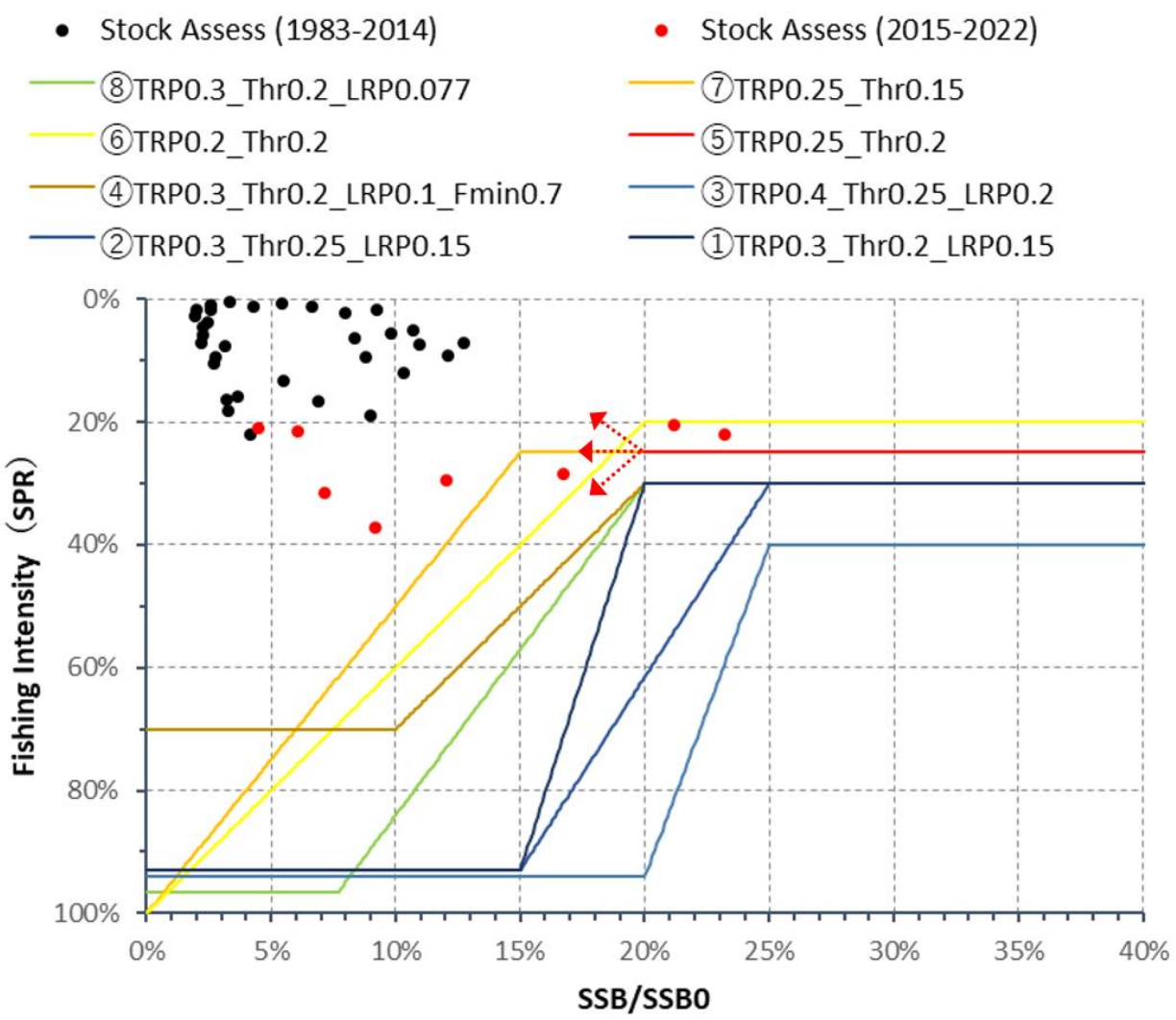


Management Procedure Overview

- Specify
  1. Harvest control rule (HCR) to be applied (see next slide)
  2. How stock status estimates will be calculated (here, via a stock assessment)
  3. How data will be monitored (same as for current assessment)
- The MPs in this MSE only differ in terms of the HCRs and associated control points used
- JWG decided to establish a TAC by fleet segment:
  - Eastern Pacific Ocean (EPO)
  - Western and Central Pacific Ocean (WCPO) small fish
  - WCPO large fish
- JWG agreed to limit TAC changes to 25% of previous TAC unless SSB below limit reference point (LRP)

Harvest Control Rules - HCRs

HCR number	F_{TARGET}	Control Point 1 (ThRP)	Control Point 2 (LRP)	Number of Control Points	F_{min}	WCPO: EPO Impact Ratio
1	FSPR30%	$20\%SSB_{F=0}$	$15\%SSB_{F=0}$	2	10% F_{TARGET}	80:20
2	FSPR30%	$25\%SSB_{F=0}$	$15\%SSB_{F=0}$	2	10% F_{TARGET}	80:20
3	FSPR40%	$25\%SSB_{F=0}$	$20\%SSB_{F=0}$	2	10% F_{TARGET}	80:20
4	FSPR30%	$20\%SSB_{F=0}$	$10\%SSB_{F=0}$	2	FSPR70%	80:20
5	FSPR25%	$20\%SSB_{F=0}$	NA	1	NA	80:20
6	FSPR20%	$20\%SSB_{F=0}$	NA	1	NA	80:20
7	FSPR25%	$15\%SSB_{F=0}$	NA	1	NA	80:20
8	FSPR30%	$20\%SSB_{F=0}$	$7.7\%SSB_{F=0}$	2	5% F_{TARGET}	80:20
9	FSPR30%	$20\%SSB_{F=0}$	$15\%SSB_{F=0}$	2	10% F_{TARGET}	70:30
10	FSPR30%	$25\%SSB_{F=0}$	$15\%SSB_{F=0}$	2	10% F_{TARGET}	70:30
11	FSPR40%	$25\%SSB_{F=0}$	$20\%SSB_{F=0}$	2	10% F_{TARGET}	70:30
12	FSPR30%	$20\%SSB_{F=0}$	$10\%SSB_{F=0}$	2	FSPR70%	70:30
13	FSPR25%	$20\%SSB_{F=0}$	NA	1	NA	70:30
14	FSPR20%	$20\%SSB_{F=0}$	NA	1	NA	70:30
15	FSPR25%	$15\%SSB_{F=0}$	NA	1	NA	70:30
16	FSPR30%	$20\%SSB_{F=0}$	$7.7\%SSB_{F=0}$	2	5% F_{TARGET}	70:30



PBF Management Objectives and Performance Indicators – set by JWG

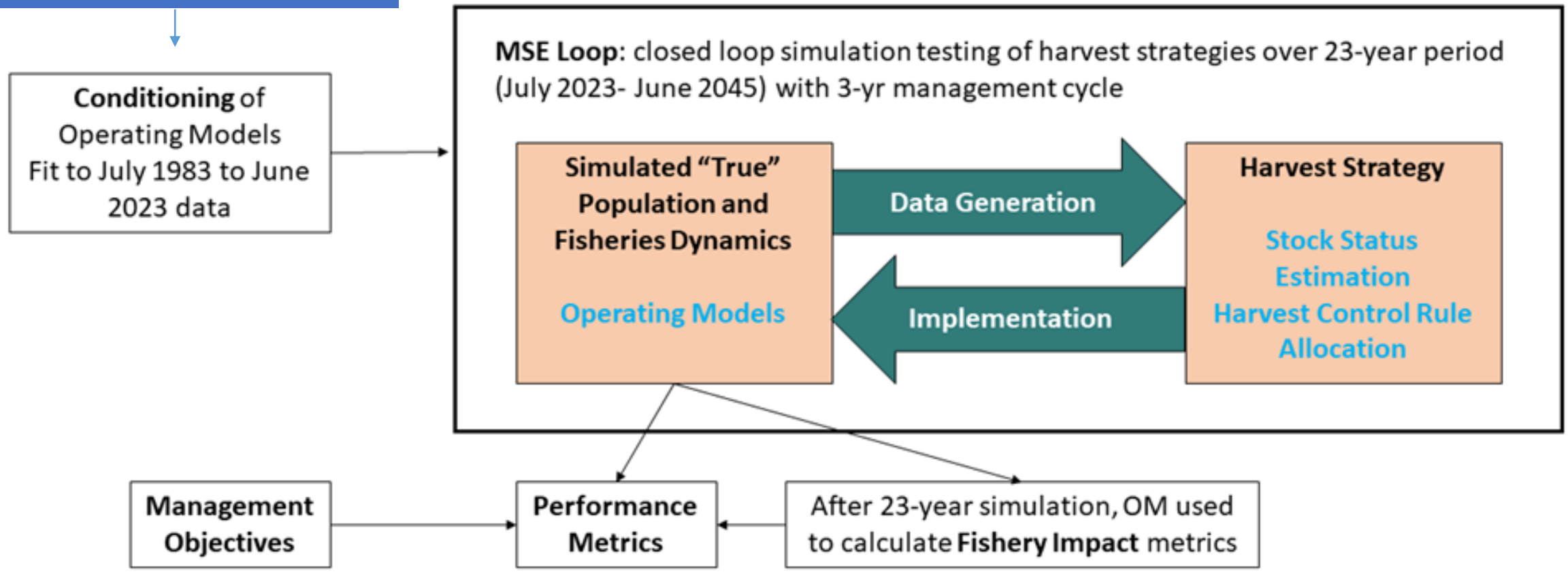
- Quantitative indicators used to evaluate HCR performance for each management objective
- Computed over 20 years evaluation period from 2026 (when first TAC applied) to 2045

CANDIDATE OPERATIONAL MANAGEMENT OBJECTIVES AND PERFORMANCE INDICATORS FOR PACIFIC BLUEFIN TUNA

Category	Operational Management Objective	Performance Indicator
Safety	There should be a less than 20%[4] probability of the stock falling below the LRP	Probability that SSB< LRP in any given year of the evaluation period
Status	To maintain fishing mortality at or below FTarget with at least 50% probability	Probability that F≤FTARGET in any given year of the evaluation period Probability that SSB is below the equivalent biomass depletion levels associated with the candidates for FTARGET
Stability	To limit changes in overall catch limits between management periods to no more than 25%, unless the ISC has assessed that the stock is below the LRP[5]	Percent change upwards in catches between management periods excluding periods when SSB<LRP Percent change downwards in catches between management periods excluding periods when SSB<LRP
Yield	Maintain an equitable balance in proportional fishery impact between the WCPO and EPO	Median fishery impact (in %) on SSB in the terminal year of the evaluation period by fishery and by WCPO fisheries and EPO fisheries
	To maximize yield over the medium (5-10 years) and long (10-30 years) terms, as well as average annual yield from the fishery.	Expected annual yield over years 5-10 of the evaluation period, by fishery. Expected annual yield over years 10-30 of the evaluation period, by fishery. Expected annual yield in any given year of the evaluation period, by fishery.
	To increase average annual catch in all fisheries across WCPO and EPO	

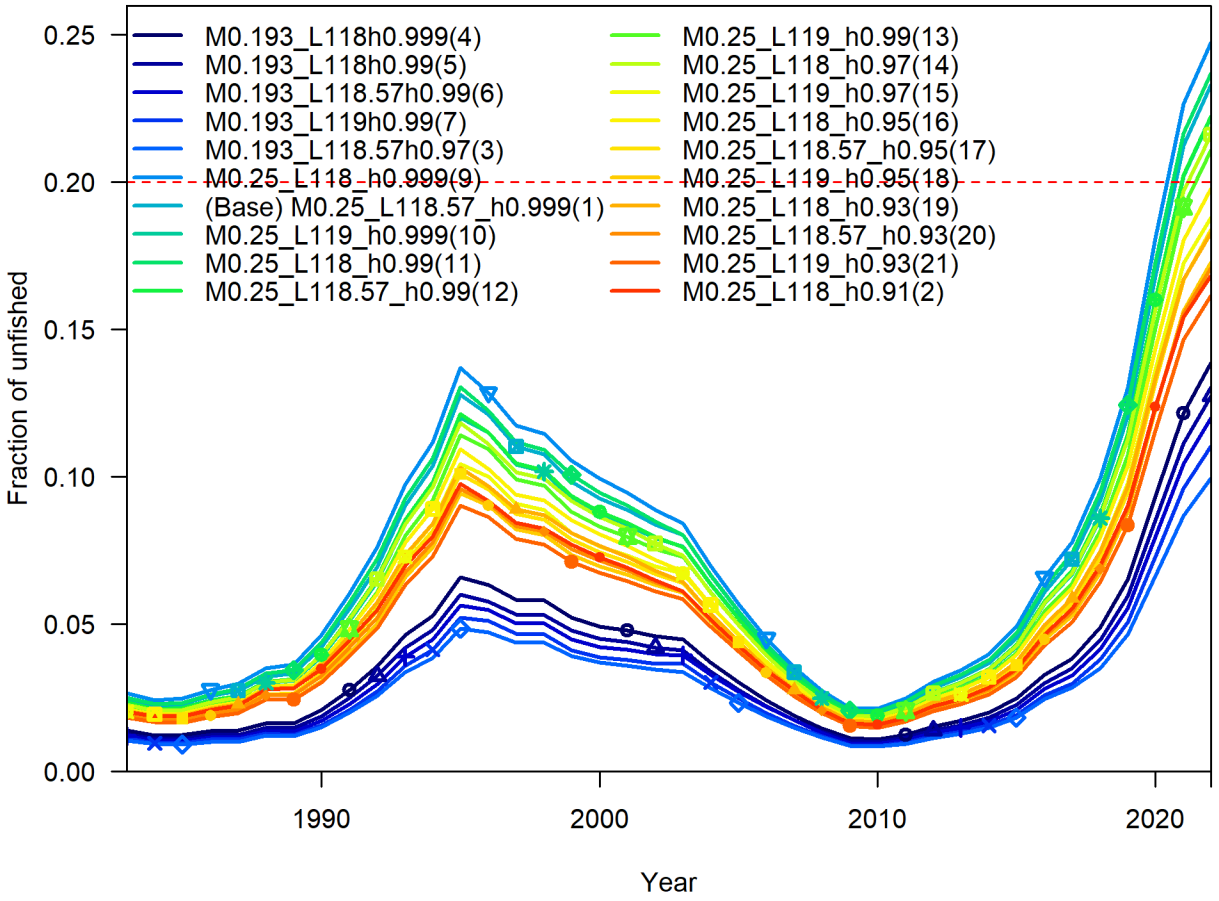
PBF MSE Feedback Loop

Ensures models are plausible, i.e. can reasonably reconstruct past pattern in PBF observations



Uncertainty – Reference set of PBF Operating Models (OMs)

- Growth, natural mortality, steepness identified as most influential sources of uncertainty for PBF
- OMs represent the range of uncertainty in stock productivity - different "what if" scenarios in terms of biology
- Reference OMs – Equally plausible versions of true dynamics of the system



How did we arrive at these specific parameter ranges? Natural Mortality for age 2 and older (M_{2+})

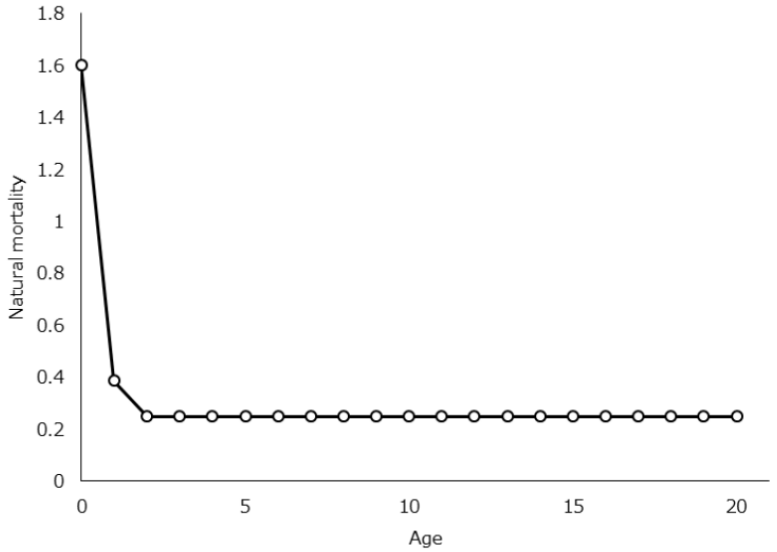
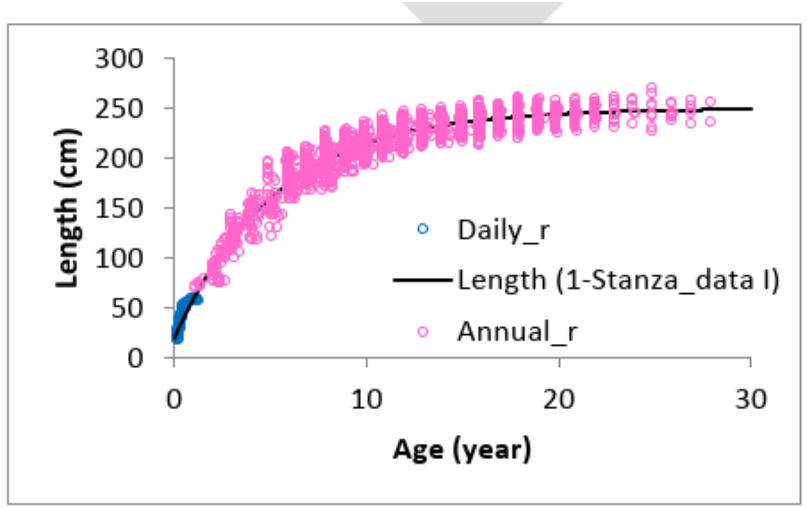


Figure 2-5. Assumed natural mortality (*M*) at age of Pacific bluefin tuna (*Thunnus orientalis*) used in this stock assessment.

- *M* in the current assessment:
  - Age 0 fish was from a conventional tagging study
  - Age-1 fish was based on length-adjusted M estimated from conventional tagging studies on southern bluefin tuna
  - Age-2 and older fish was from the median value obtained across a suite of empirical and life-history based methods, 0.25 year^{-1}
- Maunder et al. (2023) reviewed methods for examining *M* and recommended focusing on the maximum observed age (*tmax*)
- Based on historical age data, *tmax* is 28 years, corresponding to an $M_2{}^+$ value of 0.193 year^{-1}
- 0.25 year^{-1} corresponds to a *tmax* of 22 years
- Explored potential OMs with M_{2+} specified at 0.193 year^{-1} or 0.25 year^{-1}

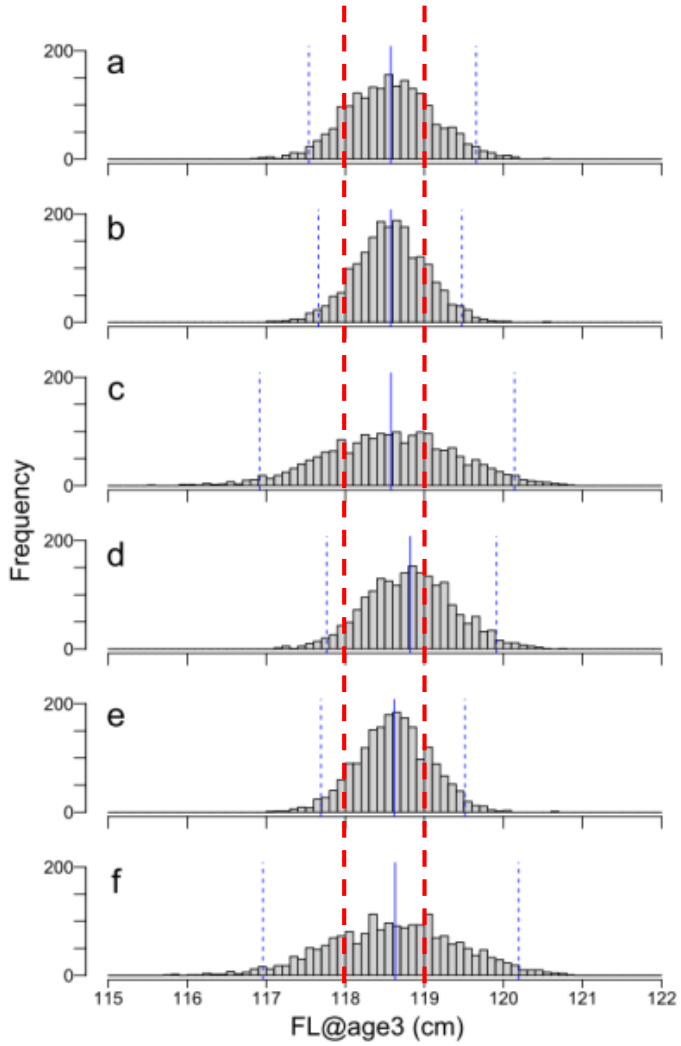
How did we arrive at these specific parameter ranges? Length at age 3 (L_2)



- Annuli data for 1,782 fish (70.5-271 cm in FL, 1-28 yrs old)
- Daily increment data for 228 fish (18.6-60.1 cm in FL, 51-453 days old after hatching)

Fukuda et al. 2015
ISC/15/PBFWG-2/11

Bootstrapping



Ishihara et al. 2023

- The median of estimated L_2 ranged from 118.57 to 118.82
- The 95% confidence interval for the estimated L_2 was within $\pm$2 cm from the median.
- We consequently selected a range of L_2: 118, 118.57, and 119 cm

How did we arrive at these specific parameter ranges? Steepness (*h*)

- Less information to guide choice of a range for parameter *h* - lack of early life history data
- Independent estimates of steepness that incorporate biological and ecological characteristics of the stock (Iwata 2012; Iwata et al. 2012b) reported that the mean of *h* was around 0.999
- We explored a broad range of *h* values, ranging from 0.81 to 0.999

66 Potential OMs

		M_{2+}=0.193			M_{2+}=0.25		
		L_2=118 (L_{inf}=248.6)	L_2=118.57 (L_{inf}=249.9)	L_2=119 (L_{inf}=250.9)	L_2=118 (L_{inf}=248.6)	L_2=118.57 (L_{inf}=249.9)	L_2=119 (L_{inf}=250.9)
Steepness	0.81						
	0.83						
	0.85						
	0.87						
	0.89						
	0.91						
	0.93						
	0.95						
	0.97						
	0.99						
	0.999					Base OM	

Previous work showed that potential OMs with *h* 0.6-0.8 only able to reasonably fit the data with M_{2+} higher than 0.25 and are less plausible given PBF's fishing history (Lee et al. 2023)

How were the 20 OMs selected from the potential grid?

Quantitative diagnostic tests applied to each of the potential OMs to assess their plausibility. Final reference OMs had to pass the convergence diagnostic and at least 2 additional diagnostics (Lee and Tommasi 2023, Lee and Tommasi 2024)

		M_{2+}=0.193			M_{2+}=0.25		
		L_2=118 (L_{inf}=248.6)	L_2=118.57 (L_{inf}=249.9)	L_2=119 (L_{inf}=250.9)	L_2=118 (L_{inf}=248.6)	L_2=118.57 (L_{inf}=249.9)	L_2=119 (L_{inf}=250.9)
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	0.87						
	0.89						
	0.91						
	0.93						
	0.95						
	0.97						
	0.99						
	0.999						

1. *Convergence*

   0% jitter runs with a positive-definite Hessian matrix = Fail

2. *R_0 likelihood profile*

   R_0 for a size data component not within the 95% CI of the R_0 at the minimal total likelihood estimate = Fail

3. *Retrospective analyses*

   Absolute Mohn's rho > base OM (0.1) = Fail

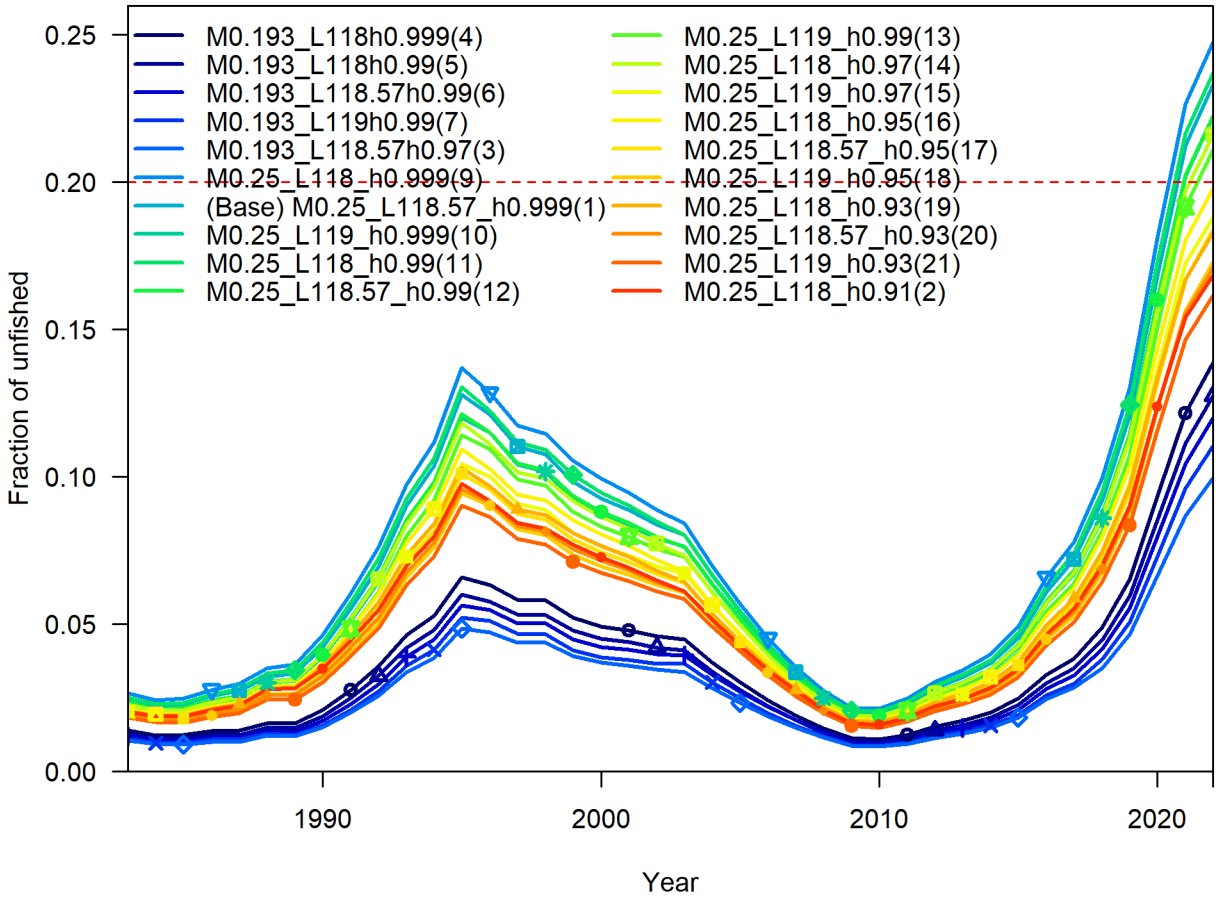
4. *Age-structured production model with recruitment (ASPM-R)*

   Statistically significant degradation of model fit (i.e., NLL) relative to base OM = Fail

Final set of reference OMs

- Passed quantitative model selection criteria
- Given equal weight in calculation of performance metrics
- Span a wide range of relative SSB (relative SSB: 0.8% to 2.1% in 2010 and 10.7% to 25.5% in 2023)

OM #	M_{2+}	L_2	h	OM #	M_{2+}	L_2	h
1	0.25	118.57	0.999	12	0.25	118.57	0.99
2	0.25	118	0.91	13	0.25	119	0.99
3	0.193	118.57	0.97	14	0.25	118	0.97
4	0.193	118	0.999	15	0.25	119	0.97
5	0.193	118	0.99	16	0.25	118	0.95
6	0.193	118.57	0.99	17	0.25	118.57	0.95
7	0.193	119	0.99	18	0.25	119	0.95
9	0.25	118	0.999	19	0.25	118	0.93
10	0.25	119	0.999	20	0.25	118.57	0.93
11	0.25	118	0.99	21	0.25	119	0.93



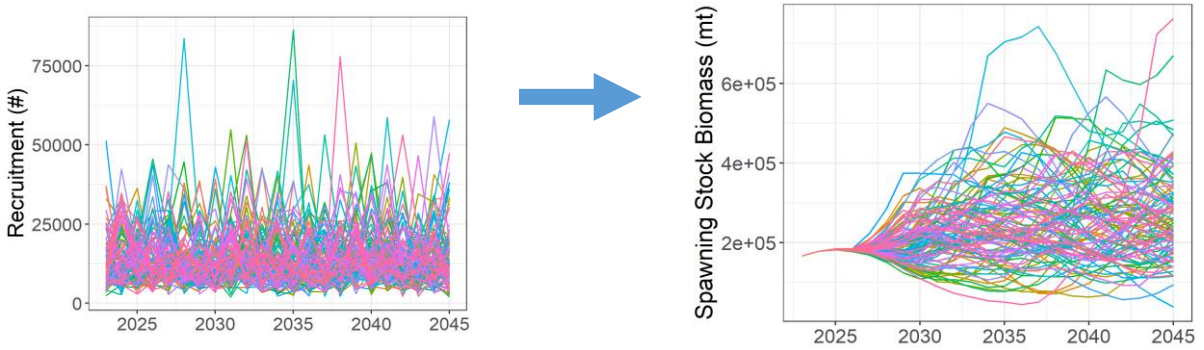
Uncertainty – Robustness Set

- 3 robustness OMs – less likely than reference set but still conceivable
- Test HCR behavior under extreme conditions
- Run with OM1
- Doubling of discards
- Effort creep for the Taiwanese longline fleet on which the main index of abundance is based
- About 40% recruitment drop for 10 years
- Recruitment drop simulations lasts longer, until 2066. Drop starts in 2042 after median SSB for all HCRs reached target levels. Performance metrics still computed over 20 year long period, but from 2047 to 2066

Uncertainty in Future Recruitment

- 100 different future recruitment trajectories tested for each OM – process uncertainty
- Future recruitment deviations sampled from a normal distribution with a mean of 0 and standard deviation of 0.6 in log space
- Past analysis (ISC 2022) found no autocorrelation in estimated recruitment, so not considered
- Of the 256,000 EM conducted <1% had estimation issues
- The associated iterations were removed for all HCRs, OMs, and simulation years, laving 81 iterations to compute performance metrics with

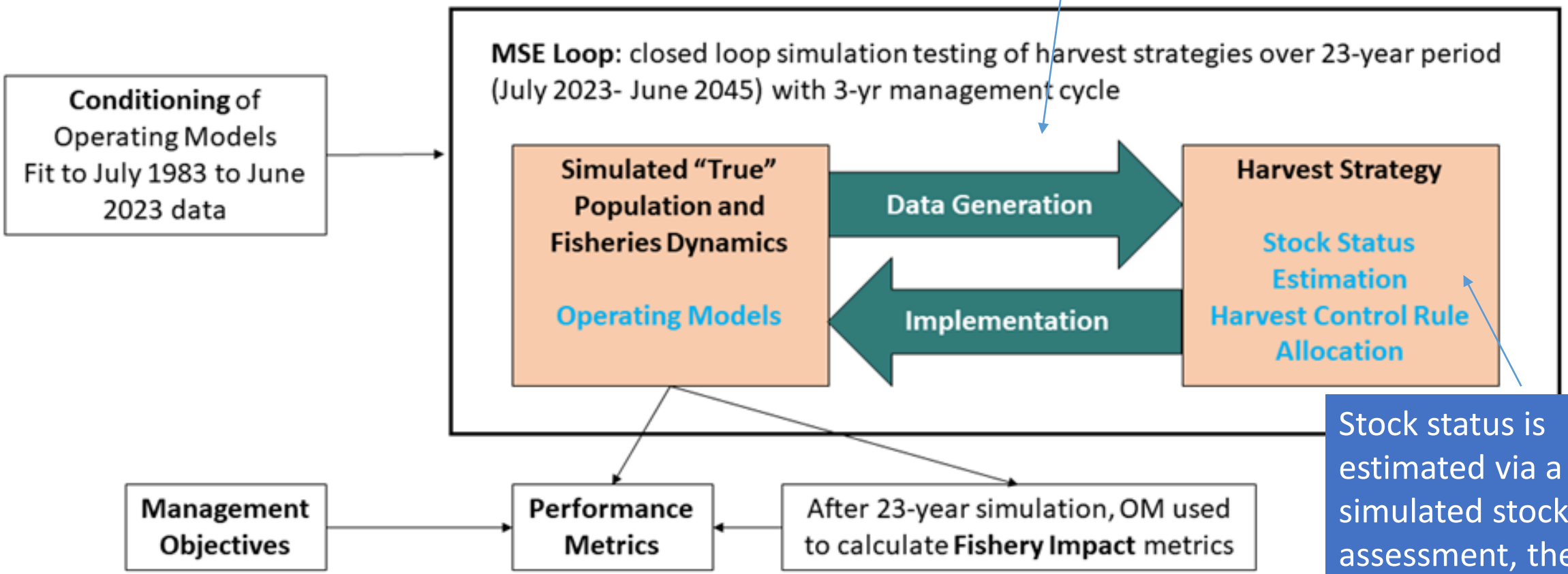
100 different runs for each OM and each HCR



Observation and Estimation Error

MSE loop recreates real world process to ensure management procedures will work even given errors in the observations and the simulated assessment model (i.e., EM)

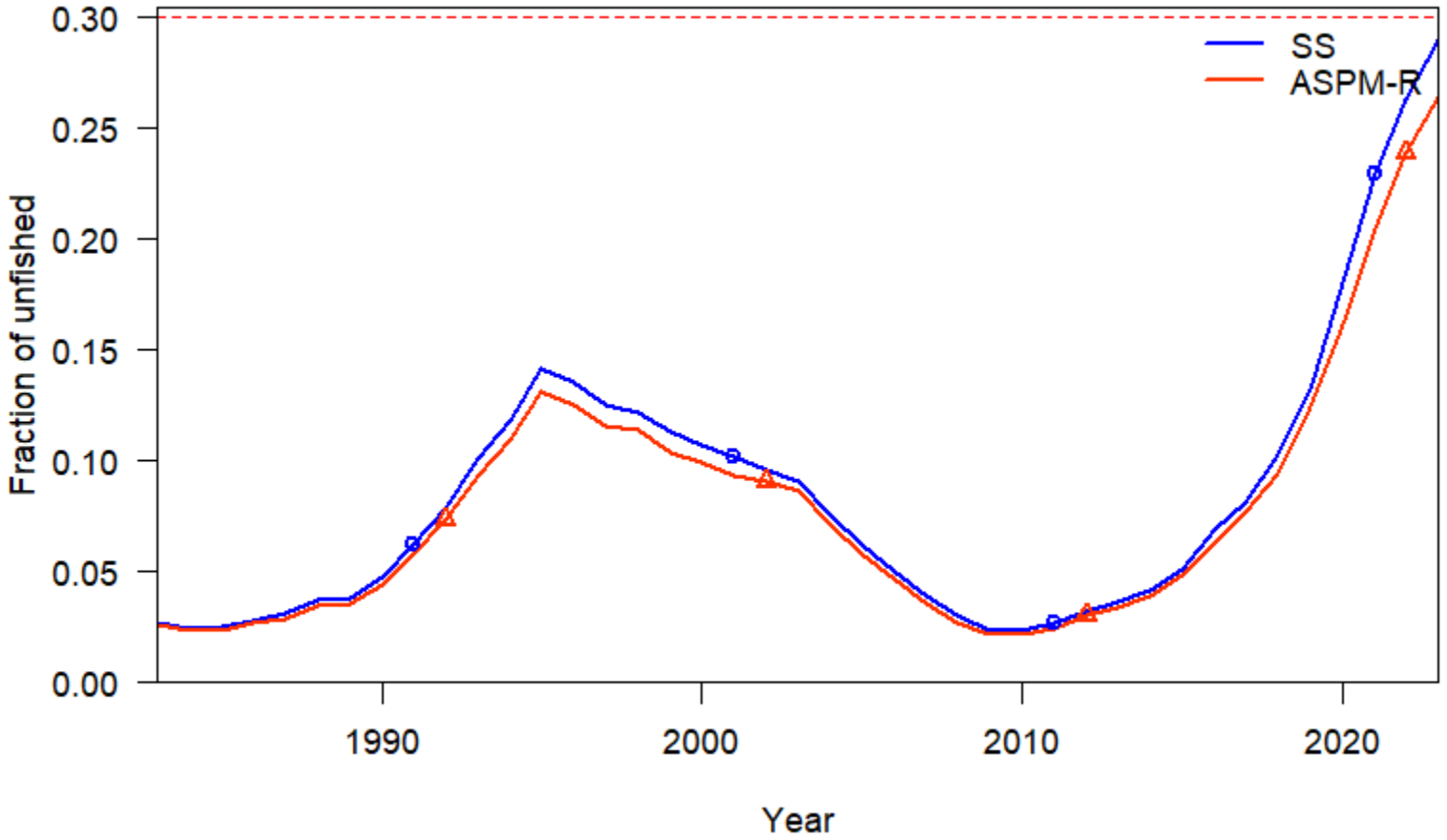
As in the real world, data on catch, size frequency, and index of abundance (Chinese Taipei longline) is generated with error and input into the EM



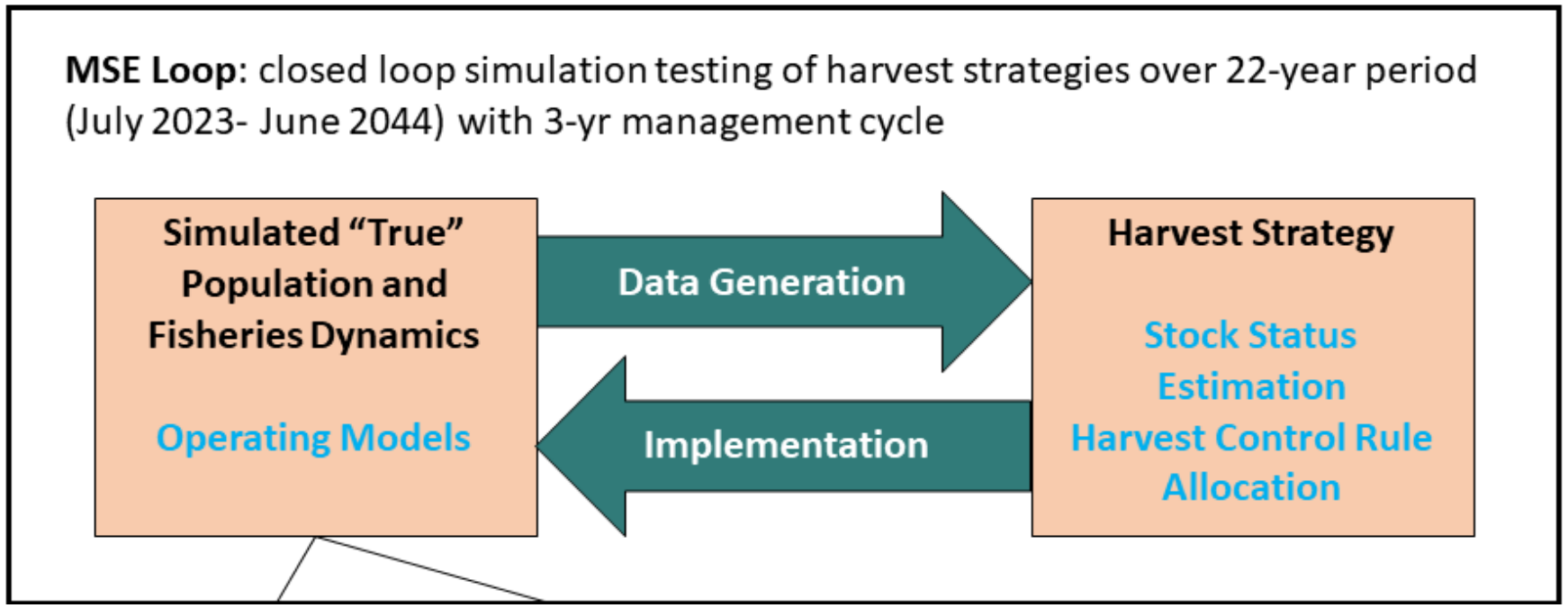
Stock status is estimated via a simulated stock assessment, the EM

Estimation Model

- Simulated stock assessment model
- Based on age structured production model with recruitment deviates (ASPM-R+)
- + as size frequency data from the Taiwanese and Japanese longline fleets were included and their selectivities estimated
- Simplified version of 2024 assessment
- Most similar to OM 1



Implementation Error



HCR sets TAC by fleet segments, but due to discards catches are assumed to be higher than set by HCR

TAC EPO (includes rec catches)

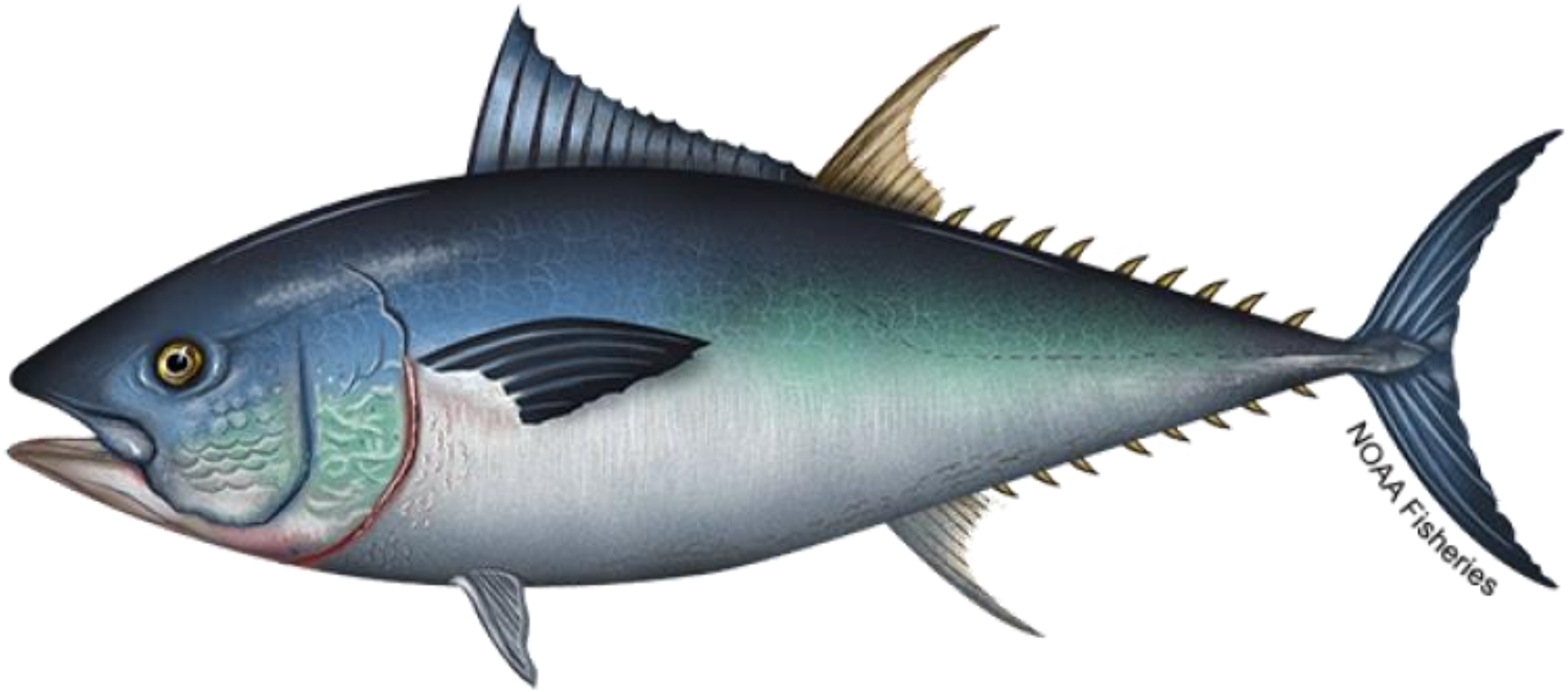
TAC WCPO small fish

TAC WCPO large fish

Total TAC

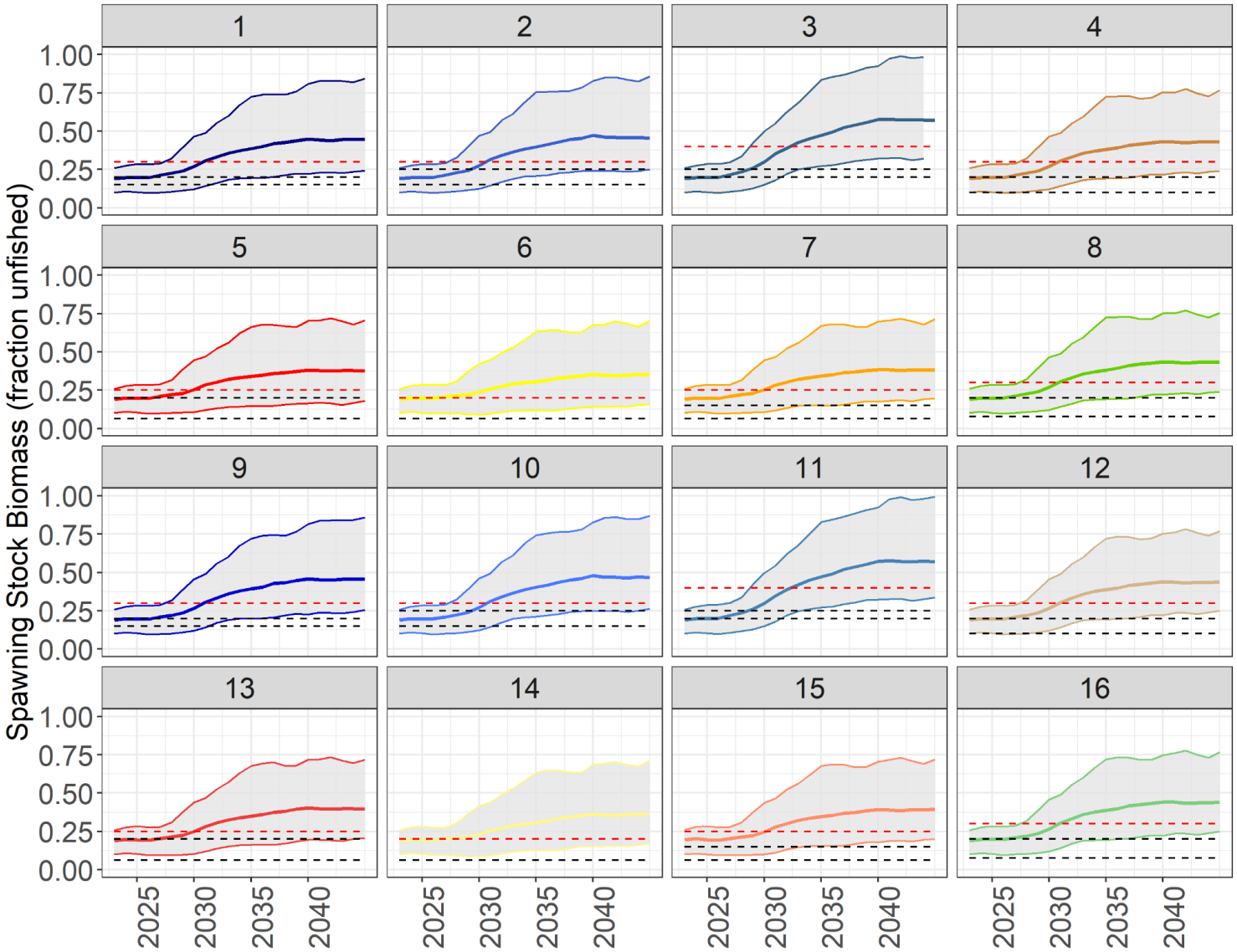
Discards

- 5% of the WCPO total TAC except for Japanese troll for penning
- 100% of Japanese troll for penning catches
- 1.2% of EPO recreational catches



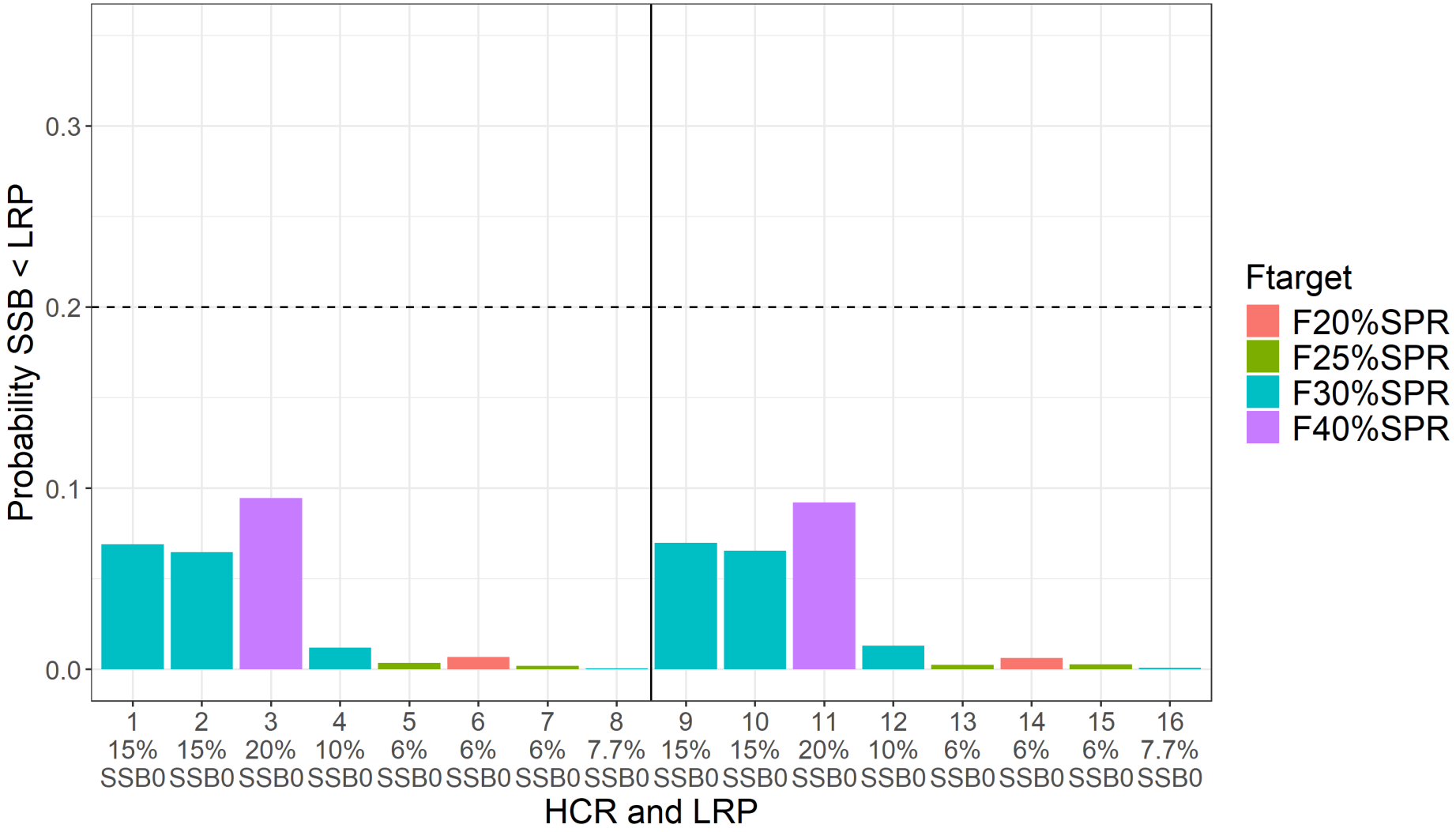
PBF MSE Results

Safety Performance



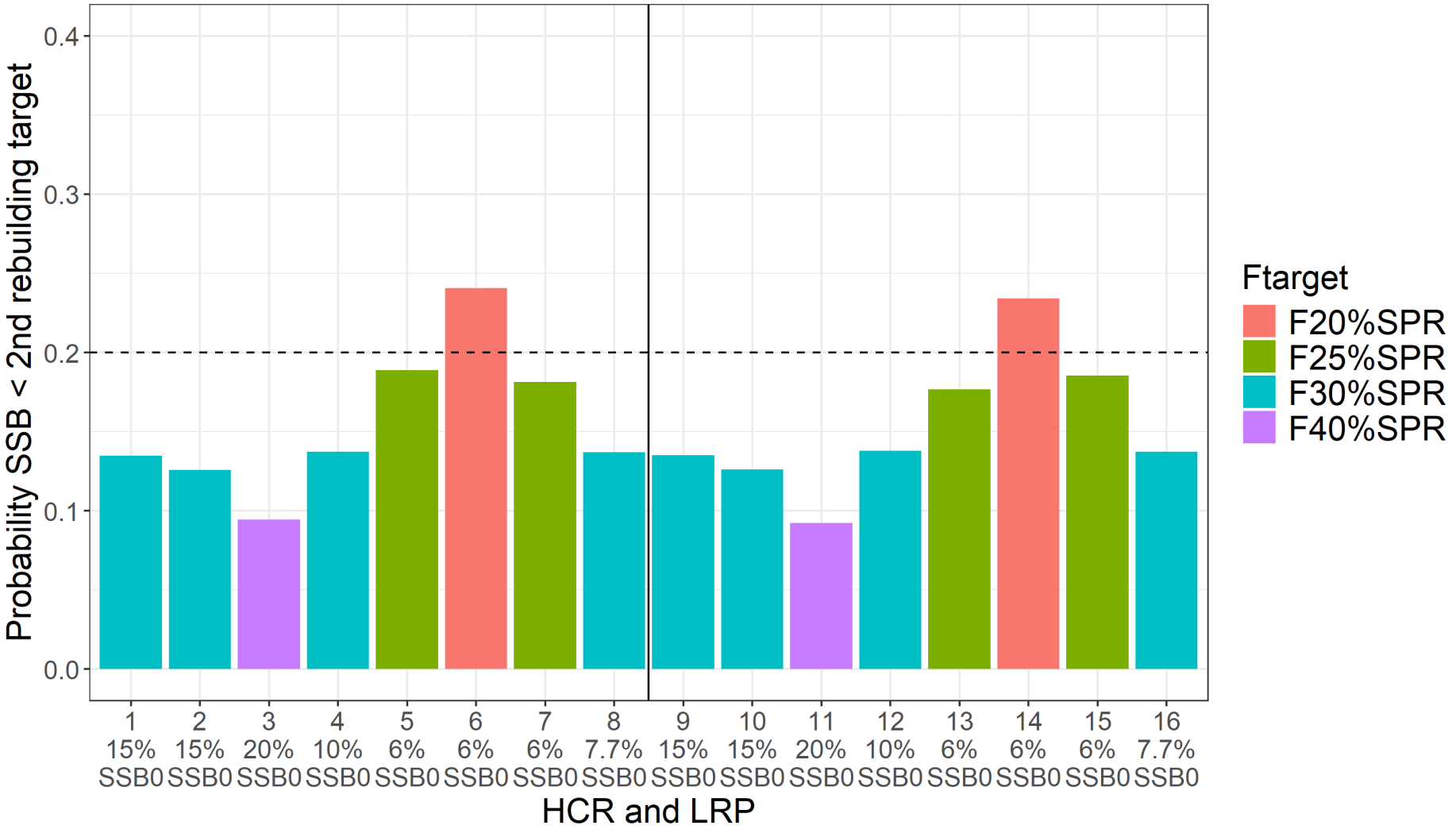
- *OBJECTIVE: There should be a less than 20% probability of the stock falling below the LRP*
- *HCRS 1, 2, 3, 9, 10, and 11 have the highest LRP*
- *Therefore, at start of simulation median SSB is closer to their LRP than for other HCRs*
- *By the end of the simulation, all HCRs have rebuilt SSB to above target levels*

Safety Performance



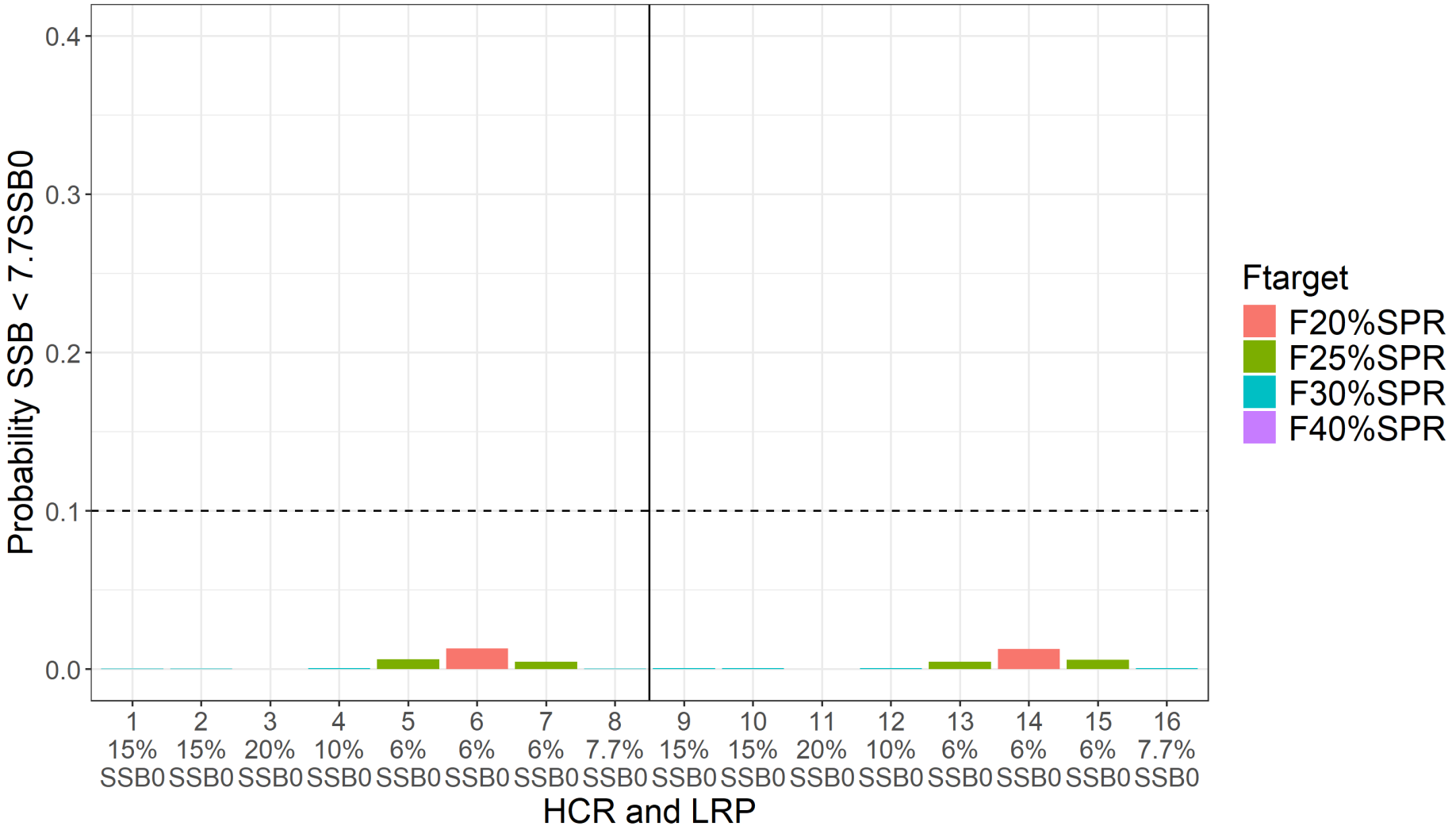
- *OBJECTIVE: There should be a less than 20% probability of the stock falling below the LRP*
- *PERFORMANCE METRIC: Probability that SSB < LRP in any given year of the evaluation period – Low is good*
- *LRP = LRP put forward with each HCR*
- All HCRs have a probability of breaching their own LRP less than 20%
- HCRs 1, 2, 3, 9, 10, 11 perform poorer due to their higher LRP and hence high probability of breaching it at the start of the simulation
- Also indicator of probability of drastic management intervention as when SSB<LRP low F and TAC can change more than 25%

Safety Performance – common reference point 1



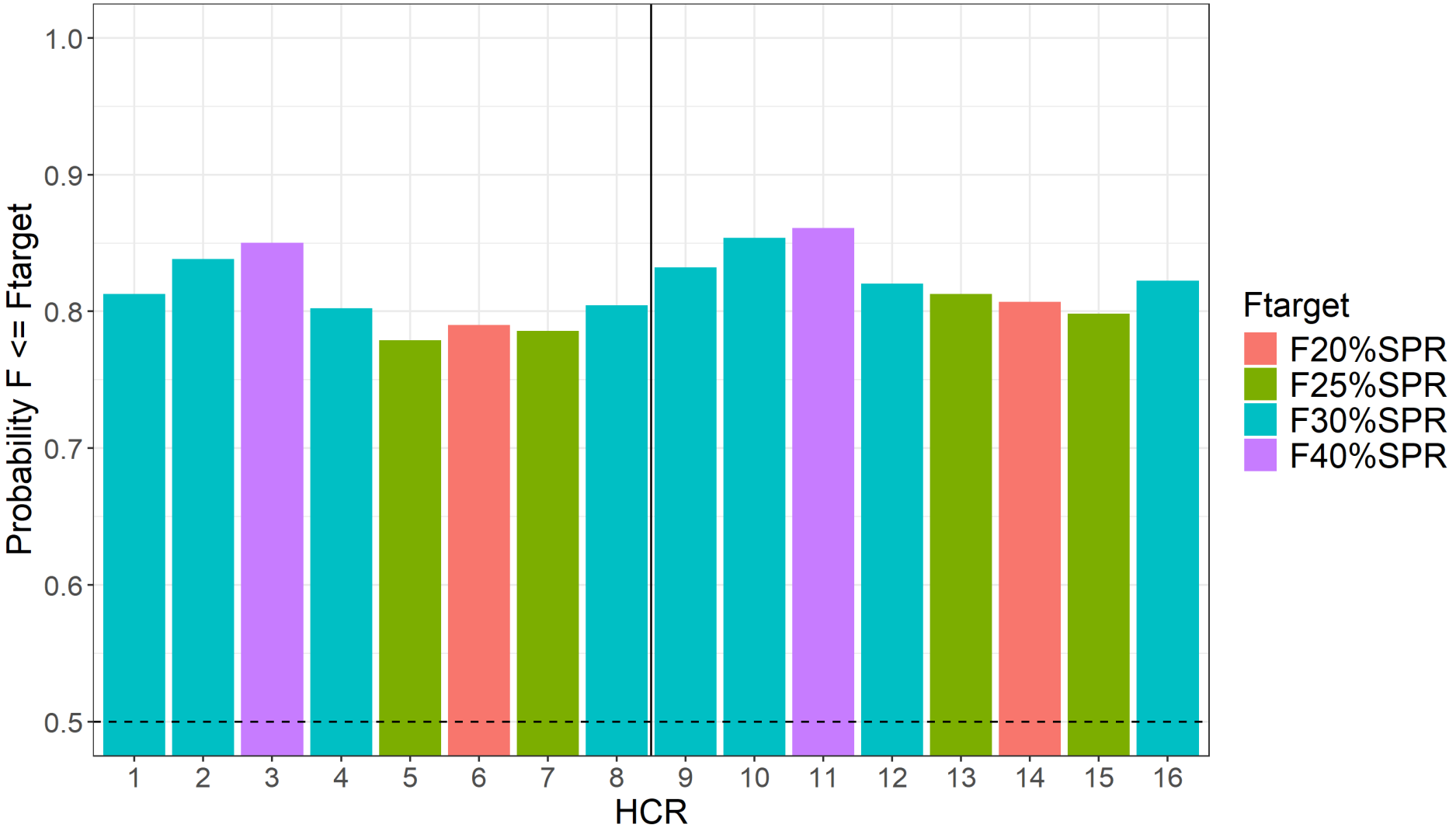
- *OBJECTIVE: There should be a less than 20% probability of the stock falling below the LRP*
- *PERFORMANCE METRIC: Probability that SSB < LRP in any given year of the evaluation period – Low is good*
- *LRP = 20%$SSB_{F=0}$, second rebuilding target*
- All HCRs except 6 and 14 have a less than 20% probability of breaching the second rebuilding target
- HCRs with the highest target fishing mortality do poorest and with the lowest do best

Safety Performance – common reference point 2



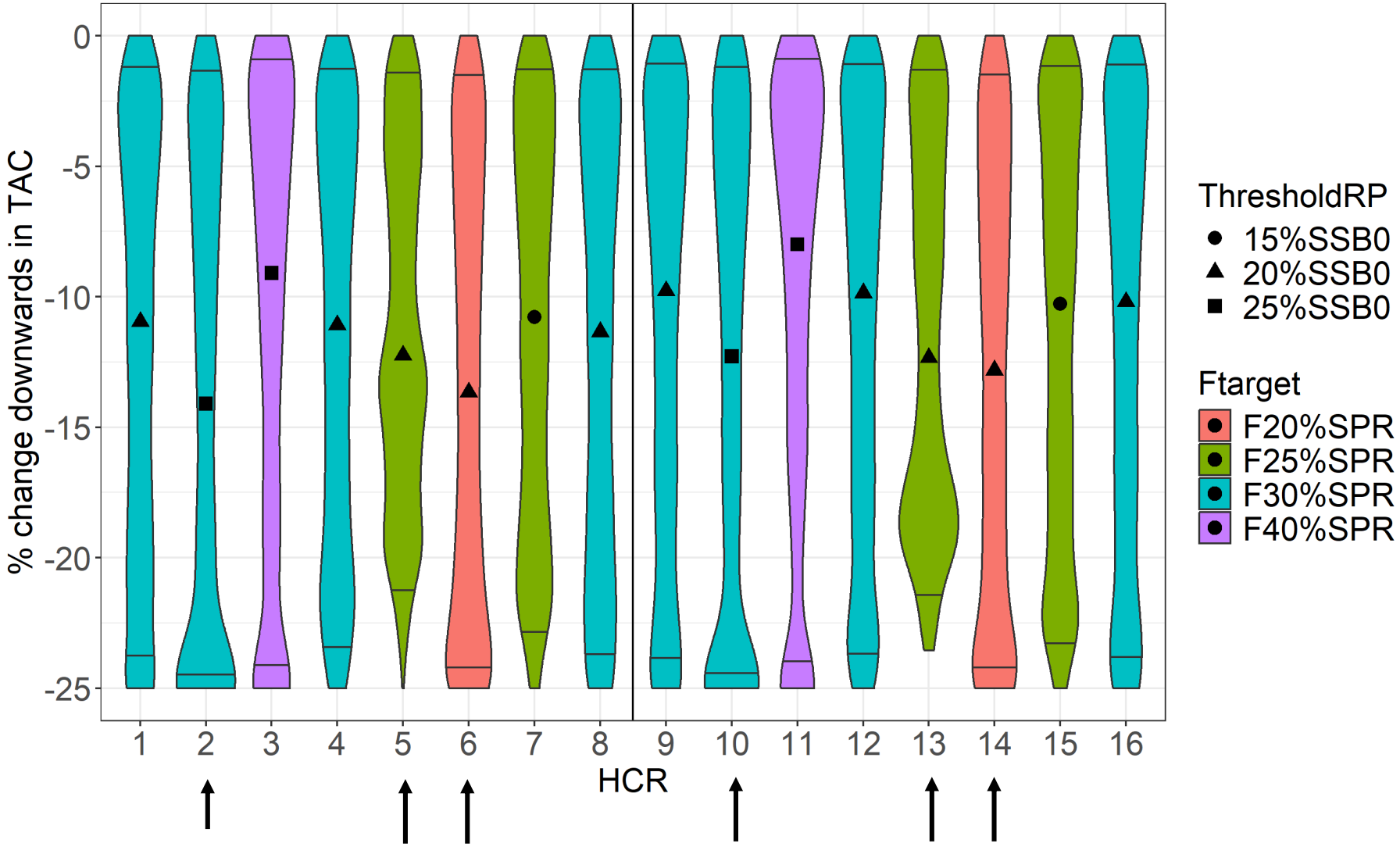
- *OBJECTIVE: There should be a less than 20% probability of the stock falling below the LRP*
- *PERFORMANCE METRIC: Probability that SSB < LRP in any given year of the evaluation period – Low is good*
- *LRP = 7.7%$SSB_{F=0}$, IATTC's interim LRP*
- All HCRs have a less than 10% probability of breaching IATTC's interim LRP
- HCRs with the highest target fishing mortality do poorest and with the lowest do best

Status Performance



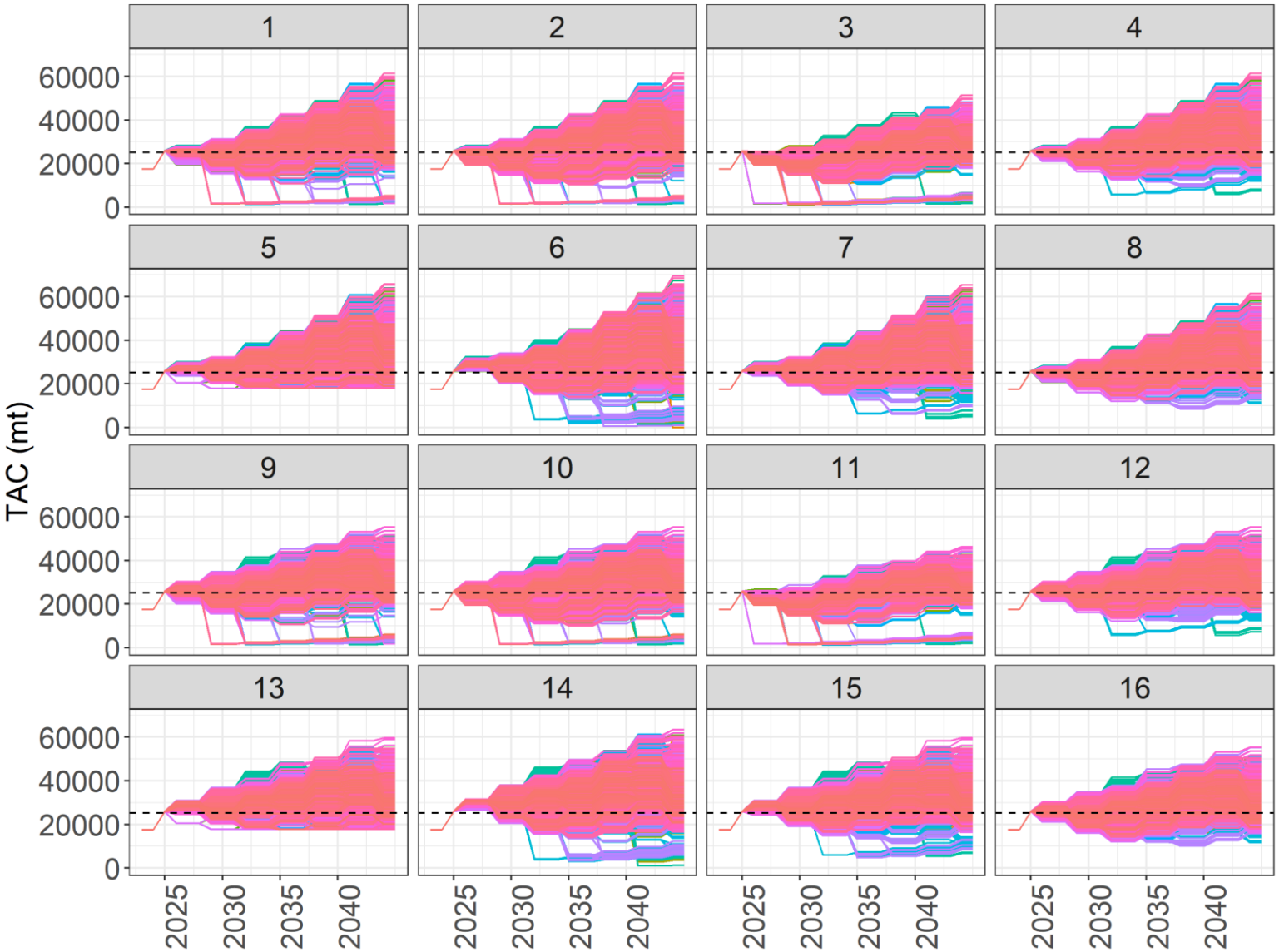
- *OBJECTIVE: To maintain fishing mortality at or below F_{TARGET} with at least 50% probability*
- *PERFORMANCE METRIC: Probability that $F \leq F_{TARGET}$ in any given year of the evaluation period*
- All HCRs have a probability of F being lower or equal to their F_{TARGET} that is at least 50%

Stability Performance



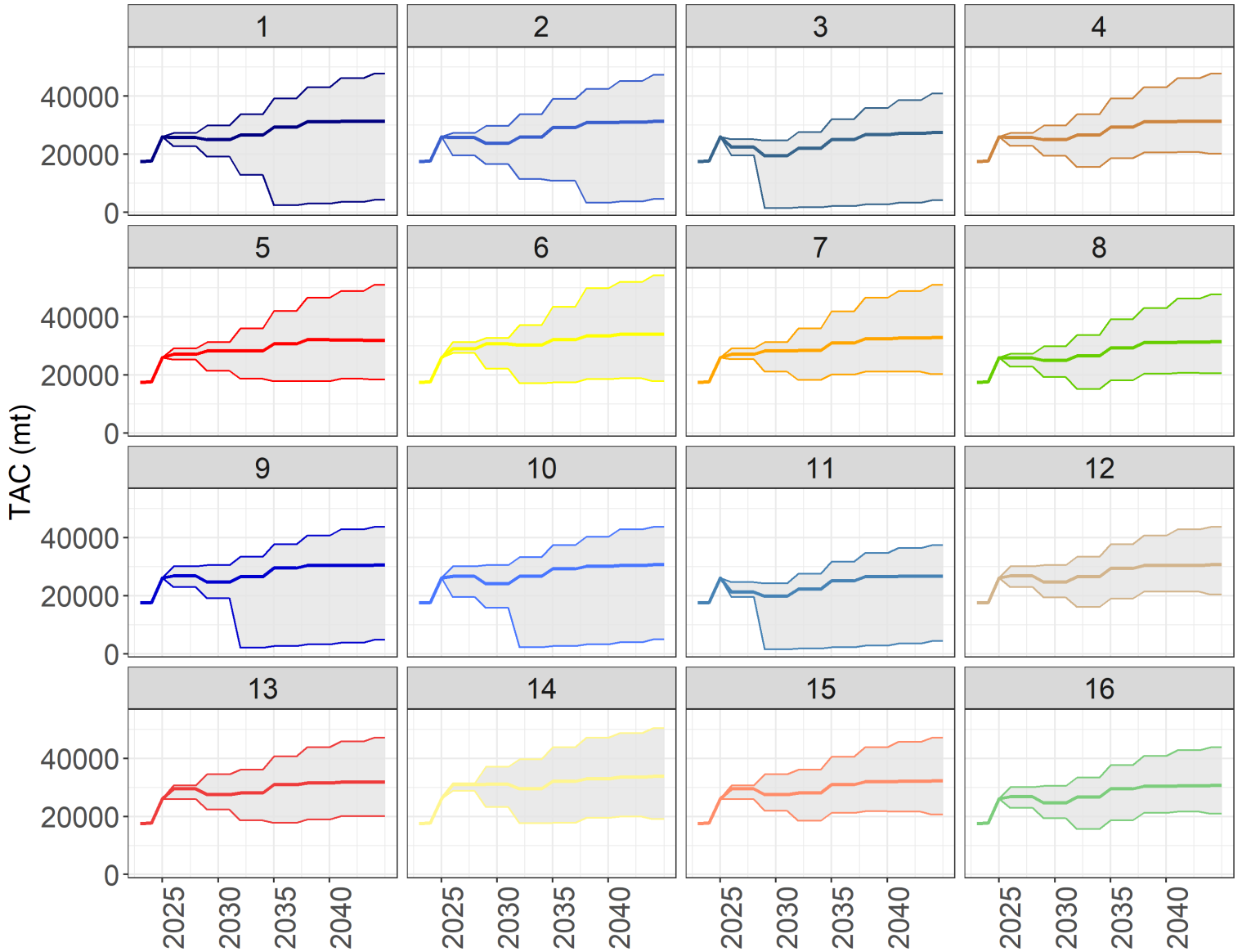
- *OBJECTIVE: To limit changes in overall catch limits between management periods to no more than 25%, unless the ISC has assessed that the stock is below the LRP*
- *PERFORMANCE METRIC: Percent change downwards in catches between management periods excluding periods when SSB<LRP*
- The max % change downwards in TAC was 25% when SSB >LRP
- HCRs with a first control point (i.e., ThRP) closer to the SSB_{TARGET} had lower catch stability

Stability Performance



- *OBJECTIVE: To limit changes in overall catch limits between management periods to no more than 25%, unless the ISC has assessed that the stock is below the LRP*
- *PERFORMANCE METRIC: Percent change downwards in catches between all management periods*
- HCRs 1, 2, 3, 9, 10, and 11 had more instances of drastic (>25%) declines in TAC due to severe management intervention resulting from breaching their respective LRP more often than other HCRs

Stability Performance



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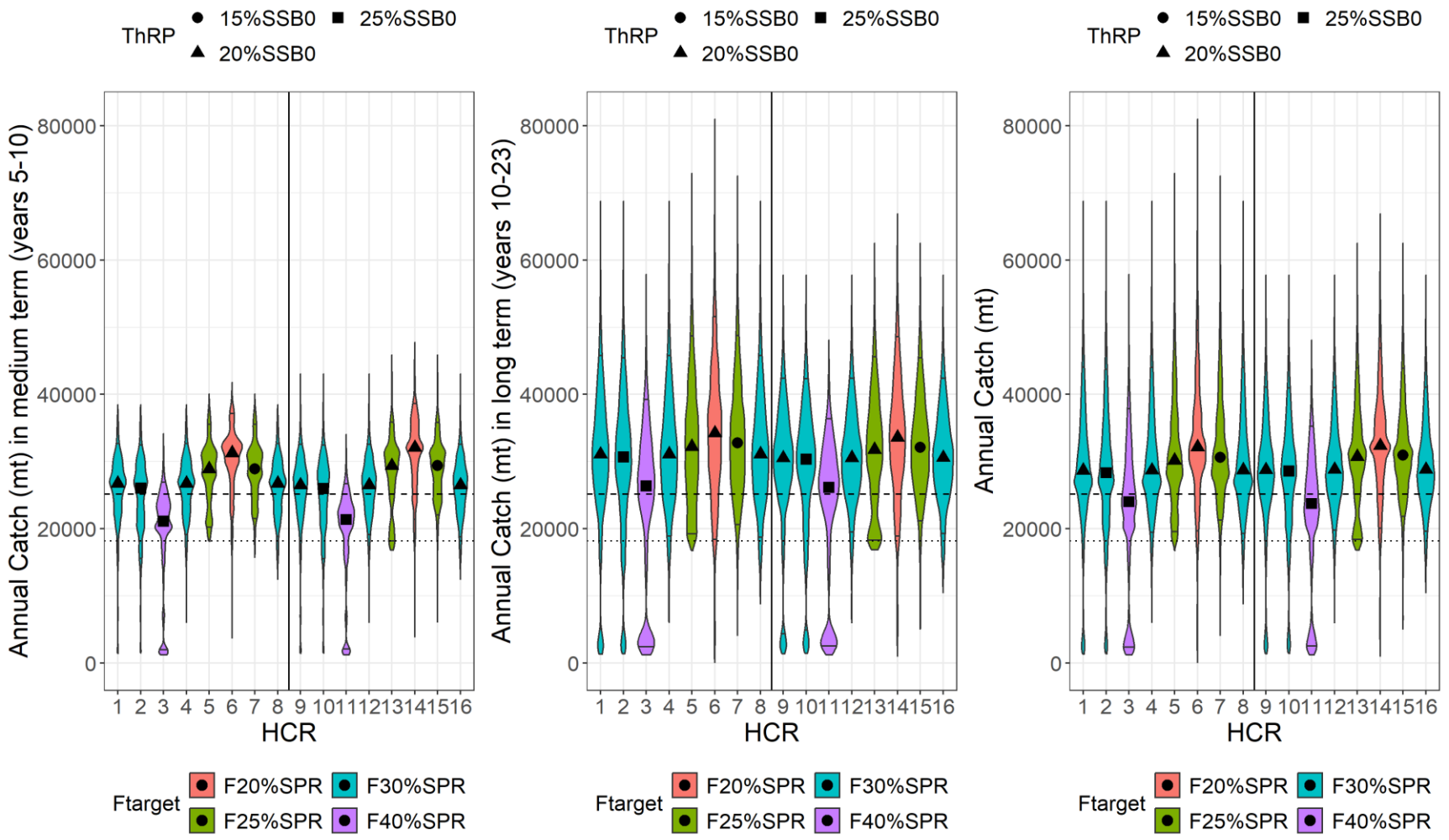
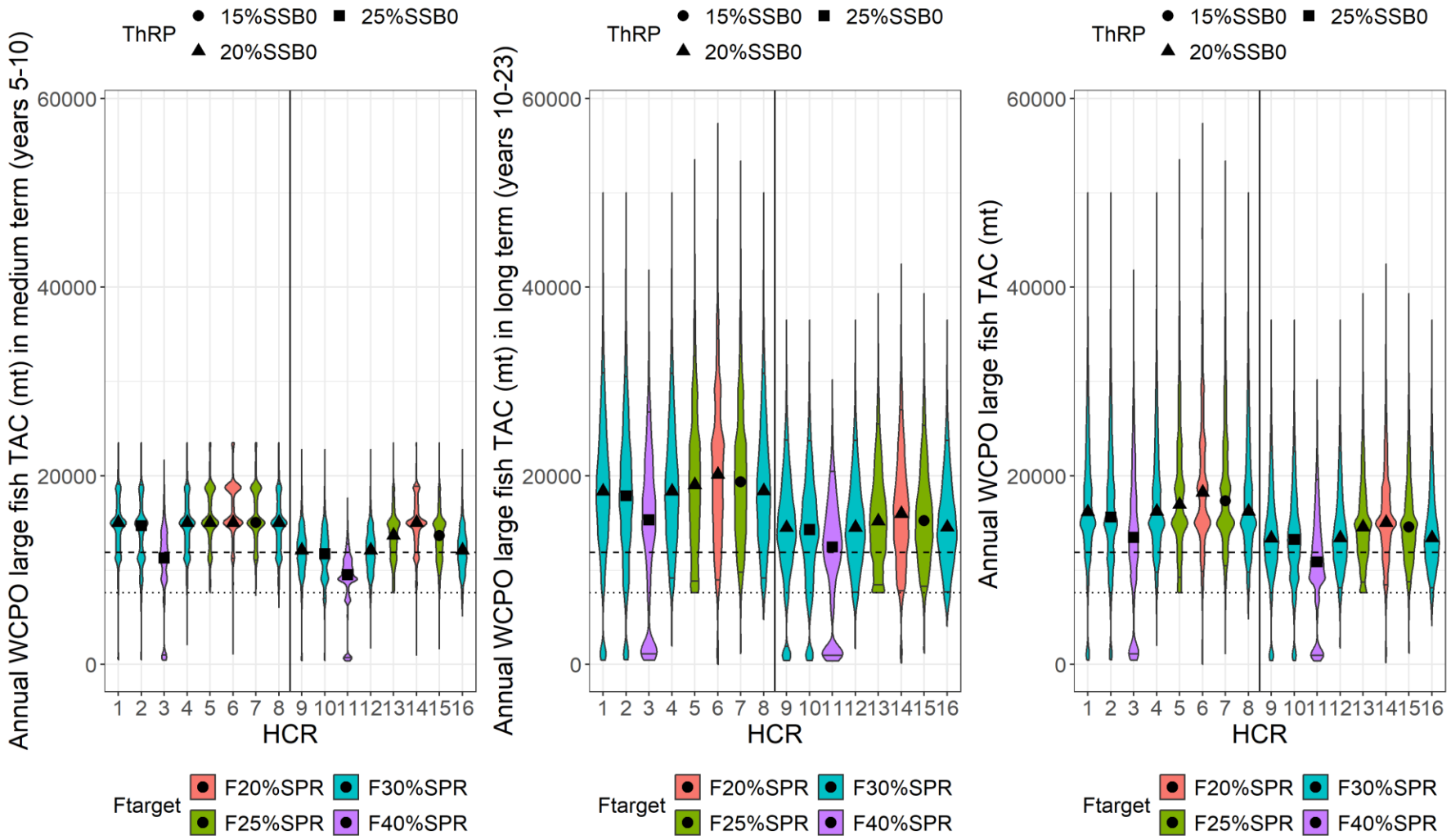
Yield Performance



- *OBJECTIVE: To maximize yield over the medium (5-10 years) and long (10-30 years) terms, as well as average annual yield*
- HCRs with the highest target fishing mortality do best and with the lowest poorest
- In the long term median annual catch was above the current catch limits for all HCRs
- Median annual catch in the medium term or over the entire evaluation period was above the current catch limits except for HCRs 3 and 11

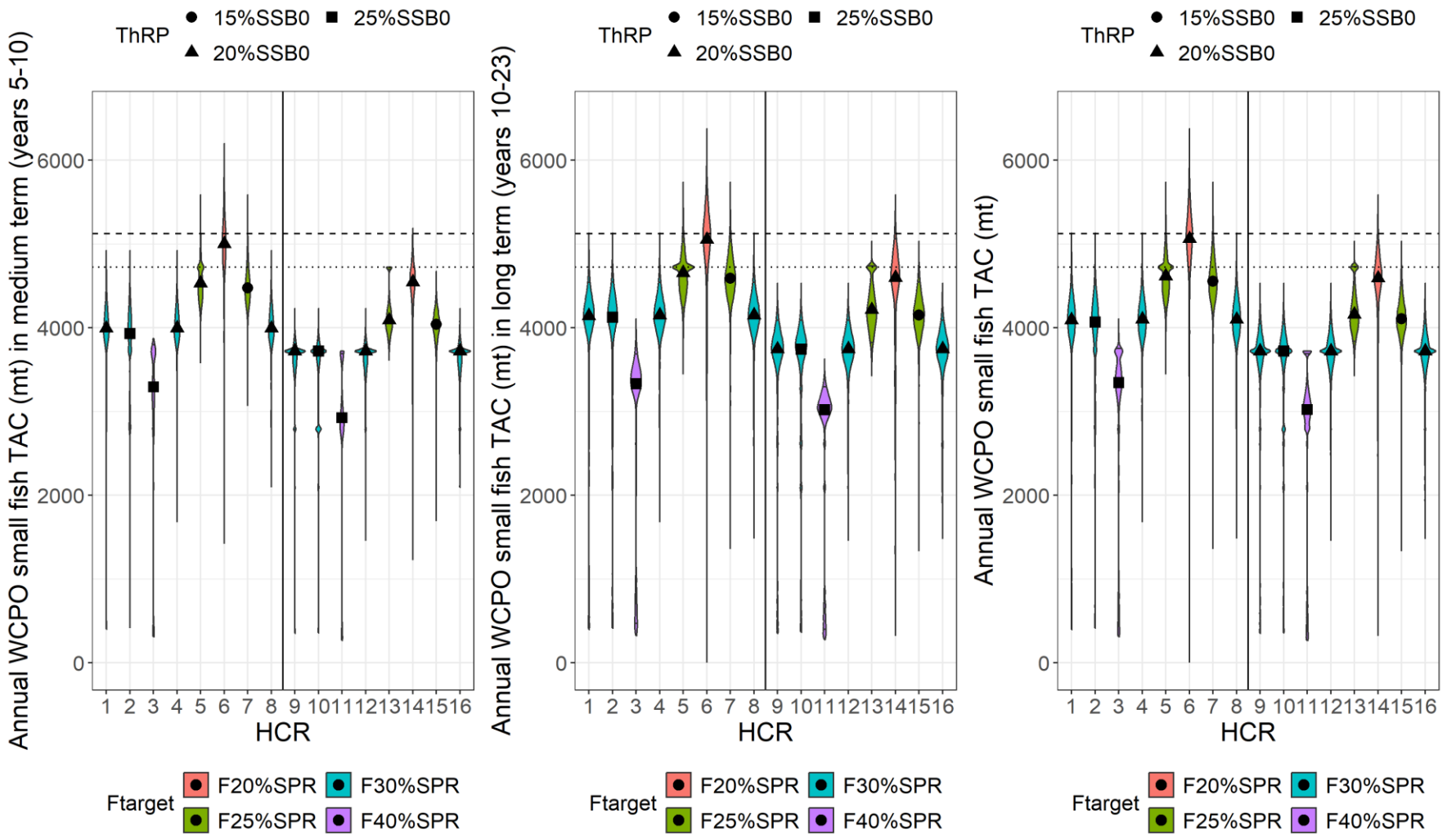
CMM 23-02 + Resolution C-21-05 + 2023 EPO rec catches CMM 24-01 + Resolution C-24-02 + 2023 EPO rec catches

Yield Performance



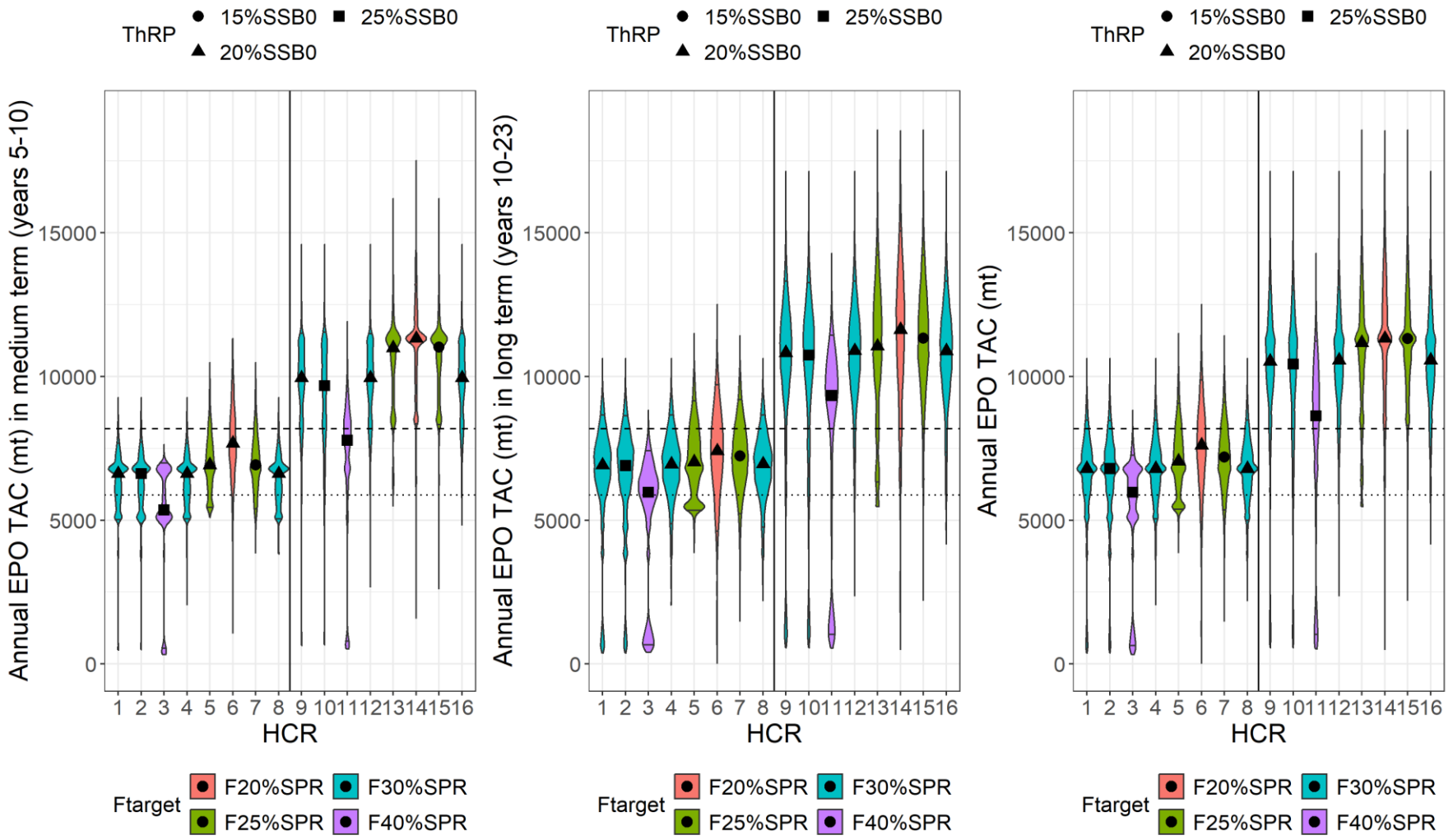
- *OBJECTIVE: To maximize yield over the medium (5-10 years) and long (10-30 years) terms, as well as average annual yield*
- HCRs with the highest target fishing mortality do best and with the lowest poorest
- Lower catch for HCRs 9-16 due to lower WCPO impact
- In the long term median annual WCPO large fish TAC was above the current catch limits for all HCRs
- Median annual catch in the medium term or was above the current catch limits except for HCRs 3 and 11
- Median annual catch was above the current catch limits except for HCR 11

Yield Performance



- *OBJECTIVE: To maximize yield over the medium (5-10 years) and long (10-30 years) terms, as well as average annual yield*
- HCRs with the highest target fishing mortality do best and with the lowest poorest
- Lower catch for HCRs 9-16 due to lower WCPO impact
- Median annual catch always lower than current catch limit
- Dependent on terminal year recruitment which is uncertain and estimated at stock-recruitment curve average

Yield Performance

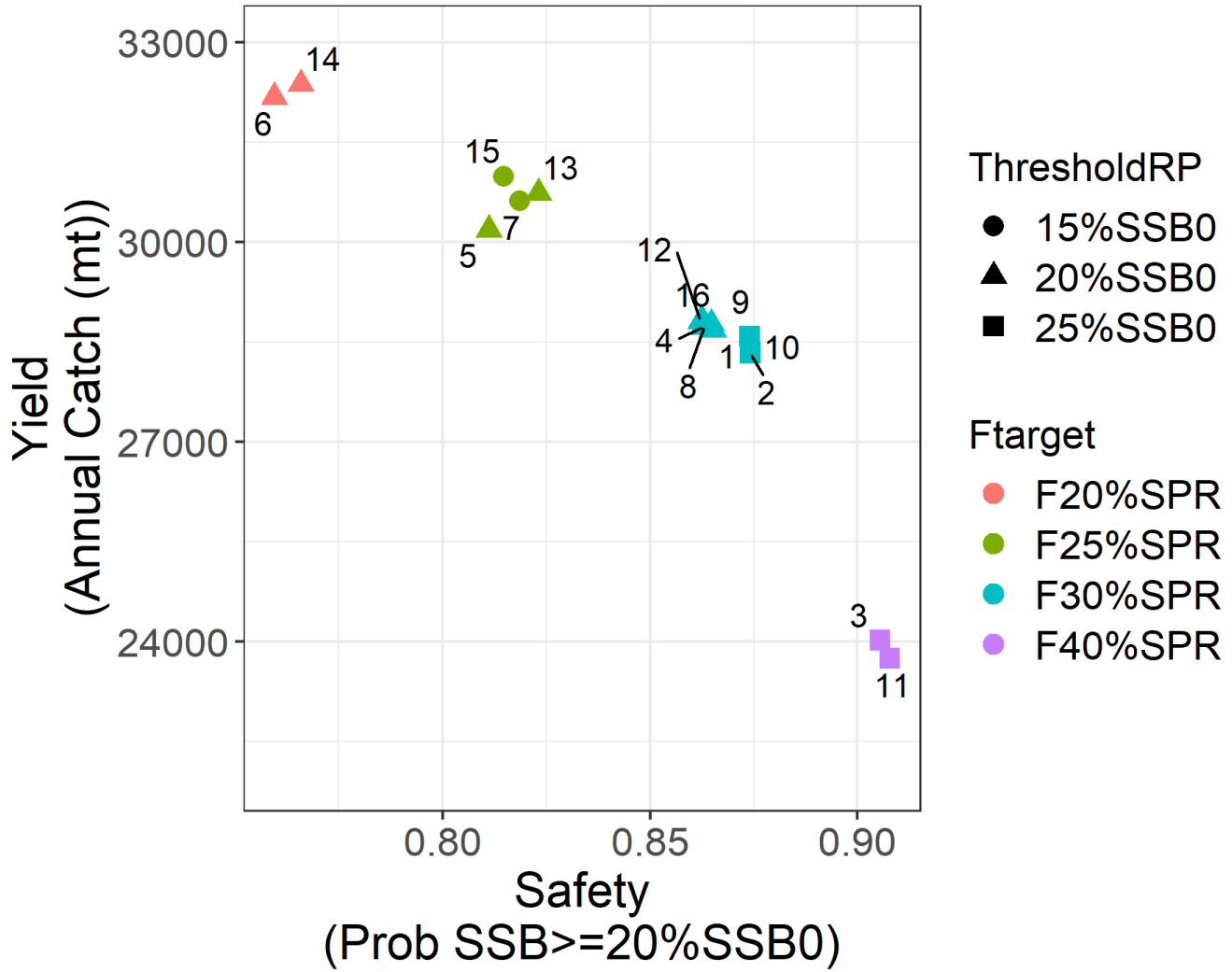


- *OBJECTIVE: To maximize yield over the medium (5-10 years) and long (10-30 years) terms, as well as average annual yield*
- HCRs with the highest target fishing mortality do best and with the lowest poorest
- Median annual catch in the long term or over the entire evaluation period was above the current catch limits for HCRs 9 to 16, which have a higher EPO impact

Resolution C-21-05 + 2023 EPO rec catches

Resolution C-24-02 + 2023 EPO rec catches

Yield and Safety tradeoff



- *HCRs that had the highest probability of SSB being at or above the second rebuilding target had the lowest yield metrics and vice-versa.*

Quilt table has all performance metrics

Performance Indicators

Reference Set

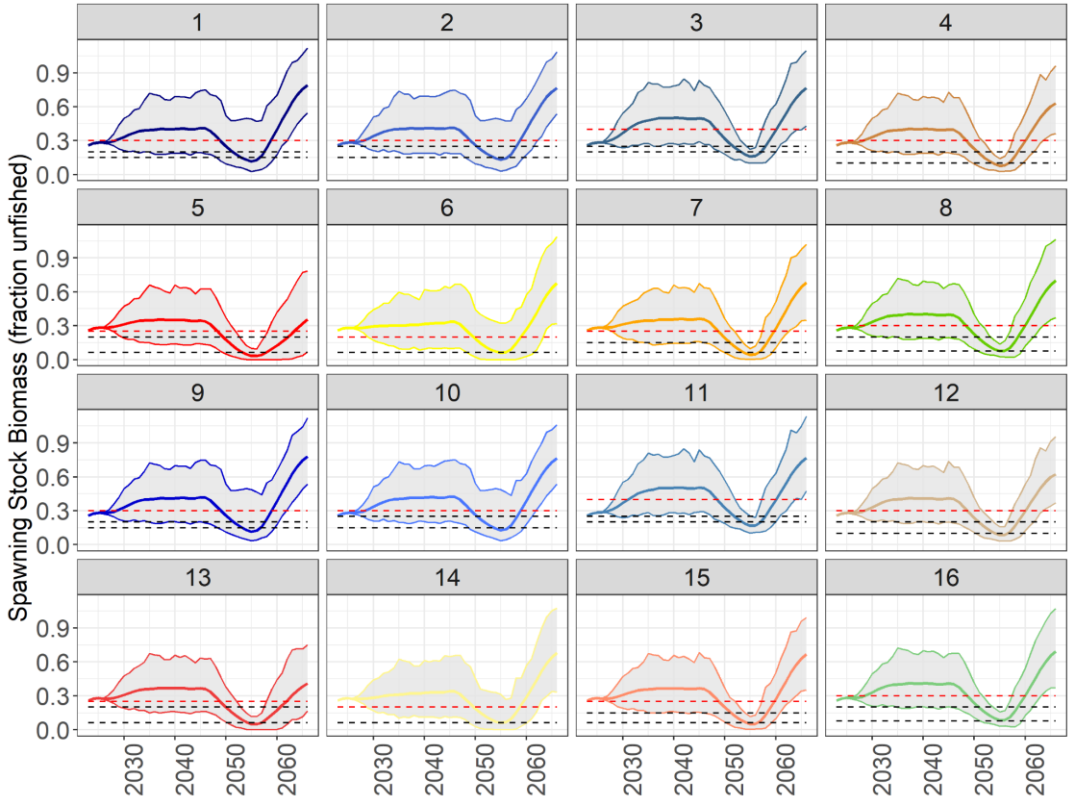
	Prob SSB => LRP	Prob SSB => 20%SSBo	Prob F <= Ftarget	Prob SSB => SSBtarget	% change TAC +	% change TAC -	EPO Impact	Median annual catch	Median years 5-10 annual catch	Median years 11-23 annual catch	Median WCPO large fish annual TAC	Median WCPO small fish annual TAC	Median EPO annual TAC	2026 TAC	2026 TAC WCPO large fish	2026 TAC WCPO small fish	2026 TAC EPO
1	93	87	81	62	-14	-11	23	28685	26744	31094	16174	4093	6794	25868	14836	4512	6520
2	94	87	84	64	-15	-14	23	28330	26054	30691	15618	4069	6794	25868	14836	4512	6520
3	91	91	85	56	-17	-9	24	24026	21135	26361	13472	3346	5971	24366	14836	3844	5686
4	99	86	80	61	-13	-11	23	28722	26745	31124	16221	4102	6794	25868	14836	4512	6520
5	100	81	78	66	-13	-12	22	30183	28894	32227	16965	4617	7054	27485	14836	5161	7488
6	99	76	79	76	-14	-14	22	32174	31286	34249	18243	5063	7609	29437	14836	5939	8662
7	100	82	79	67	-13	-11	23	30616	28940	32814	17330	4557	7192	27485	14836	5161	7488
8	100	86	80	61	-14	-11	23	28741	26746	31127	16222	4101	6794	25868	14836	4512	6520
9	93	86	83	63	-13	-10	32	28773	26503	30537	13378	3722	10528	27942	14073	4392	9476
10	93	87	85	65	-16	-12	32	28582	25973	30368	13242	3722	10433	27942	14073	4392	9476
11	91	91	86	56	-16	-8	32	23748	21378	26147	10877	3023	8632	23653	10724	3844	9085
12	99	86	82	62	-12	-10	33	28812	26505	30572	13414	3722	10568	27942	14073	4392	9476
13	100	82	81	68	-13	-12	30	30735	29380	31768	14567	4160	11175	29323	14836	5010	9476
14	99	77	81	77	-15	-13	31	32369	32077	33617	15040	4592	11323	30061	14836	5749	9476
15	100	81	80	67	-12	-10	32	30988	29413	32137	14567	4108	11323	29323	14836	5010	9476
16	100	86	82	62	-12	-10	33	28826	26507	30582	13413	3722	10565	27942	14073	4392	9476

- Color reflects range of each column. Highest have dark green, lowest light yellow, different shades of green to yellow in between – highlights differences; Safety metrics reversed so higher is better; upwards change in TAC made – so higher is better

Robustness Tests

All HCRs were robust to discard and effort-creep uncertainty, but performance deteriorated under extreme drops in recruitment over a 10-year period

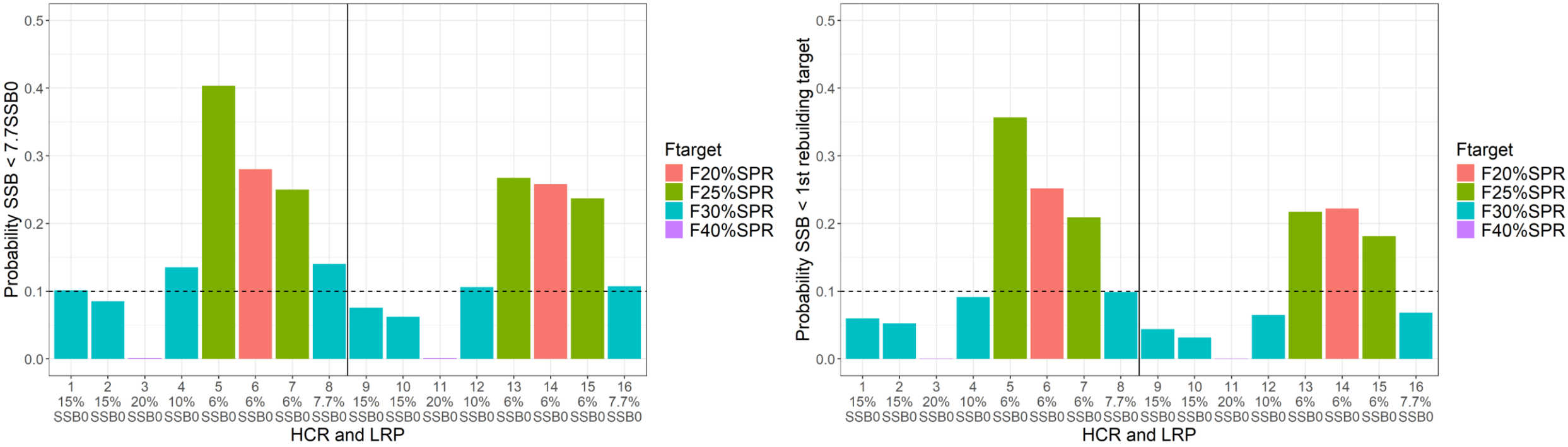
Recruitment drop robustness results



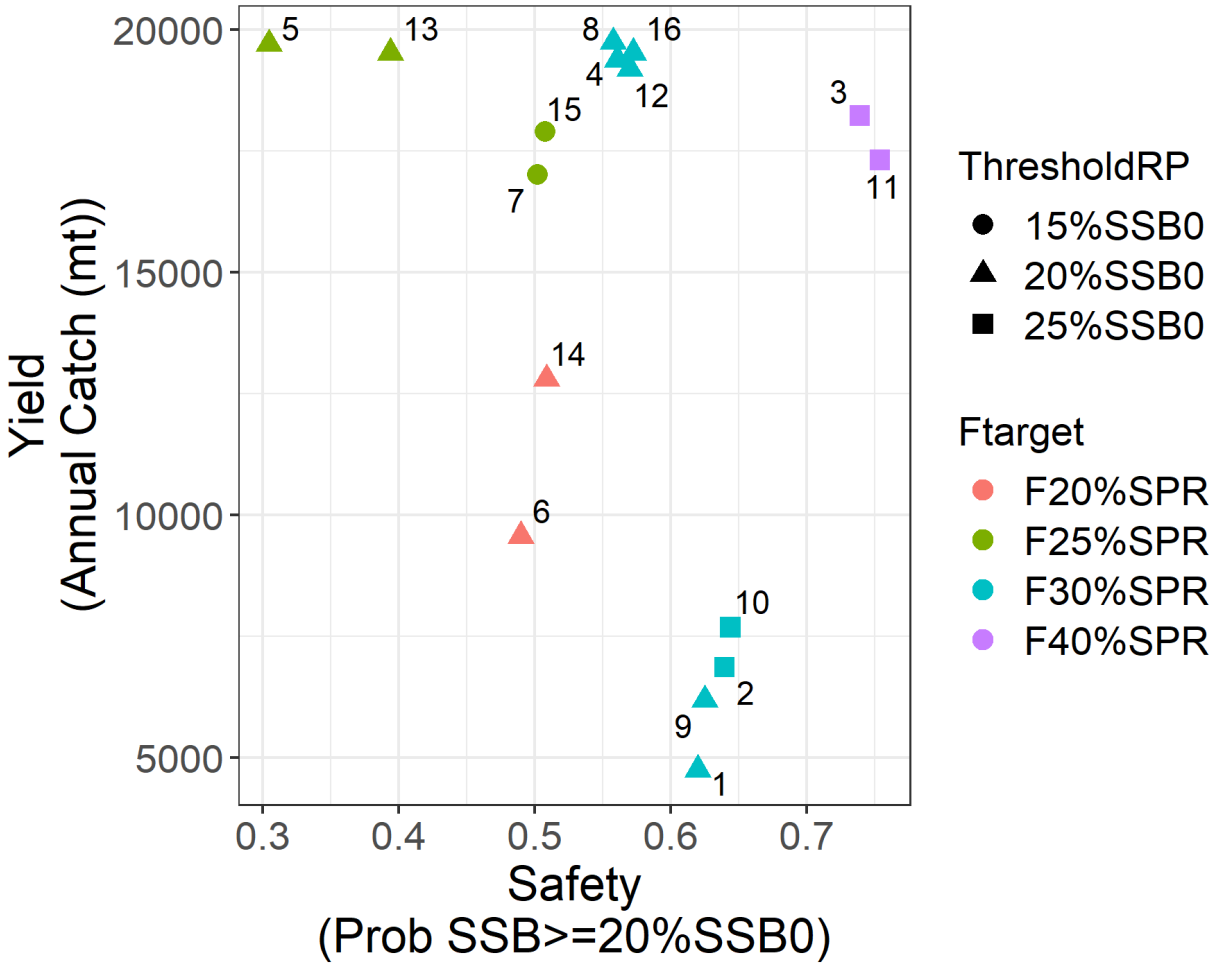
Consider inclusion of recruitment drop as part of exceptional circumstances determination

Robustness Tests

Given their different $F_{TARGETS}$ and thus different starting relative SSB levels, median SSB for some HCRs did not fall as low as others and able to maintain a lower than 10% probability of breaching the interim IATTC LRP of 7.7%$SSB_{F=0}$ or the first rebuilding target for PBF of 6.3%$SSB_{F=0}$



Robustness Tests



- The tradeoff between yield and safety of reference set was not apparent. HCRs 3 and 11, with the lowest F_{TARGET}, had the highest safety, but not the lowest yield
- HCRs 6 and 14, which had the highest F_{TARGET}, did not have the highest yield
- HCRs 5 and 13 had a high yield due to switching to constant catch control, but this came at the cost of safety
- HCRs 4, 8, 12, and 16 had similar yield to HCRs 5 and 13, but had better safety
- Variable yield performance among HCRs with a F30%SPR target. HCRs 1, 2, 9, 10 had lower yield and lower catch stability, but a slight improvement in safety

Summary

1. *All HCRs were able to maintain a low probability (<20%) of the stock breaching their respective LRP and the IATTC's interim reference point for tropical tunas of 7.7%$SSB_{F=0}$. In addition, all HCRs except for HCRs 6 and 14 were also able to maintain a low probability (<20%) of breaching the second rebuilding target of 20%$SSB_{F=0}$. Under all HCRs, median SSB increased from initial conditions to levels above their respective targets (Fig. ES4).*
2. *There was a tradeoff between the safety metrics (e.g., probability of being at or above the second rebuilding target of 20%$SSB_{F=0}$) and yield metrics (e.g., median annual catch in mt). Those HCRs that had the highest probability of SSB being at or above the second rebuilding target had the lowest yield metrics and vice-versa.*
3. *Catch in the medium and long term for all HCRs is expected to be higher than the current catch limit, except for HCRs 3 and 11 in the medium term. However, the expected TAC trends differ among fleets, with only the WCPO large fish fleet and the EPO fleet under a 70:30 impact ratio increasing above current catch limits.*

Summary

4. *HCRs 1, 2, 3, 9, 10, and 11 had more instances of drastic (>25%) declines in catches due to severe management intervention resulting from breaching their respective LRP more often than other HCRs*
5. *HCRs with a first control point (i.e., ThRP) closer to the target SSB (SSB associated with their F_{TARGET}) had lower catch stability.*
6. *All HCRs met the status objective of maintaining fishing mortality at or below the F_{TARGET} with at least 50% probability.*
7. *The different fisheries impact ratios only affected yield metrics but other performance metrics remained almost unchanged.*
8. *Under robustness tests, all HCRs were robust to discard and effort-creep uncertainty, but performance deteriorated under extreme drops (40%) in recruitment over a 10-year period.*

The PBF MSE code is available at https://github.com/detommas/PBF_MSE

Results are available via a shiny app at https://connect.fisheries.noaa.gov/ISCPBF-MSE-tool

Thank you!