

Comisión Interamericana del Atún Tropical
Inter-American Tropical Tuna Commission



Management Strategy Evaluation for bigeye tuna in the eastern Pacific Ocean

Haikun Xu and Mark N. Maunder

Inter-American Tropical Tuna Commission

3rd Meeting of the Working Group on Management Strategy Evaluation
Online meeting, April 20-21 2026

Outline

1. MSE additional explorations **before the informal session held in mid February**
2. Full MSE simulation results **after the informal session held in mid February**

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Outline (Document MSE-03-04)

INTER-AMERICAN TROPICAL TUNA COMMISSION

AD HOC WORKING GROUP TO STRENGTHEN THE DIALOGUE AMONG
SCIENTISTS, MANAGERS AND OTHER STAKEHOLDERS ON MANAGEMENT
STRATEGY EVALUATION (WORKING GROUP ON MSE)

3rd MEETING

(by videoconference)

XX-XX 2026

DOCUMENT MSE-03-04

PRELIMINARY RESULTS OF THE MANAGEMENT STRATEGY
EVALUATION FOR BIGEYE TUNA IN THE EASTERN PACIFIC OCEAN

Haikun Xu and Mark N. Maunder
Inter-American Tropical Tuna Commission

1. INTRODUCTION

An open-source R package (*IATTCMSE*) has been developed to conduct management strategy evaluation (MSE) for tropical tunas in the eastern Pacific Ocean (EPO) and is publicly available at <https://github.com/HaikunXu/IATTCMSE>. The package has been rigorously tested for bigeye tuna in the EPO using the suite of reference models included in the 2024 benchmark stock assessment (SAC-15-02). This report presents preliminary results intended to support discussion at the second MSE workshop.

Since the previous meeting of the MSE working group (MSEWG) in December 2025, additional analyses and simulations have been conducted to address comments provided during that meeting. These comments fall into three broad categories: performance indicators, harvest control rules (HCRs), and MSE specifications. In response to comments on performance indicators, the MSE code was updated to generate maximum sustainable yield (MSY)-related quantities, enabling calculation of the probability that spawning biomass exceeds $50\%S_{MSY}$ and the probability that the stock remains in the green quadrant of the Kobe plot ($S > S_{MSY}$ and $F < F_{MSY}$). Projected longline catch and catch-per-unit-effort (CPUE) is compared with historical levels. Projected total longline catch was also compared with the current total longline quota specified in Resolution C-21-04. The explicit inclusion of a limit reference point ($50\%S_{MSY}$) in the HCR was also explored, and its effects on MSE performance were evaluated. With respect to MSE specifications, implementation error was incorporated into the management module to assess its influence on simulation outcomes.

In addition to addressing the comments from the previous meeting, the staff evaluated the performance of the eight candidate HCRs identified for prioritization in the previous meeting to facilitate finalization of the set of HCRs to be tested for bigeye tuna in the EPO.

2. MSE FRAMEWORK

2.1. Operating models

The operating models (OMs) used in the MSE consist of the 36 reference models included in the 2024 risk analysis (ensemble of stock assessment models). For the purposes of the MSE, these models were updated

COMISIÓN INTERAMERICANA DEL ATÚN TROPICAL

GRUPO DE TRABAJO ESPECIAL PARA FORTALECER EL DIÁLOGO ENTRE CIENTÍFICOS,
ADMINISTRADORES Y OTROS INTERESADOS SOBRE LA EVALUACIÓN DE
ESTRATEGIAS DE ORDENACIÓN (GRUPO DE TRABAJO SOBRE EEO)

3ª REUNIÓN

(por videoconferencia)

XX-XX de 2026

DOCUMENTO MSE-03-04

RESULTADOS PRELIMINARES DE LA EVALUACIÓN DE ESTRATEGIAS DE
ORDENACIÓN DEL ATÚN PATUDO EN EL OCÉANO PACÍFICO ORIENTAL

Haikun Xu y Mark N. Maunder
Comisión Interamericana del Atún Tropical

1. INTRODUCCIÓN

Se desarrolló un paquete en R de código abierto (*IATTCMSE*) para realizar la evaluación de estrategias de ordenación (EEO) para los atunes tropicales en el Océano Pacífico oriental (OPO) y está disponible al público en <https://github.com/HaikunXu/IATTCMSE>. El paquete ha sido rigurosamente probado para el atún patudo en el OPO usando el conjunto de modelos de referencia incluidos en la evaluación de referencia de 2024 (SAC-15-02). Este informe presenta resultados preliminares para apoyar las discusiones en el segundo taller sobre EEO.

Desde la reunión anterior del Grupo de Trabajo sobre EEO (GTEEO), celebrada en diciembre de 2025, se han realizado análisis y simulaciones adicionales para abordar los comentarios recibidos durante dicha reunión. Estos comentarios se dividen en tres grandes categorías: indicadores de desempeño, reglas de control de extracción (RCE) y especificaciones de la EEO. En respuesta a los comentarios sobre los indicadores de desempeño, se actualizó el código de EEO para generar cantidades relacionadas con el rendimiento máximo sostenible (RMS), lo que permite calcular la probabilidad de que la biomasa reproductora rebase $50\%S_{RMS}$ y la probabilidad de que la población permanezca en el cuadrante verde de la gráfica de Kobe ($S > S_{RMS}$ y $F < F_{RMS}$). La captura de palangre proyectada y la captura por unidad de esfuerzo (CPUE) se comparan con los niveles históricos. La captura de palangre total proyectada también se comparó con la cuota de palangre total actual especificada en la resolución C-21-04. También se estudió la inclusión explícita de un punto de referencia límite ($50\%S_{RMS}$) en la RCE y se evaluaron sus efectos sobre el desempeño de la EEO. Con respecto a las especificaciones de la EEO, se incorporó el error de implementación en el módulo de ordenación para evaluar su influencia en los resultados de las simulaciones.

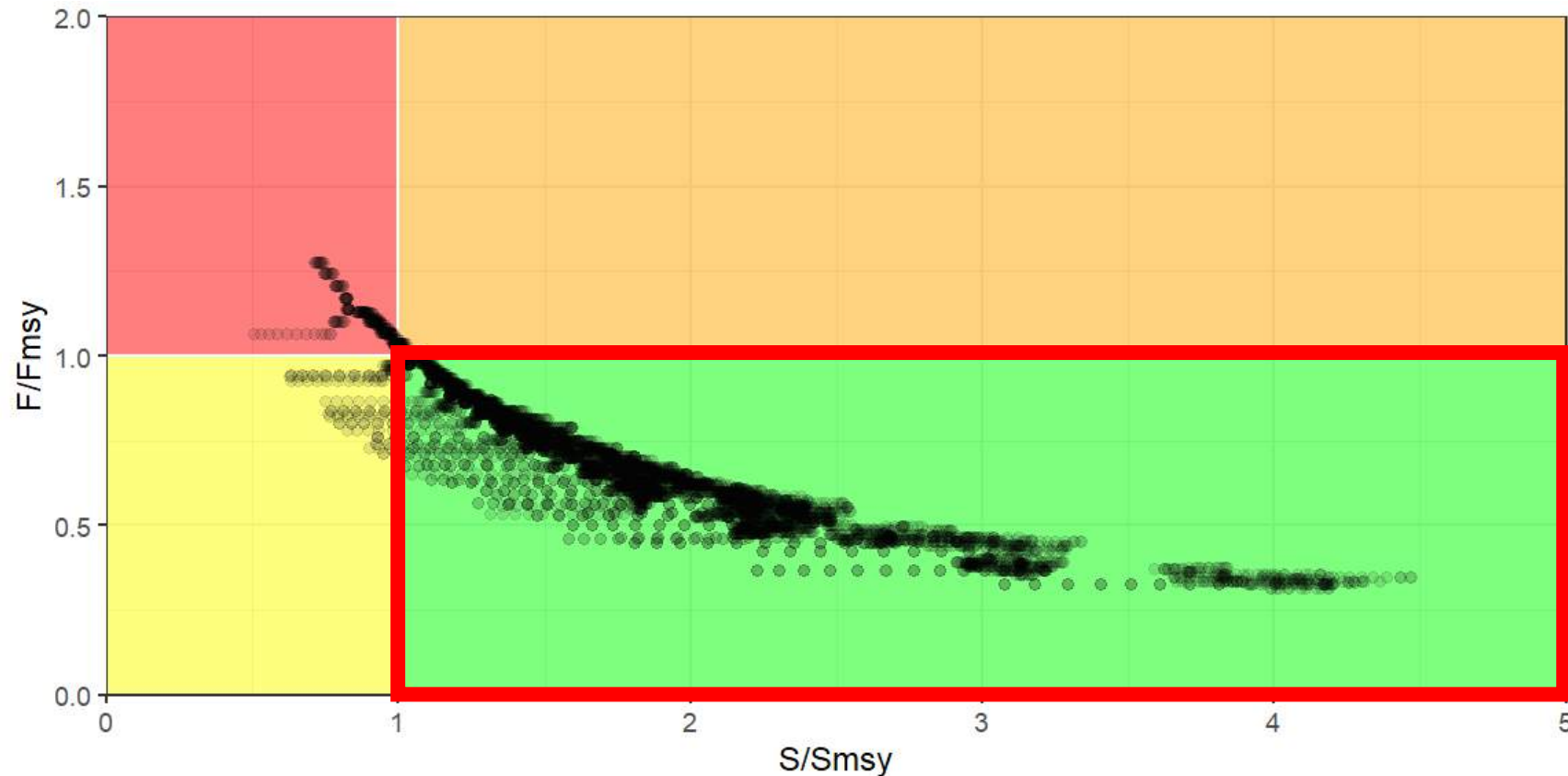
Además de abordar los comentarios de la reunión anterior, el personal evaluó el desempeño de las ocho RCE candidatas identificadas como prioritarias en la reunión anterior para facilitar la finalización del conjunto de RCE que se probarán para el atún patudo en el OPO.



Additional performance indicators – Kobe plot

For the stock under the staff HCR:

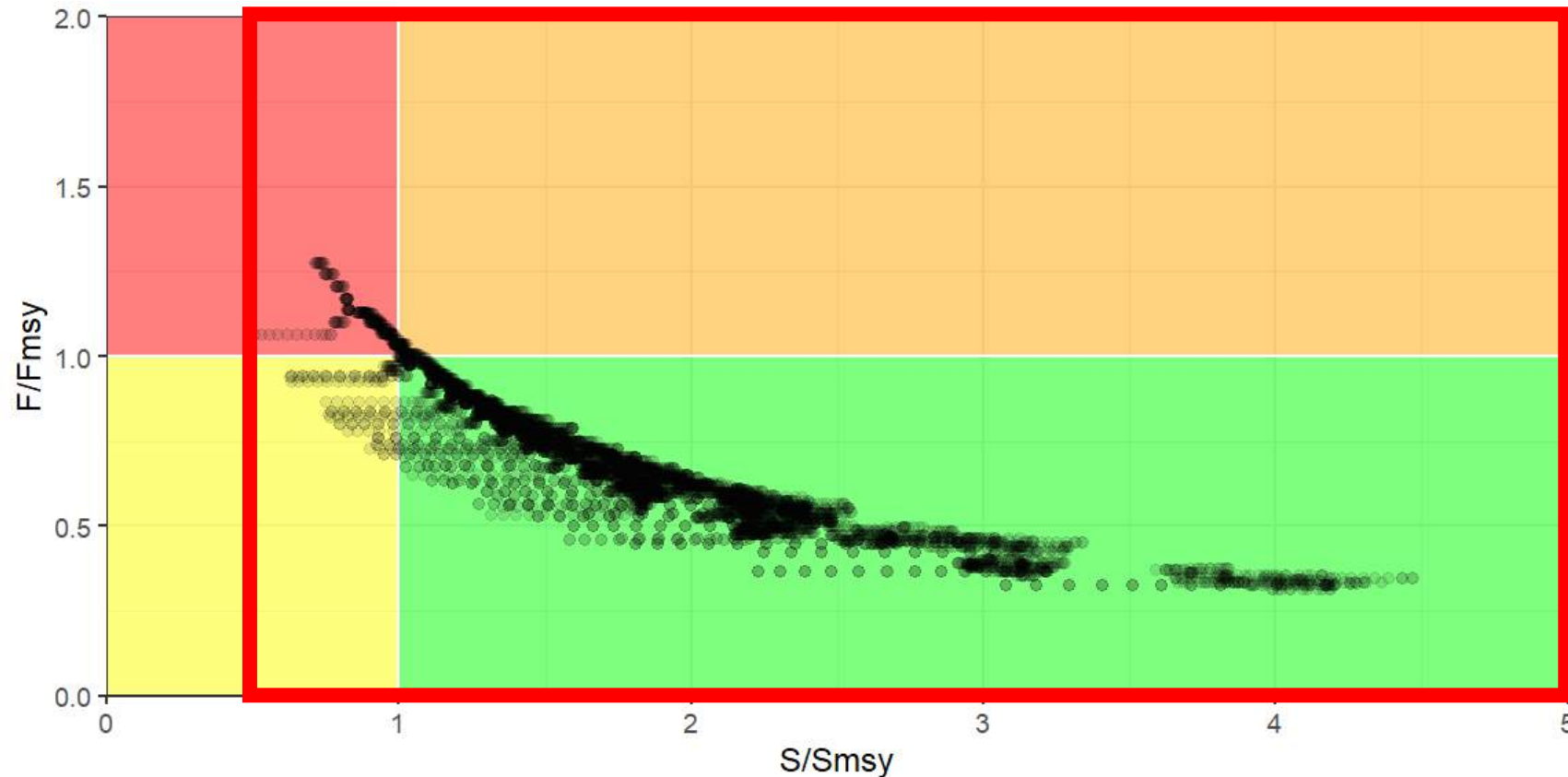
- The probability of being in the green quadrant of the Kobe plot is 92%



Additional performance indicators – Kobe plot

For the stock under the staff HCR:

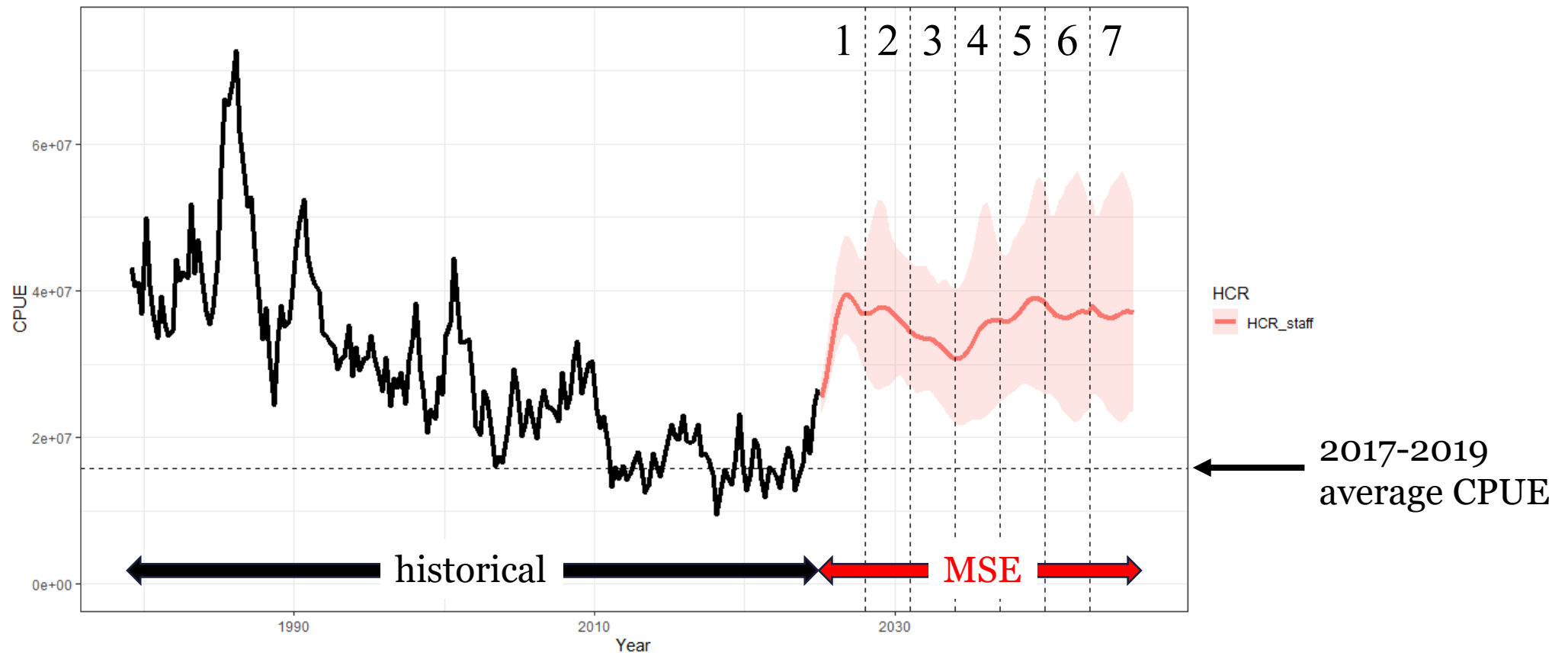
- The probability of being in the green quadrant of the Kobe plot is 92%
- The probability of being above 50%SMSY is 100%



Additional performance indicators - longline CPUE

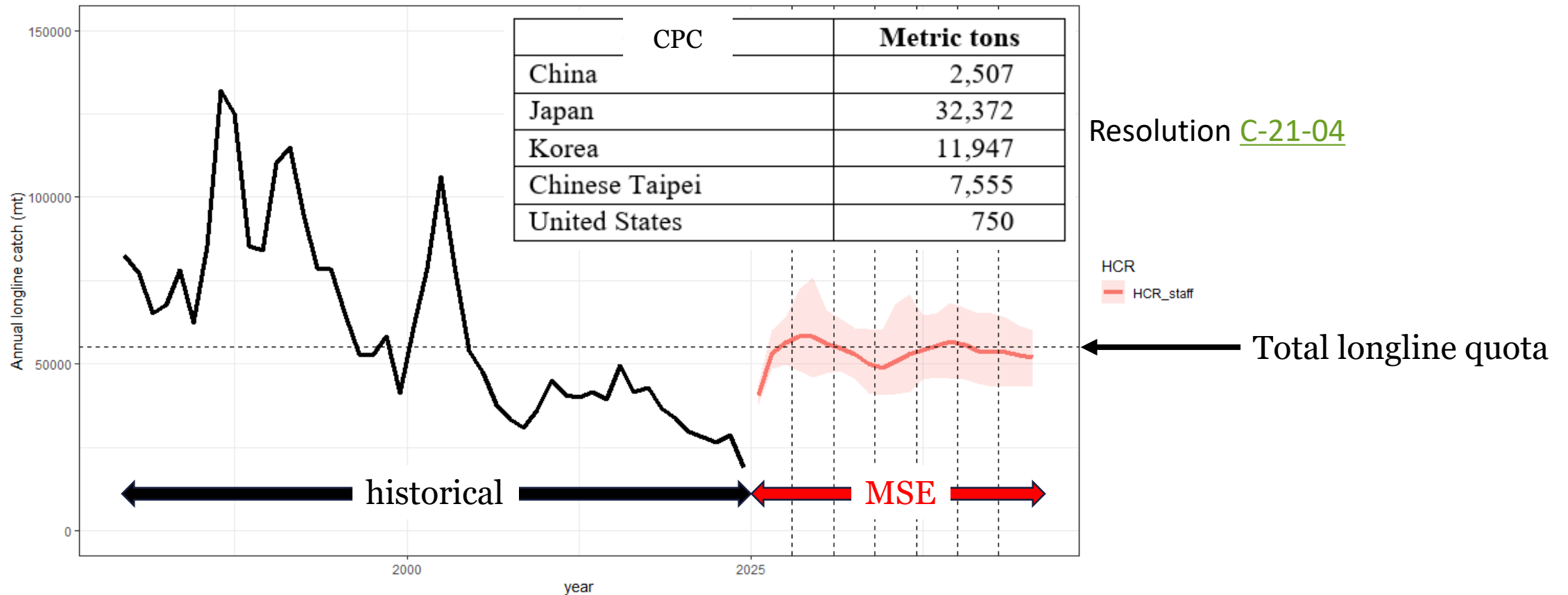
For the stock under the staff HCR:

Longline CPUE is projected to reach to about $2 \times$ average for 2017-2019



Additional performance indicators - longline catch

For the stock under the staff HCR:
longline catch is projected to be close to the total quota (55,131 mt)

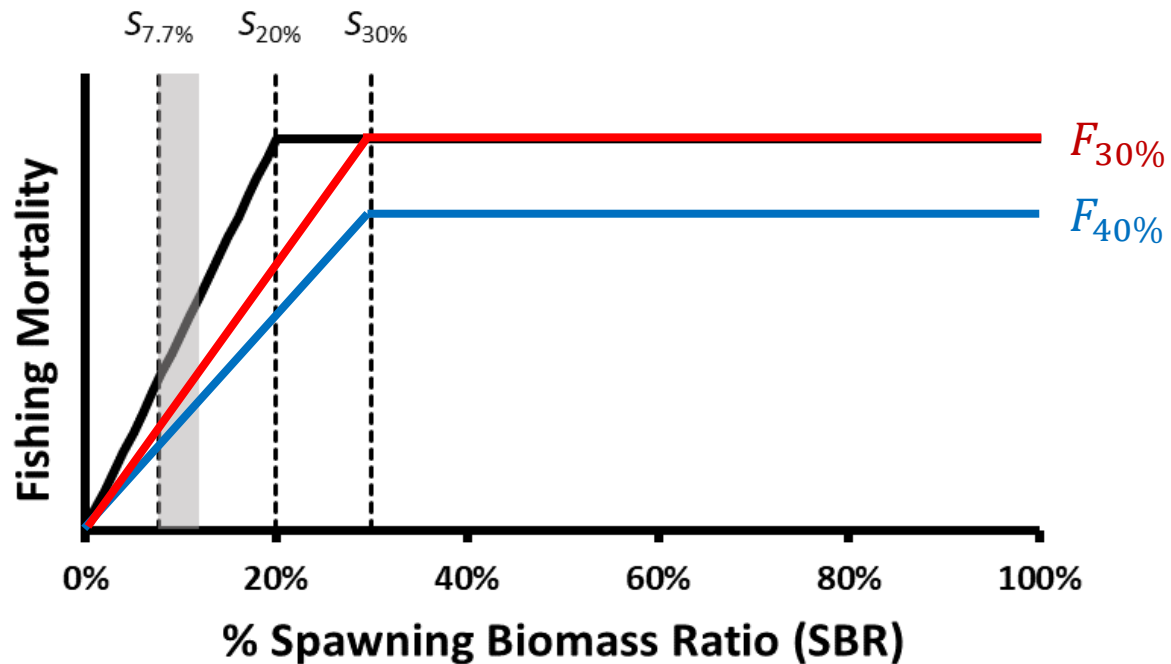


Discussion - longline catch quota

- The MSE cannot set a longline catch quota in simulations due to technical difficulties (unable to resolve in the near term), so all simulations assume no quota for longline fisheries
- Longline CPUE for bigeye tuna is expected to reach approximately twice the historical average observed during 2017–2019
- Simulations suggest that future longline catches, under the current longline fishing effort, could exceed the total quota in a significant portion (>33%) of future years

Evaluate the performance of some HCRs

The MSEWG proposes to remove the 10-day cap for the increase in fishery closure when the stock is estimated to be below the control point, allowing for rapid response to depletion

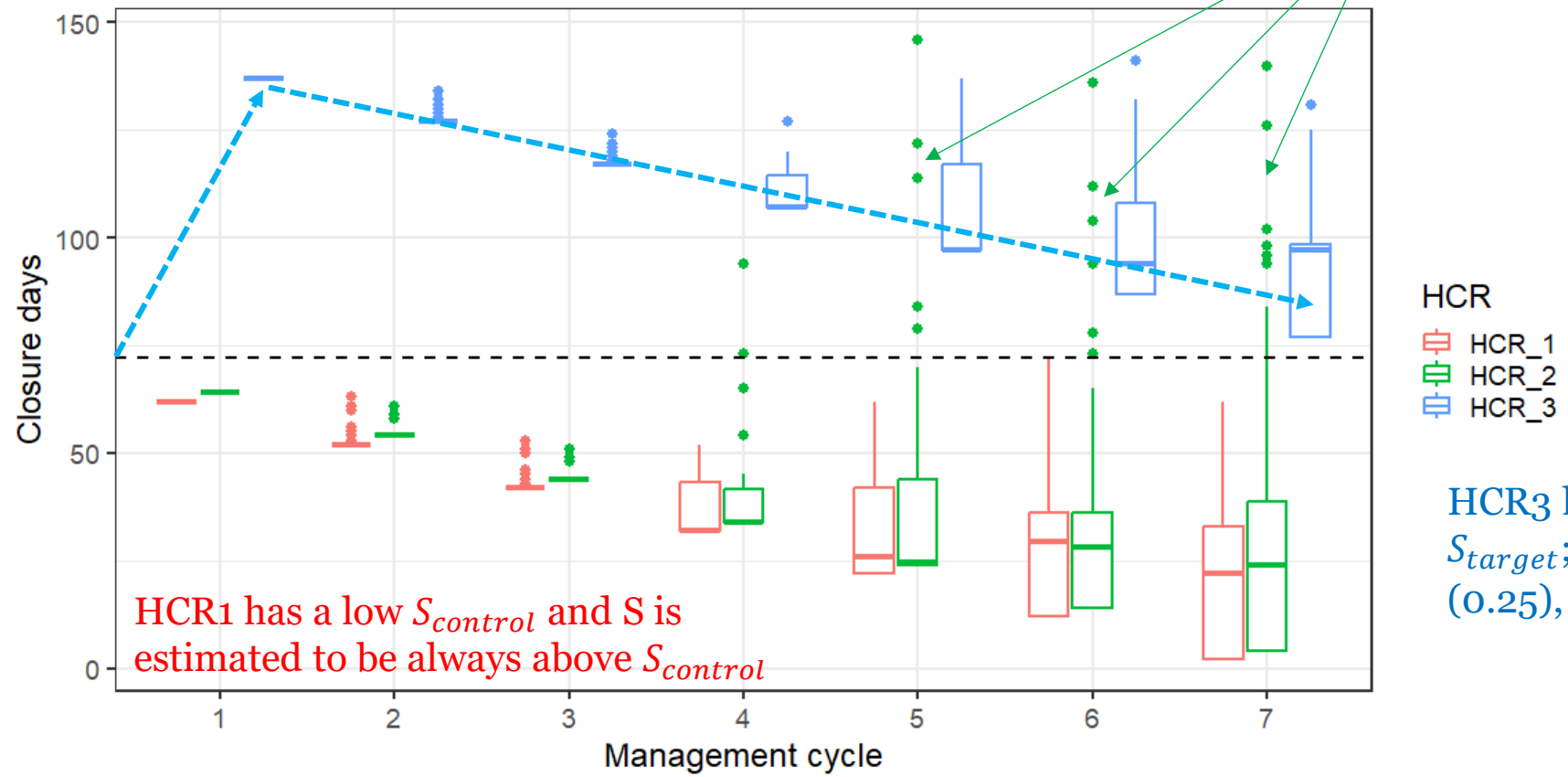


Component	HCR1	HCR2	HCR3
F_{max}	$F_{30\%}$	$F_{40\%}$	$F_{30\%}$
$S_{control}$	$S_{20\%}$	$S_{30\%}$	$S_{30\%}$
Max change in closure when $S > S_{control}$	10 days	10 days	10 days

Evaluate the performance of some HCRs

Component	HCR1	HCR2	HCR3
F_{max}	$F_{30\%}$	$F_{30\%}$	$F_{40\%}$
$S_{control}$	$S_{20\%}$	$S_{30\%}$	$S_{30\%}$
Max change in closure when $S > S_{control}$	10 days	10 days	10 days

HCR2 has same $S_{control}$ and S_{target} ;
occasionally leading to some extreme closures

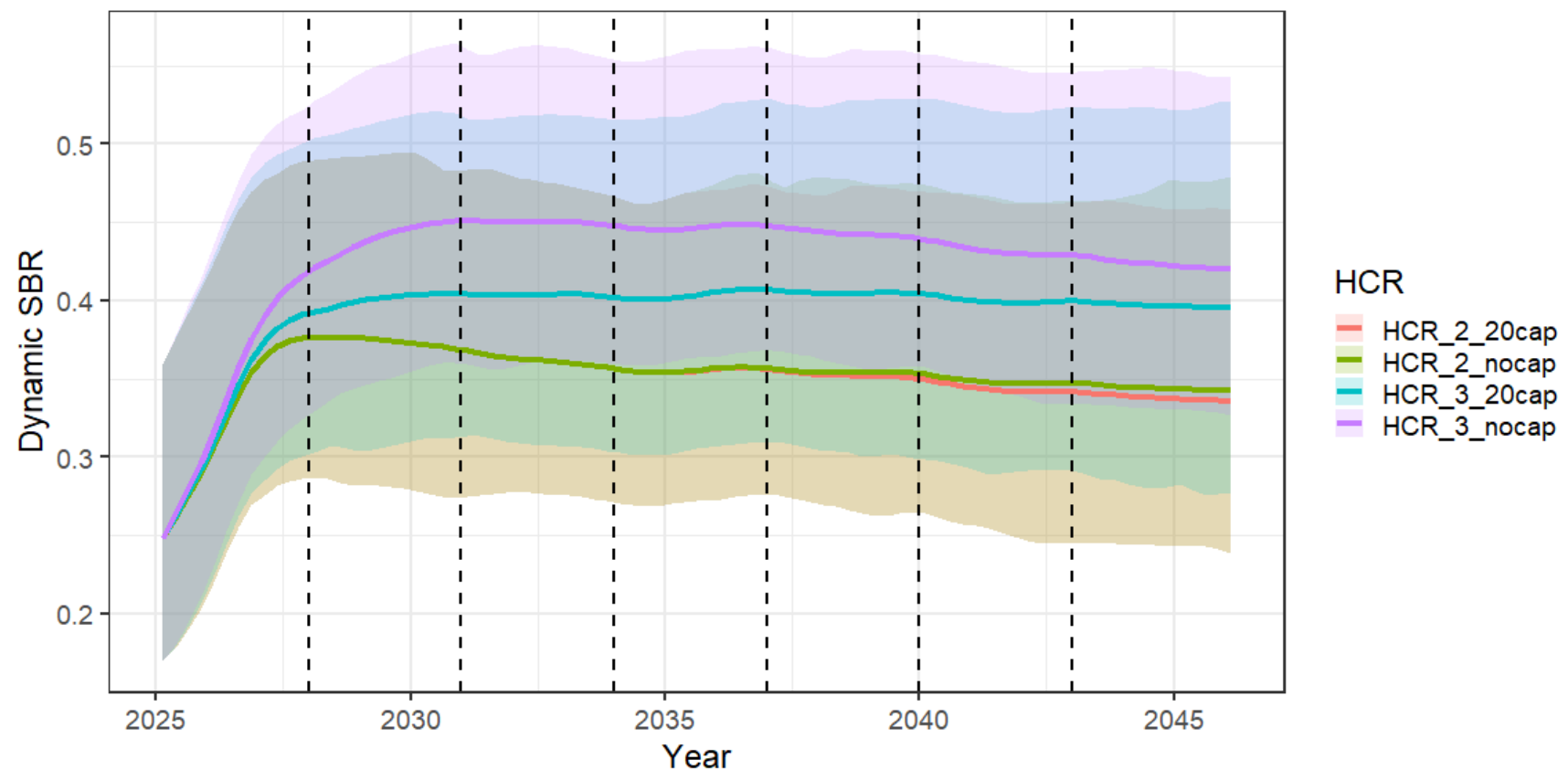


Evaluate the performance of some HCRs

- Removing the 10-day cap when $S < S_{\text{control}}$ intends to impose rapid response to depletion but leads to undesirable outcomes:
 - Instability (HCR2): large increases in closure day are occasionally observed
 - Inflexibility (HCR3): management action can get “stuck” in the excessively conservative zone when S rebuilds above S_{control} due to the 10-day cap when $S > S_{\text{control}}$
- A 20-day cap instead of no cap when $S < S_{\text{control}}$ is tested for HCR2 and HCR3

Evaluate the performance of some HCRs

Component	HCR2_20cap	HCR2_nocap	HCR3_20cap	HCR3_nocap
F_{max}	$F_{30\%}$	$F_{30\%}$	$F_{40\%}$	$F_{40\%}$
$S_{control}$	$S_{30\%}$	$S_{30\%}$	$S_{30\%}$	$S_{30\%}$
Max change in closure	10 days ($S > S_{control}$) 20 days ($S < S_{control}$)	10 days ($S > S_{control}$) No cap ($S < S_{control}$)	10 days ($S > S_{control}$) 20 days ($S < S_{control}$)	10 days ($S > S_{control}$) No cap ($S < S_{control}$)

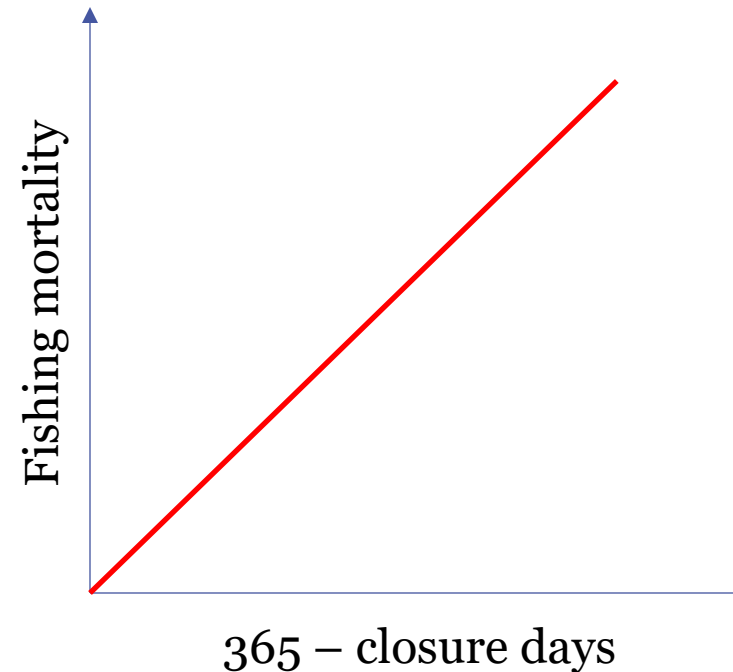


Evaluate the performance of some HCRs

- Removing the 10-day cap when $S < S_{\text{control}}$ intends to impose fast response to stock depletion but does not work well:
 - Instability (HCR2): large increases in the closure are occasionally observed due likely to recruitment-induced stock depletion
 - Inflexibility (HCR3): management action can get “stuck” in the overly conservative zone when S rebuilds above S_{control} due to the 10-day cap when $S > S_{\text{control}}$
- A 20-day cap when $S < S_{\text{control}}$ allows faster responses to depletion while preserving stability:
 - HCR2: get rid of those extremely large increases in the closure
 - HCR3: the stock reaches the target level after just two cycles

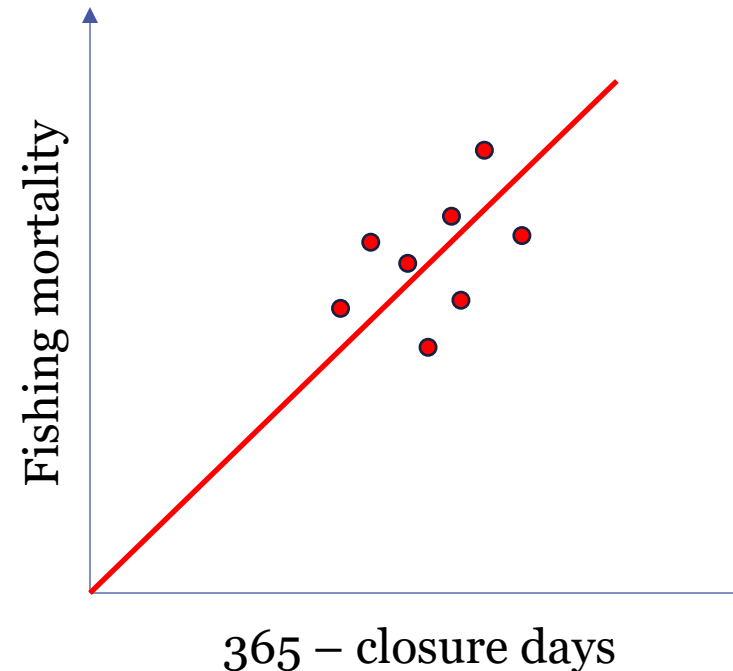
Impact of including implementation error

- We assume that fishing mortality is proportional to $(365 - \text{days of closure})$



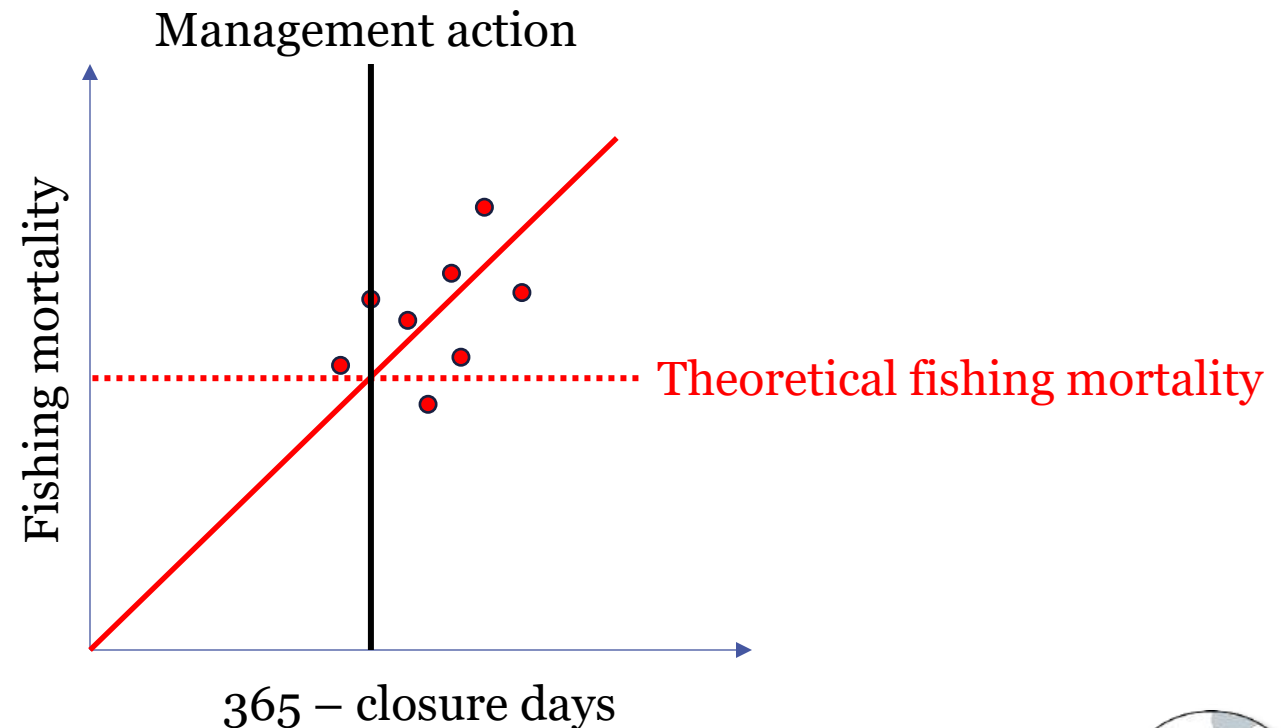
Impact of including implementation error

- We assume that fishing mortality is proportional to (365 – days of closure)
- In the real world, fishing mortality can deviate from this linear relationship due to various factors such as:
 - Fleet capacity
 - Bigeye individual vessel threshold
 - Skipjack abundance
 - Number of active FADs
 - Diesel price



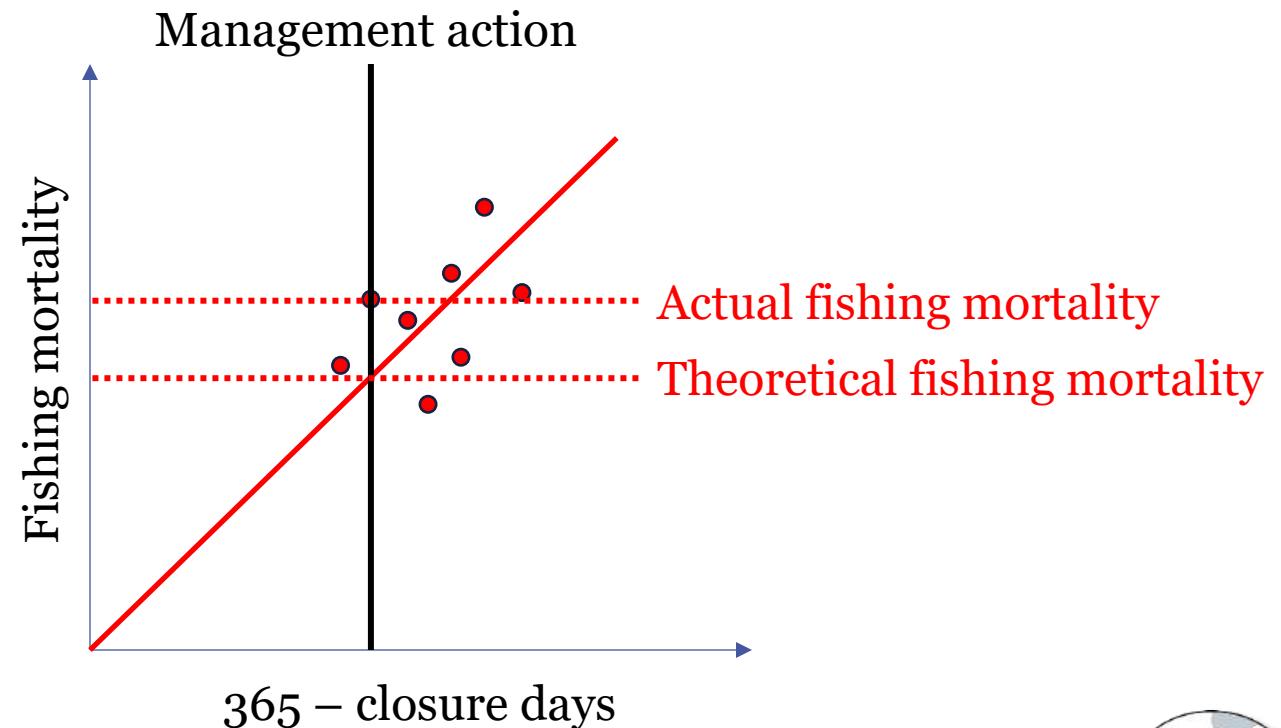
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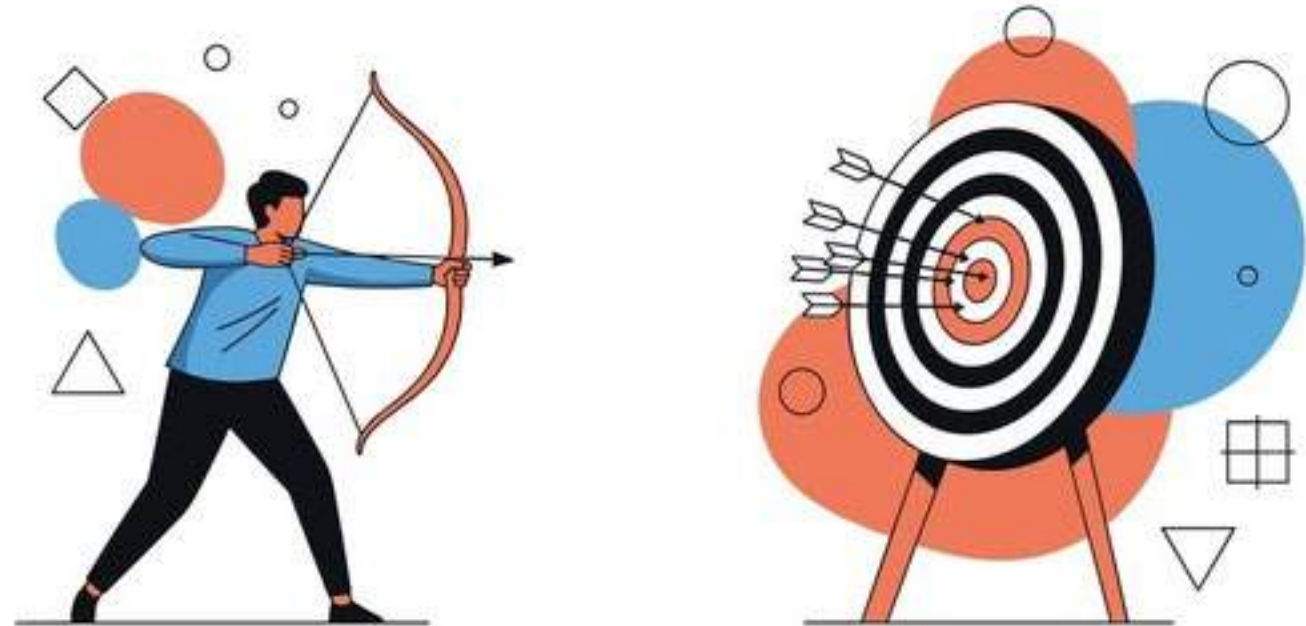
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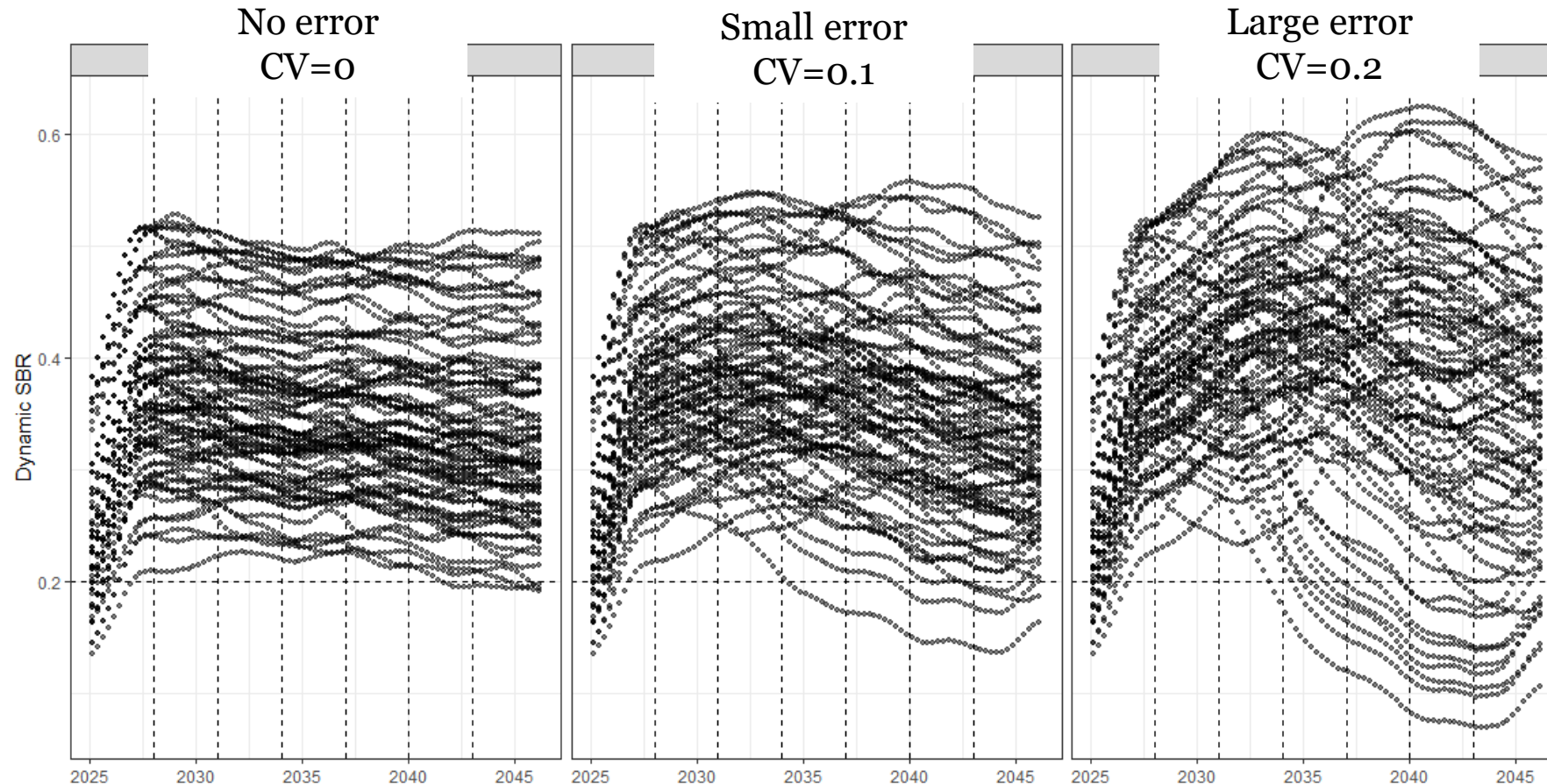


Impact of including implementation error

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- In the real world, fishing mortality can deviate from this linear relationship due to various factors such as:
 - Fleet capacity
 - Bigeye individual vessel threshold
 - Skipjack abundance
 - Number of active FADs
 - Diesel price
- We simulate the MSE using the staff HCR with or without implementation error to evaluate the impact of implementation error on MSE results

Impact of including implementation error

The uncertainty of dynamic SBR is strongly influenced by the degree of implementation error



Discussion: implementation error

- Large implementation error leads to more extreme trajectories, potentially impacting the probability of breaching the limit reference points
- Fishing mortality is influenced by factors beyond fishery closure, including implementation error can enhance the realism and robustness of MSE outcomes
- A remaining question for further discussion is the appropriate magnitude of implementation error – no quantitative estimate for EPO purse-seine fisheries is available
- The implementation error is applied to a fishing mortality that is constant over three years, so $CV=0.1$ seems more likely than $CV=0.2$

Outline

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2. Full MSE simulation results **after the informal session held in mid February**

Comparing the eight candidate HCRs

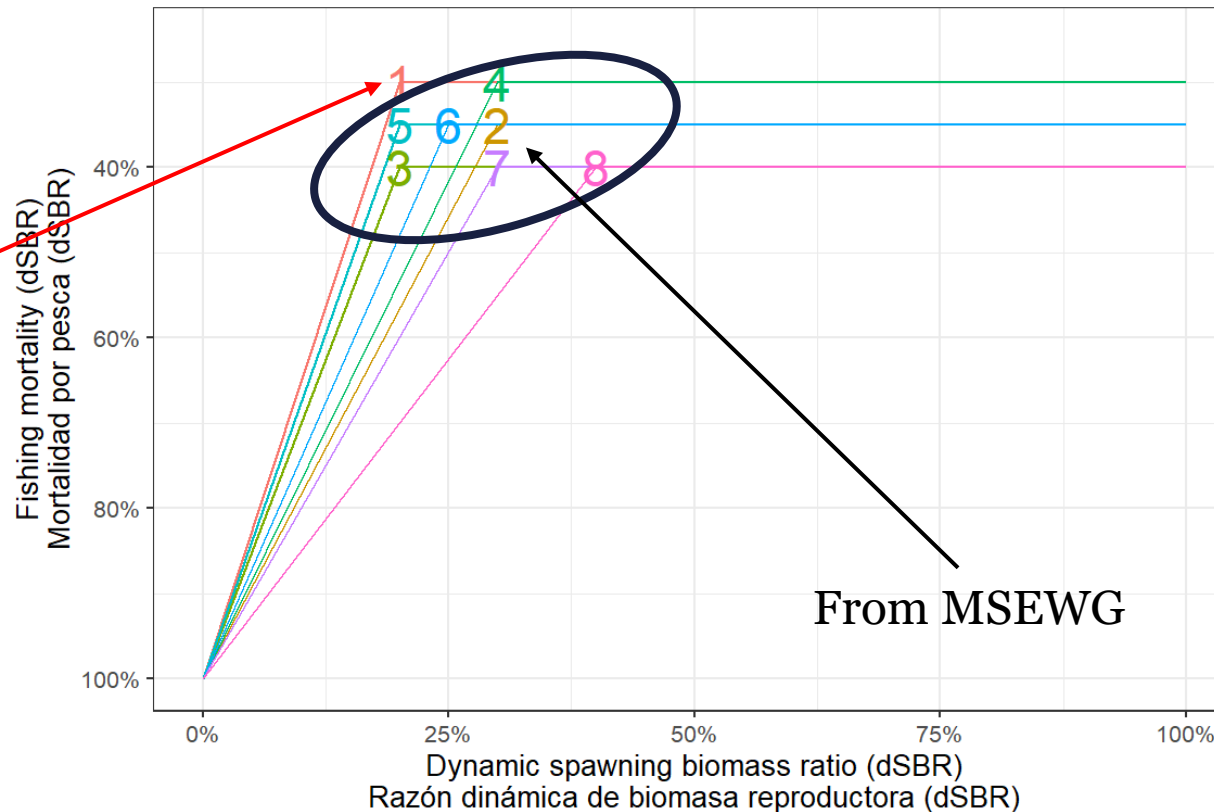
- Implementation error (CV=0.1) is included
- 10/20-day asymmetric cap when the stock is above/below the control point
- 1,200 iterations per HCR – full MSE results

Component	Staff	WG1	WG2	WG3	WG4	WG5	WG6	WG7
Number	1	2	3	4	5	6	7	8
F_{max}	$F_{30\%}$	$F_{35\%}$	$F_{40\%}$	$F_{30\%}$	$F_{35\%}$	$F_{35\%}$	$F_{40\%}$	$F_{40\%}$
$S_{control}$	$S_{20\%}$	$S_{30\%}$	$S_{20\%}$	$S_{30\%}$	$S_{20\%}$	$S_{25\%}$	$S_{30\%}$	$S_{40\%}$
Range for closure change (day): $S > S_{control}$	-10 to 10	-10 to 10	-10 to 10	-10 to 10	-10 to 10	-10 to 10	-10 to 10	-10 to 10
Range for closure change (day): $S < S_{control}$	-10 to 20	-10 to 20	-10 to 20	-10 to 20	-10 to 20	-10 to 20	-10 to 20	-10 to 20
Name	F30-S20	F35-S30	F40-S20	F30-S30	F35-S20	F35-S25	F40-S30	F40-S40

Comparing the eight candidate HCRs

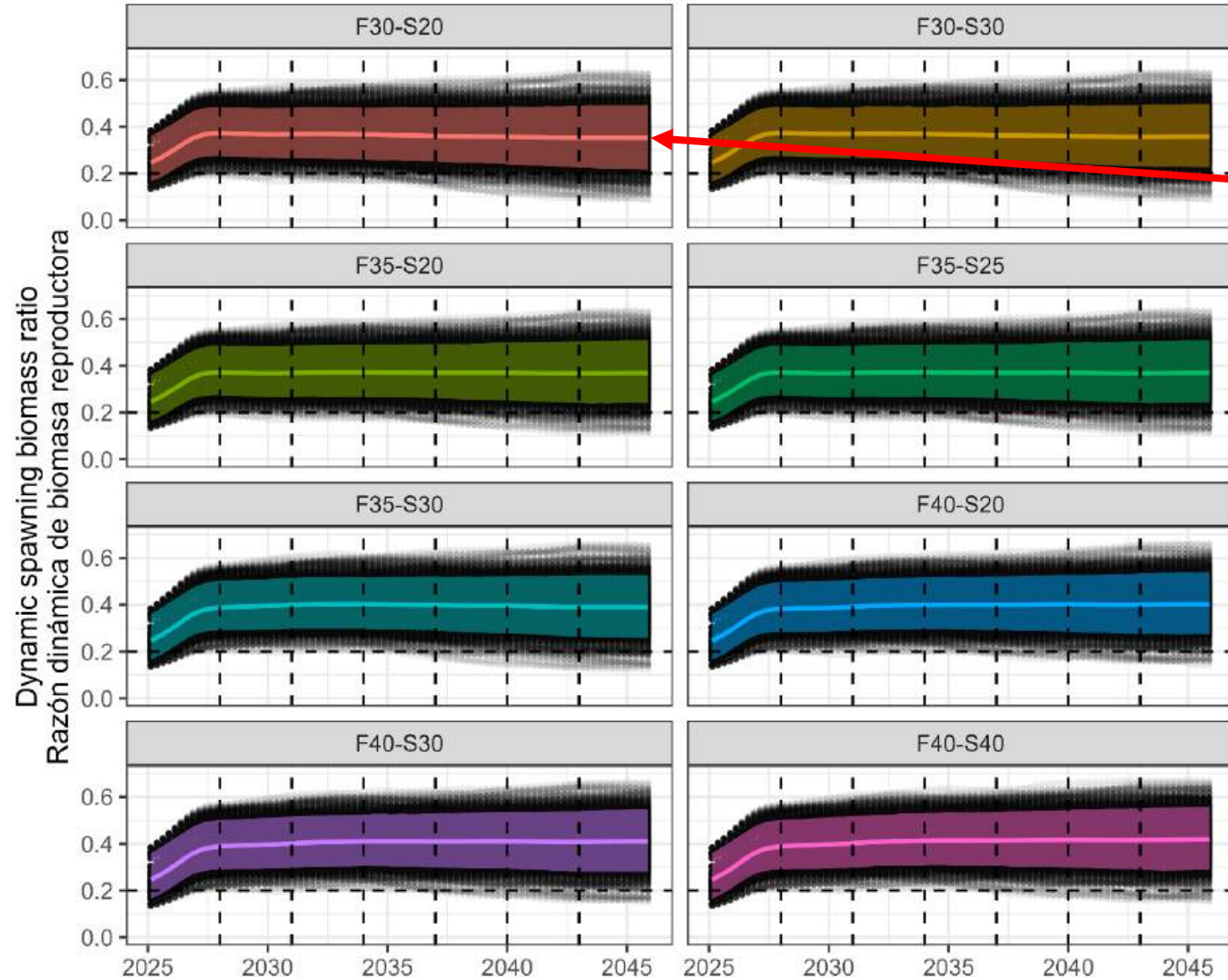
- Implementation error (CV=0.1) is included
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- 1,200 iterations per HCR – full MSE results

From staff
F30-S20

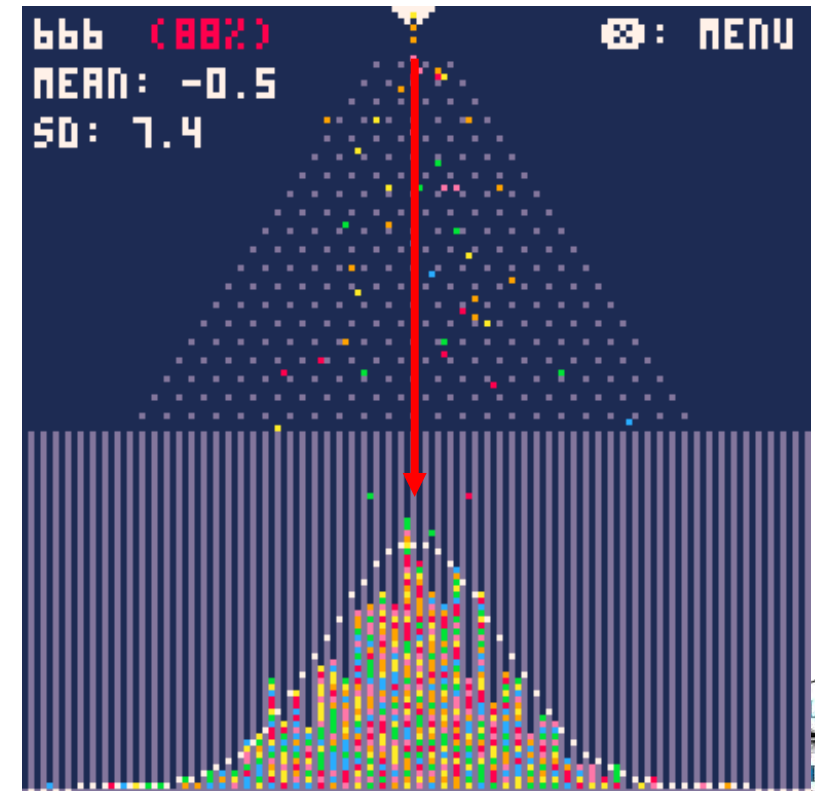


From MSEWG

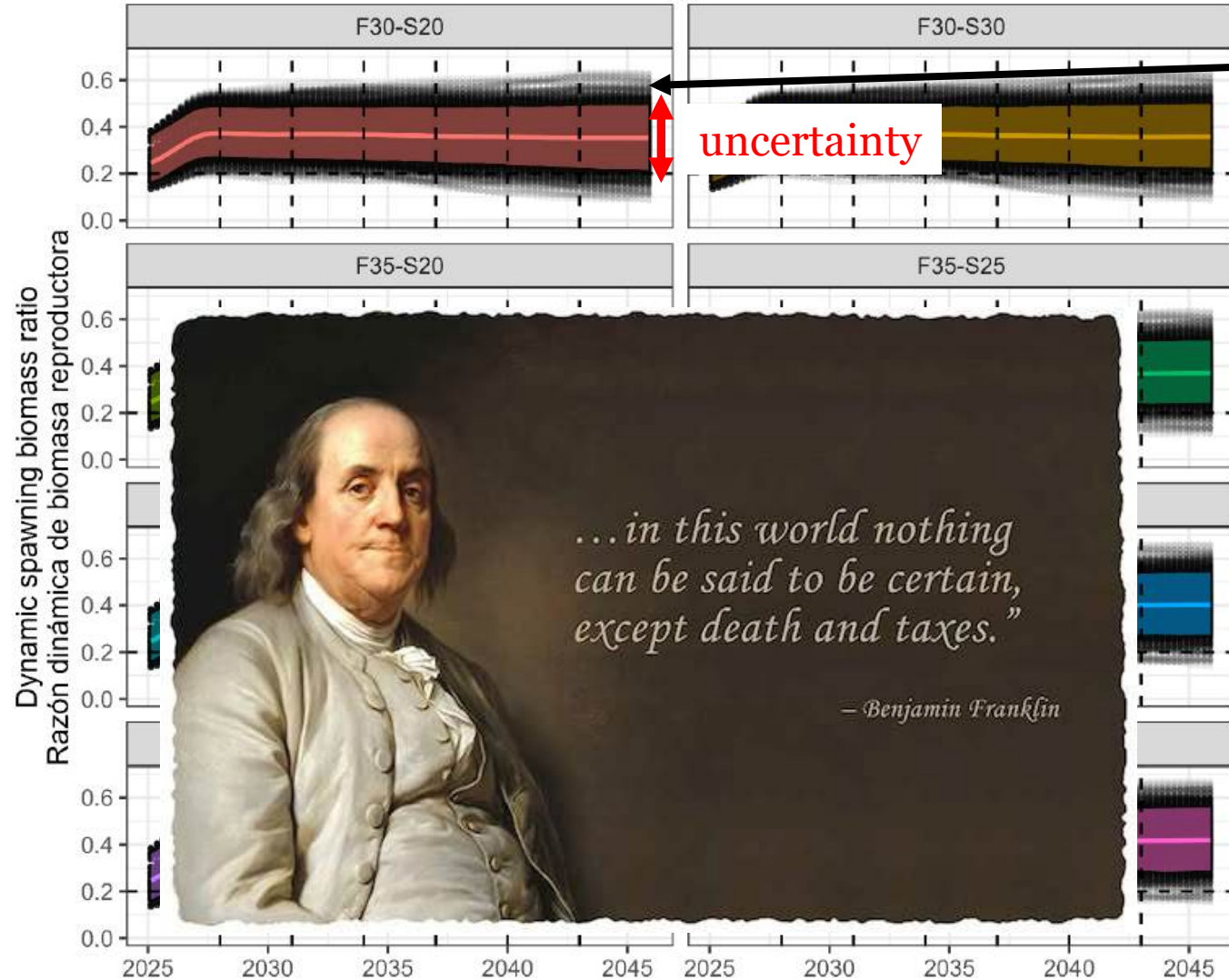
Results: dynamic SBR



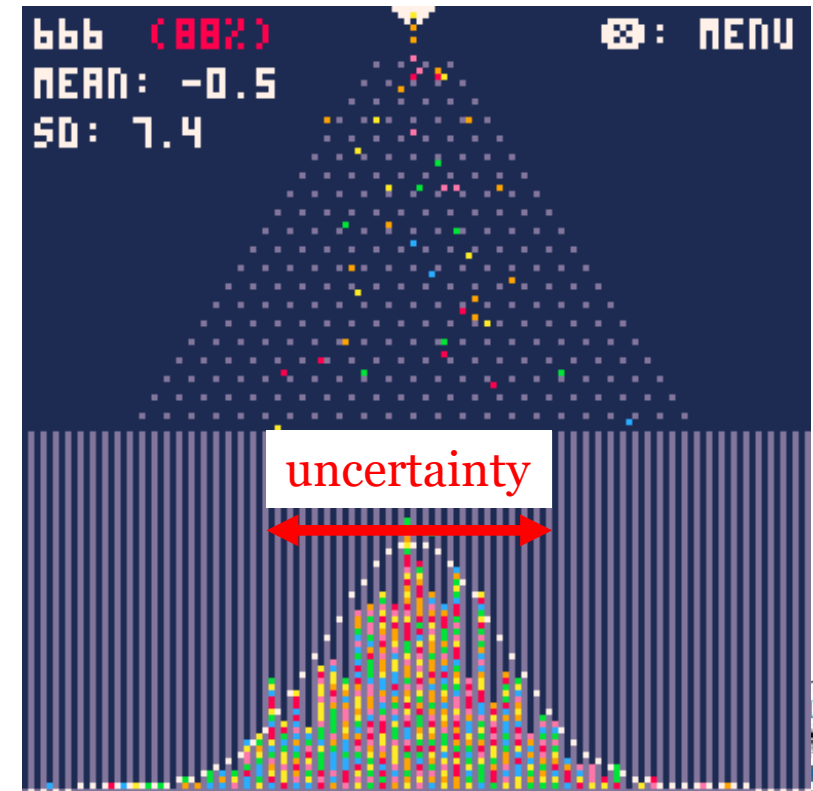
Mean



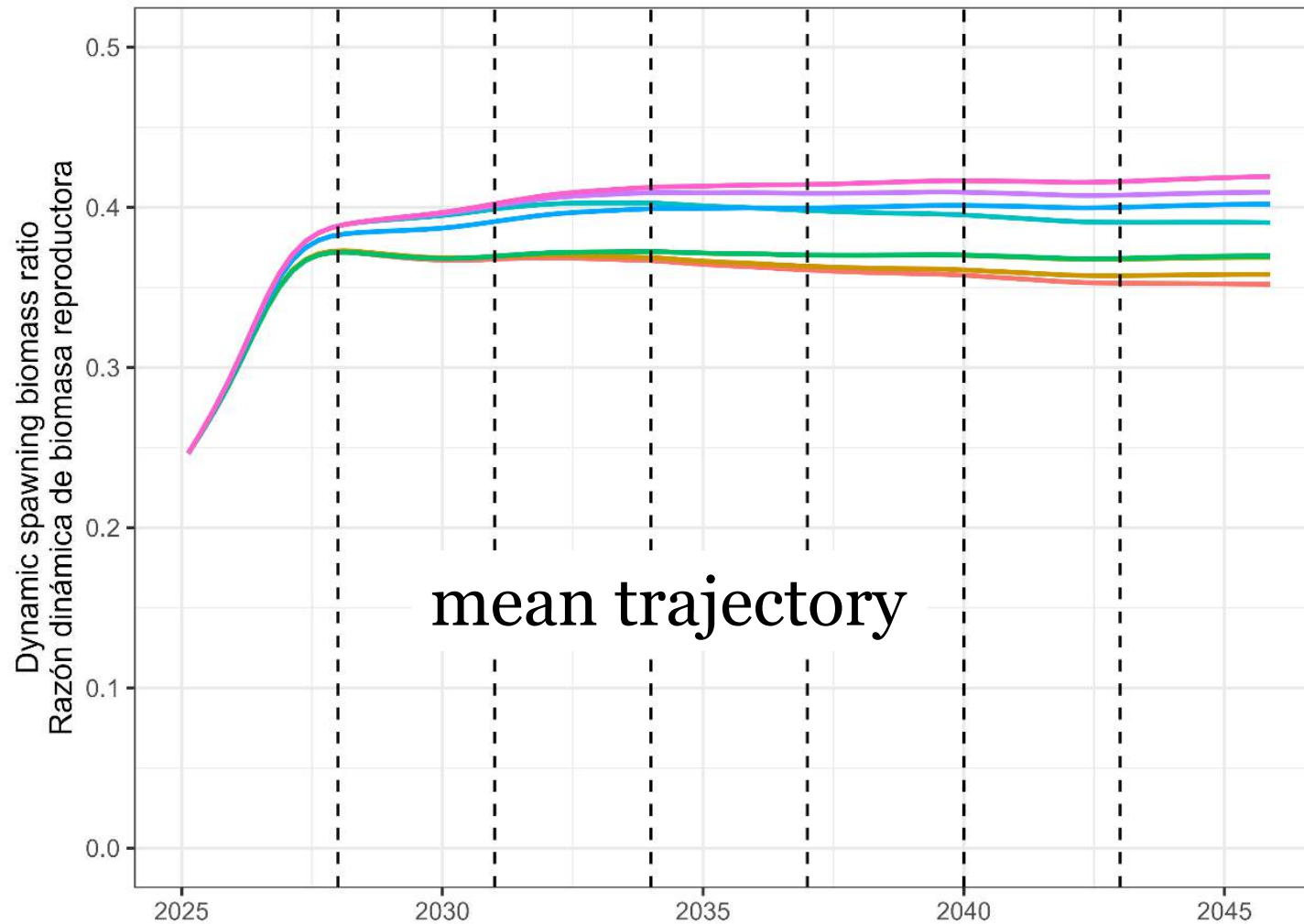
Results: dynamic SBR



- We “drop 1,200 balls” in the MSE to estimate a probability distribution
- Each black line represents the trajectory of a “ball” over 21 years



Results: dynamic SBR



HCR

— F30-S20	— F35-S20	— F35-S30	— F40-S30
— F30-S30	— F35-S25	— F40-S20	— F40-S40

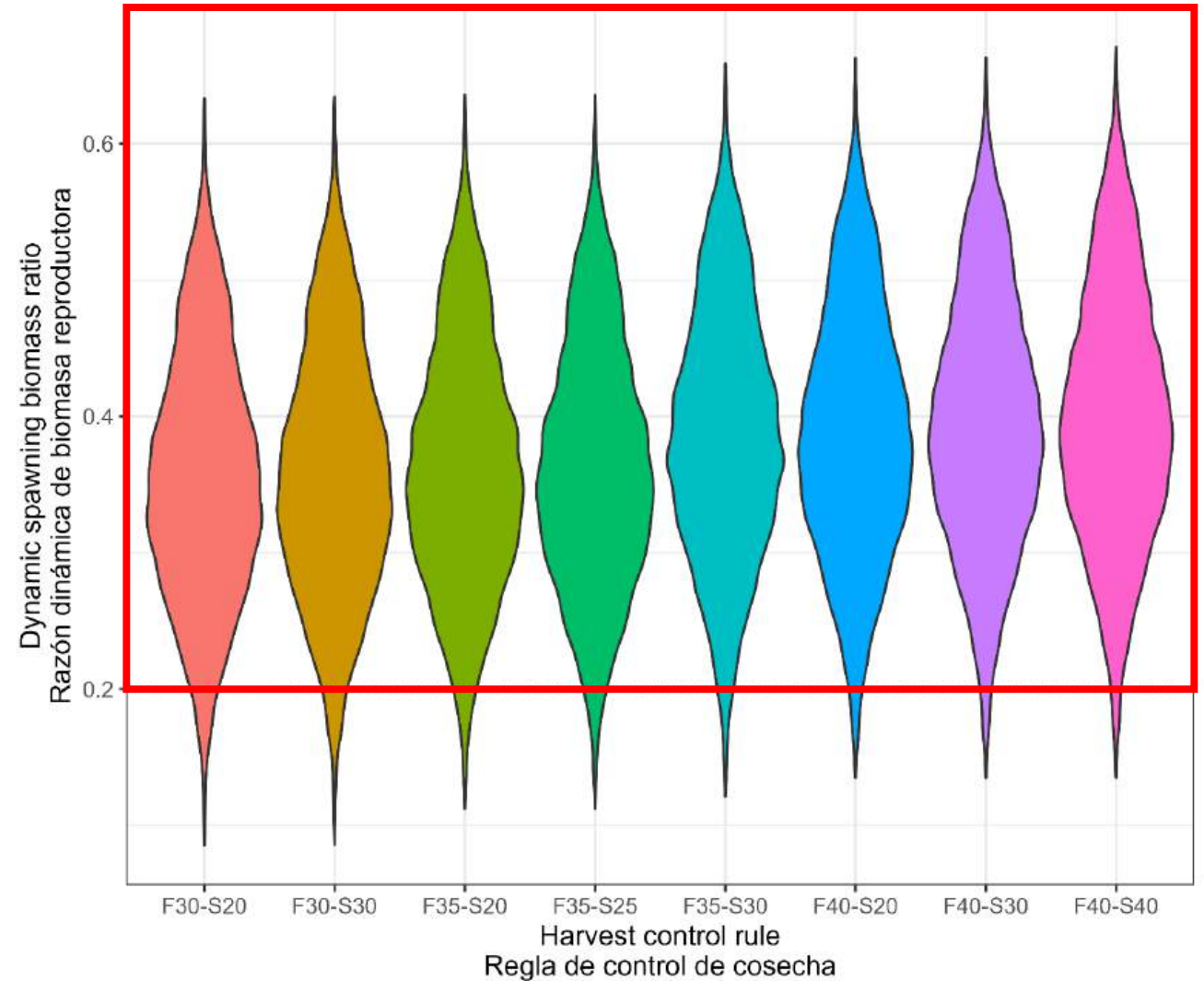
Performance indicators

Management objective	Performance indicator	Unit	Description
Safety	$p(dSBR > 0.2)$	%	The probability that dynamic spawning biomass ratio is larger than 0.2
	$p(SBR > 0.077)$	%	The probability that equilibrium spawning biomass ratio is larger than 0.077
	$p(SB > 0.5SB_{MSY})$	%	The probability that spawning biomass is larger than 50% of the spawning biomass at the maximum sustainable yield
Status	$p(Kobe \text{ in green})$	%	The probability that the stock is in the green quadrant of the Kobe plot
Stability	$AAV(catch)$	%	Average annual variability in annual catch
	$p(closure + 20)$	%	The probability that the closure will increase by 20 days
Yield	$PS \text{ catch}$	ton	Average annual purse-seine catch
	$LL \text{ catch}$	ton	Average annual longline catch
Effort	$closure$	day	Average fishery closure
Abundance	$CPUE$	%	The ratio of average longline CPUE to the average level for 2017-2019

Performance indicators: safety

The probability that dynamic spawning biomass ratio is larger than 0.2

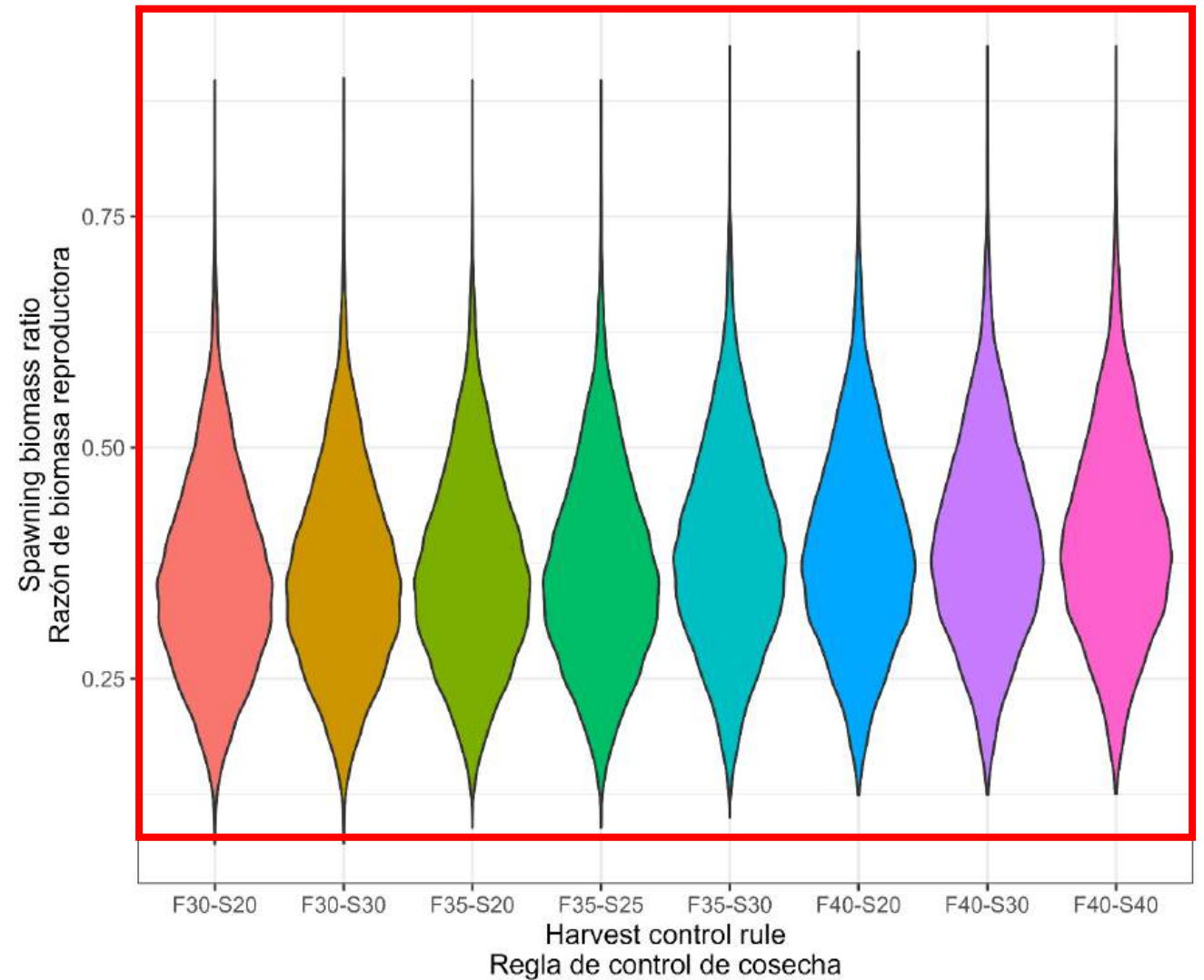
HCR	Prob (%) dSBR > 0.2	Prob (%) SBR > 0.077	Prob (%) $S > 0.5S_{MSY}$
F30-S20	96.5	99.9	99.9
F30-S30	96.7	99.9	99.9
F35-S20	97.5	100.0	100.0
F35-S25	97.5	100.0	100.0
F35-S30	98.3	100.0	100.0
F40-S20	98.5	100.0	100.0
F40-S30	98.7	100.0	100.0
F40-S40	98.8	100.0	100.0



Performance indicators: safety

The probability that equilibrium spawning biomass ratio is larger than 0.077

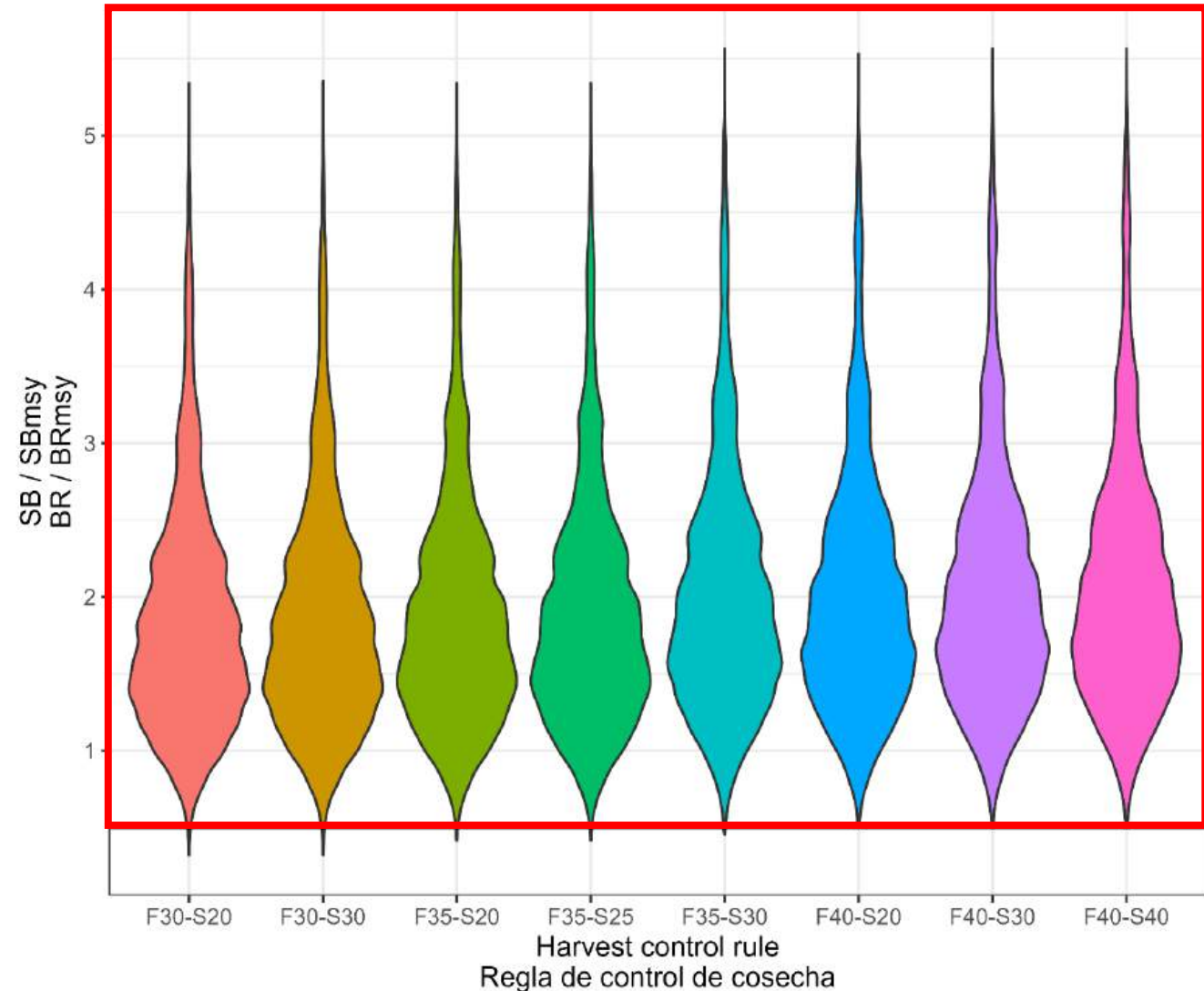
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F35-S20	97.5	100.0	100.0
F35-S25	97.5	100.0	100.0
F35-S30	98.3	100.0	100.0
F40-S20	98.5	100.0	100.0
F40-S30	98.7	100.0	100.0
F40-S40	98.8	100.0	100.0



Performance indicators: safety

The probability that spawning biomass is larger than 50% of the spawning biomass at MSY

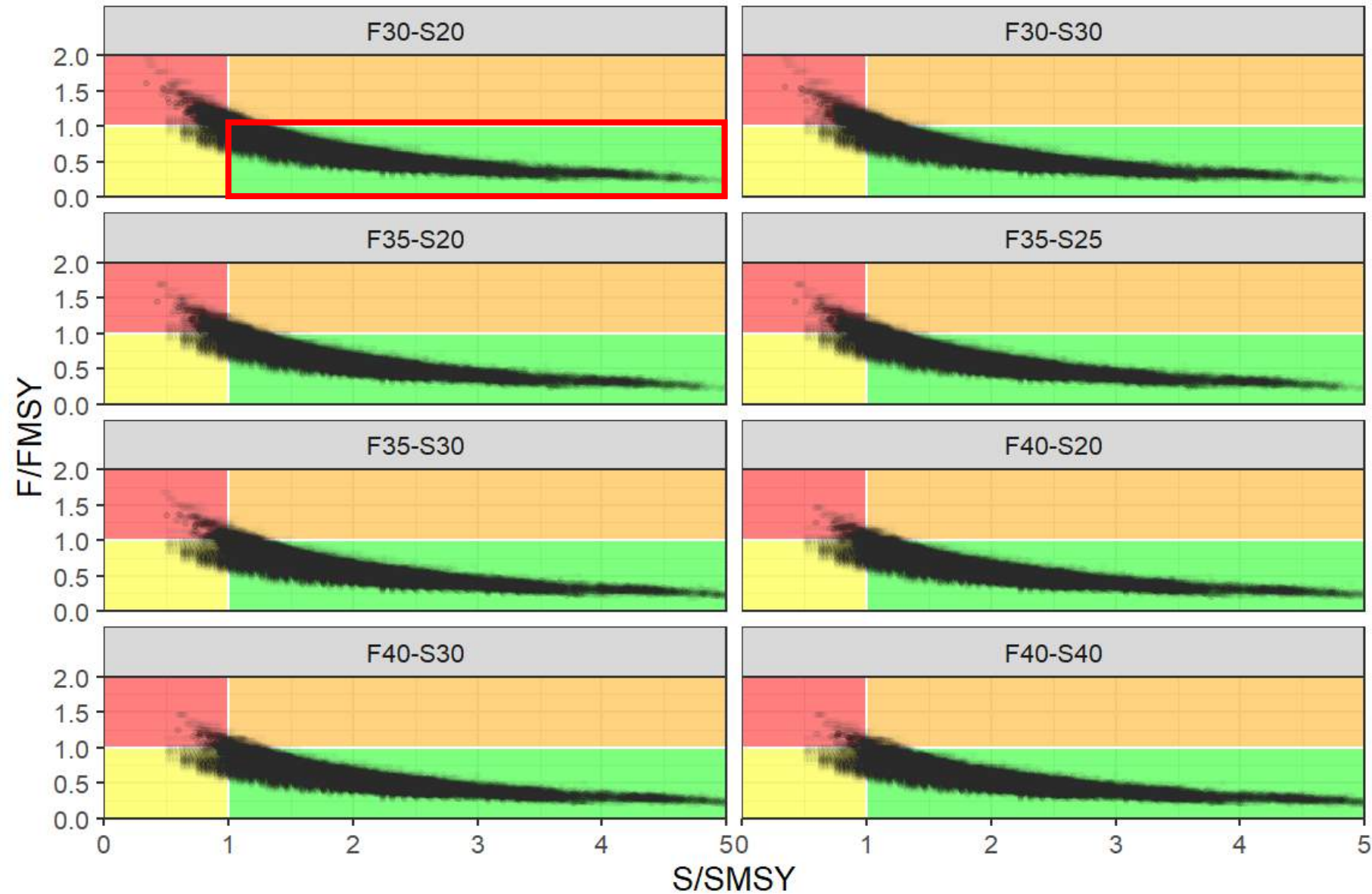
HCR	Prob (%) dSBR > 0.2	Prob (%) SBR > 0.077	Prob (%) S > 0.5S_{MSY}
F30-S20	96.5	99.9	99.9
F30-S30	96.7	99.9	99.9
F35-S20	97.5	100.0	100.0
F35-S25	97.5	100.0	100.0
F35-S30	98.3	100.0	100.0
F40-S20	98.5	100.0	100.0
F40-S30	98.7	100.0	100.0
F40-S40	98.8	100.0	100.0



Performance indicators: status

The probability that the stock is in the green quadrant of the Kobe plot

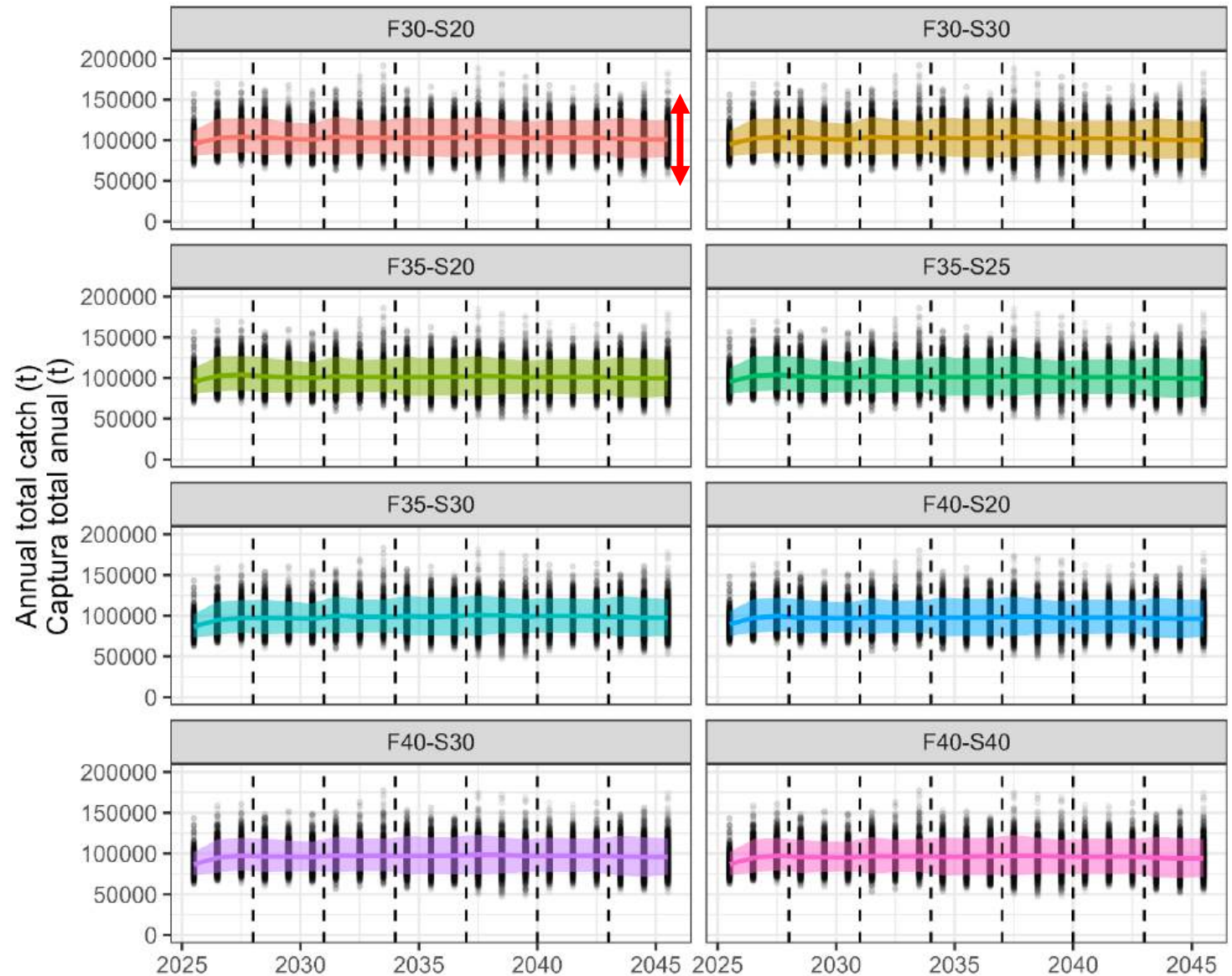
HCR	Prob (%) Kobe = green
F30-S20	89.6
F30-S30	90.0
F35-S20	91.6
F35-S25	91.6
F35-S30	94.0
F40-S20	94.6
F40-S30	95.2
F40-S40	95.5



Performance indicators: stability

Average annual variability in annual bigeye catch

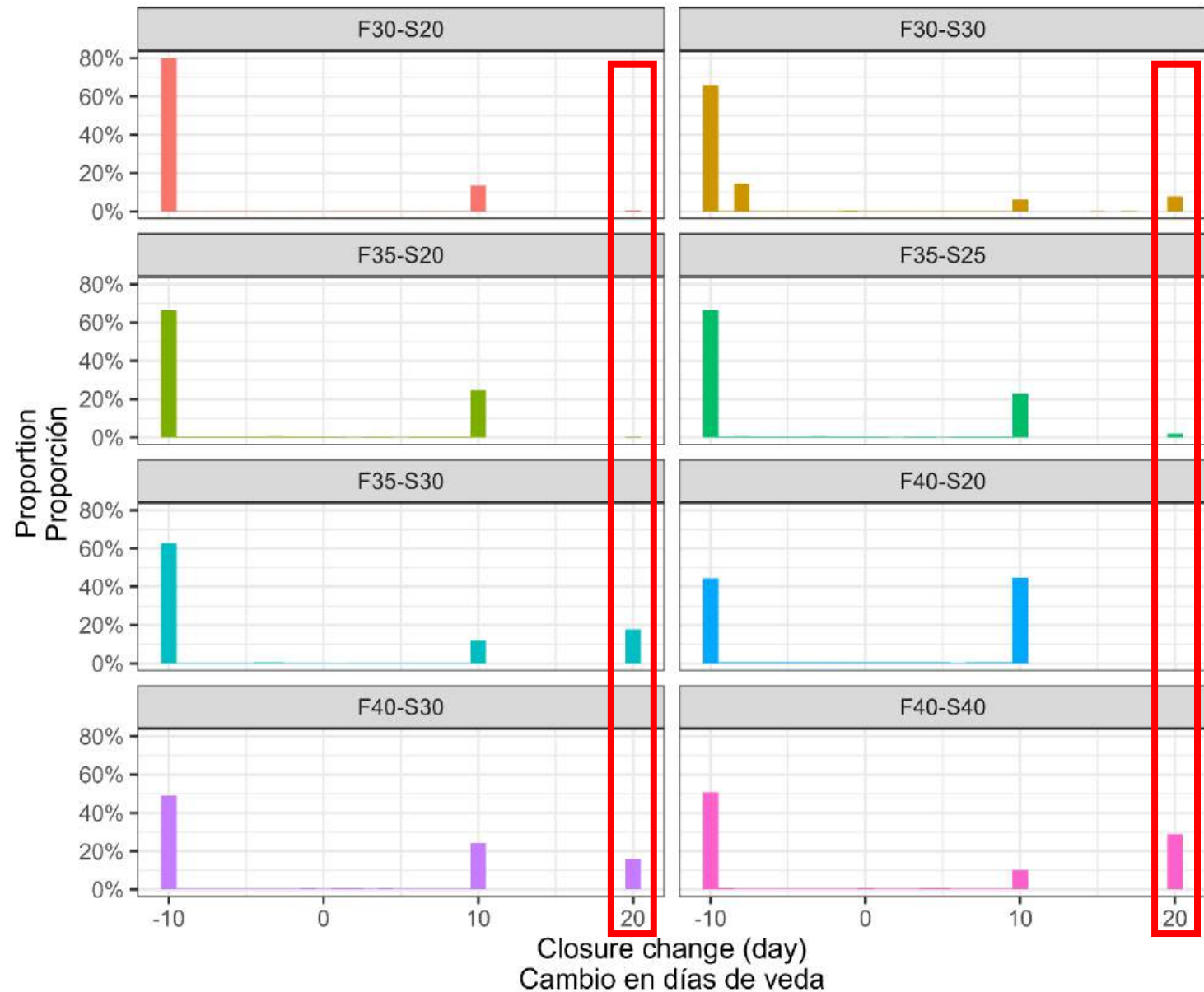
HCR	AAV (%) in catch	Prob (%) change = 20
F30-S20	7.3	0.8
F30-S30	7.3	7.7
F35-S20	7.3	0.4
F35-S25	7.3	1.9
F35-S30	7.2	17.6
F40-S20	7.2	0.1
F40-S30	7.2	16.3
F40-S40	7.3	28.9



Performance indicators: stability

The probability that the closure will increase by 20 days

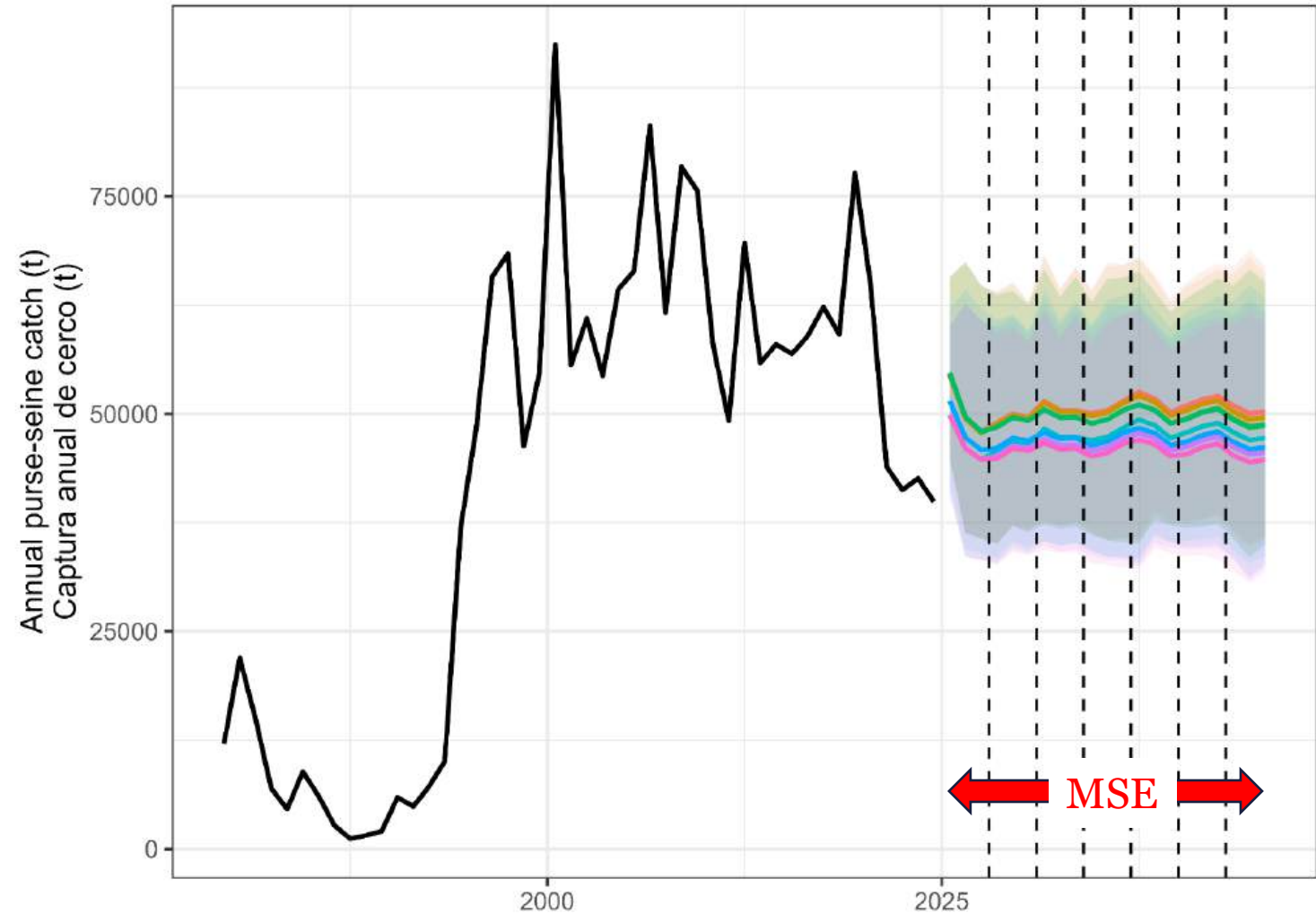
HCR	AAV (%) in catch	Prob (%) change = 20
F30-S20	7.3	0.8
F30-S30	7.3	7.7
F35-S20	7.3	0.4
F35-S25	7.3	1.9
F35-S30	7.2	17.6
F40-S20	7.2	0.1
F40-S30	7.2	16.3
F40-S40	7.3	28.9



Performance indicators: yield

Average annual purse-seine catch

HCR	Annual PS catch (mt)	Annual LL catch (mt)
F30-S20	50722	51663
F30-S30	50384	51509
F35-S20	49785	51277
F35-S25	49746	51250
F35-S30	47514	50533
F40-S20	47221	50258
F40-S30	46456	49966
F40-S40	45911	49624



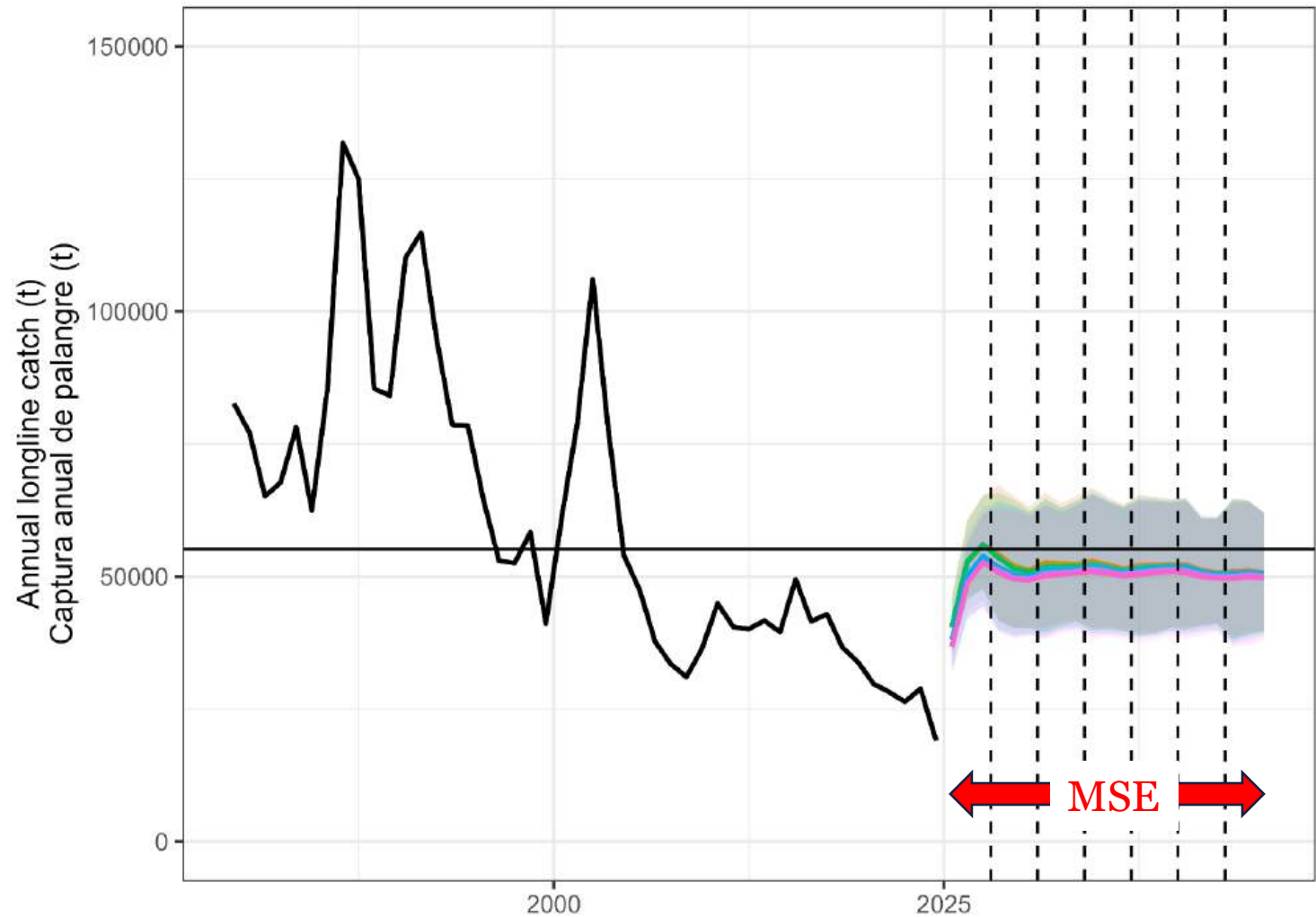
HCR

- F30-S20
- F35-S20
- F35-S30
- F40-S30
- F30-S30
- F35-S25
- F40-S20
- F40-S40

Performance indicators: yield

Average annual longline catch

HCR	Annual PS catch (mt)	Annual LL catch (mt)
F30-S20	50722	51663
F30-S30	50384	51509
F35-S20	49785	51277
F35-S25	49746	51250
F35-S30	47514	50533
F40-S20	47221	50258
F40-S30	46456	49966
F40-S40	45911	49624



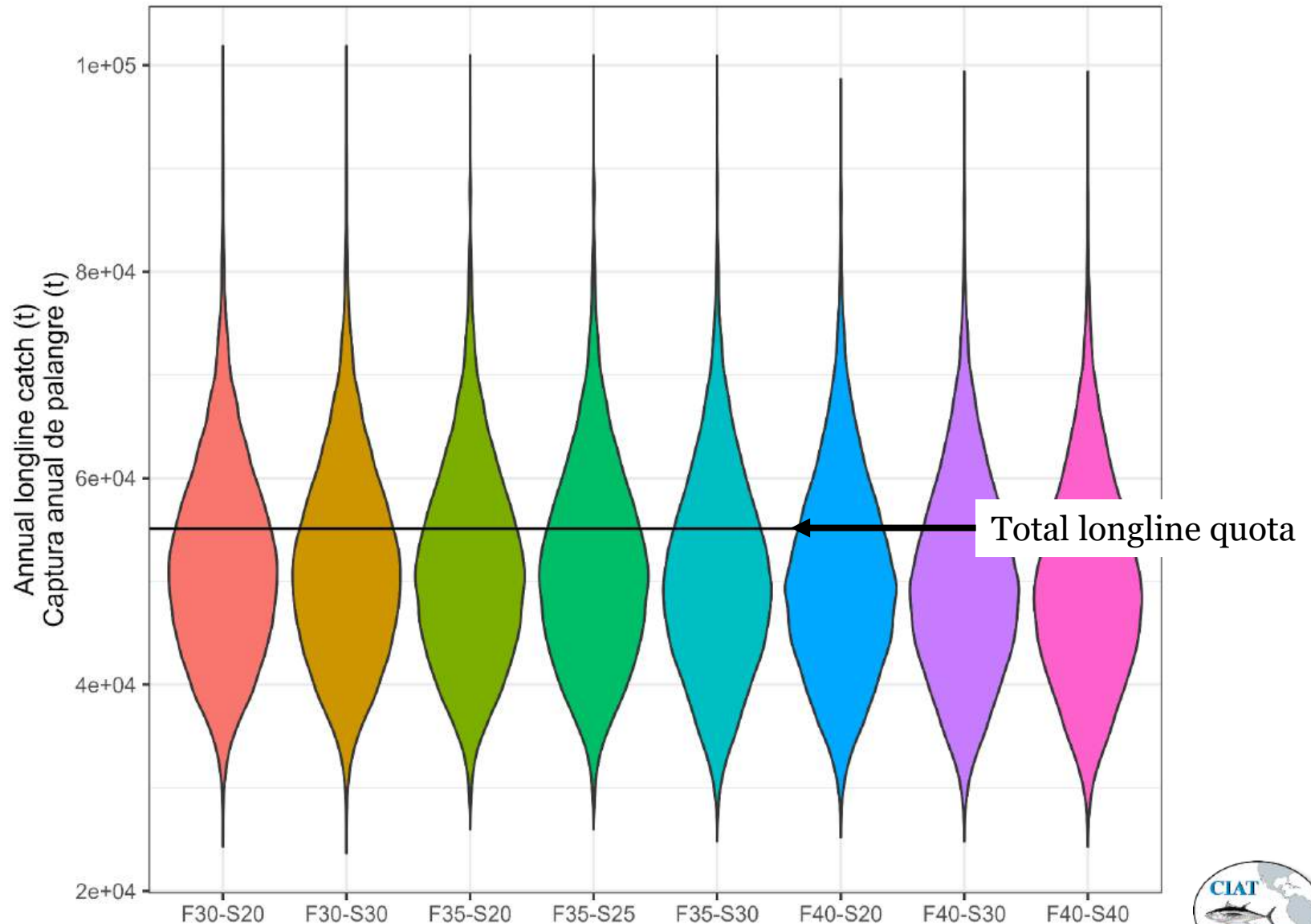
HCR

—	F30-S20	—	F35-S20	—	F35-S30	—	F40-S30
—	F30-S30	—	F35-S25	—	F40-S20	—	F40-S40

Performance indicators: yield

Average annual longline catch

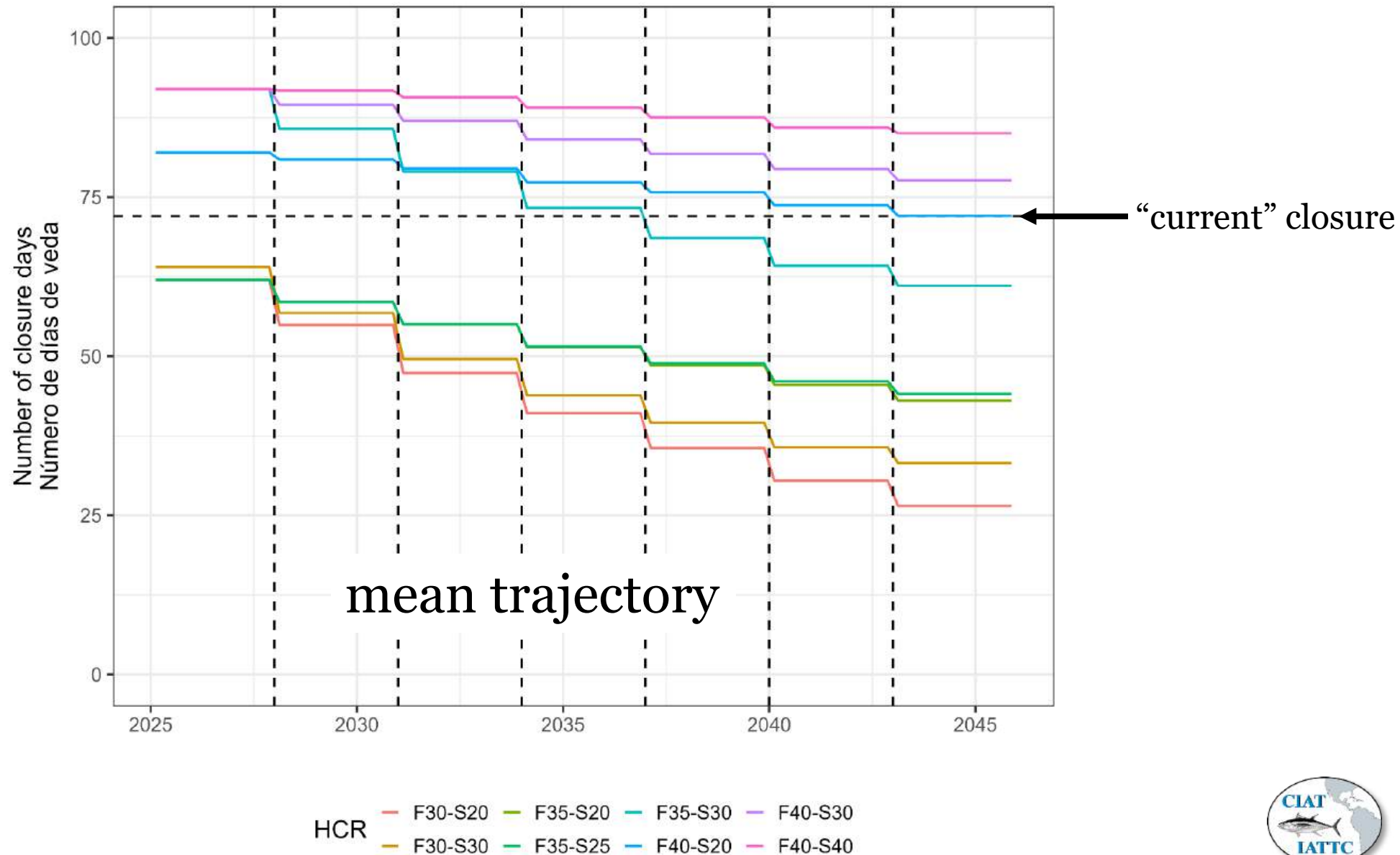
HCR	Annual PS catch (mt)	Annual LL catch (mt)
F30-S20	50722	51663
F30-S30	50384	51509
F35-S20	49785	51277
F35-S25	49746	51250
F35-S30	47514	50533
F40-S20	47221	50258
F40-S30	46456	49966
F40-S40	45911	49624



Performance indicators: effort

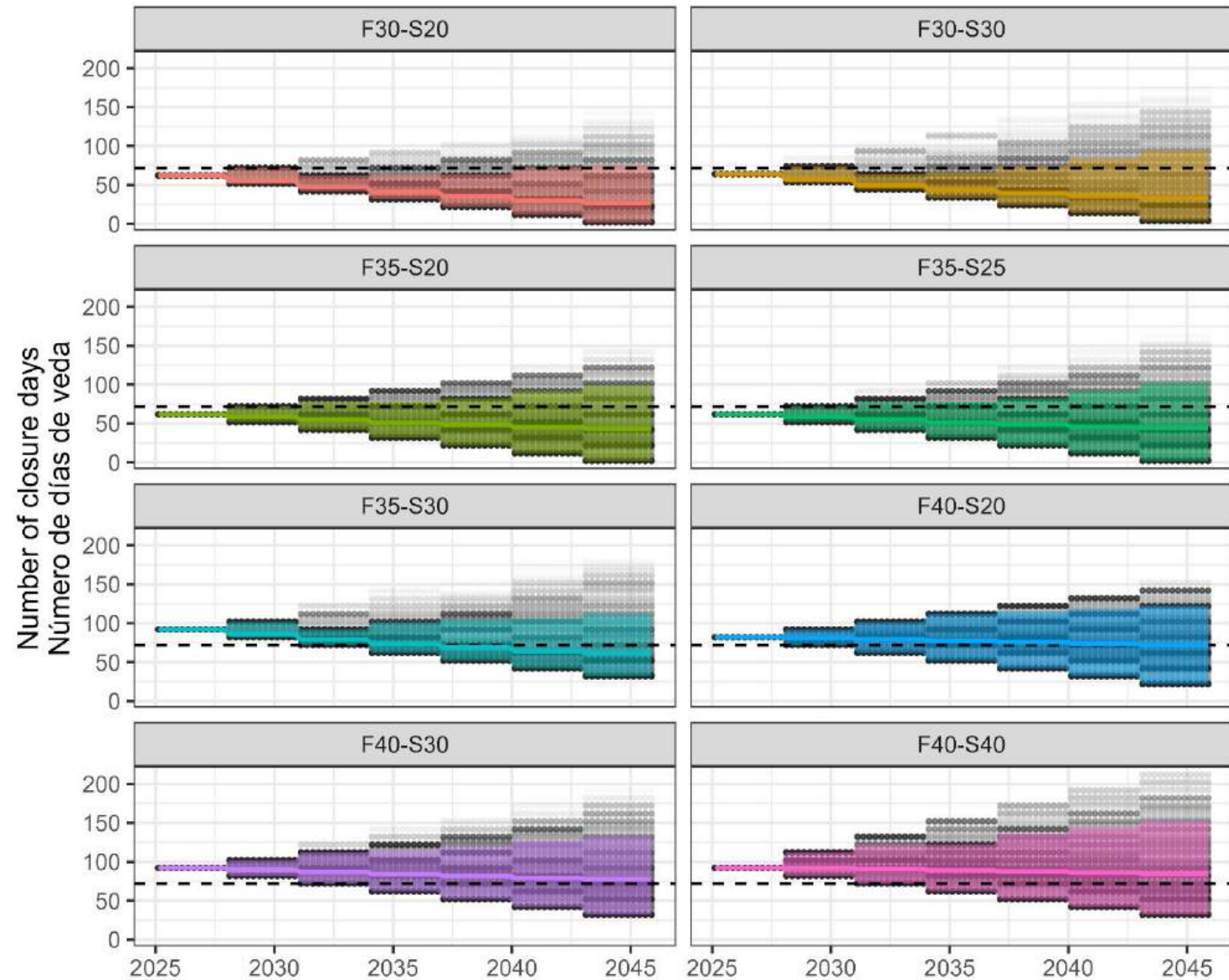
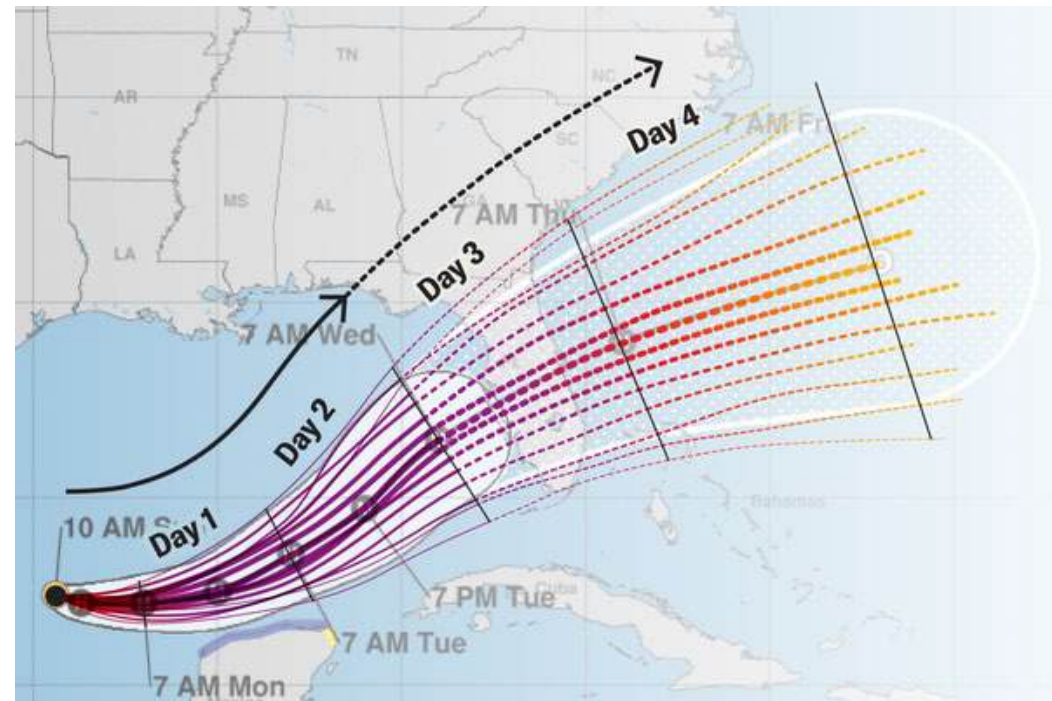
Average fishery closure

HCR	Average closure (day)
F30-S20	43
F30-S30	46
F35-S20	52
F35-S25	52
F35-S30	75
F40-S20	77
F40-S30	84
F40-S40	89



Performance indicators: effort

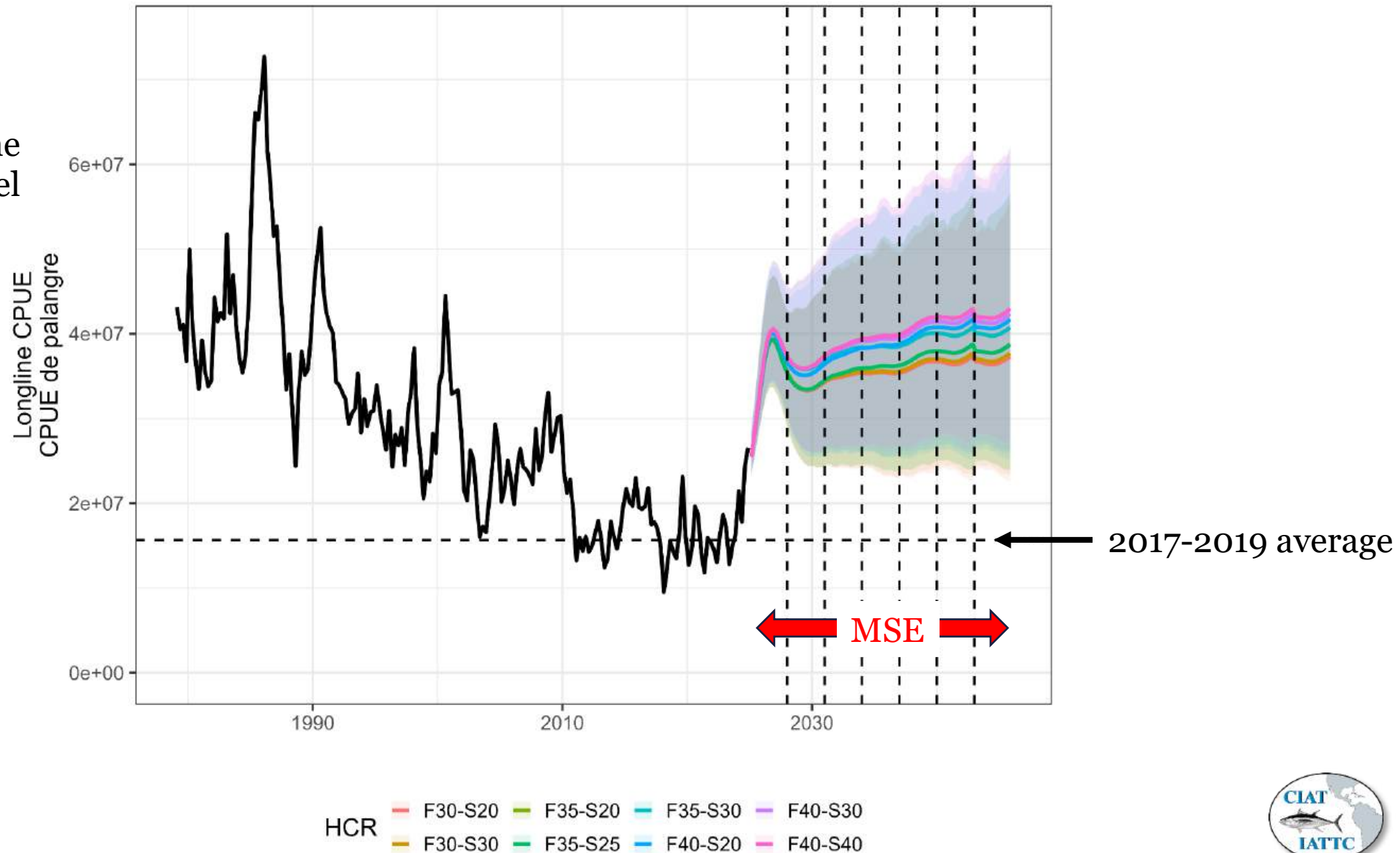
The further we project into the future, the more uncertain the projection becomes.



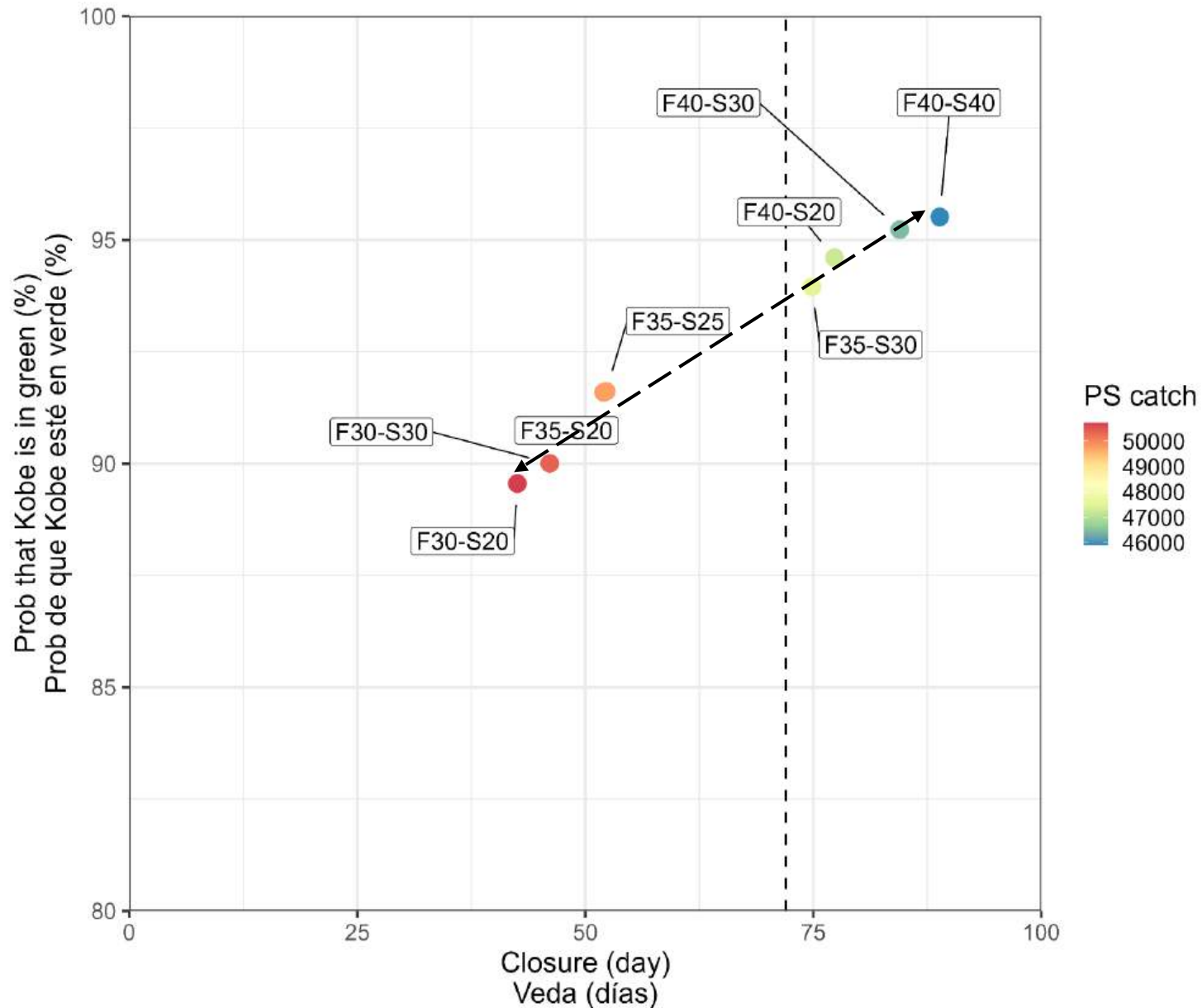
Performance indicators: abundance

The ratio of average longline CPUE to the 2017-2019 level

HCR	CPUE ratio
F30-S20	2.26
F30-S30	2.28
F35-S20	2.31
F35-S25	2.31
F35-S30	2.44
F40-S20	2.45
F40-S30	2.49
F40-S40	2.51



Trade-off: status vs. effort



Performance indicators: summary

- All HCRS have less than 5% probabilities of breaching the soft limit reference point (0.2 dynamic SBR)
- All HCRs have less than 0.1% probabilities of breaching the two hard limit reference points (0.077 SBR and $0.5 S_{MSY}$)
- All HCRs have high probabilities (89.6%-95.5%) of being in the green quadrant of the Kobe plot
- These HCRs differ mainly in average closure duration (43–89 days), average annual purse-seine catch (45,911–50,722 mt), and the probability of having a 20-day increase in the closure (0.1%-28.9%)
- The probability of having a 20-day increase in the closure is less than 2% when the control point is 0.2 or 0.25

Performance indicators: summary

HCR	Prob dSBR > 0.2	Prob SBR > 0.077	Prob $S > 0.5S_{MSY}$	Prob Kobe = green	AAV in catch	Prob change = 20	Annual PS catch	Annual LL catch	Average closure	CPUE ratio
F30-S20	96.5	99.9	99.9	89.6	7.3	0.8	50722	51663	43	2.26
F30-S30	96.7	99.9	99.9	90.0	7.3	7.7	50384	51509	46	2.28
F35-S20	97.5	100.0	100.0	91.6	7.3	0.4	49785	51277	52	2.31
F35-S25	97.5	100.0	100.0	91.6	7.3	1.9	49746	51250	52	2.31
F35-S30	98.3	100.0	100.0	94.0	7.2	17.6	47514	50533	75	2.44
F40-S20	98.5	100.0	100.0	94.6	7.2	0.1	47221	50258	77	2.45
F40-S30	98.7	100.0	100.0	95.2	7.2	16.3	46456	49966	84	2.49
F40-S40	98.8	100.0	100.0	95.5	7.3	28.9	45911	49624	89	2.51

Robustness test

- Evaluate the performance of the candidate HCRs under a sustained 25% reduction in recruitment regime beginning in 2025.
- This scenario is intended to assess HCR behavior under unfavorable environmental conditions that substantially reduce stock productivity.
- Except for the imposed regime shift in recruitment, all simulation specifications for the robustness test were identical to those used in the base-case MSE.
- Due to time constraints, the robustness test was conducted only for the least conservative candidate HCR, F30–S20, which is expected to be most vulnerable to declines in recruitment.

Robustness test

- The least conservative HCR, F30-S20, is robust to a downward regime shift in recruitment:
 - Less than 1% probabilities in breaching the two hard limit reference points
 - Less than 5% probability in breaching the soft limit reference point
 - More than 85% probability that the stock is in the green quadrant of the Kobe plot

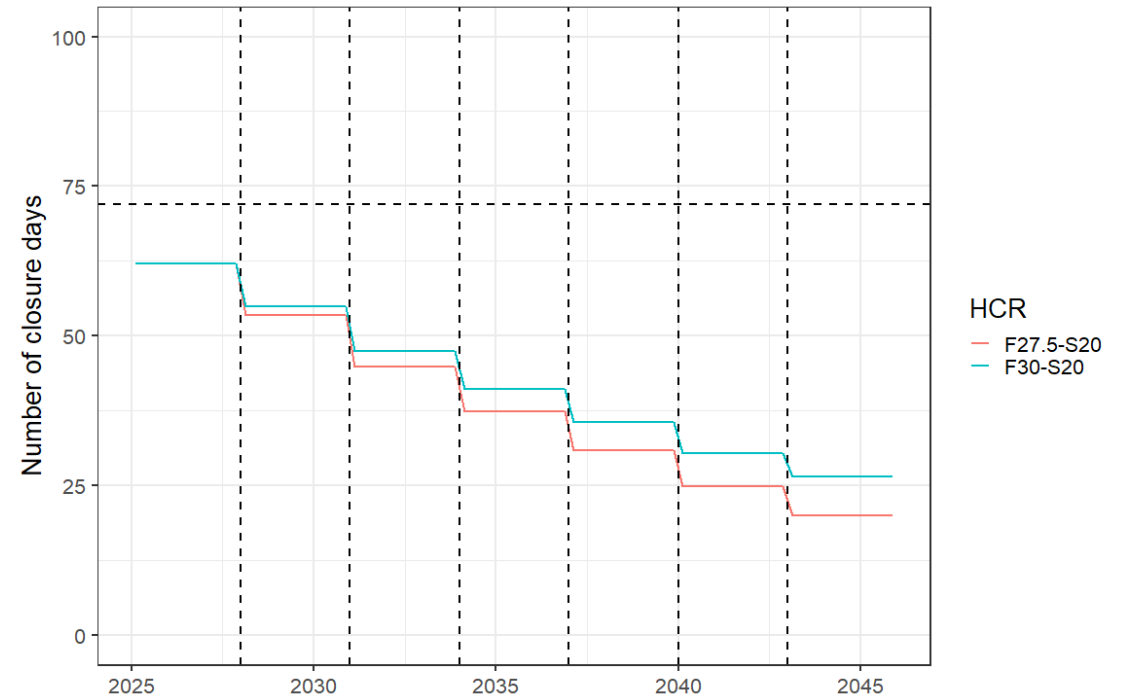
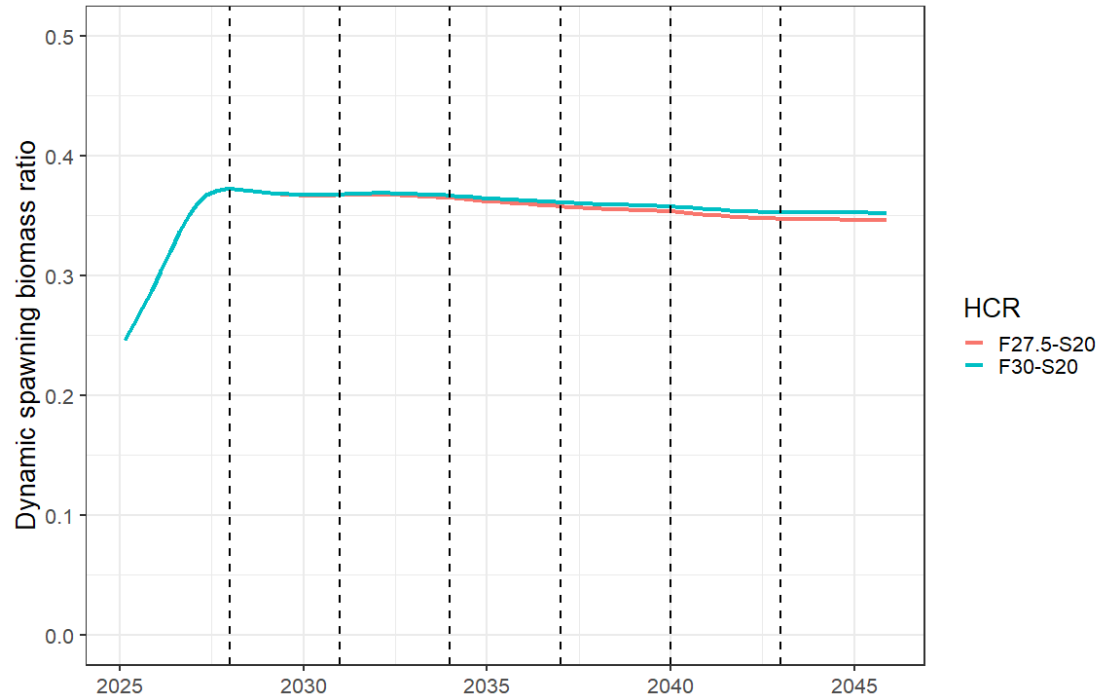
Ro	Prob dSBR > 0.2	Prob SBR > 0.077	Prob $S > 0.5S_{MSY}$	Prob Kobe = green	AAV in catch	Prob change = 20	Annual PS catch	Annual LL catch	Fishery closure	CPUE ratio
75%	95.4	99.0	99.8	88.5	7.2	1.5	38646	41096	38	1.76
100%	96.5	99.9	99.9	89.6	7.3	0.8	50722	51663	43	2.26



Questions



F27.5-S20

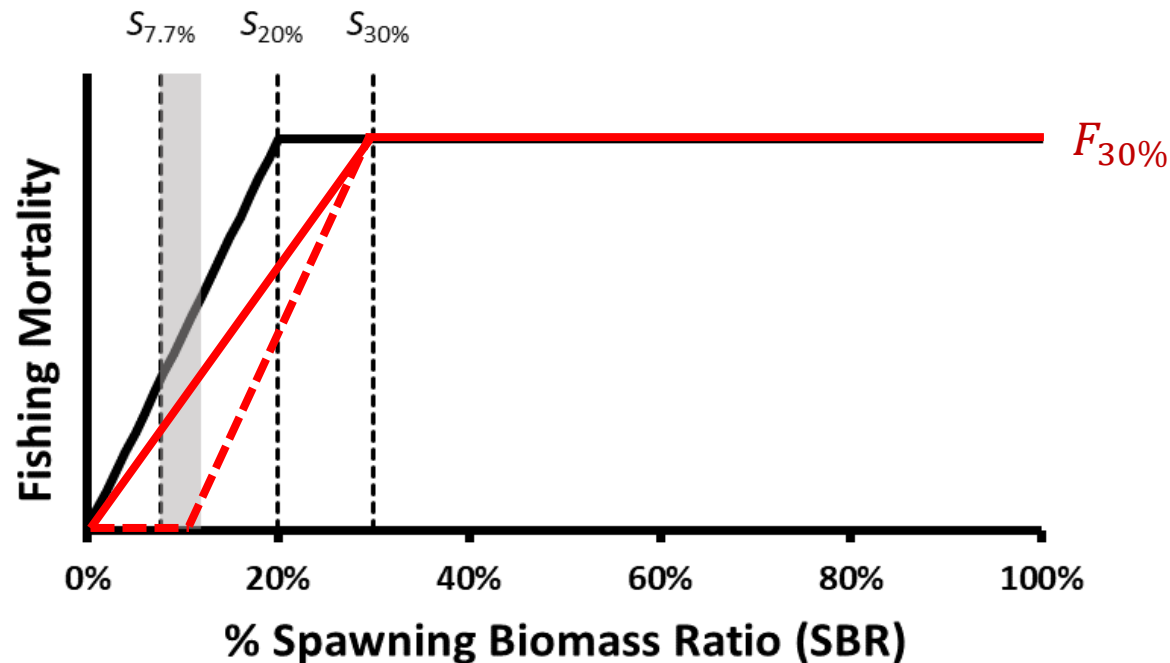


HCR	Prob dSBR > 0.2	Prob SBR > 0.077	Prob $S > 0.5S_{MSY}$	Prob Kobe = green	AAV in catch	Prob change = 20	Annual PS catch	Annual LL catch	Fishery closure	CPUE ratio
F27.5-S20	96.1	99.8	99.9	88.8	7.3	1.1	51072	51797	39	2.25
F30-S20	96.5	99.9	99.9	89.6	7.3	0.8	50722	51663	43	2.26



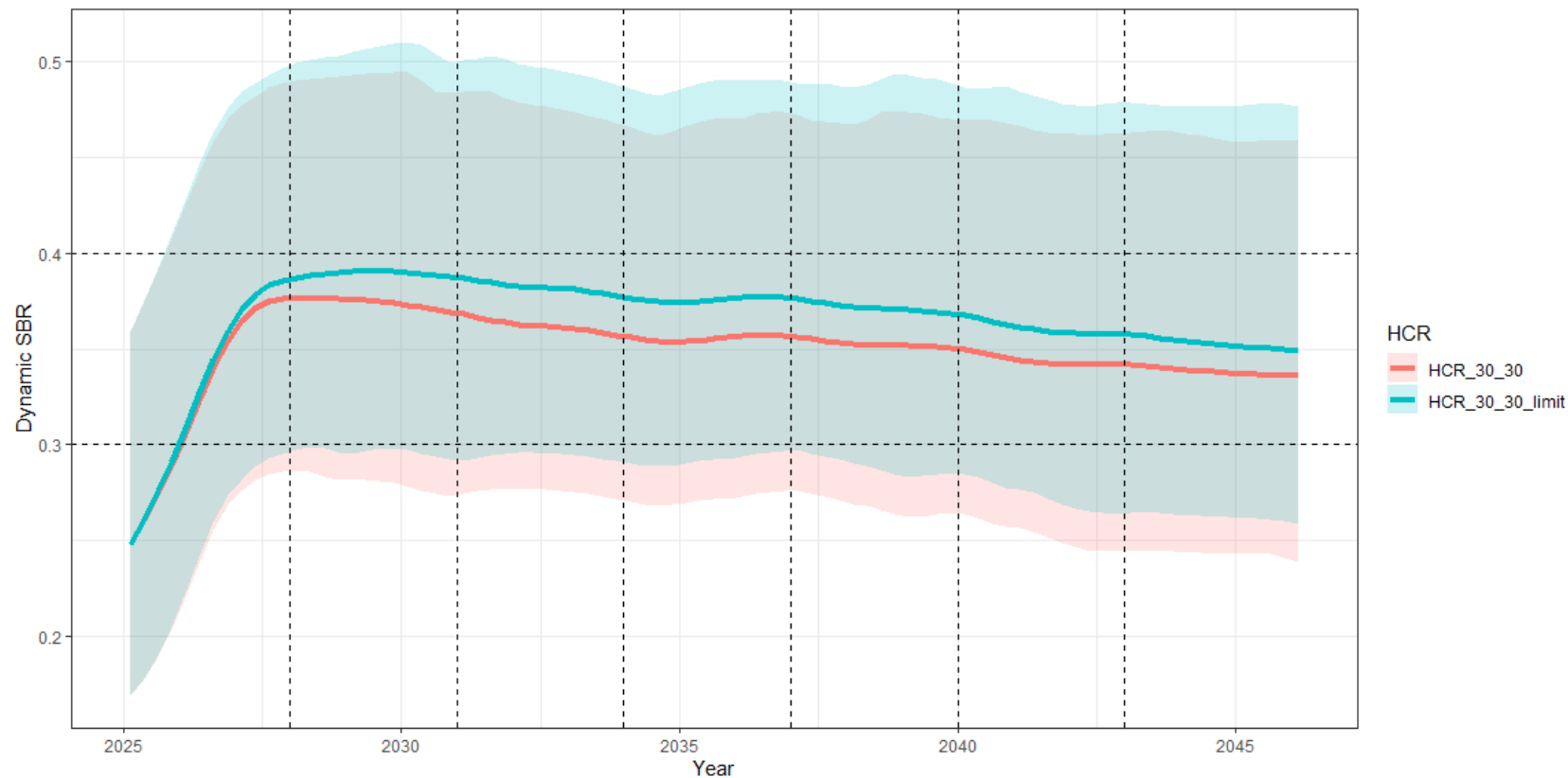
Impact of considering a second control point to the HCR

A second control point of 50% S_{MSY} ($=0.1S_0$) is considered in the HCR
Fishing mortality decreases linearly between the two control points, reaching 0 when the second point is breached



Impact of considering a second control point of 50% S_{MSY} in the HCR leads to more conservative management actions

Considering a second control point of 50% S_{MSY} in the HCR leads to more conservative management actions



Discussion: adding another control point to the HCR

- All eight HCRs have a zero probability of breaching the two hard limit reference points
- If an asymmetric cap on closure changes (10/20-day cap) is used to enable rapid responses to depletion before breaching limit reference points, explicit inclusion of a second control point in the HCR may be unnecessary
- Incorporating a second control point increases the number of HCR parameters, further complicating negotiations surrounding the harvest strategy for bigeye tuna in the EPO
- Recommend do not explicitly including a second control point in the HCR unless the full results for the chosen HCR suggest that the probability of breaching the two hard limit reference points is $>1\%$