Stock assessment of skipjack tuna in the eastern Pacific Ocean: 2024 benchmark assessment

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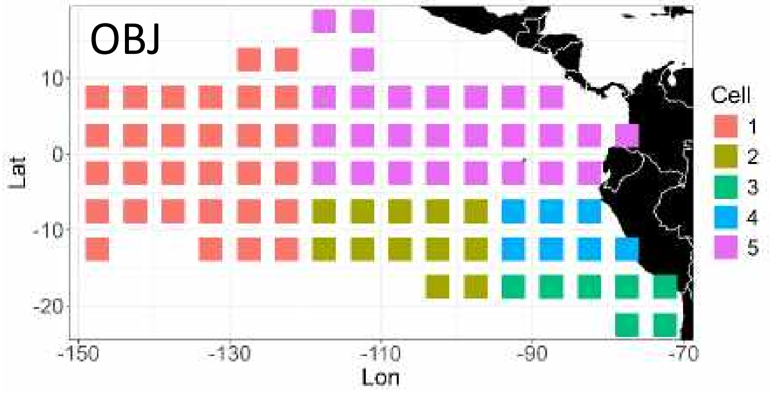
1. Introduction

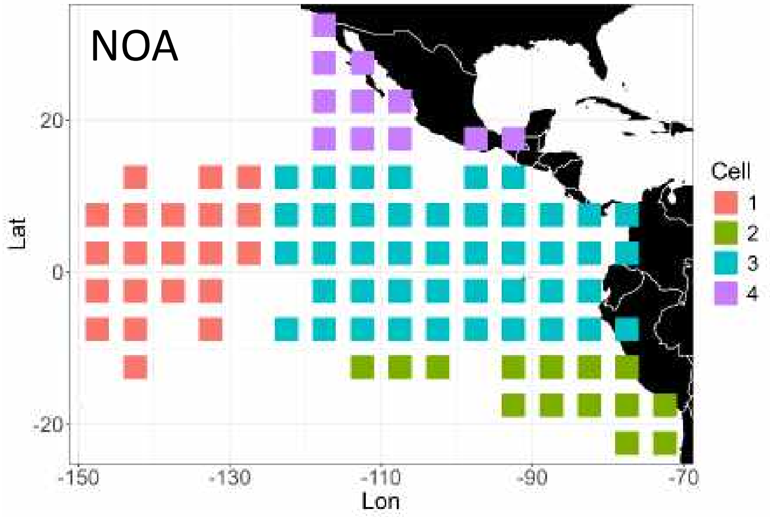
- Benchmark assessment
- A significant improvement from the initial *interim* assessment conducted in 2022.
- Advanced assessment methodologies incorporated with new datasets, including absolute biomass estimate from tagging data.
- Based on Stock Synthesis (v3.30.22.beta), an integrated age-structured assessment model.
- One stock of skipjack in the eastern Pacific Ocean (EPO) – using the 'areas-as-fleets' approach.
- Model 2006-2023 with a quarterly time step.
- The maximum population age is 20 quarters.

2. Fleet definition – Fisheries

Fishery definitions based on fitting a regression tree to length compositions.

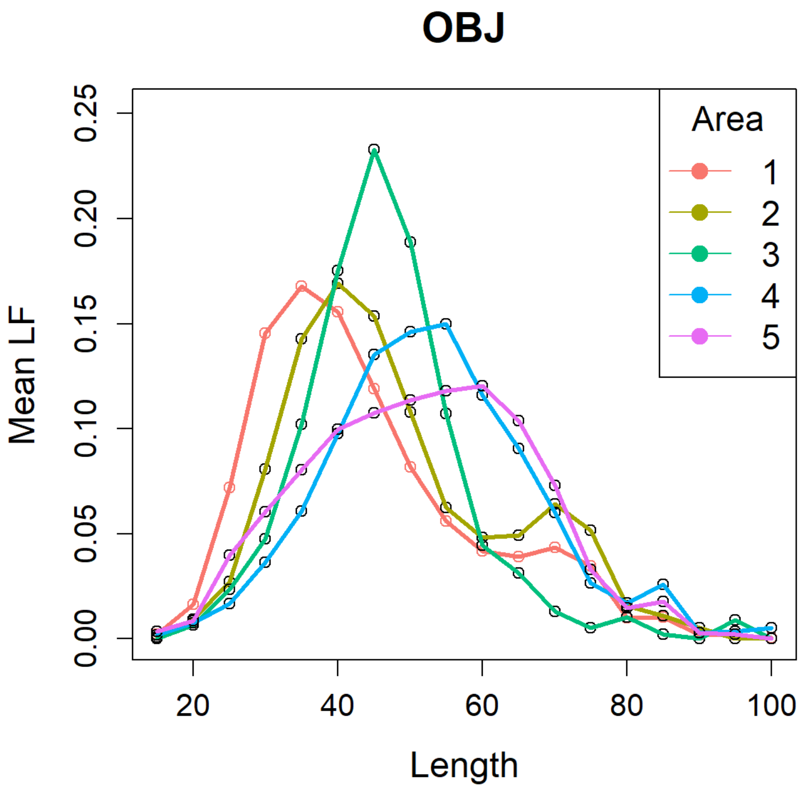
Gear	Set type	Area	Area name	Catch data	Units
Purse seine	Floating-object associated (OBJ)	1	Offshore	Retained catch + discards (inefficiency) (+ pole-and-line catch for OBJ fishery in area 5)	Metric tons
		2	Central		
		3	Southern coastal		
		4	Central coastal		
		5	Northern coastal		
	Unassociated (NOA)	1	Offshore		Metric tons
		2	South		
		3	Central		
		4	North		
	Dolphin-associated (DEL)	1	North		Metric tons
		2	South		
Purse seine discards	-	-	EPO	Discards (size-sorting)	Metric tons
Longline	-	-	EPO	Retained catch only	1,000s

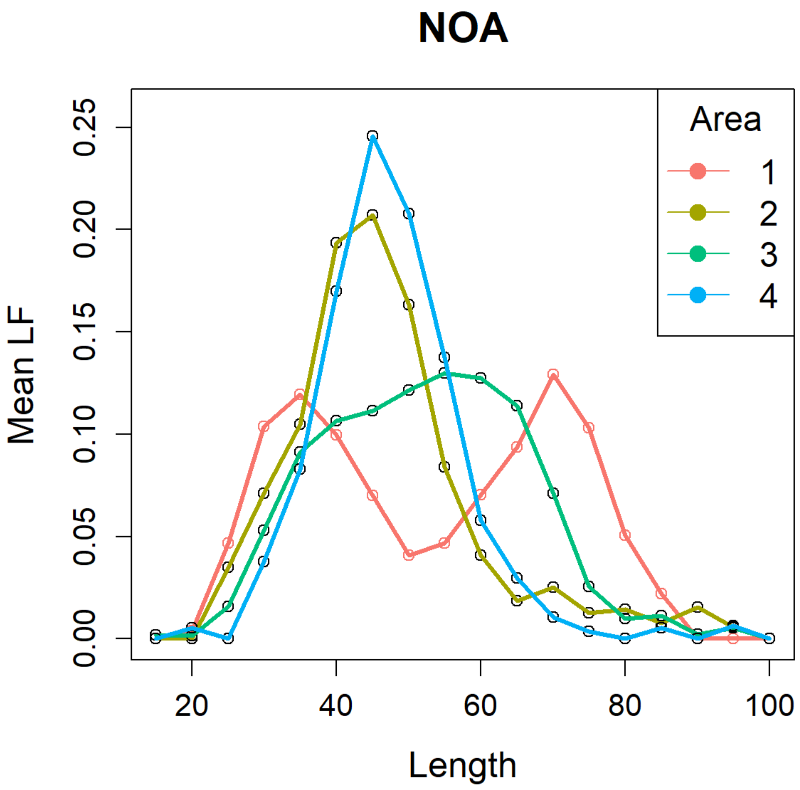




2. Fleet definition – Fisheries splitting

Fishery definitions based on fitting a regression tree to length compositions.





2. Fleet definition – 16 fisheries defined

Fishery	Gear	Set type	Area	Area name	Fish size	Catch data	Units
F1	Purse seine	OBJ	1	Offshore	Small	Retained catch + discards (inefficiency) (+ pole-and-line catch for OBJ fishery in area 5)	Metric tons
F2					Large		
F3			2	Central	Small		
F4					Large		
F5			3	Southern coastal	-		
F6			4	Central coastal	-		
F7			5	Northern coastal	-		
F8		NOA	1	Offshore	Small		Metric tons
F9					Large		
F10			2	South	-		
F11			3	Central	-		
F12			4	North	-		
F13		DEL	1	North	-		Metric tons
F14			2	South	-		
F15	Purse seine discards	-	-	EPO	-	Discards (size-sorting)	Metric tons
F16	Longline	-	-	EPO	-	Retained catch only	1,000s

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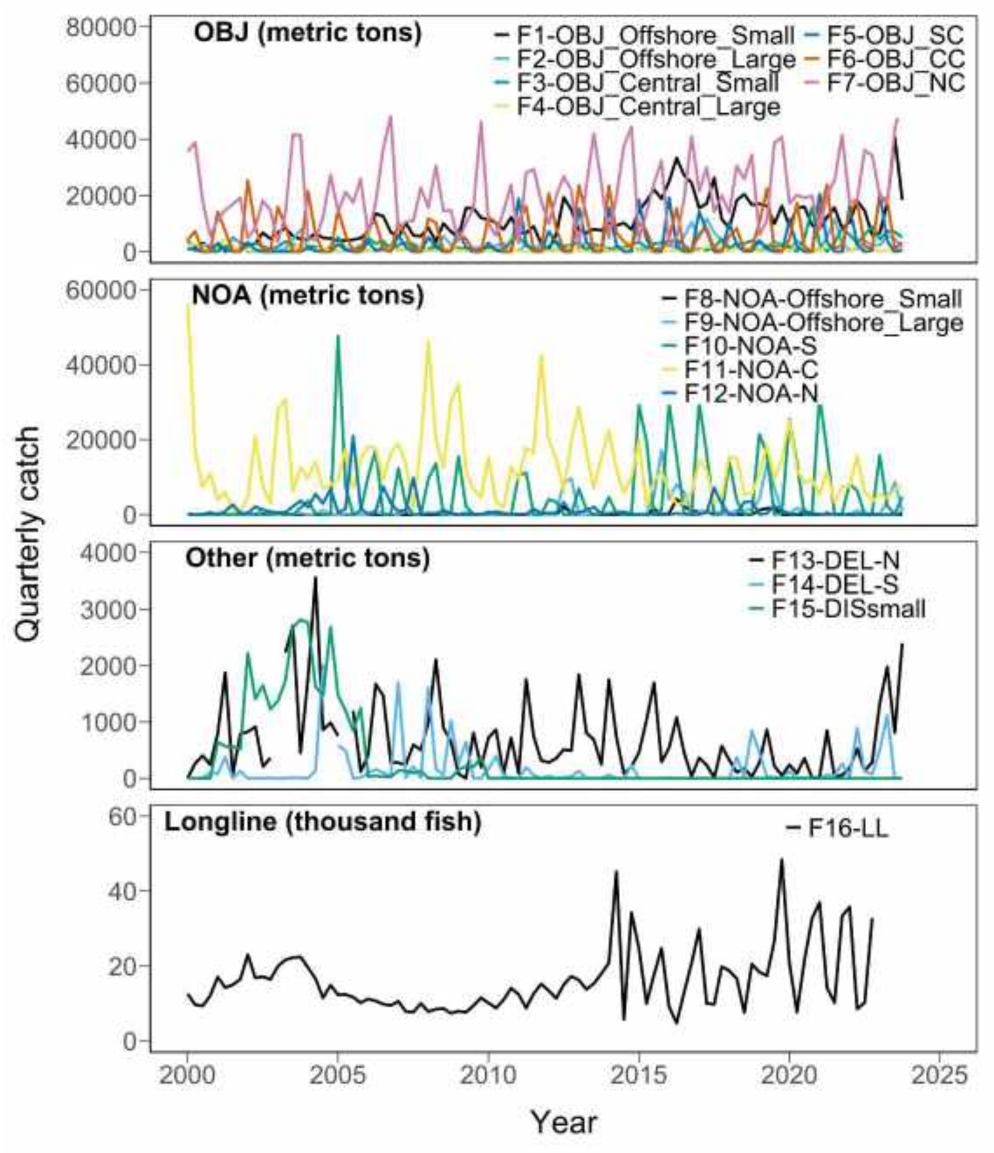
2. Fleet definition – “Surveys”

Survey	Gear	Set type	Index	Size comps
S1	Purse seine	OBJ	Relative	✓
S2		NOA	Relative	✓
S3	Echosounder buoy	-	Relative	✗
S4	Tagging-based	-	Absolute	✗
S5		-	Relative	✗

- In Stock Synthesis: a “survey” is modeled as a fleet that has data, such as indices of abundance and age/length compositions but takes no catch.
- Five “surveys” considered.
- The selectivities of S3, S4 and S5 are determined by fitting to the size-composition data from S1.

3. Data – Catch



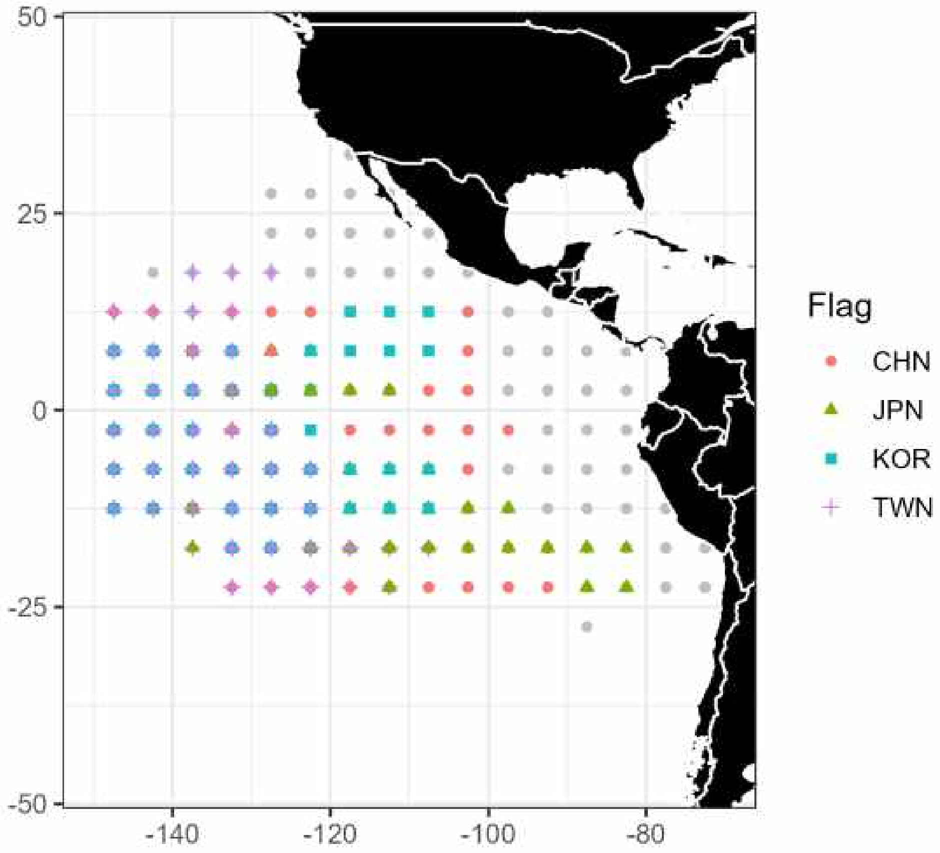
- Catch primarily taken by the purse-seine fisheries, especially OBJ and NOA.
- Significant seasonal variation observed in purse-seine catch.
- Discards (F15) began decreasing around 2003; nearly ceased by 2006 following IATTC resolutions against discarding juvenile tunas.

3. Data – Longline catch*

- *Last Interim:*
  - Catch data sourced from the Fishery Status Report (FSR).

- *Current Benchmark:*
  - Longline catch calculated by the product of reported hooks from all available CPCs and nominal CPUE.
  - Nominal CPUE derived from observer data from four IATTC Members: China, Chinese Taipei, Japan, and Korea.

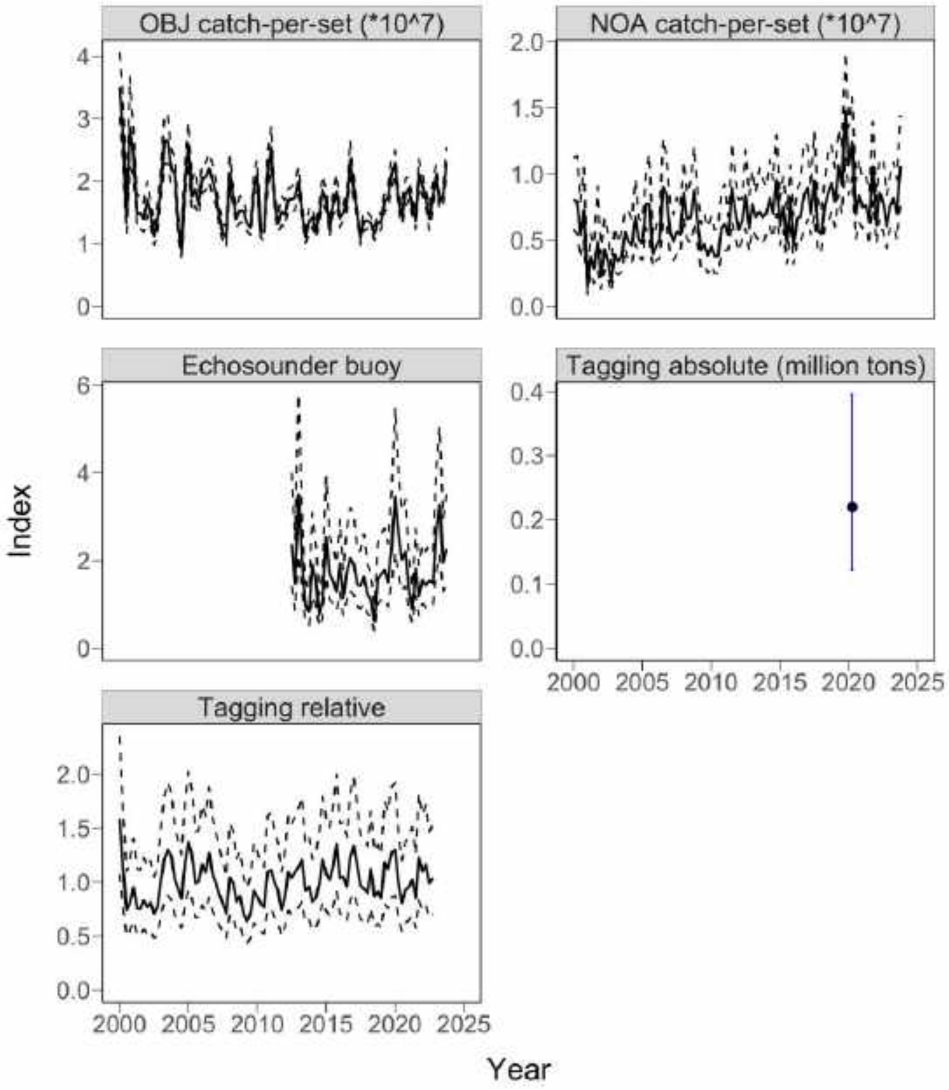
- Improvement:
  - The value in the FSR may be negatively biased.



Coverage of longline observer data from the four Members. Grey points indicate the locations of purse-seine catch and effort data. Data are aggregated into a 5 by 5 grid.

3. Data – Index of abundance

Survey	Index	Data source
S1	Purse seine OBJ catch-per-set	Standardized through a spatiotemporal model using VAST
S2	Purse seine NOA catch-per-set	
S3	Echosounder buoy (ECHO) index	Developed based on the signal from satellite-linked GPS tracking echosounder buoys used in the purse-seine OBJ fishery (FAD-08-02)
S4	Tagging-based absolute biomass	Derived from a spatiotemporal Petersen-type model applied to tag-recapture data (SAC-15 INF-G)
S5	Tagging-based relative biomass	Derived from a tagging biomass model using a flexible effort assumption (SAC-15 INF-G)



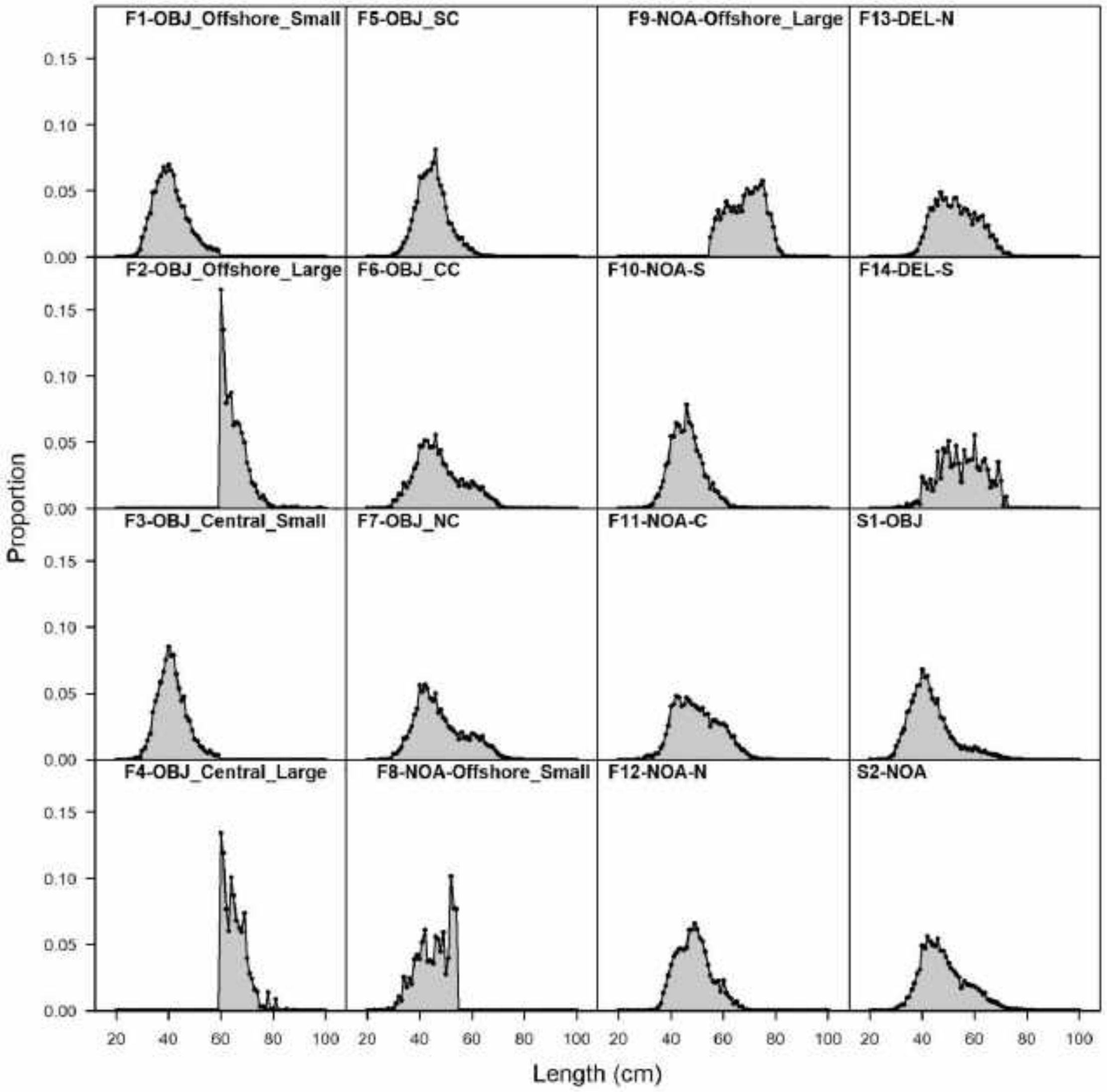
3. Data – No longline index*

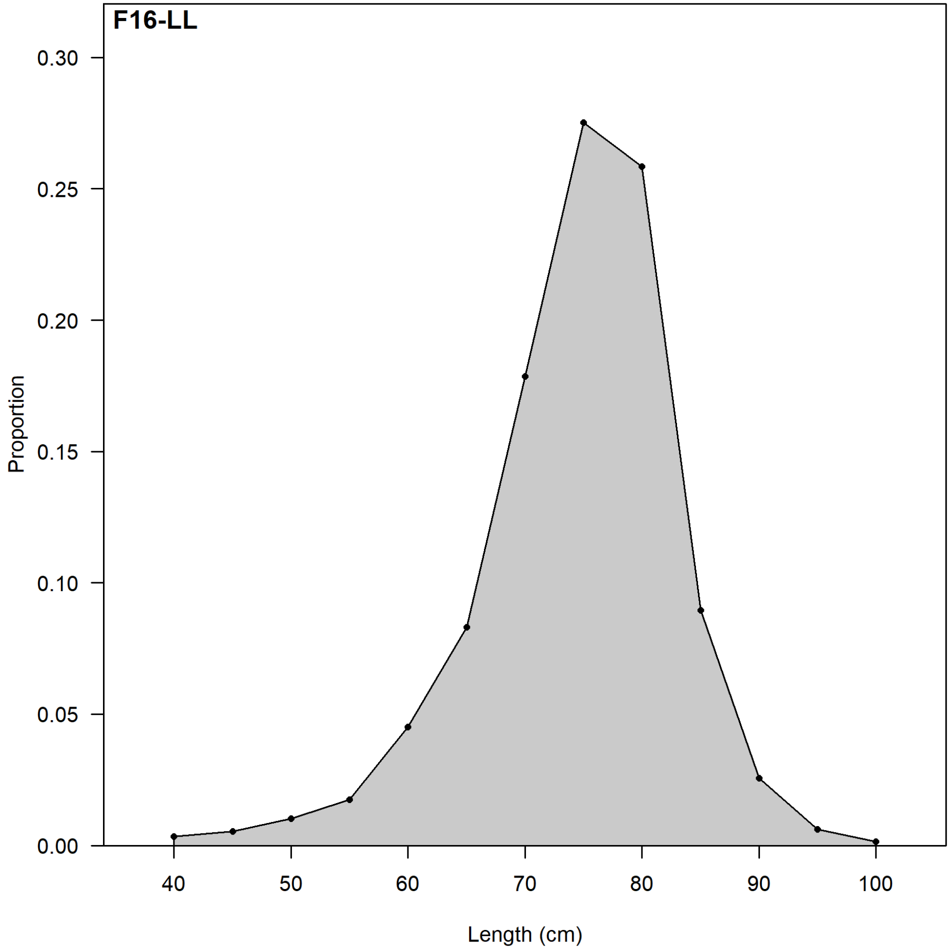
- *Last Interim*: Included Japanese longline nominal CPUE, but no tagging-based indices.
- *Current Benchmark*: No longline CPUE; added tagging-based absolute and relative indices.
- High uncertainty, average coefficient of variation (CV) = 0.62,in the standardized longline CPUE, derived from a spatiotemporal model using observer data from China, Chinese Taipei, Japan, and Korea.
- Biased nominal CPUE, including all effort data even when only observed trips reported skipjack catch.
- Japan FRA SAC-15 INF-U: the low catch and limited spatial coverage indicate using Japanese longline data alone is not enough to get reliable longline CPUE.
- No longer reliant on longline index due to absolute biomass estimates from tagging analysis.

3. Data – Size compositions

Fishery/Survey	Gear	Set type	Method	Length bins
F1-F7	Purse seine	OBJ	A design-based algorithm (Best Scientific Estimates or BSE)	1 cm intervals, from ≤20 to 100+ cm
F8-F12		NOA		
F13, F14		DEL		
F15	Purse seine discards	-	-	-
F16	Longline	-	A length-specific spatiotemporal model using VAST, fitted to observer data from the four members	5 cm intervals, from 40 to 100+ cm
S1	Purse seine	OBJ	Summing raw length-frequency observations across 5° areas, weighted by the catch-per-set predicted by the spatiotemporal model	1 cm intervals, from ≤20 to 100+ cm
S2		NOA		
S3	Echosounder buoy	-	-	-
S4	Tagging-based absolute	-	-	-
S5	Tagging-based relative	-	-	-

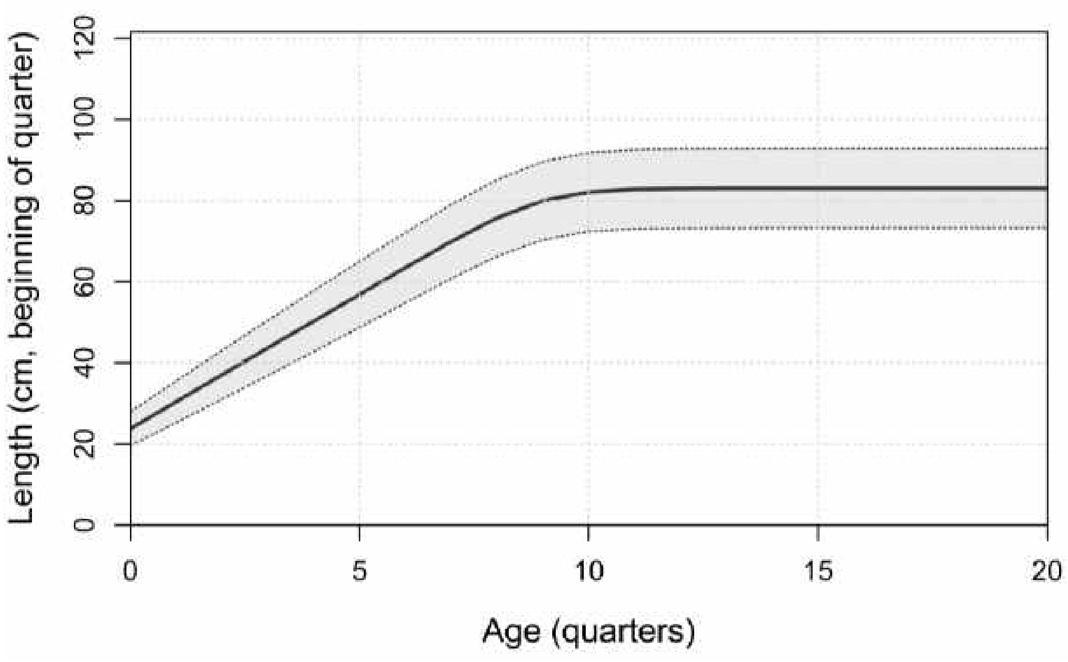
3. Data – Plot of size compositions





4. Model assumption – Growth

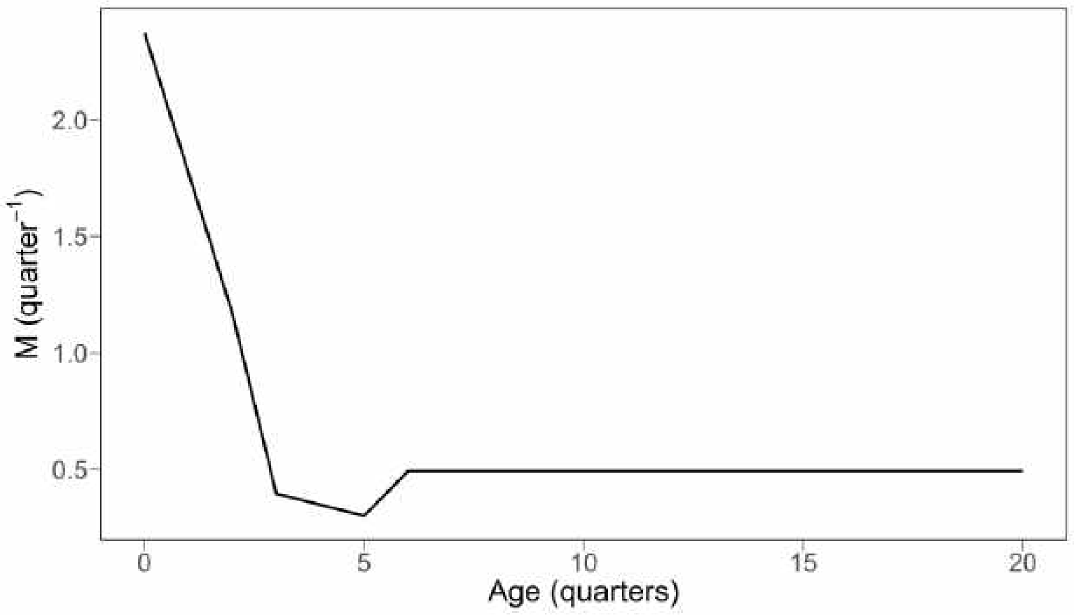
- Followed the settings used in the interim assessment.
- The mean length-at-age was estimated by fitting a growth cessation model to tagging data.
- The asymptotic length was determined using the length-frequency data from the longline fishery (75% quantile, 83 cm).
- The age at 37 cm is 2 quarters.



The shaded region represents variation in length-at-age, assuming a CV = 9% at age 0 and 6% at age 20 quarters (mean $\pm$ 1.96 standard deviations).

4. Model assumption – Natural mortality

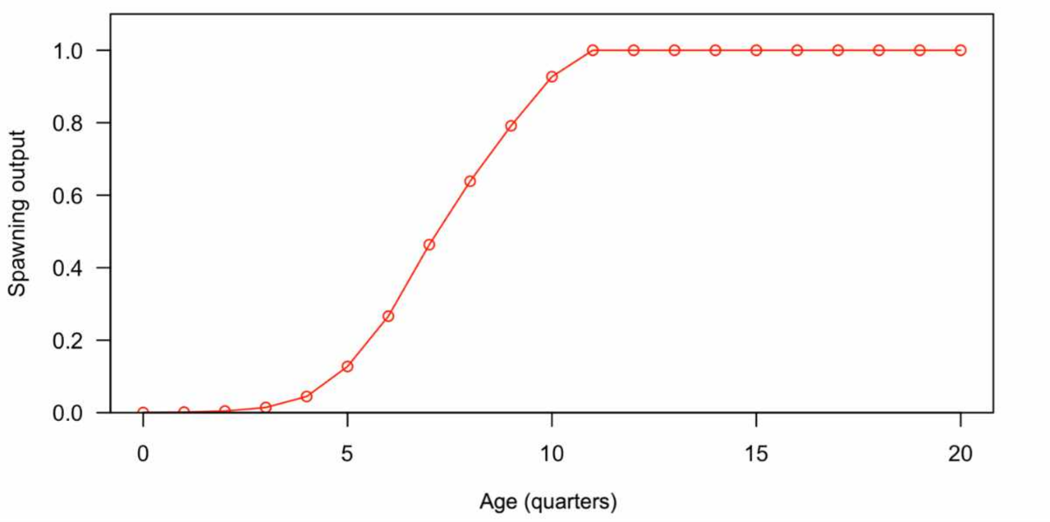
- Followed the settings used in the interim assessment.
- It assumes the natural mortality by length class for skipjack tuna estimated by Hampton (2000) with linear interpolation between the mid points of the length classes.
- Natural mortality is constant after a length of 65 cm.
- High natural mortality for young fish has little impact on the assessment results.



4. Model assumption – Recruitment

- Followed the settings used in the interim assessment.
- Beverton-Holt stock-recruit relationship.
- Recruitment is quarterly: use the quarter-as-year approach.
- Recruitment is independent of stock size (steepness *h* = 1).
- No autocorrelation in recruit deviates.
- Recruitment variability (σ_R) = 0.6 (quarterly).
- Bias adjustment follows Methot and Taylor (2011).

The maturity and batch fecundity relationships with length are taken from Schaefer and Fuller (2019). The age-specific reproductive output, which is the product of maturity and fecundity:



4. Model assumption – Stock structure

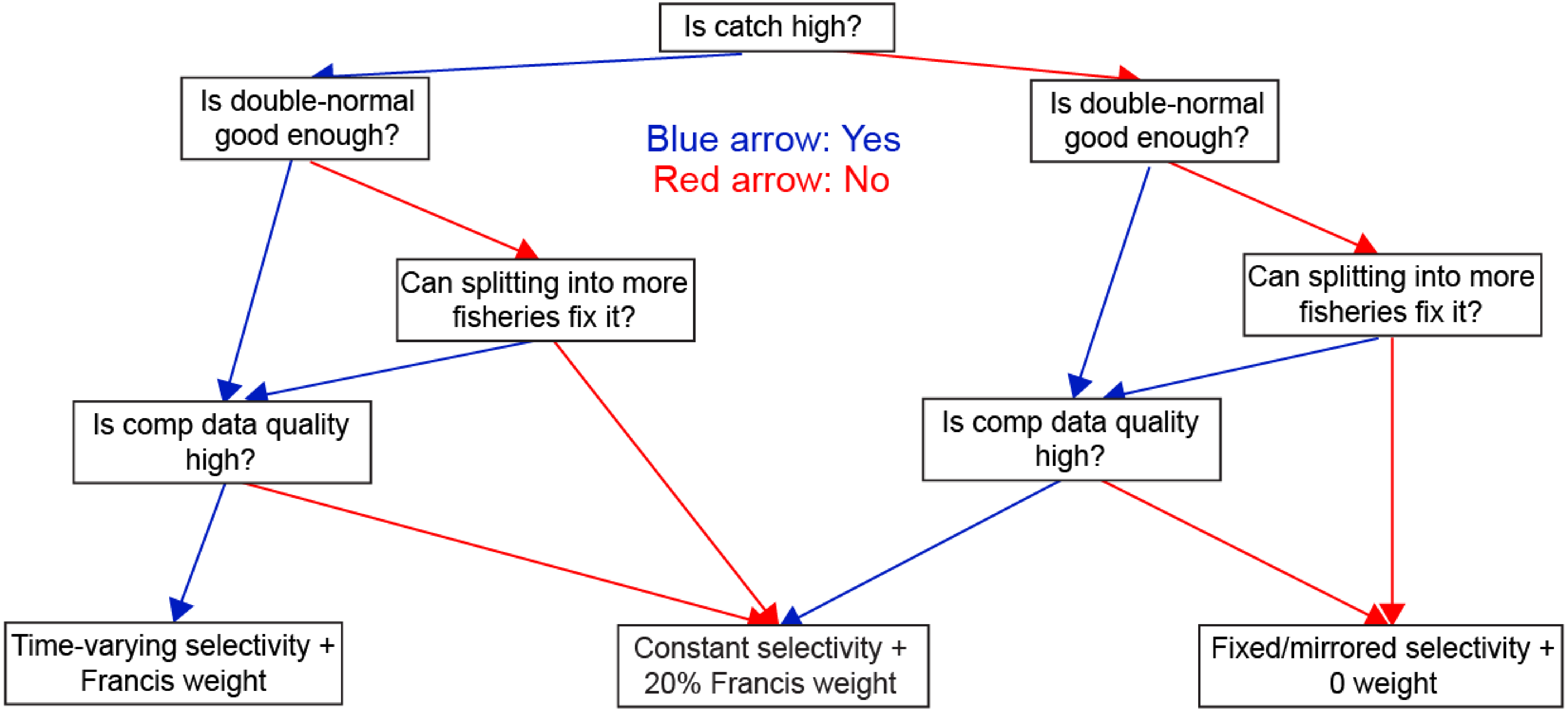
- Followed the settings used in the interim assessment.
- It assumes that the EPO is comprised of a single stock to fulfill management requirements.

4. Model assumption – Initial conditions

- Followed the settings used in the interim assessment.
- Model starts from a non-virgin equilibrium state:
  - Initial Recruitment (R_{init}): Offset of virgin recruitment, reflecting a regime shift.
  - Initial Fishing Mortality (F_{init}): Estimated without penalty associated with initial equilibrium catch, corresponds to purse-seine fishery F7 (OBJ in the northern coastal area) due to significant skipjack catch.
- Additional estimates: 10 recruitment deviations estimated for quarters prior to the model's initial quarter.

4. Model assumptions – Selectivity and data weighting

A decision tree is developed for selectivity and data weighting



4. Model assumptions – Selectivity and data weighting

Fleet Number	Fleet type	Fleet name	Catch amount	Double-normal	Data quality
1	OBJ Fishery	F1-OBJ_Offshore_Small	High	Yes	High
2		F2-OBJ_Offshore_Large	Low	Yes	High
3		F3-OBJ_Central_Small	Low	Yes	High
4		F4-OBJ_Central_Large	Low	Yes	High
5		F5-OBJ_SC	Low	Yes	Low
6		F6-OBJ_CC	High	Yes	High
7		F7-OBJ_NC	High	Yes	High
8	NOA Fishery	F8-NOA-Offshore_Small	Low	Yes	Low
9		F9-NOA-Offshore_Large	Low	Yes	Low
10		F10-NOA-S	High	Yes	Low
11		F11-NOA-C	High	Yes	High
12		F12-NOA-N	Low	Yes	High
13	DEL Fishery	F13-DEL-N	Low	Yes	High
14		F14-DEL-S	Low	Yes	Low
15	Other Fishery	F15-DISsmall	Low	No	NA
16		F16-LL	Low	No	NA
17	Survey	S1-OBJ	NA	Yes	High
18		S2-NOA	NA	Yes	High
19		S3-Echo	NA	Yes	High
20		S4-TAG	NA	Yes	High
21		S5-TAG-RELATIVE	NA	Yes	High

4. Model assumptions – Selectivity and data weighting

Fleet Number	Fleet type	Fleet name	Catch amount	Double-normal	Data quality	**Selectivity**	Time blocks	Weighting scaler
1	OBJ Fishery	F1-OBJ_Offshore_Small	High	Yes	High	Estimated	2006-2015; 2016-2023	1
2		F2-OBJ_Offshore_Large	Low	Yes	High	Estimated	NA	0.2
3		F3-OBJ_Central_Small	Low	Yes	High	Estimated	NA	0.2
4		F4-OBJ_Central_Large	Low	Yes	High	Estimated	NA	0.2
5		F5-OBJ_SC	Low	Yes	Low	Estimated	NA	0.2
6		F6-OBJ_CC	High	Yes	High	Estimated	2006-2015; 2016-2023	1
7		F7-OBJ_NC	High	Yes	High	Estimated	2006-2015; 2016-2023	1
8	NOA Fishery	F8-NOA-Offshore_Small	Low	Yes	Low	Estimated	NA	0.2
9		F9-NOA-Offshore_Large	Low	Yes	Low	Estimated	NA	0.2
10		F10-NOA-S	High	Yes	Low	Estimated	NA	0.2
11		F11-NOA-C	High	Yes	High	Estimated	2006-2015; 2016-2023	1
12		F12-NOA-N	Low	Yes	High	Estimated	NA	0.2
13	DEL Fishery	F13-DEL-N	Low	Yes	High	Estimated	NA	0.2
14		F14-DEL-S	Low	Yes	Low	Mirror F13	NA	0
15	Other Fishery	F15-DISsmall	Low	No	NA	Fixed	NA	0
16		F16-LL	Low	No	NA	Estimated	NA	0.2
17	Survey	S1-OBJ	NA	Yes	High	Estimated	NA	1
18		S2-NOA	NA	Yes	High	Estimated	NA	0
19		S3-Echo	NA	Yes	High	Mirror S1	NA	0
20		S4-TAG	NA	Yes	High	Mirror S1	NA	0
21		S5-TAG-RELATIVE	NA	Yes	High	Mirror S1	NA	0

4. Model assumptions – Selectivity and data weighting

Fleet Number	Fleet type	Fleet name	Catch amount	Double-normal	Data quality	**Selectivity**	Time blocks	Weighting scaler
1	OBJ Fishery	F1-OBJ_Offshore_Small	High	Yes	High	Estimated	2006-2015; 2016-2023	1
2		F2-OBJ_Offshore_Large	Low	Yes	High	Estimated	NA	0.2
3		F3-OBJ_Central_Small	Low	Yes	High	Estimated	NA	0.2
4		F4-OBJ_Central_Large	Low	Yes	High	Estimated	NA	0.2
5		F5-OBJ_SC	Low	Yes	Low	Estimated	NA	0.2
6		F6-OBJ_CC	High	Yes	High	Estimated	2006-2015; 2016-2023	1
7		F7-OBJ_NC	High	Yes	High	Estimated	2006-2015; 2016-2023	1
8	NOA Fishery	F8-NOA-Offshore_Small	Low	Yes	Low	Estimated	NA	0.2
9		F9-NOA-Offshore_Large	Low	Yes	Low	Estimated	NA	0.2
10		F10-NOA-S	High	Yes	Low	Estimated	NA	0.2
11		F11-NOA-C	High	Yes	High	Estimated	2006-2015; 2016-2023	1
12		F12-NOA-N	Low	Yes	High	Estimated	NA	0.2
13	DEL Fishery	F13-DEL-N	Low	Yes	High	Estimated	NA	0.2
14		F14-DEL-S	Low	Yes	Low	Mirror F13	NA	0
15	Other Fishery	F15-DISsmall	Low	No	NA	Fixed	NA	0
16		F16-LL	Low	No	NA	Estimated	NA	0.2
17	Survey	S1-OBJ	NA	Yes	High	Estimated	NA	1
18		S2-NOA	NA	Yes	High	Estimated	NA	0
19		S3-Echo	NA	Yes	High	Mirror S1	NA	0
20		S4-TAG	NA	Yes	High	Mirror S1	NA	0
21		S5-TAG-RELATIVE	NA	Yes	High	Mirror S1	NA	0

5. Reference model – Assumptions and data

- Longline fishery selectivity is modeled using a cubic spline with selectivity constant after 80 cm.
- The asymptotic length is 83 cm.
- The coefficient of variation (CV) of the length-at-age is a linear function of length (0.09 for age zero fish and 0.06 for age 20 quarters).
- The ECHO index and tagging-based absolute biomass are proportional to the population abundance selected by the purse-seine OBJ “survey”, and the other indices (OBJ “survey”, NOA “survey” and tagging-based relative biomass) are not used.
- Only the most precise tagging-based absolute biomass (2020 Q2, CV = 0.3) is used in the assessment.
- Size compositions from the NOA “survey” are excluded from the analysis; only those from the OBJ “survey” are used for the ECHO and tagging-based indices.

6. Sensitivity analysis

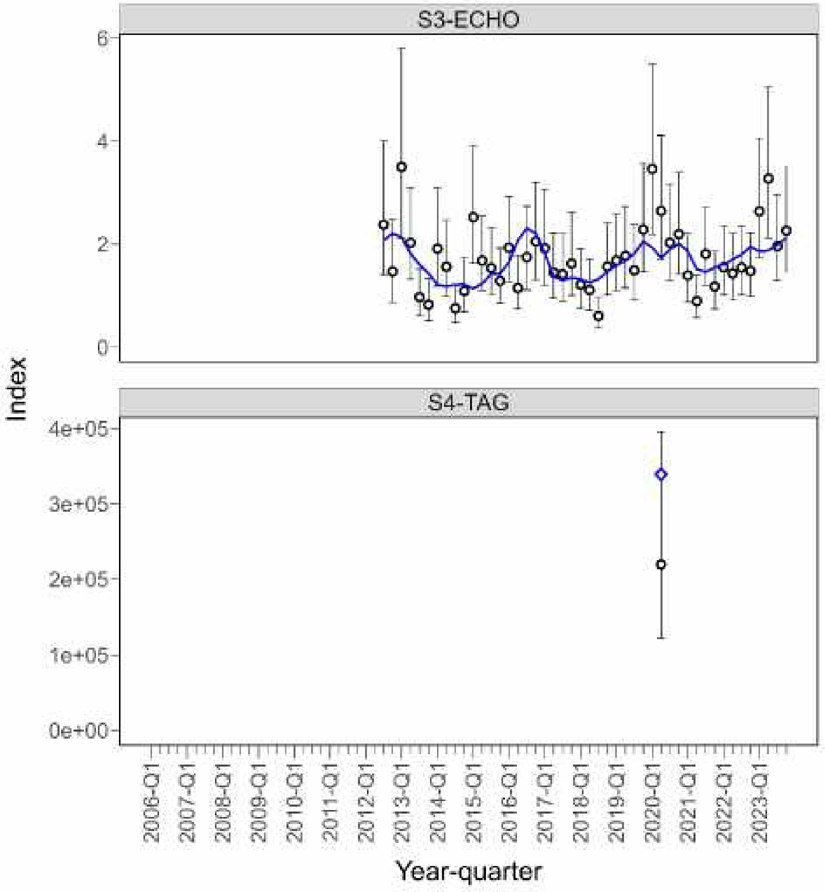
Process	Model	Brief	Description
Growth	A1	Asymptotic length	Estimating asymptotic length.
	A2		Lower asymptotic length. The asymptotic length is set at 78 cm.
	A3		Higher asymptotic length. The asymptotic length is set at 88 cm.
	A4	Length-at-age CV	Estimating CV of the variation of length-at-age for the oldest individuals.
	A5		Lower CV of the variation of length-at-age for the oldest individuals. The CV is fixed at 0.03.
	A6		Higher CV of the variation of length-at-age for the oldest individuals. The CV is fixed at 0.09.
	A7	Growth shape	Estimating growth shape parameter (Cessation_Fem_GP_1).
Selectivity	B1	Longline	Longline fishery selectivity is constant after 78 cm.
	B2		Longline fishery selectivity is constant after 83 cm.
	B3		Longline fishery selectivity is constant after 88 cm.
	B4	F9	The selectivity of fleet F9 is asymptotic, defined through a double-normal function. The selectivity of the longline fishery is fixed as in the reference model, and its size composition is not used in the analysis (i.e., λ = 0).
Tagging-absolute	C1	Upweight	The most precise tagging-based absolute biomass (2020 Q2, CV = 0.3) is used in the analysis and is upweighted by ten times (i.e., λ = 10).
	C2	More indices	Four tagging-based absolute biomass indices with low CVs (0.3-0.6) and low correlation coefficients (<0.13) during 2006-2023 are used in the analysis and are fully weighted (i.e., λ = 1).
Indices	D1	No tagging absolute	Excluding the tagging-based absolute index from the assessment model.
	D2	No ECHO	Excluding the echosounder buoy index from the assessment model.
	D3	Add longline	Inclusion of the longline survey index, obtained from a VAST model fitted with observer data from the four Members of the IATTC (CV = 0.2; the estimated CV is much higher than 0.2, so this index is not included in the reference model). Inclusion of the longline survey size composition, derived from a VAST model fitted with observer data from the four Members of the IATTC, weighted by CPUE.
Steepness	E1	-	Steepness = 0.75.

7. Model diagnostics – Convergence

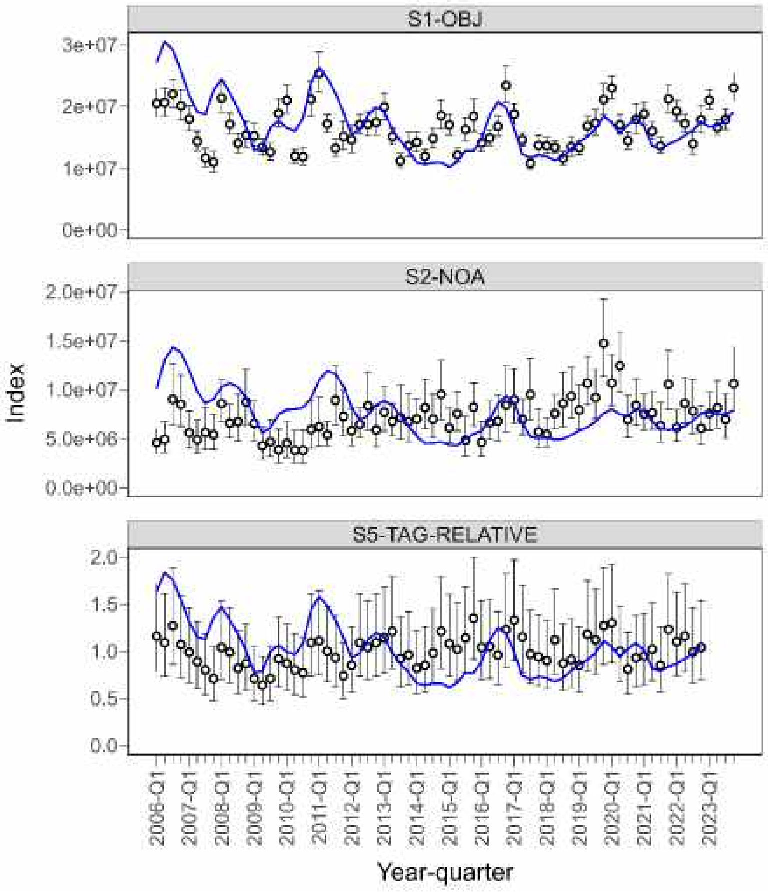
- The reference model converged with a low maximum gradient component of 9.60e-05 and a positive definite hessian. No parameters were on the bounds.
- All sensitivity models converged. No parameters were on the bounds.

7. Model diagnostics – Reference model fits to index

Fitted indices

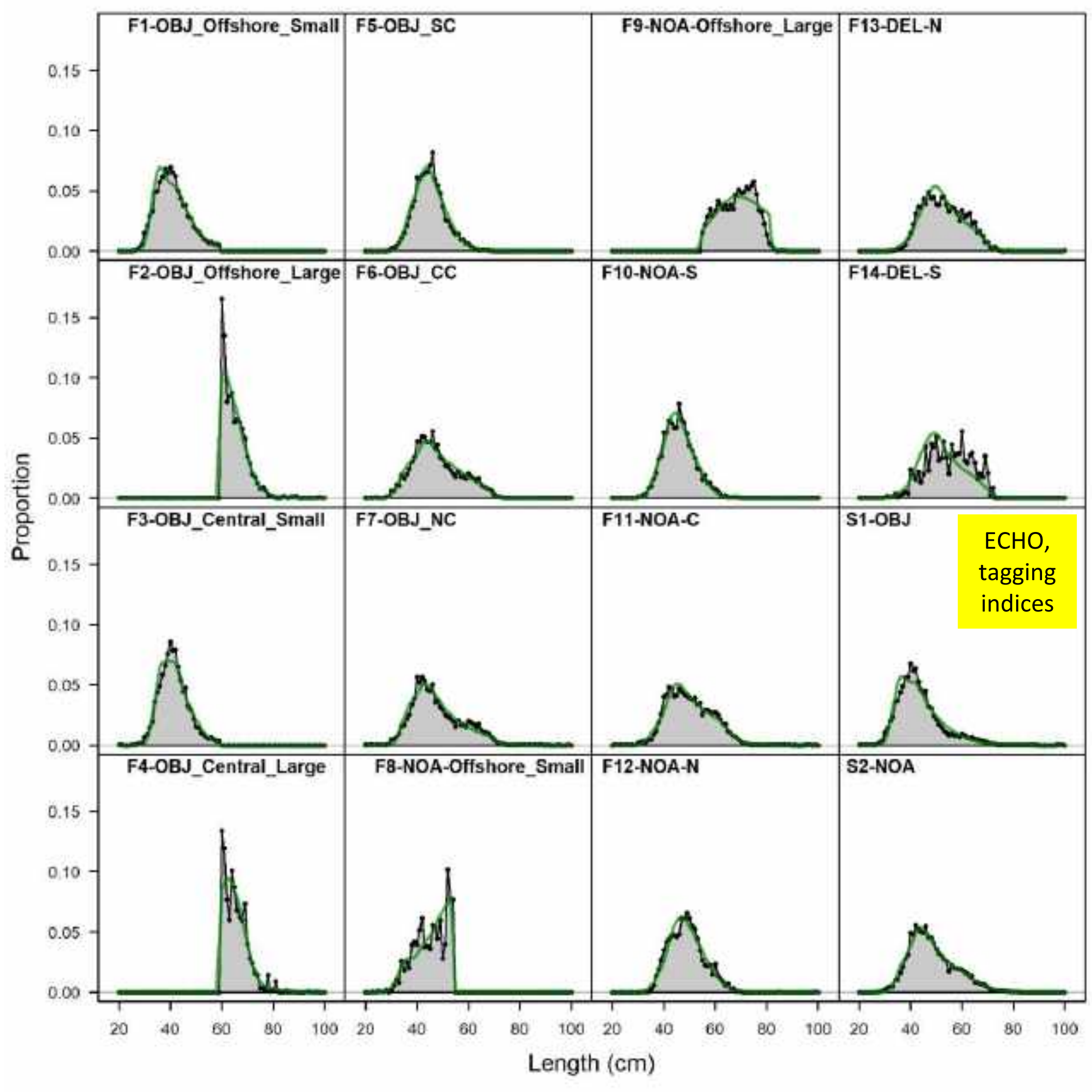


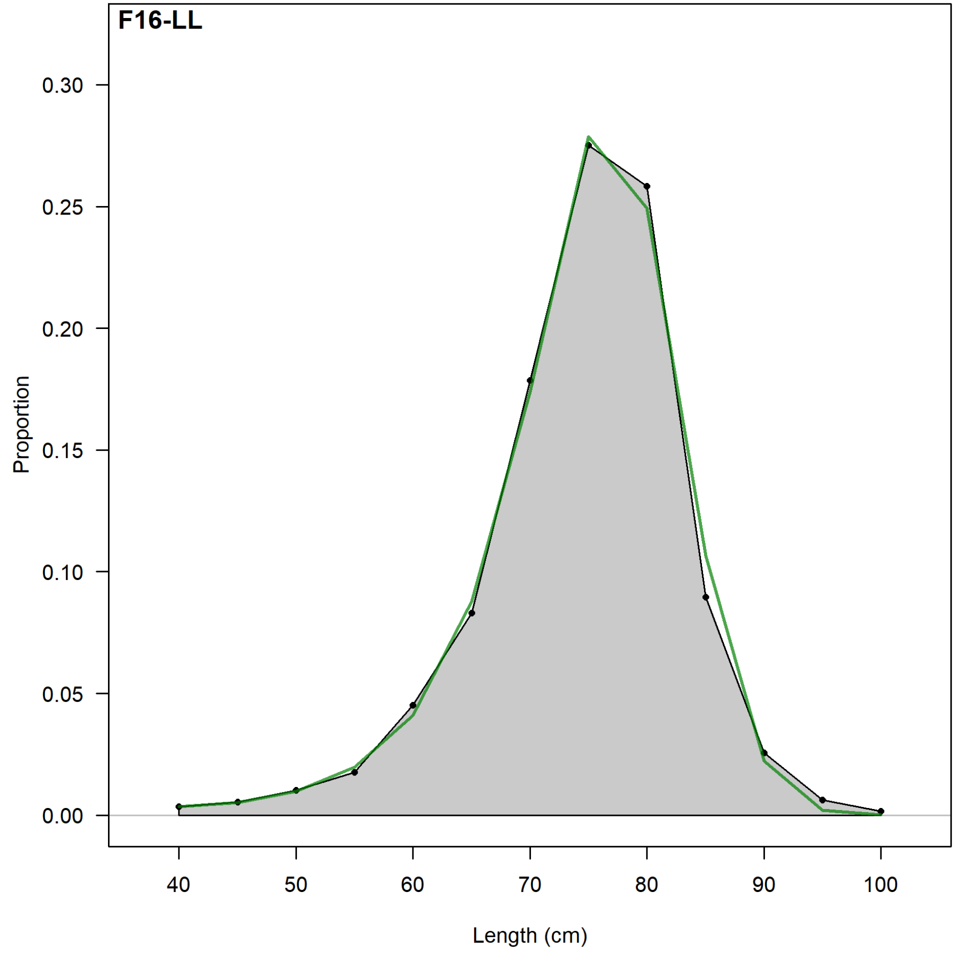
Not-fitted indices



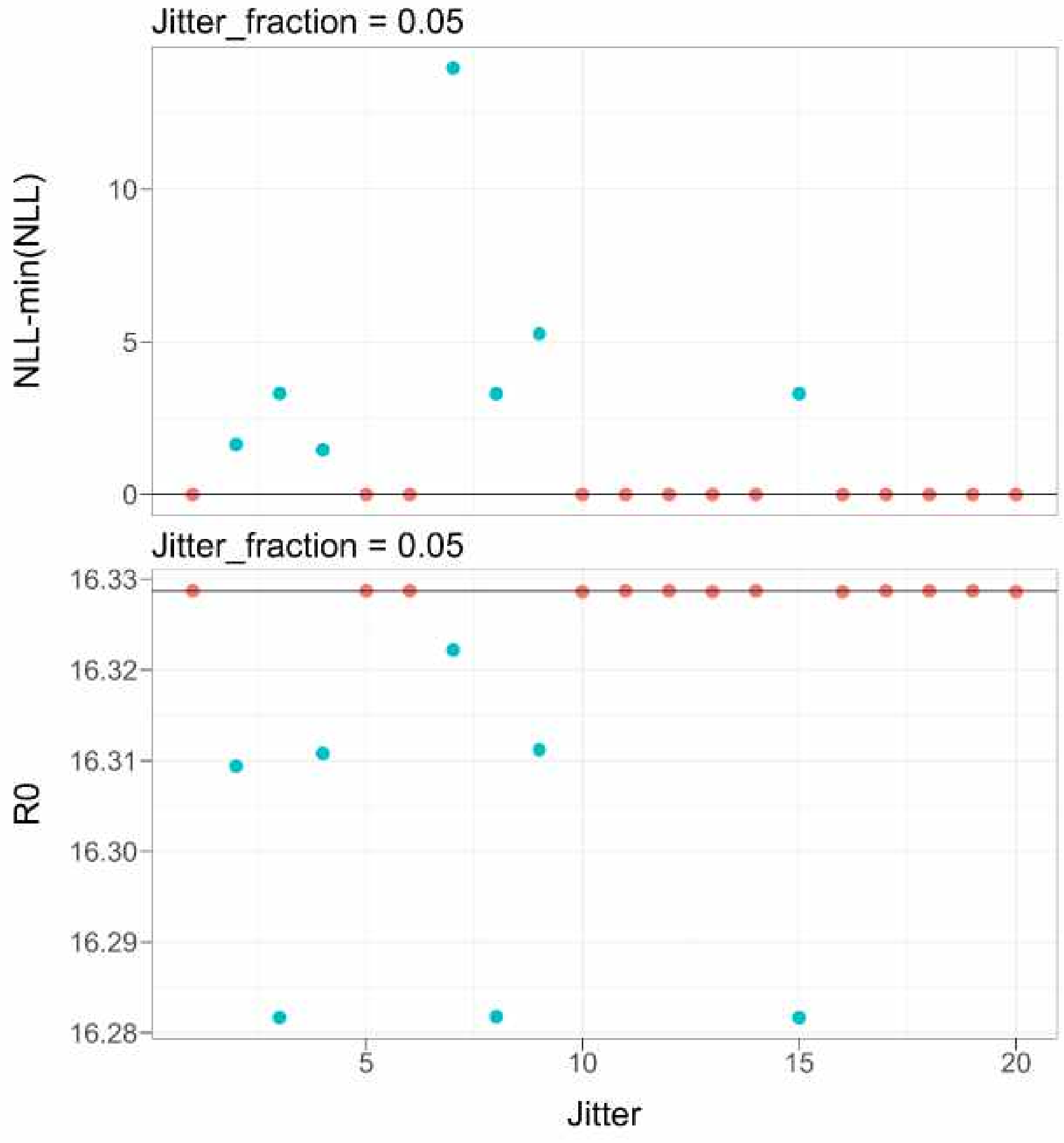
(The blue line and diamond represent the estimated indices, the black circles are the observed CPUE values, and the vertical lines represent the uncertainty in the observations.)

7. Model diagnostics – Reference model fits to size comps



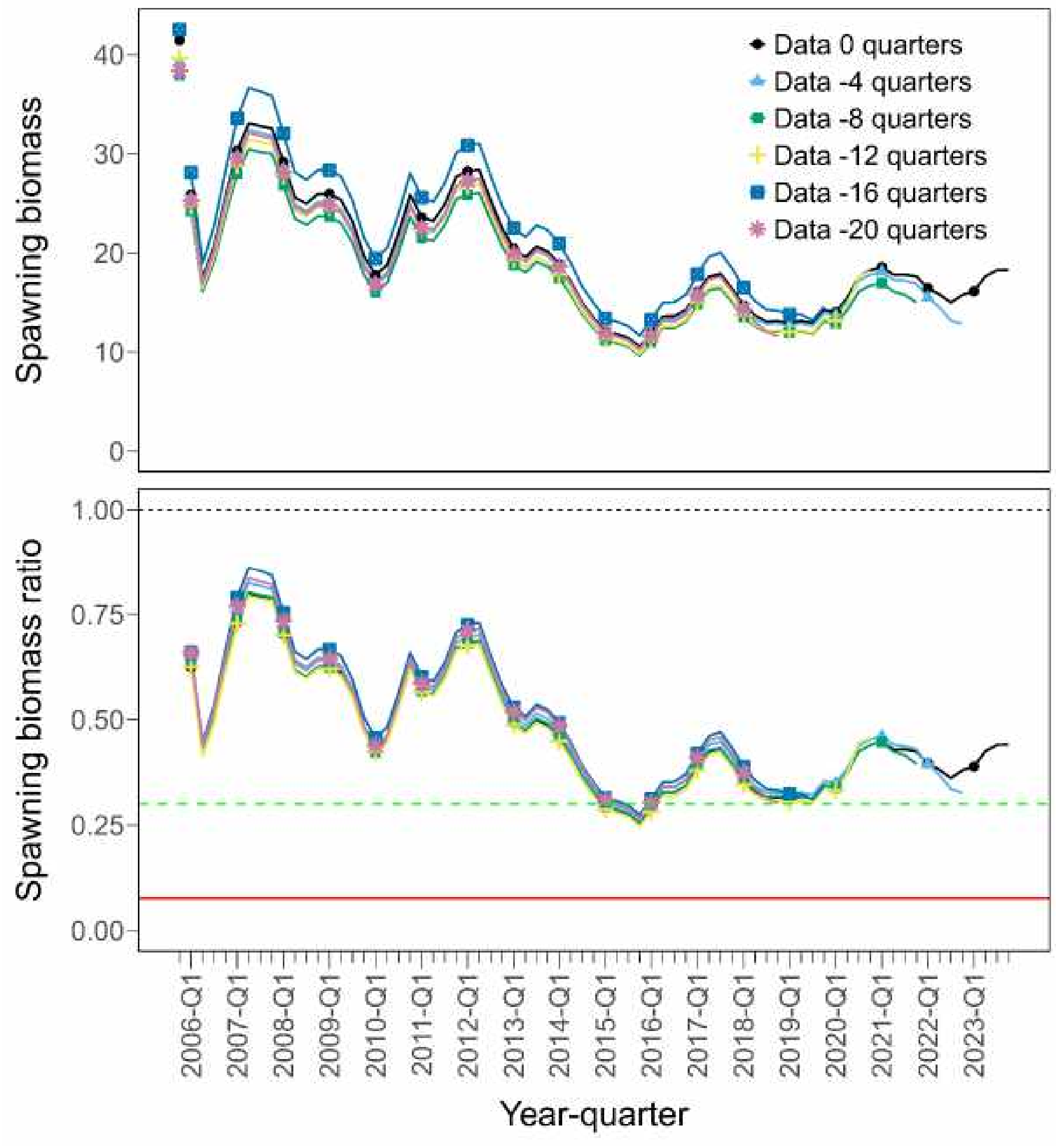


7. Model diagnostics – Jitter



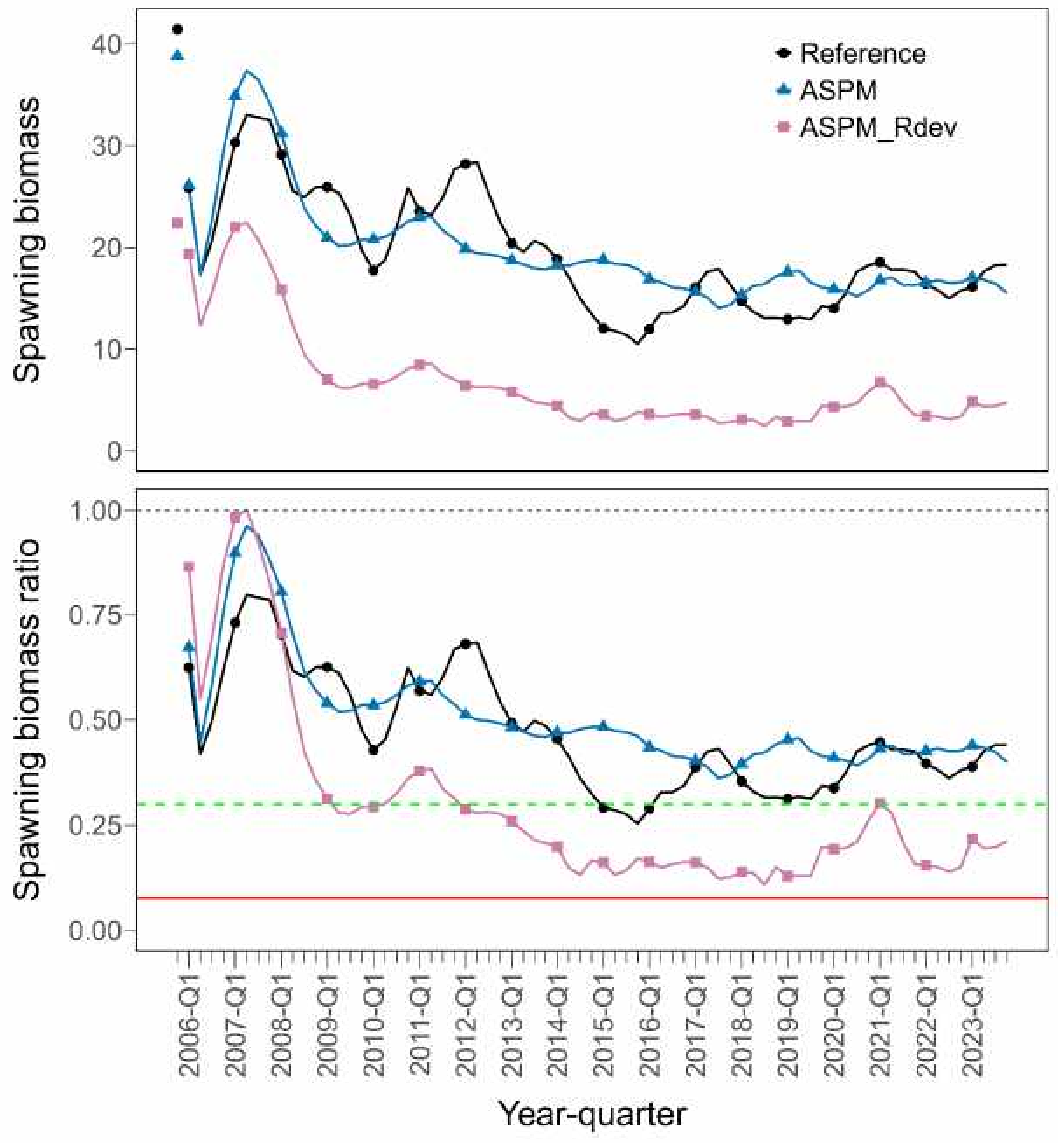
- A Jitter analysis was conducted for the reference model to evaluate whether the negative log-likelihood (NLL) of the reference model has reached global minimum.
- Black lines: NLL and R_0 estimates from the reference model.
- The reference model passes the jitter diagnostics, in terms of the NLL and R_0 estimates.

7. Model diagnostics – Retrospective



- A retrospective analysis was conducted by iteratively removing the data from the last year (4 quarters) five times.
- The estimated spawning biomass and spawning biomass ratio (SBR; *i.e.*, the ratio of the spawning biomass of the current stock to that of the unfished stock) shows little influence of eliminating years of data and no systematic pattern.

7. Model diagnostics – ASPM

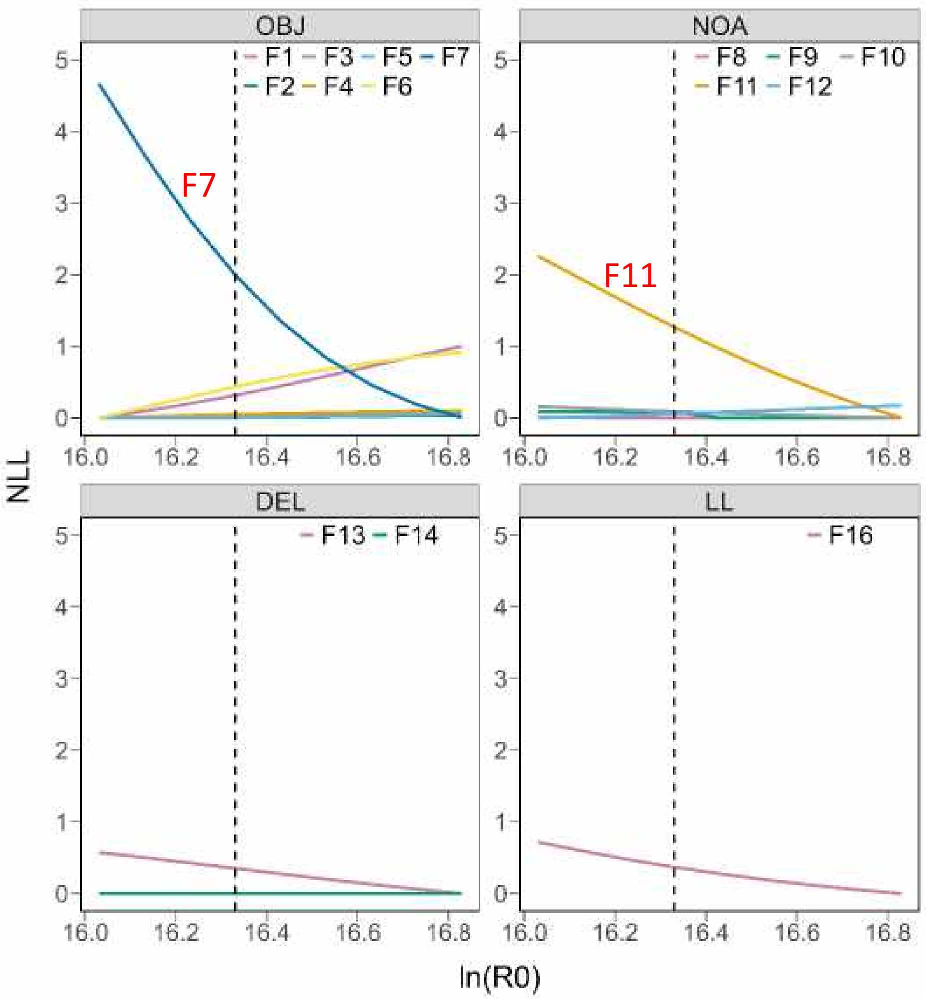


- The age-structured production model (ASPM) method sets selectivity parameters based on the reference model and excludes all composition likelihood components from total model likelihood.
- The ASPM without recruitment deviates (ASPM) shows a more stable population， indicating the index of abundance lacks detailed population trend information.
- With estimated recruitment deviations (ASPM_Rdev), the model shows a smaller population but following a similar trend, suggesting the need for recruitment deviations and composition data to accurately reflect population trend and control abundance estimates.

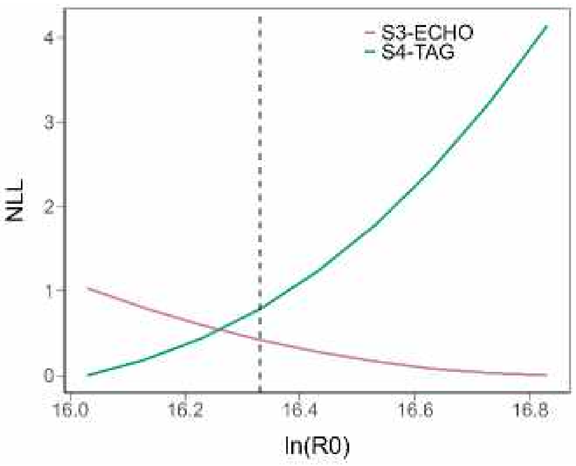
7. Model diagnostics – R_0 likelihood profile

- Virgin recruitment (R_0) scales absolute abundance.
- Running the reference model several times with R_0 fixed at values around the maximum likelihood estimate, to get a profile of model likelihood against R_0.
- R_0 likelihood profile is a diagnostic tool to assess how different data sets influence estimates of absolute abundance.

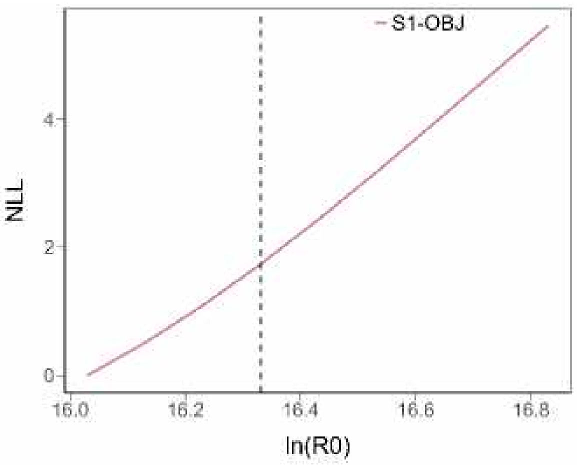
Fisheries' size comps



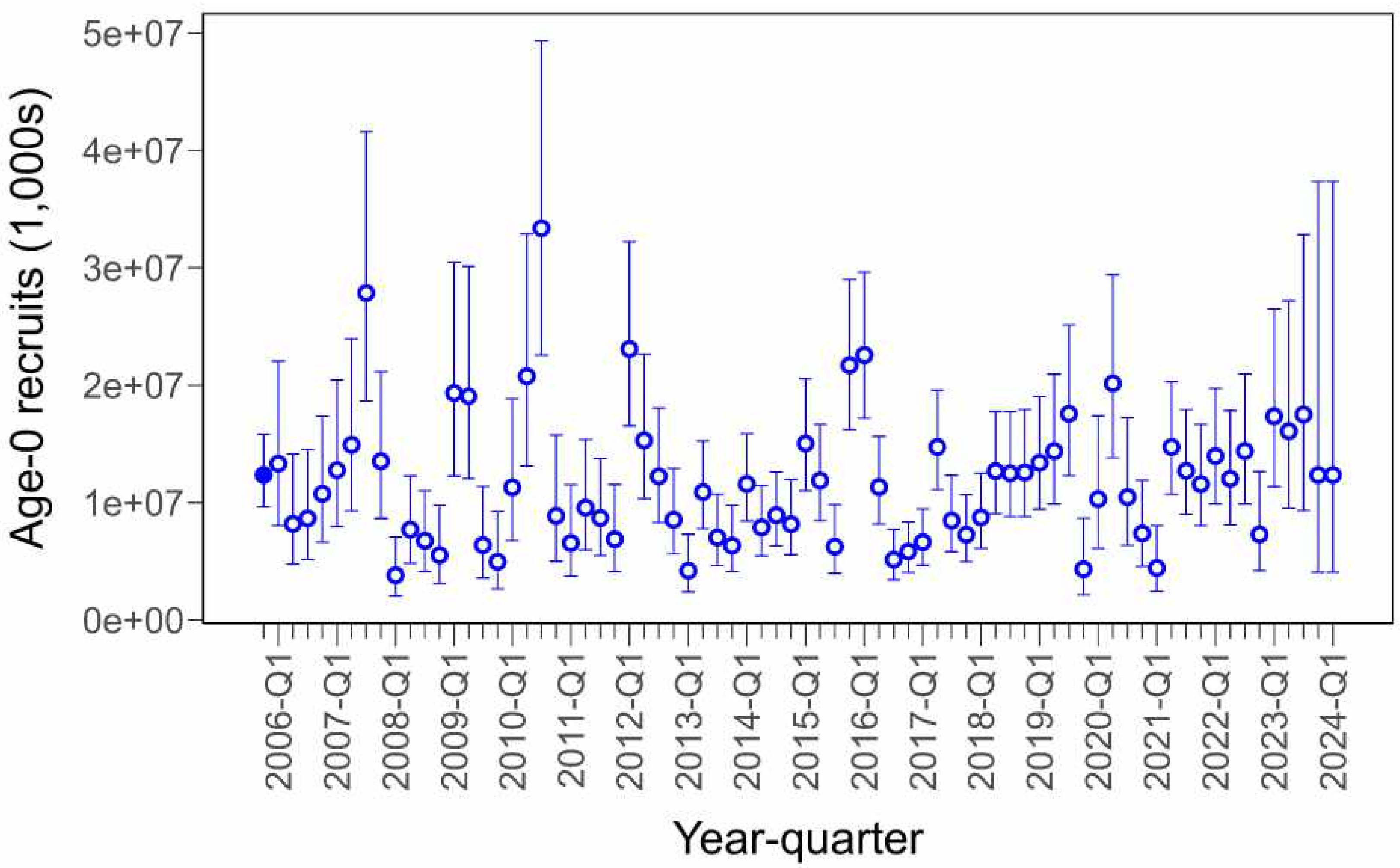
Index



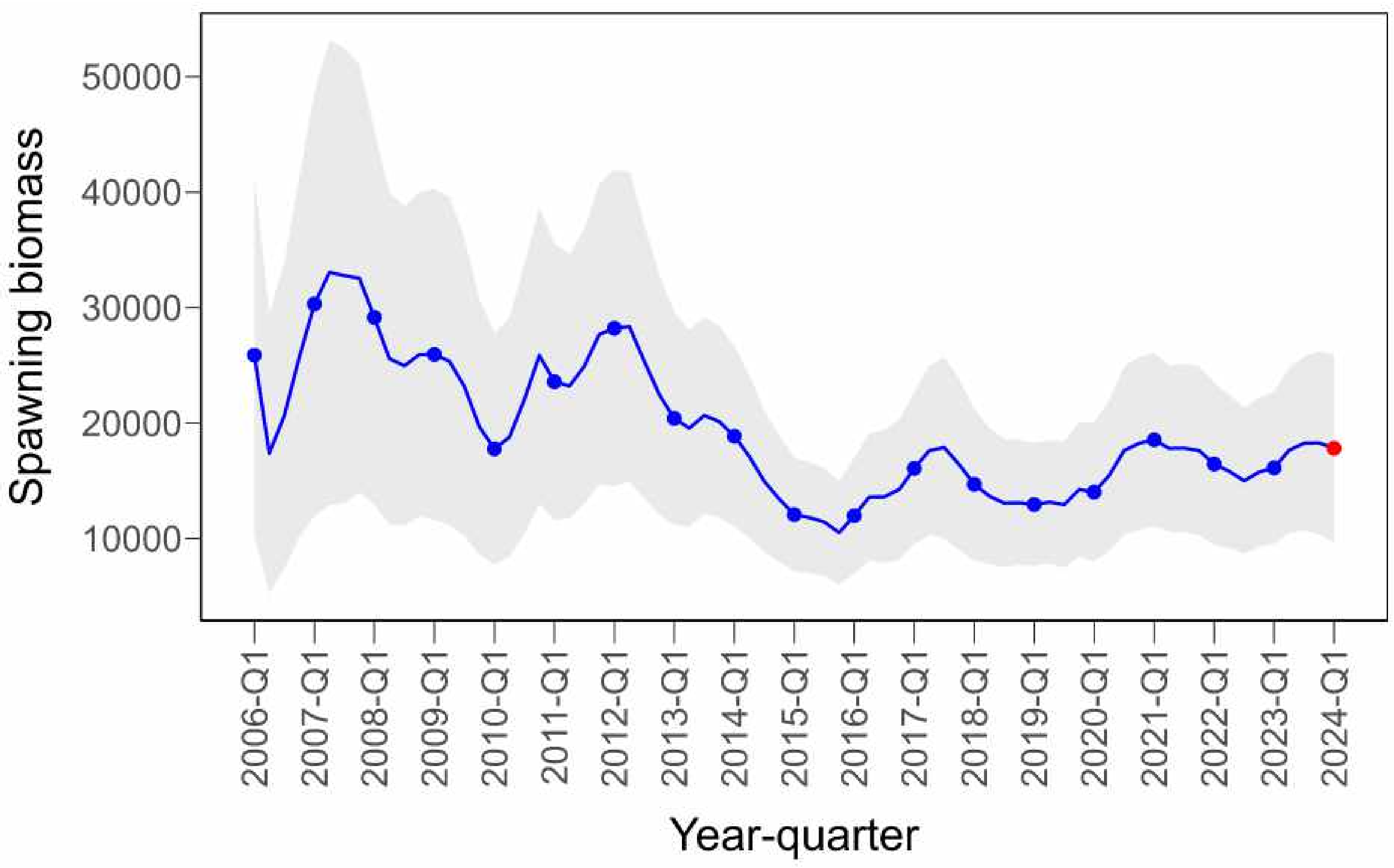
Survey's size comps



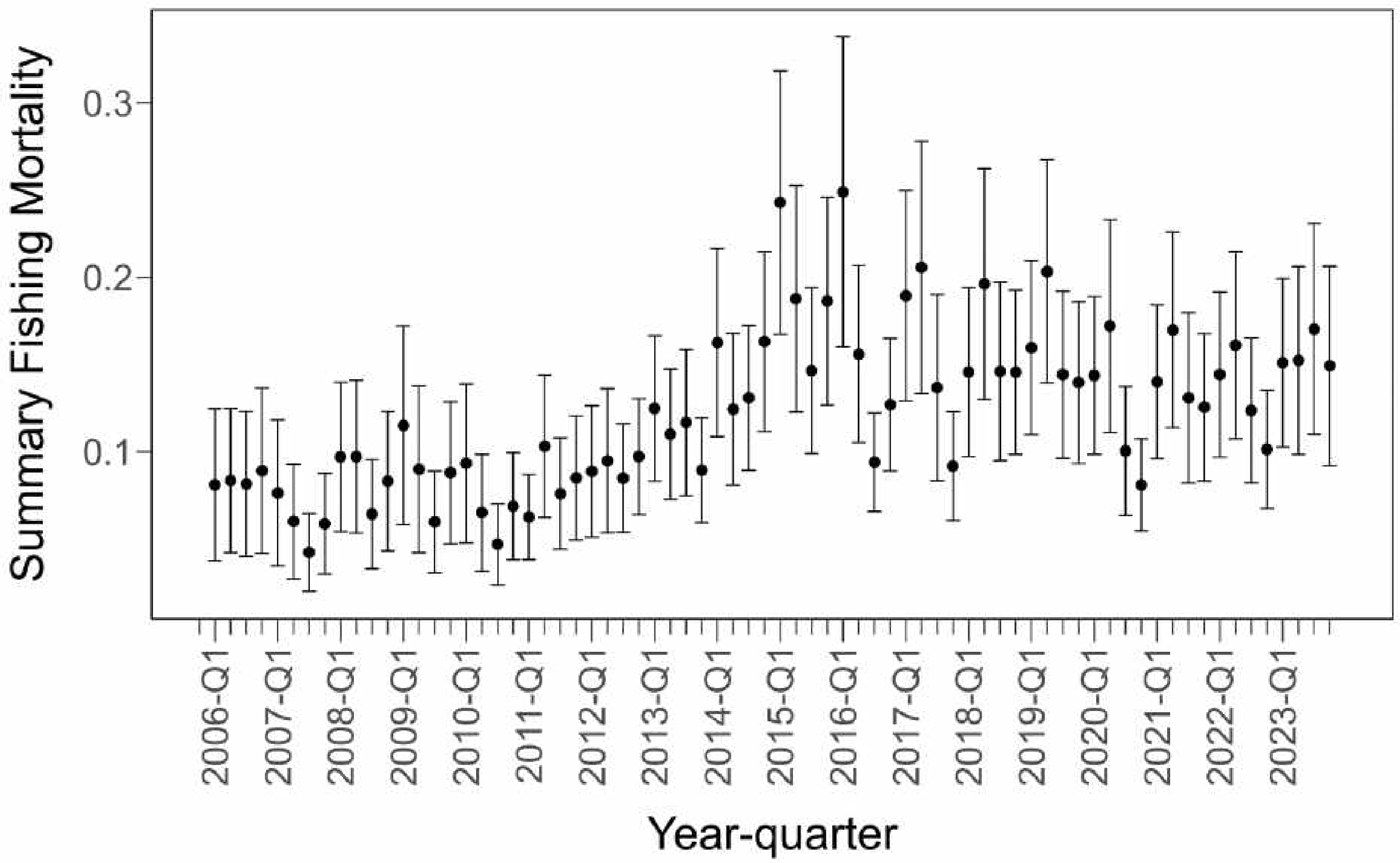
8. Results of reference model – Recruitment



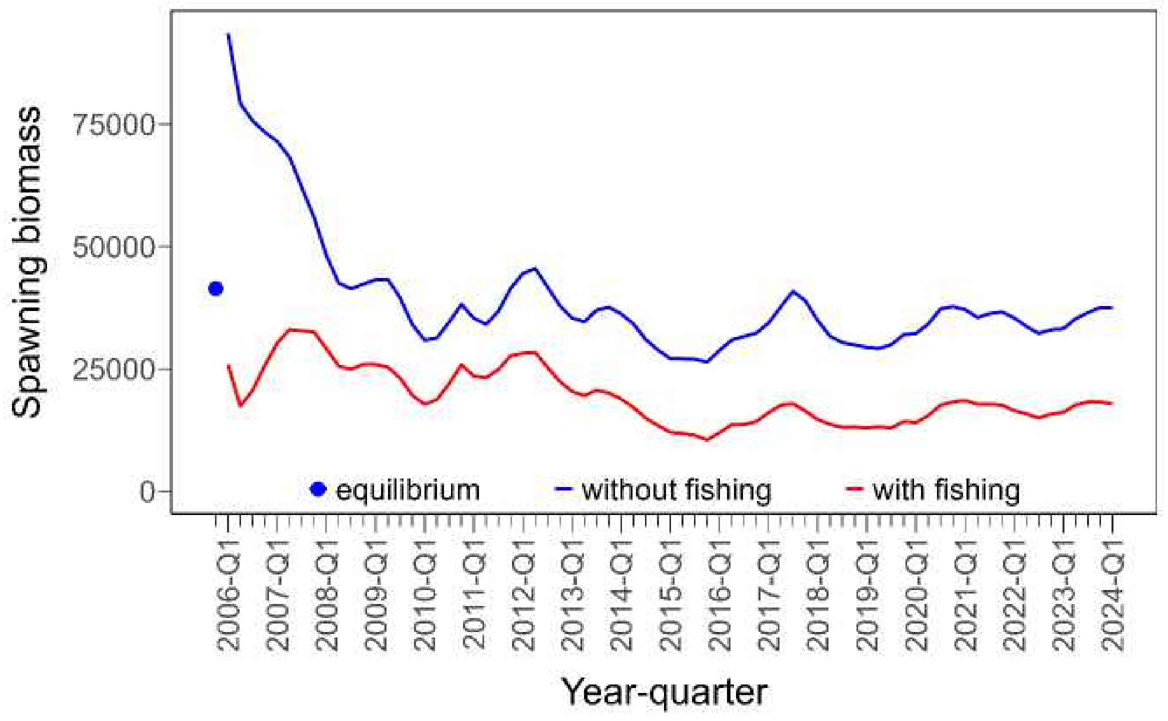
8. Results of reference model – Spawning biomass

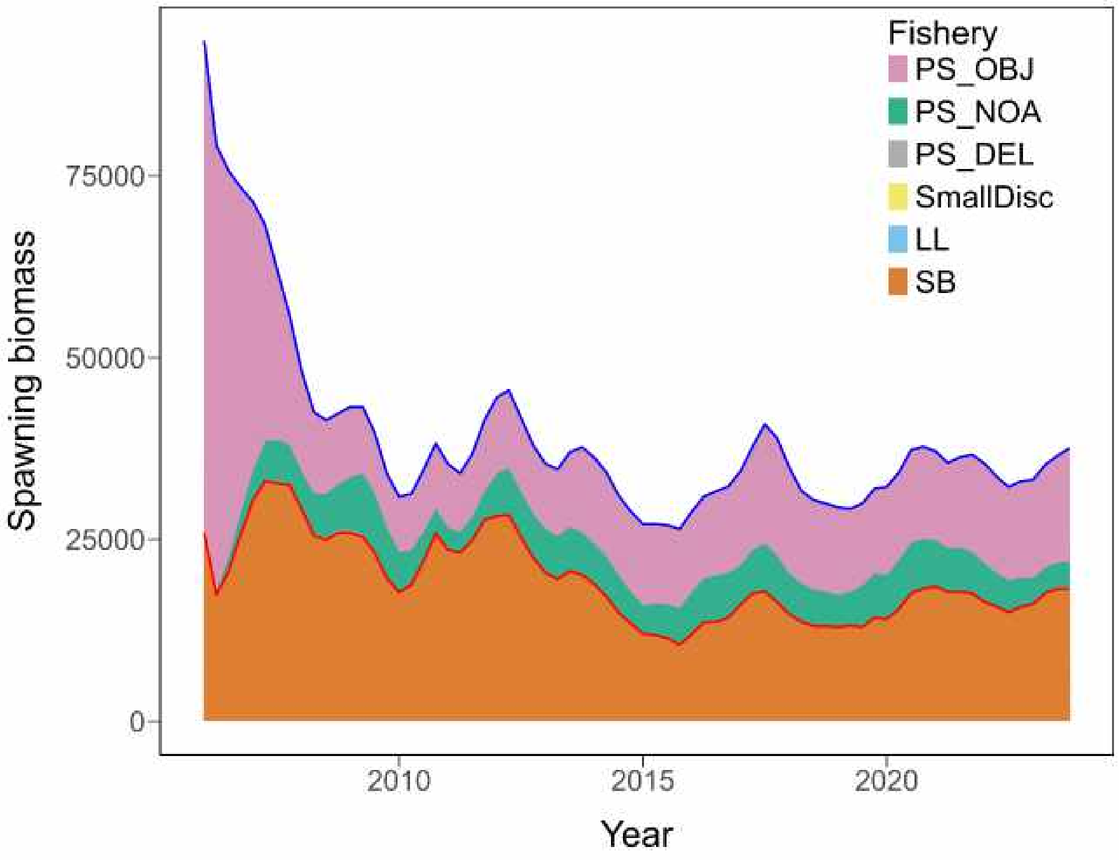


8. Results of reference model – Fishing mortality

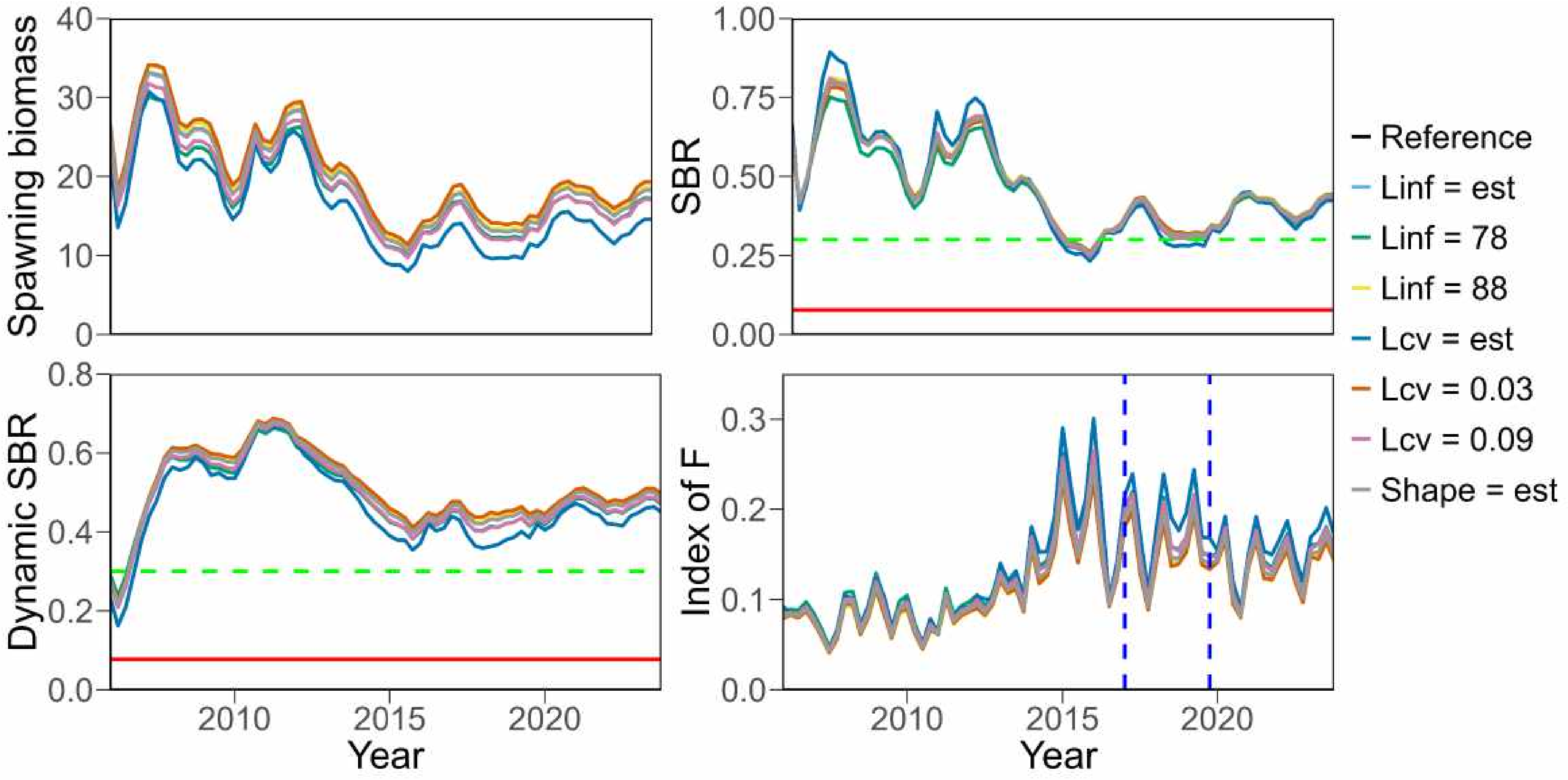


8. Results of reference model – Fisheries impacts





9. Results of sensitivity analysis – Growth



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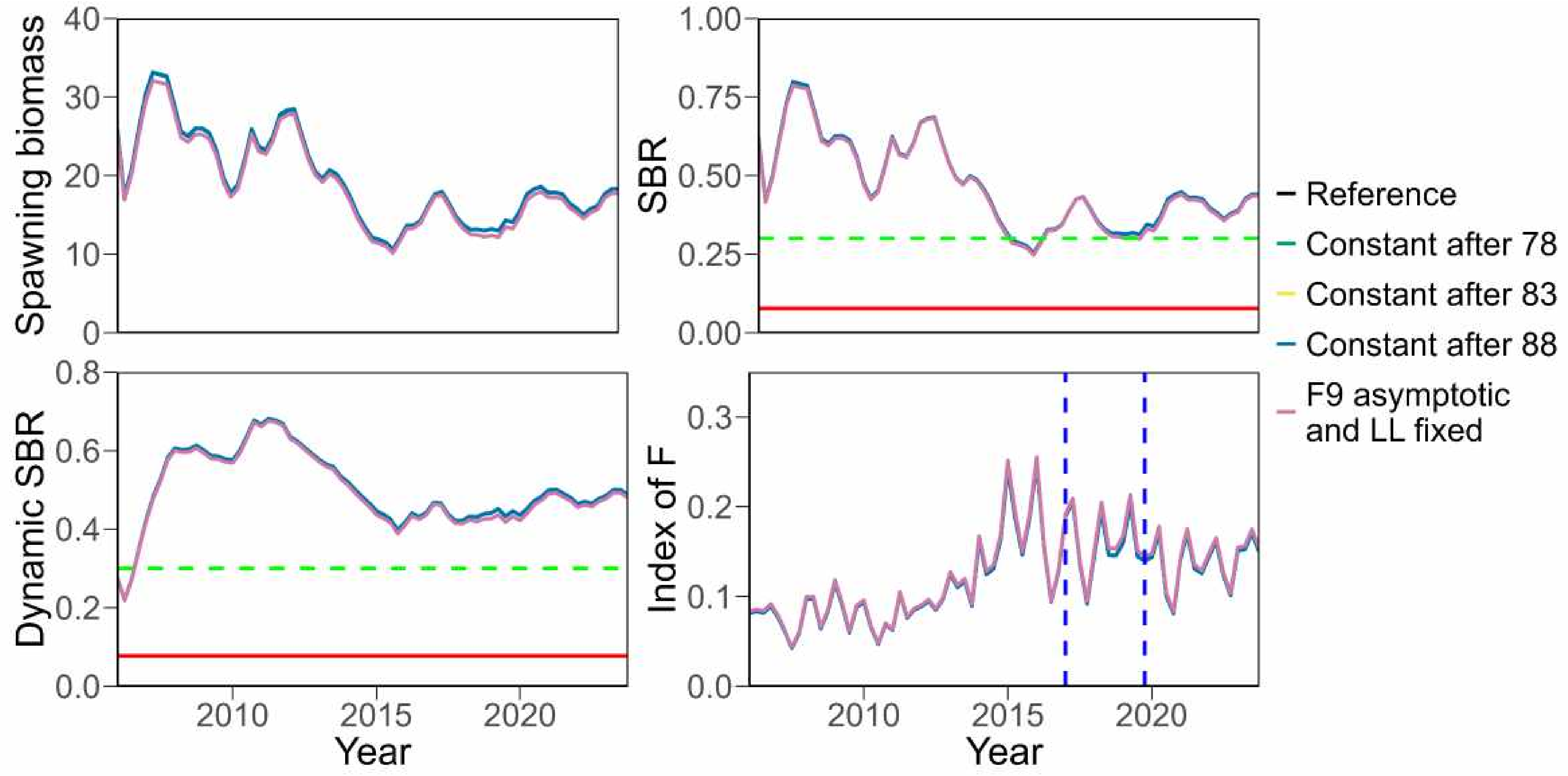
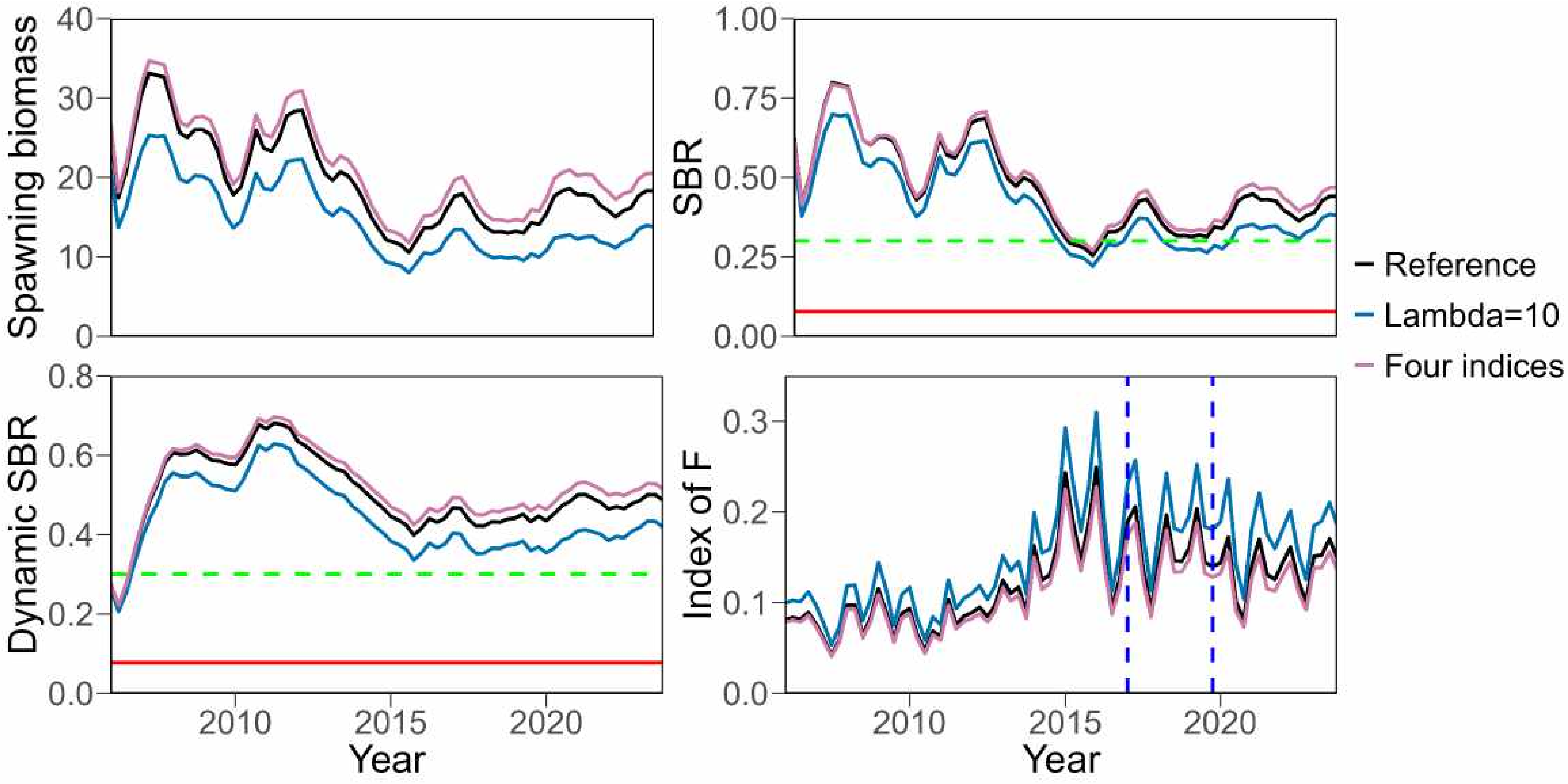
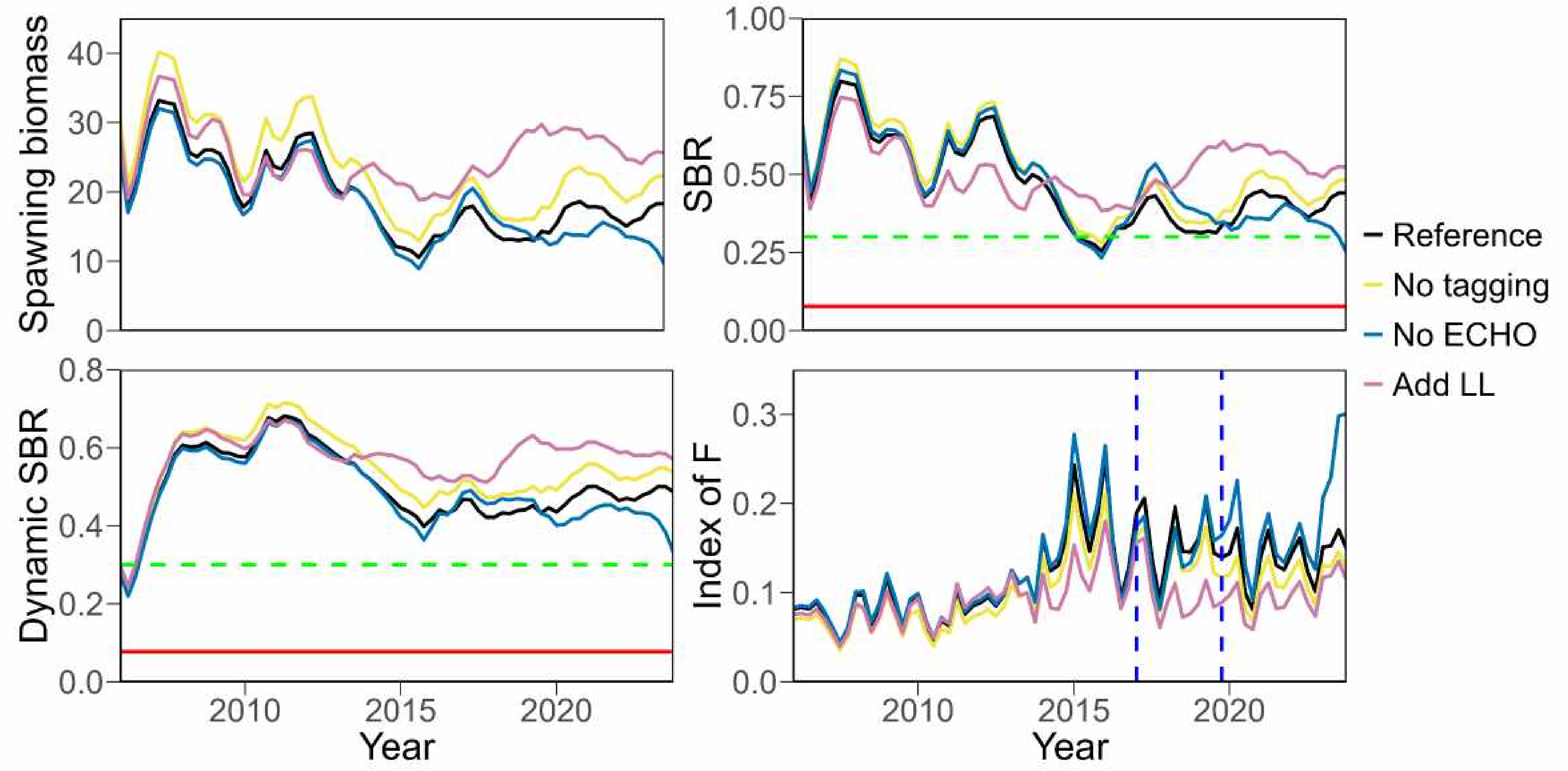
9. Results of sensitivity analysis – Selectivity



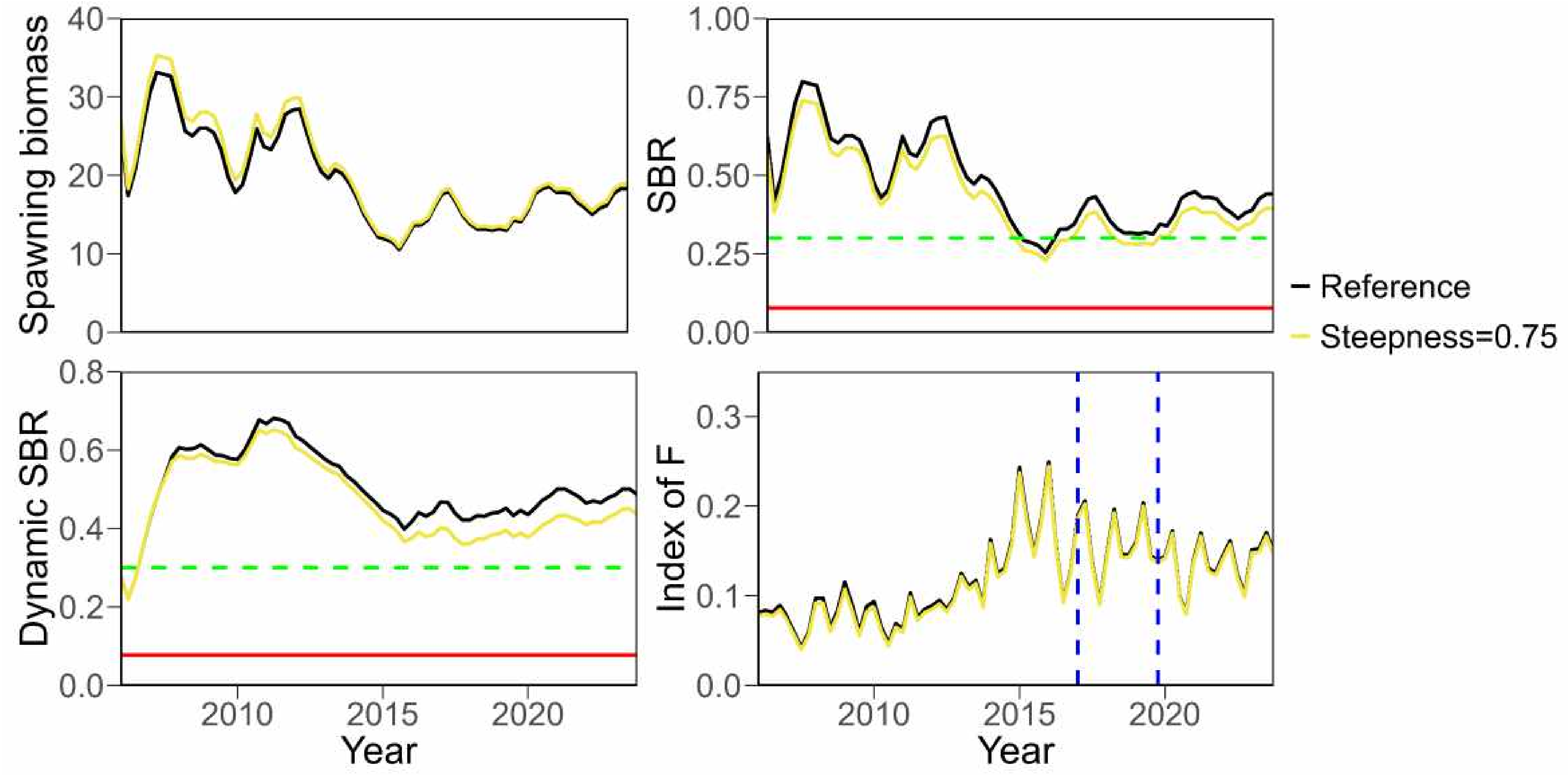
9. Results of sensitivity analysis – Tagging absolute



9. Results of sensitivity analysis – Indices



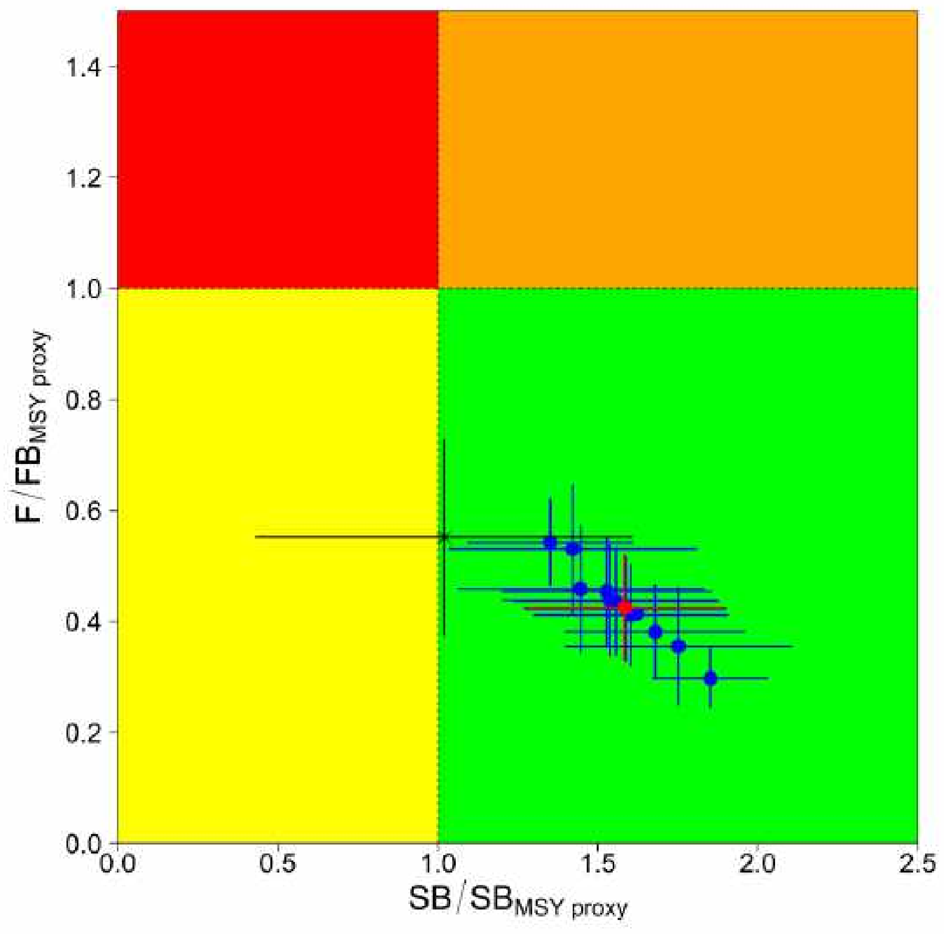
9. Results of sensitivity analysis – Steepness



10. Stock status – Biomass target

- Used the reference points proposed in the interim assessment.
- MSY-based metrics are unreliable, due to the growth-mortality tradeoff and the assumption of recruitment independence from stock size, so a conservative *proxy* for target biomass is used.
- **Target reference point**: dynamic spawning biomass ratio (dSBR) at 0.3.
- The dSBR accounts for variability in recruitment.
- **Limit reference point**: SBR at 0.077 .

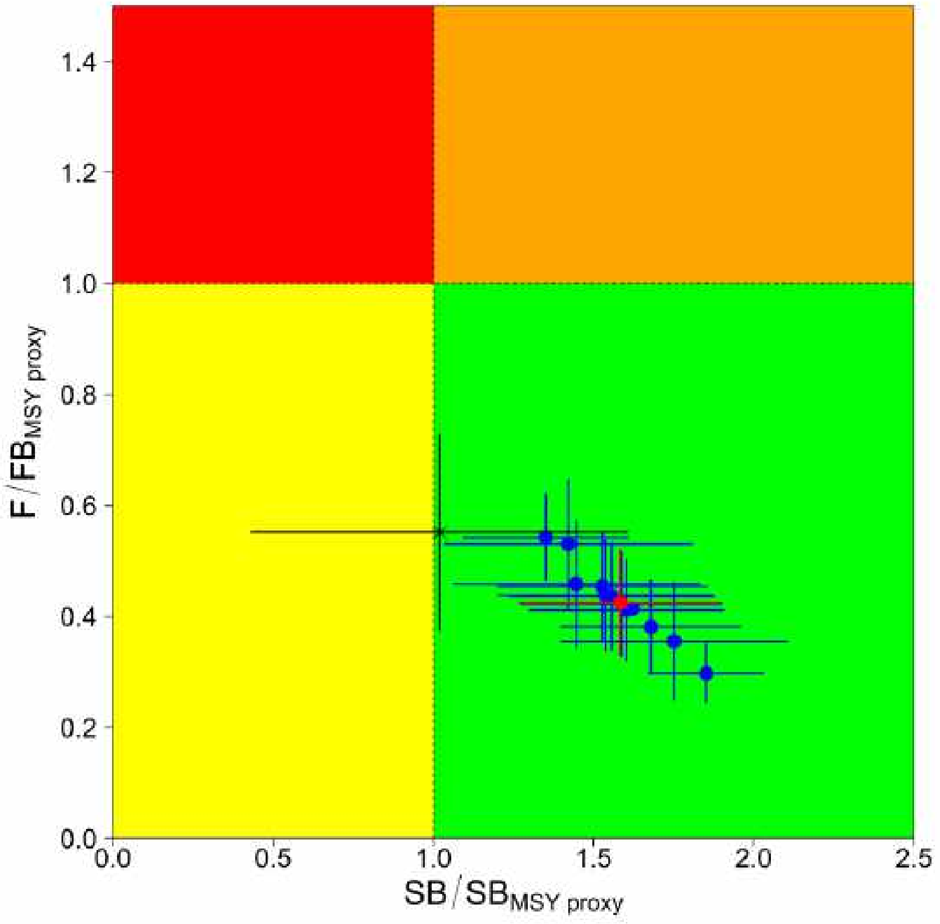
10. Stock status



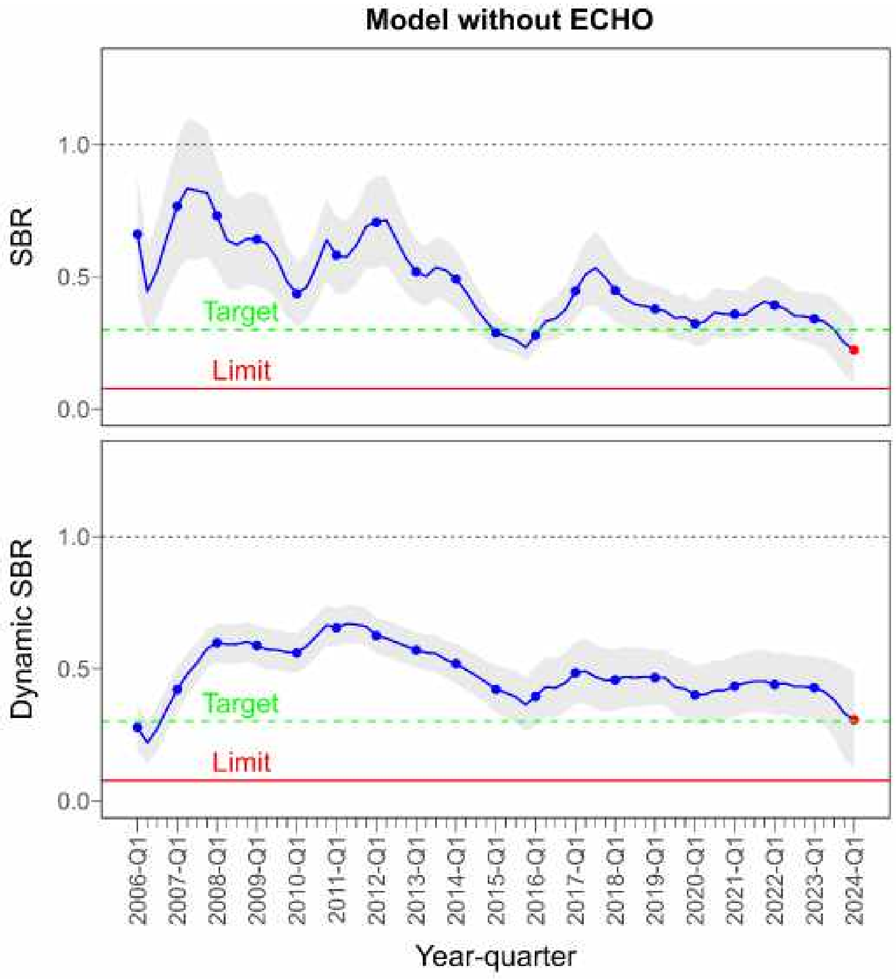
*Each dot is based on the average *F* over the most recent three years, 2021-2023.

- The reference model (marked in red) and most sensitivity models estimate that the spawning biomass (SB) is currently above the target proxy of 30% of the unexploited SB under dSBR, and this is statistically significant.
- Only one sensitivity model, which excludes the ECHO index (marked in black), estimates that the stock is not significantly above the target proxy.

10. Stock status



*Each dot is based on the average *F* over the most recent three years, 2021-2023.



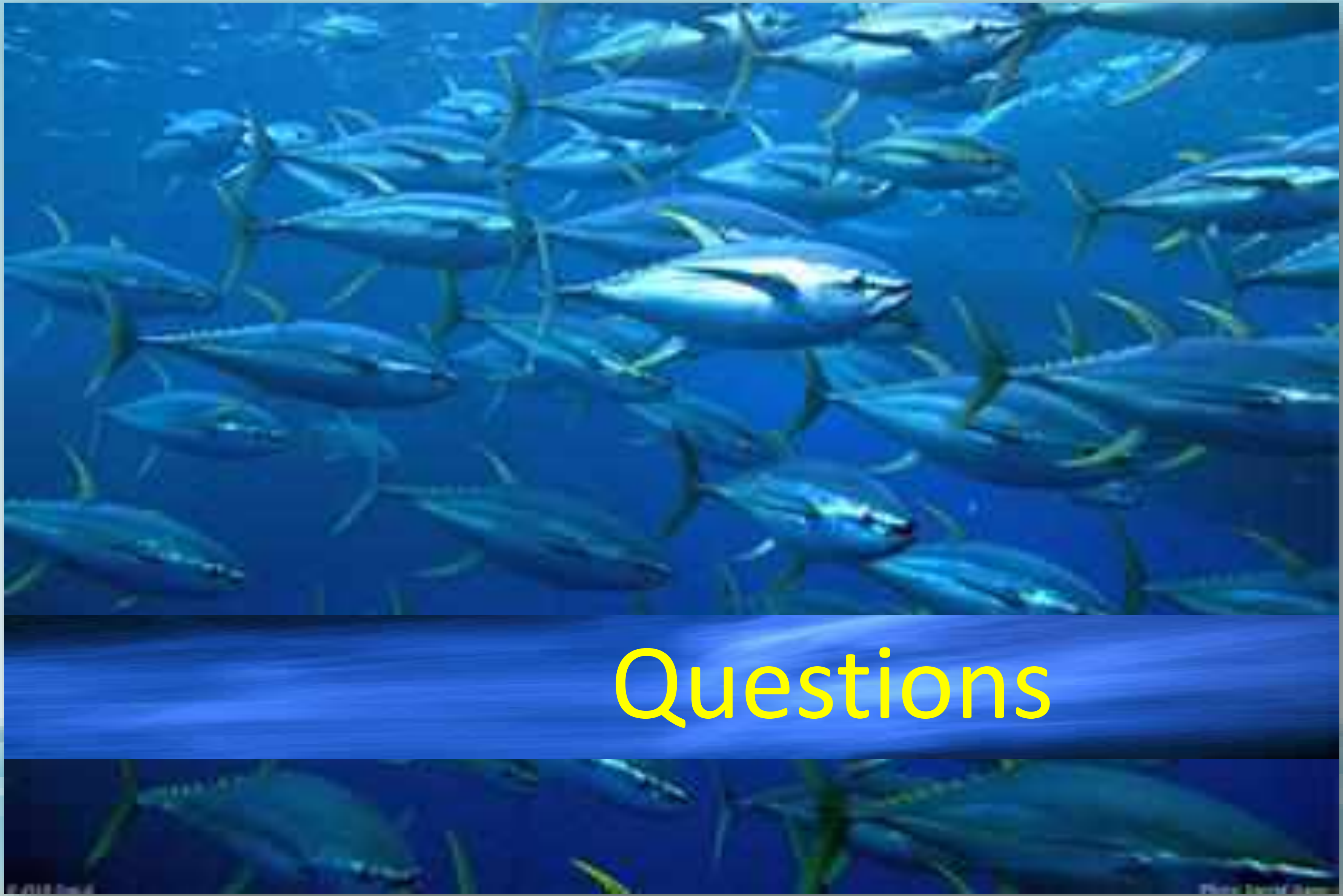
*80% CIs would represent the 10% probability of exceeding the reference point.

Summary

- The first benchmark assessment for skipjack tuna in the EPO was conducted in 2024.
- This assessment represents a significant improvement from the *interim* assessment conducted in 2022.
- It reflects major advancements in the assessment methodologies and incorporates new data sets, including an updated index of relative abundance based on recently developed echosounder buoy data, and an absolute biomass estimate derived from the tagging data collected under the Regional Tuna Tagging Program in the EPO.
- There is substantial uncertainty about several model assumptions and sensitivity analyses were conducted and determined that the management advice is robust to the uncertainty.
- The conclusion that the skipjack stock is healthy is generally robust to data usage and model assumption.

Future research

- **Collection of new and updated information**
  - Continue the biological and tagging studies to improve the understanding of the biology of skipjack in the EPO, especially the growth, natural mortality, biomass, and length-weight relationship.
  - In particular, a comprehensive tagging program is essential to improve the skipjack assessment and to provide management advice in the future.
- **Refinements to the assessment model and methods**
  - Improve the estimates of biomass and natural mortality through further development of the tagging analysis;
  - Improve estimates of growth using the tagging data and other available information;
  - Explore sex-specific natural mortality, growth and selectivity;
  - Continue to improve the echosounder buoy index;
  - Develop a risk analysis.



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