Western and Central Fisheries Commission
20th Regular Session of the Scientific Committee

Stock assessment of shortfin mako shark in the North Pacific Ocean through 2022

ISC SHARK Working Group

August 16, 2024

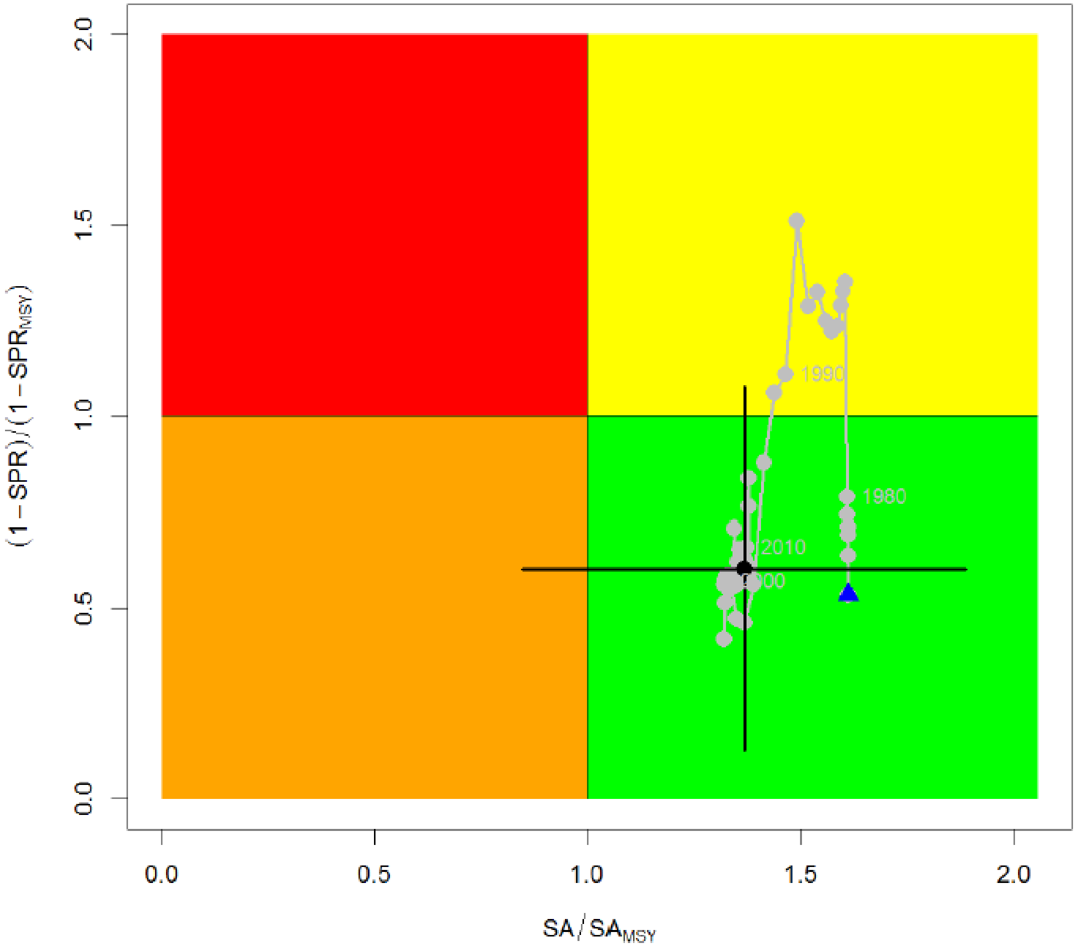
Overview

- Overview of the 2018 benchmark stock assessment
- Conceptual model
- Key data inputs
- Modelling approach
  - Stock Synthesis model
  - Bayesian State-Space Surplus Production Model (BSPM)
- 2024 Assessment results
  - Model fit & diagnostics
  - Model ensemble
  - Projections
- Discussion

Overview of the 2018 stock assessment

- Stock Synthesis 3.24U (ISC 2018)
- $SA_{2016} / SA_{MSY} = 1.36$
- $\frac{1-SPR_{2013-2015}}{1-SPR_{MSY}} = 0.62$

North Pacific Ocean (NPO) shortfin mako shark (SMA) was **not experiencing overfishing** and **not overfished** relative to MSY-based reference points



2018 stock assessment: background

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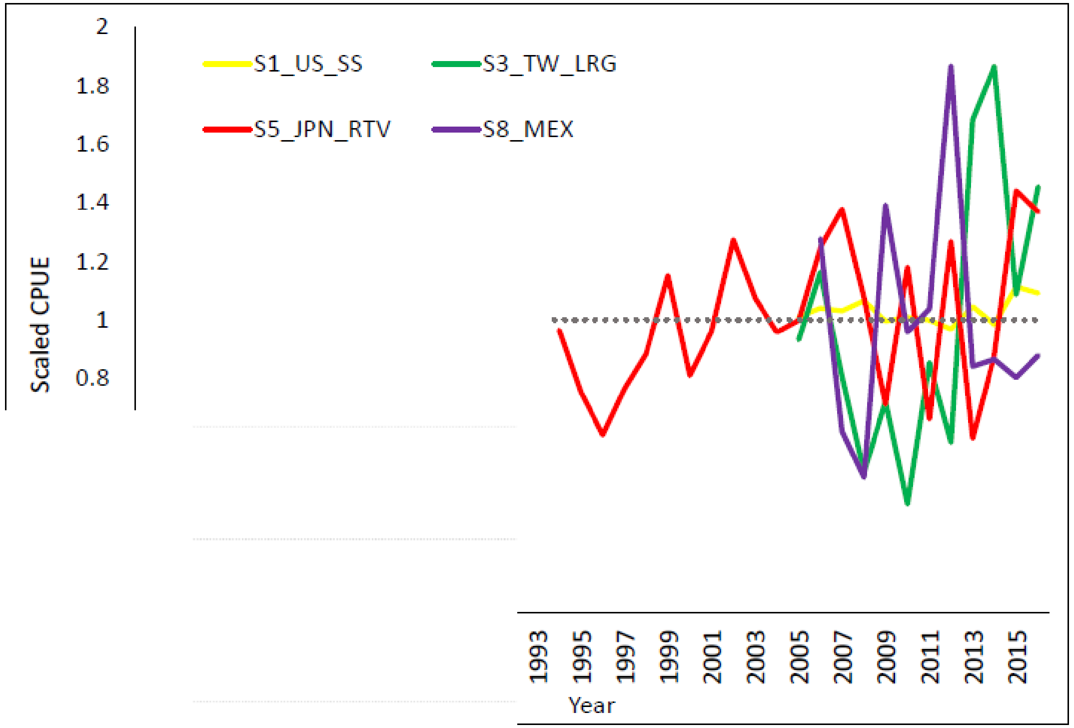

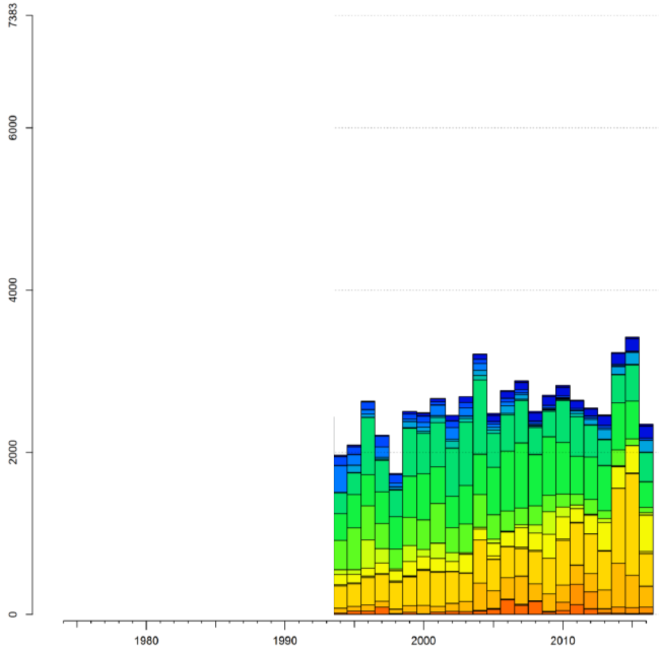

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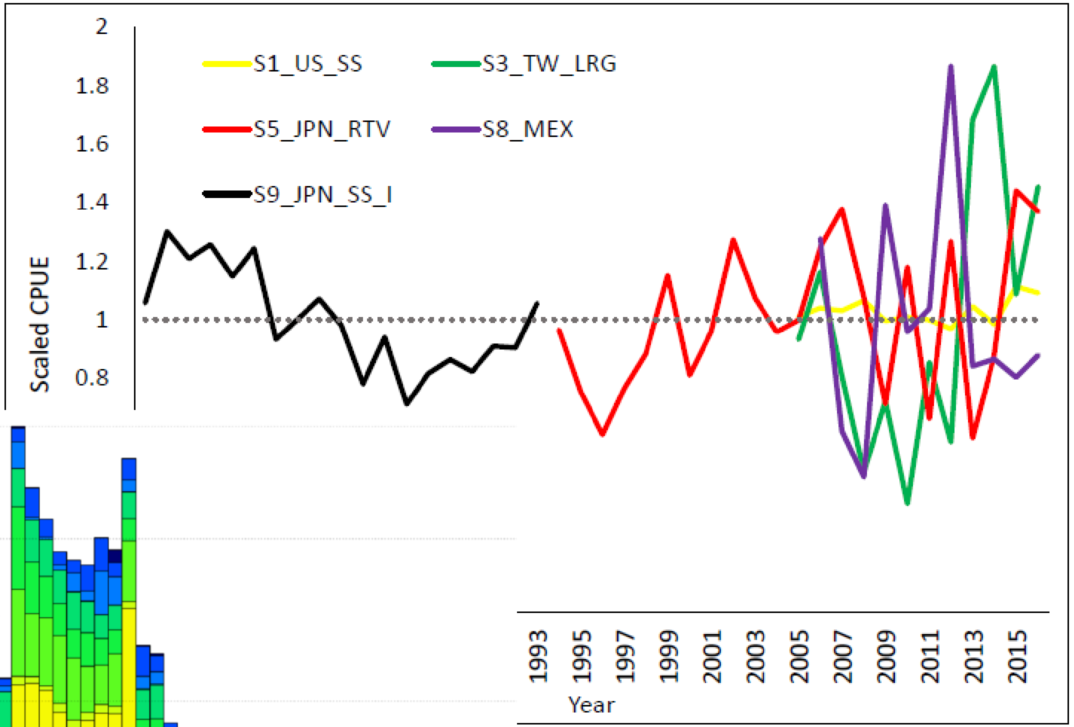
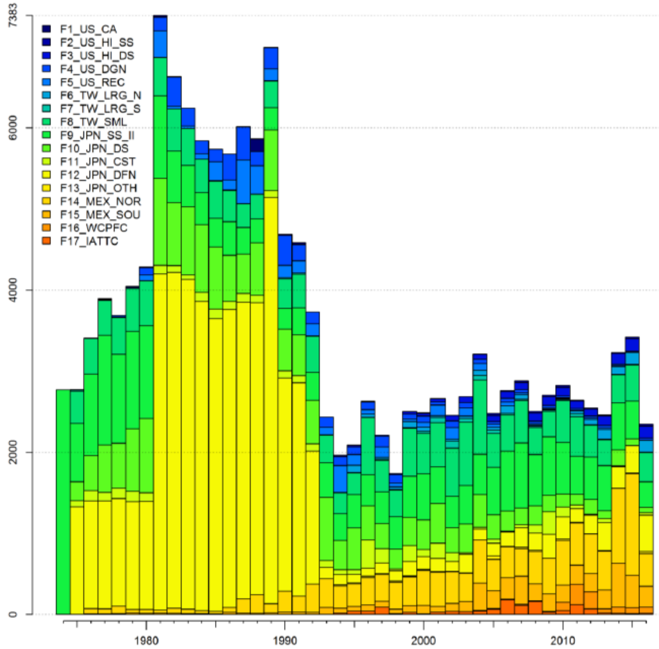
- The 2018 assessment was only able to achieve convergence following the inclusion of these data.





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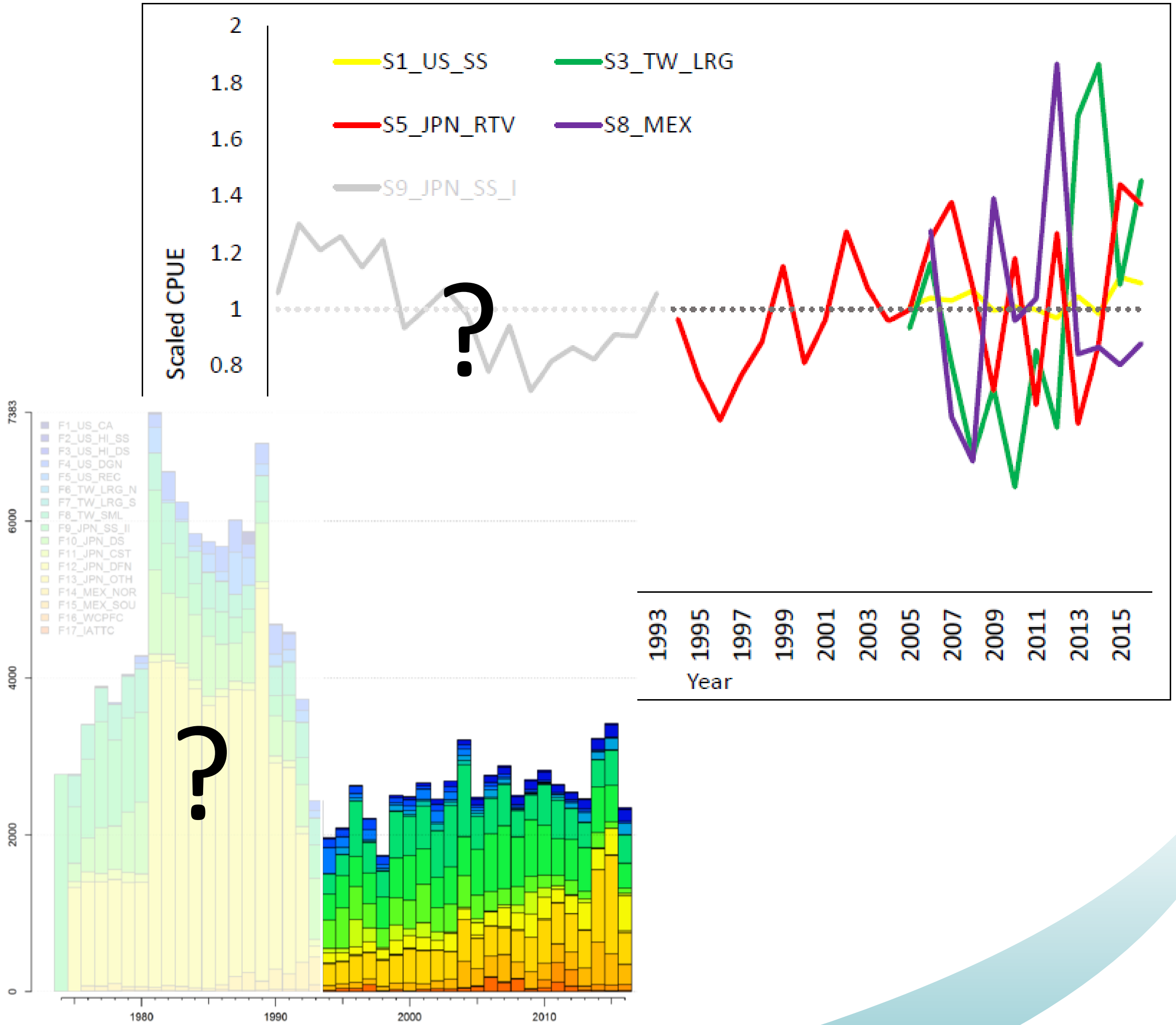
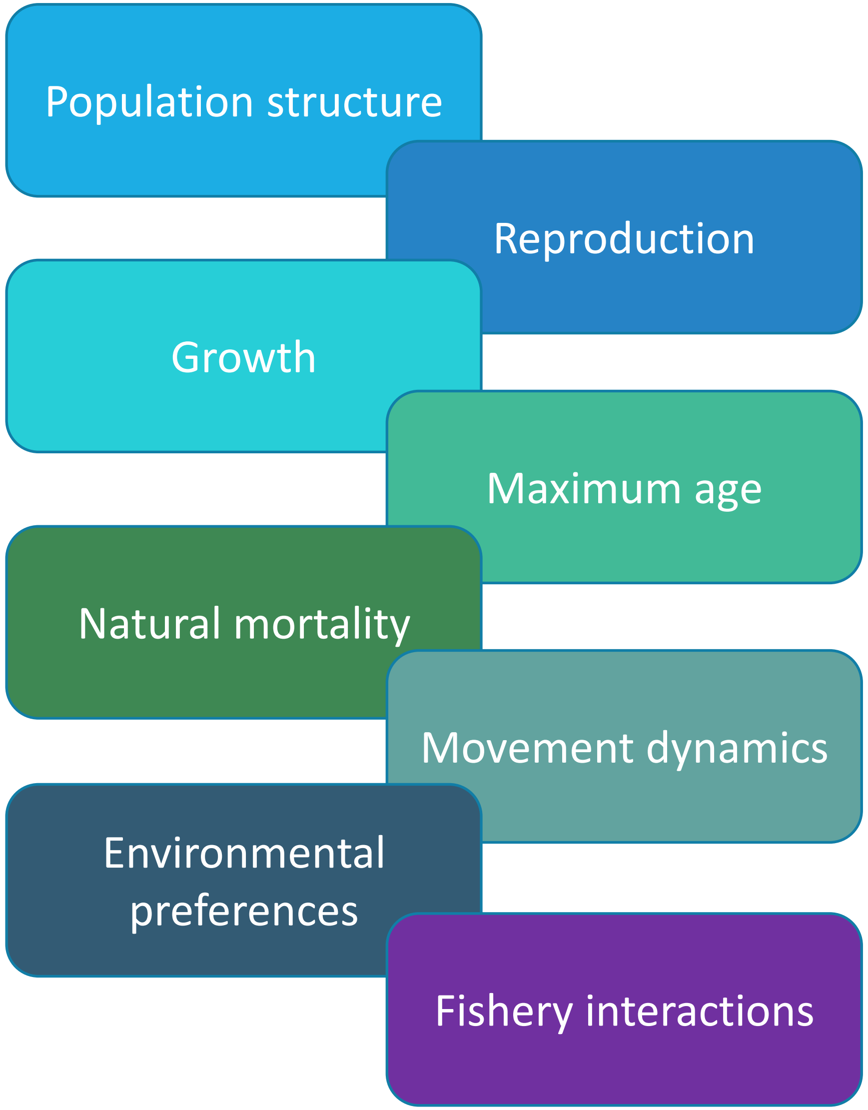
- The 2018 assessment was only able to achieve convergence following the inclusion of these data.
- However, it is uncertain how representative these data are given that SMA represented a small proportion of shark catch, and that the majority of the shark catch is blue shark, which have different life history and fishery interactions.



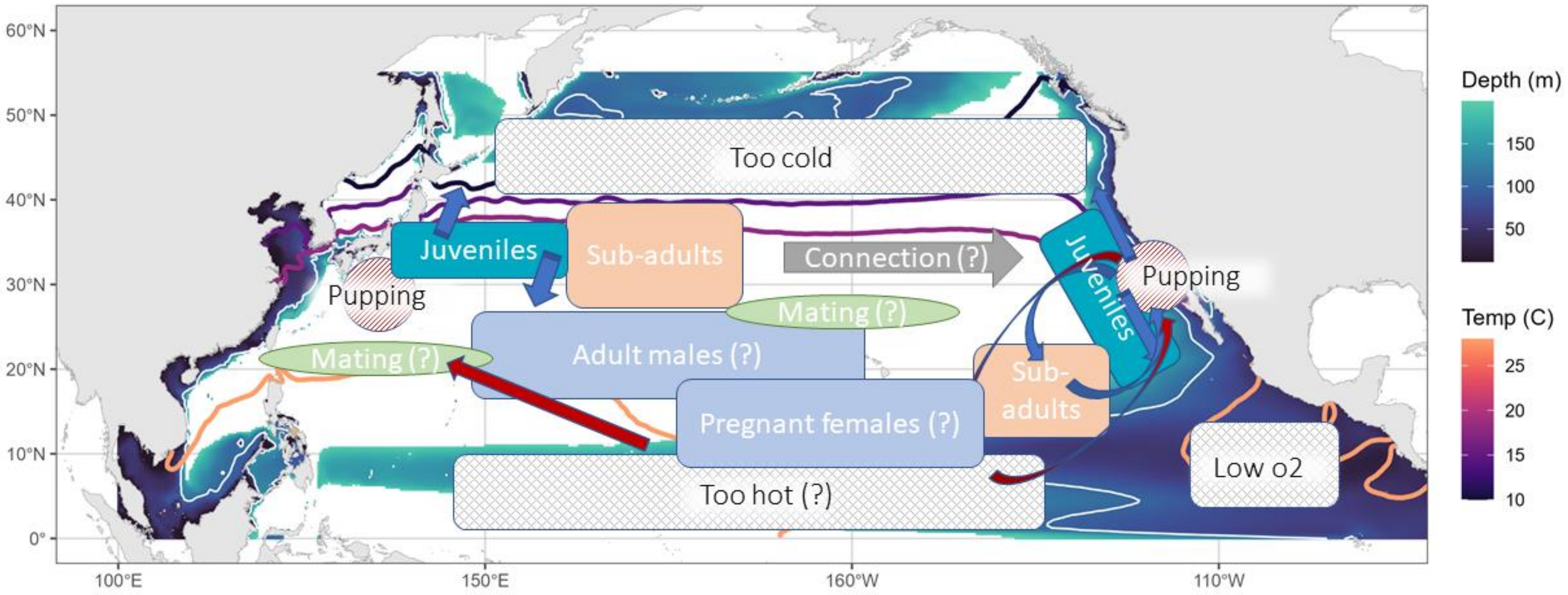
Conceptual model

- Two online intersessional meetings of the ISC SHARKWG were held (May & June 2023) to review & summarize current understanding of SMA biology, life-history and fishery interactions, and explicitly define a conceptual model based on the recommendations of recent research.



Minte-Vera et al., 2024. The use of conceptual models to structure stock assessments: A tool for collaboration and for "modelling what to model". Fisheries Research

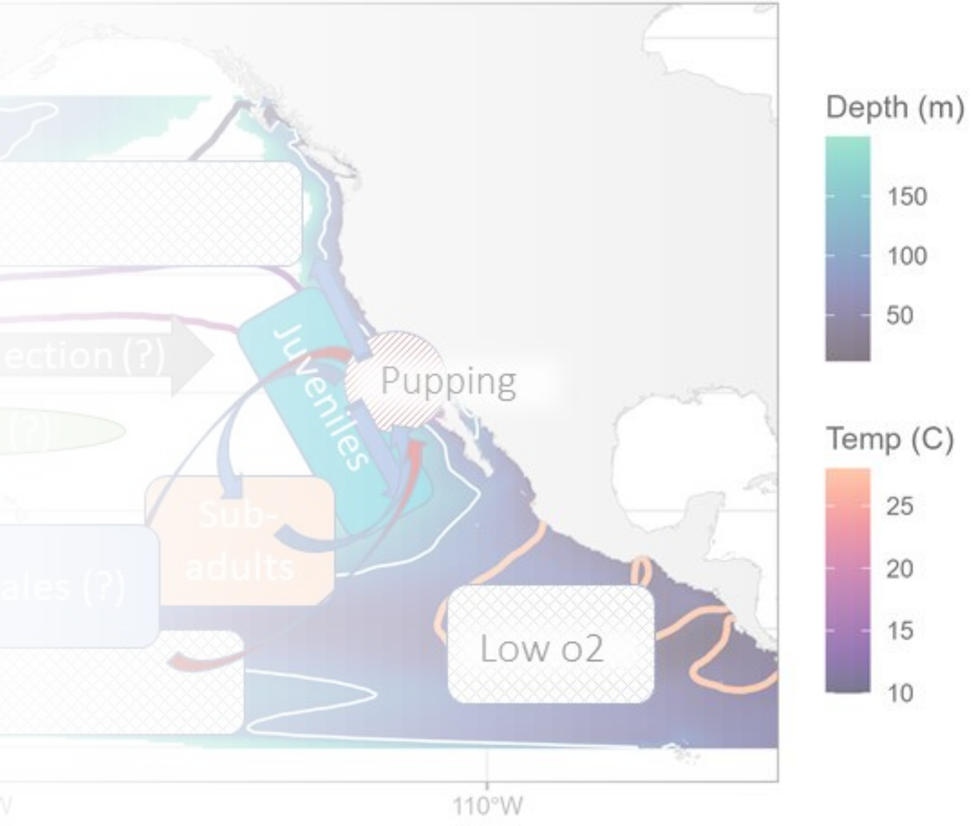
Conceptual model



Identified uncertainties

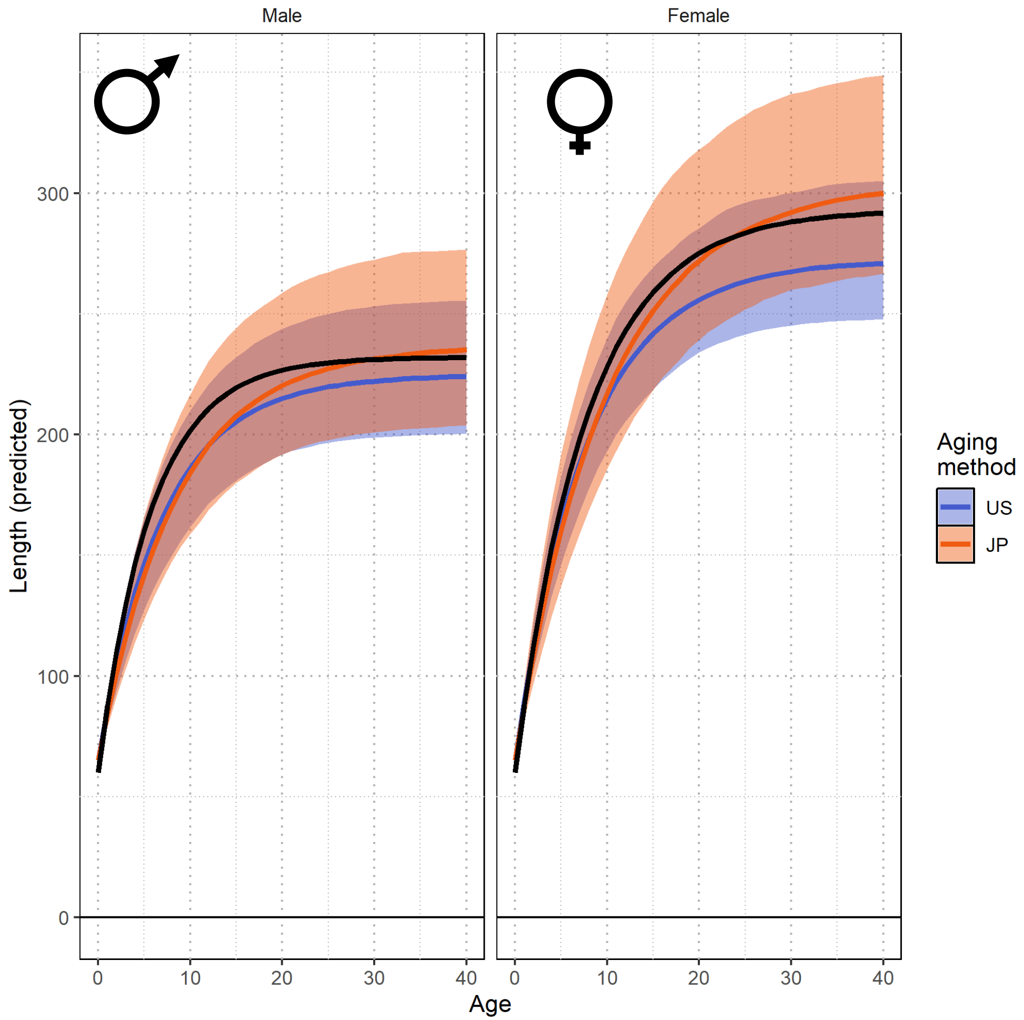
Key uncertainties were identified in developing the conceptual model:

- *Stock structure is unknown in the NPO*. Multiple parturition sites raises the possibility that multiple stocks exist depending on the level of genetic exchange between sites
- *Biological uncertainties exist*. The lack of observations for large females complicates the understanding of SMA biology with regards to maximum age, growth, reproduction and natural mortality.
- *Fisheries inputs are uncertain*. Post-1994 catch is uncertain due to unknown levels of discard reporting in logbooks, pre-1994 catch is uncertain due to lack of species-specific data for sharks. No fishery indexes the entire spatial distribution or mature females.



Biology and life-history

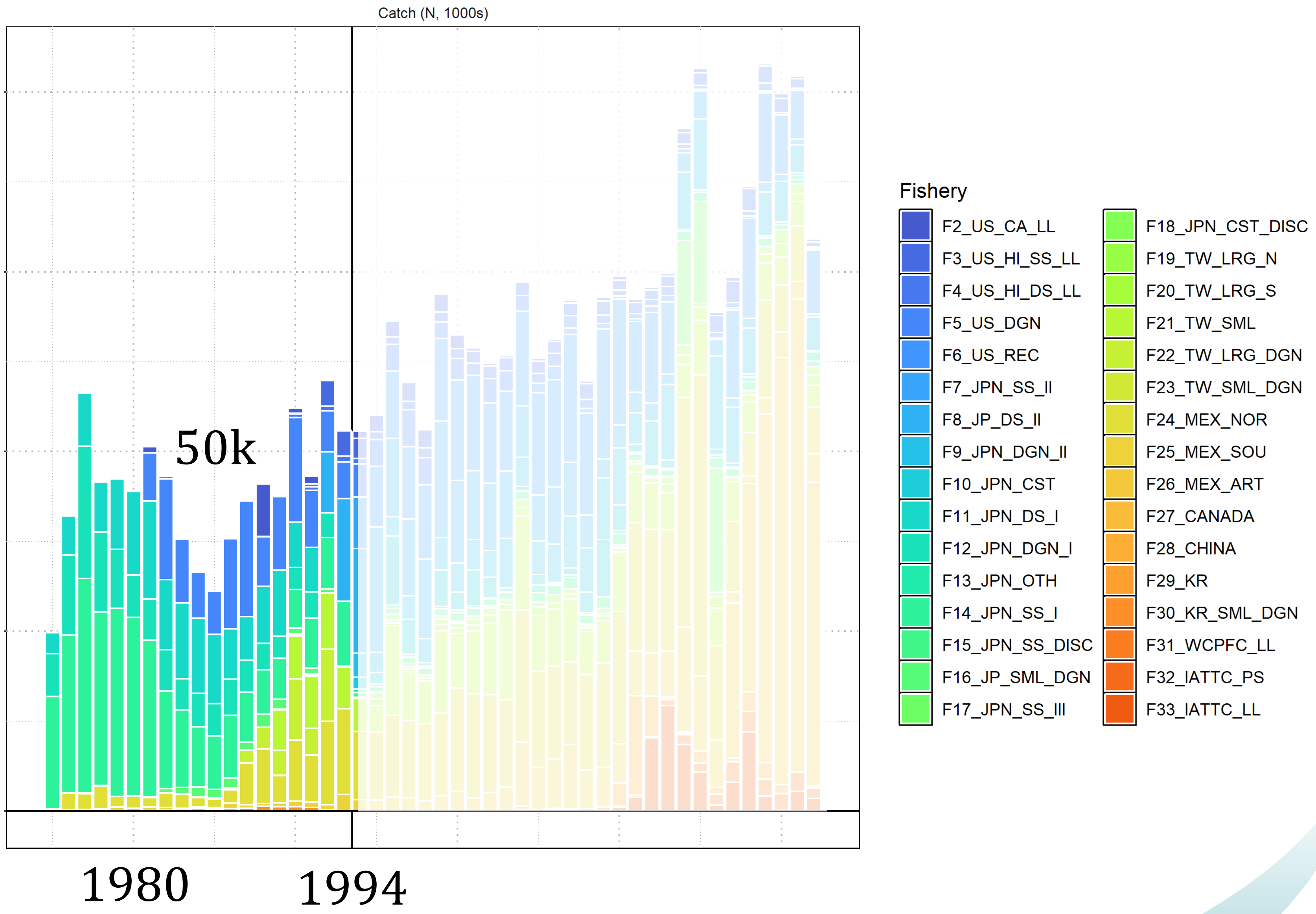
- Biological assumptions were largely consistent with the 2018 assessment.
  - Maximum age ~31 years
  - Reproduction occurred every 2-3 years
  - Female length @ 50% maturity ~233cm PCL
  - Litter size either constant (~12) or a function of maternal length.
- Growth curves were updated to account for methodological differences in determining age from vertebrae.
- Adult levels of natural mortality were updated using a meta-analytic approach that considered empirical relationships with maximum age, age at maturity and growth.
  - 0.13 – 0.17 for females & 0.18 – 0.2 for males



2018 growth curve
2024 growth curve: US aging
2024 growth curve: JP aging

Fisheries

- Large-scale fishery interactions have likely existed since the 1950s
- Impacts from longline and high-seas driftnet fisheries may be significant but are highly uncertain prior to 1994 due to the lack of species-specific shark data



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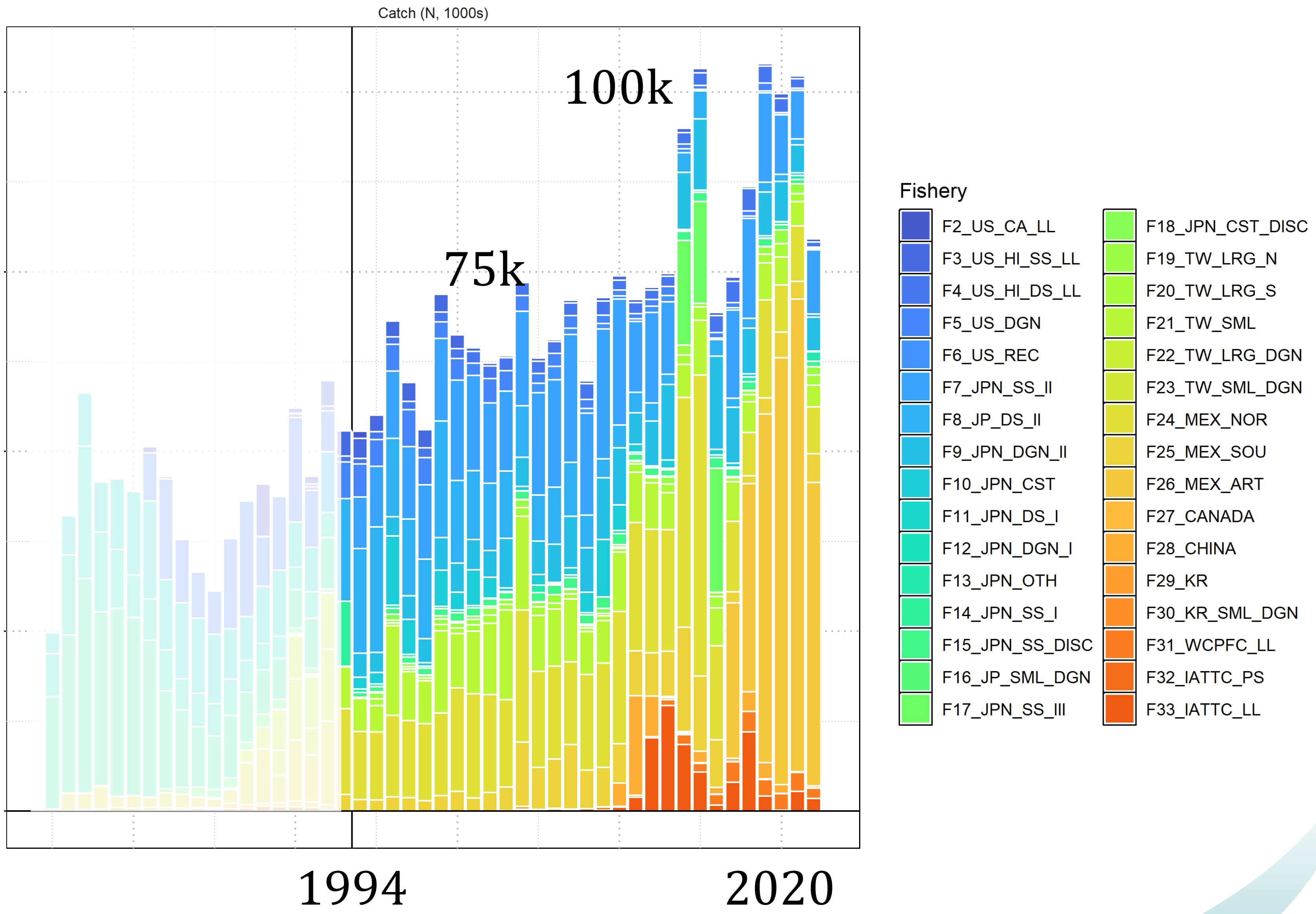
- Post-1994 catches come predominantly from longline.



Size composition

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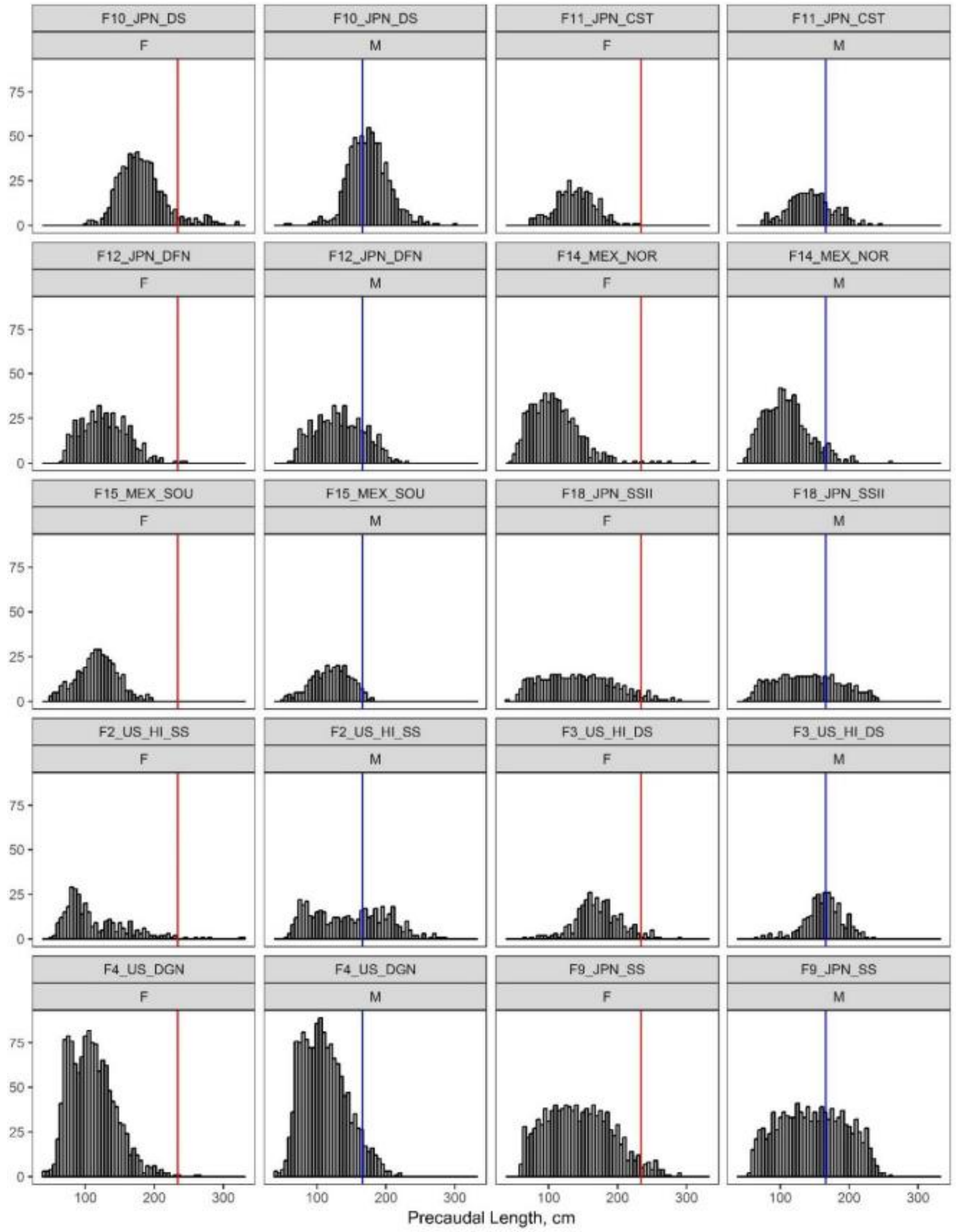


Figure 4; ISC, 2018

Size composition

- Size composition data was available for a number of fisheries, and all lengths were converted to pre-caudal length (PCL)
- Very few fisheries were observed to interact with females larger than the length @ 50% maturity (~233 cm PCL)
- The SHARKWG considered this to be evidence of strong dome-shaped selectivity rather than a sharp increase in female natural mortality post maturity.

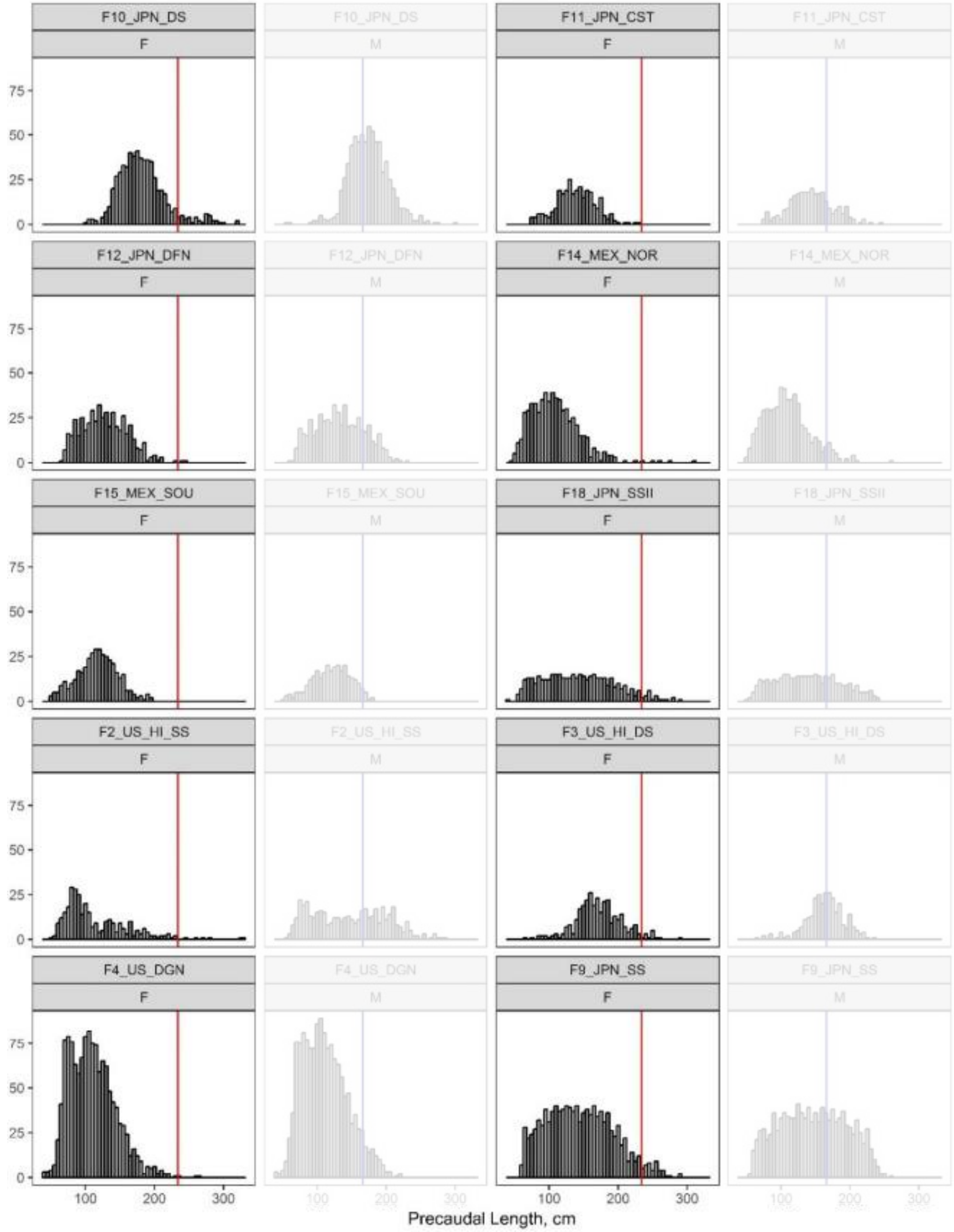
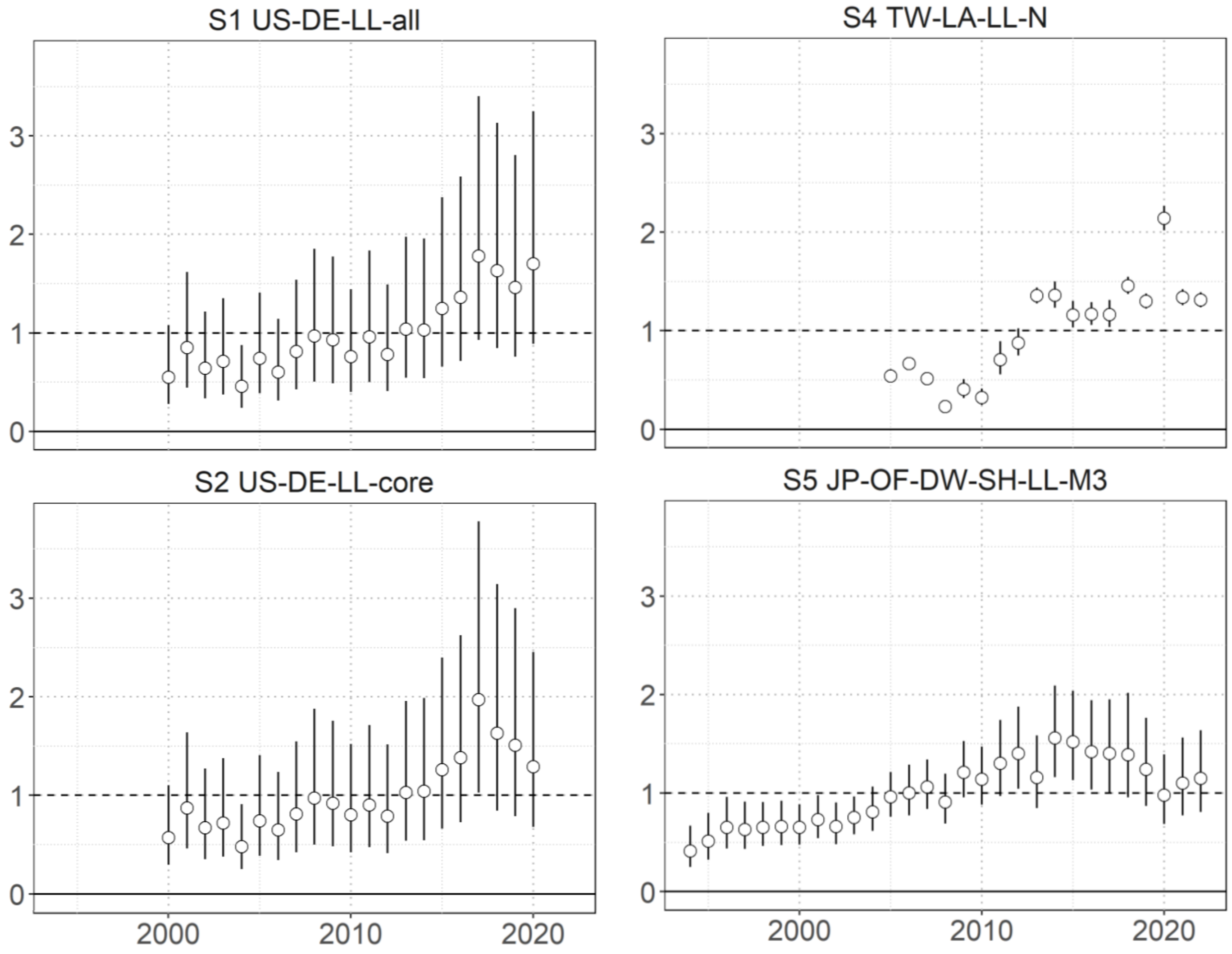


Figure 4; ISC, 2018

Standardized CPUE

- The SHARKWG considered a number of indices and evaluated their representativeness based the data source, overlap with conceptual distribution of the stock, and appropriateness of the standardization model.



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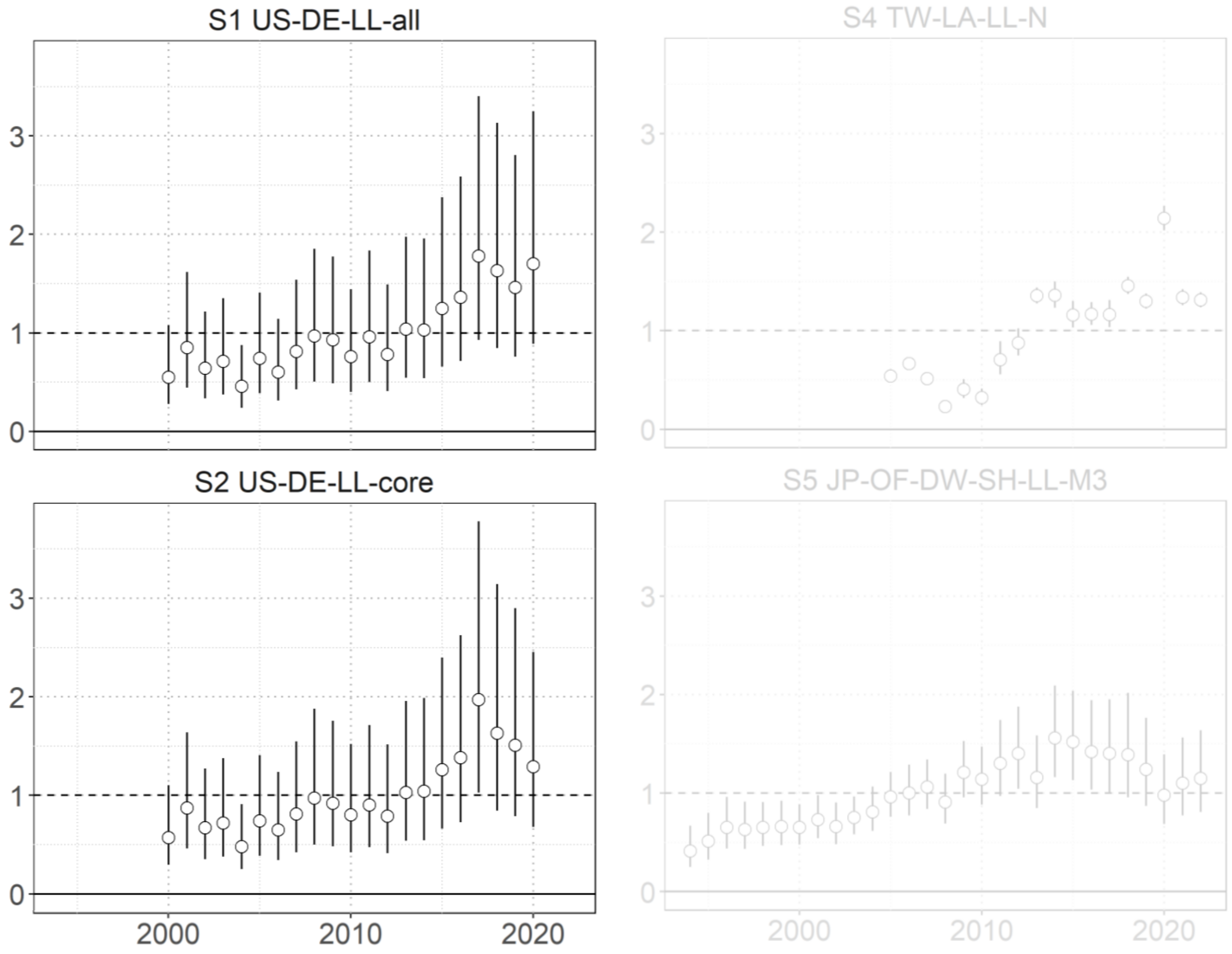

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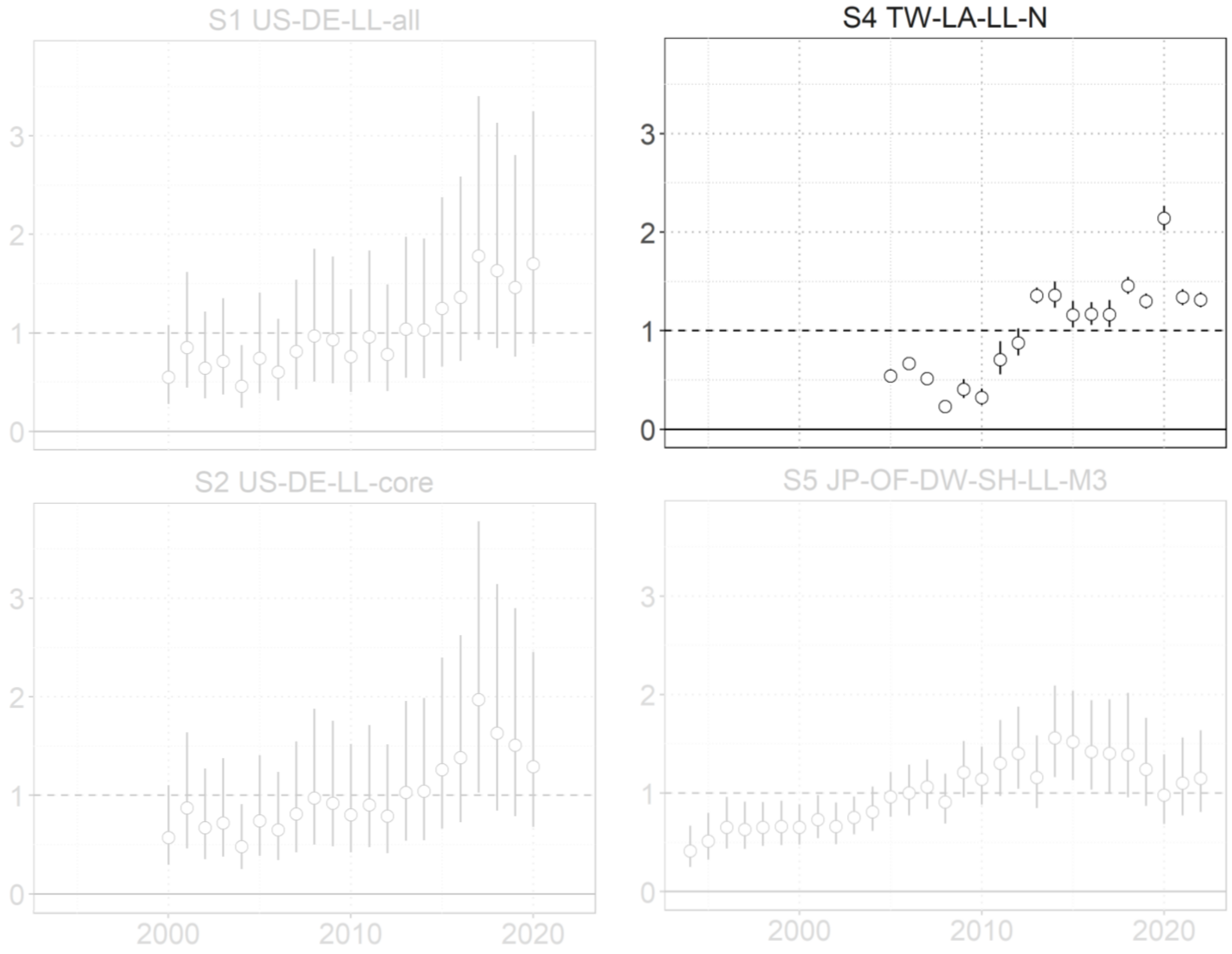

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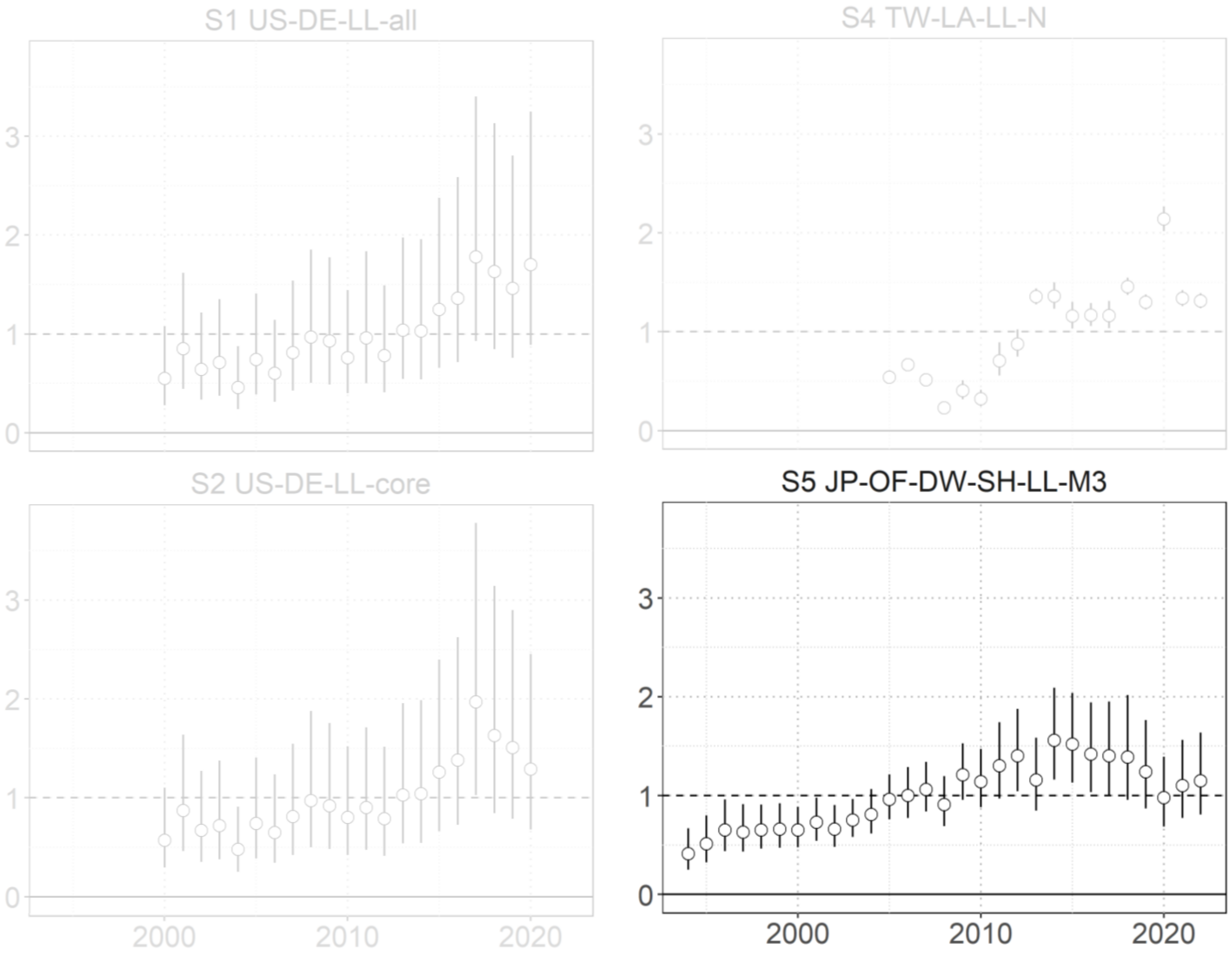
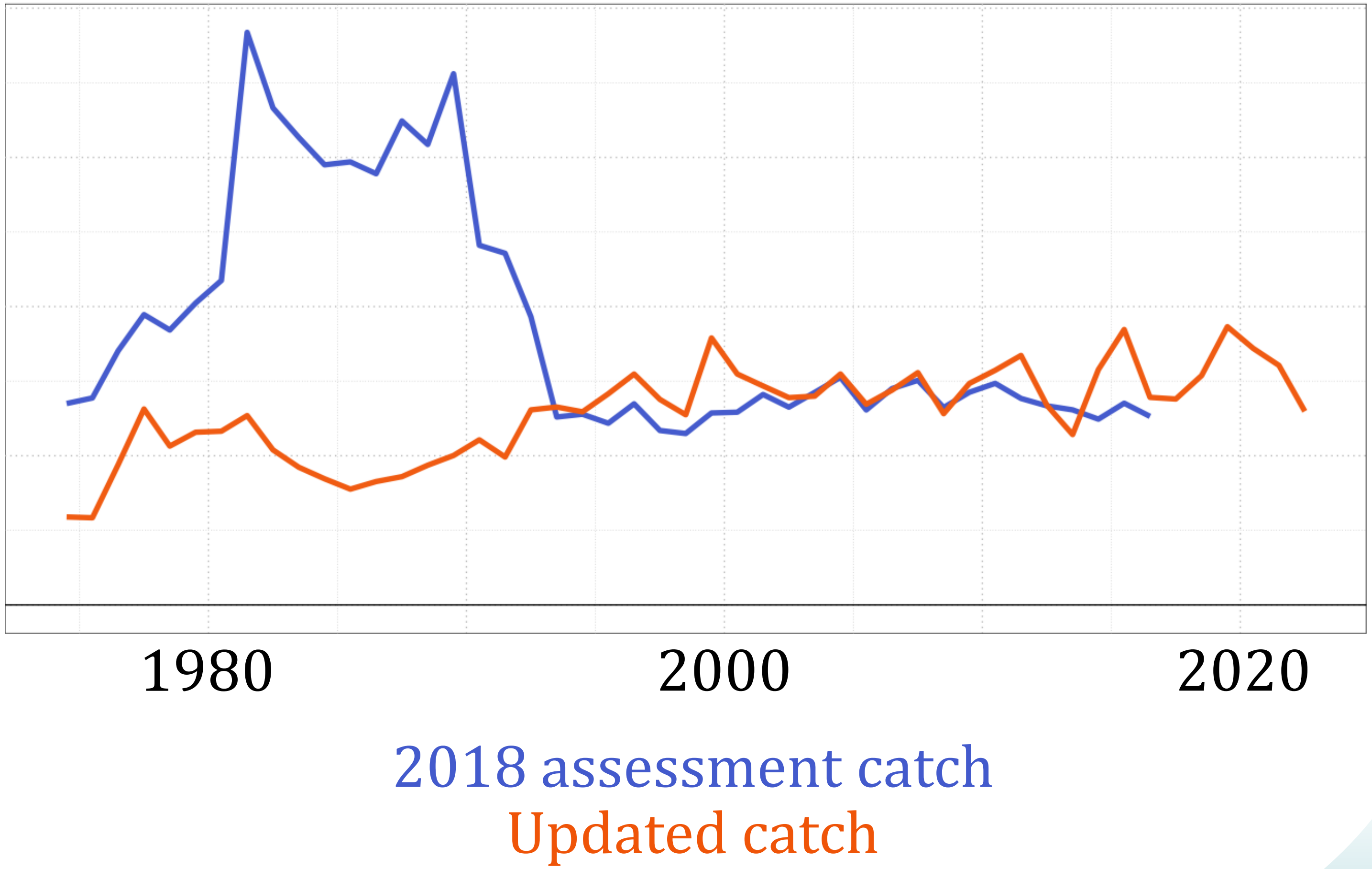
  - Chinese-Taipei large scale longline north of 25 ° N
  - Japanese shallow-set longline



Modeling approach

- Initial plans were to update the 2018 Stock Synthesis (SS3) model, and estimate stock status from 1975 – 2022.
- Given the assumed biology, SS3 models were unable to reconcile increasing catch and CPUE post-1994 following the removal of the 1975 – 1993 index and revision of the high seas drift net catch (pre-1994).
- The SHARKWG made a strategic pivot and developed a Bayesian state-space surplus production model (BSPM) to more efficiently account for key uncertainties and estimate stock status from 1994 – 2022.



Bayesian State-Space Surplus Production Model (BSPM)

- BSPMs were developed and implemented using the STAN probabilistic programming language.
- Briefly BSPMs are a simplified, age-aggregated representation of population dynamics where the key leading parameters are population carrying capacity (K), initial depletion (x_0), maximum intrinsic rate of increase (R_{Max}), and shape of the production function (n).

$$x_1 = x_0$$

$$x_t = \begin{cases} \left(x_{t-1} + R_{Max}\, x_{t-1}\left(1 - \frac{x_{t-1}}{h}\right) - C_{t-1}\right) \times \epsilon_{t-1}, & x_{t-1} \leq D_{MSY}; t > 1 \\ (x_{t-1} + x_{t-1}(\gamma \times m)(1 - x_{t-1}^{n-1}) - C_{t-1}) \times \epsilon_{t-1}, & x_{t-1} > D_{MSY}; t > 1 \end{cases}$$

$$\epsilon_t = \exp\left(\delta_t - \frac{\sigma_P^2}{2}\right)$$

$$\delta_t \sim N(0, \sigma_P)$$

Fletcher-Schaefer hybrid; random-effects formulation

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<u>Prior development workflow</u>

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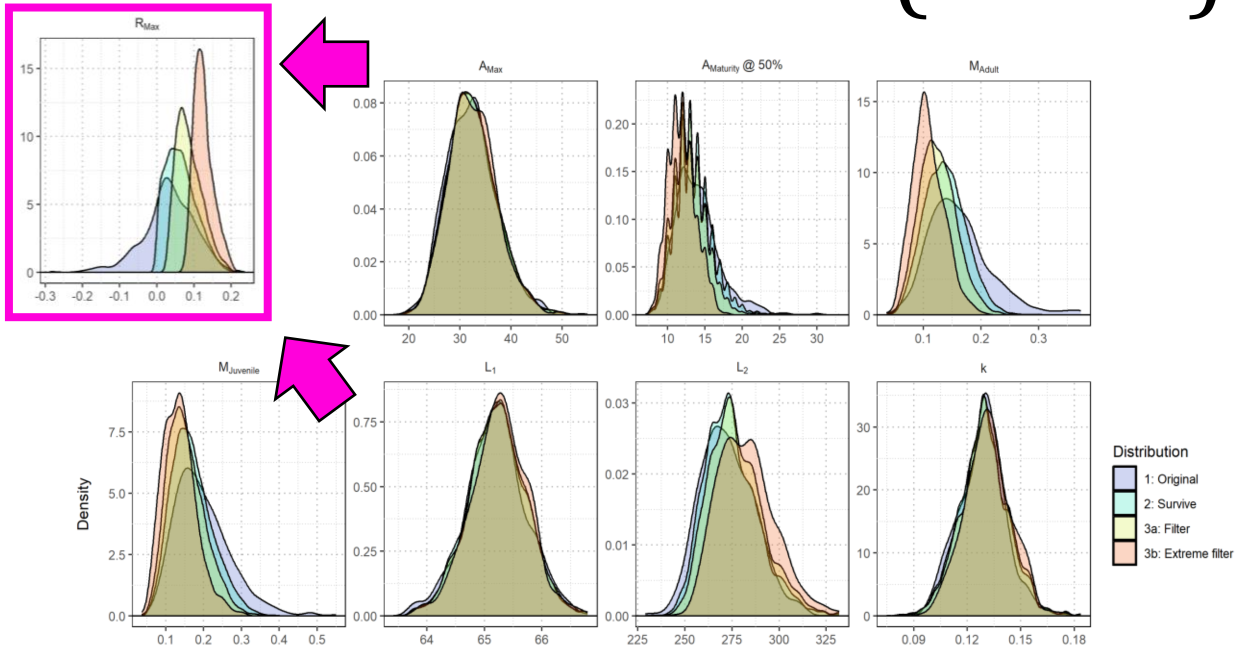

Rapid Communication

Maximum intrinsic rate of population increase in sharks, rays, and chimaeras: the importance of survival to maturity

Authors: Sebastián A. Pardo, Holly K. Kindsvater, John D. Reynolds, and Nicholas K. Dulvy | AUTHORS INFO & AFFILIATIONS

Publication: Canadian Journal of Fisheries and Aquatic Sciences • 10 June 2016 • https://doi.org/10.1139/cjfas-2016-0069

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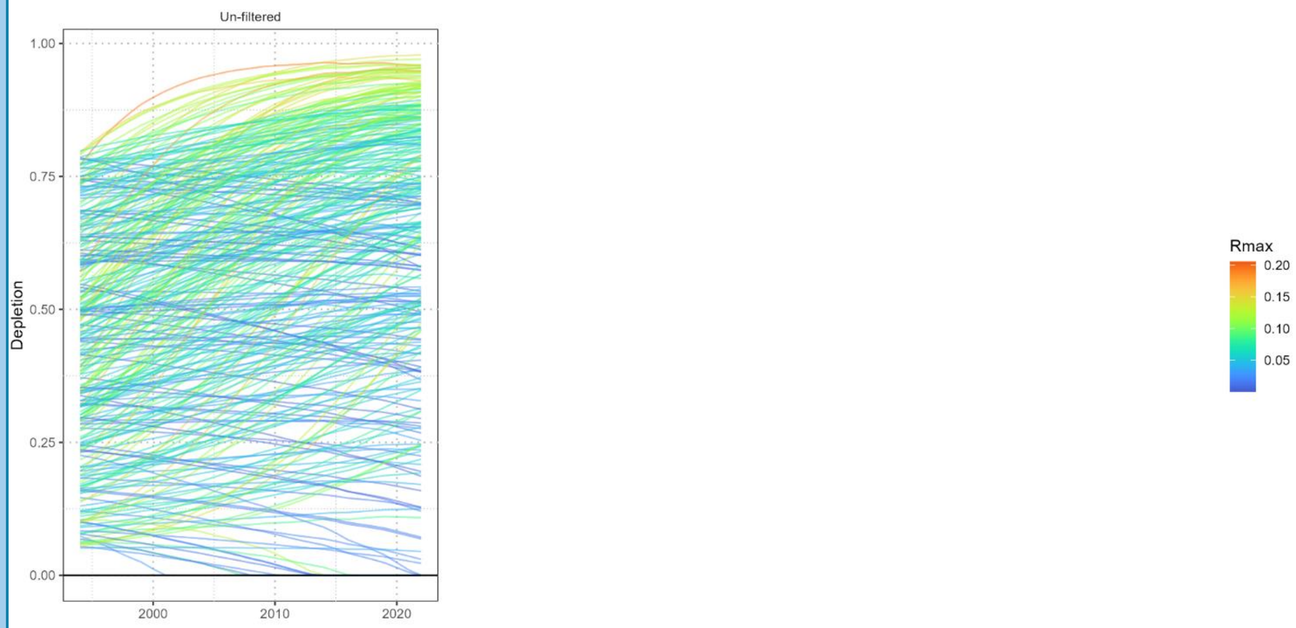

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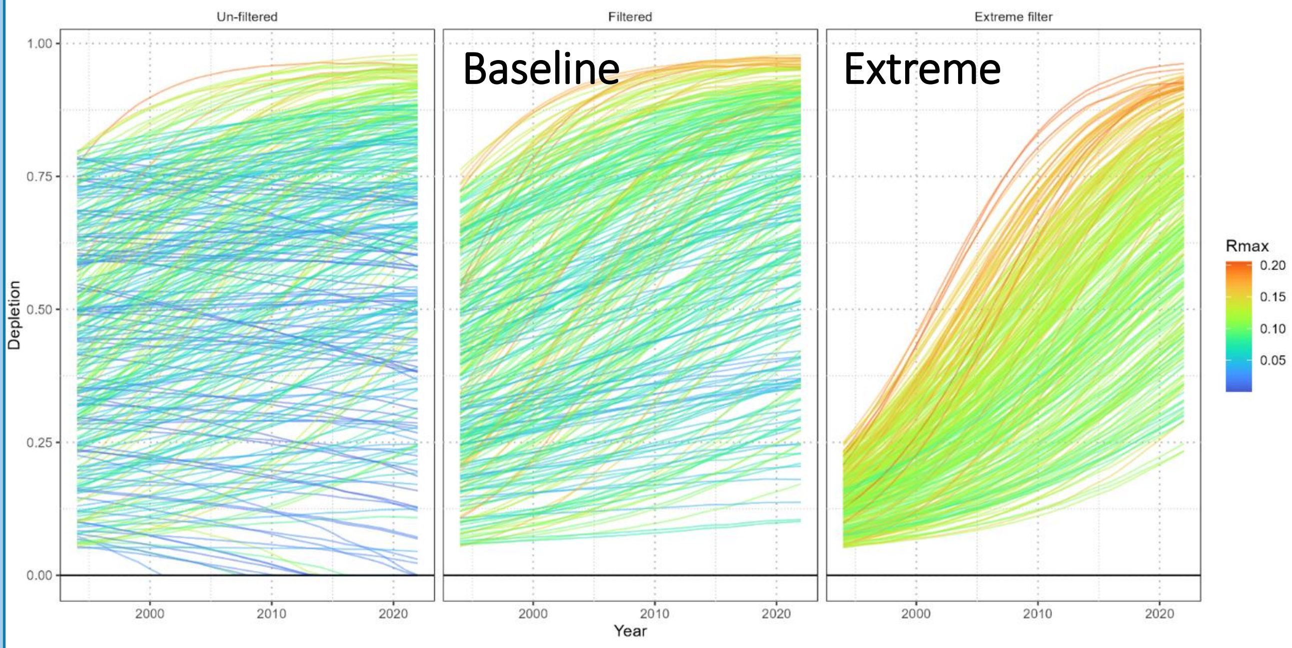

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4. Develop parametrized prior distributions based on parameter distributions corresponding to filtered, simulated population trajectories (e.g., $R_{Max} \sim \text{Lognormal}(-2.52, 0.41)$).

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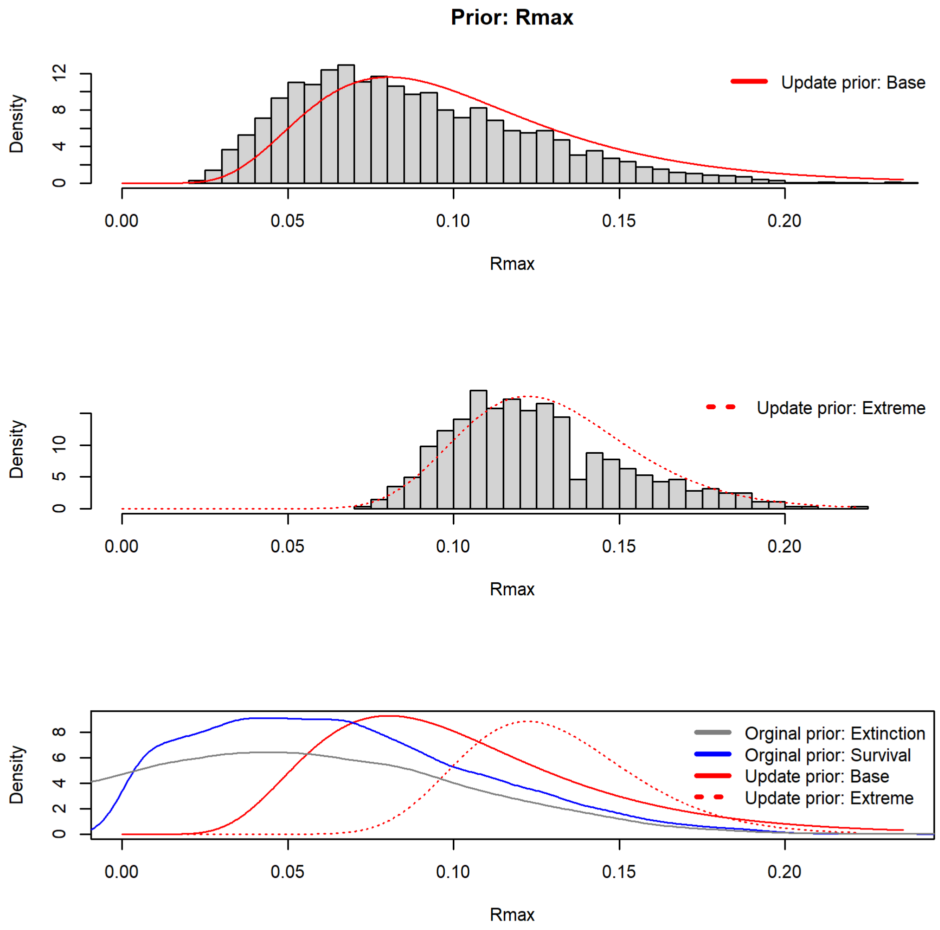

Bayesian State-Space Surplus Production Model (BSPM)

- A single index was fit (*Lognormal* likelihood) within each BSPM and model results were sensitive to the **choice of index**, treatment of the catch, and level of filtering used to define informative priors.

CPUE

- US HI all
- US HI core
- TW
- JP

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Catch

- Estimated using LL effort
- F directly estimated: $\sigma_F \sim N^+(0, 0.0125)$
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Prior filtering
- Baseline: 20% increase in simulated populations
- Extreme: 200% increase in simulated populations

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- Key uncertainties were dealt with using a 32 model, full-factorial ensemble with unequal weighting **(relative weight)**:
  - US indices were down-weighted to not over-represent this data source
  - Estimated catch using longline (LL) effort down-weighted given that this represented an outlier scenario in terms of catch magnitude.

CPUE

- US HI all **(~16.6%)**
- US HI core **(~16.6%)**
- TW **(33%)**
- JP **(33%)**

Prior filtering

- Baseline: 20% increase in simulated populations **(50%)**
- Extreme: 200% increase in simulated populations **(50%)**

Catch

- Estimated using LL effort **(5%)**
- F directly estimated: $\sigma_F \sim N^+(0, 0.0125)$ **(~31.6%)**
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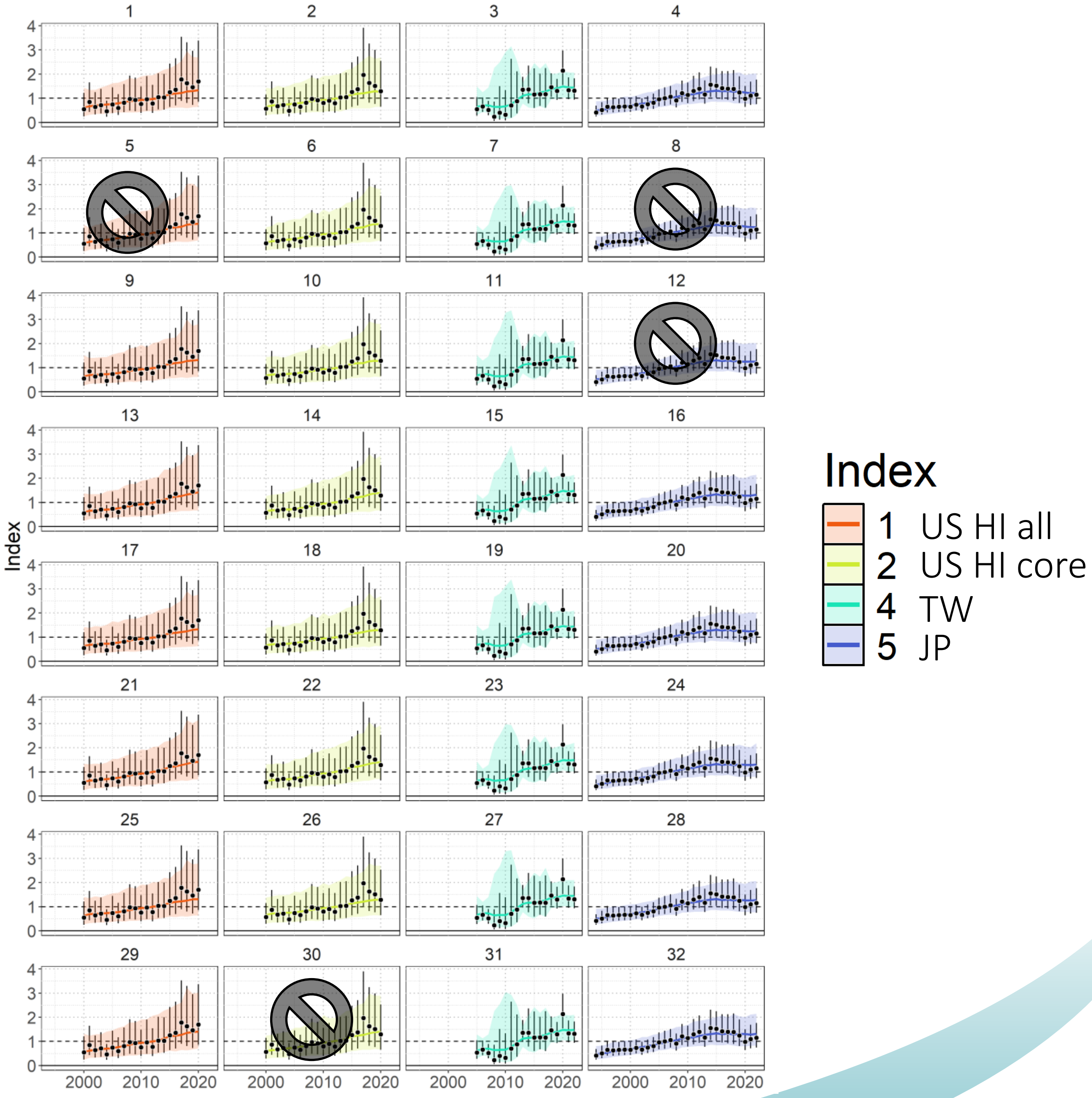
BSPM diagnostics

- Diagnostics across the ensemble were good with only 4 of 32 models failing convergence criteria (0 divergent transitions, ESS > 500 and $\hat{R}$<1.01).
- Model fits to indices were good (relative to estimated observation error), and posterior predictive checks indicated that the BSPMs were able to replicate the observed indices.



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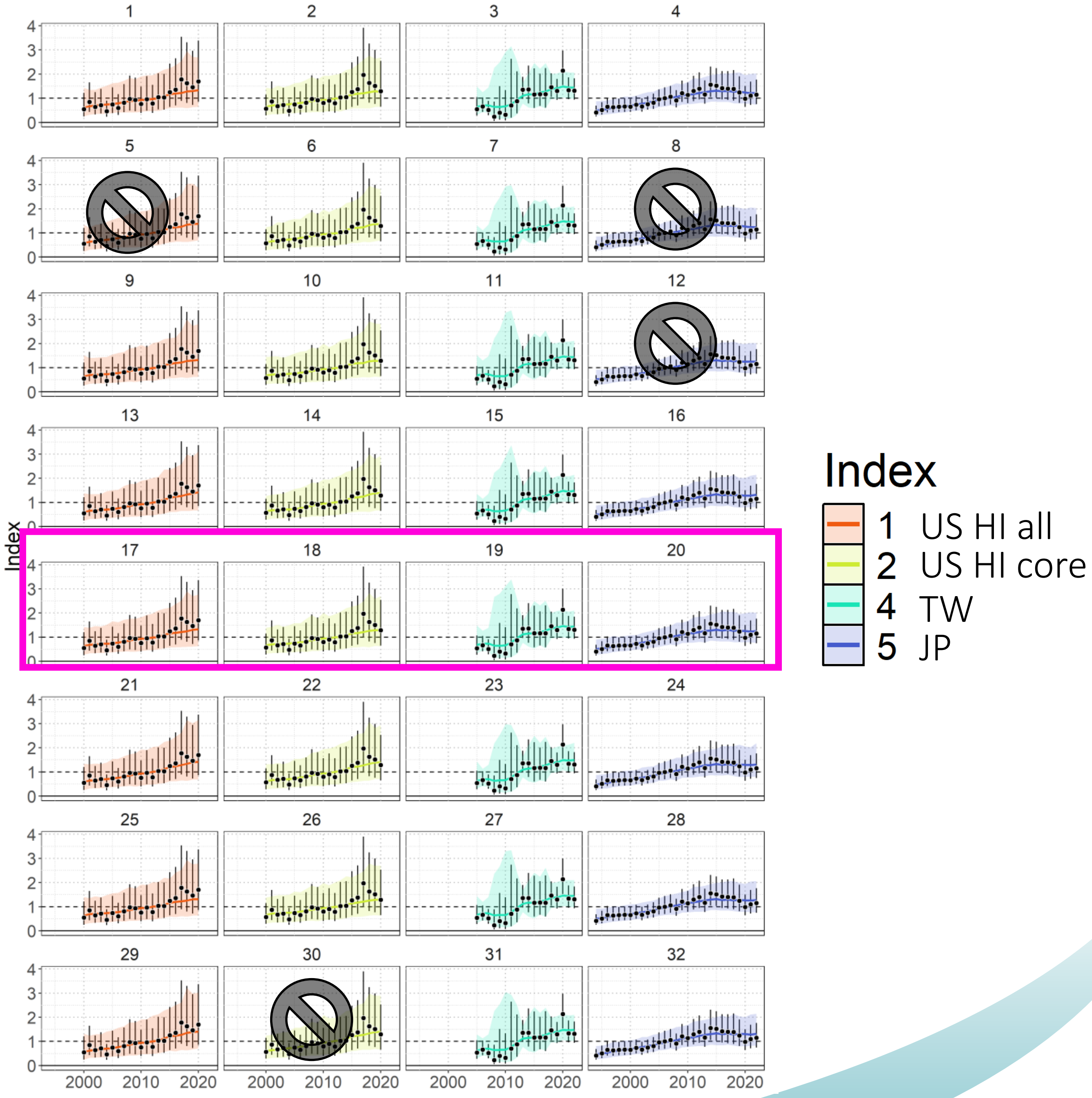

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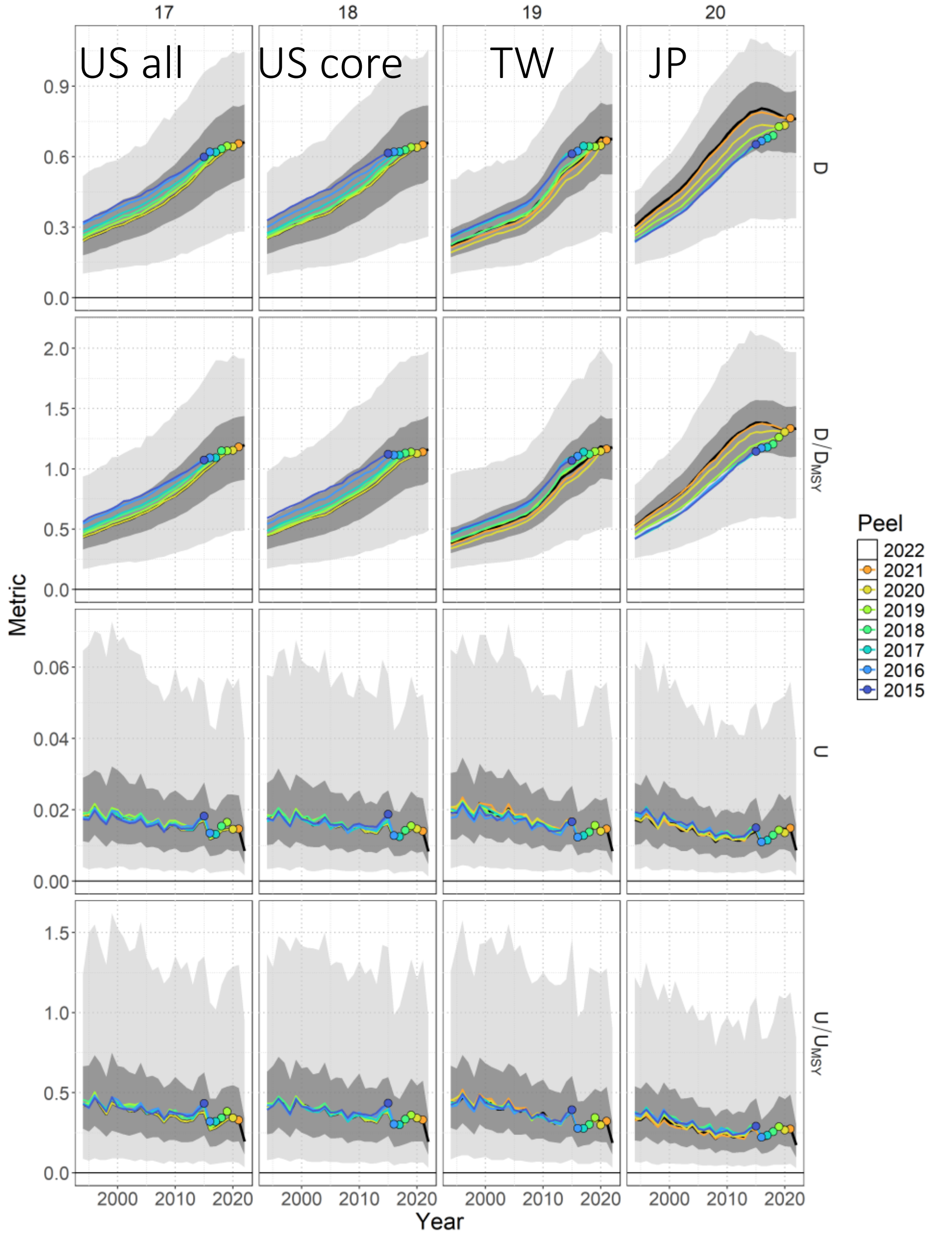
- Overall retrospective bias was low and estimates of management quantities relative to MSY were consistently within the credible intervals of the full model.



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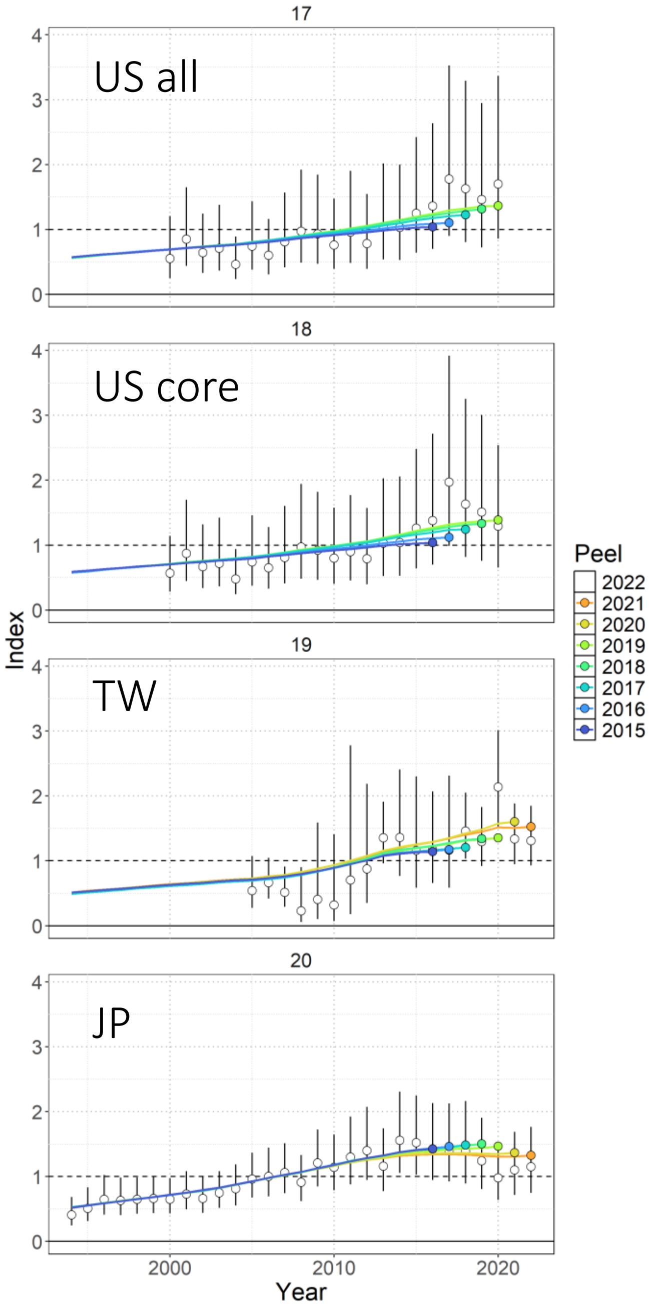
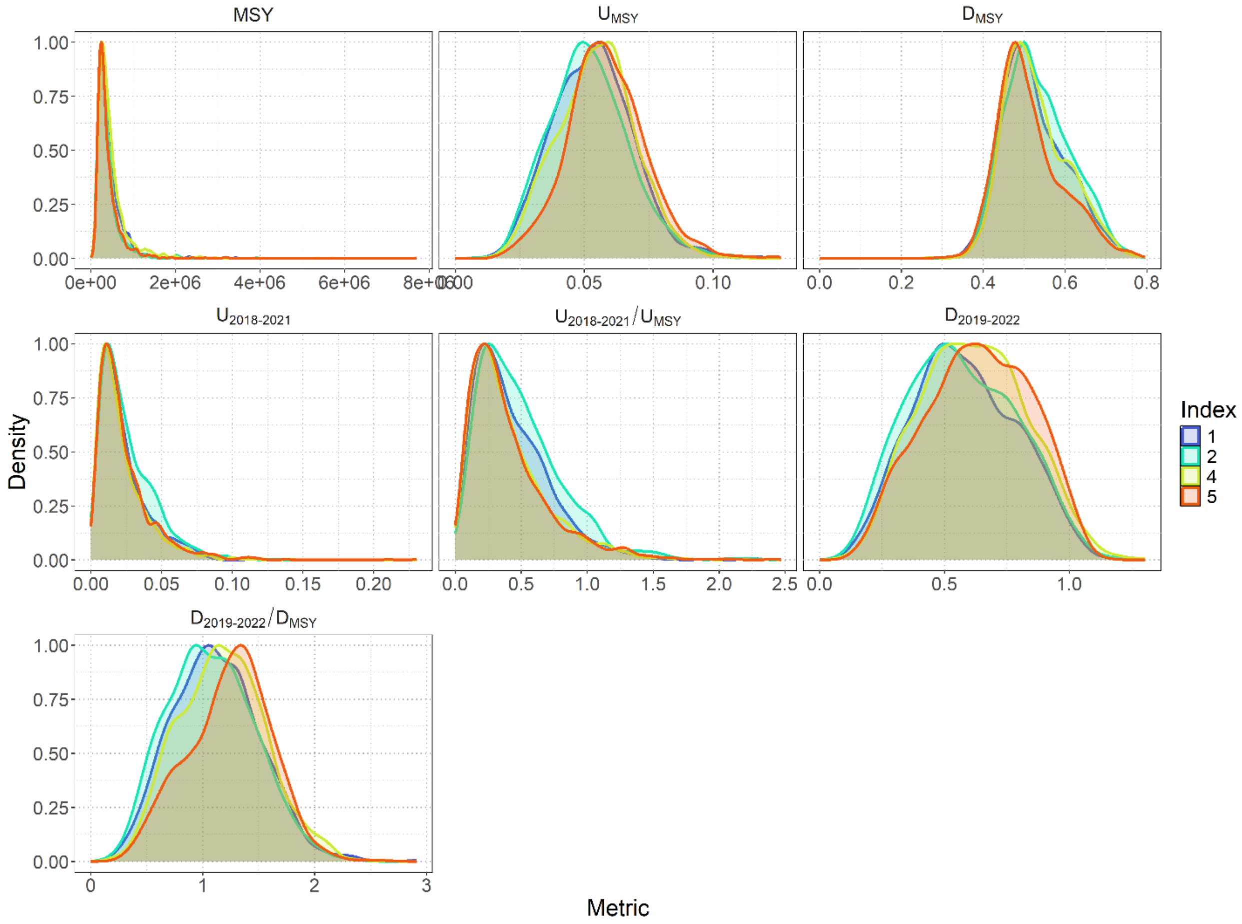
- Hindcast cross-validation was poor.



BSPM results

- Excluding non-converged models (4 of 32) did not change distributions of management reference points
- Models fitting to the Japanese index (5) were most optimistic



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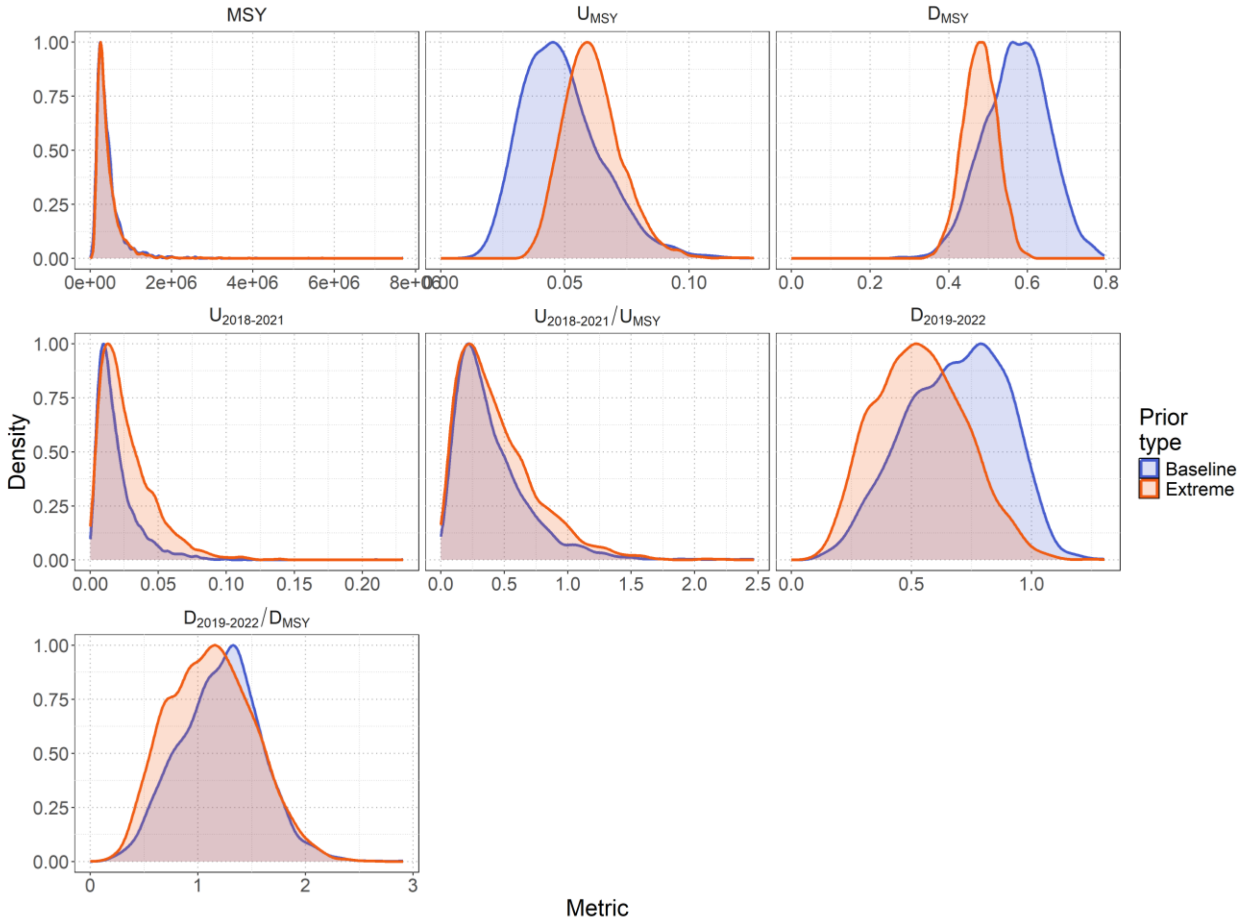

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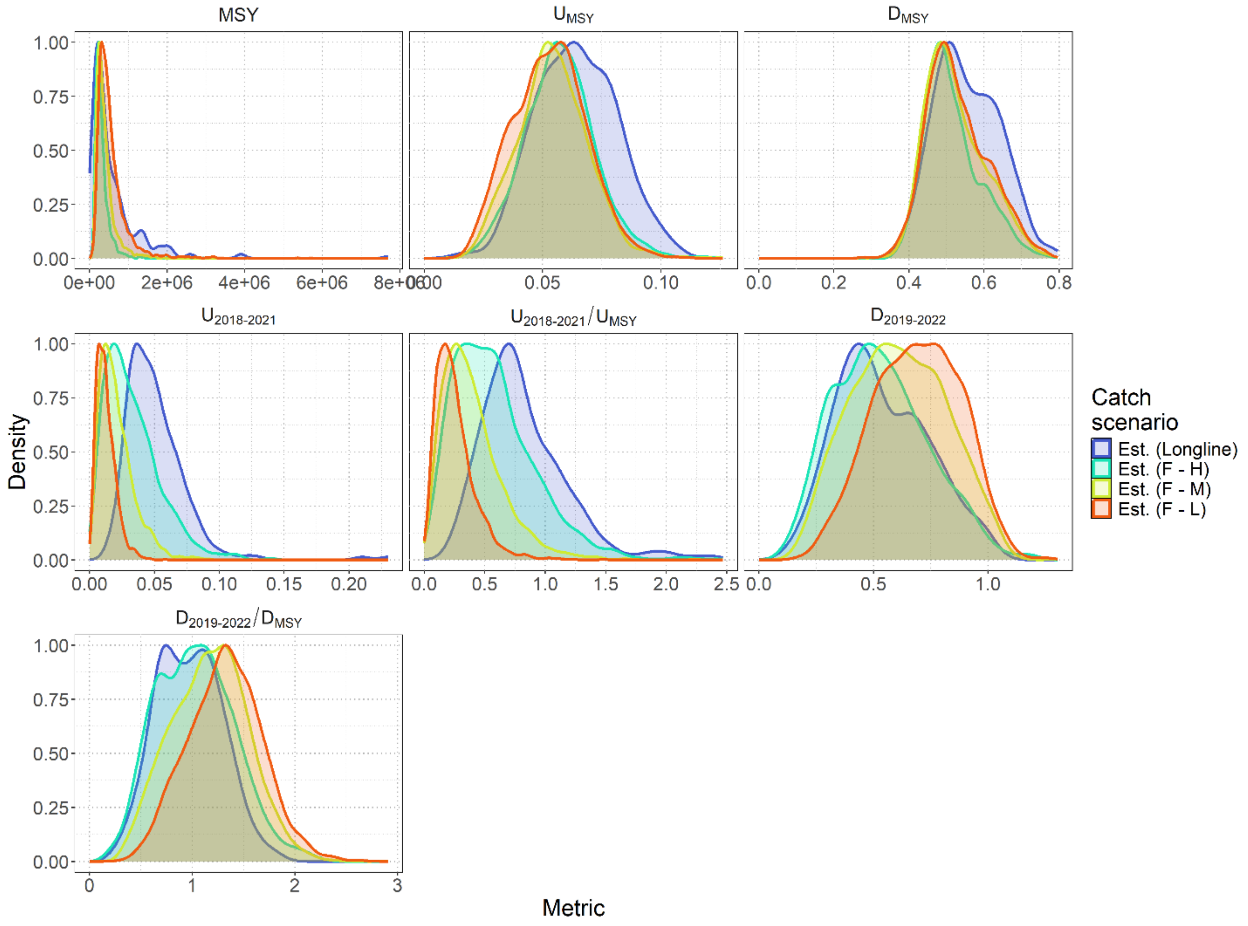
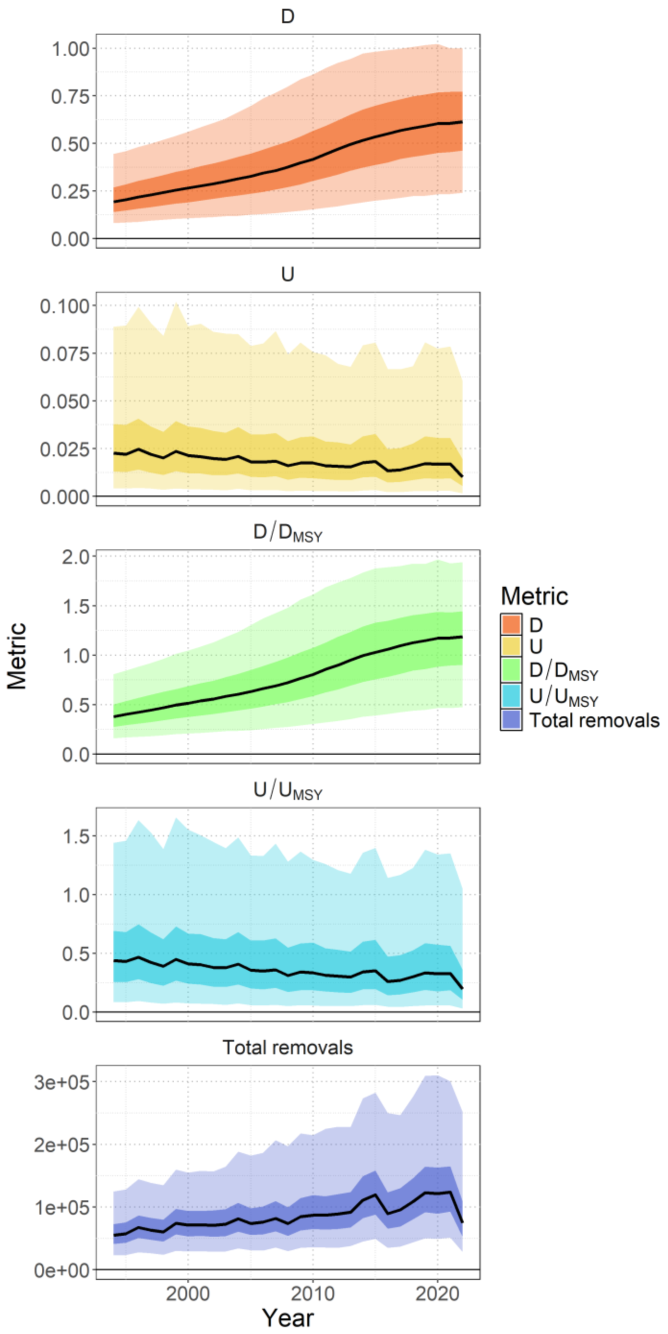
- Models assuming the “extreme” prior were more pessimistic
- Estimating removals using longline effort was more pessimistic, as were models that assumed broader priors for σ_F



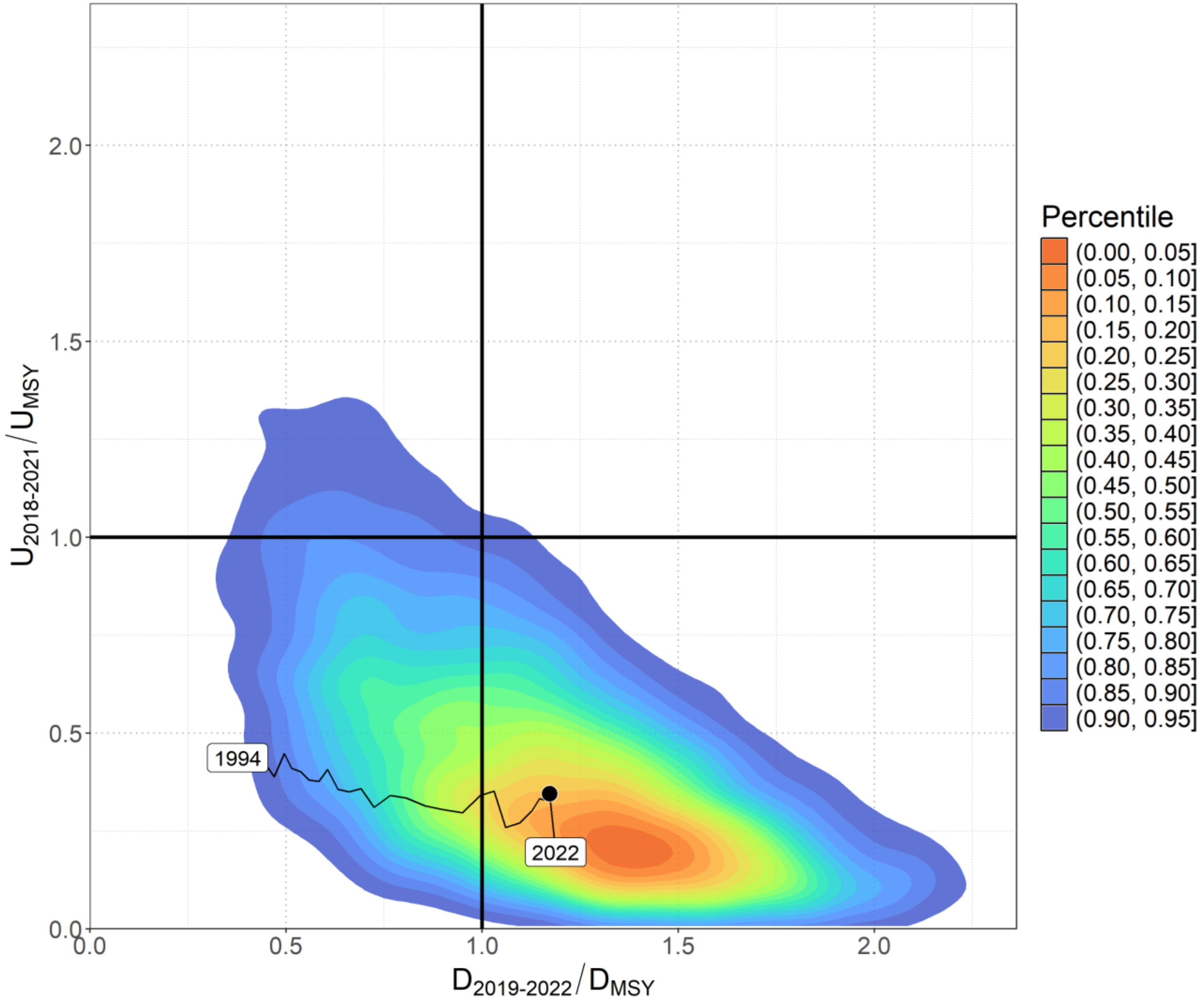


Stock status

- No biomass-based or fishing mortality-based limit or target reference points have been established for NPO SMA by the IATTC or WCPFC;
- Recent median D ($D_{2019-2022}$) is estimated from the model ensemble to be 0.60 (95% CI = 0.23-1.00). The recent median $D_{2019-2022}$ is 1.17 times D_{MSY} (95% CI = 0.46-1.92) and the stock is likely (66% probability) not in an overfished condition relative to MSY-based reference points.
- Recent U ($U_{2018-2021}$) is estimated from the model ensemble to be 0.018 (95% CI = 0.004-0.07). $U_{2018-2021}$ is 0.34 times (95% CI = 0.07-1.20) U_{MSY} and overfishing of the stock is likely not occurring (95% probability) relative to MSY-based reference points.

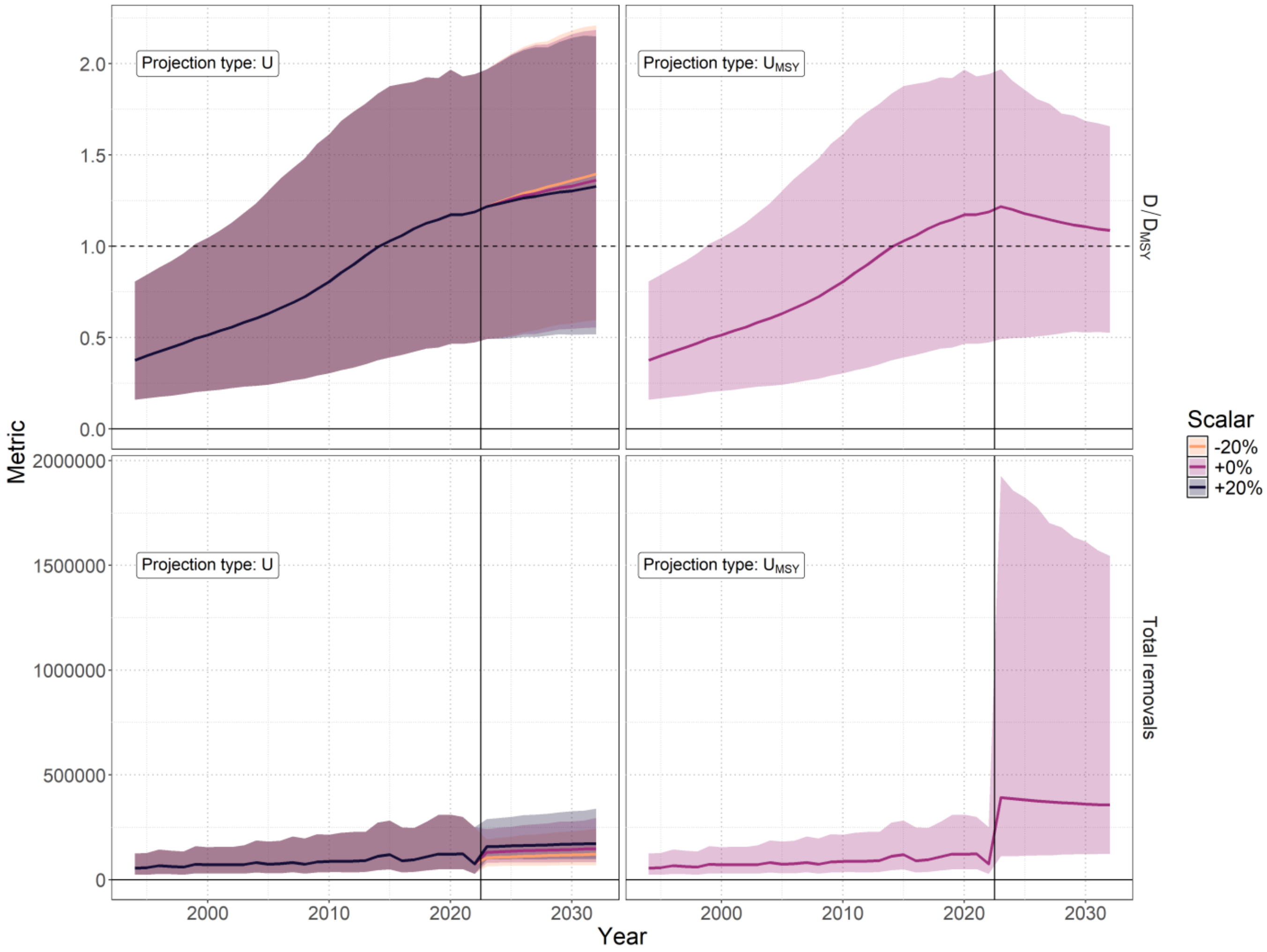
Stock status

- The model ensemble results show that there is a 65% joint probability that the North Pacific SMA stock is not in an overfished condition and that overfishing is not occurring relative to MSY based reference points.
- Several uncertainties may limit the interpretation of the assessment results including uncertainty in catch (historical and modeled period) and the biology and reproductive dynamics of the stock, and the lack of CPUE indices that fully index the stock.



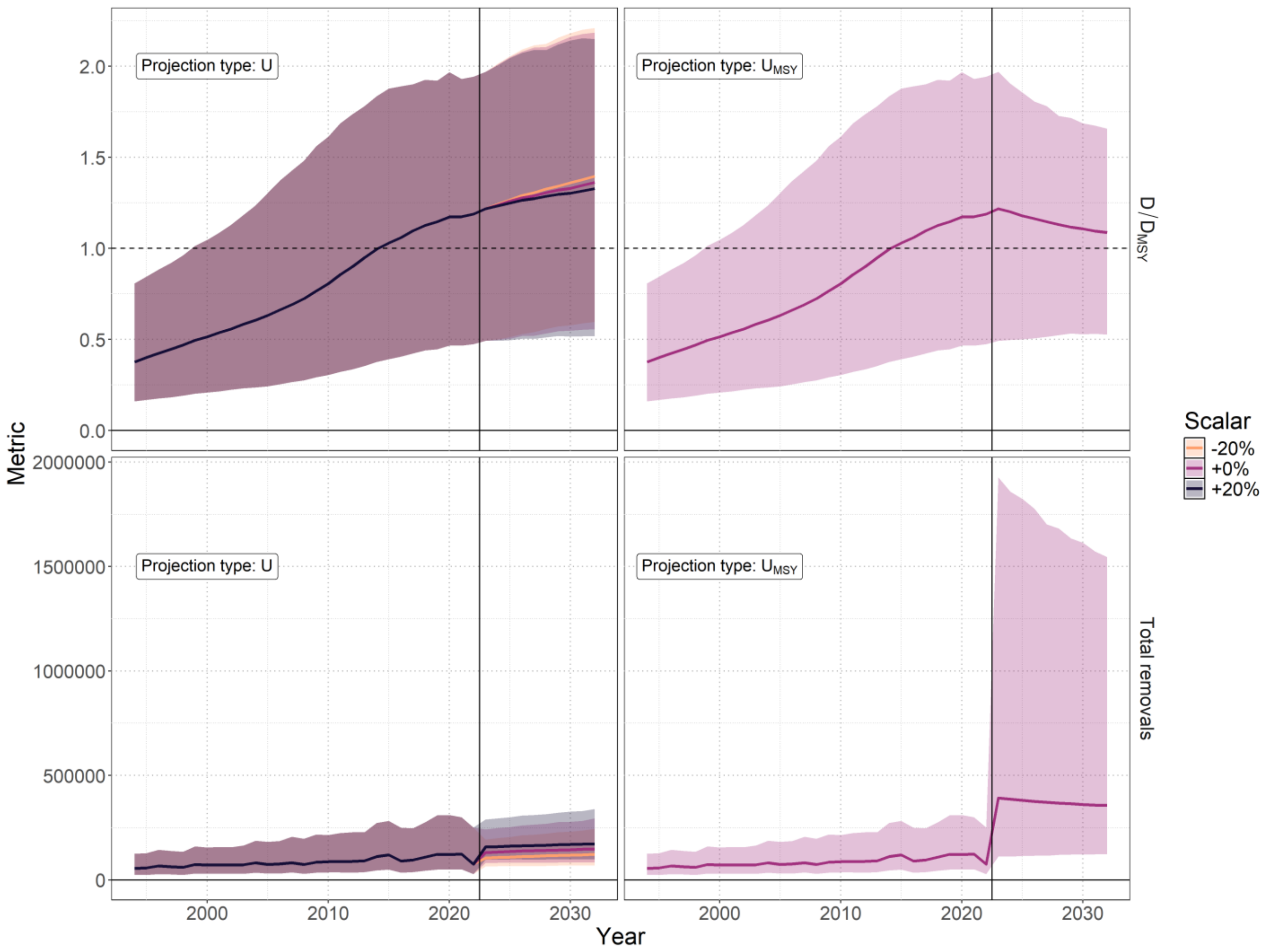
Projections

- 4 exploitation U based scenarios to conduct 10-year stochastic future projections for NPO SMA: the average exploitation rate from 2018-2021 $U_{2018-2021}$, $U_{2018-2021} + 20\%$, $U_{2018-2021} - 20\%$, and the exploitation rate that produces maximum sustainable yield U_{MSY}.



Conservation information

- Future projections in three of the four harvest scenarios (*$U_{2018\text{-}2021}$*, *$U_{2018\text{-}2021}$+20%*, and *$U_{2018\text{-}2021}$-20%*) showed that median D in the North Pacific Ocean will likely (>50% probability) increase; only the U_{MSY} harvest scenario led to a decrease in median D.
- Median estimated D of SMA in the North Pacific Ocean will likely (>50% probability) remain above D_{MSY} in the next ten years for all scenarios except U_{MSY}; harvesting at U_{MSY} decreases D towards D_{MSY} .
- Model projections using a surplus-production model may over simplify the age-structured population dynamics and as a result could be overly optimistic.



Discussion: General remarks

- Stock status is trending upwards, however understanding of status relative to MSY is based on aggregated population dynamics. Moving back into an age-structured modeling approach for the next assessment can more appropriately characterize the stock and population dynamics given the important age-structured dynamics observed for NPO SMA.
- Data availability for shark assessments is a concern going into the future. Conservation measures and adoption of electronic monitoring may reduce the number of observed interactions and impact the ability to take biological samples. The CITES Appendix II listing also impedes sharing of biological samples between institutes. This all may impact the quality of data going into future assessments, and the ISC SHARKWG should adjust and plan accordingly in order to continue to provide stock status information.

Discussion: Challenges, limitations & uncertainties

- As mentioned previously, the lack of age-structure is a limitation to the assessment given the important age-structured dynamics & the length of the model period relative to the population generation time.
- There appears to be little information in the available data to estimate total population scale. Incorporating size composition information (in an integrated age-structured model) may not necessarily improve this given the strong likelihood of dome-shaped selectivity.
- Catch is highly uncertain both historically (lack of species-specific data for sharks) and in the recent period (uncertainty in level of reporting of discards & associated mortality). Additionally, the Mexican artisanal catches make up an important component of recent catches and this is a challenging fishery to collect data from.

Discussion: Challenges, limitations & uncertainties

- Model results are conditioned on the assumption that the indices are representative of the stock dynamics. However, there are reasons (lack of complete spatial coverage & lack of samples for the reproductive component of the population; likely due to dome-shaped selectivity) why that assumption may be violated.
- Stock structure is uncertain in the NPO (is it a single well-mixed stock or do the distinct parturition sites engender more complex regional dynamics?) as is understanding of basic biological functions (age, growth and reproduction). Failing to properly account for uncertainty in these components could bias assessment outcomes and limit our understanding of the stocks productivity.

Discussion: Research recommendations

Future research is needed to resolve many of the highlighted uncertainties with the model and the input data. Research priorities include:

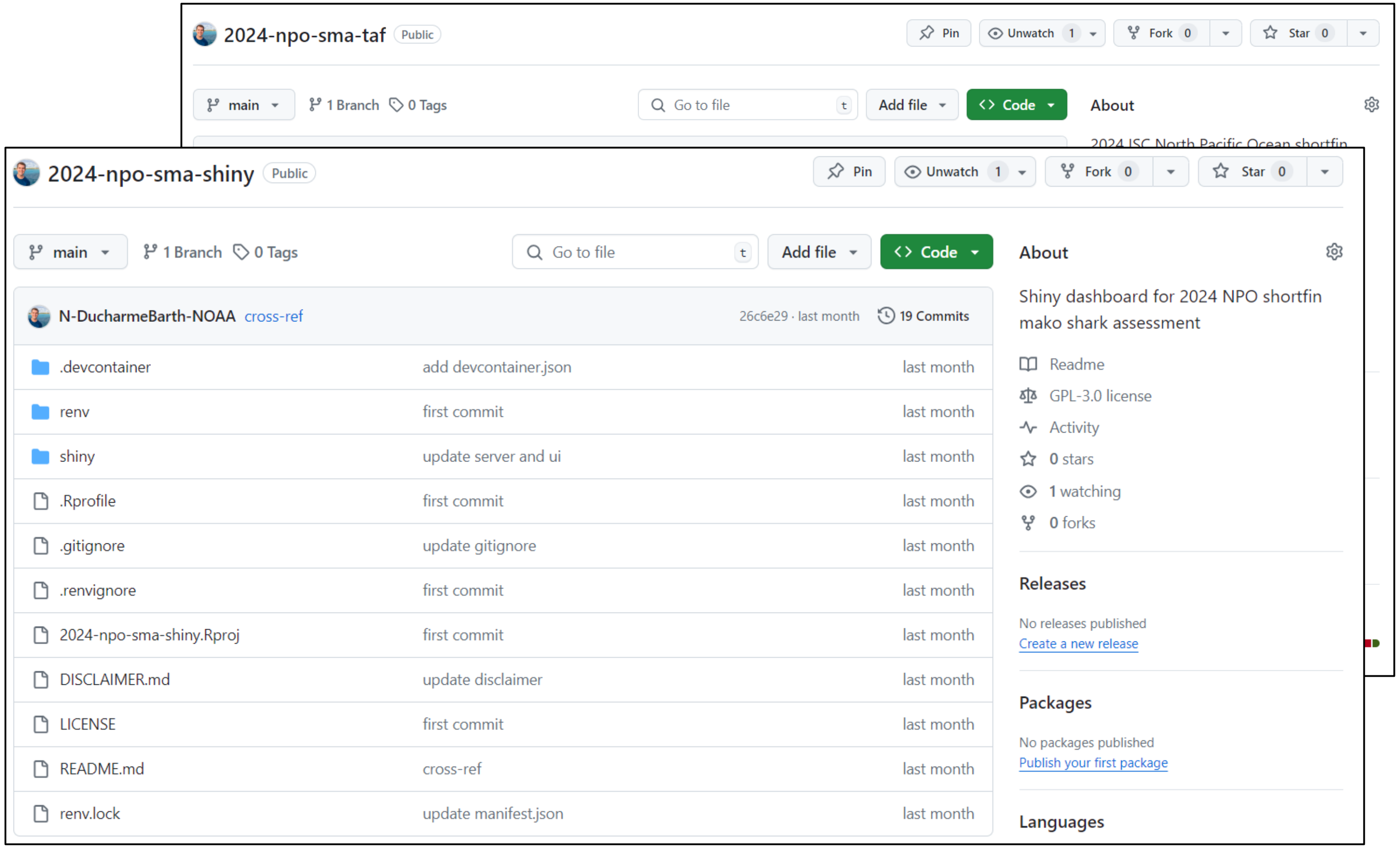
- Scoping study to develop and evaluate a genetic sampling plan for close-kin mark-recapture (CKMR). CKMR could help resolve many issues related to population scale, information about the reproductive component of the population and stock structure.
- Improving aging estimates and methods used for determining age
- Improving catch estimates
- Improve the spatial representativeness of the index (a joint spatiotemporal analysis of operational longline data)
- Building on the BSPM and age-structured simulation by developing a Bayesian age-structured estimation model.
  - If using an age-structured approach, standardize size composition data

Acknowledgements

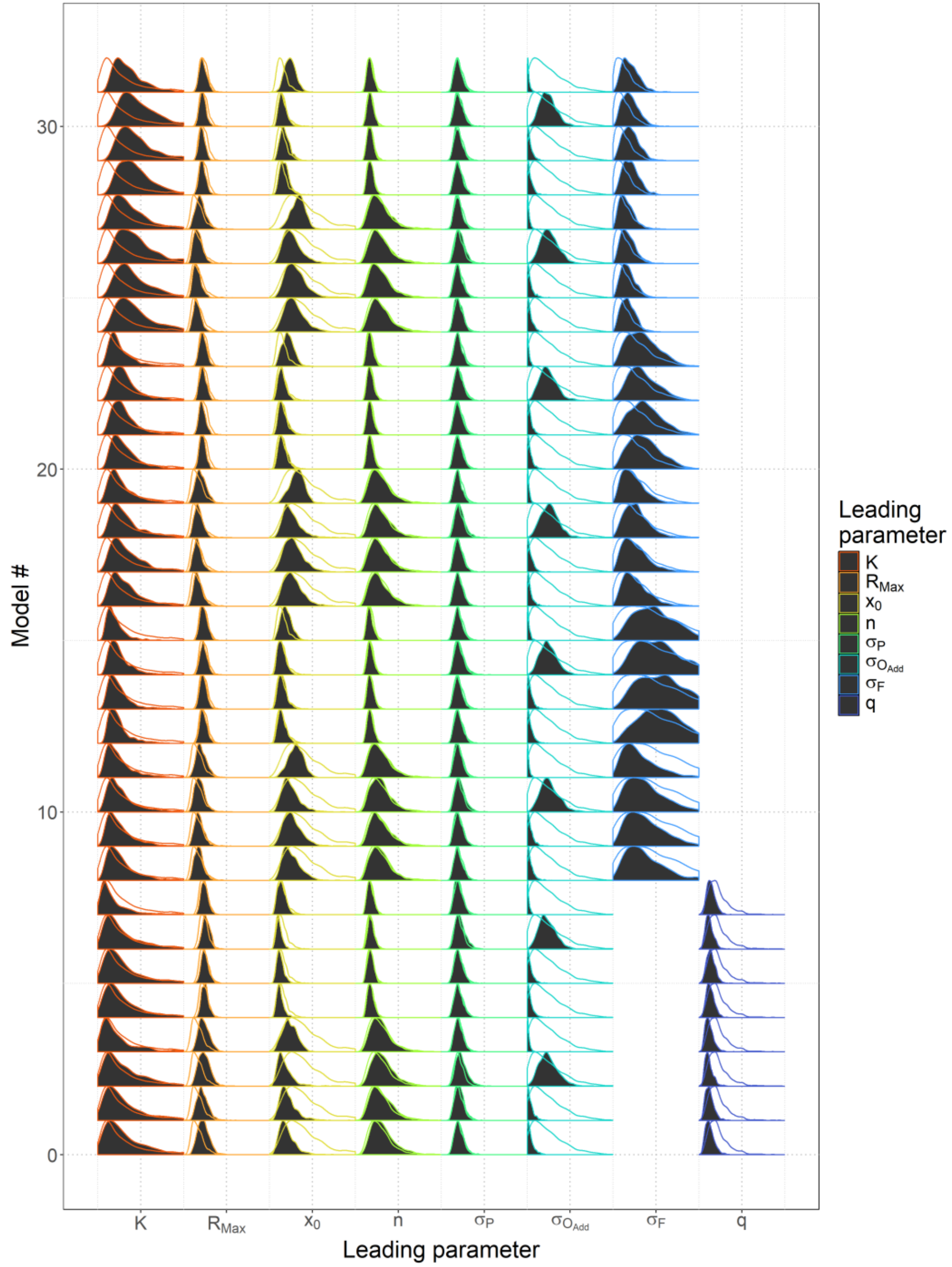
- Thank you to members of the of the SHARKWG for the collaboration that made this stock assessment possible.
- Thank you also to non-working group members including Davies, N., Kim, K., Neubauer, P., and Soto, E.A for their valuable insights and contributions to discussions.
- Thank you to the fisheries agencies and observers of ISC and non-ISC member countries for collecting and providing the data used in the current stock assessment.
- Research to develop the age-structured simulation model, and estimation of bias correction was greatly facilitated using services provided by the OSG Consortium, which is supported by the National Science Foundation awards #2030508 and #1836650.

GitHub repositories

- Model code and input data for replicating the model ensemble can be found at the 2024-npo-sma-taf GitHub repository: https://github.com/N-DucharmeBarth-NOAA/2024-npo-sma-taf
- A Shiny dashboard displaying full diagnostics and estimated quantities for final models can be found at the 2024-npo-sma-shiny GitHub repository: https://github.com/N-DucharmeBarth-NOAA/2024-npo-sma-shiny

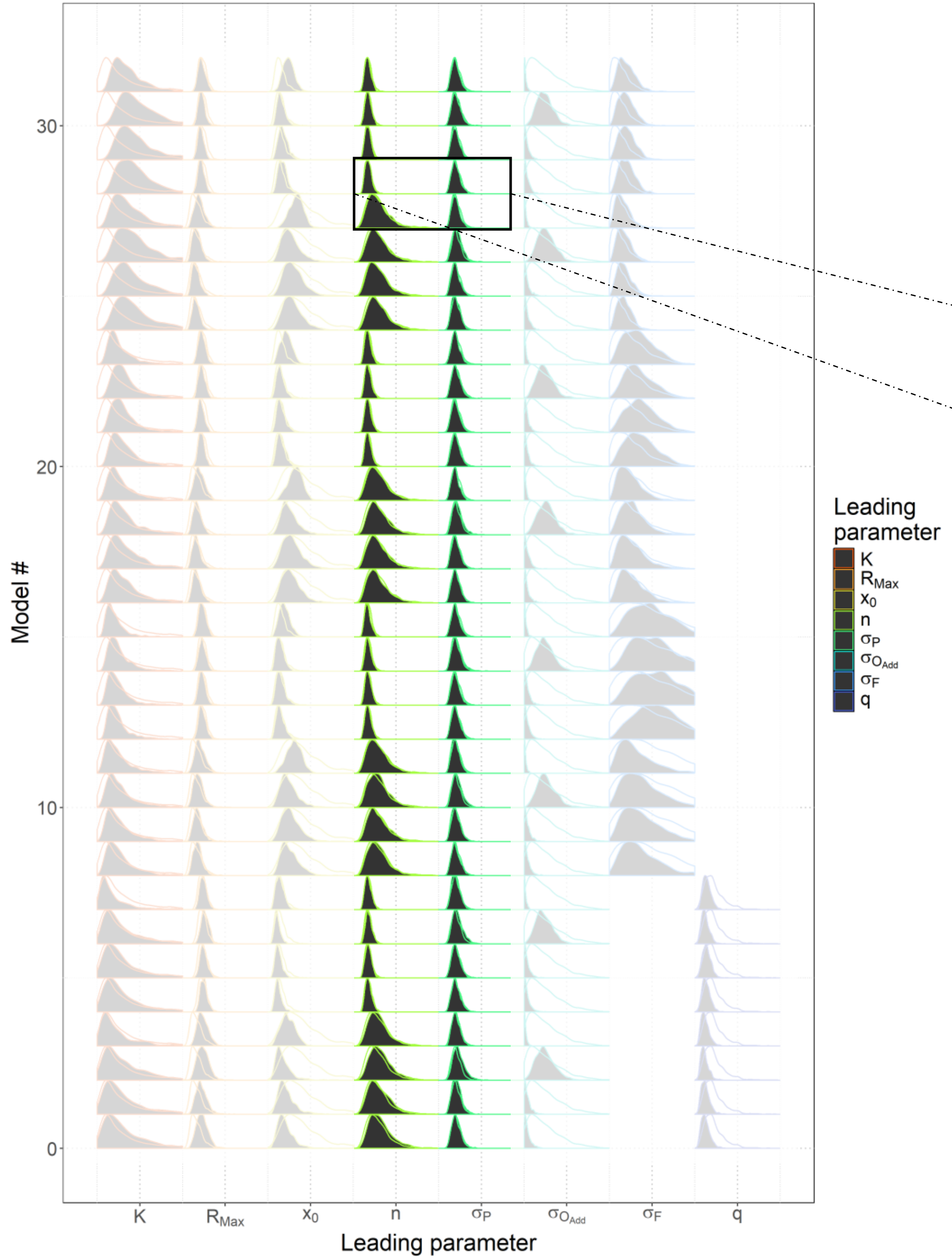


Extra slides



BSPM posterior updates

- Both the shape parameter n and the process error variability σ_P show minimal posterior update.



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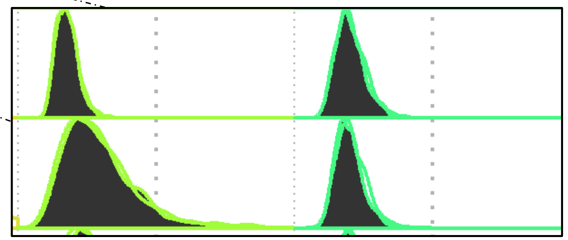

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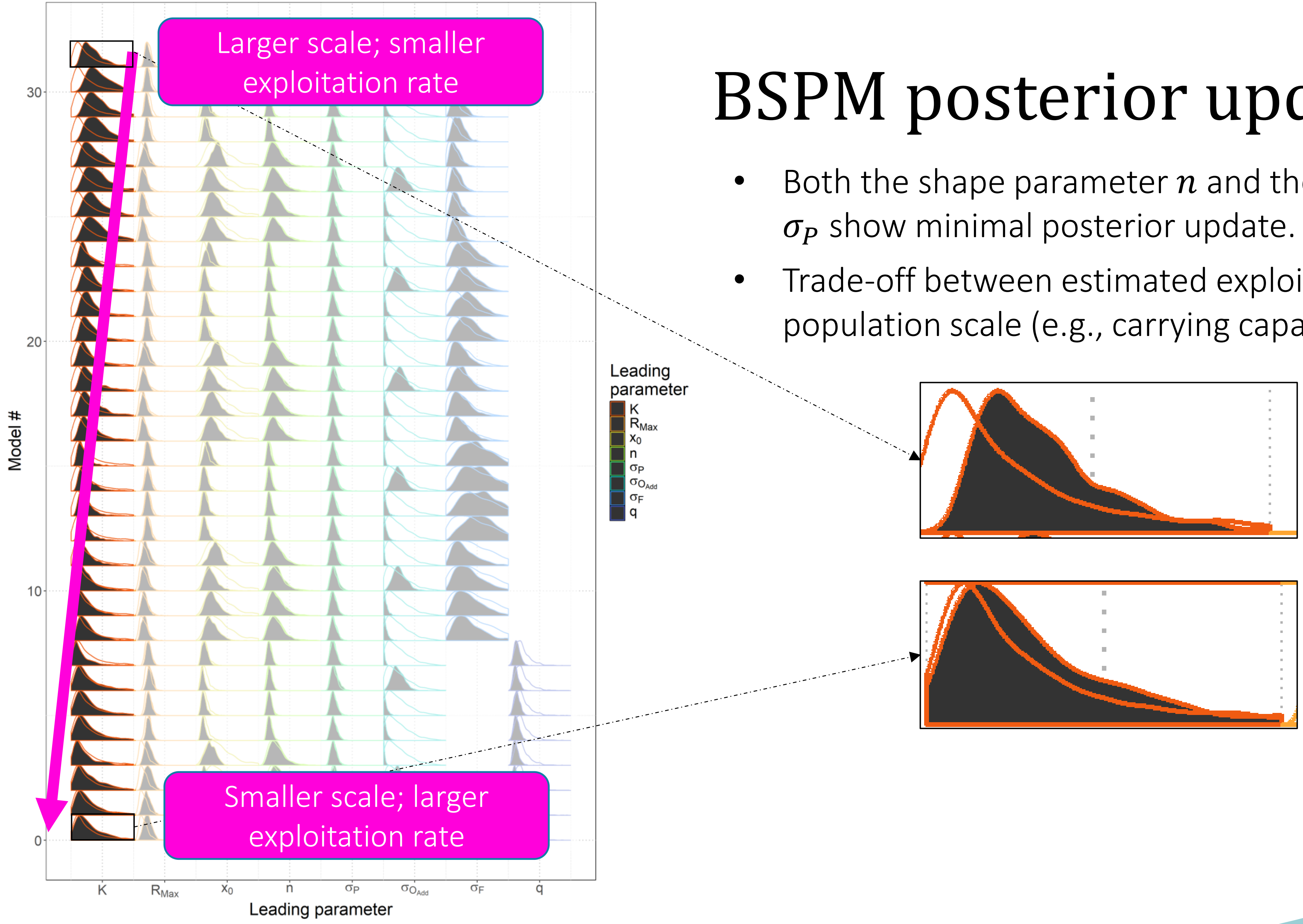
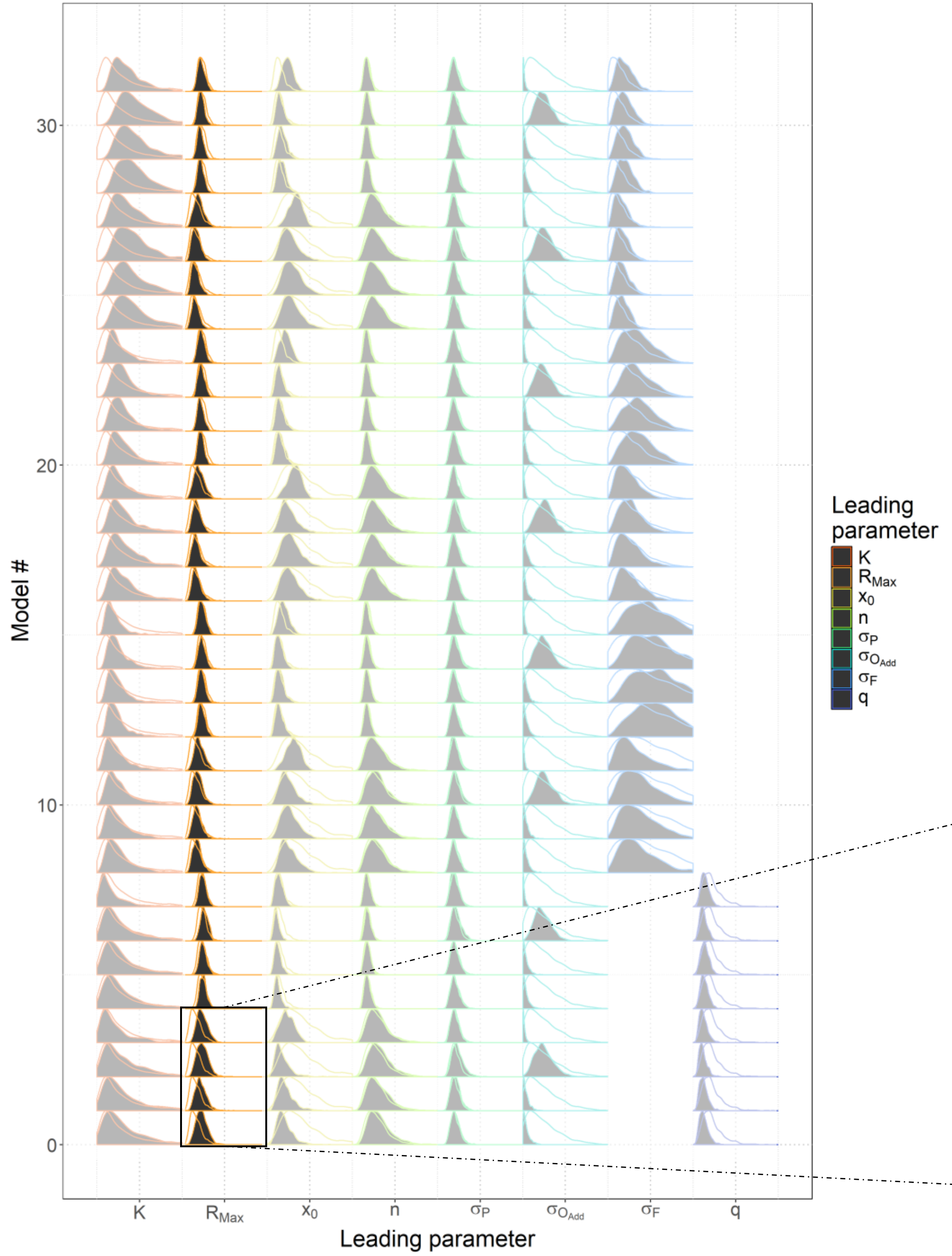
- Trade-off between estimated exploitation rate and estimated population scale (e.g., carrying capacity K).





BSPM posterior updates

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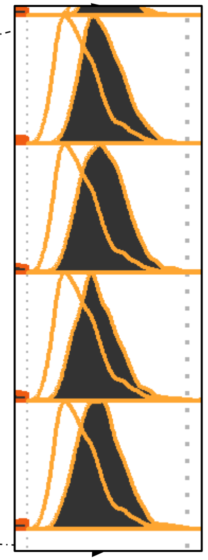
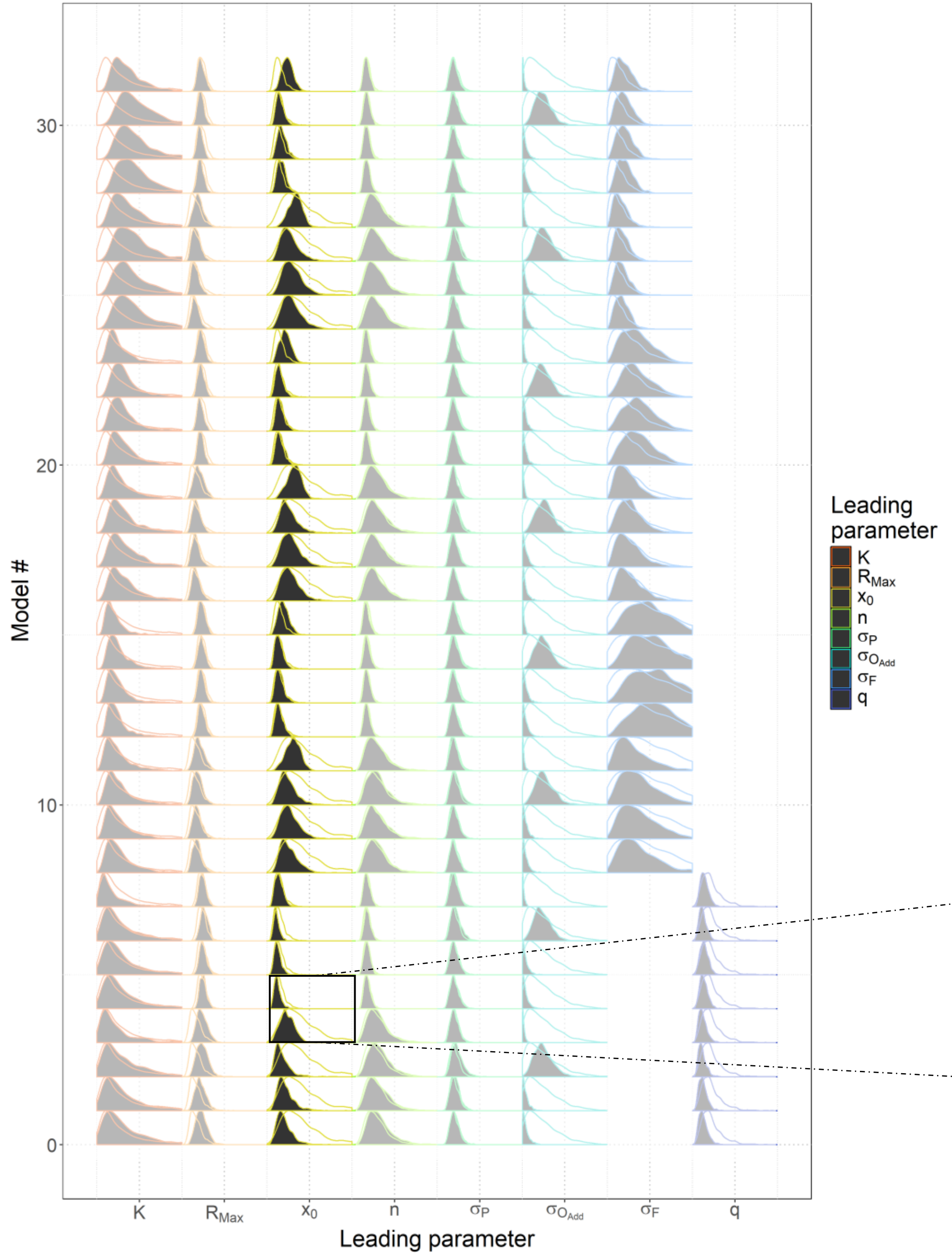
- Trade-off between estimated exploitation rate and estimated population scale (e.g., carrying capacity K).
- R_{Max} estimated consistently with prior except for models with removals driven by longline effort and assuming the baseline level of prior filtering.





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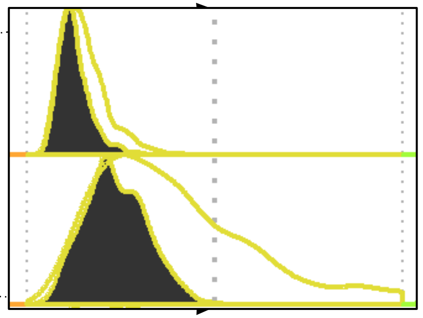
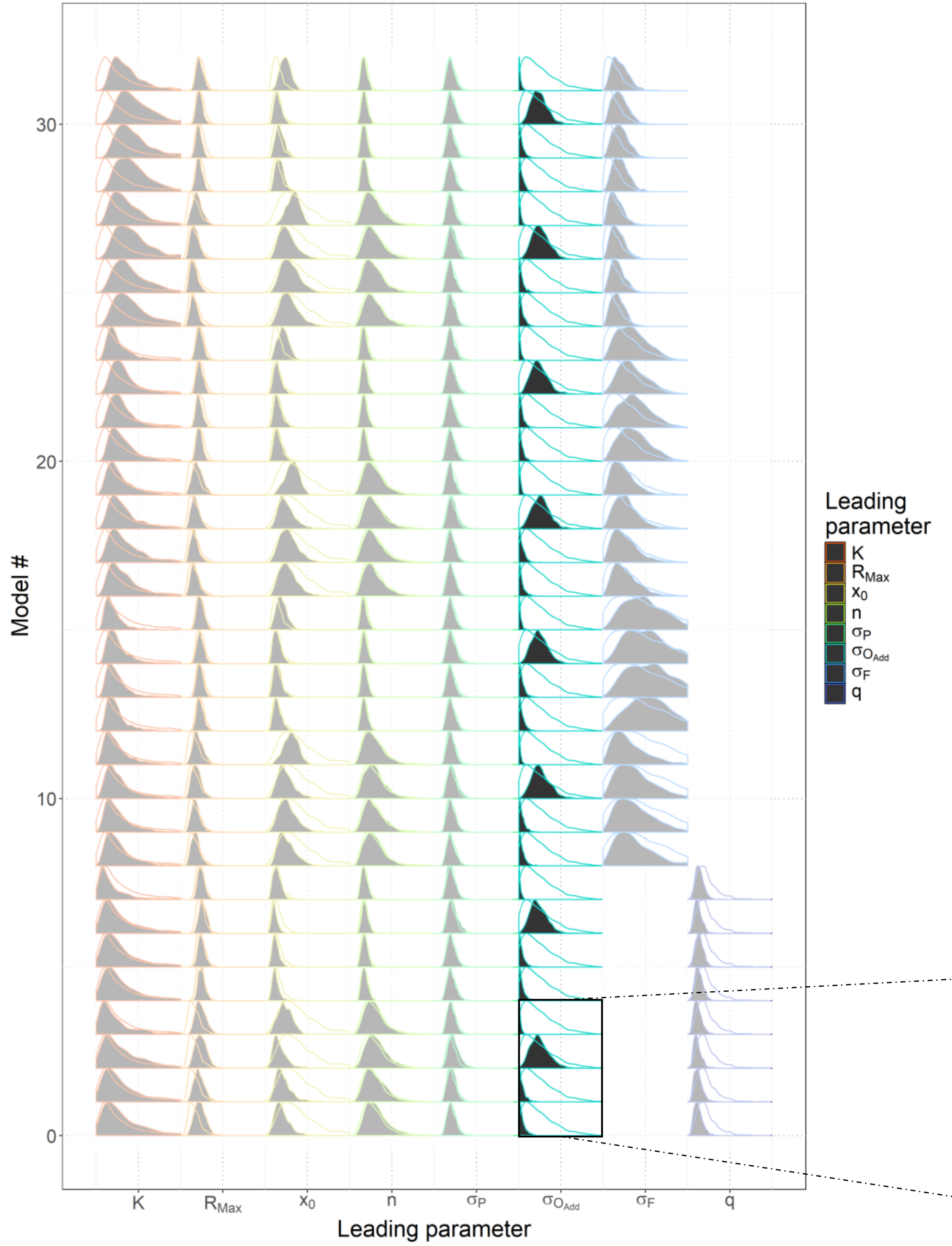
- Data supports a more depleted initial condition x_0 relative to baseline prior.





BSPM posterior updates

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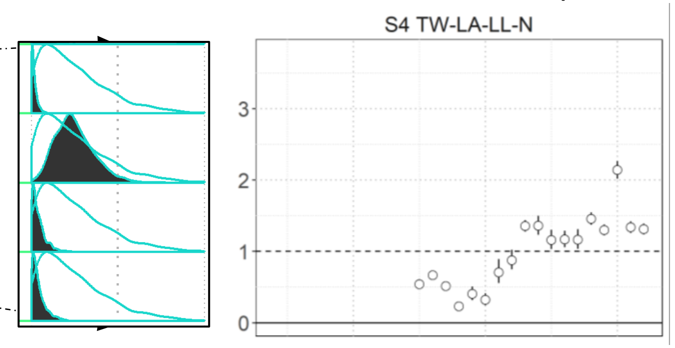
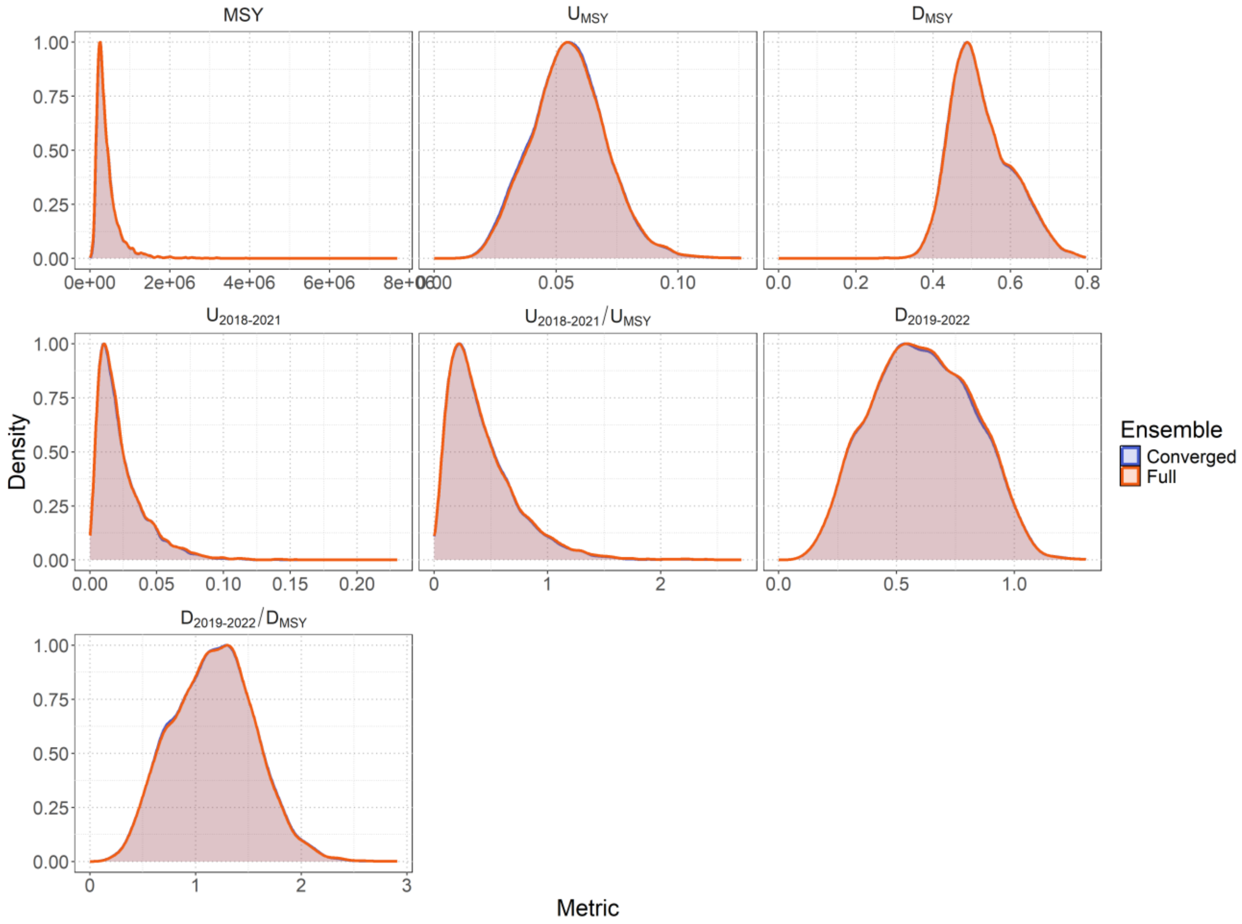
- R_{Max} estimated consistently with prior except for models with removals driven by longline effort and assuming the baseline level of prior filtering.
- Data supports a more depleted initial condition x_0 relative to baseline prior.
- Substantial extra observation error $\sigma_{O_{Add}}$ is estimated in order to fit the Chinese Taipei index.



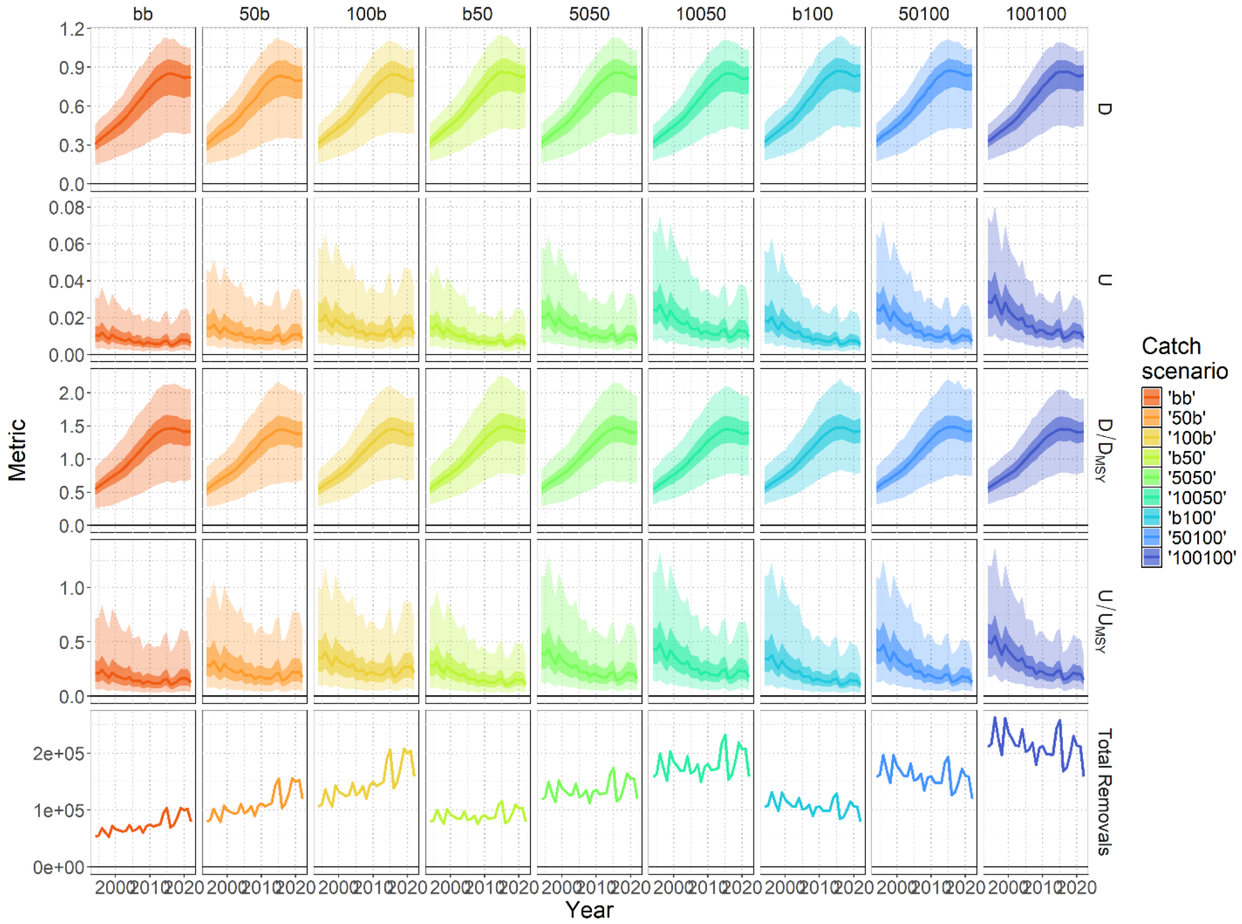
BSPM results

- Excluding non-converged models (4 of 32) did not change distributions of management reference points



BSPM sensitivities

- Additional sensitivities were investigated to look at the effect of:
  - Treating catch as fixed



Estimates are stable across alternative fixed catch scenarios

BSPM sensitivities

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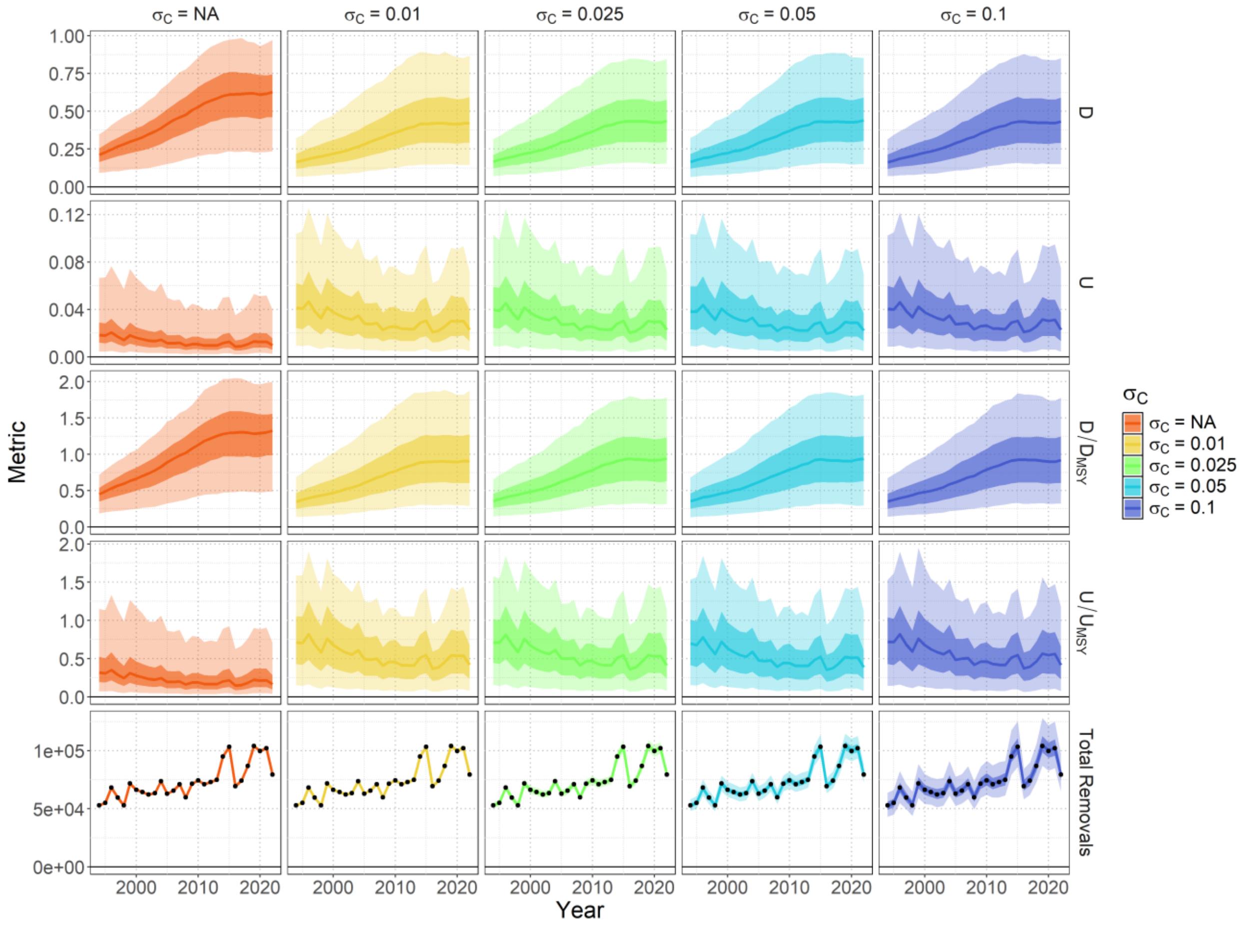
  - Varying the level of error in the catch likelihood



Changing σ_C has little impact on model estimates

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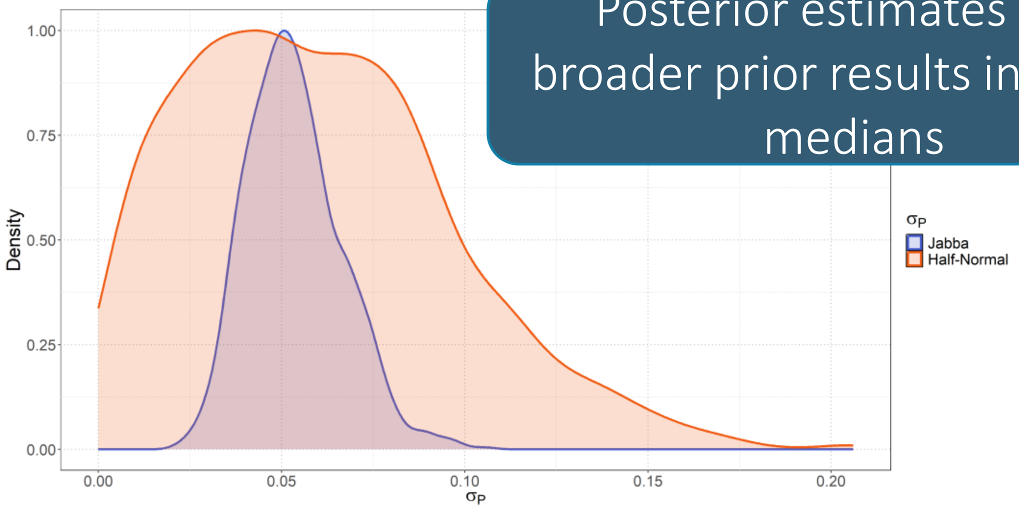
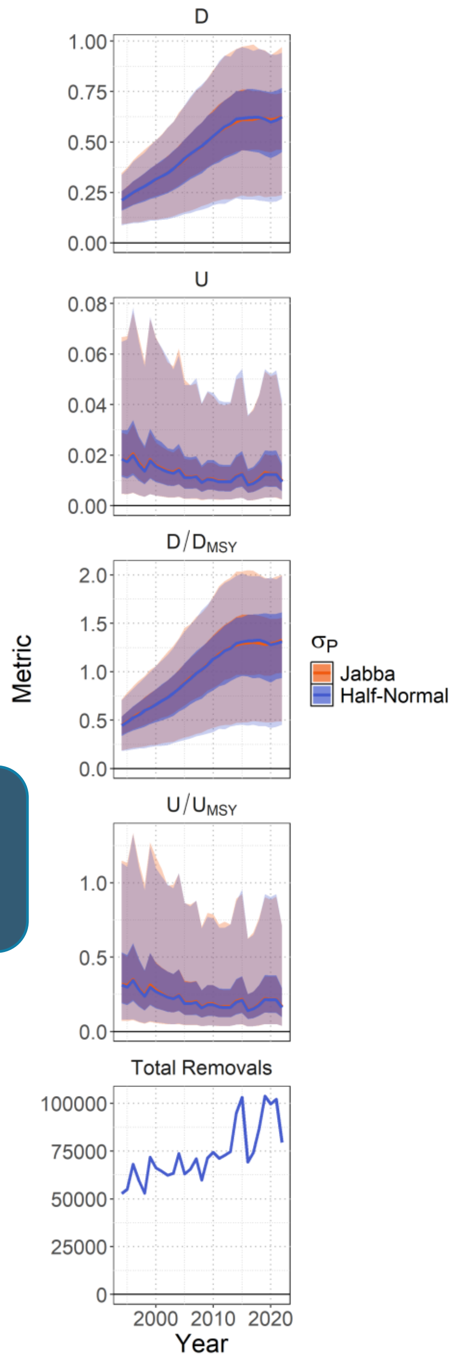
  - Varying the level of error in the catch likelihood
  - An alternative prior for σ_P



Posterior estimates with broader prior results in similar medians



Greater variability in the prior/posterior does not translate to greater variability in management quantities

BSPM sensitivities

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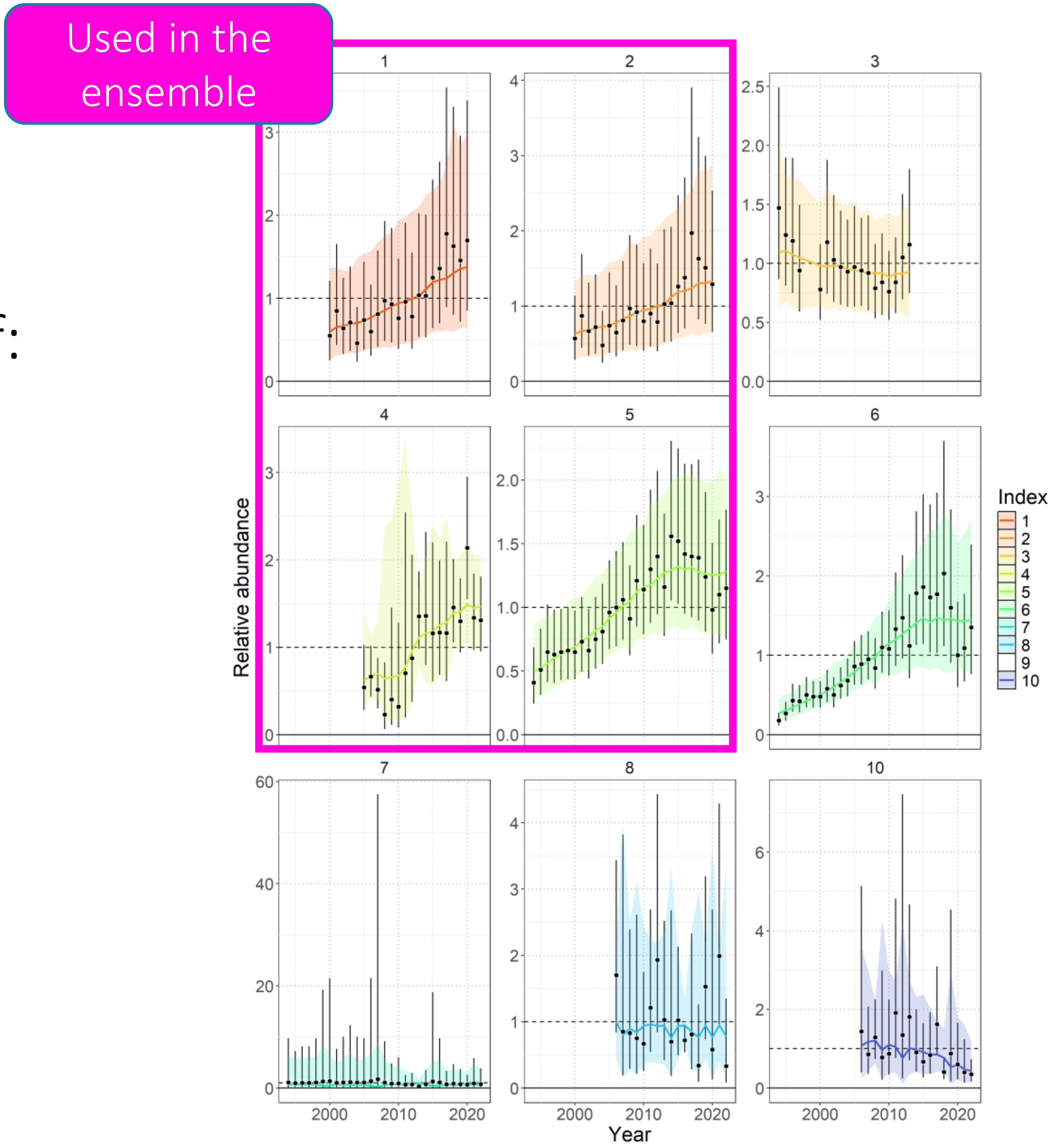
  - Varying the level of error in the catch likelihood
  - An alternative prior for σ_P
  - Alternative CPUE indices



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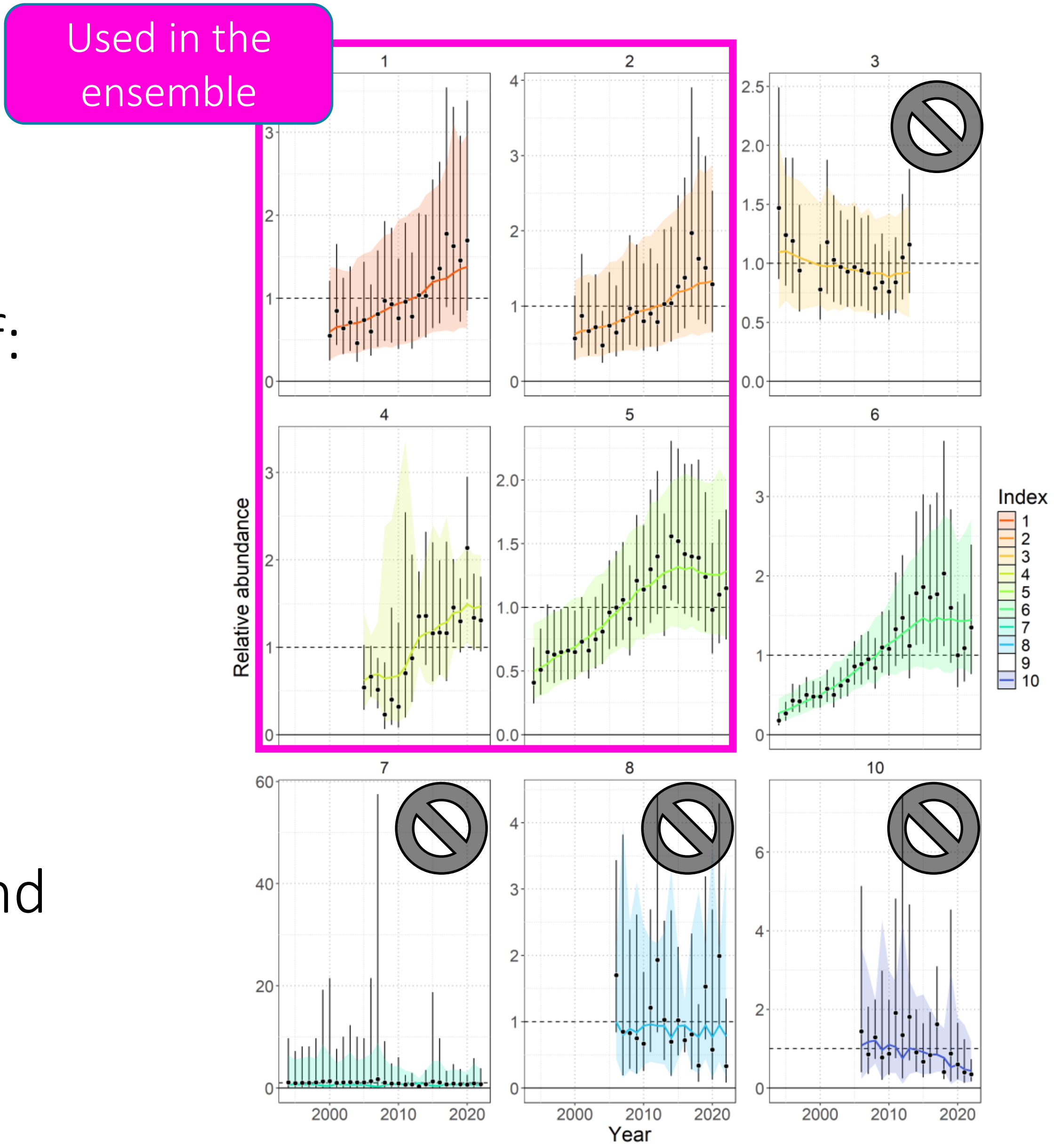
    - The SHARKWG did not consider indices 3, 7, 8, 9 and 10 to be representative or appropriate for the BSPM



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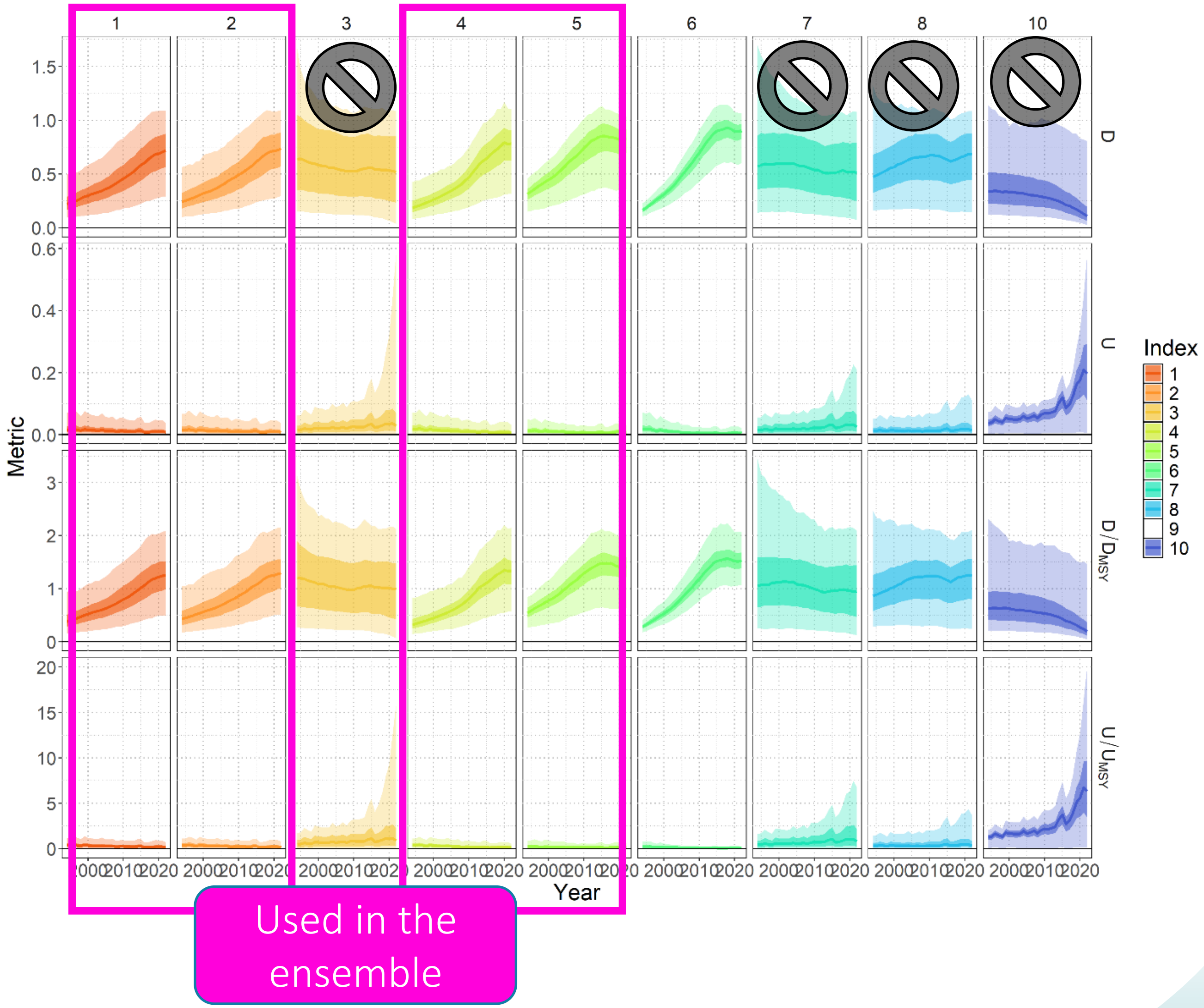
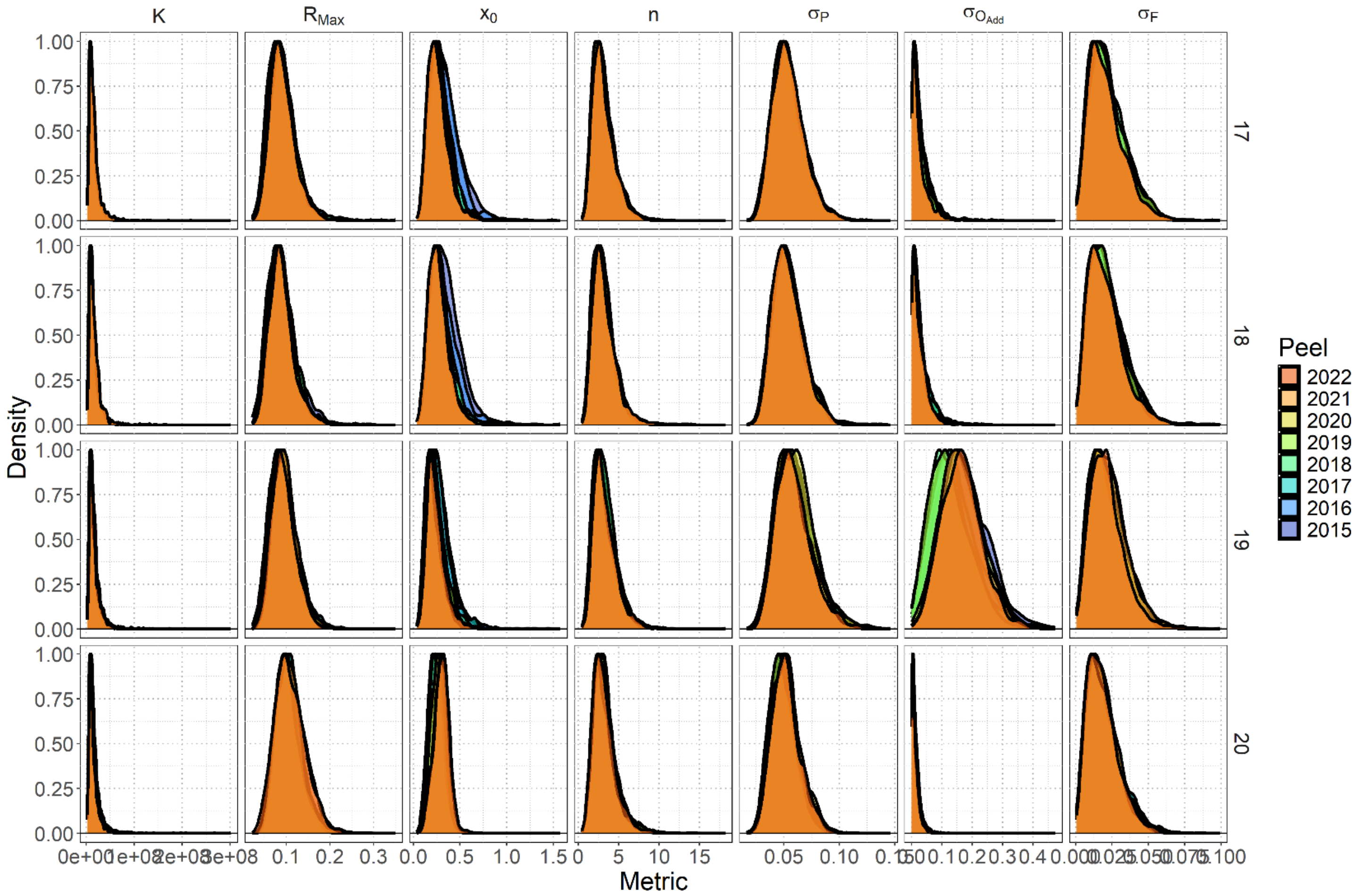
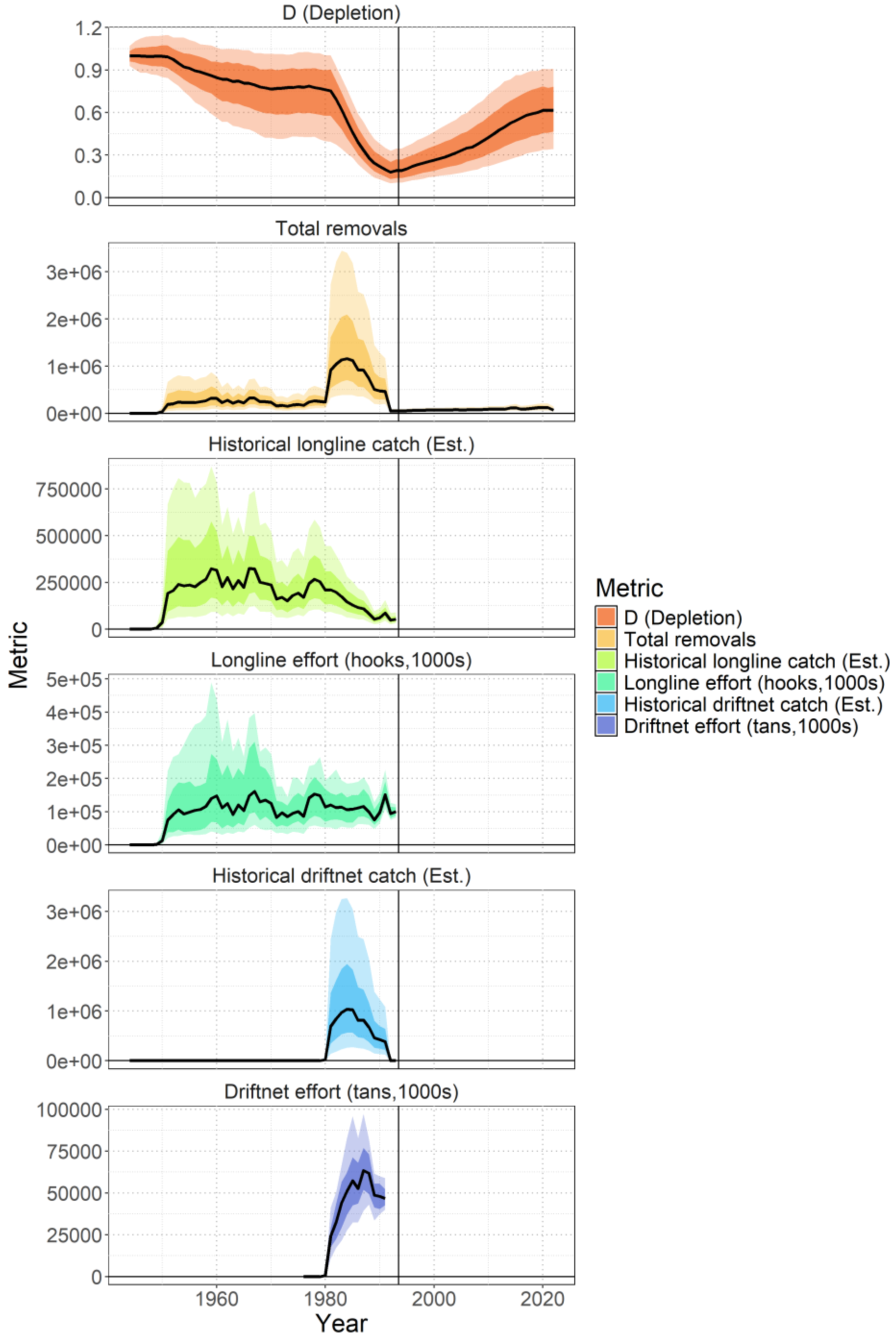


BSPM diagnostics

- Estimates of leading parameters reasonably stable across retrospectives.





Projections

- Retrospective projections were conducted, based on historical levels of longline fishing effort and high seas driftnet effort, to investigate likely historical trajectories of removals given estimated initial conditions in 1994.
- Substantial levels of removals in the 1980s, most likely associated with the high-seas driftnet, were required in order to match the rebuilding trends implied by the 1994-2022 indices.

BSPM bias calculation

- Concerns exist that the BSPM may over simplify stock dynamics given the long lag to maturity for mako shark (age at 50% maturity is 10+ years).
- 1000 representative simulations were conducted using a fully age-structured model, and 18 BSPM estimation models were fit to the simulated fisheries data from each population.
- 140 simulations were retained as they simulated indices that increased by at least 50%.
- 935 of the 2520 estimation models fit to the 140 simulated populations converged.
- These models indicated that the 'true' simulated level of depletion, in terms of spawning output, was contained in the estimation model credible interval 97.2% of the time, and that on average the BSPM over-estimated depletion by 7.3%.