Stock assessment of WCPO silky shark
(*Carcharhinus falciformis*, FAL)

SA-WP-04

Philipp Neubauer
Kyuhan Kim
Kath Large
Stephen Brouwer

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SAGGITUS

DRAGONFLY
Data Science

Summary

- Inputs and assumptions across assessments:
    - Stock structure
    - Biology - growth
    - Data inputs

- Alternative models: overview
    - SS3 model - key outcomes
    - Dynamic surplus production
    - Length-based hybrid spatial risk assessment model
    - Length and age-structured model

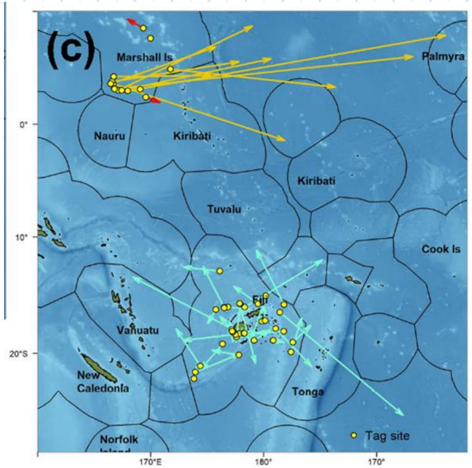
2024 Assessment: Inputs

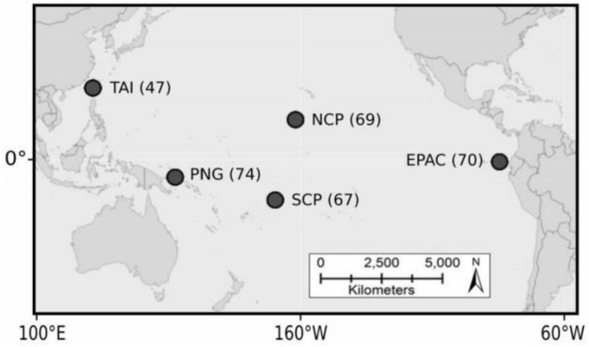
Stock structure

- Open question, conflicting hypotheses
- Tagging: Hutchinson et al. (2019),Francis et al. (2023)

  Long range movements possible, but also some local movements
- Genomics: Kraft et al. (2018, SC14-EB-IP-04)

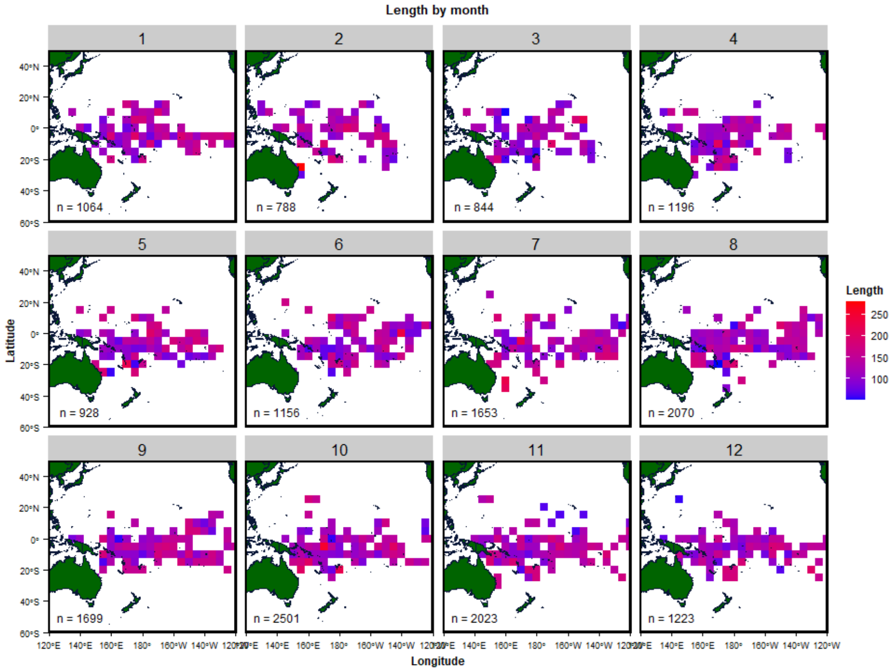
  Nuclear markers yielded significant population structure between five regions

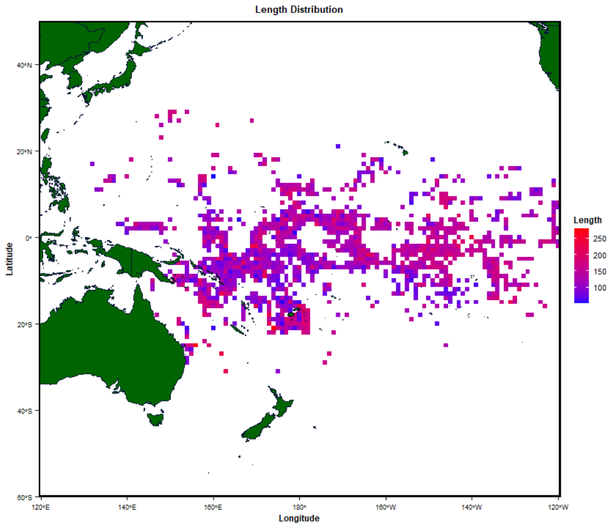




Stock structure

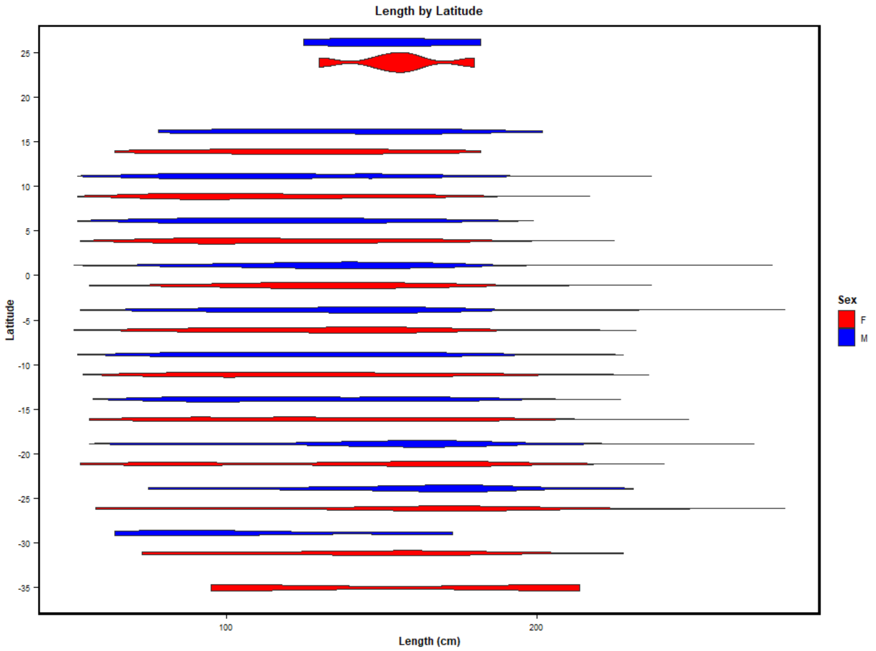
- No indication of strong patterns in mean length in space





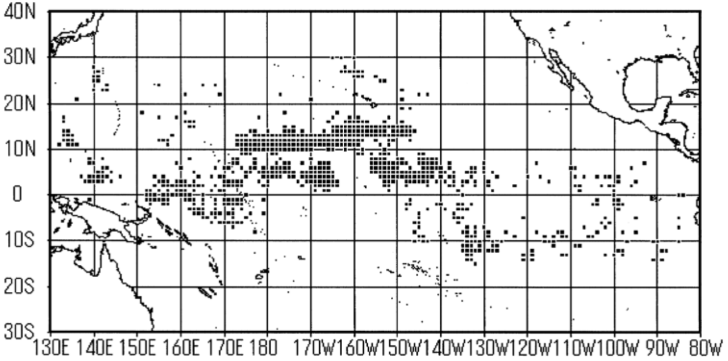
Stock structure

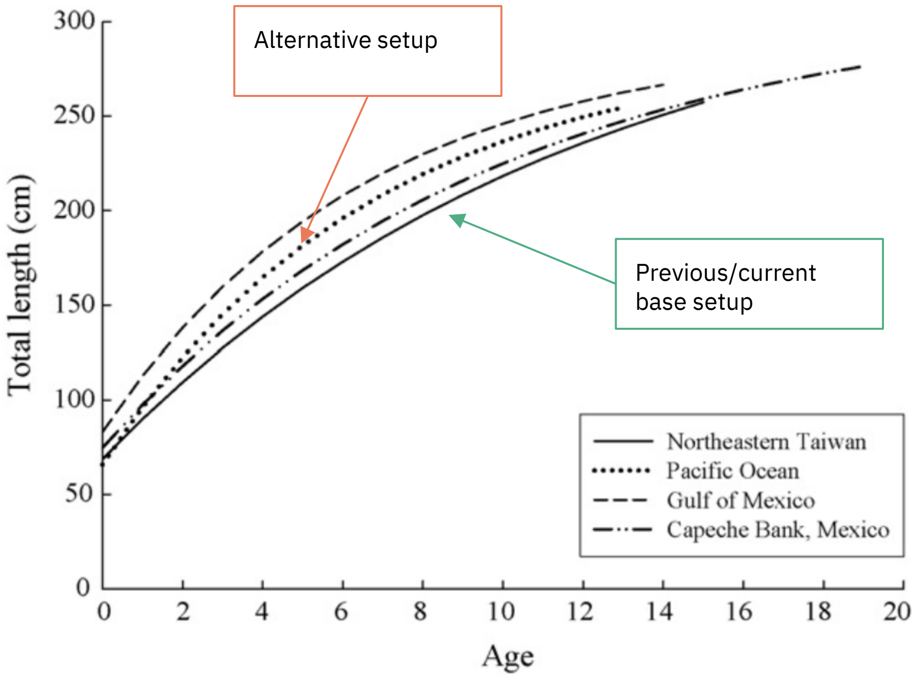
- No indication of strong patterns in mean length in space
- No data to inform spatially structured model



Growth

- Two growth curves available
  - Oshitani et al. 2003
  - Joung et al 2008
- Oshitani study based on individuals caught in tropical longline fishery, mostly WCPO





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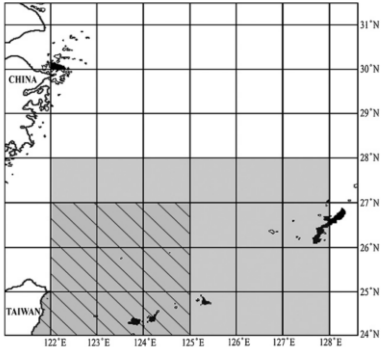

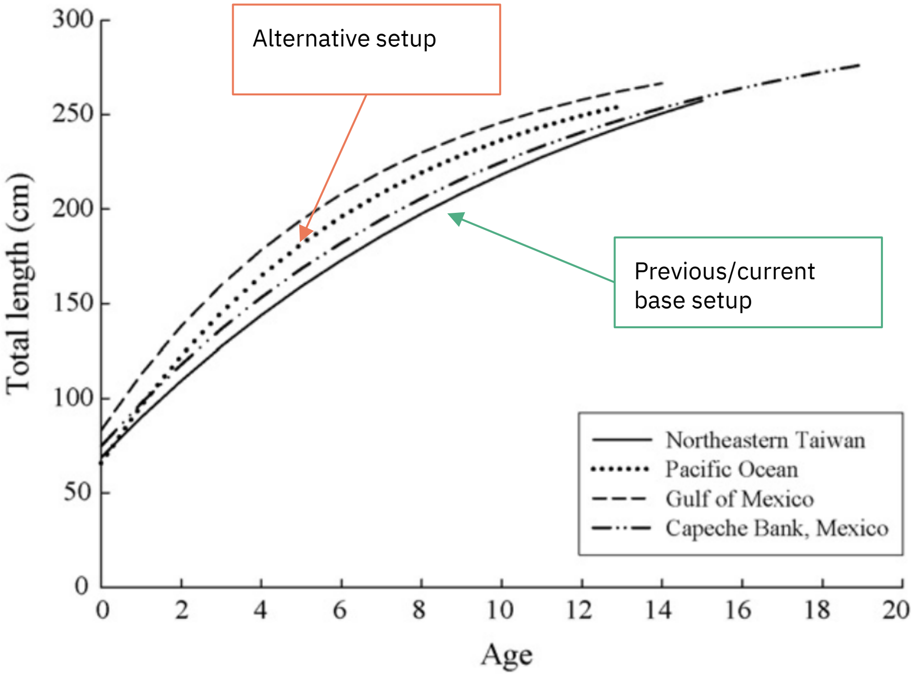

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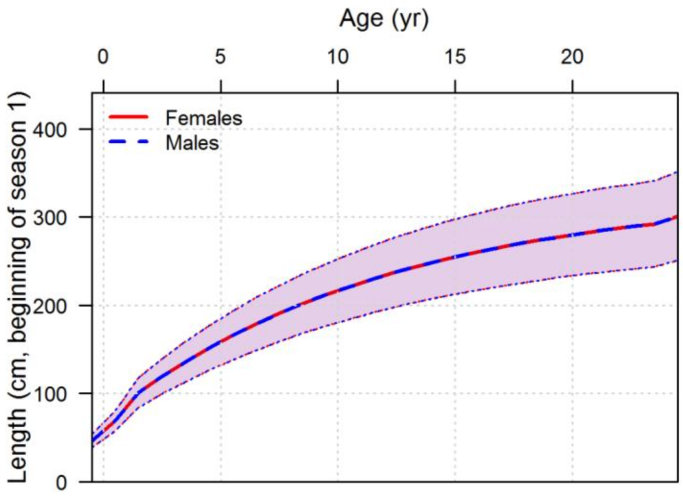
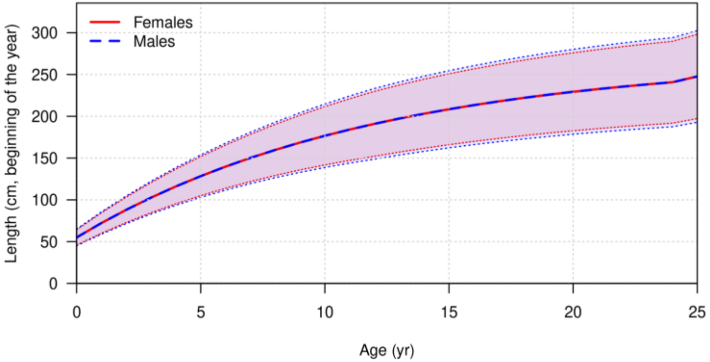
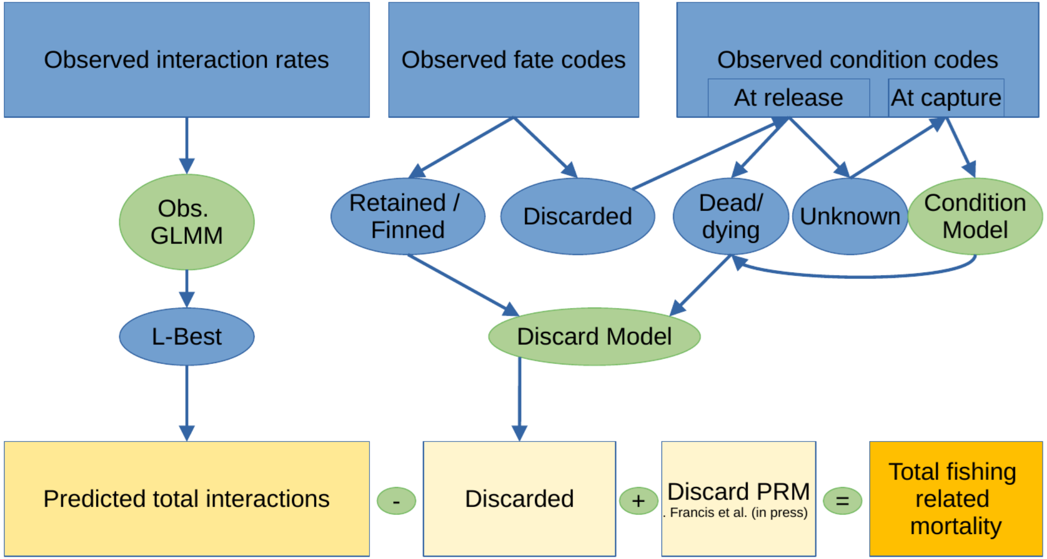




- Model LFs are in terms of fork length (as mostly recorded by observers).
- Previous growth model used TL for parameters;
- Conversion leads to different growth assumption.

Catch

- Model uses predicted catch from catch reconstruction, not reported catch
- Need to account for discarding and survival in recent years
  - **Condition model**: estimated condition at release (dead (A3/D) or alive (A1/A2) from condition at capture.
  - **Discard model**: attempts to estimated proportion of sharks released alive
  - **PRM** (0.15 LL, 0.85 PS) applied to total discarded catch.



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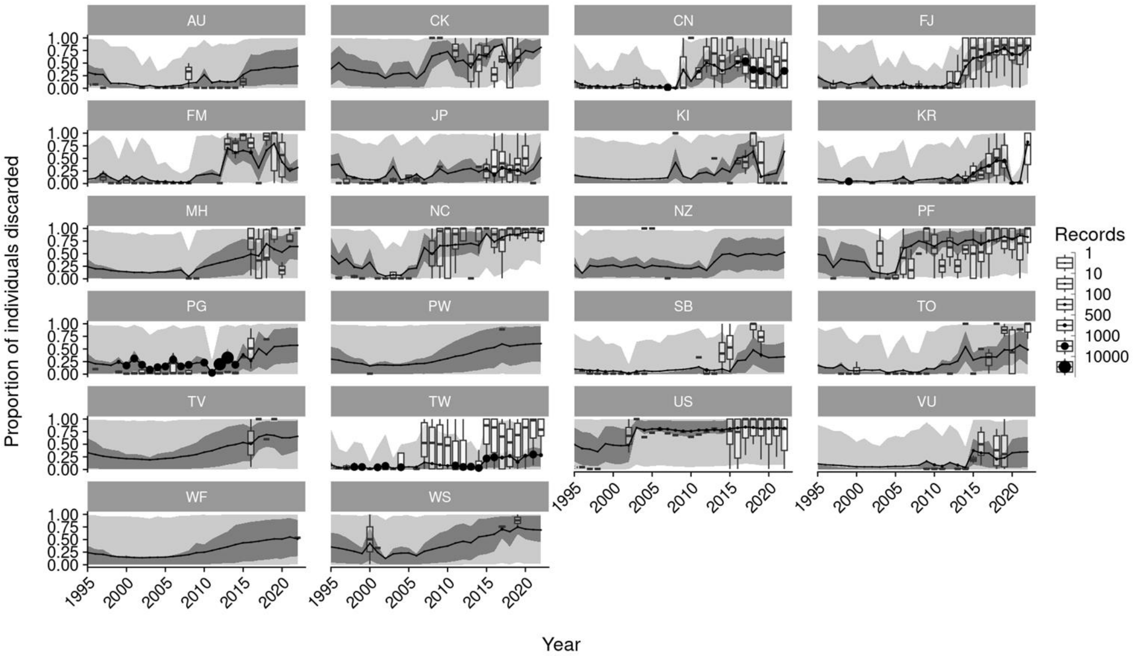

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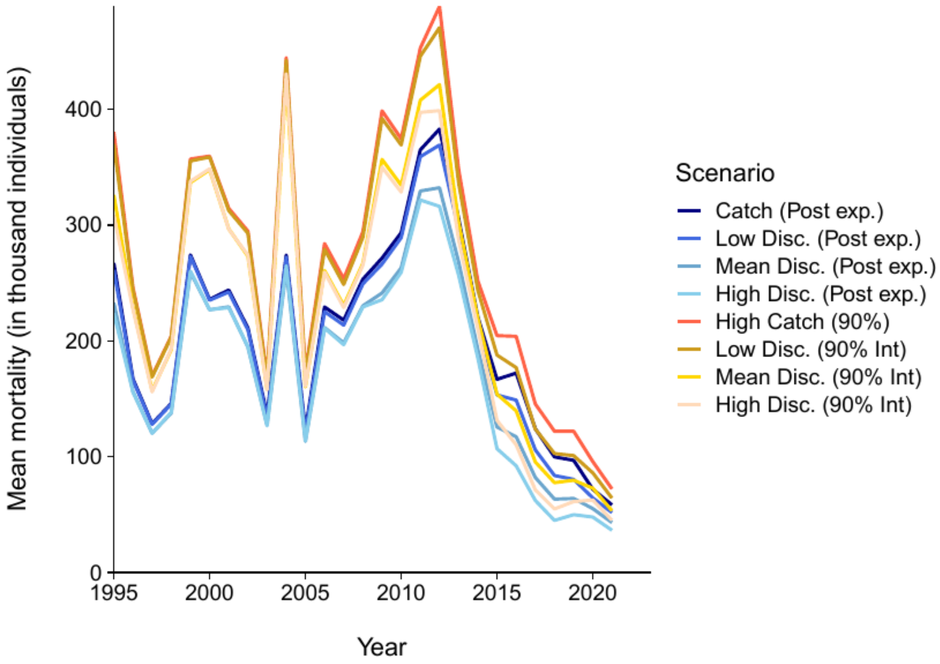

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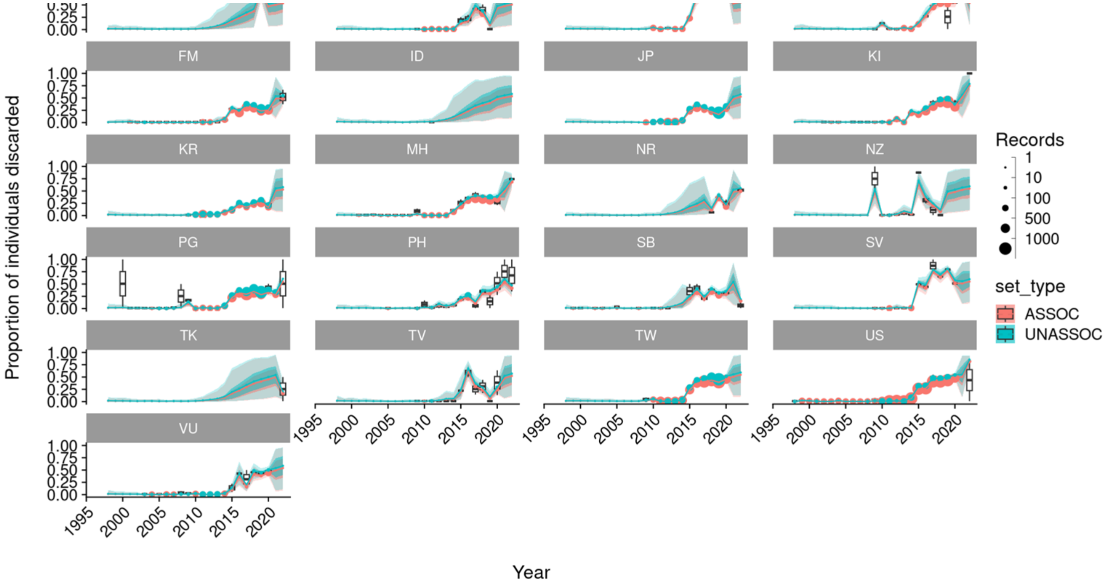

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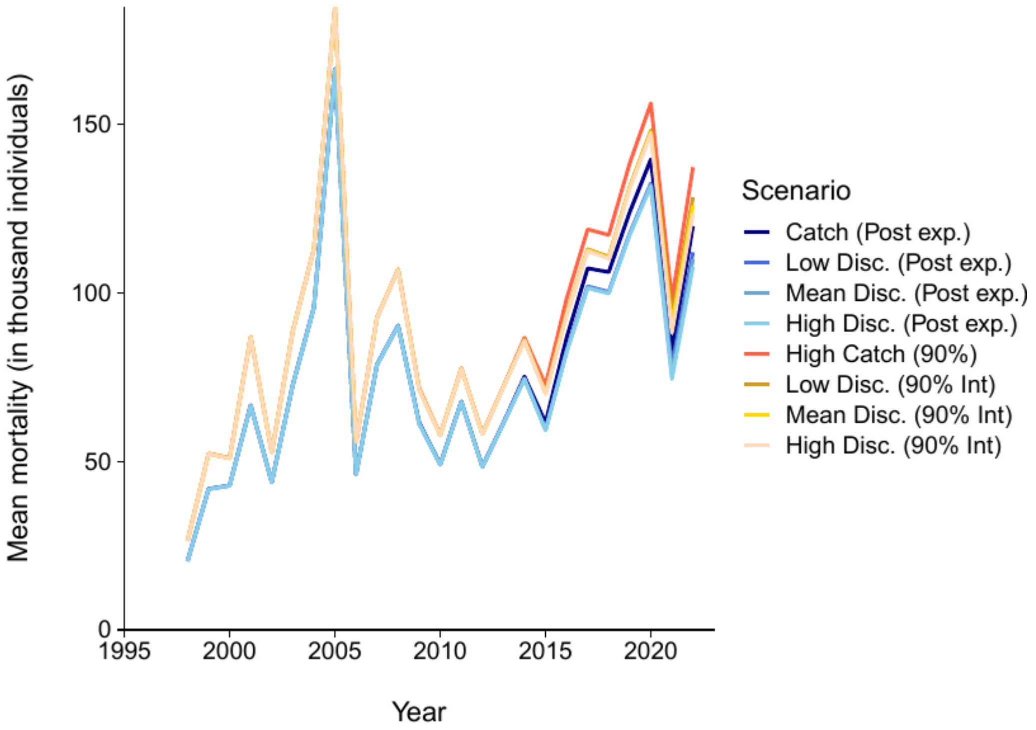
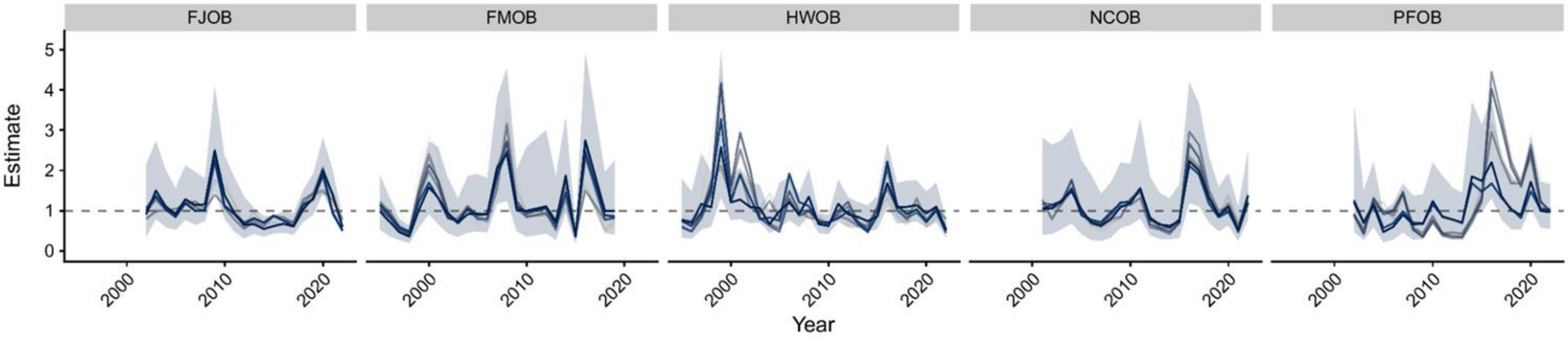


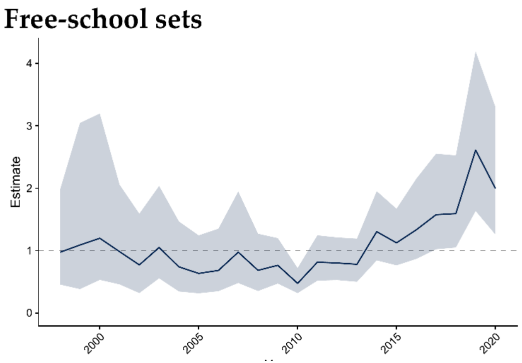
CPUE

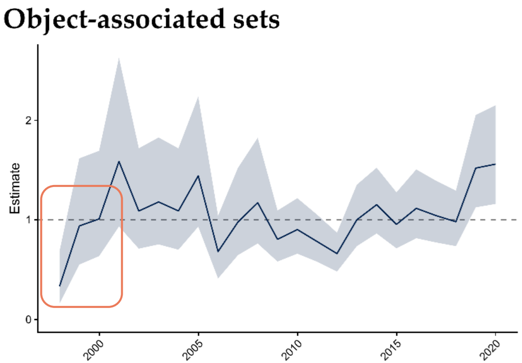
- Previous models used longline CPUE:
    - Inconsistent between assessments
    - Inconsistent between regions, very sensitive to inclusion of particular datasets

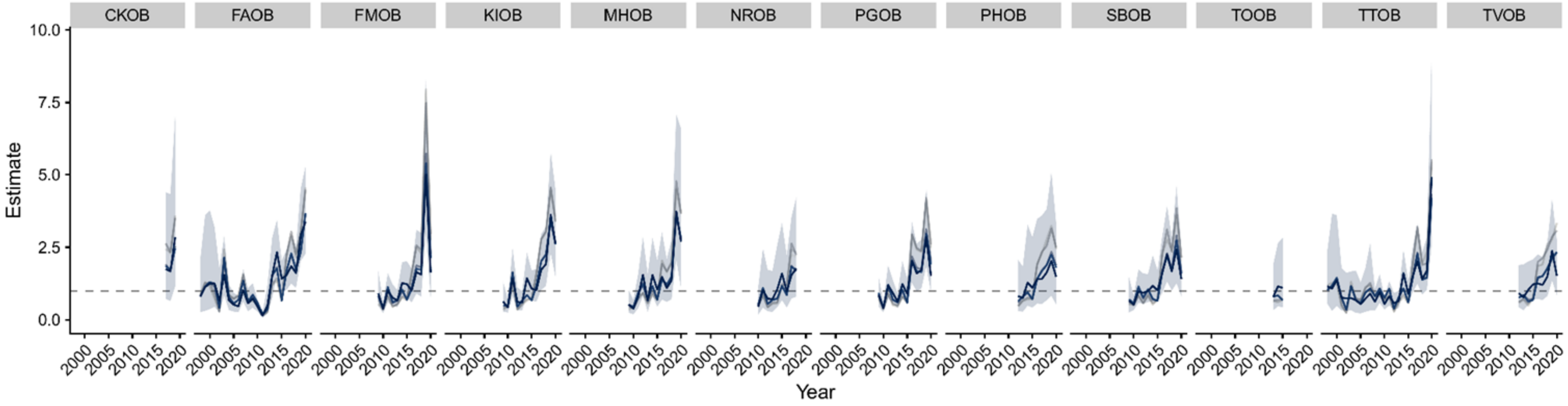


CPUE

- PS CPUE is very consistent, shows recent increase;
- High obs coverage means much more representative sample
- Standardisation by







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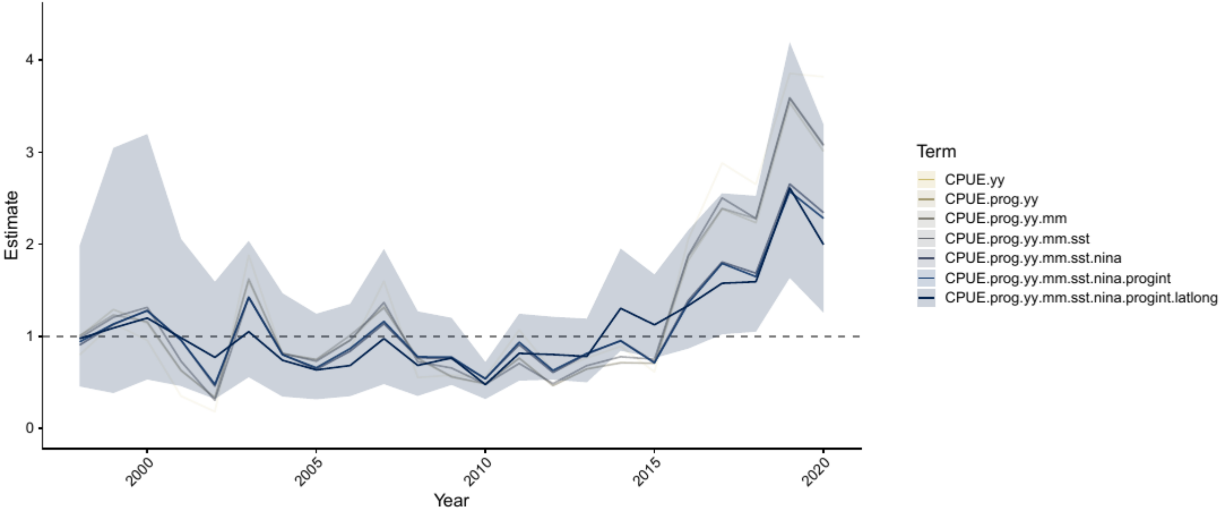

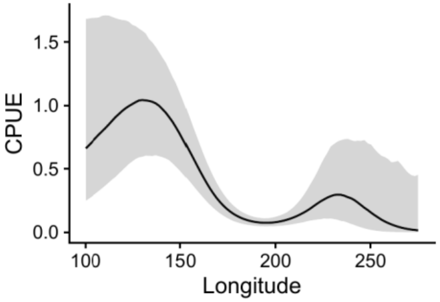

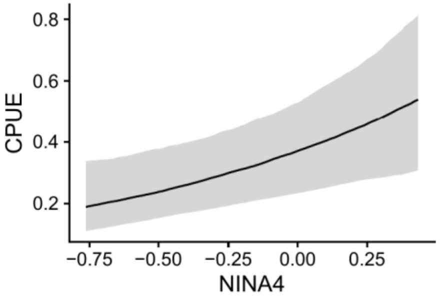

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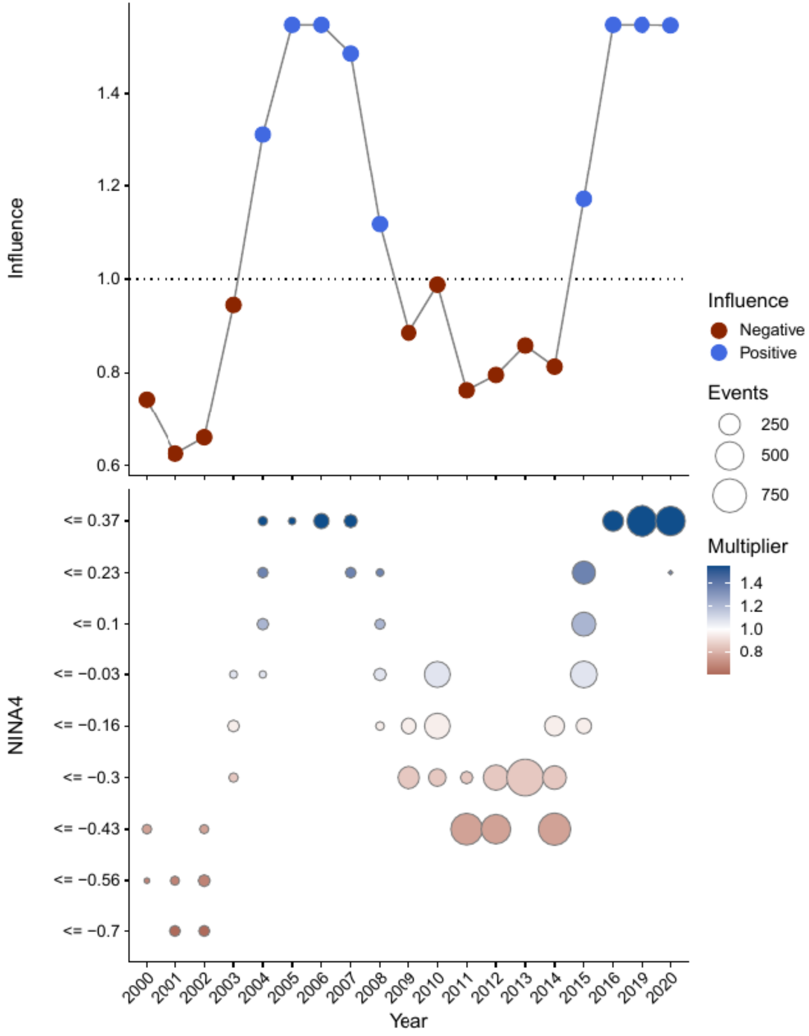

CPUE

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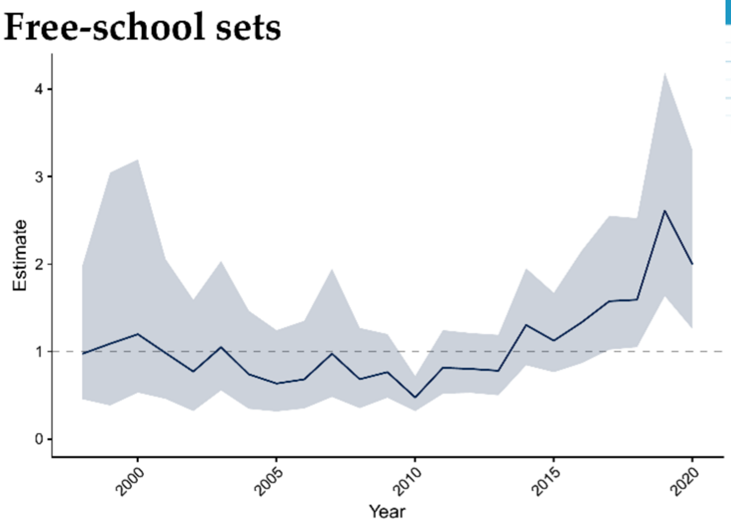
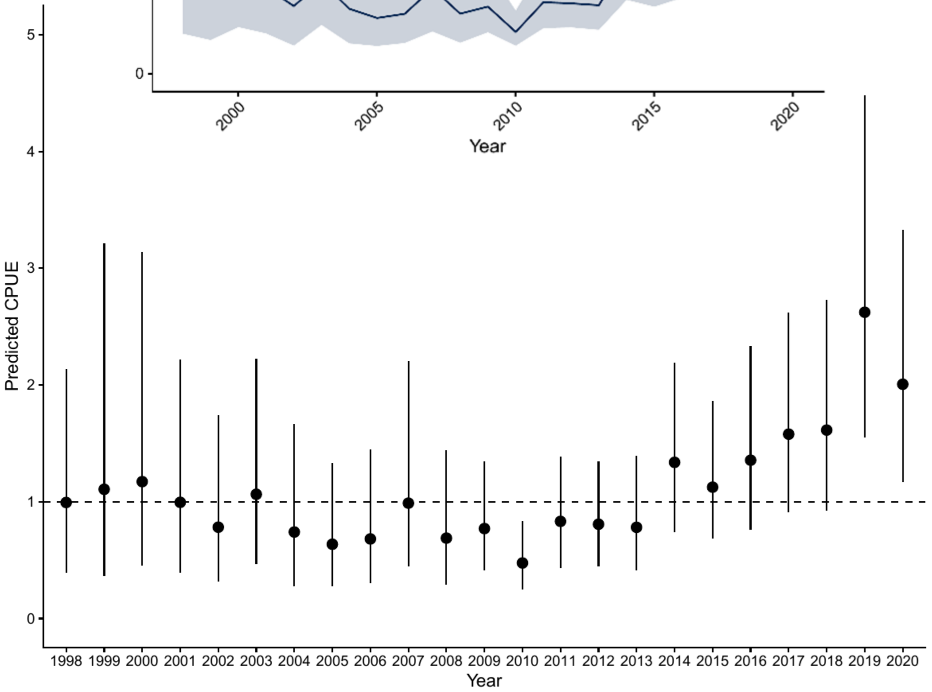
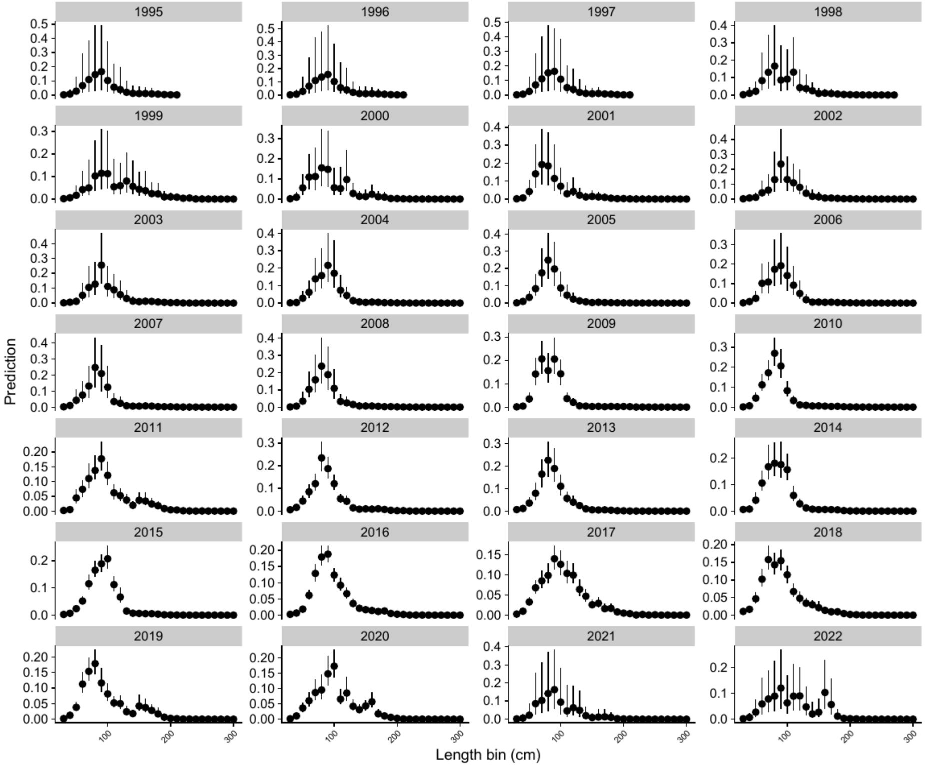
- High obs coverage means much more representative sample
- Standardisation by spatial and ENSO terms
- Spatio-temporal model with lat-long-year effect tested to understand if effects due to inconsistent spatial coverage of the fleet
- Index produced by predicting lat-lon-year effect over a consistent area
- Index near identical to original index



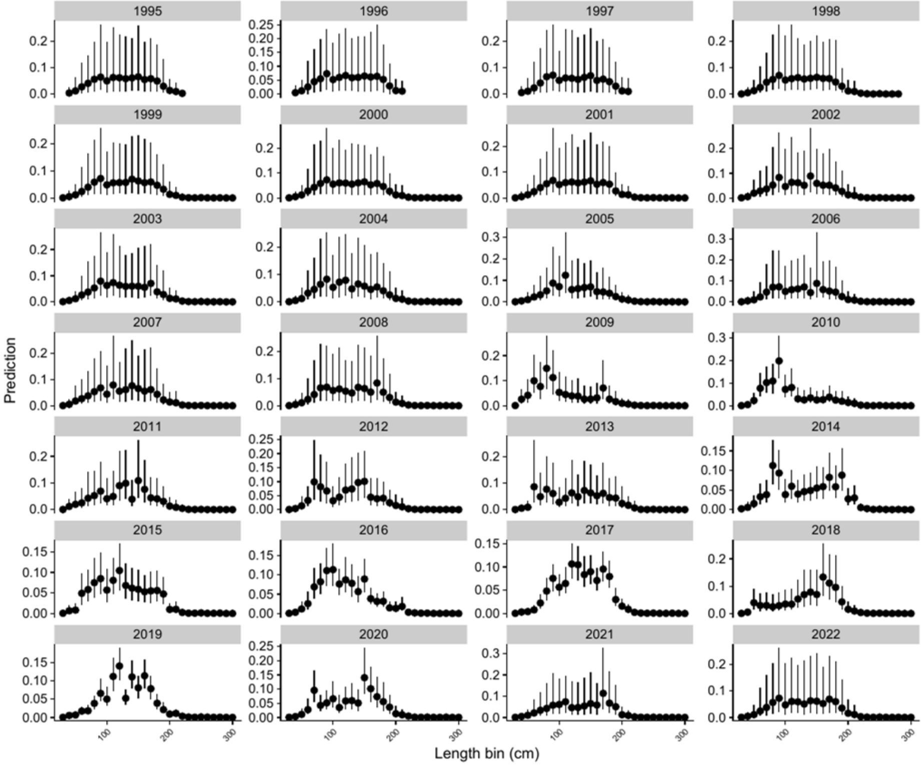


Scaled LFs - catch

Purse-seine: Object-associated



Purse-seine: Free-school



Scaled LFs - CPUE

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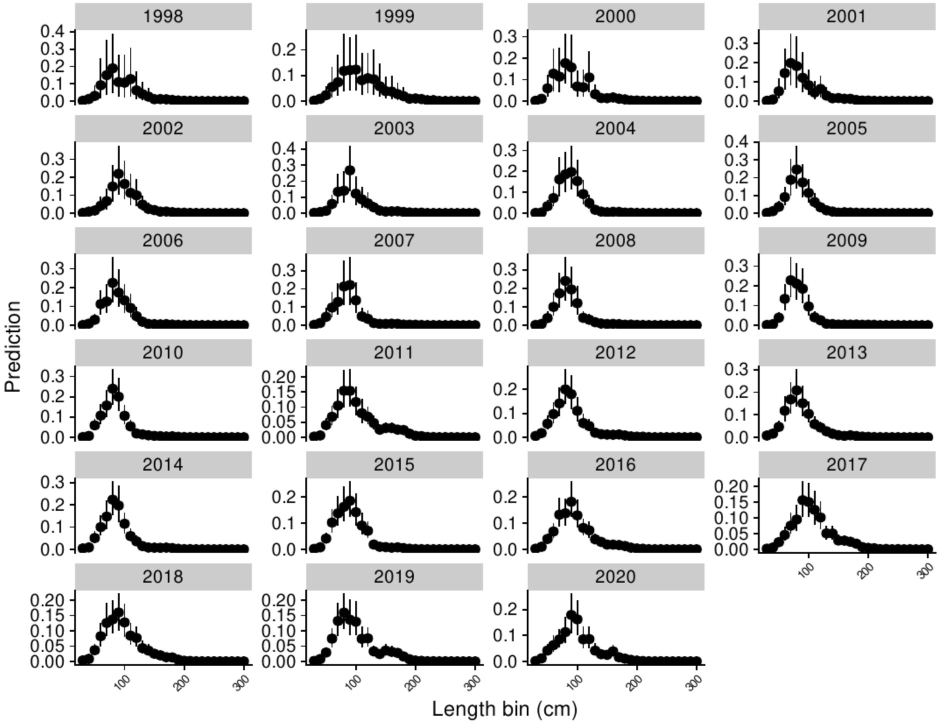

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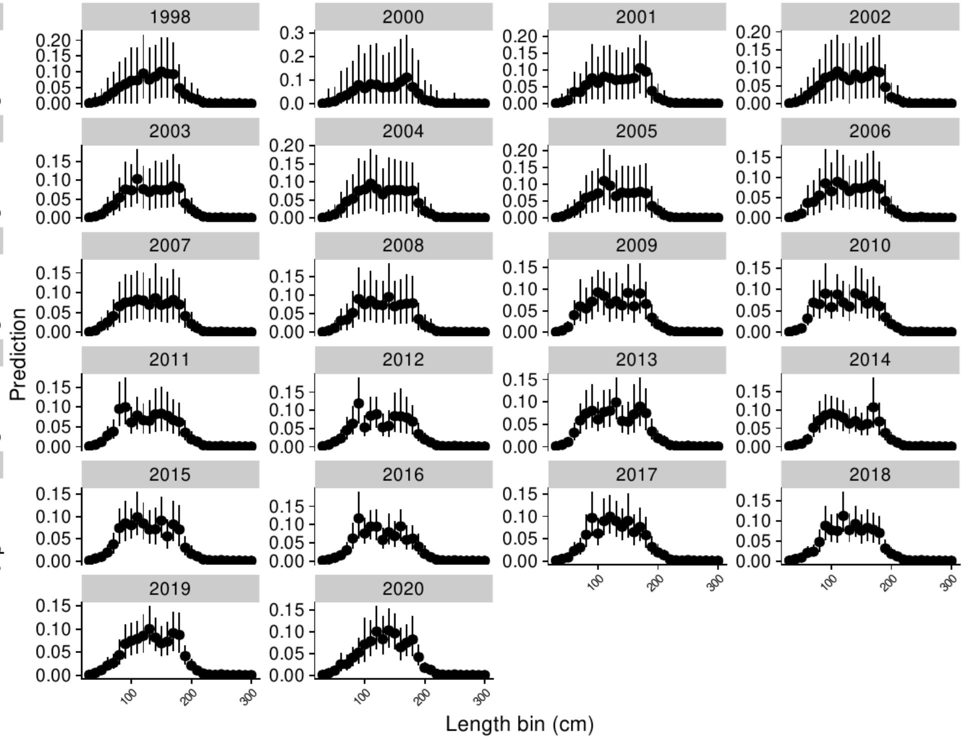
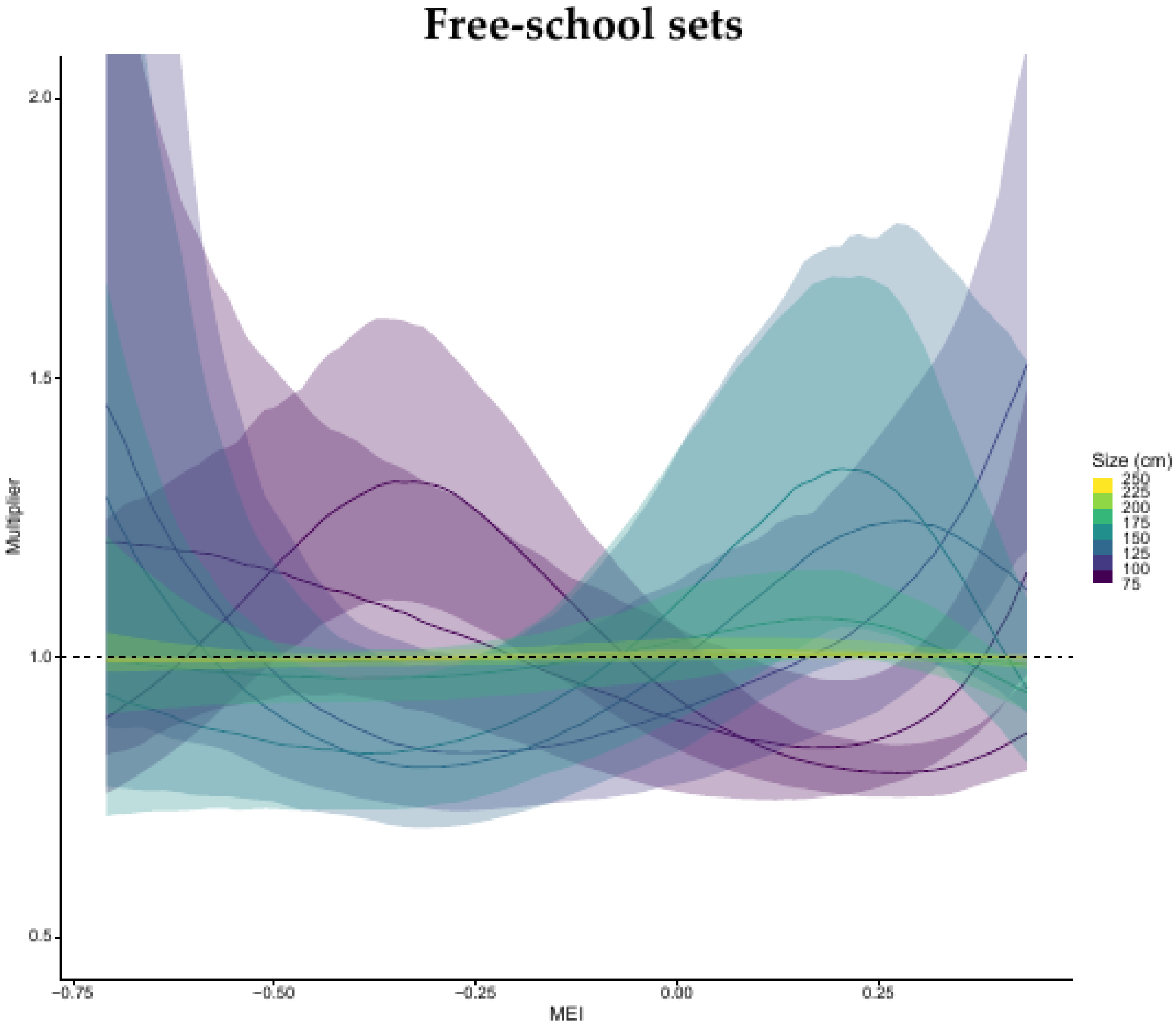


Scaled LFs - CPUE

- Clear ENSO effect on size compositions



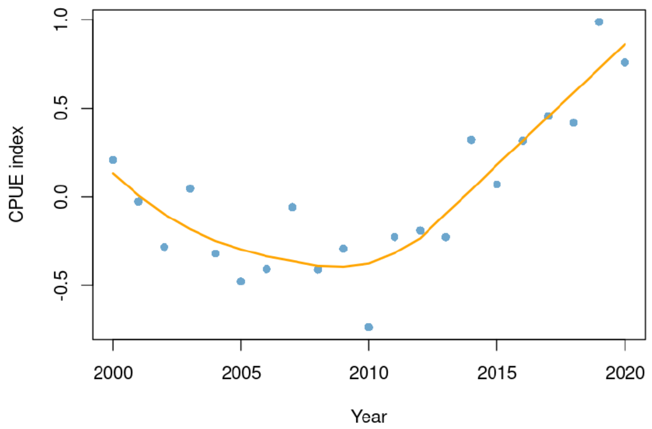
2024 Assessment: Stock synthesis

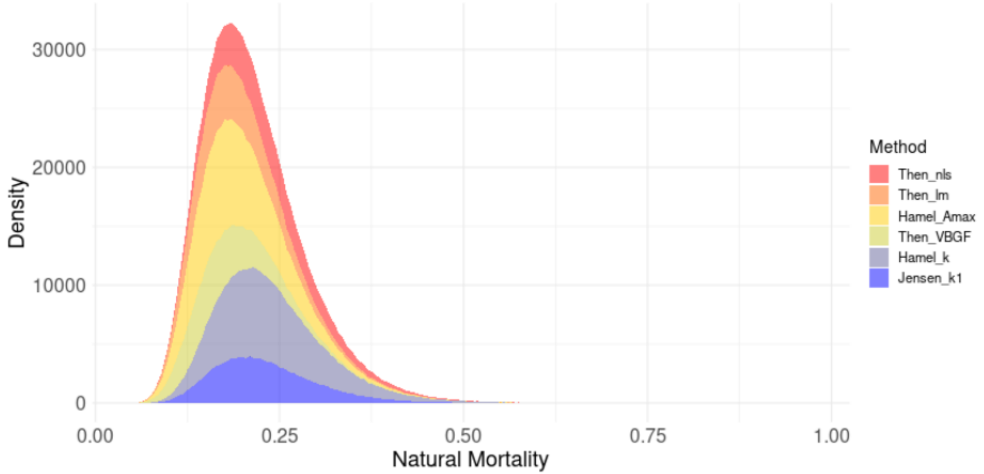
Model setup

- CPUE:
  - Free-school purse-seine used to fit model,
  - Object associated (juvenile fish only) not fitted but compared with model predictions
- LFs:
  - Capture fisheries (Longline, Purse Seine x2)
  - Index fisheries - free-school and object associated purse-seine

Model setup

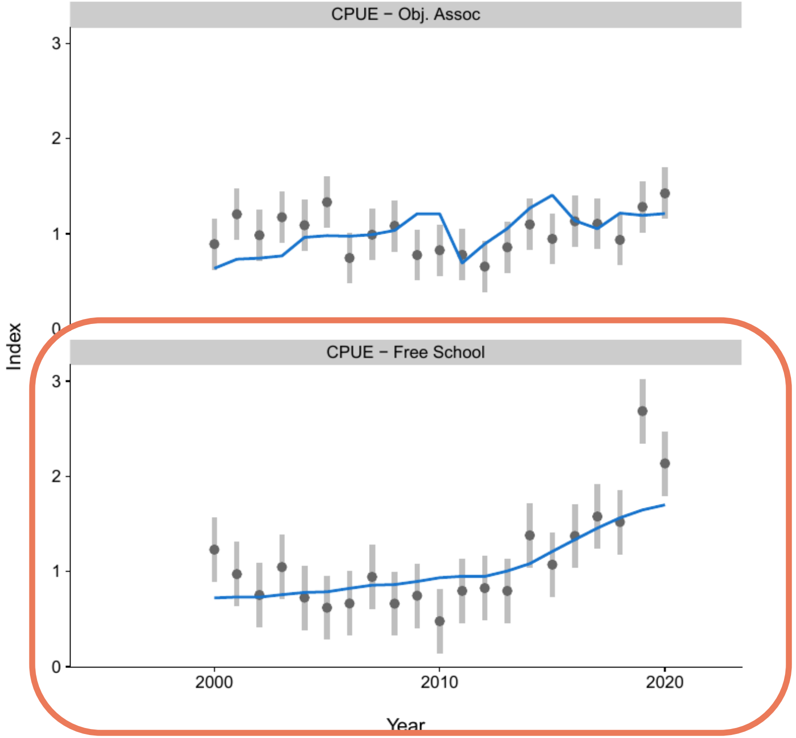
- Capture fishery LFs fitting using time-varying selectivities (2DAR)
- Index fishery LFs use constant selectivity
- CPUE/LF weighted using Francis (2011) method (not converging)
- M estimated from informed prior derived from meta-analysis with relatively high SD (0.2)
- Stock recruitment used survival-based function with estimated degree of over-compensation (BH did not work)





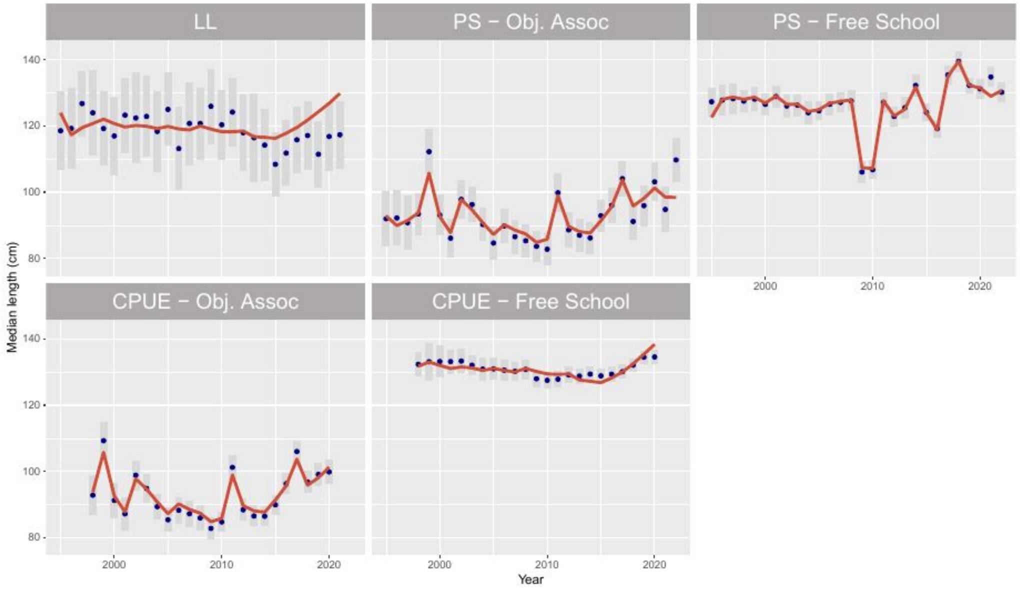
SS model fits

- Model fits to CPUE are not great



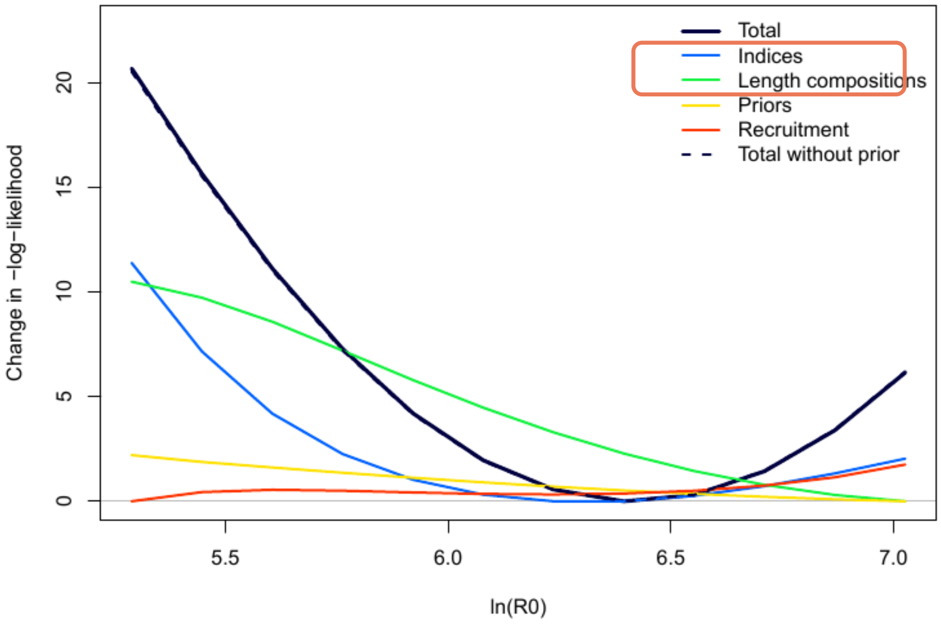
SS model fits

- Model fits to CPUE are not great
- Fits to Length Compositions are good except for LL



SS model diagnostics

- Model fits to CPUE are not great
- Fits to Length Compositions are good except for LL
- R0 and M were well-estimated, but conflict between length-comps and index.
    - Indices suggest smaller R0 and M than LFs



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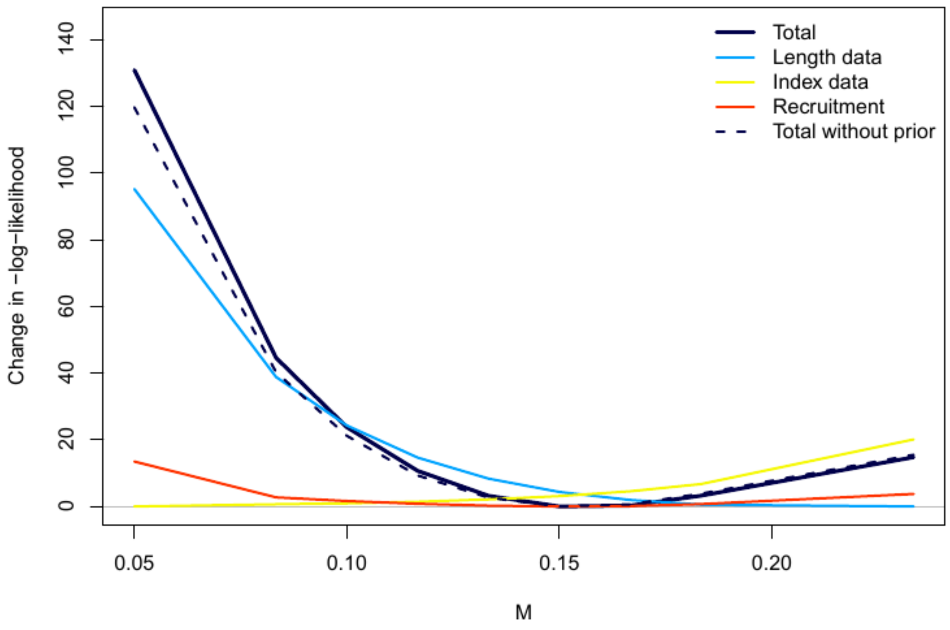

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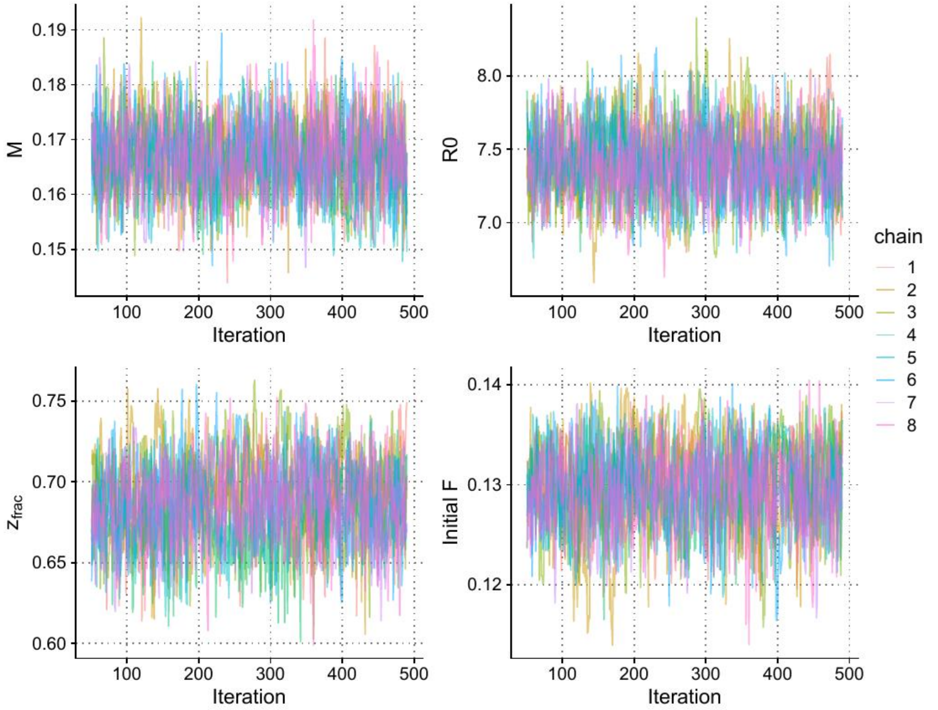
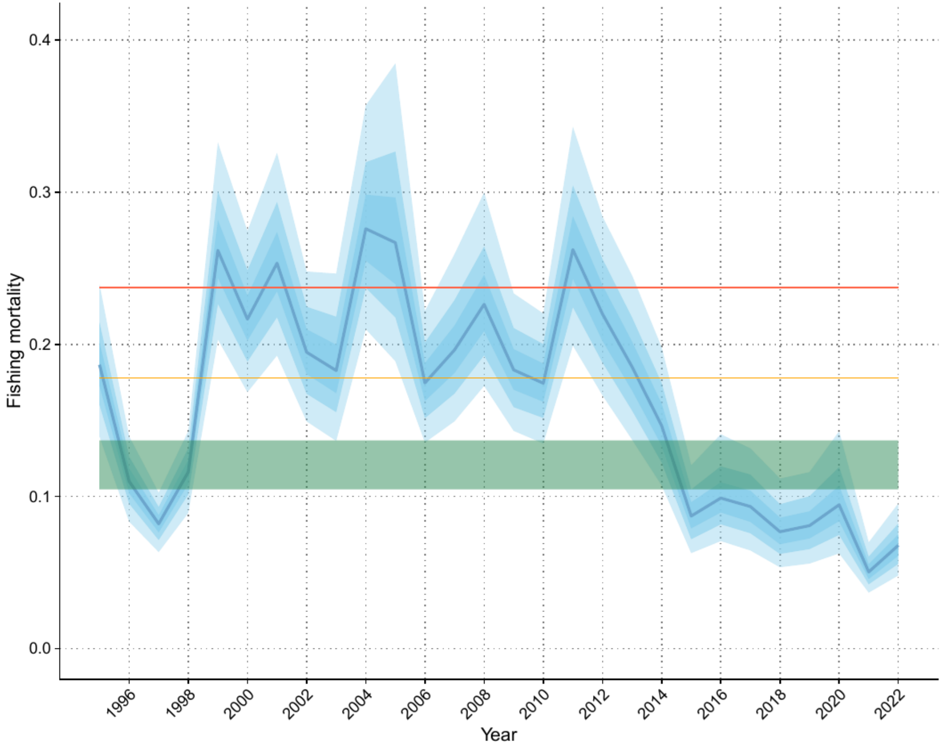
- Fits to Length Compositions are good except for LL
- R0 and M were well-estimated, but conflict between length-comps and index.
    - Indices suggest smaller R0 and M than LFs
- MCMC attempts led to poor MCMC for most models (divergent transitions), few for base model
- Divergences linked to time-varying selectivity - model cannot fit LFs without it



SS model outputs

- Model estimates declining fishing mortality, to below F_{MSY}



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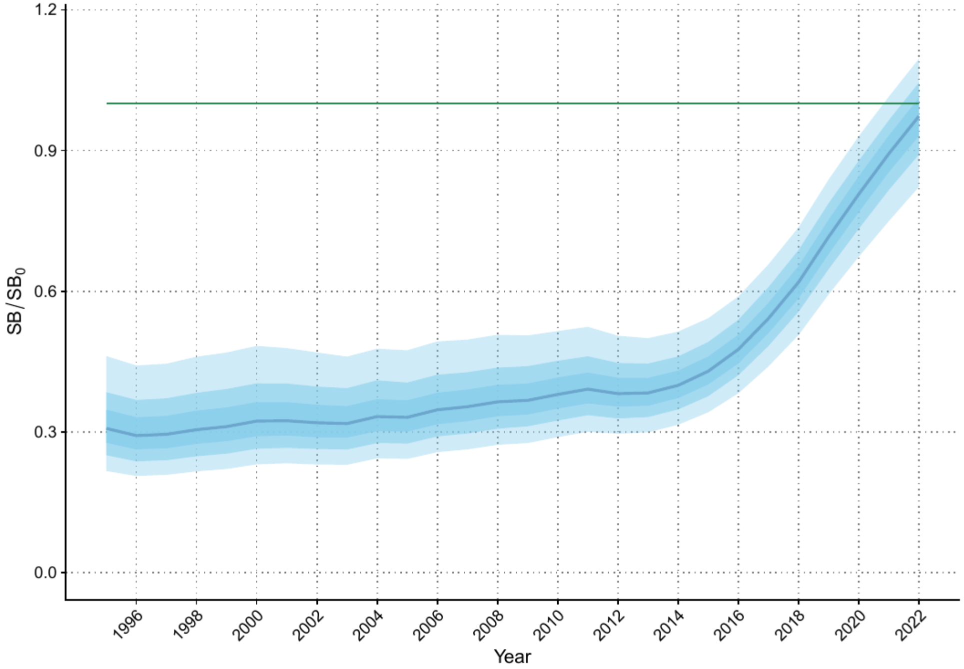
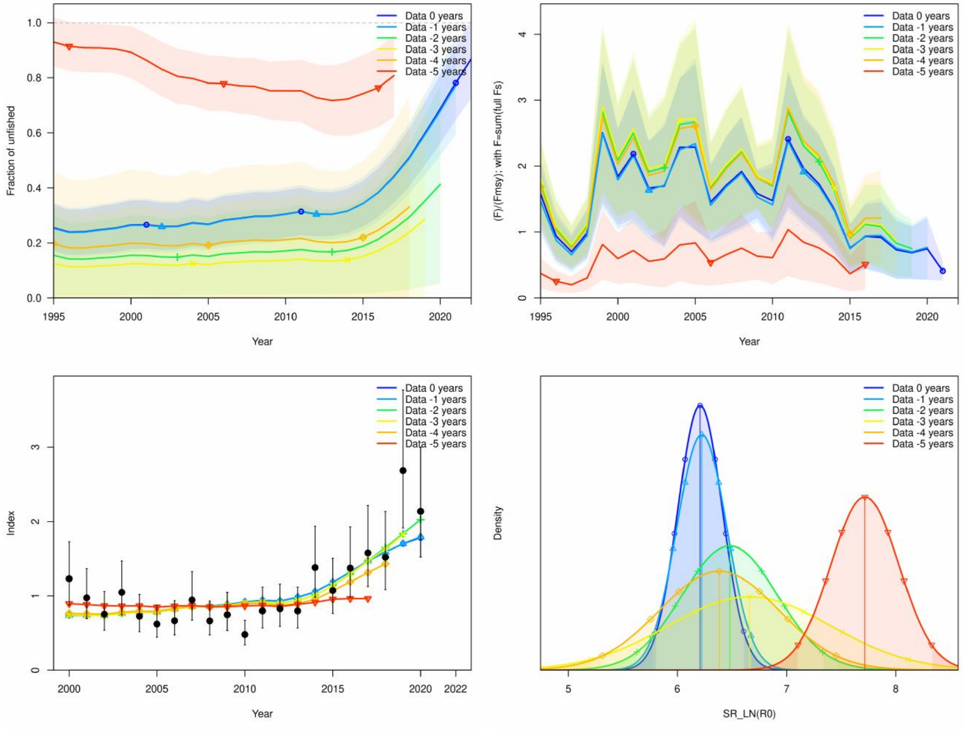
- Model estimates declining fishing mortality, to below F_{MSY}
- Increasing stock status to near B_0 in recent years



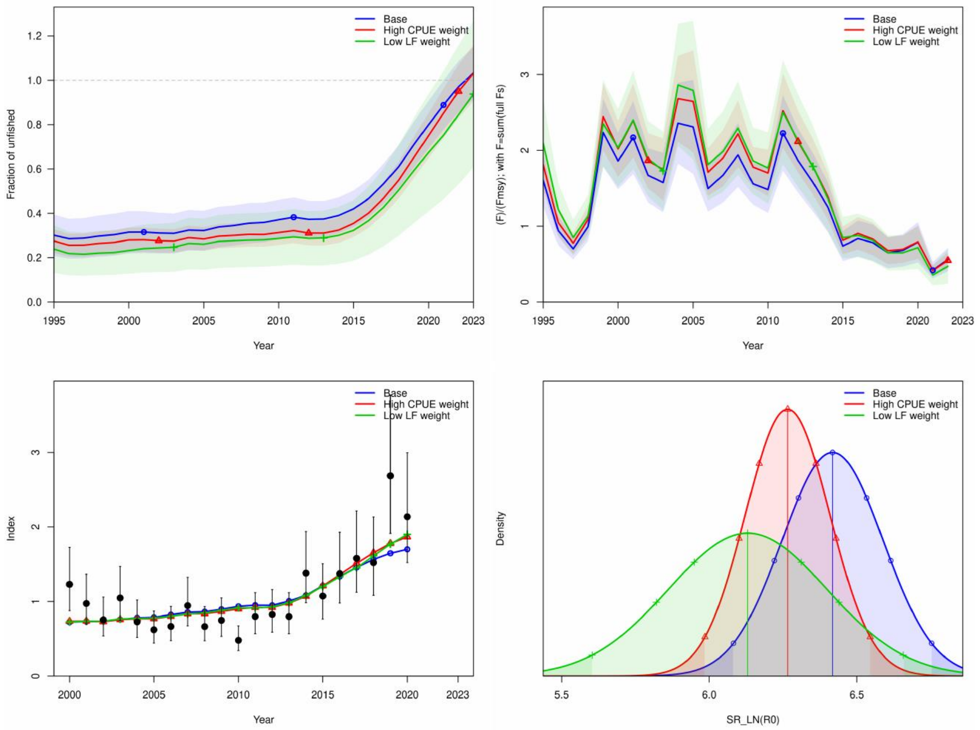
SS model outputs

- Model estimates declining fishing mortality, to below F_{MSY}
- Increasing stock status to near B_0 in recent years
- Retrospectives show that recent information contributes to status estimates



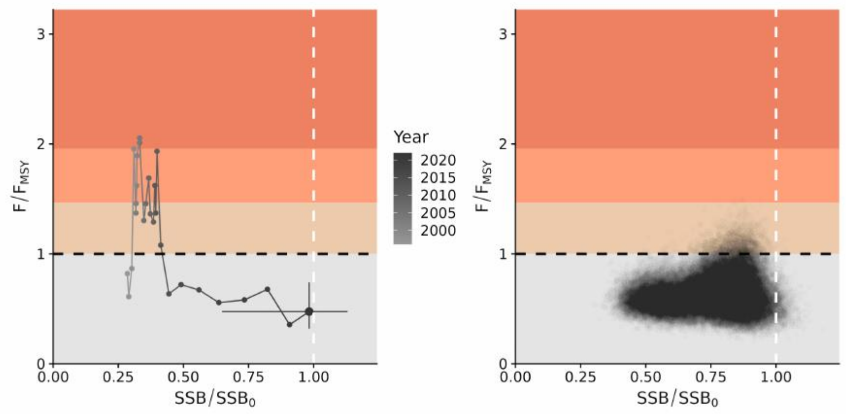
SS model outputs

- Model estimates declining fishing mortality, to below F_{MSY}
- Increasing stock status to near B_0 in recent years
- Retrospectives show that recent information contributes to status estimates
- Data weighting does not change the picture appreciably



SS model summary

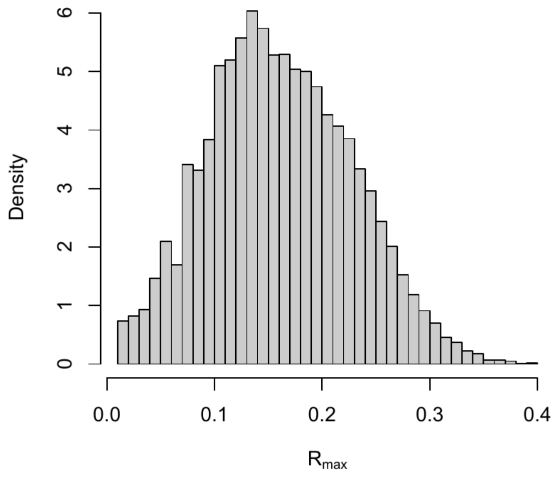
- All models showed recent increase in biomass and reduction in fishing mortality
- Data conflict and CPUE fit suggests some work needs to be done to improve the model
- Poor MCMC performance and non-convergence of data weighting a concern. May require further investigation of time-varying selectivity in these regards.

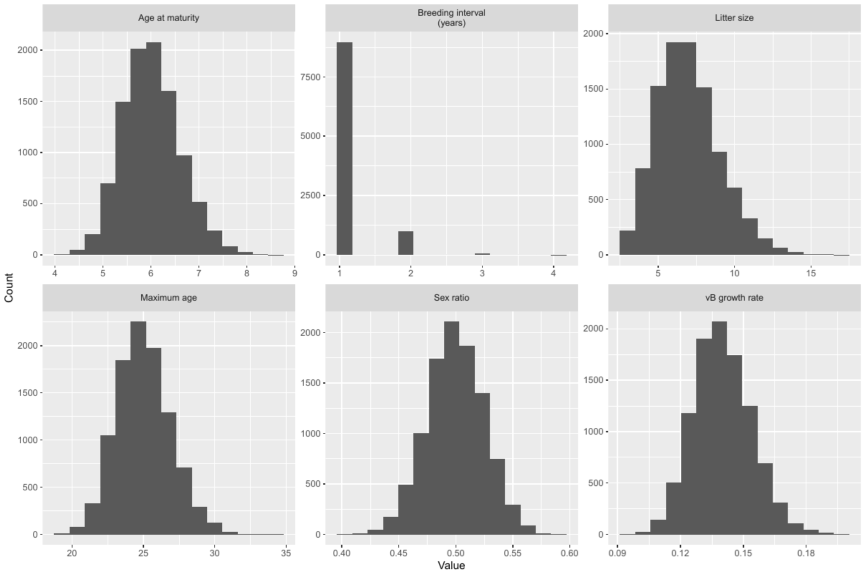


2024 Assessment: Dynamic surplus production model (DSP)

DSP model

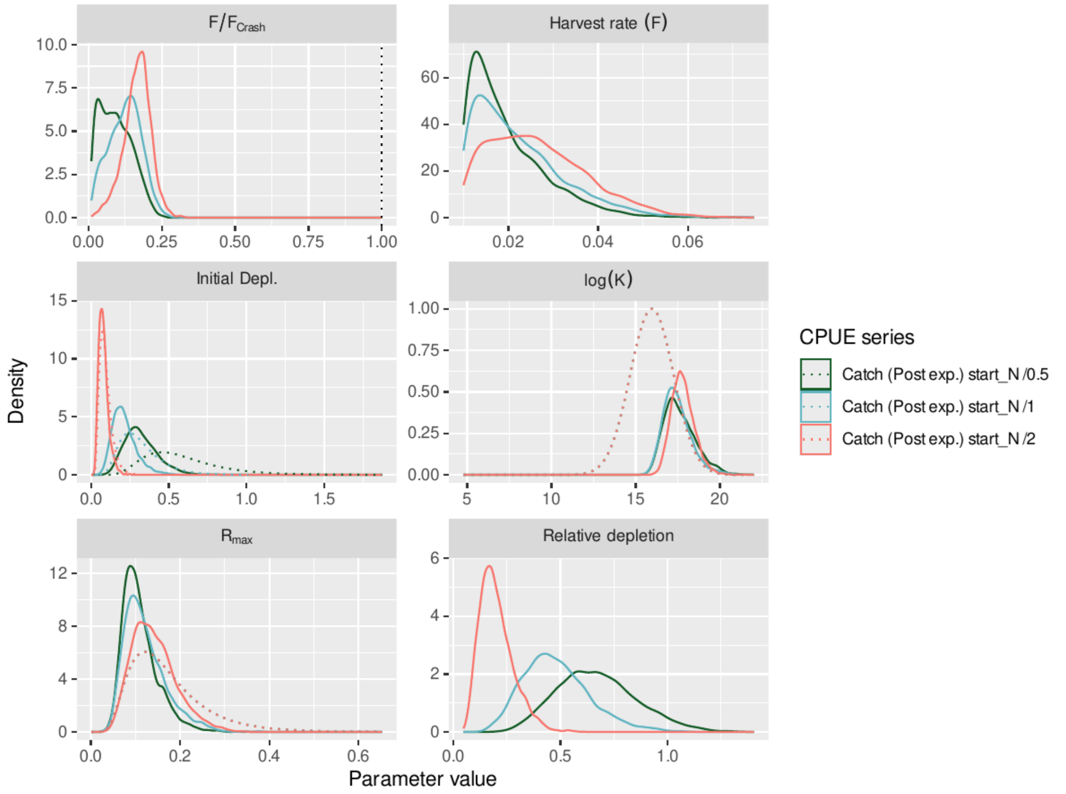
- R_{max} prior derived from meta-analysis as done for previous shark assessments





DSP model

- R_{max} prior derived from meta-analysis as done for previous shark assessments.
- Model fitted to CPUE index with same observation error as for SS assessment.
- Three alternative prior distributions for initial depletion .



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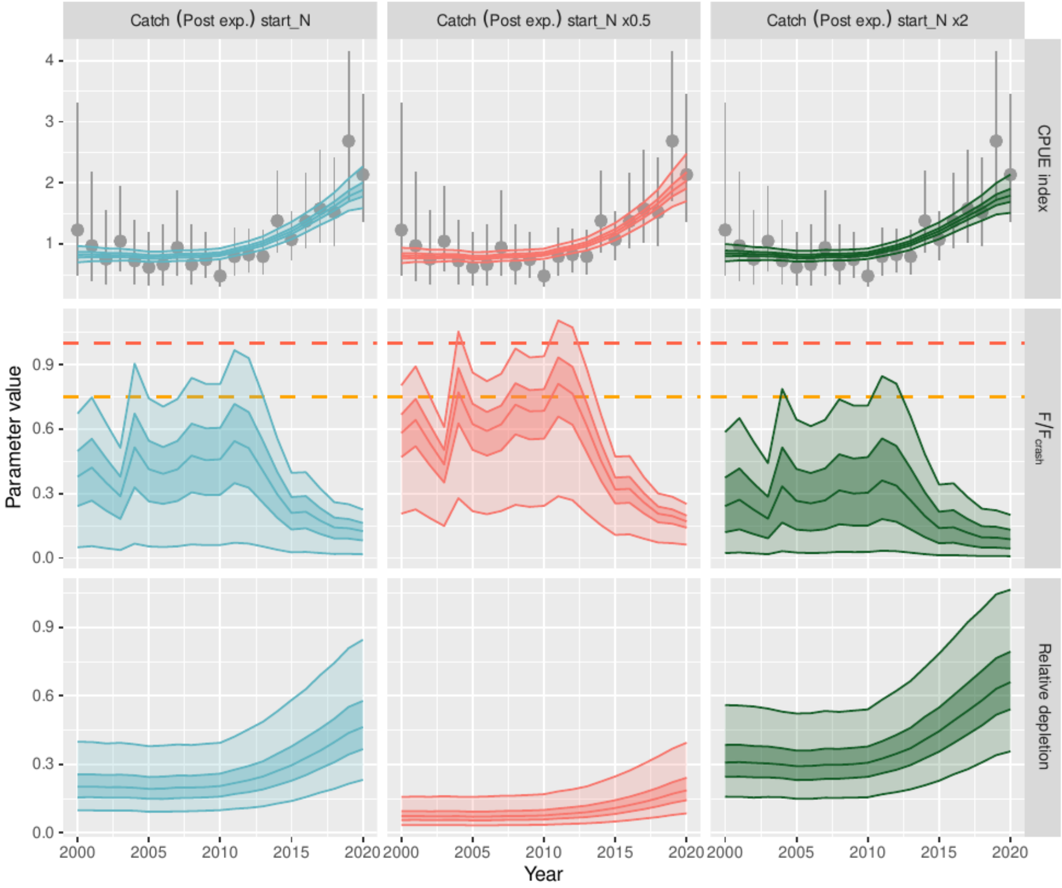

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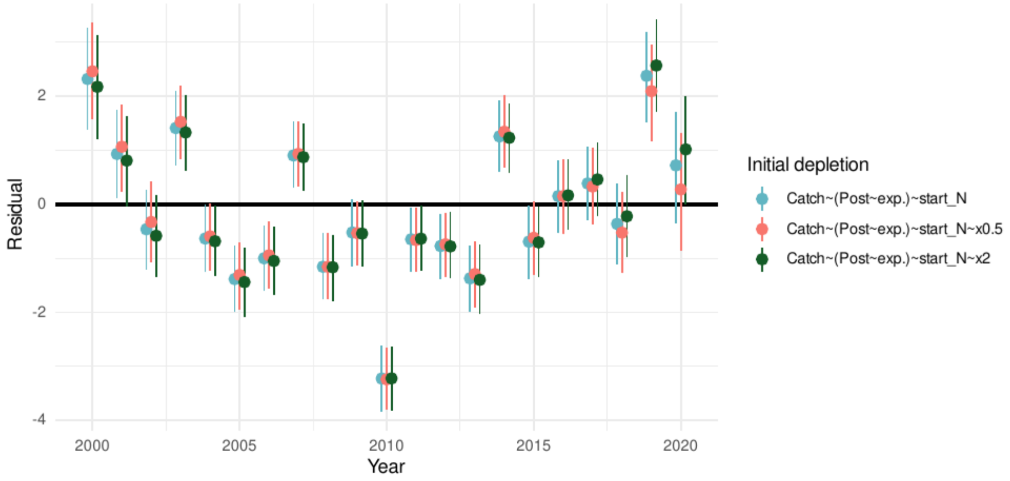
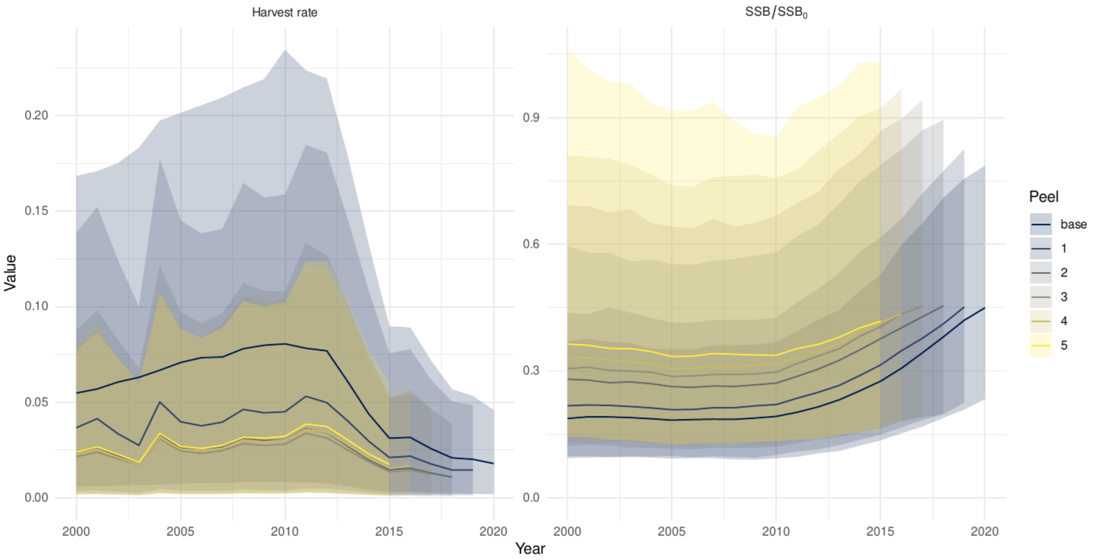


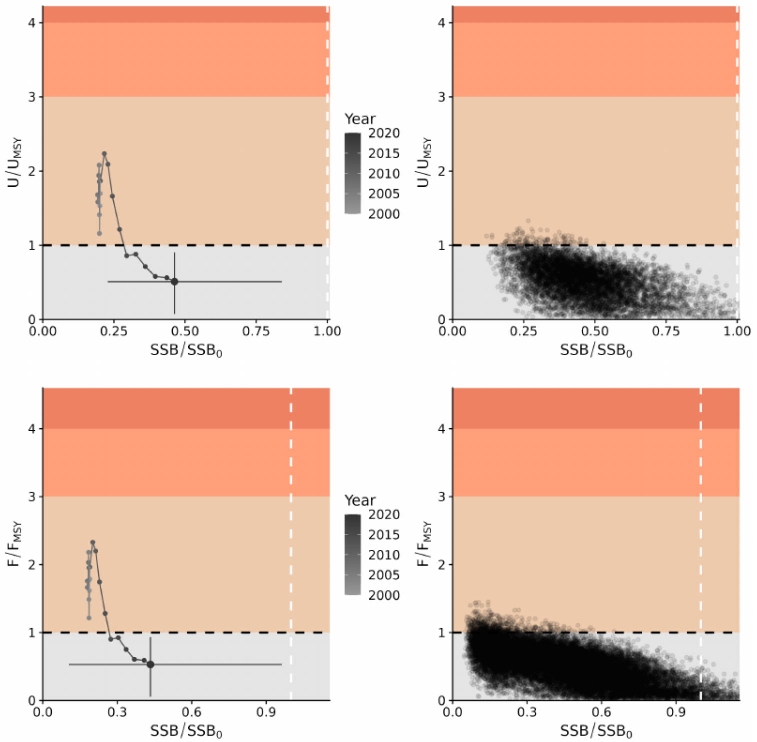
DSP model

- R_{max} prior derived from meta-analysis as done for previous shark assessments
- Model fitted to CPUE index with same observation error as for SS assessment.
- Three alternative prior distributions for initial depletion
- Retrospectives suggests increasing amount of information from recent increase - high uncertainty in past estimates contains more recent estimates



DSP model outcomes

- High uncertainty about recent stock status
- Low uncertainty about recent fishing mortality being below U_{MSY} and potential limit reference points



2024 Assessment: Length and age-structured model (LAM)

Rationale for LAM Development

- Conventional length-based age-structured models (e.g., SS3 and MULTIFAN-CL) often assume time-invariant age-specific length distributions:
  - However, if large individuals are selectively removed by fishing, the surviving populations will become dominated by slower-growing individuals.
  - Incorporating the cumulative impact of size-selective mortality using age-structured dynamics is challenging without introducing additional parameters (e.g., the platoon approach in SS3).

- Cumulative impacts of size-dependent mortality can be substantial, particularly for species with low fecundity and late maturation, such as sharks.

- Combining length-based dynamics with age structure can provide a more realistic representation of population dynamics by incorporating the cumulative impacts of length-dependent processes while tracking the age structure.

LAM structure

- Within each age group, LAM follows length-structured dynamics, where growth transitions are age-specific (i.e., **G** in the equations) due to age-specific growth variability.
  - Only surviving individuals within each age group, where mortality is length-dependent, can transition to the next time step with increments in both length and age.
- The model was developed in `Stan`:
  - Other submodel structures follow those in SS3 (e.g., growth, stock-recruitment, etc.)
  - A catch-conditioned approach, similar to that in MULTIFAN-CL (i.e., no error in catch), was also implemented.

Age-structured model

$$N_{t,a} = \begin{cases} R_t & \text{for} \quad a = 0 \\ S_{t-1,a-1}N_{t-1,a-1} & \text{for} \quad 0 < a < A \\ S_{t-1,a-1}N_{t-1,a-1} + S_{t-1,a}N_{t-1,a} & \text{for} \quad a = A \end{cases}$$

+

Length-structured model

$$\mathbf{N}_t = \mathbf{G}\mathbf{S}_{t-1}\mathbf{N}_{t-1} + \mathbf{R}_t$$

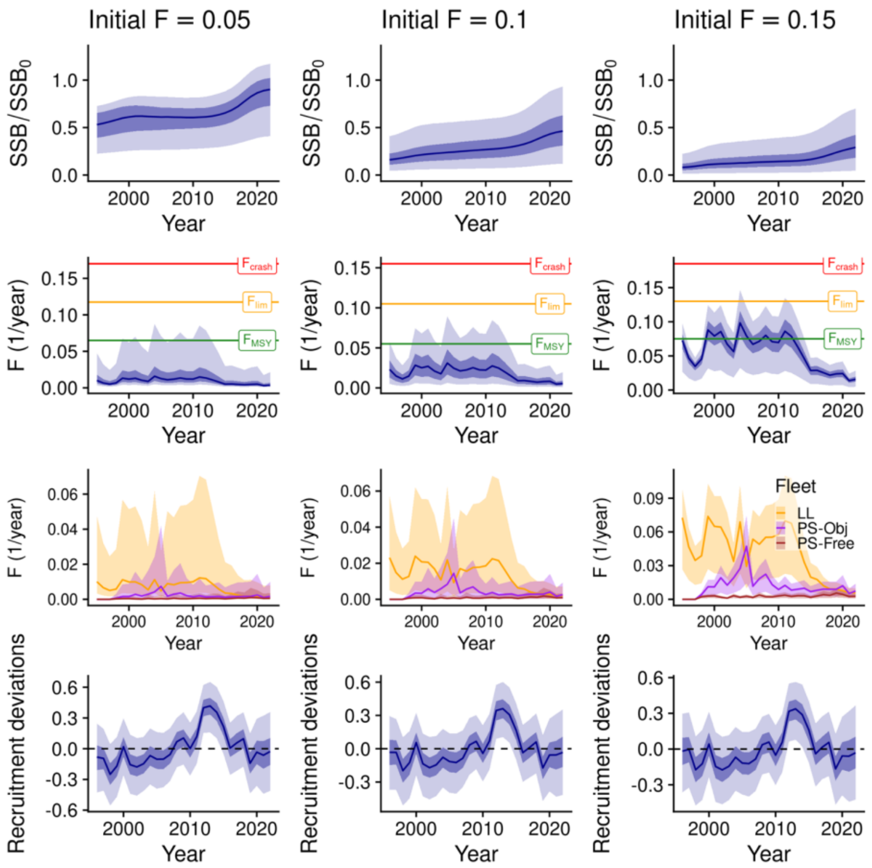
Length and age-structured model

$$\mathbf{N}_{t,a} = \begin{cases} \mathbf{R}_t & \text{for} \quad a = 0 \\ \mathbf{G}_{a-1}\mathbf{S}_{t-1}\mathbf{N}_{t-1,a-1} & \text{for} \quad 0 < a < A \\ \mathbf{G}_{a-1}\mathbf{S}_{t-1}\mathbf{N}_{t-1,a-1} + \mathbf{S}_{t-1}\mathbf{N}_{t-1,a} & \text{for} \quad a = A \end{cases}$$

Results

- The models were sensitive to assumptions on initial F values but generally showed **increasing trends in stock status** and **decreasing trends in fishing mortality**, similar to those observed in the SS3 and the dynamic surplus production model results.

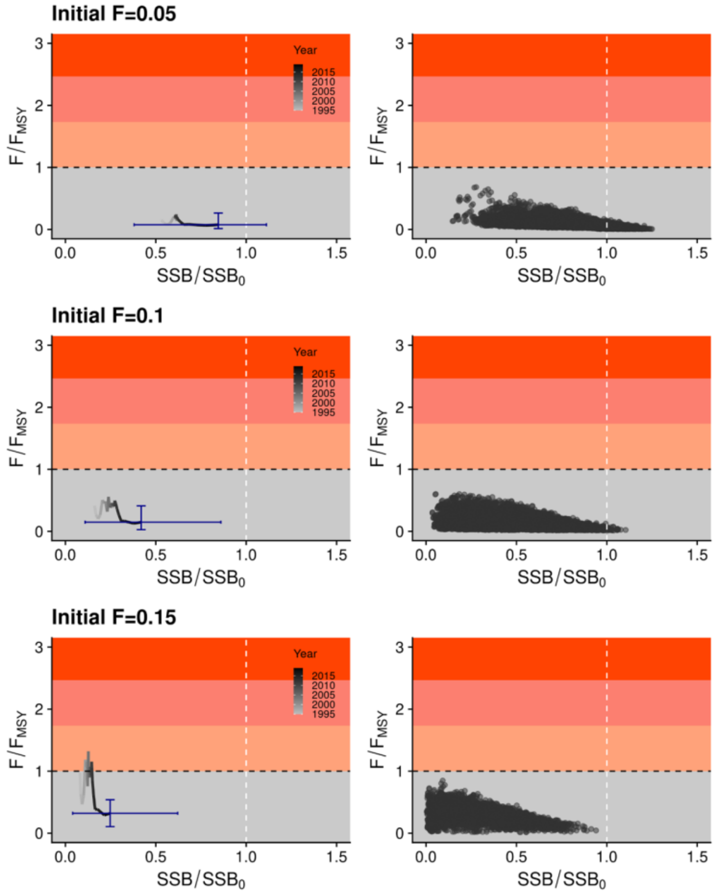
- For all three models, the longline fleet showed the highest fishing mortality rates, followed by purse-seine object-associated sets and purse-seine free-school sets (as shown in the panels in the third row)



Results

- The stock status in the recent two years (2019–2020) underwent lower fishing mortality rates than the corresponding FMSY across all three models.

- The model with the highest initial fishing mortality rate (init F = 0.15) showed the lowest stock status in the recent two years, approximately 25% of its unfished status, whereas the model with the lowest initial fishing mortality rate (init F=0.05) showed the highest stock status, around 90% of its unfished status.



Discussion

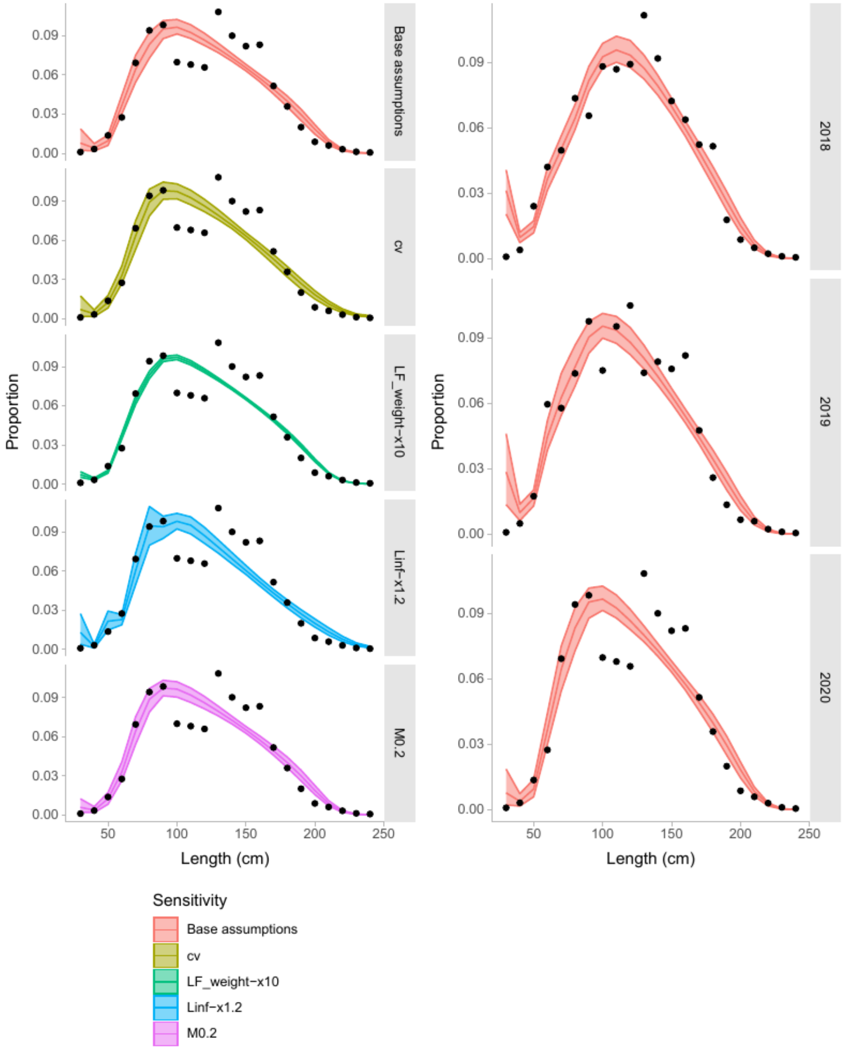
- The LAM uses the same number of parameters as the SS3 models, but provides a better representation of population dynamics, naturally incorporating the cumulative impact of fishing pressures on the length distribution of the population.
    - Although the complexity of the LAMs was not well supported by the current information on LFs and CPUE data, we believe that the model provides a useful avenue of research towards incorporating cumulative impacts of fishing pressure.

- A parameter for determining growth variability, which was fixed in the SS3 models, was estimated.
    - However, LF fits for some years were not satisfactory, indicating that further studies on spatio-temporal growth may be required to apply this type of integrated model.

2024 Assessment: Length-based hybrid spatial risk assessment model

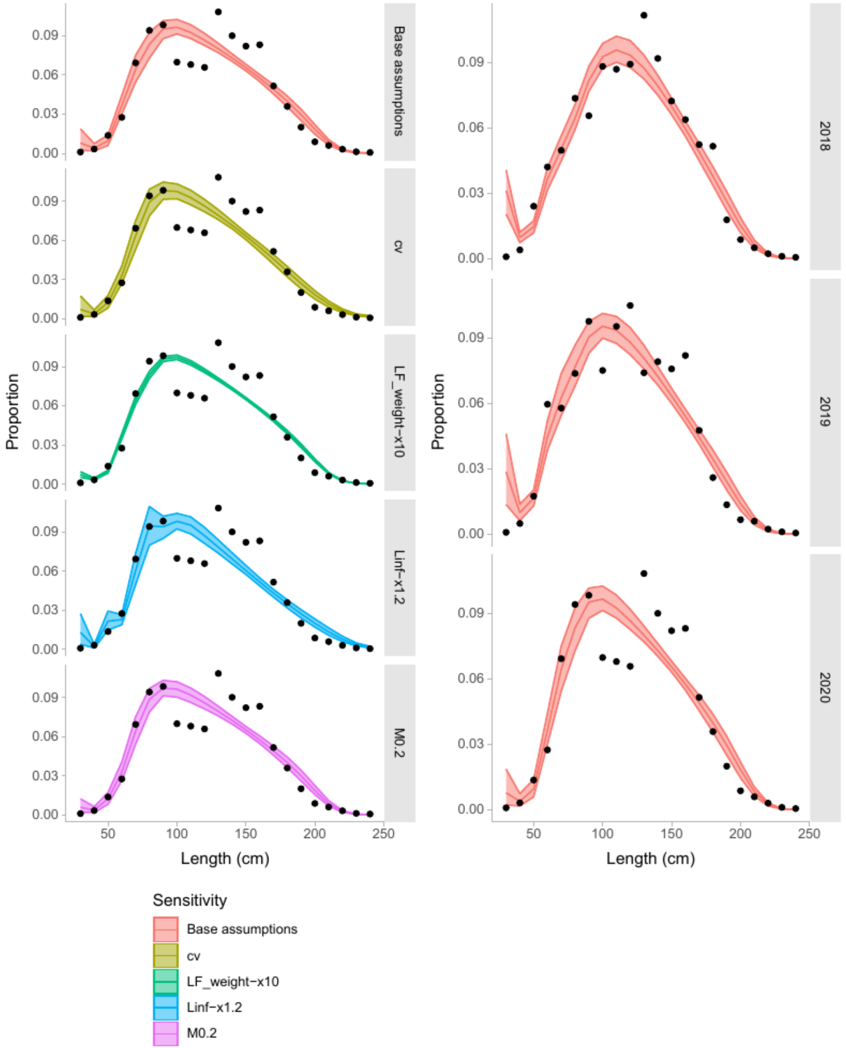
Summary

- Most risk assessment methods are assumption driven based on overlap with fishing effort and species life-history
- Statistical risk assessment approaches attempt to fit to data, but require information to scale from observed interaction to total fishing mortality and risk
    - Discussion at PAW - difficult for many stocks, especially for longline and purse-seine
    - If no reliable index, LF data can inform of status (assuming equilibrium with F).



Summary

- Hybrid method uses LFs to derive total fishing mortality, then partitions the mortality across fleets or areas.
- Requires representative LFs - used standardised LFs from purse-seine
- Custom model in Stan based on eSafe model used for OCS, but integrated estimation of F and spatial density of FAL.
- Data weight (LFs vs observed captures) largely affects uncertainty, but not location of estimates.



Summary

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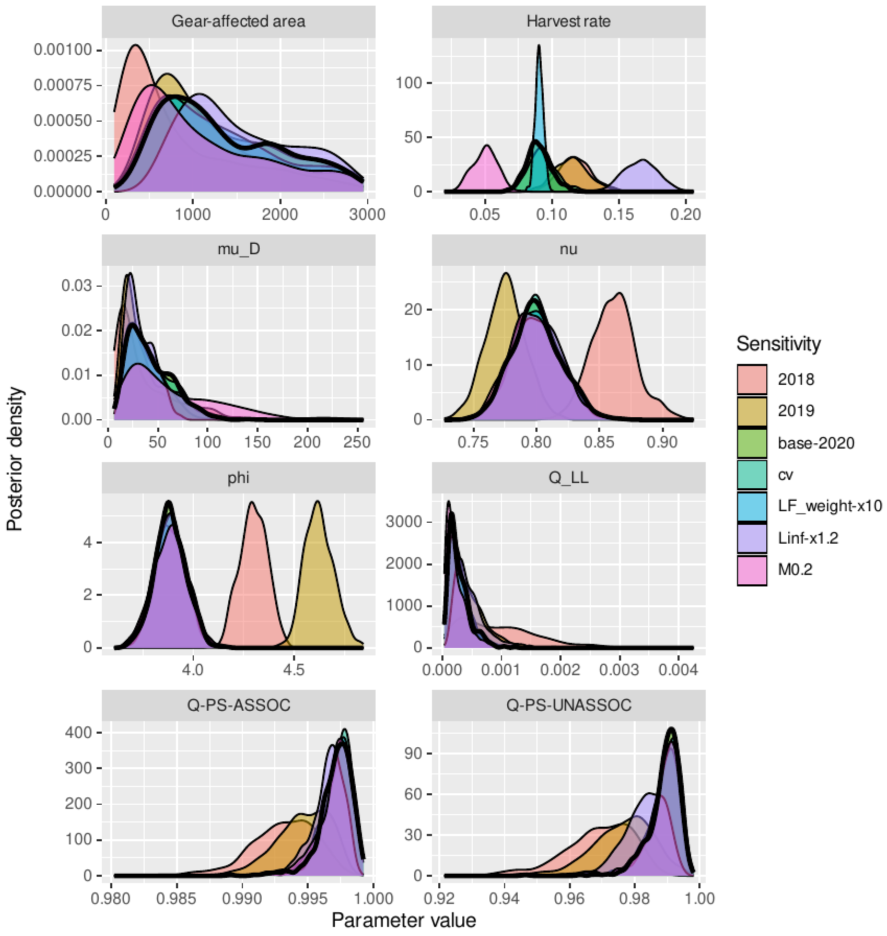
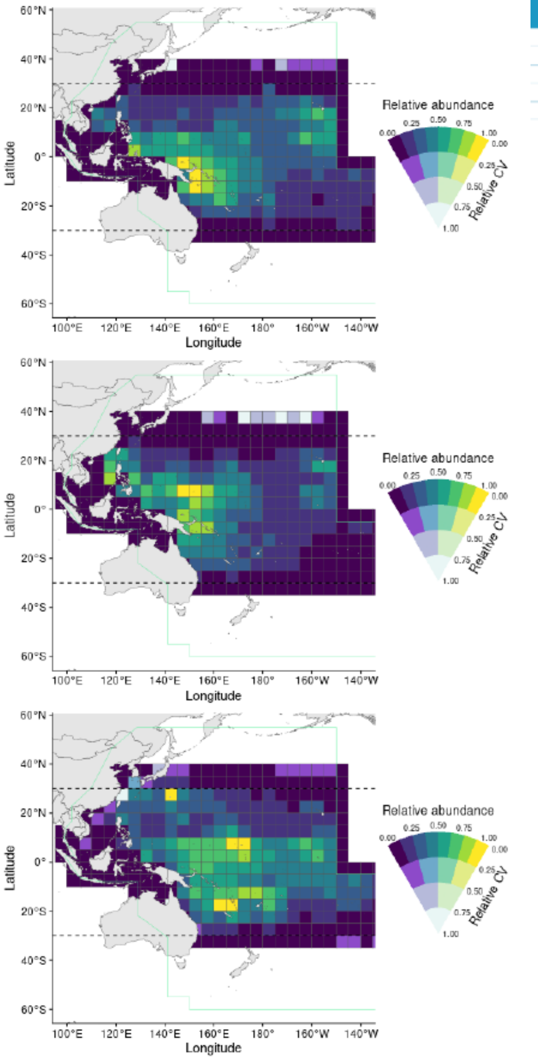
- Requires representative LFs - used standardised LFs from purse-seine
- Custom model in Stan based on eSafe model used for OCS, but integrated estimation of F and spatial density of FAL.
- Data weight (LFs vs observed captures) largely affects uncertainty, but not location of estimates.
- Sensitive to life-history assumptions



Summary

- Spatial harvest rate and relative density estimates are highly variable between years



Summary

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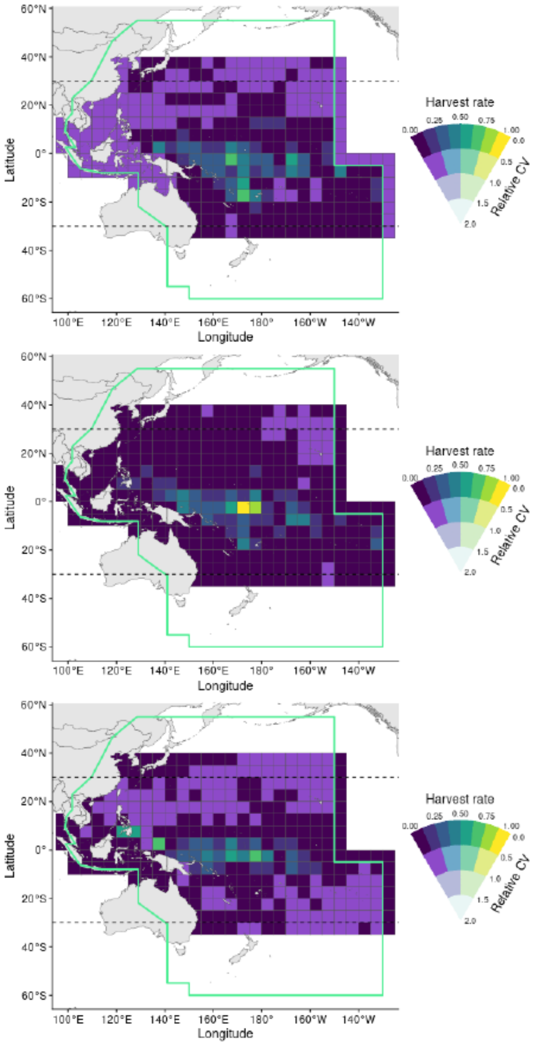
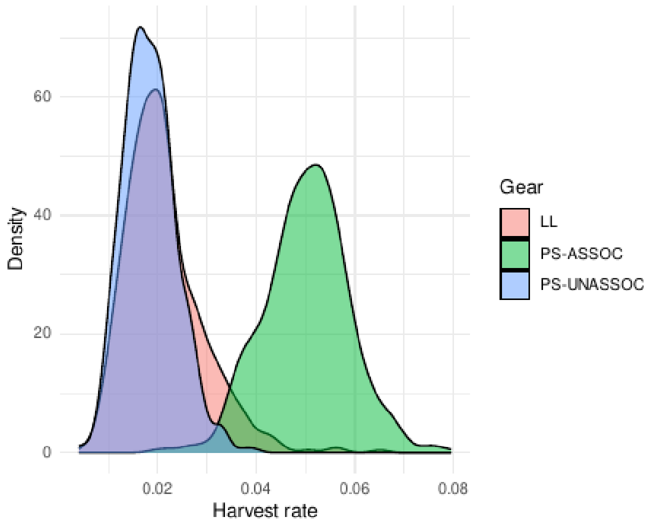
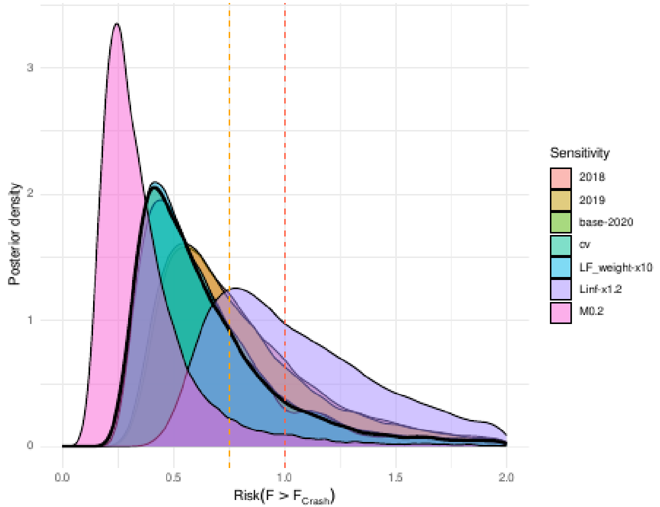


Summary

- Spatial harvest rate and relative density estimates are highly variable between years
- Highest harvest rate currently from object-associated PS
- High risk only if growth mis-specified (L_{inf} too small), otherwise low risk of $F>F_{crash}$

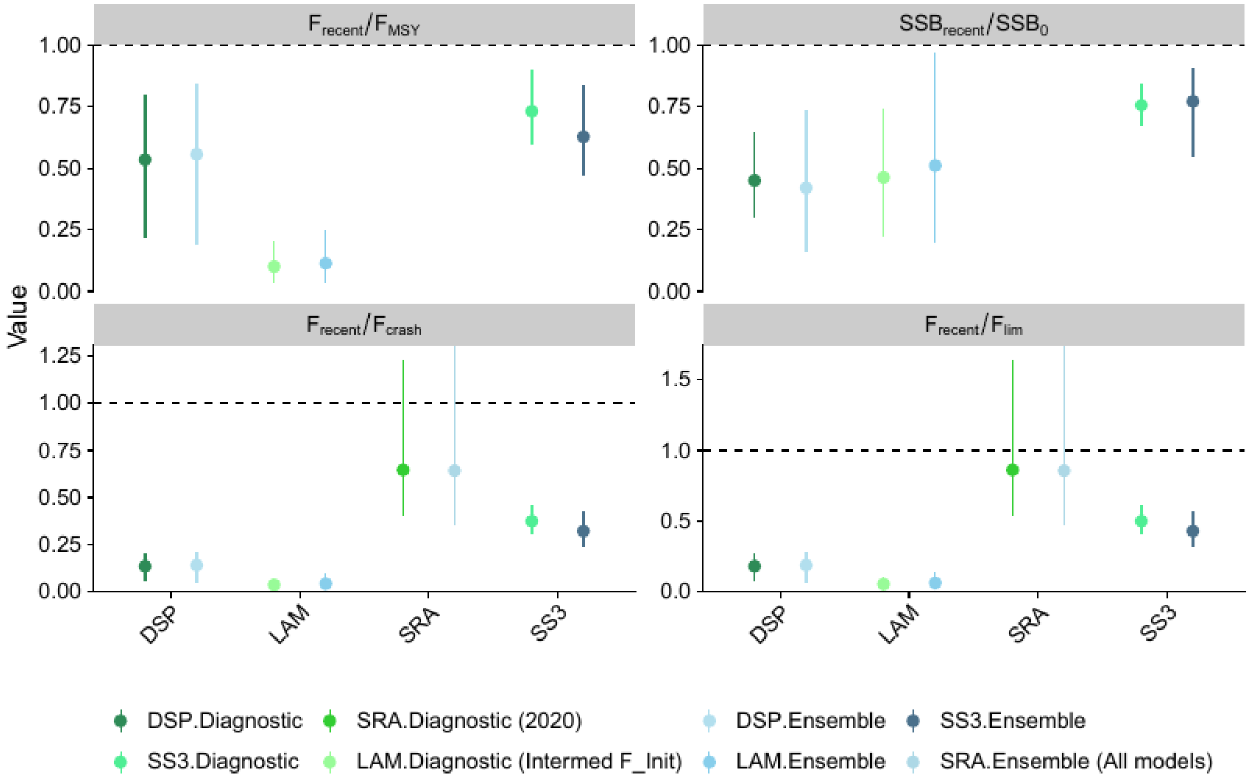




2024 Assessment: Summary & Recommendations

Summary

- Comparable ranges of estimates for status across assessments
- Low probability of $F_{recent} > F_{crash}$



Conclusions

The multi-model approach to assessing silky shark resulted in an uncertain stock status, but high confidence that recent fishing mortality is below levels that would preclude stock rebuilding.

We suggest that the dynamic surplus production model be used for providing management advice.

The model ensemble across initial depletion priors may be over-representing uncertainty (especially the prior for low initial depletion), -> suggest output from the intermediate assumption as a candidate model for management advice

The largest fishing mortality was estimated to have come from longline fisheries capturing nearly the full size-range of silky sharks, and reductions in interactions as a result of changes in fishing practices over the last decade may have substantially reduced this source of mortality, allowing the stock to rebuild.

The stock status has been improving since 2010, and the recent fishing mortality rates are below biological reference points for the ensemble (Diagnostic F_{recent} / F_{crash} : 0.13 [0.01–0.25]; $P(F_{recent} / F_{crash} > 1) = 0$; $P(F_{recent} / F_{lim} > 1) = 0$).

Conclusions

With respect to other shark stocks with lower levels of information:

- Surplus production models should be used when composition data are problematic
- Risk assessments should only be used in the context of prioritisation across species.
    - However, data driven risk assessments could provide an avenue to use a risk assessment approach when time-series are not sufficiently long or reliable to estimate productivity
    - With non-retention measures leading to sharks and other bycatch species being cut free from longlines, data collection may be problematic. In these cases, the only alternative to provide estimates of risk would be methods such as EASI- fish, which estimate risk from assumptions about fishery overlap with the species distributions and vulnerability to fishing effort.

Recommendations

- Additional tagging should be carried out using satellite tags in a range of locations as well as high seas areas to resolve fundamental questions about the species interactions with local oceanography and the dynamics of ENSO.
- Additional growth studies and validation of aging methods from a range of locations could help build a be er understanding of typical growth, as well as regional growth differences. Current growth data are conflicting, with insufficient data to understand the underlying process.
- Additional genetic/genomic studies across a broader set of locations could be undertaken to augment the tagging and existing genomics work to help resolve the stock/sub-stock structure patterns.

Thank you for your input!

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