INTERNATIONAL PACIFIC
HALIBUT COMMISSION

Development of the 2022 stock assessment

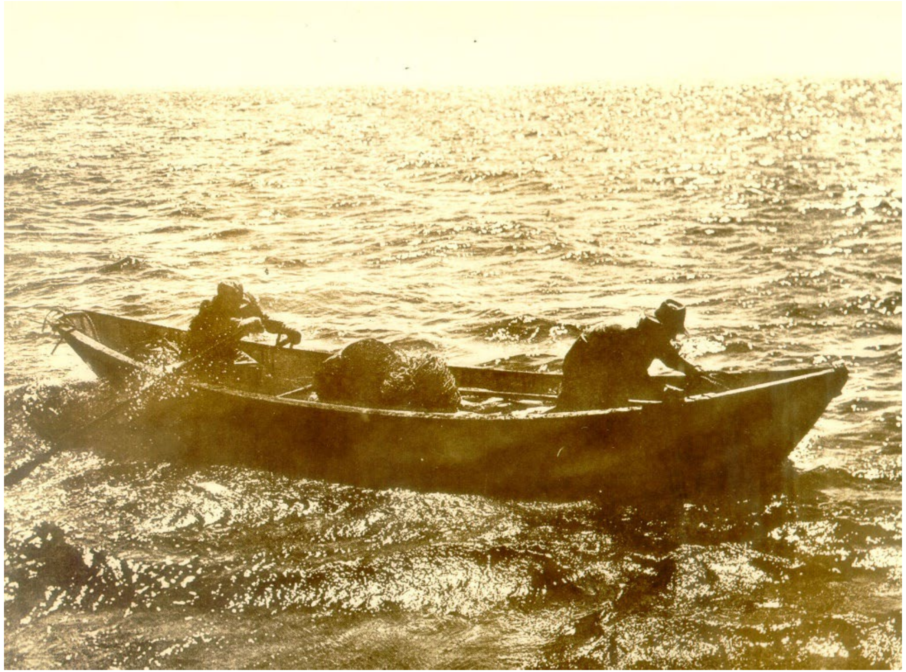
Agenda item: 6

IPHC-2022-SRB020-07

(I. Stewart)

Outline (1)

- IPHC process and recent SRB requests
- Data
  - Data sources included
  - External information on M
  - Age data
  - Marine mammal depredation
- Modelling
  - Multi-model approach
  - Structural assumptions
  - Technical configuration
  - Changes from 2021
  - Diagnostics and results



Outline (2)

- Evaluation of uncertainty
  - Sensitivity analyses
  - Likelihood profiles
  - Retrospective analyses
  - Other considerations
- Ensemble
  - Methods
  - Weighting based on predictive skill
  - Preliminary results for 2022
- Research priorities and future development

IPHC Assessment and review process

- Annual assessments
  - Full analyses ~ every 3 years (2015, 2019, 2022)
  - Updates in between
    - Include all new data available and limited model changes
- Annual improvements reviewed by the SRB in June
- Refined and finalized for the September SRB
- Final data added in early November
- Results presented at the Interim Meeting

Stock assessment web-page

Documentation

- The assessment document (IPHC-2022-SRB020-07)
- Additional files (Appendix A):
  - Input files for each model
  - Output files and graphics for each model
  - Software documentation
  - Recent data overview and stock assessments
  - Relevant manuscripts
  - Full history of assessment and review (assessment web site)

SRB requests (SRB019)

Para. 31:

*The SRB **REQUESTED** that the IPHC Secretariat consider the following topics for inclusion in the 2022 full stock assessment and presentation for SRB evaluation at SRB020 in June 2022:*

a) Sensitivity analysis of the assessment to processes being investigated by the Biological and Ecosystem Research Program, e.g. spatiotemporal differences in maturity schedules, discard mortality, and length-weight relationships;

b) Continued exploration of data weighting;

c) Evaluation of treatment of commercial sex ratio;

d) Use of the Pacific Decadal Oscillation (PDO) and other environmental covariates to predict recruitment;

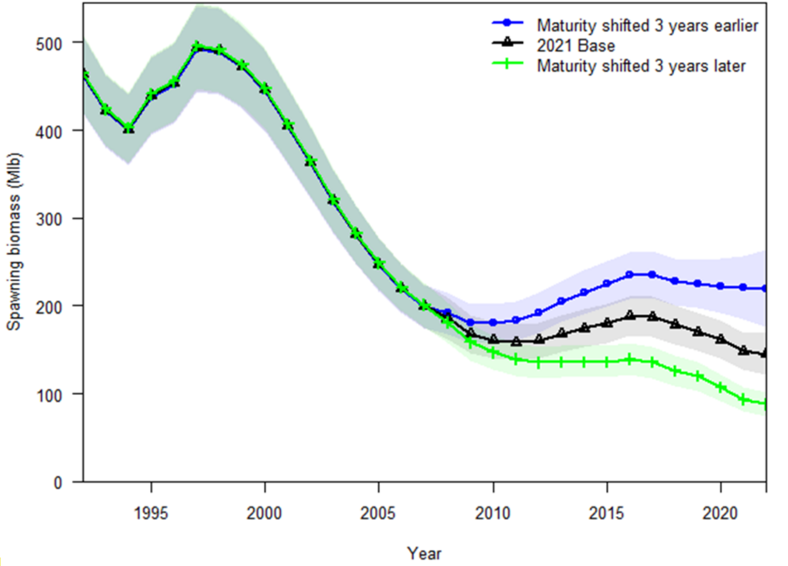
e) Estimation of whale depredation mortality for potential explicit inclusion in the assessment model; and

f) Other factors discussed since the last stock assessment.

SRB requests (SRB019)

a) Sensitivity analysis of the assessment to processes being investigated by the Biological and Ecosystem Research Program, e.g. spatiotemporal differences in maturity schedules, discard mortality, and length-weight relationships;

- Sensitivity to depredation mortality, temporal change in maturity, PDO relationship included in 2021 assessment (IPHC-2022-SA-01)



SRB requests (SRB019)

b) Continued exploration of data weighting;

- Bootstrapping of the raw age data to better inform the relative data weights among sources and across years

SRB requests (SRB019)

c) Evaluation of treatment of commercial sex ratio;

With 4 years of sex-specific age compositions (5 will be available for the final 2022 assessment), sex-ratio is allowed to vary over time.

- ‘Disconnects’ recent dynamics from historical period
- Improved retrospective analyses
- Does not require additional model changes to track sex-ratio in the future

SRB requests (SRB019)

d) Use of the Pacific Decadal Oscillation (PDO) and other environmental covariates to predict recruitment;

- Investigation of 5 methods for using the PDO as a recruitment covariate

(*Status quo* performed the best)

SRB requests (SRB019)

e) Estimation of whale depredation mortality for potential explicit inclusion in the assessment model; and

- Exploratory data analysis suggested relatively low additional mortality
- Additional work to be done on methods for data collection, creating incentives for reporting

SRB requests (SRB019)

f) Other factors discussed since the last stock assessment.

- As described throughout;
- Natural mortality was identified as a critical area of uncertainty in the 2019 full assessment; therefore, this was the focus of most additional exploration for 2022

Outline (1)

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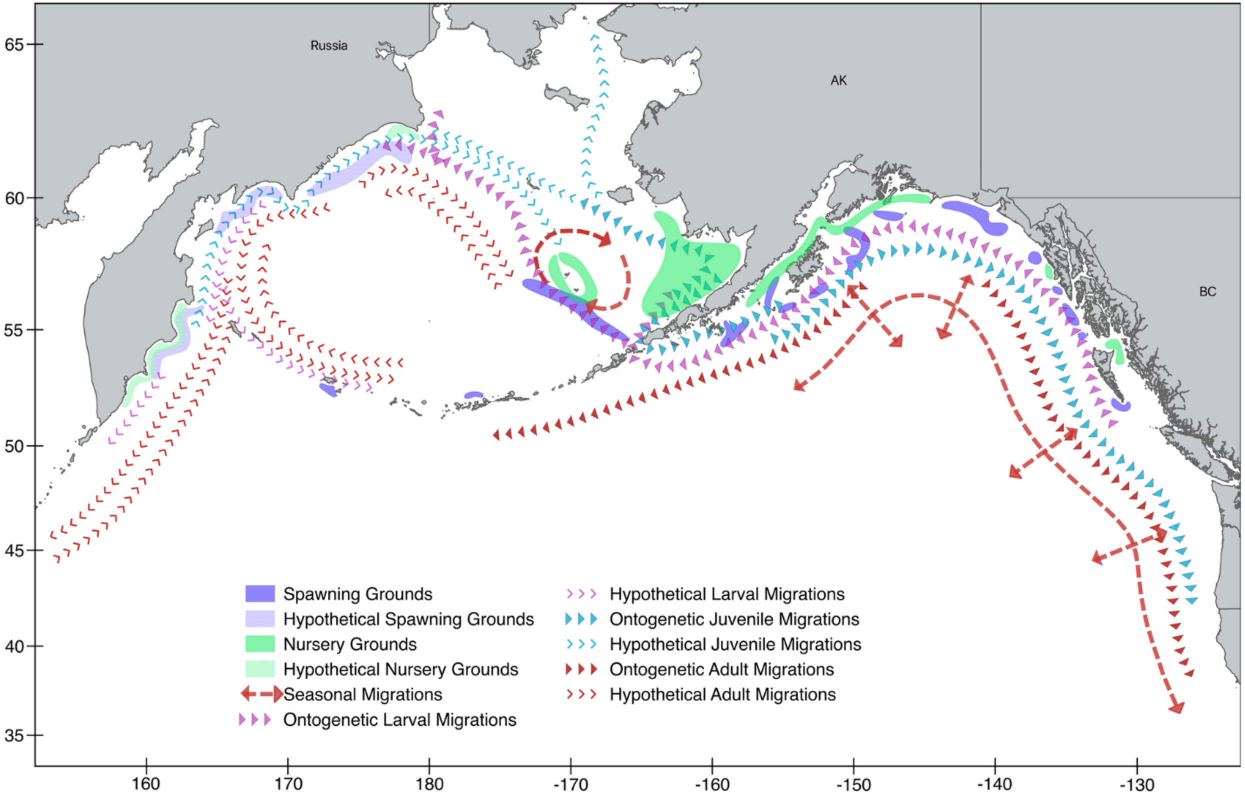
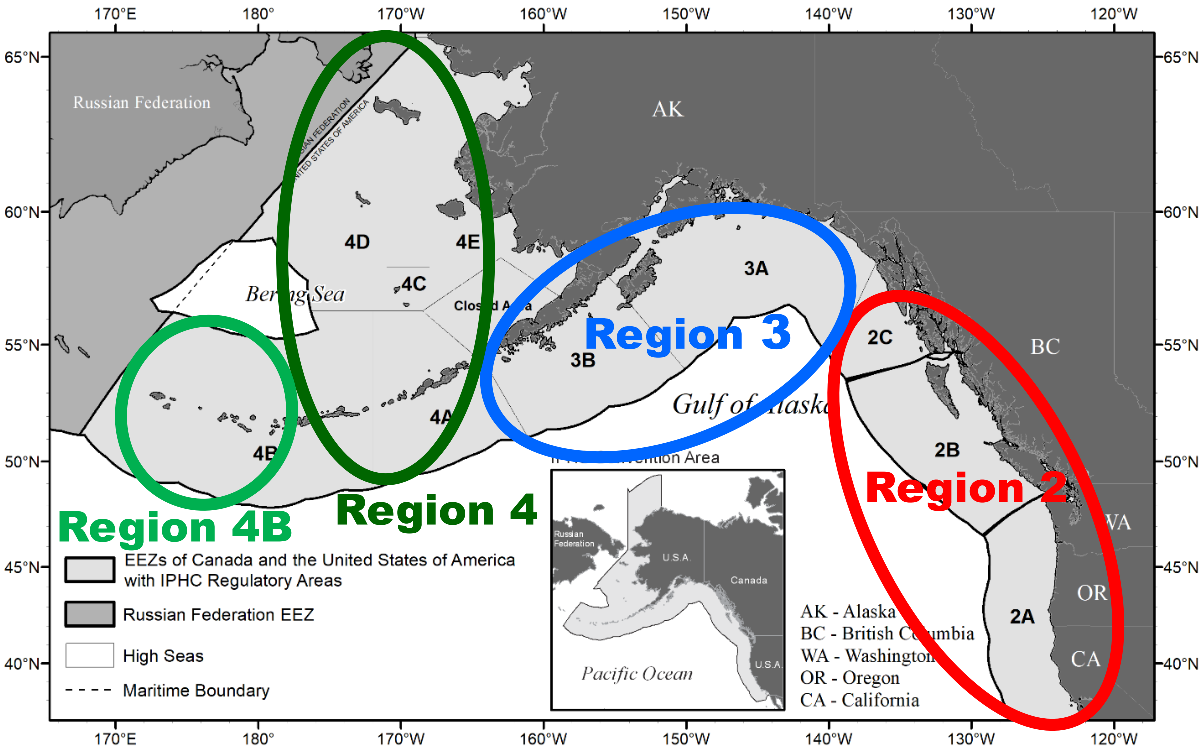
Basic life history

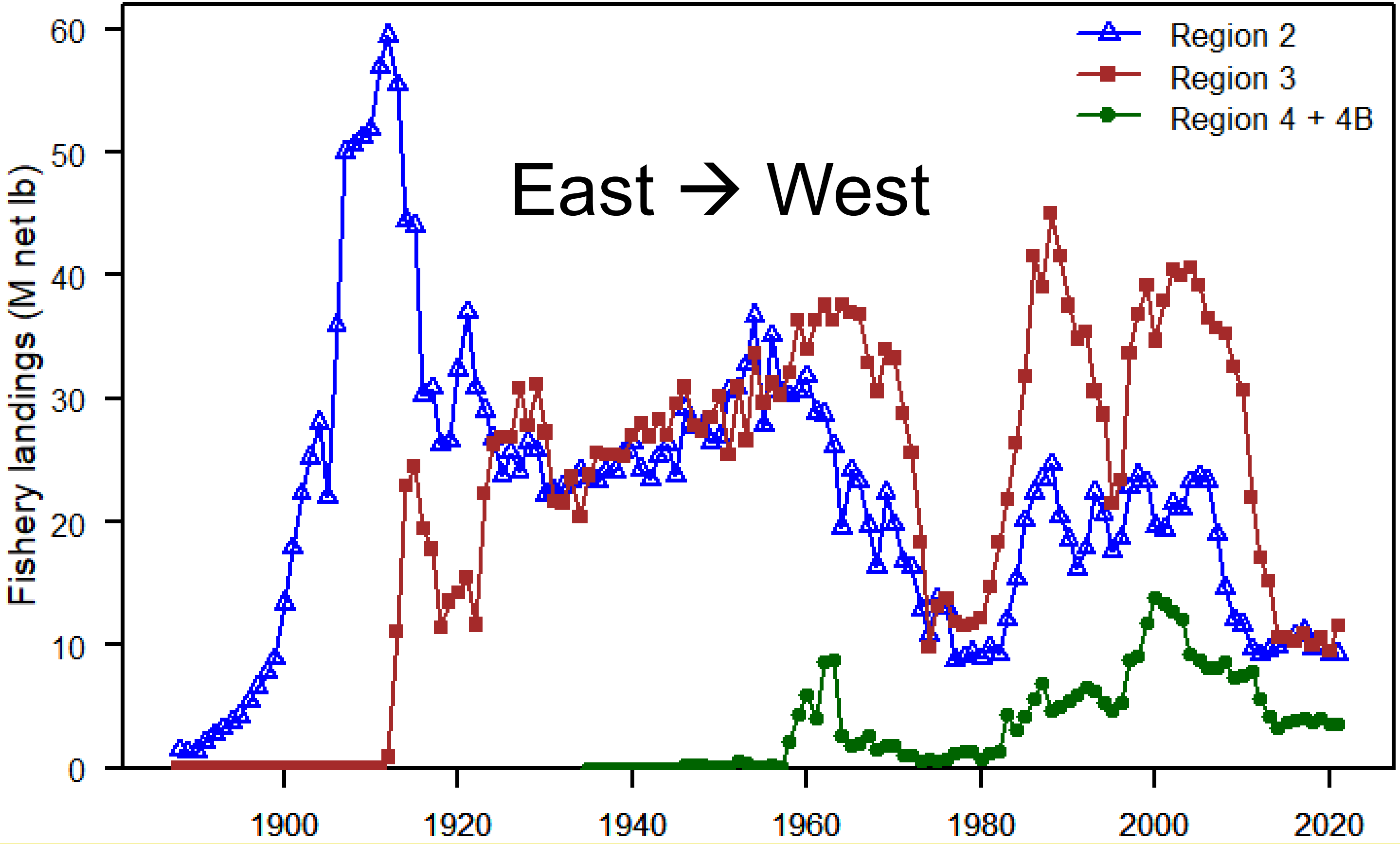


Carpi, P., Loher, T., Sadorus, L.L., Forsberg, J.E., Webster, R.A., Planas, J.V., Jasonowicz, A., Stewart, I.J., and Hicks, A.C. 2021. Ontogenetic and spawning migration of Pacific halibut: a review. Reviews in Fish Biology and Fisheries. doi:10.1007/s11160-021-09672-w.

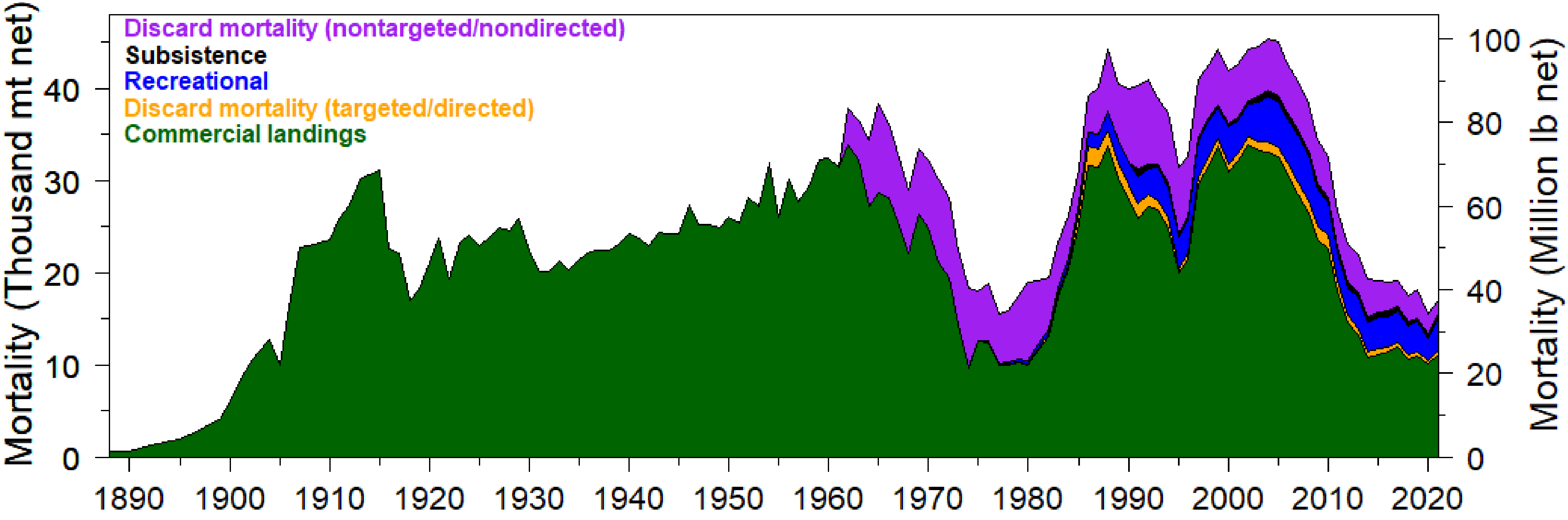
One stock, four Biological Regions



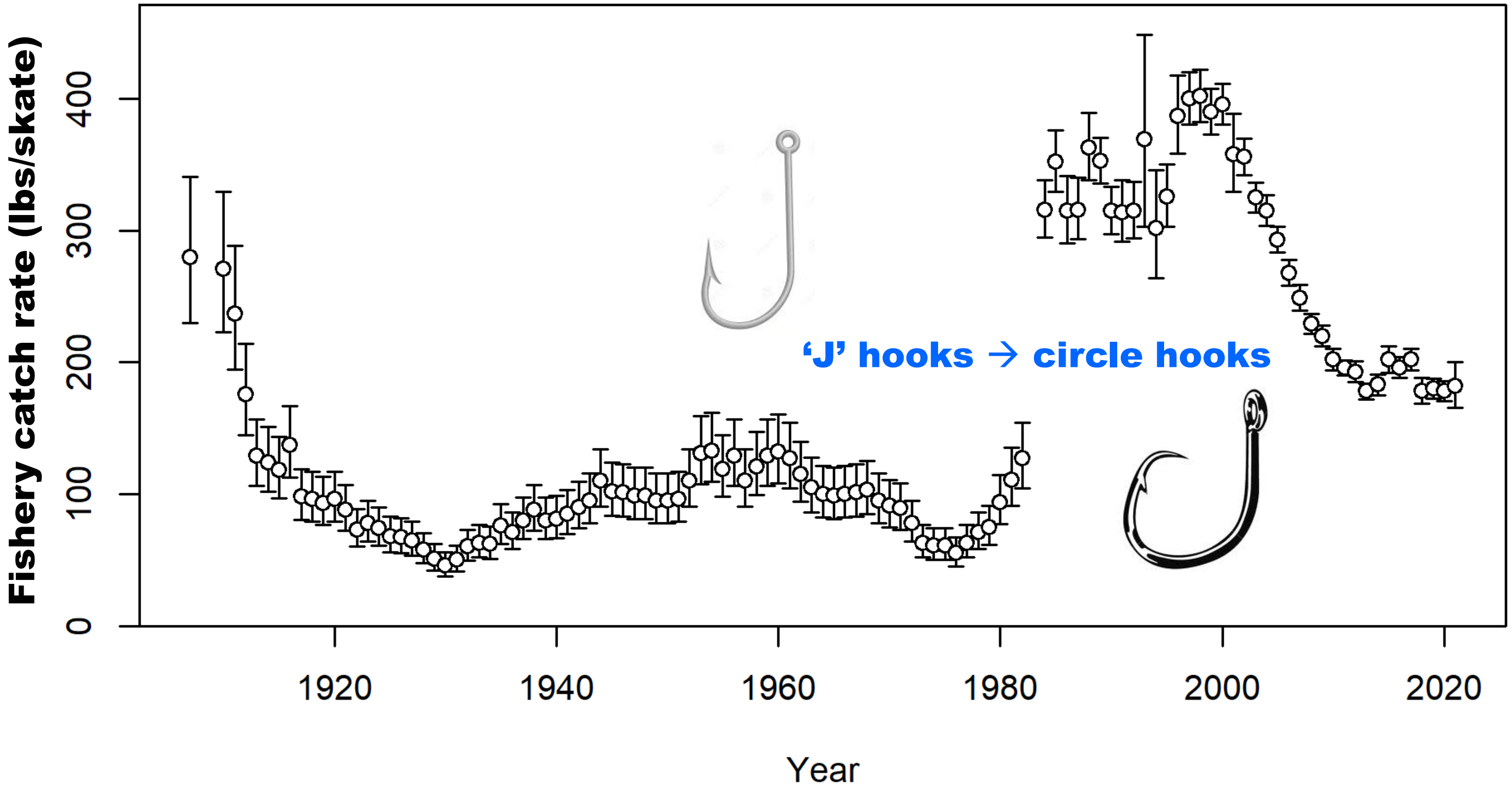
Historical directed commercial fishery



Historical mortality by sector



Historical CPUE



Management notes

- 32” Commercial minimum size limit
- Commercial seasons: March-December
  - FISS: June-August
- IFQ/ITQ in AK and BC (Derby in WA/OR/CA)
- Longline and pot gear legal
  - Trawl gear must discard all halibut
- Recreational, personal use/subsistence managed differently by IPHC Regulatory Area
  - Size, bag, temporal and possession limits
- Discard mortality rates vary from 4-100% by fishery

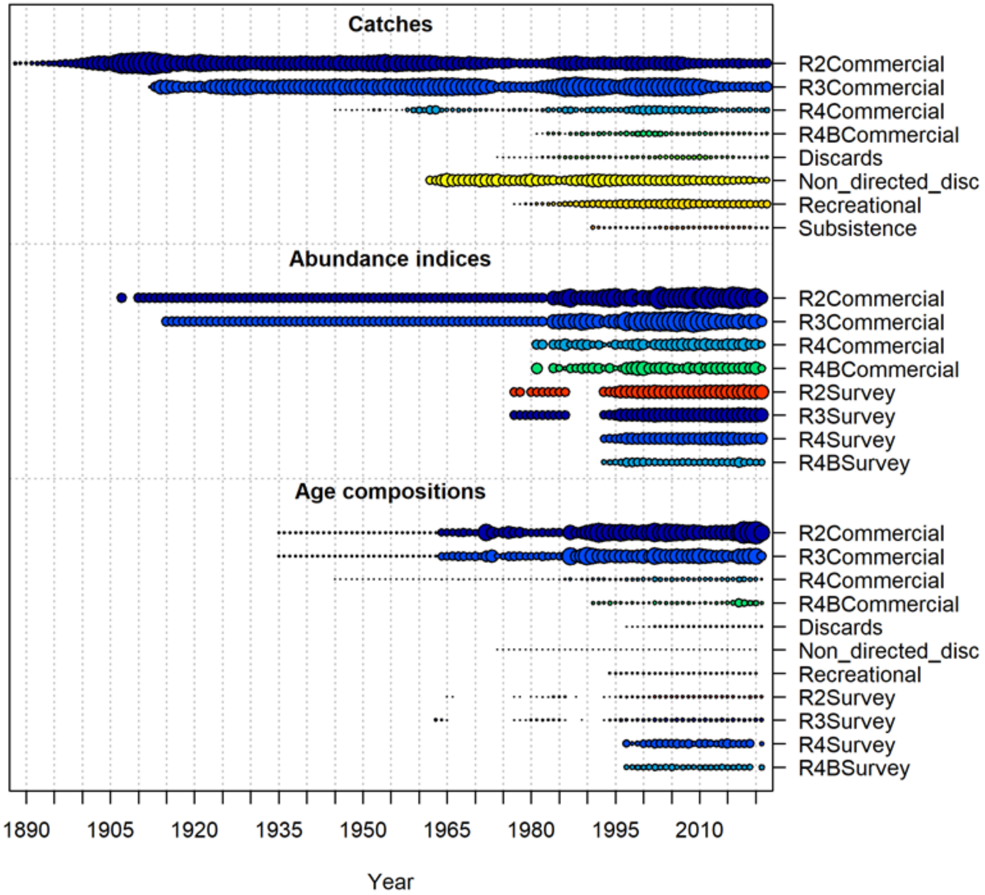
Basic data sources

Mortality time-series' very complete

Indices: fishery only before 1992

Excellent age data: FISS + commercial

Poor information for directed discards, recreational, non-directed discards, subsistence

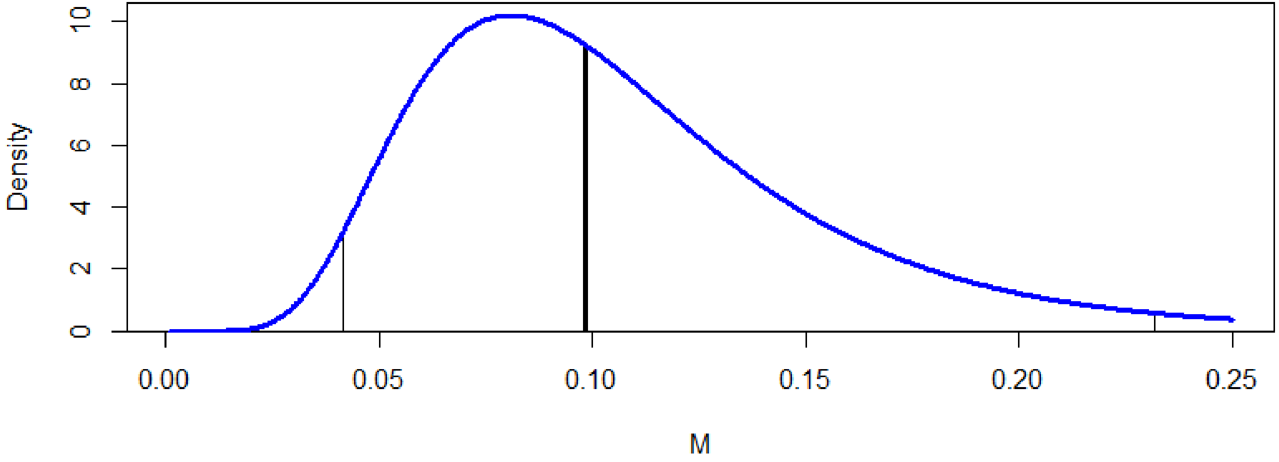


Other data inputs (Table 8)

- PDO index
- Maturity ogive
- Fecundity information
- Weight-at-age
- Length-weight relationship
- Ageing error (bias and imprecision)
- ‘Priors’ on bycatch, discard and recreational selectivity

External information on M

- Generalized prior for marine fish (Hamel 2014)

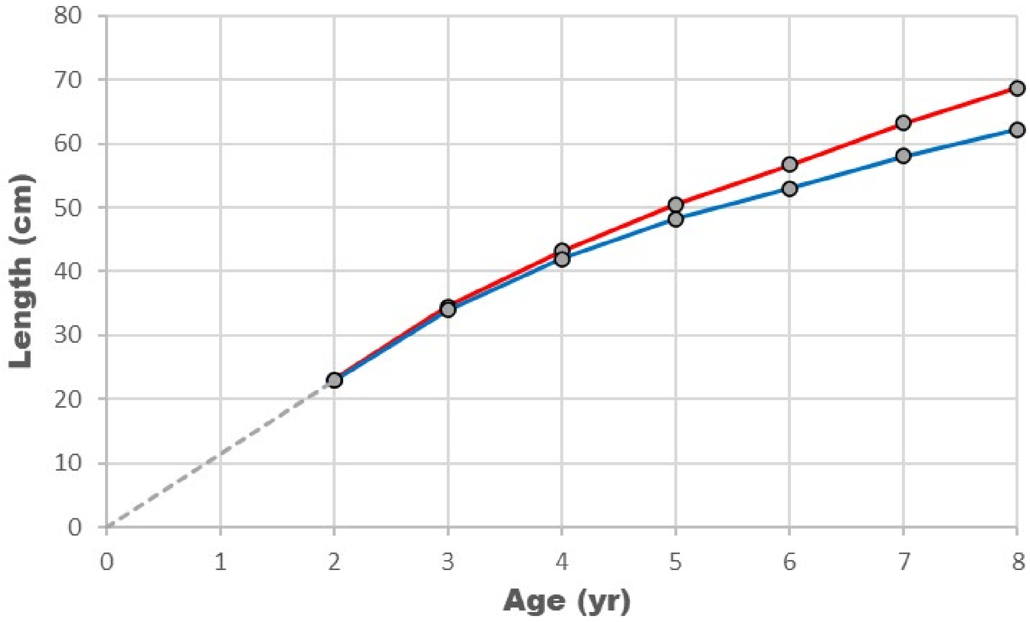


- Size-dependent information via 26 flatfish stocks in the NE Pacific (Table 9)

Size/age dependent M

- CAPAM: we should expect size/age dependent M from first principles
  - What ages/sizes should this apply to?
  - How extreme?
  - Why does it matter if there is little data on these ages?

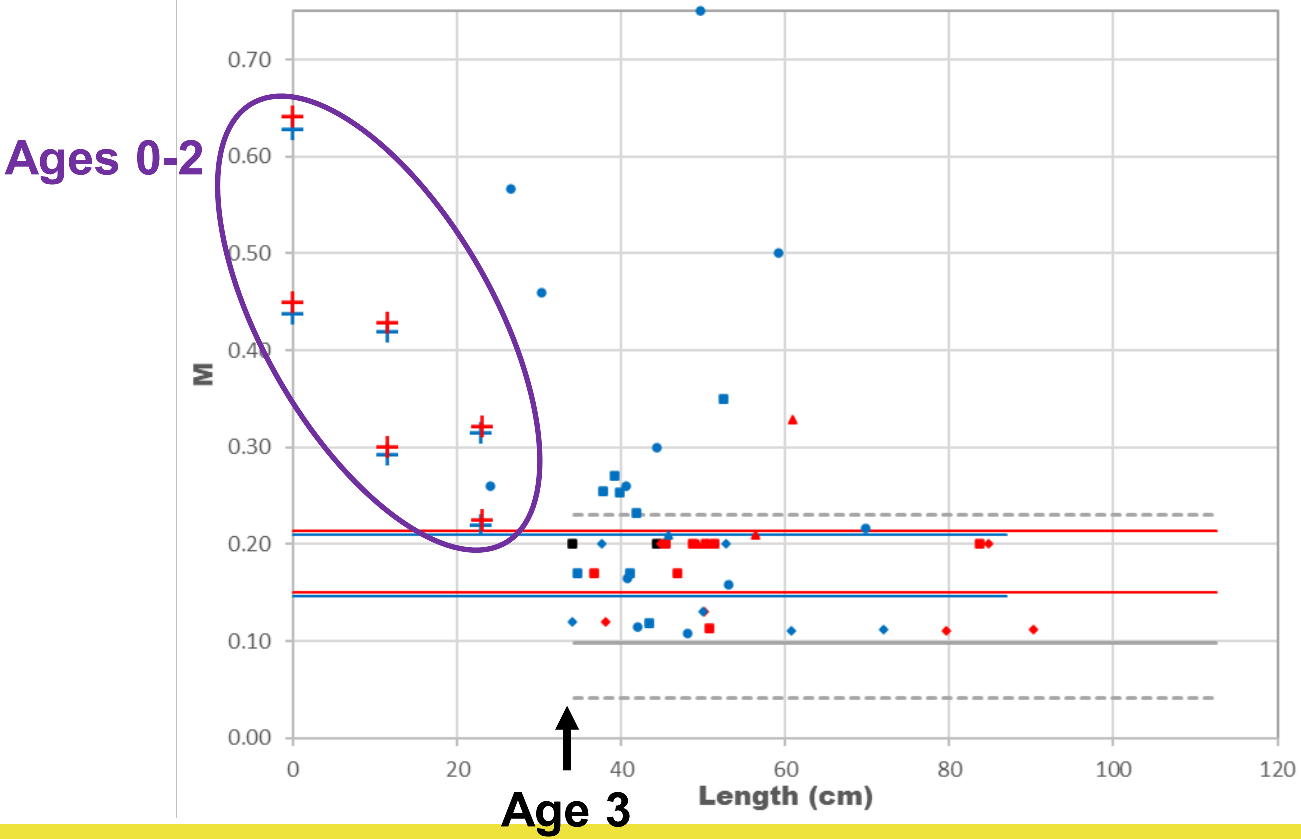
Size/age dependent M



Size-at-age from trawl survey data: dimorphic growth not important at younger ages

Ages/sizes at which M may be higher

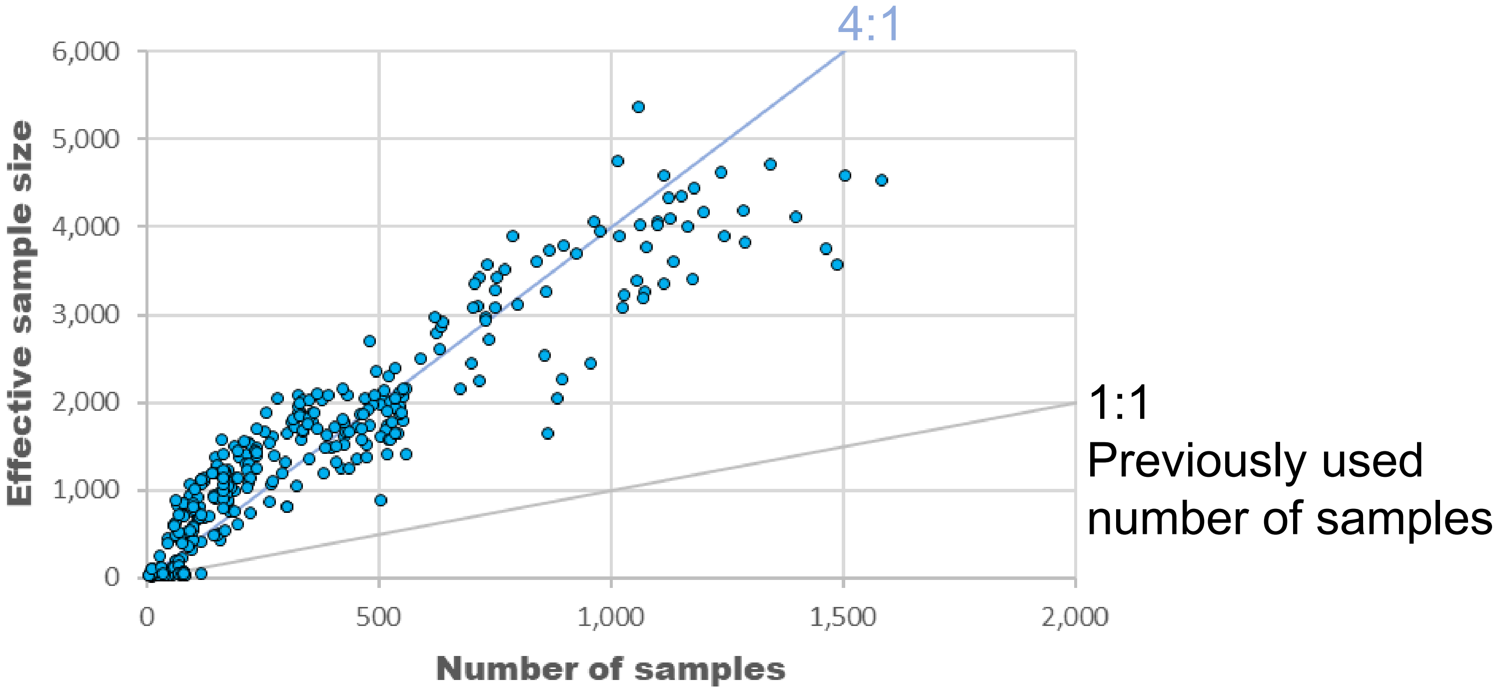
By ages 3-5 Pacific halibut are as large as most flatfish at L_∞



Bootstrapping age composition sample sizes

- A quantitative estimate of the minimum variance associated with each year's specific age composition
- Does not include variance associated with missing areas
- Better than the previously-used raw number of samples (fishery trips or survey stations)

Bootstrapping age composition sample sizes



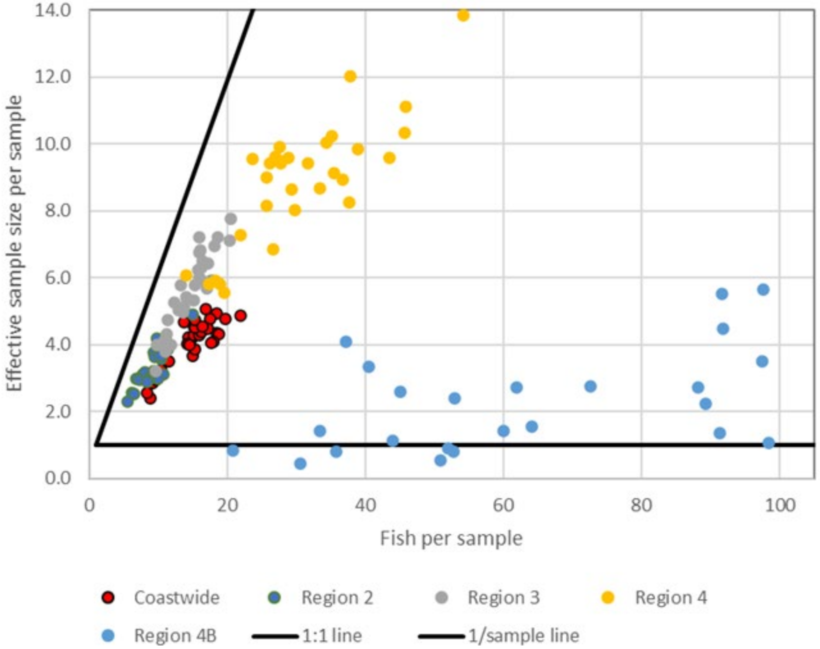
(Averages by data type provided in Table 10)

Bootstrapping age composition sample sizes

- Generally increased maximum value used for tuning in the models (Tables 11-13)
- Also provides a basis for refinement of sampling targets for trips/stations vs. # of fish

  4B stands out as an area with a high degree of clustering among samples

  → more fish are not as informative as more samples.



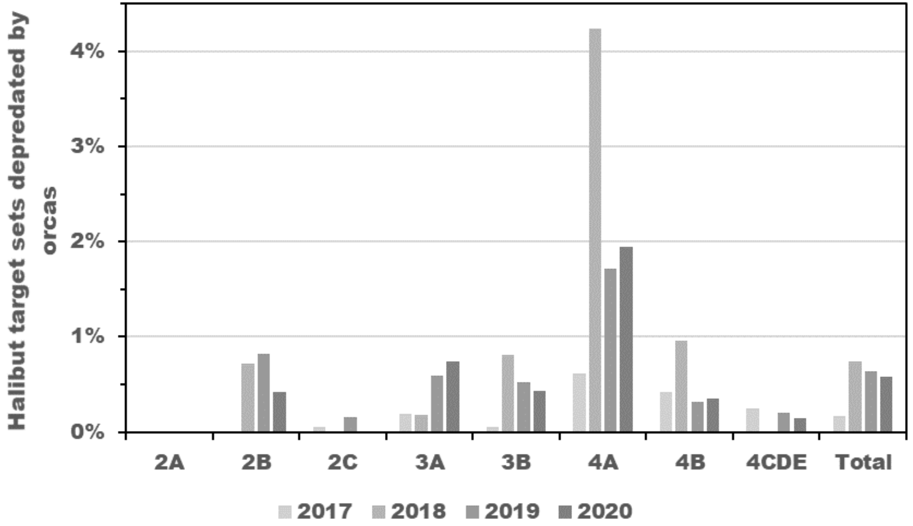
Marine mammal depredation

- Known source of ‘fishing related’ mortality
- Difficult to quantify
- Ideal solution:
  - Use survey catch rates in the space time model to estimate a ‘depredation effect’ when present
    (IPHC-2021-SRB019-05)
  - Use fishery data to determine the frequency of occurrence

Marine mammal depredation

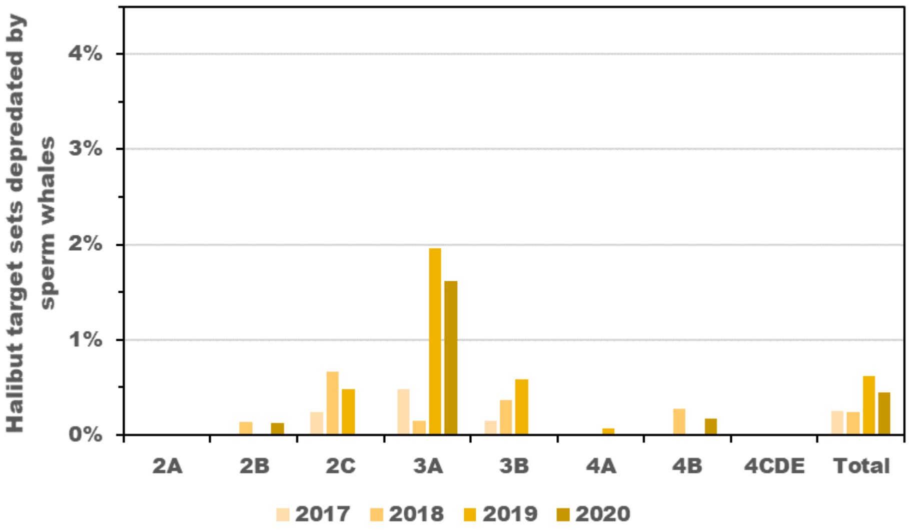
- Logbook fields added in 2017
- Ongoing 'slow rollout' as old logs are replaced
  - Canadian logs still do not contain this information
- Participation and clear data collection protocols are still improving
- Therefore, this is a very preliminary evaluation

Marine mammal depredation



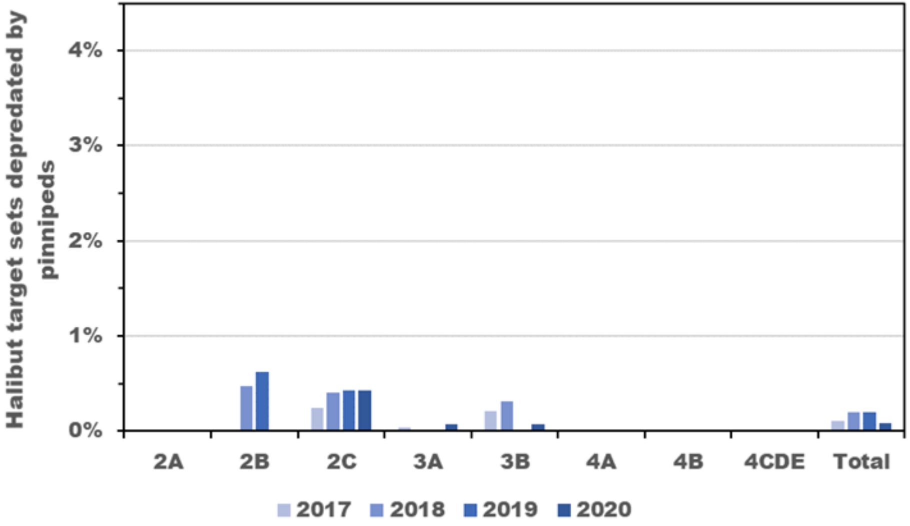
Orca activity in 4A consistent with FISS observations
Very low rates of observed whales and gear/catch damage
Raw effect on average catch-rates similar to FISS

Marine mammal depredation



Sperm whale activity in 3A also consistent with FISS observations
Very low rates of observed whales and gear/catch damage
Raw effect on catch-rates highly variable.

Marine mammal depredation



Very low rates of observed pinniped activity and gear/catch damage
Raw effect on catch-rates highly variable.

Marine mammal depredation

- A depredation mortality estimate not yet included in the assessment
- Next steps:
  - Refine codes and collection procedures to improve accuracy and clarity of records
  - Outreach program to encourage the fleet to report should include specific ways in which the data will and will not be used
- Marine mammal interactions remain a sensitive topic for many fisheries

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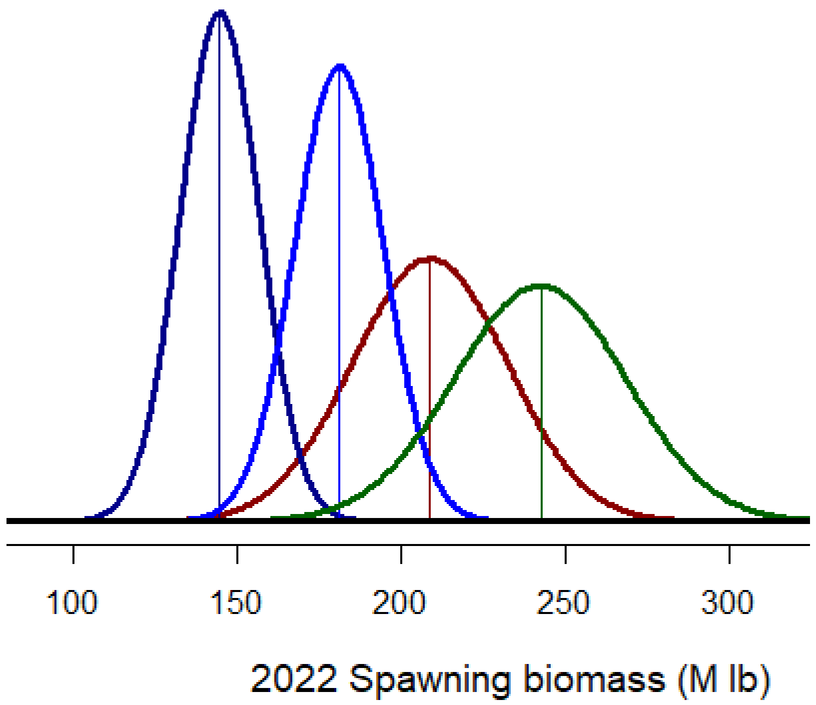
  - Changes from 2021
  - Diagnostics and results

Ensemble approach: four individual models



- Four ways to aggregate the data
- Respond differently to trend and age data by Region
- Provides stability from year to year as individual model results change

Ensemble approach: four individual models

- 2 x 2 cross of Coastwide (CW) vs. Areas-As-Fleets (AAF) and long (1888+) vs. short (1992+) time-series
- Spans the basic types of models commonly used for NE Pacific groundfish stocks
- Each model could be a stand-alone assessment

Basic structural assumptions (Table 14)

- Age-based models with empirical weight-at-age
- Pope's approximation for fishing mortality
- Beverton-Holt S-R relationship, with tuned annual deviations, fixed steepness (0.75), initial offset (short models) and PDO coefficient (long models)

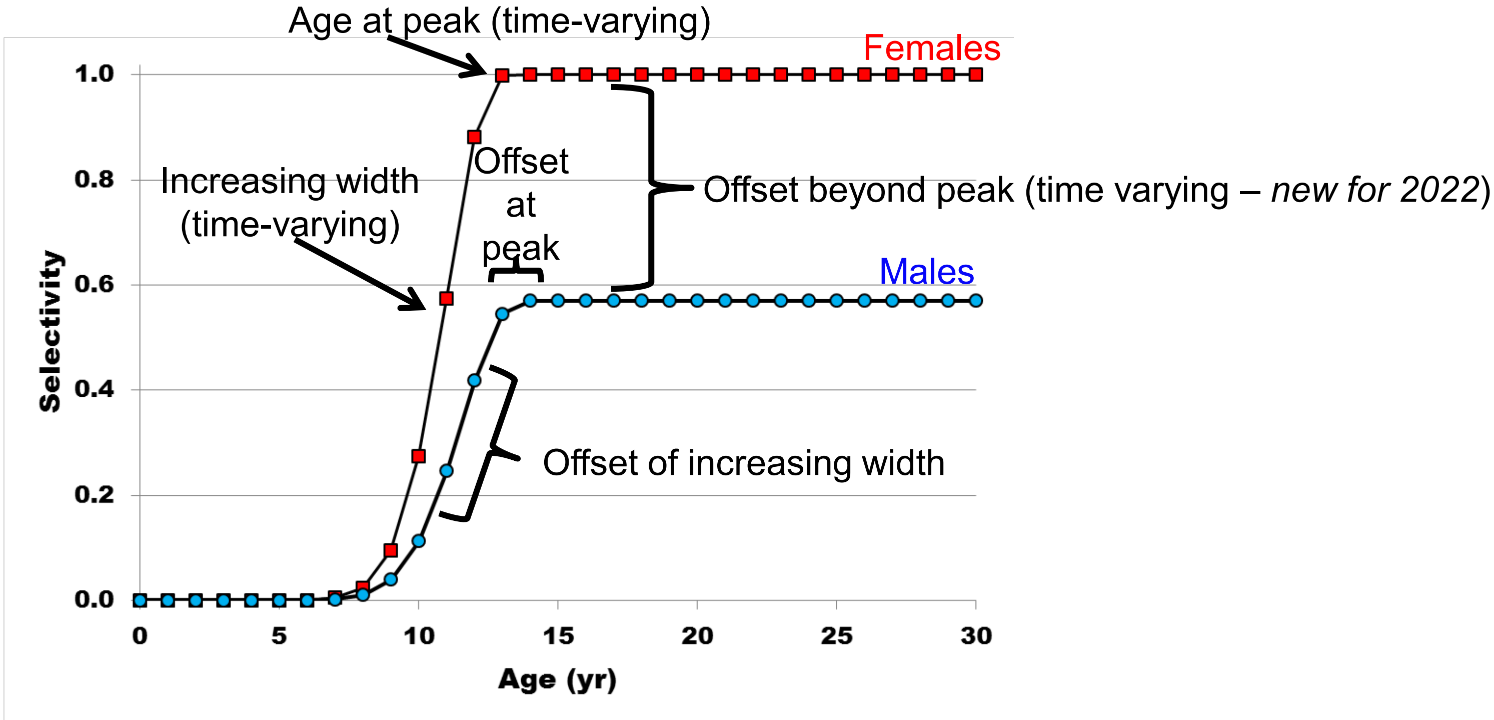
Basic structural assumptions (Table 14)

- Asymptotic (coastwide models) or domed (AAF models) selectivity
- Time-varying ascending limb, peak and scale (for males) for commercial fishery
- All process deviations tuned to reflect process and estimation variance:

$$\sigma_{tuned} \sim \sqrt{SE_{devs}^{2} + \bar{\sigma}_{dev}^{\,2}}$$

- Results in internal consistency and unbiased variance (e.g., Methot and Taylor 2011)

Treatment of time-varying selectivity



Commercial sex-ratios

	Coastwide % female	Region 2	Region 3	Region 4	Region 4B
2017	82%	82%	82%	92%	65%
2018	80%	82%	78%	91%	65%
2019	78%	80%	76%	89%	51%
2020	80%	79%	81%	84%	54%

2021 genetic assay data will be available for the final 2022 assessment
Rate and frequency of application to be reviewed based on 5 years completed

Treatment of the PDO

- Estimated link coefficient (β) adjusting the scale of the S-R relationship:

$$R_0{}' = R_0 * e^{\beta * PDO_{regime}}$$

$$R_y = f\left(SB_y, R_0{}', SB_0, h\right) * e^{r_y - \frac{\sigma^2}{2}}$$

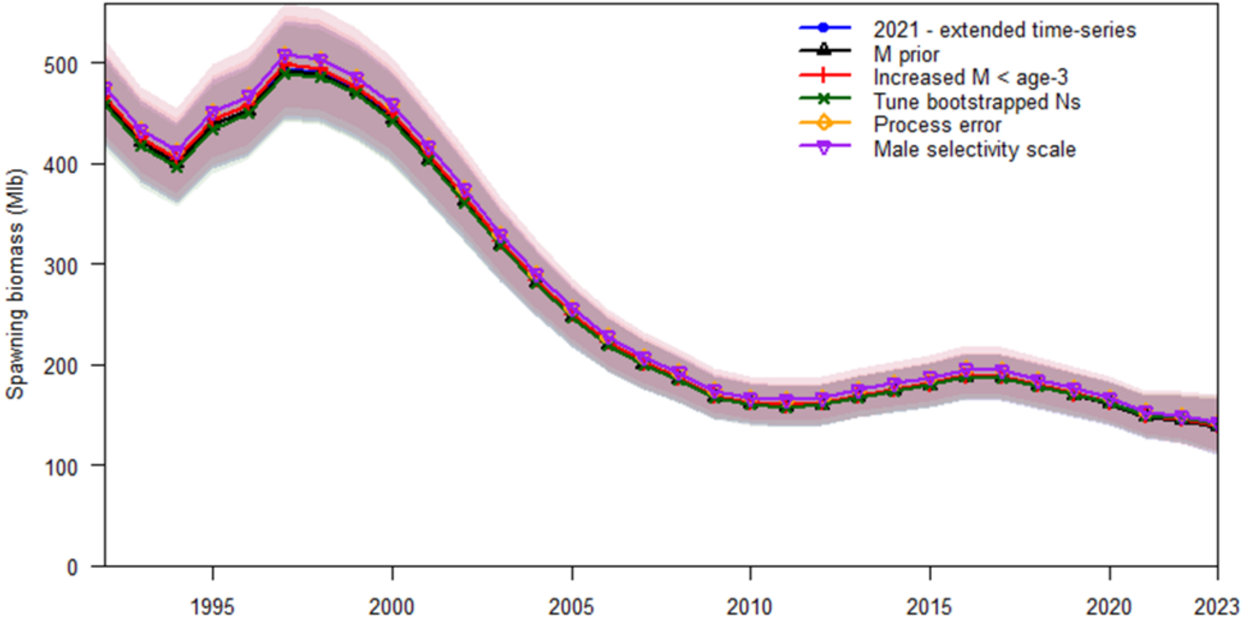
‘Priors’ on selectivity

- Down-weighted age data used as a prior for recreational/subsistence, directed discards, and non-directed discards
  - Non-directed discards – lengths converted to ages based on trawl survey age-length keys; incomplete coverage and weighting among sectors
  - Recreational – age-data from IPHC Regulatory Area 3A only
  - Directed discards – ages from FISS sublegal catch used as a proxy for discards (comparison only available in 2B)

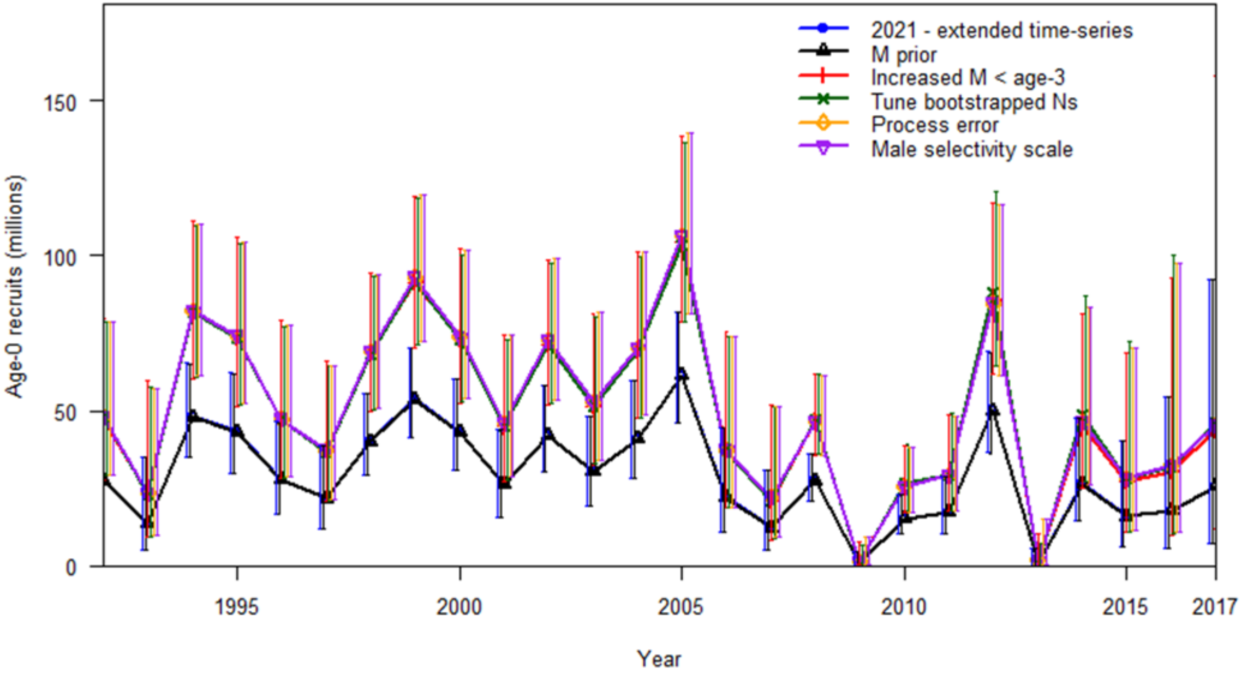
Bridge of changes from 2021

1) Extend the time series using projected mortality for 2022 (does not change the historical estimates)
2) Update the stock synthesis software (identical results)
3) Add prior on M and increased M at ages 0-2
4) Add bootstrapped age composition samples sizes
5) Retune process and observation error variances
6) Allow time-varying fishery sex-ratio (scale of male selectivity)
7) Test estimation of M in short models (relative to historically fixed value of 0.15)

Coastwide short

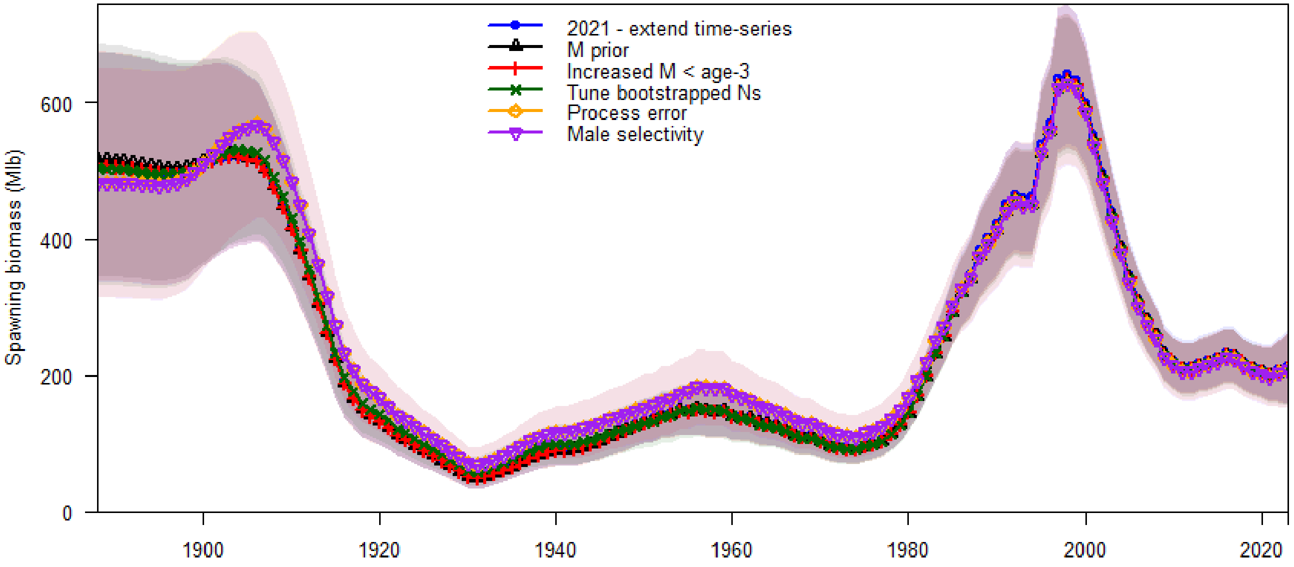


Coastwide short

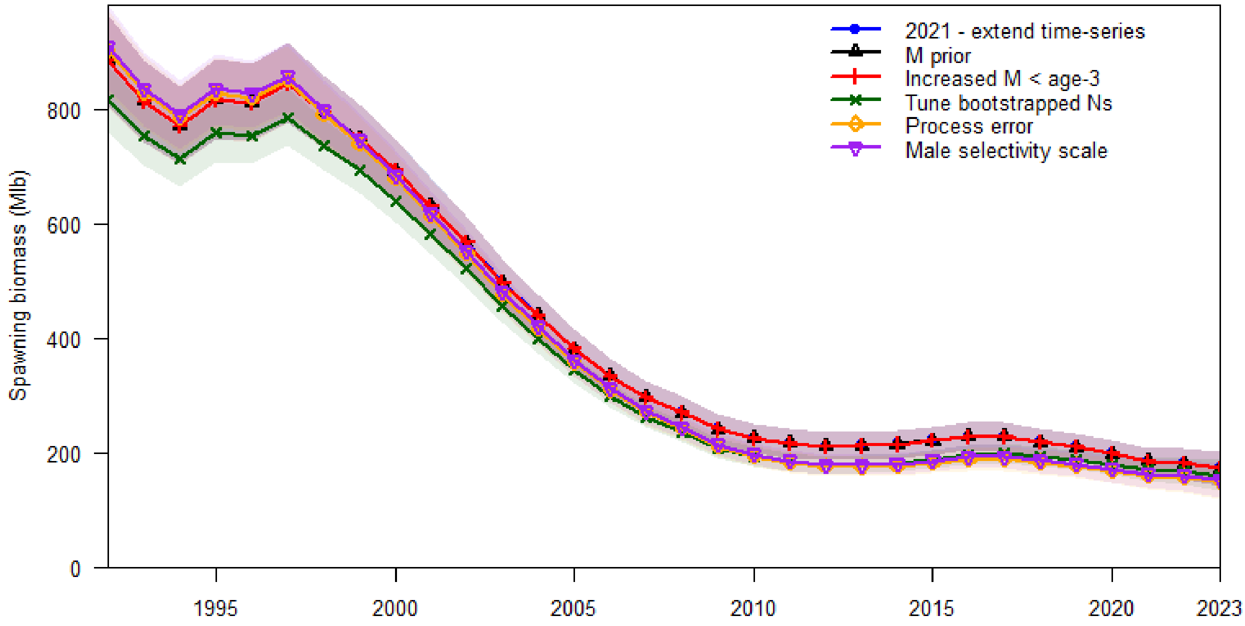


Increased M at ages 0-2 changes the scale,
but not the relative recruitment strengths at age-0

Coastwide long

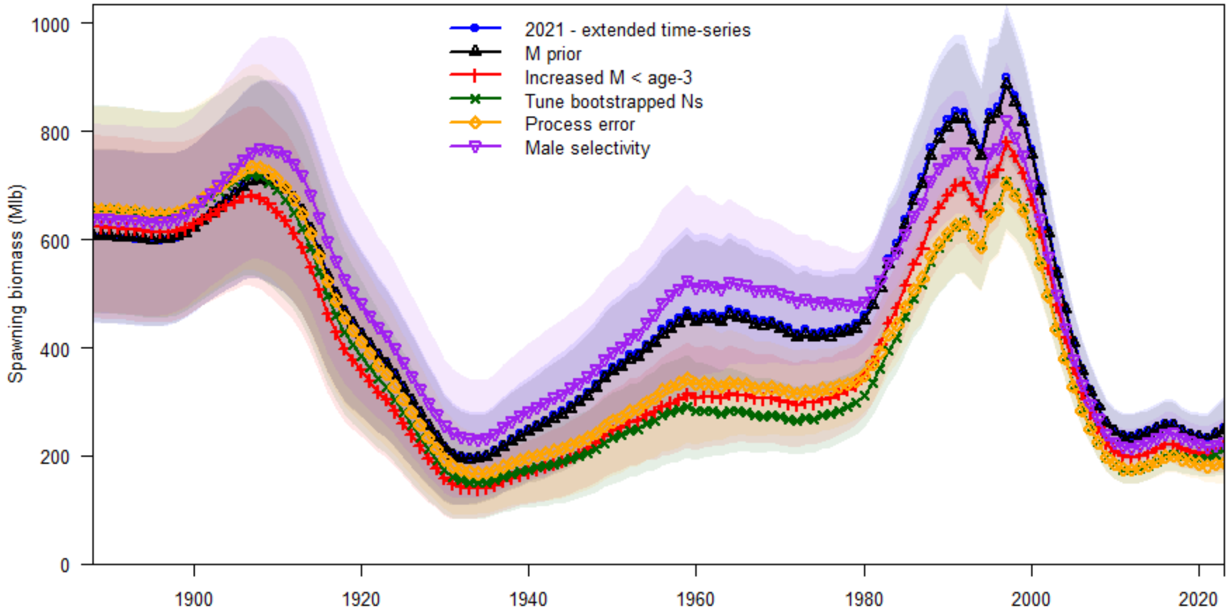


AAF short



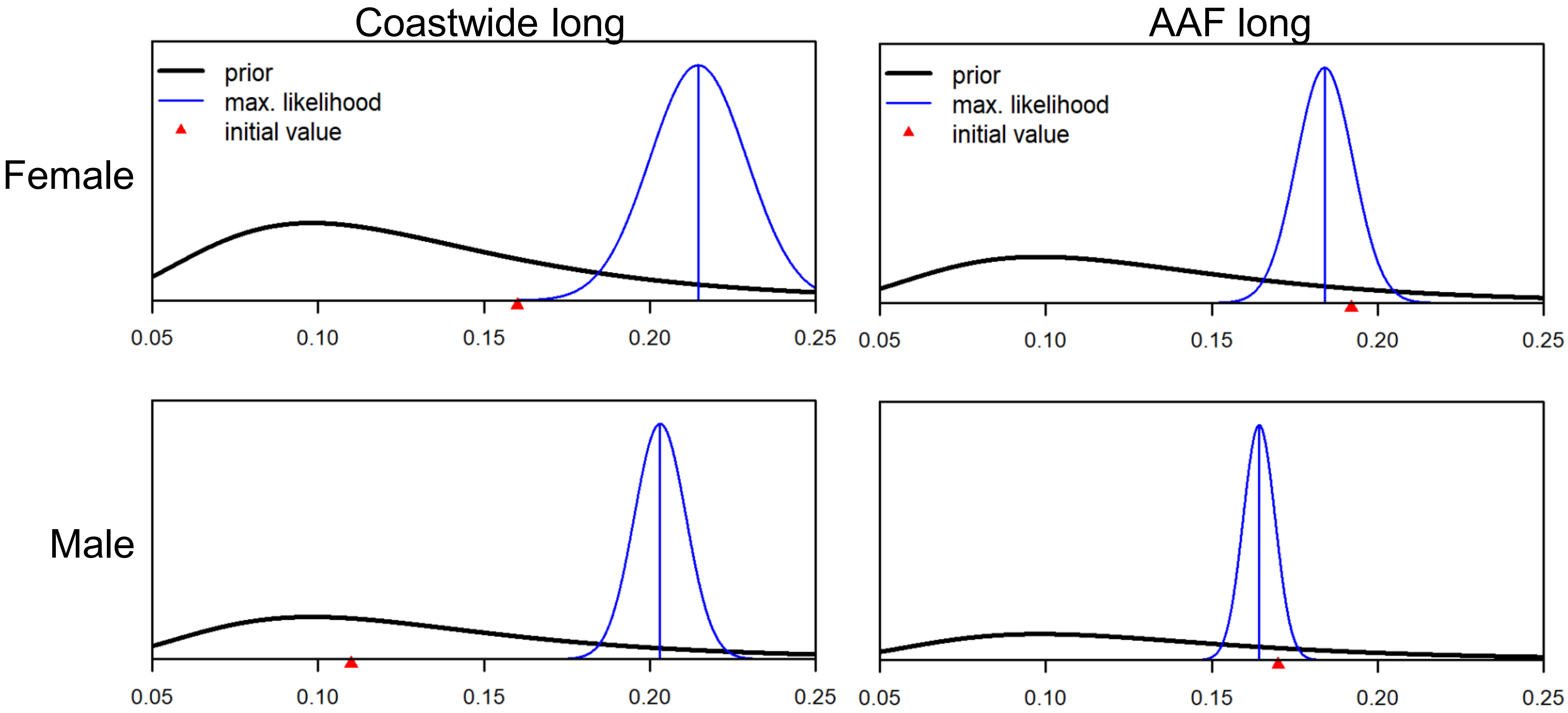
2021 - extend time-series
M prior
Increased M < age-3
Tune bootstrapped Ns
Process error
Male selectivity scale
Spawning biomass (Mlb)
0
200
400
600
800
1995
2000
2005
2010
2015
2020
2023

AAF long



Most sensitive of the 4 models, primarily in the historical period

Natural mortality - long models



Where did M = 0.15 come from?

- The 1998 assessment (Table 1 from Stewart and Martell 2014):

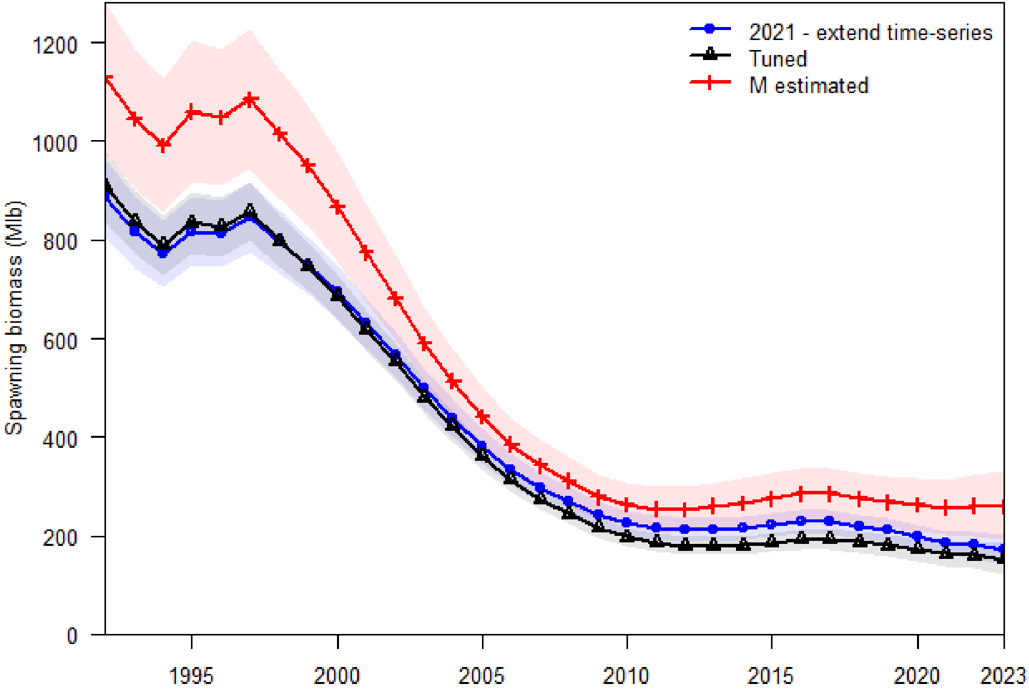
A history of stock assessments, methods employed, and major issues identified at the time.

Years	Model structure				Noted issues
	Model(s)	Spatial treatment	Natural mortality (M)	Selectivity approach	
⇐1977[a]	Yield, yield-per-recruit, simple stock-production models	Coastwide (core areas only)	Various	Simple	No growth or recruitment dynamics
1978–1981[b]	Cohort analysis	Coastwide (core areas only)	Fixed at 0.2	F-at-age by year	Unstable estimates
1982–1983[c]	Catch-AGE-ANalysis (CAGEAN)	Coastwide (core areas only)	Fixed at 0.2	Age-based	Migratory dynamics not accounted for
1984–1988[d]	CAGEAN	Coastwide and areas linked by migration	Fixed at 0.2	Age-based	"Trends differ by area"
1989–1994[e]	CAGEAN	Area-specific	Fixed at 0.2	Age-based	Retrospective pattern
1995–1997[f]	Statistical Catch-Age (SCA)	Area-specific	Fixed at 0.2	Length-based	"*M* estimate imprecise"
1998–1999[g]	SCA	Area-specific	Fixed at 0.15	Length-based	"Poor fit to the data"
2000–2002[h]	Revised SCA	Area-specific	Fixed at 0.15	Age-based	Retrospective pattern
2003–2005[i]	SCA	Area-specific	Fixed at 0.15	Length-based	"Migratory dynamics created bias"
2006–2011[j]	SCA	Coastwide (all areas)	Fixed at 0.15	Length-based	Retrospective pattern

Clark and Parma 1999:

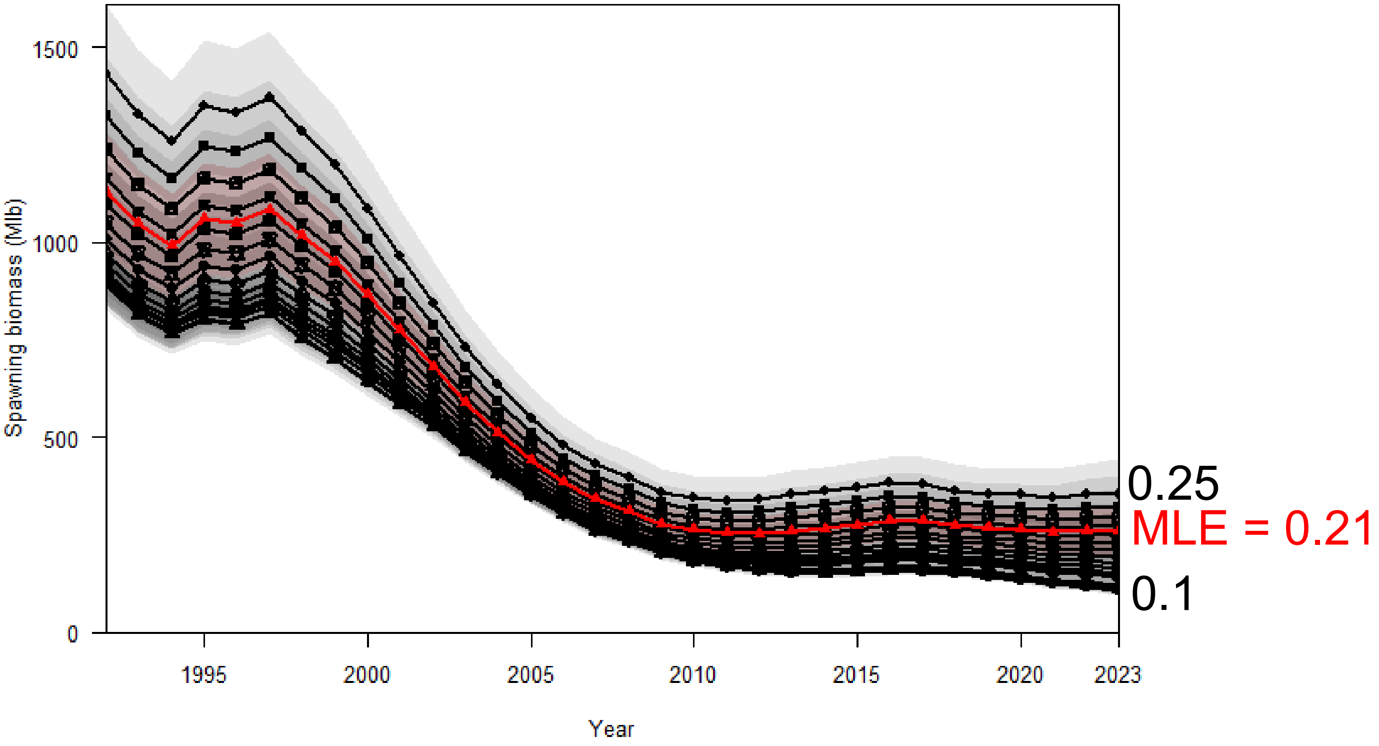
- "Until 1998 the estimate of *M* = 0.20 had been used in all assessments. This estimate is quite imprecise, and analysis done by the staff during the year suggested that a lower working value would be appropriate. The value of *M* = 0.15 was chosen and used as a standard, which lowered abundance estimates by about 30%."
- "Analysis done during the year by the staff showed that in the short term an overestimate of natural mortality could lead to a substantial overestimate of stock size when past fishing mortality rates were low, as they have been for Pacific halibut. On the other side, the consequences of an underestimate of natural mortality are less serious."

Natural mortality – short AAF model



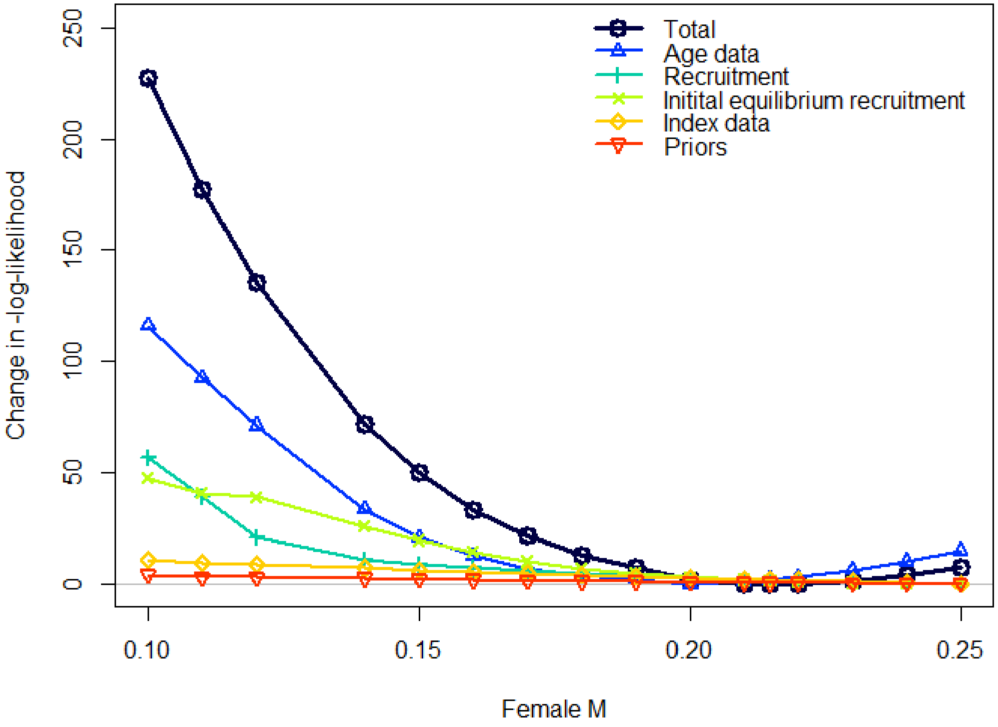
Modest effect on central tendency, large effect on uncertainty

Natural mortality – short AAF model



Scale of the estimated SB is closely correlated with M

Natural mortality – short AAF model



All data sources show improved fit at values of female M higher than 0.15

Model diagnostics and results

- Convergence criteria – no issues identified in AAF short, CW short, or CW long
- AAF long jitter analysis showed a challenging likelihood surface requiring good starting values

Model diagnostics and results

- All models generally fit the FISS and fishery indices well
- Starting from bootstrapped sample sizes only 4B age data in the AAF short and long models tuned to the input (maximum value)

Model diagnostics and results (Table 16)

	Average iterated input	Harmonic mean effective	Francis weight effective	Maximum Pearson residual
Coastwide short				
Fishery	62	294	62	2.45
Discards[1]	13	270	49	0.98
Non-directed discards[1]	5	47	39	2.25
Recreational[1]	5	114	27	0.88
FISS	242	668	242	2.06
Coastwide long				
Fishery	112	289	122	4.09
Discards[1]	6	210	90	0.78
Non-directed discards[1]	3	37	7	1.33
Recreational[1]	3	145	31	0.51
FISS	82	194	83	2.88

[1]Inputs down-weighted, and not iteratively reweighted.

Model diagnostics and results (Table 16)

	Average iterated input	Harmonic mean effective	Francis weight effective	Maximum Pearson residual
AAF short				
Region 2 fishery	723	676	1,078	4.47
Region 3 fishery	808	699	951	3.85
Region 4 fishery	23	78	36	3.54
Region 4B fishery[2]	36	138	81	1.82
Discards[1]	13	219	73	1.21
Non-directed discards[1]	5	58	22	1.12
Recreational[1]	5	143	20	0.85
Region 2 FISS	7	86	7	1.04
Region 3 FISS	18	262	18	1.25
Region 4 FISS	66	181	63	3.95
Region 4B FISS[2]	41	185	50	1.83

[1]Inputs down-weighted, and not iteratively reweighted.

[2]Iterated sample size equal to maximum (bootstrapped input).

Model diagnostics and results (Table 16)

	Average iterated input	Harmonic mean effective	Francis weight effective	Maximum Pearson residual
AAF long				
Region 2 fishery	322	304	651	4.31
Region 3 fishery	266	309	544	3.78
Region 4 fishery	18	60	28	4.36
Region 4B fishery[2]	37	129	80	1.90
Discards[1]	6	189	84	1.56
Non-directed discards[1]	3	43	8	1.12
Recreational[1]	8	151	23	0.91
Region 2 FISS	7	78	8	1.39
Region 3 FISS	12	101	13	1.26
Region 4 FISS	72	182	68	3.53
Region 4B FISS[2]	41	185	45	1.93

[1]Inputs down-weighted, and not iteratively reweighted.

[2]Iterated sample size equal to maximum (bootstrapped input).

Model diagnostics and results (Table 17)

	Model			
	Coastwide Short	Coastwide Long	AAF Short	AAF Long
Female M	0.150 (Fixed)	0.215 (0.186-0.243)	0.211 (0.195-0.227)	0.184 (0.167-0.200)
Male M	0.149 (0.138-0.159)	0.203 (0.188-0.218)	0.177 (0.167-0.187)	0.164 (0.154-0.173)
Log(R_0)	11.375 (11.167-11.582)	11.857 (11.546-12.168)	12.347 (12.115-12.579)	11.545 (11.262-11.829)
Initial log(R_0) offset	-1.469 (-1.685--1.253)	NA	-0.368 (-0.596-0.140)	NA
Environmental Link (β)	NA	0.372 (0.144-0.600)	NA	0.349 (0.129-0.569)
Survey Log(q) Δ1984 (transition to circle hooks)	NA	0.945 (0.592-1.299)	NA	R2: 1.222 (0.844-1.600) R3: 1.822 (1.553-2.092)
Fishery Log(q) Δ1984	NA	0.718 (0.541-0.895)	NA	R2: 0.586 (0.402-0.769) R3: 0.920 (0.724-1.115) R4: 0.858 (0.663-1.053) R4B: 0.529 (0.347-0.712)
2012 Recruitment (Millions)	85 (58-112)	283 (127-439)	278 (163-393)	195 (119-270)
2022 SB (Million lb)	150 (126-173)	202 (155-250)	259 (199-320)	218 (178-260)

Model diagnostics and results

- Switch to document or files as needed

Model strengths and weaknesses

- Varied
- AAF long is the most challenging technically
- Each model is internally consistent, but differs importantly from the others
- No single model clearly exceeds the others across all aspects of model fit and performance

Outline (2)

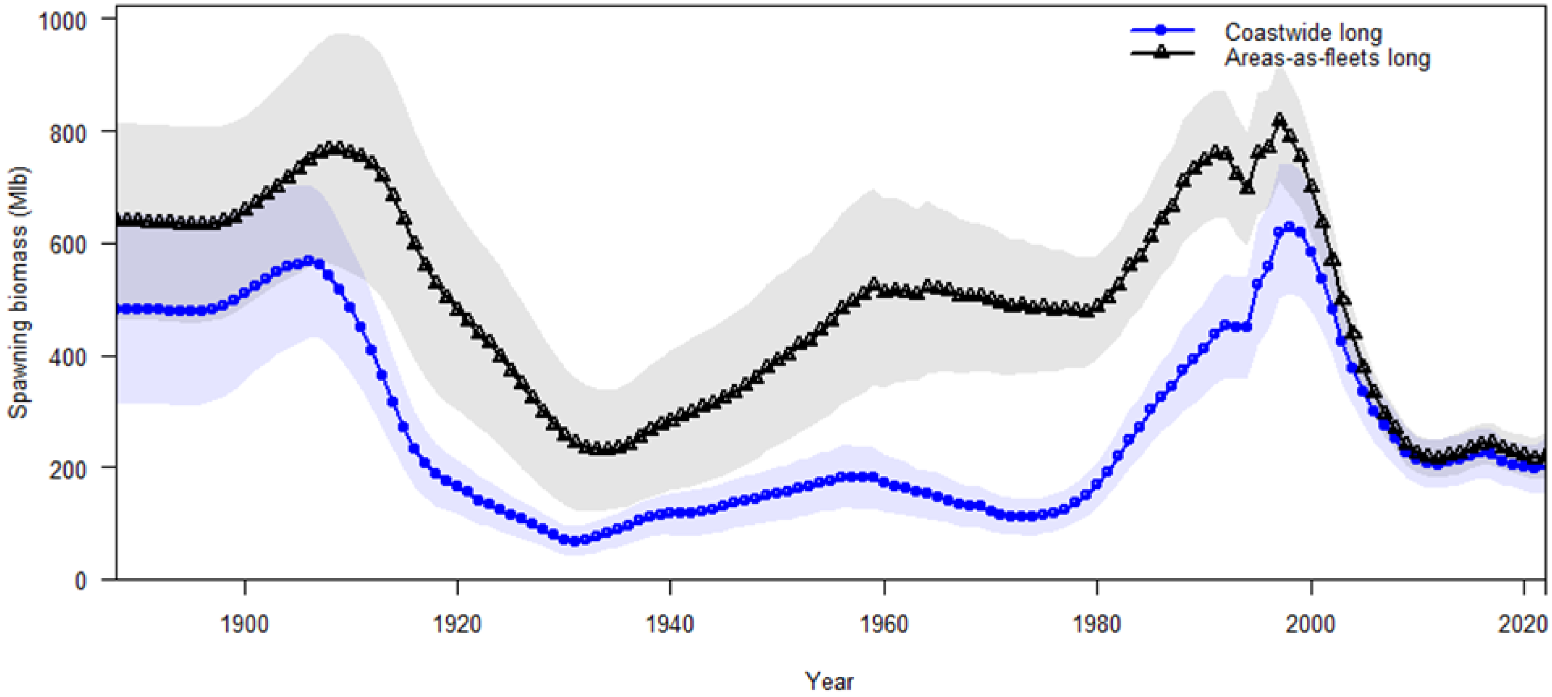
- Evaluation of uncertainty
  - Sensitivity analyses
  - Likelihood profiles
  - Retrospective analyses
  - Other considerations
- Ensemble
  - Methods
  - Weighting based on predictive skill
  - Preliminary results for 2022
- Research priorities and future development

Sensitivity analyses

- 2015: *Ensemble*, fishery *q*, M:F selectivity, *M*, *h*, historical selectivity
- 2016: *Ensemble, ma*turity, M:F selectivity, directed fishery DMRs
- 2017: *Ensemble, ma*turity, M:F selectivity, unobserved mortality (e.g., depredation)
- 2018: *Ensemble, ma*turity, M:F selectivity, unobserved mortality 2019: *Ensemble, M*, *h*, data weighting
- 2020: *Ensemble*, bridging
- 2021: *Ensemble*, unobserved mortality, PDO, maturity
- 2022: *Ensemble*, PDO, *M*

Sensitivity analyses

- Historical connectivity: long CW vs. long AAF



Treatment of the PDO

Small set of hypotheses about how recruitment is related to environmental conditions:

1. Status quo
2. Annual deviations
3. Moving average
4. Extreme values
5. Excluding the PDO

Treatment of the PDO

Test: Reduction in the Root-Mean-Squared-Error (RMSE) of the estimated recruitment deviations

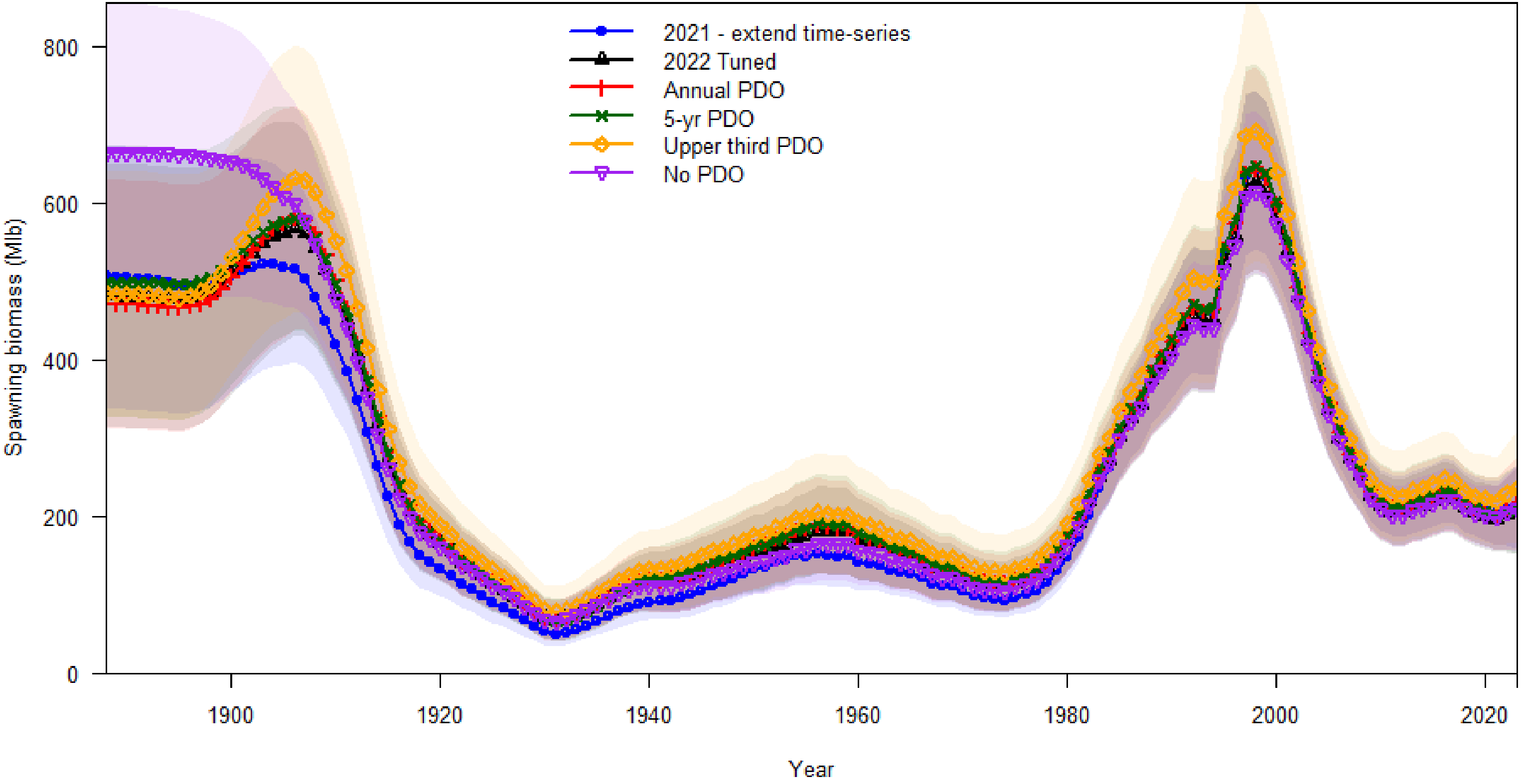
→ Have we exchanged process error for modelled process?

Treatment of the PDO (Table 18)

Treatment of the PDO	Model			
	CW long		AAF long	
	RMSE	Coefficient	RMSE	Coefficient
Status quo (binary regimes)	0.42	0.37	0.38	0.35
Annual deviations	0.44	0.45	0.38	0.38
5-year moving average	0.45	0.34	0.39	0.32
Binary on largest 1/3rd of values	0.45	0.50	Did not converge	
Exclude PDO	0.48	NA	0.42	NA

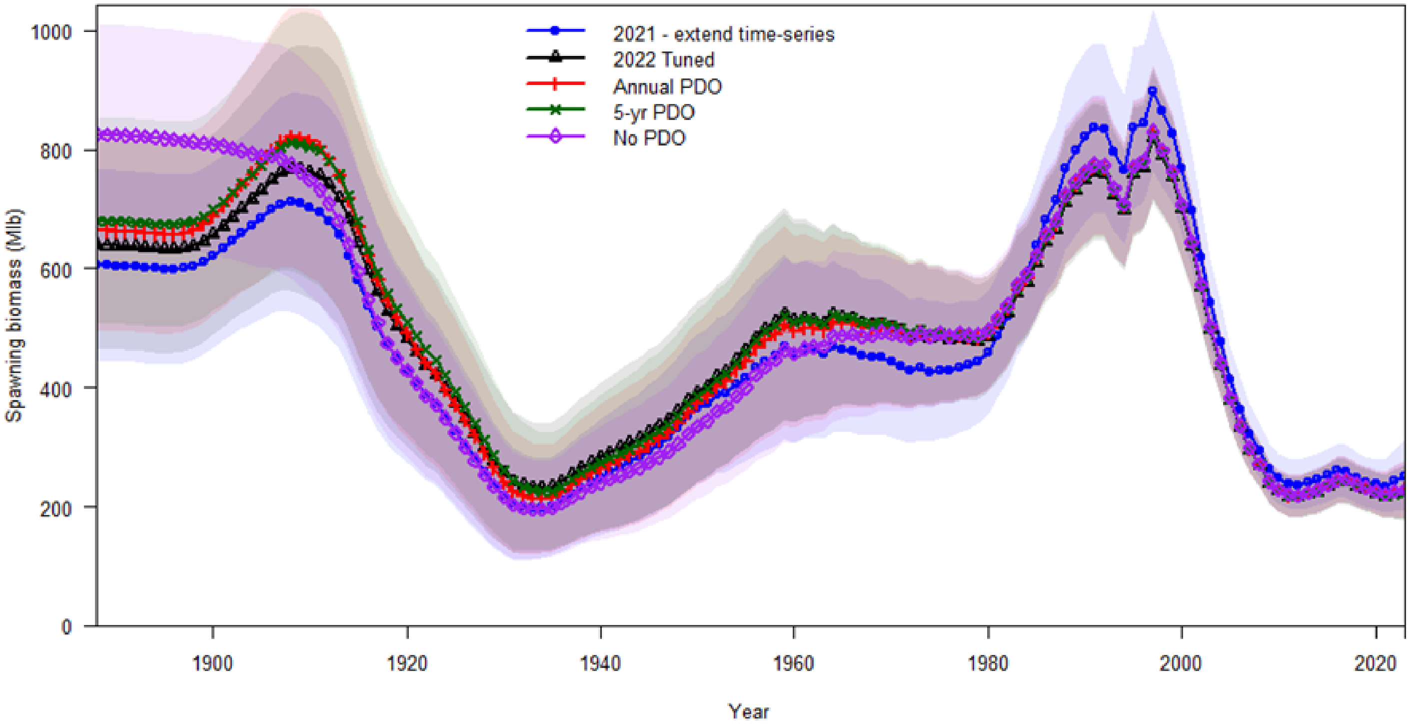
Sensitivity analyses: PDO

Coastwide long

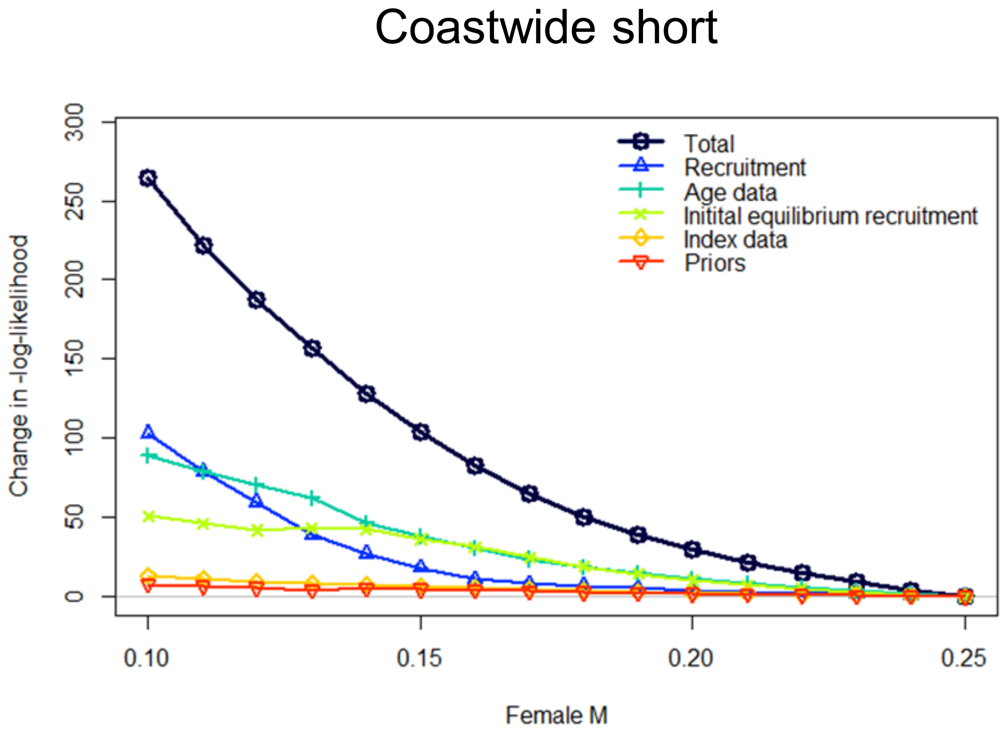


Sensitivity analyses: PDO

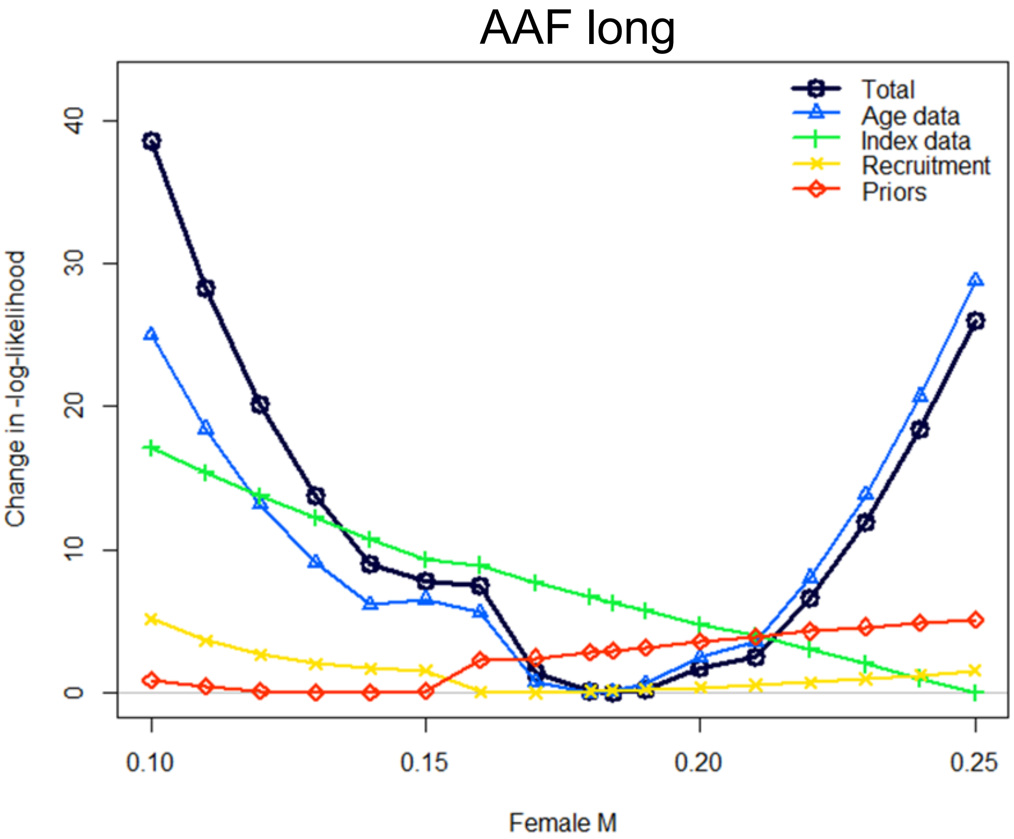
AAF long



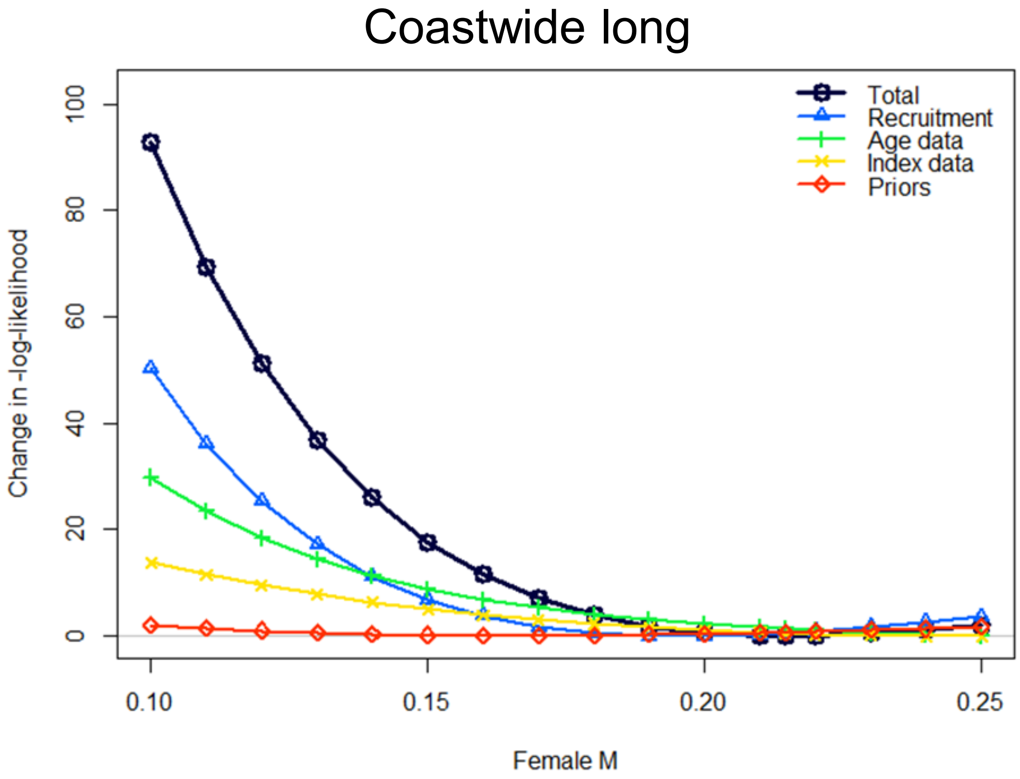
Likelihood profiles: Female M



Likelihood profiles: Female M

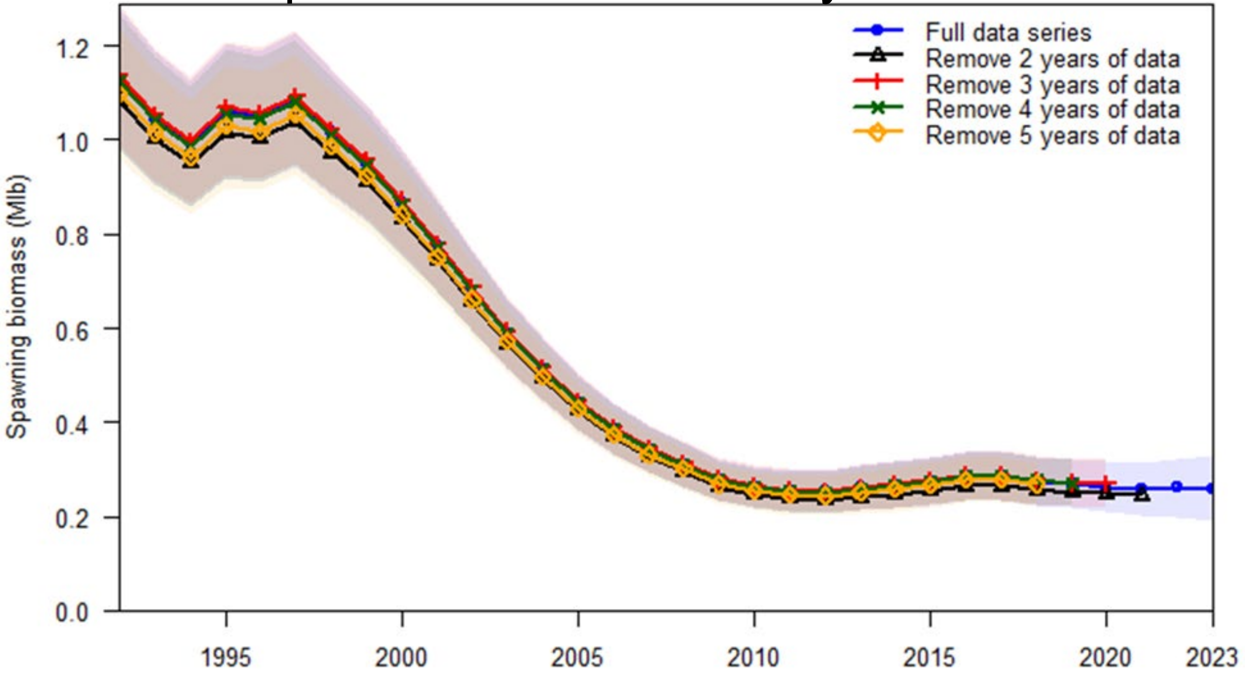


Likelihood profiles: Female M



Retrospective analyses (Figures 64-67)

- Far better performance than previous models
  - Allowing the scale of male selectivity to vary largely separates the historical period from the recent year's data



Other considerations

- No additional work done since the 2019 assessment on Bayesian models for 2022
- Spatially-explicit dynamics (e.g., alternative hypotheses about 4B, Russian waters) should continue to be considered as MSE and research program efforts are continued
- Uncertainty in sources of mortality generally addressed through sensitivity analyses; however, these could be integrated

Outline (2)

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Ensemble methods

- Random draws from each model for quantities of interest, including variance and covariance estimates
- Number (n) of replicates from each model (m) determines the weight (w) within the set of models:

$$w_m = \frac{n_m}{\sum_m n_m}$$

Weighting methods considered

- AIC
- Strength of retrospective patterns
- Fit to FISS index
- Expert opinion (*status quo*: equal weights)
- Prediction performance

Properties of weighting methods

- Does not require the same data in all models
- Inherently penalizes over- or under-parameterized models
- Based on an objective method that can be applied annually even as models, data, and performance change
- Related closely to management quantities/projections

→ Prediction performance.

FISS index is a logical proxy for the spawning biomass and the biomass available to the fisheries and therefore fishing intensity and other management quantities.

Mean Absolute Standardized Error (MASE)

$$MASE = \frac{\frac{1}{n}\sum_{t=1}^{n}|O_t - E_t|}{\frac{1}{n}\sum_{t=1}^{n}|O_t - O_{t-1}|}$$

- MASE >1: model skill is worse than the naïve prediction (last year's observation)
- 1: Equal to the naïve prediction
- <1: Better than naïve prediction
- 0: Perfect prediction

Mean Absolute Standardized Error (MASE)

$$MASE = \frac{\frac{1}{n}\sum_{t=1}^{n}\left|\frac{O_t - E_t}{\sigma_t}\right|}{\frac{1}{n}\sum_{t=1}^{n}\left|\frac{O_t - O_{t-1}}{\sigma_t}\right|}$$

- ‘Standardized’ MASE accounts for differing variance estimates for annual observations
- Interpretation of values remains unchanged

MASE weights

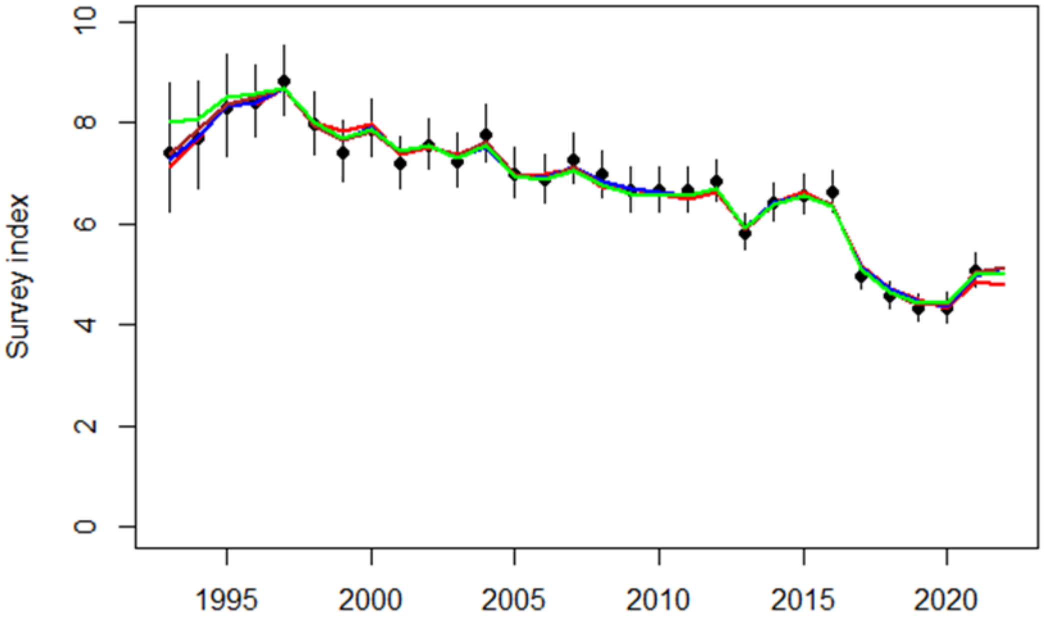
- For models with a MASE of <=1:

$$MASE\ weight_m = \frac{1 - MASE_m}{\sum_{m=1}^{M} 1 - MASE_m}$$

- A model with MASE = 1 gets zero weight
- A model with MASE = 0 gets maximum weight

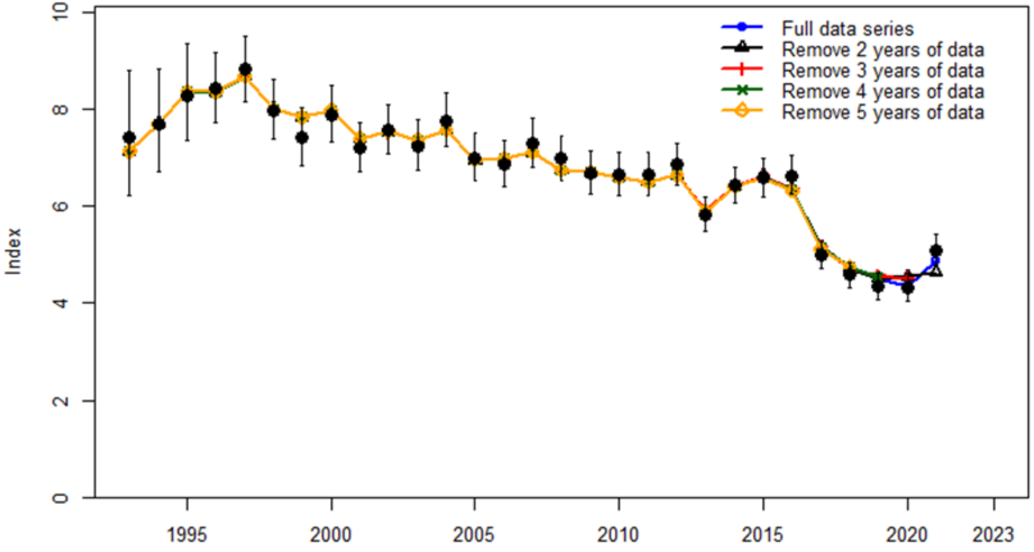
Prediction period

- Want to know the performance in predicting the unobserved index (next year's observation)

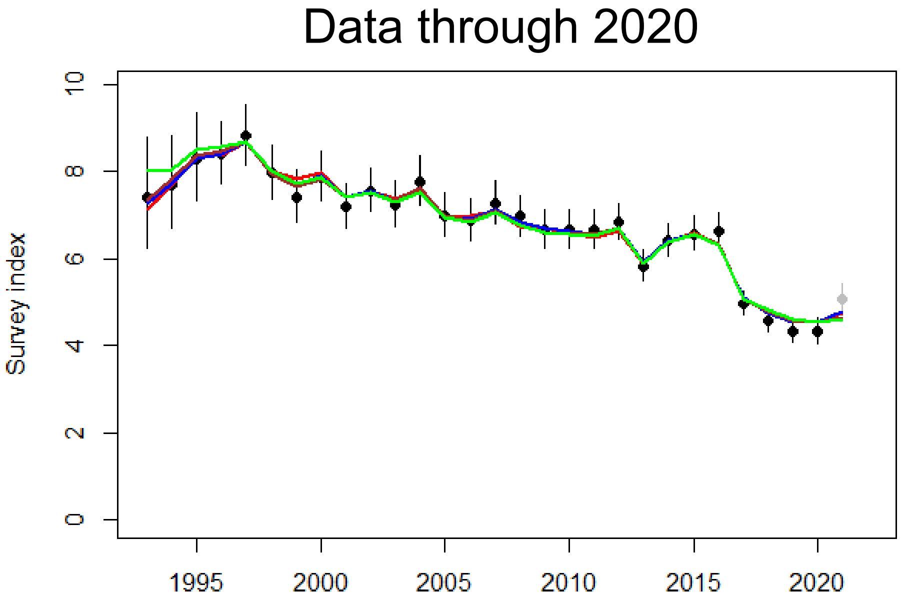


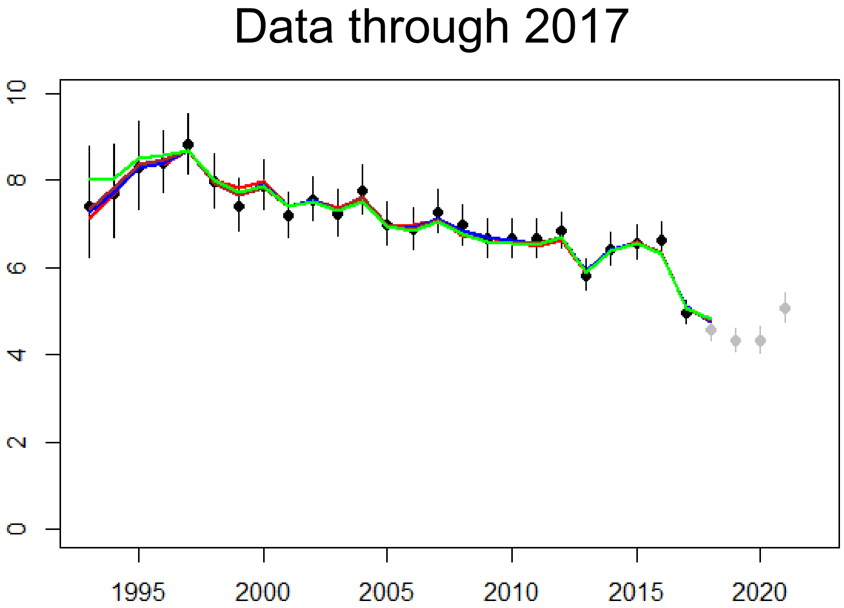
Prediction period

- By removing previous year's data and predicting forward 'recent' skill can be quantified
  - Considered a 1, 2, 3 , or 4-year average



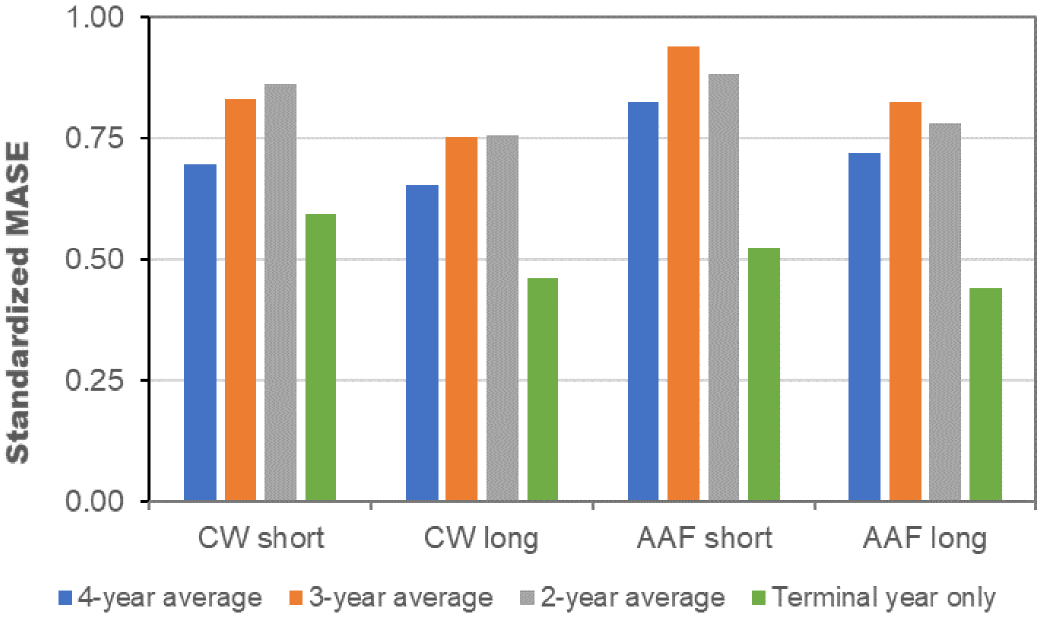
Prediction period



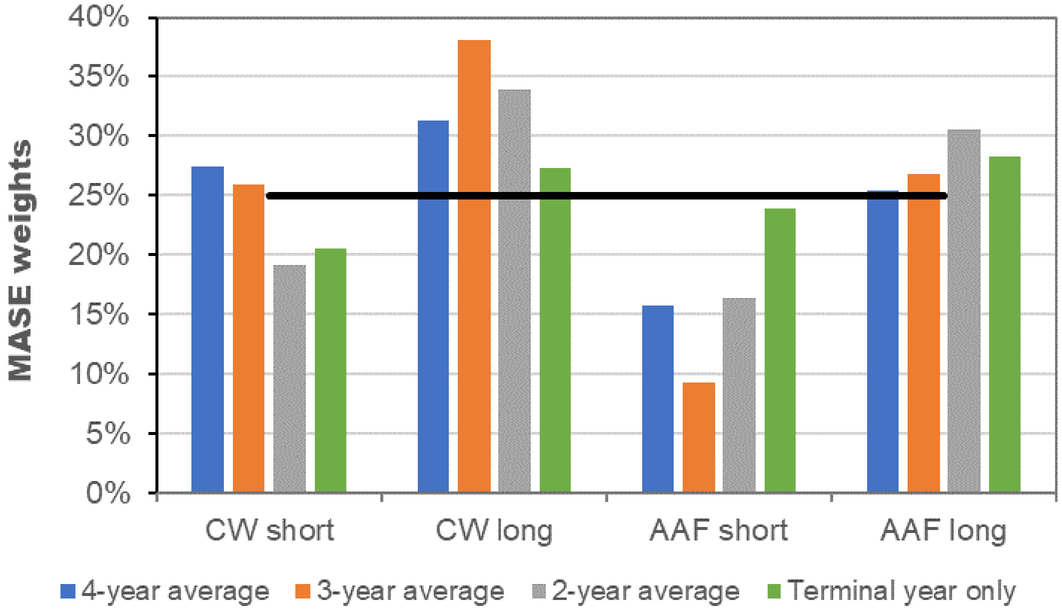


MASE estimates (Table 19)

- All models better than the naïve prediction

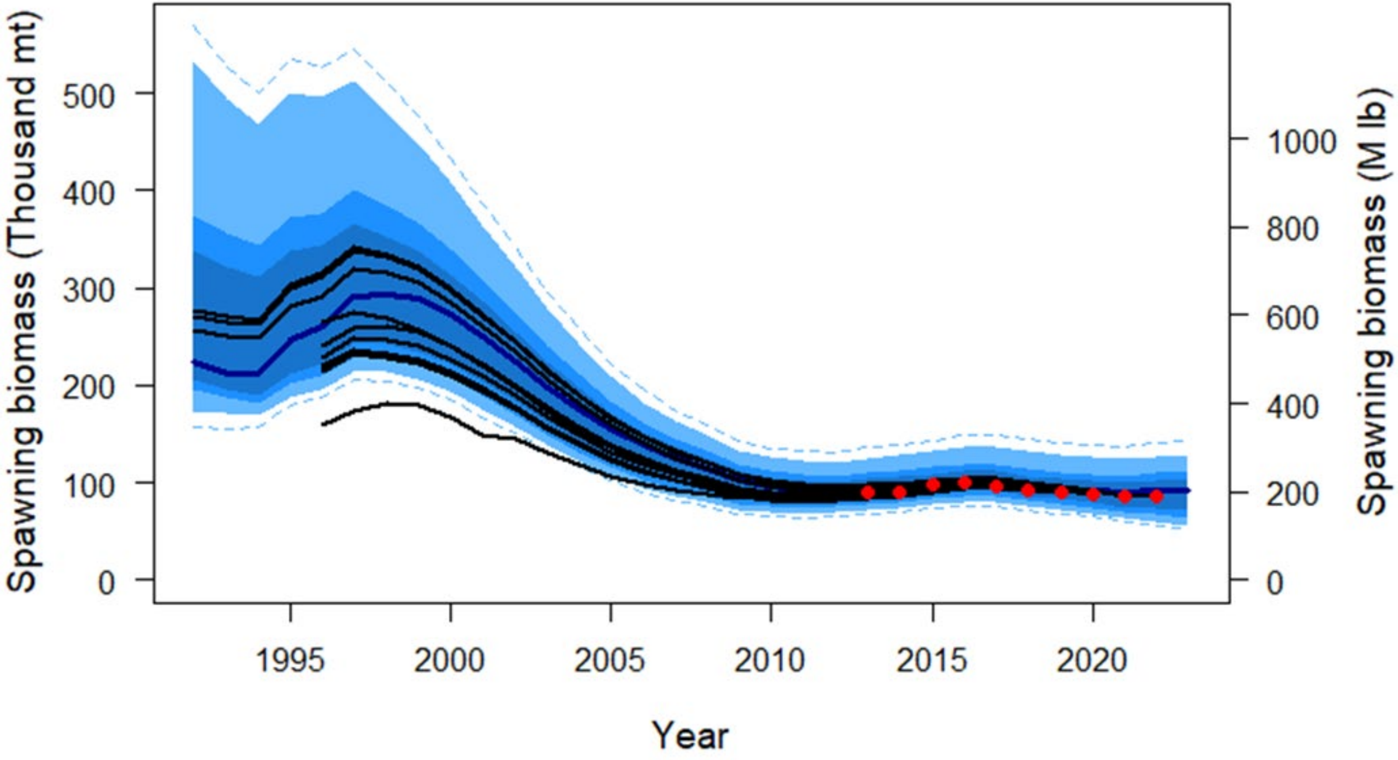


MASE weights (Table =20)

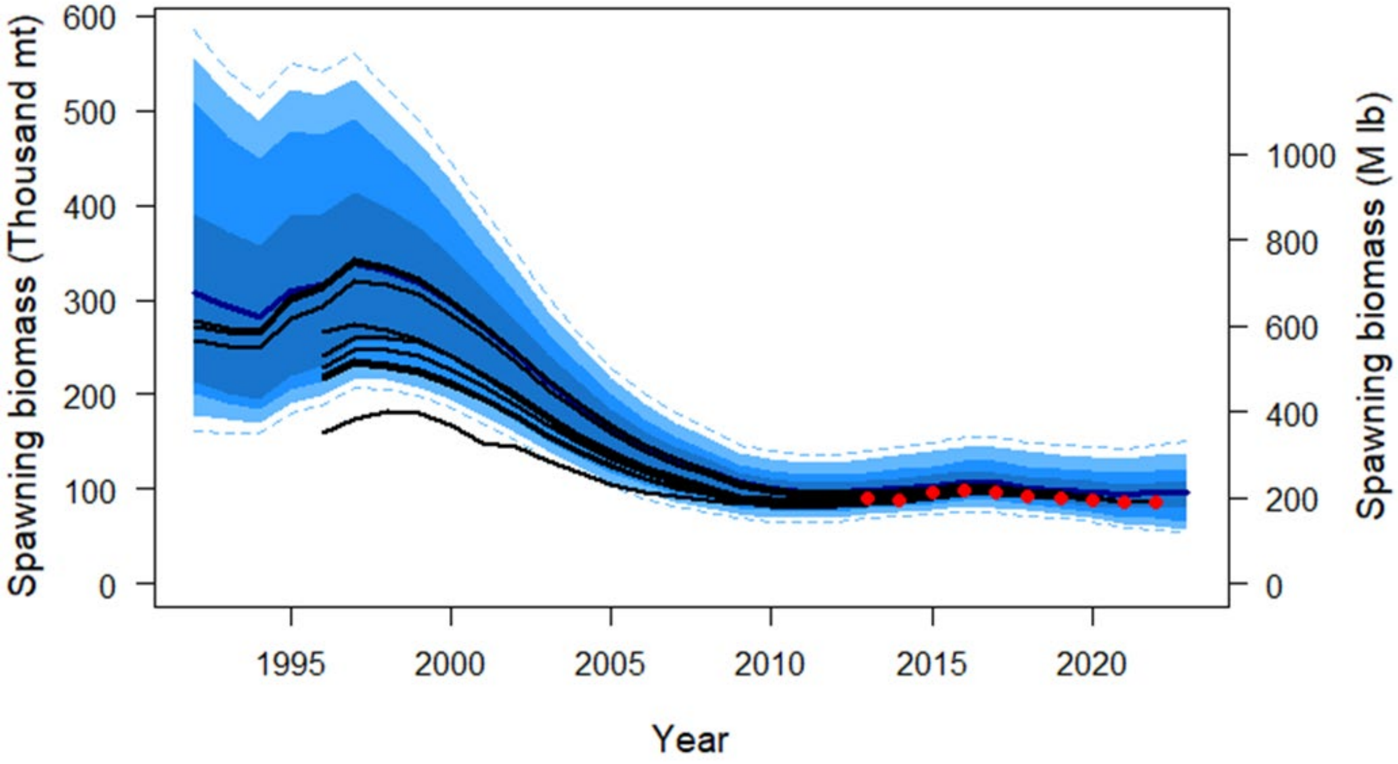


Status quo equal weights

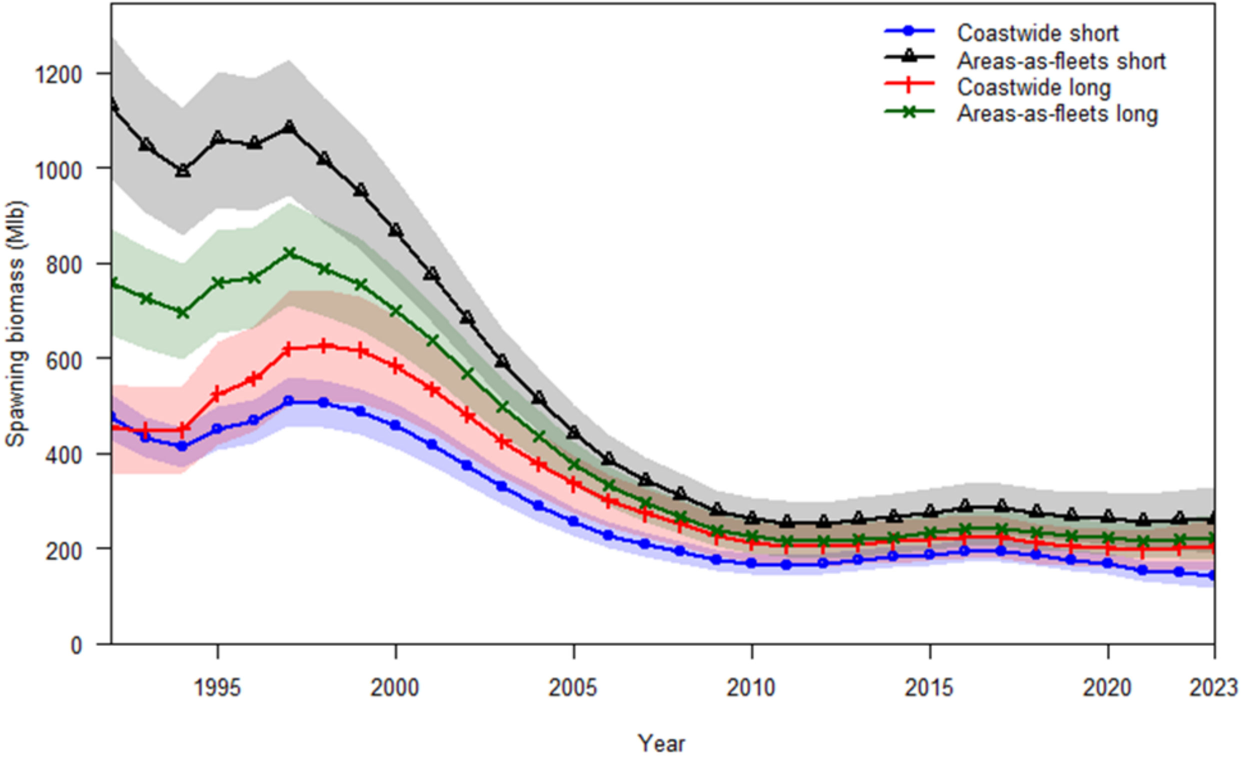
Effect on trends: 3-year MASE



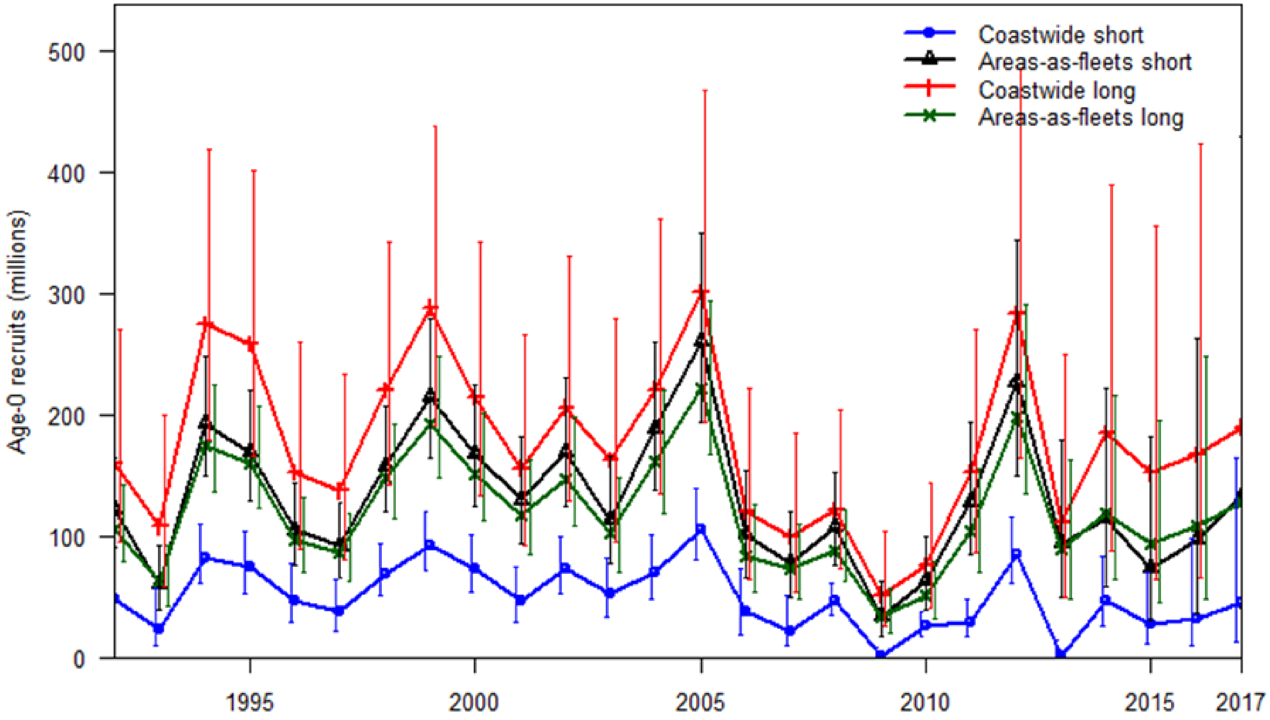
Effect on trends: 1-year MASE



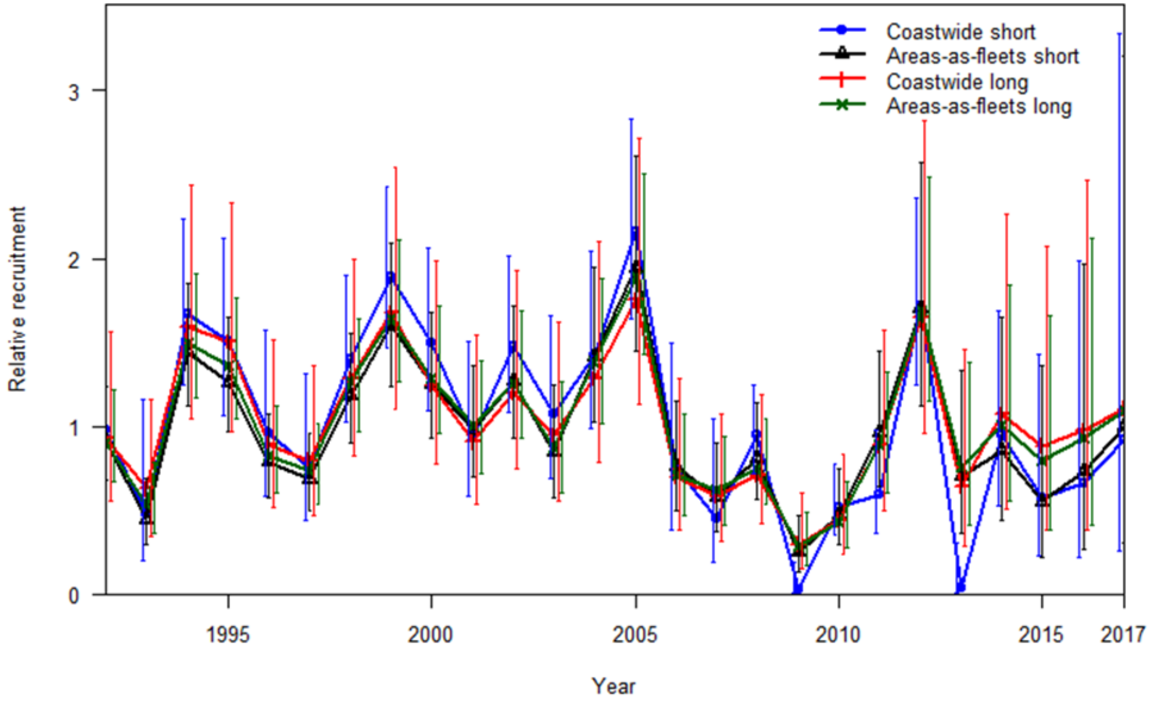
Preliminary results



Preliminary results



Preliminary results



Remaining changes for 2022

- Response to suggestions and comments from SRB020 (this meeting) and SRB021 (September)
- All 2022 data
- Sex-ratio of the 2021 commercial proportions at age

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Research priorities

- Highest priorities are elevated to the 5-year research plan
- Longer list documents and provides a record of items needing further work

Recommendation/s

That the SRB:

a) **NOTE** paper IPHC-2022-SRB020-07 which provides an overview of model development for 2022.

b) **REQUEST** any changes to be made and reviewed at SRB021.

- Key topics that would be helpful to consider:

  - Treatment of M

  - Ensemble weighting

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