INTERNATIONAL PACIFIC HALIBUT COMMISSION

Development of the 2019 stock assessment

Agenda item 6

IPHC-2019-SRB014-07

Document roadmap

Primary document (IPHC-2019-SRB014-07):
https://www.iphc.int/uploads/pdf/srb/srb014/iphc-2019-srb014-07.pdf

2018 Assessment data sources:
https://www.iphc.int/uploads/pdf/am/2019am/iphc-2019-am095-08.pdf

2018 Assessment:
https://www.iphc.int/uploads/pdf/am/2019am/iphc-2019-am095-09.pdf

Previous assessment documents:
https://www.iphc.int/management/science-and-research/stock-assessment

Electonically: All input and output files, supplementary references

Assessment history

- 2012-2015: Rapid evolution of models and the review process
- 2015: full assessment review – 4 model ensemble
- 2016-2018: updated assessments
- 2019: full assessment

Review process - SRB meetings

- June: research and development of assessment related products, major changes to assessment

  September: work meeting, informal updates for Commissioners

- September: follow up to June, minor changes as needed

  November: final data and assessment (no methods changes), Interim Meeting

- December: Optional conference call to address any issues or surprises

  January/February: Final documents and projections, Annual Meeting - mortality limits set

Outline

- Summary
- Data sources
- Model development
- Ensemble
- Research priorities

2019 Development

- Bridge analysis
  - ss version (3.24 to 3.30)
  - Sex-ratio data from 2017 (1^{st} in 100 yrs!) and M:F selectivity
  - Short time-series models extended to 1992
  - Revised survey time-series including improved whale depredation criteria
  - Retuning each model for internal consistency
    - S-R function (σR, bias-correction)
    - Observation error (Francis method)
    - Process error (selectivity and catchability)
- Sensitivity and retrospectives
- Potential extensions to the ensemble

2019 summary of preliminary results

- Version and survey series: little effect
- Model tuning far more stable than in 2015
  - ‘Linch pin’: sex-ratio data eliminated links between survey and fishery selectivity
- Estimated biomass increased slightly
  - More females in landings → more females in the population
- Estimated fishing intensity increased
  - More females in the landings → larger effect on SPR
- Stock trends very similar to previous assessments

Outline

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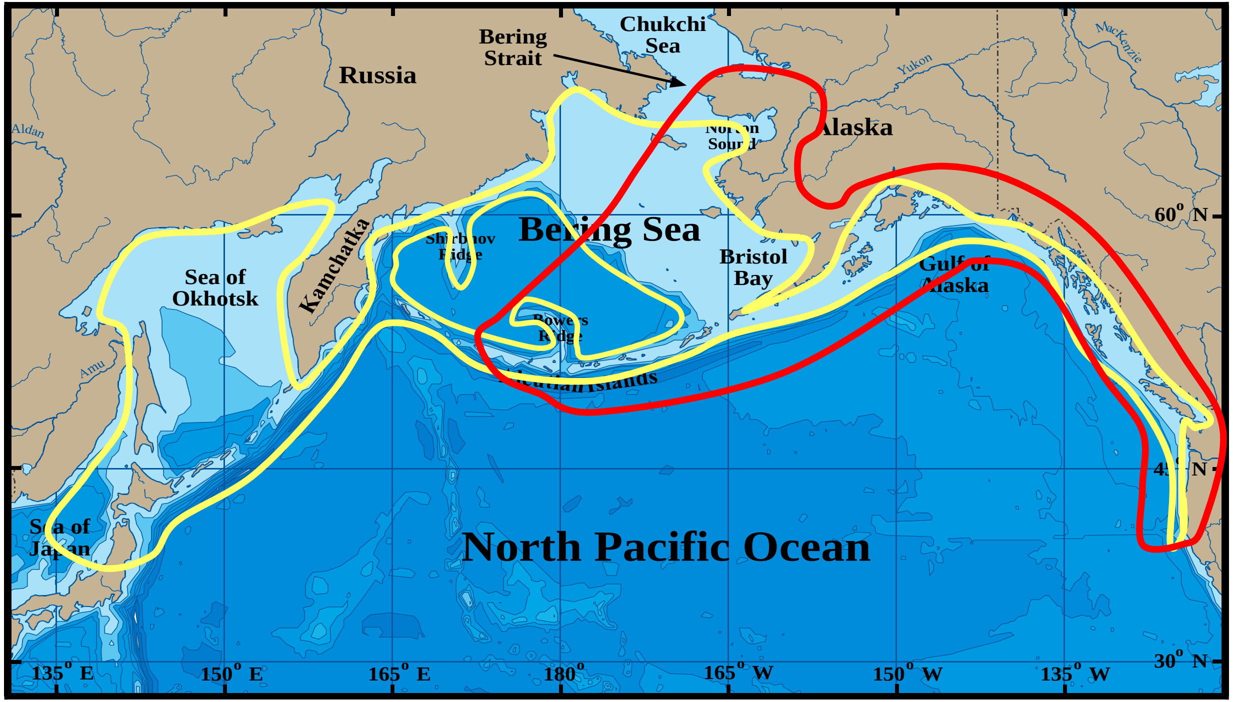
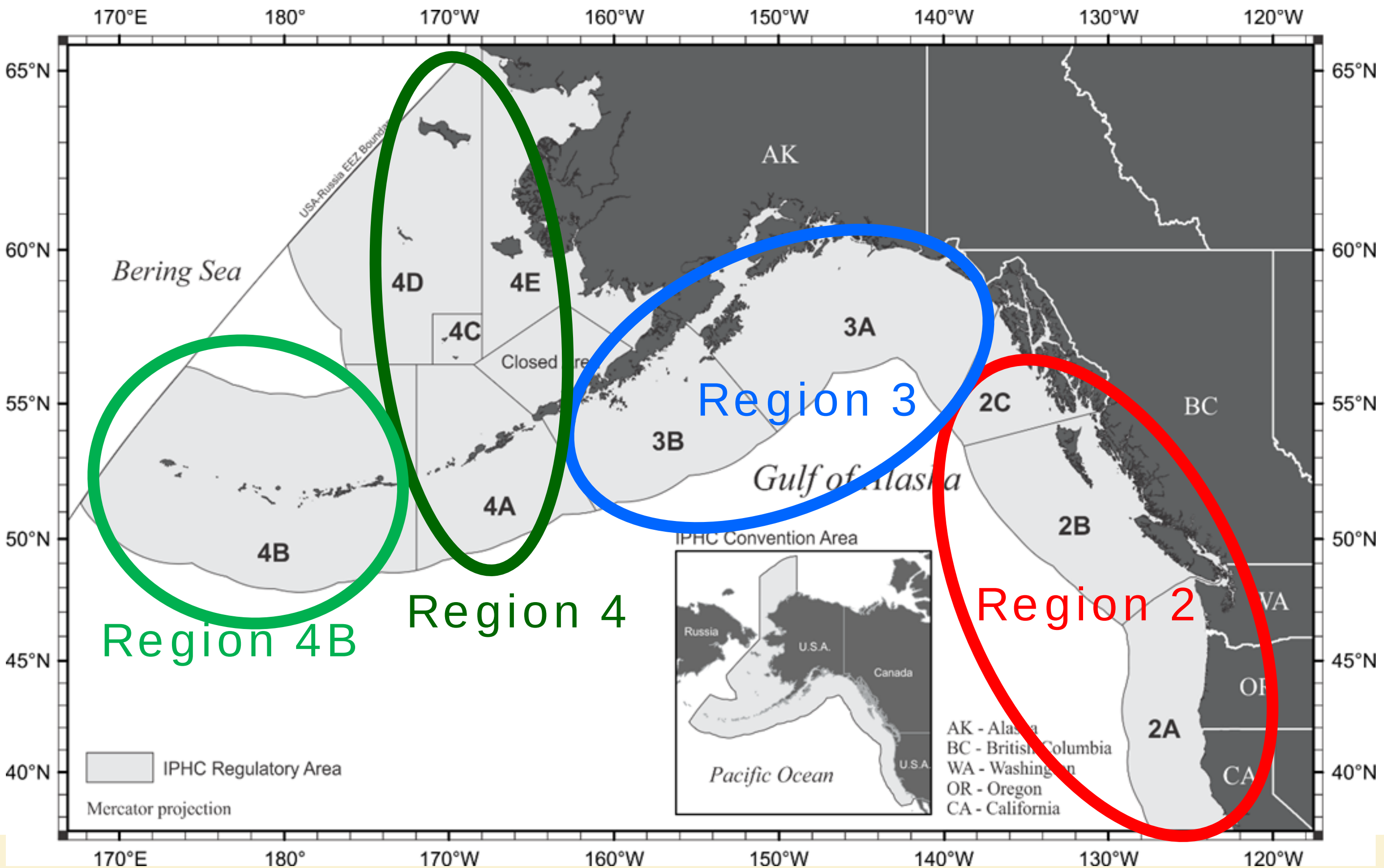
Distribution



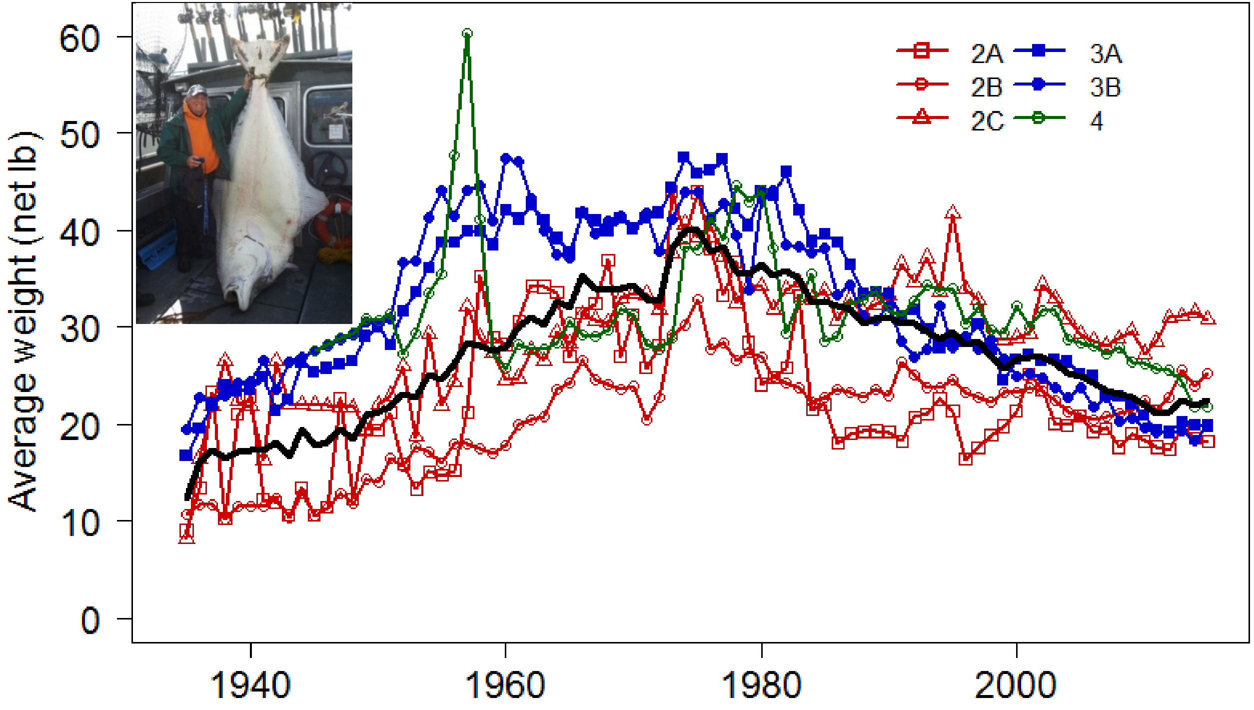
Biological regions



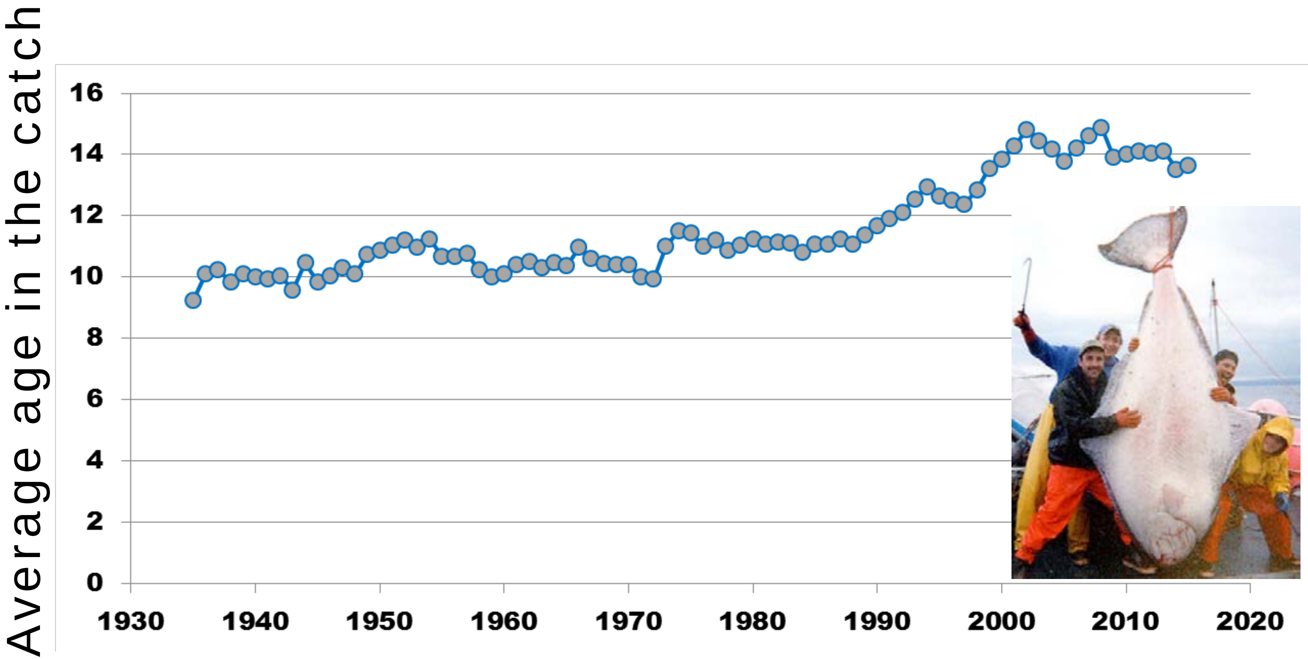
Relevant biology

- High rates of movement: age- and likely sex-dependent
  - No clear genetic stock structure (yet)
- Biological patterns (age, size-at-age, weight-at-length) among regions
- Moderately long-lived: max 55 years (8 fish >50 in survey)
- Highly dimorphic: almost all fish >100 lbs are females
- Maturity (current understanding): 50% at 11-12 yrs
  - Compare to average age in fishery: 10-14 yrs
- Large changes in size via size-at-age

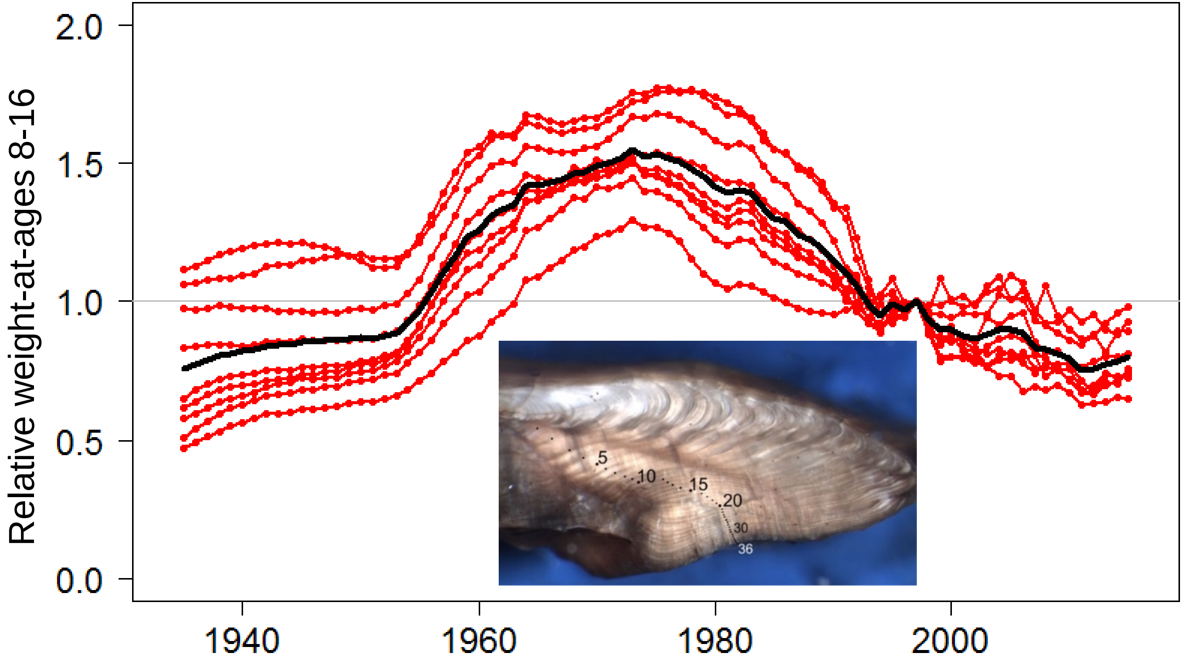
Biology: fish size in the catch



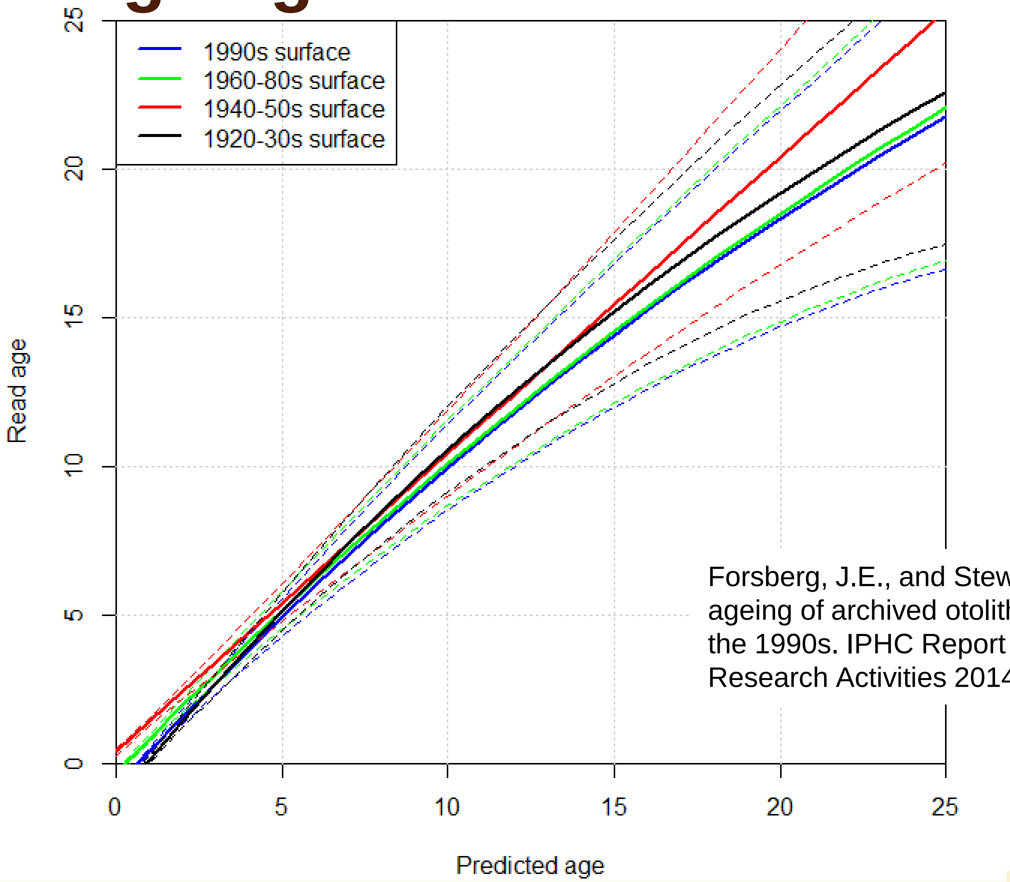
Average age in the catch



Biology: weight-at-age



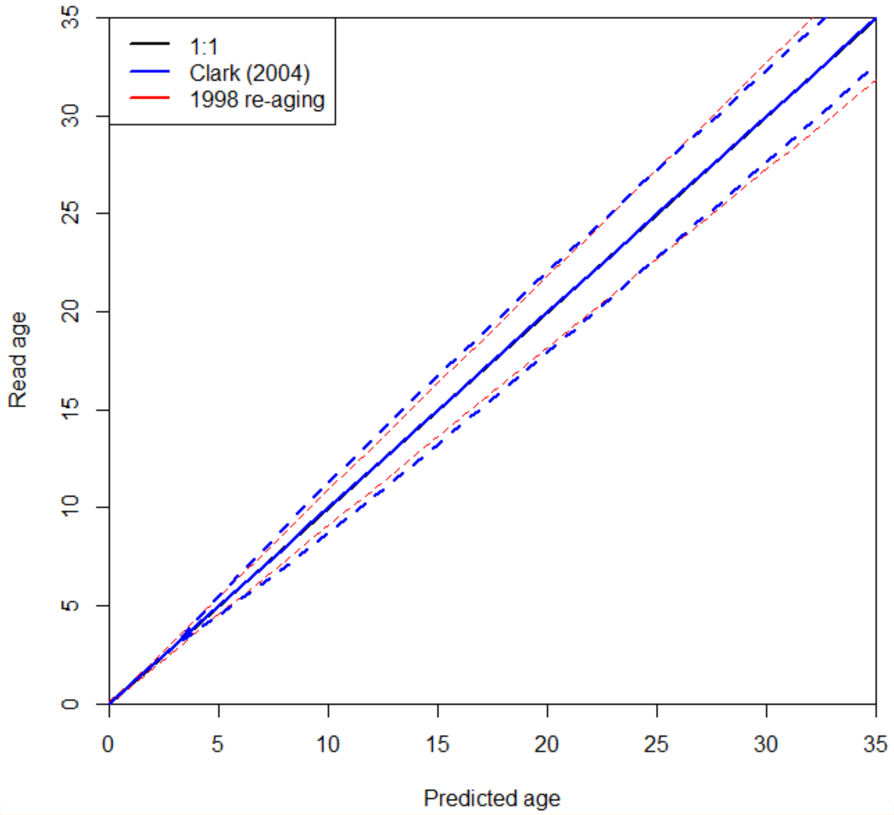
Re-ageing from the archives



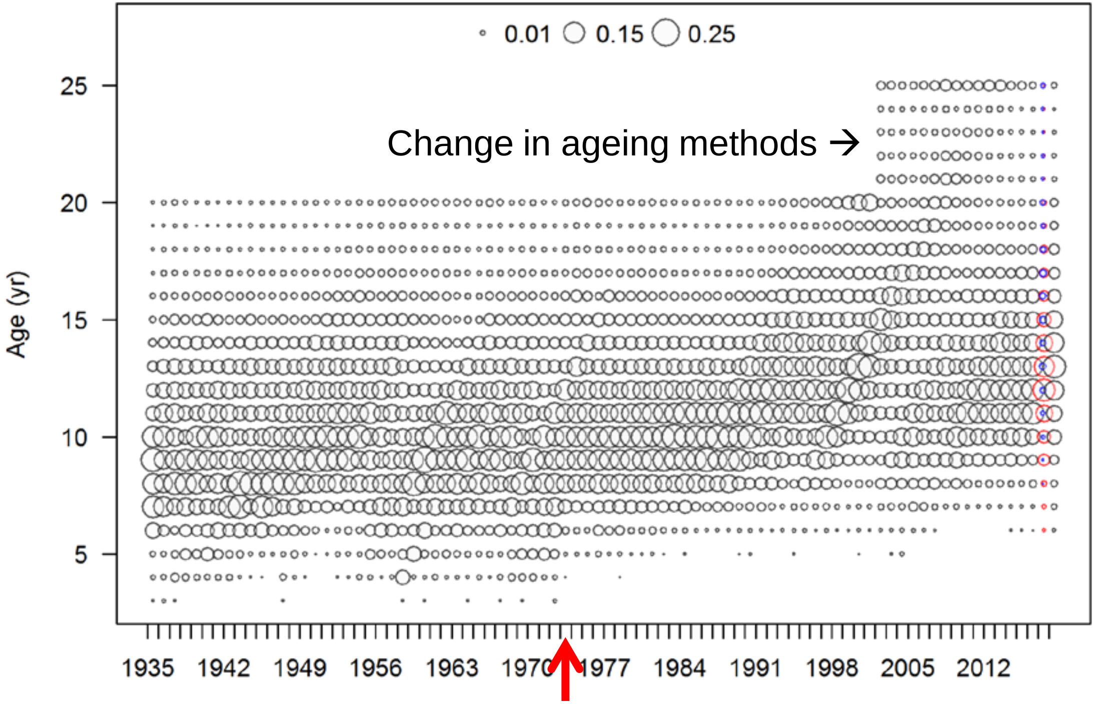
Forsberg, J.E., and Stewart, I.J. 2015. Re-ageing of archived otoliths from the 1920s to the 1990s. IPHC Report of Assessment and Research Activities 2014. p. 405-428.

Ageing error (break-and-bake)

- Precise
- Unbiased

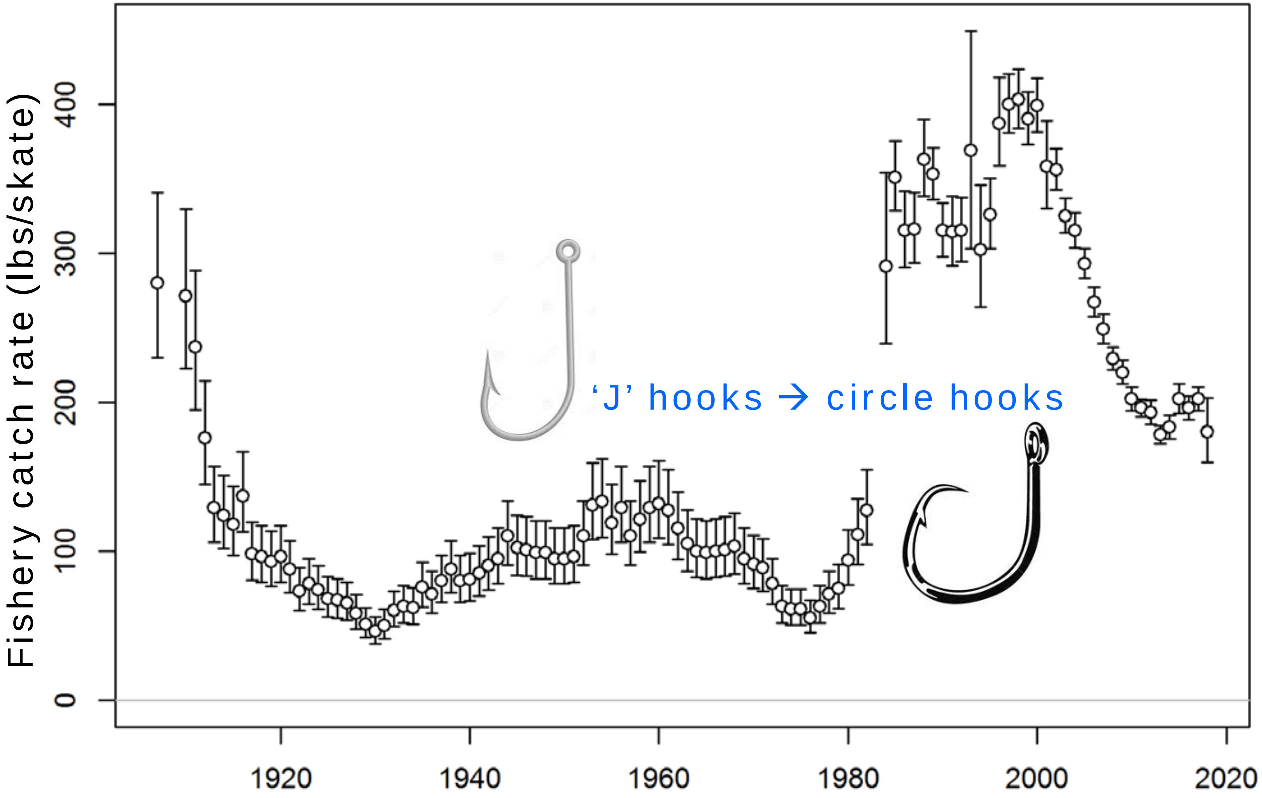


Age-frequency data to 2018

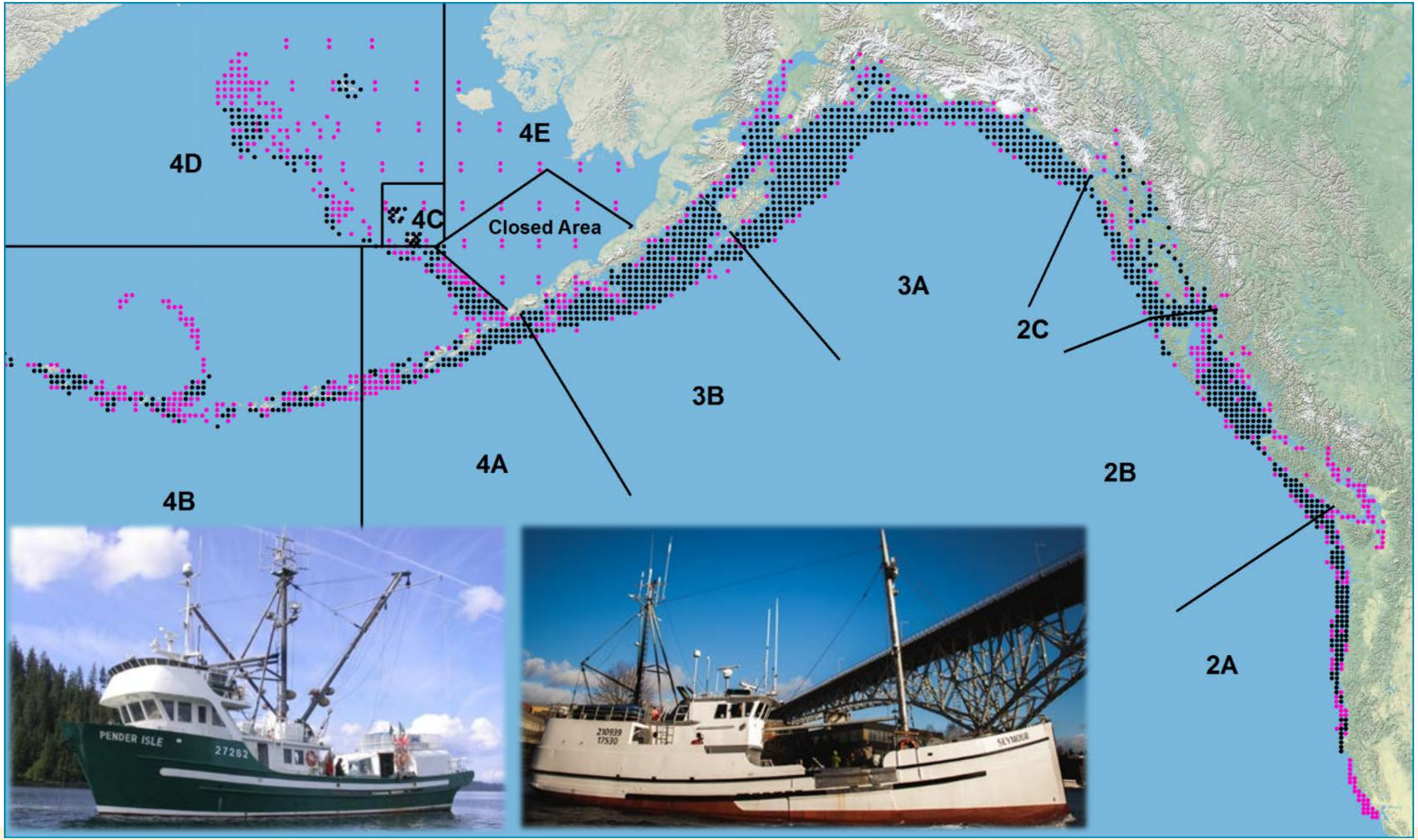


1973: 32” minimum size limit

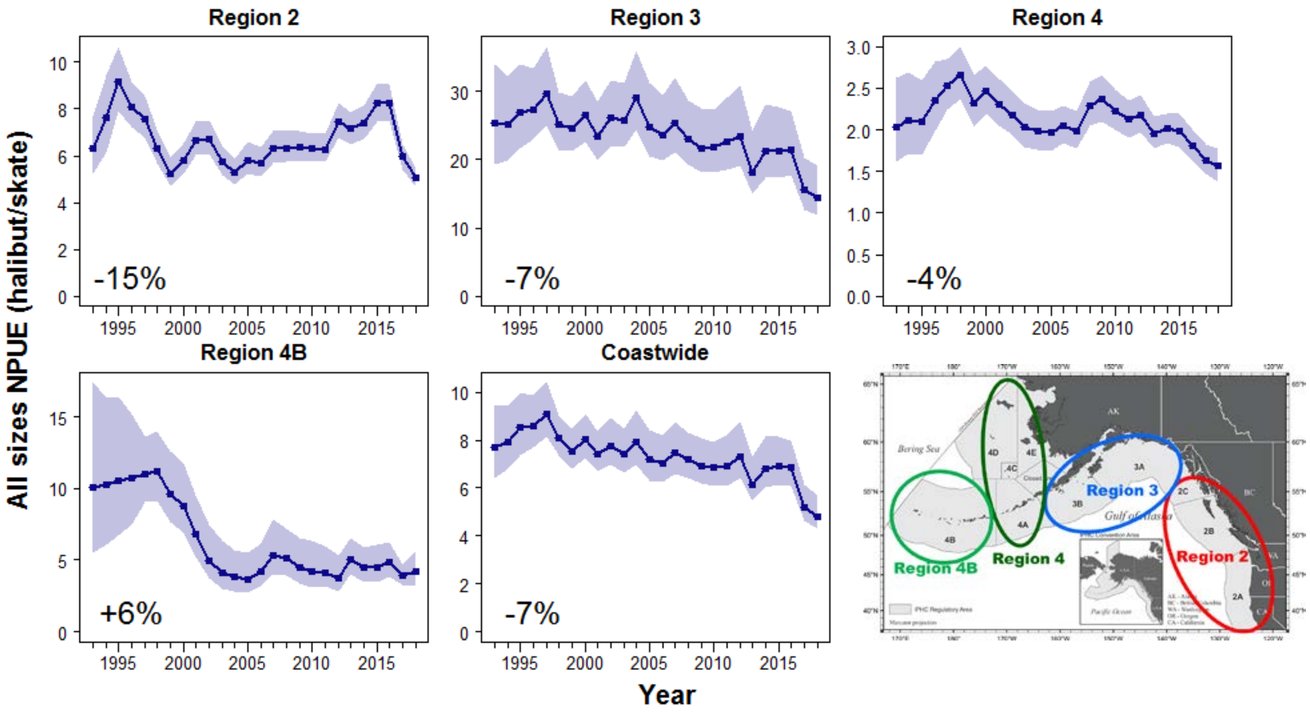
Catch rates to 2018



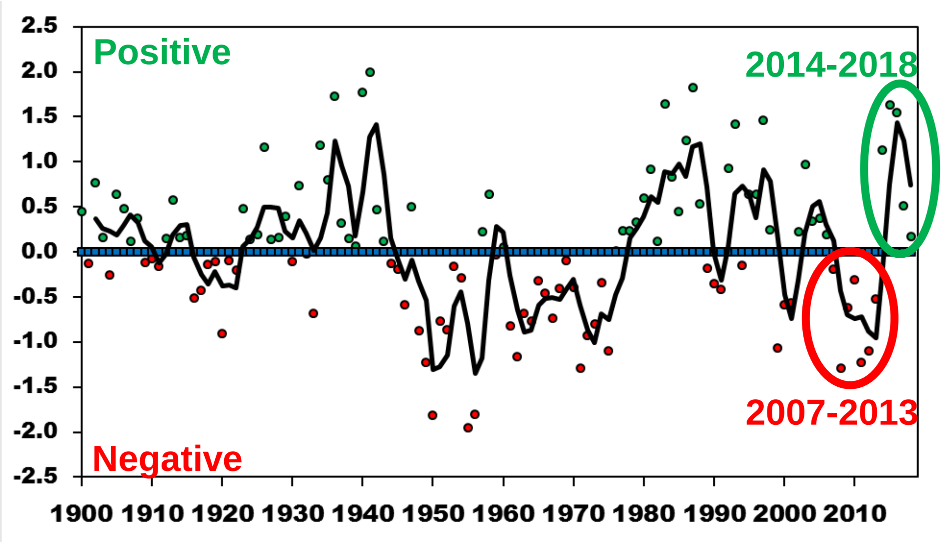
Fishery Independent Setline Survey: 1993+



Survey Numbers-Per-Unit-Effort

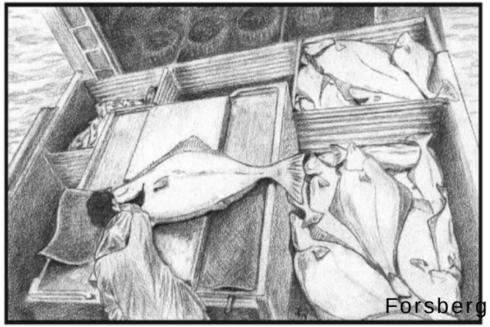


Pacific Decadal Oscillation (PDO)



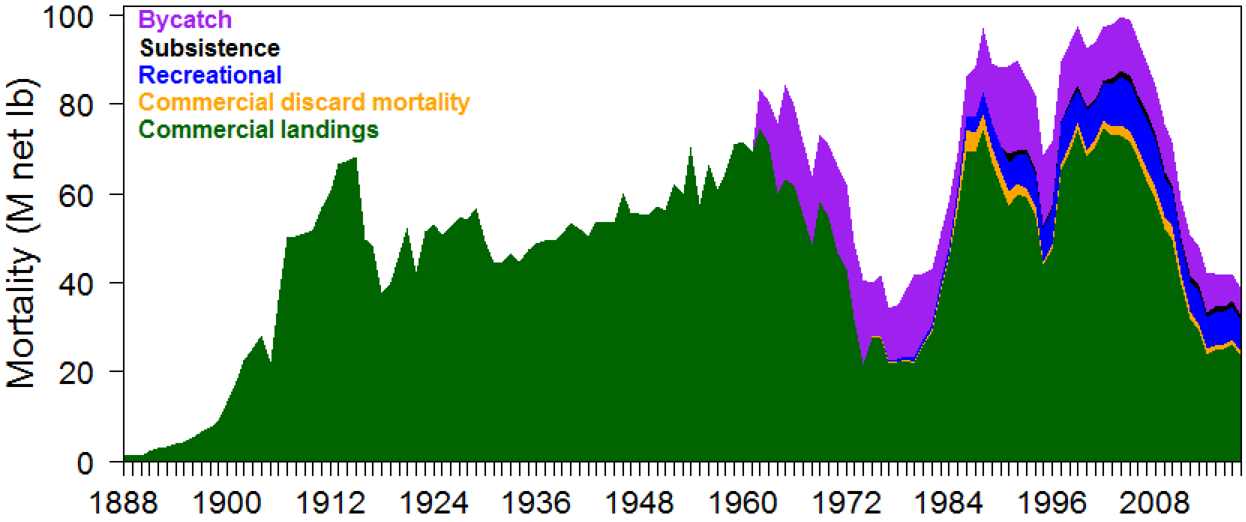
Clark, W.G., and Hare, S.R. 2002. Effects of Climate and Stock Size on Recruitment and Growth of Pacific Halibut. N. Am. J. Fish. Man. 22: 852-862.

Relevant management



- 32” Commercial minimum size limit
- Commercial seasons: March-November
  - Compare to survey: 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

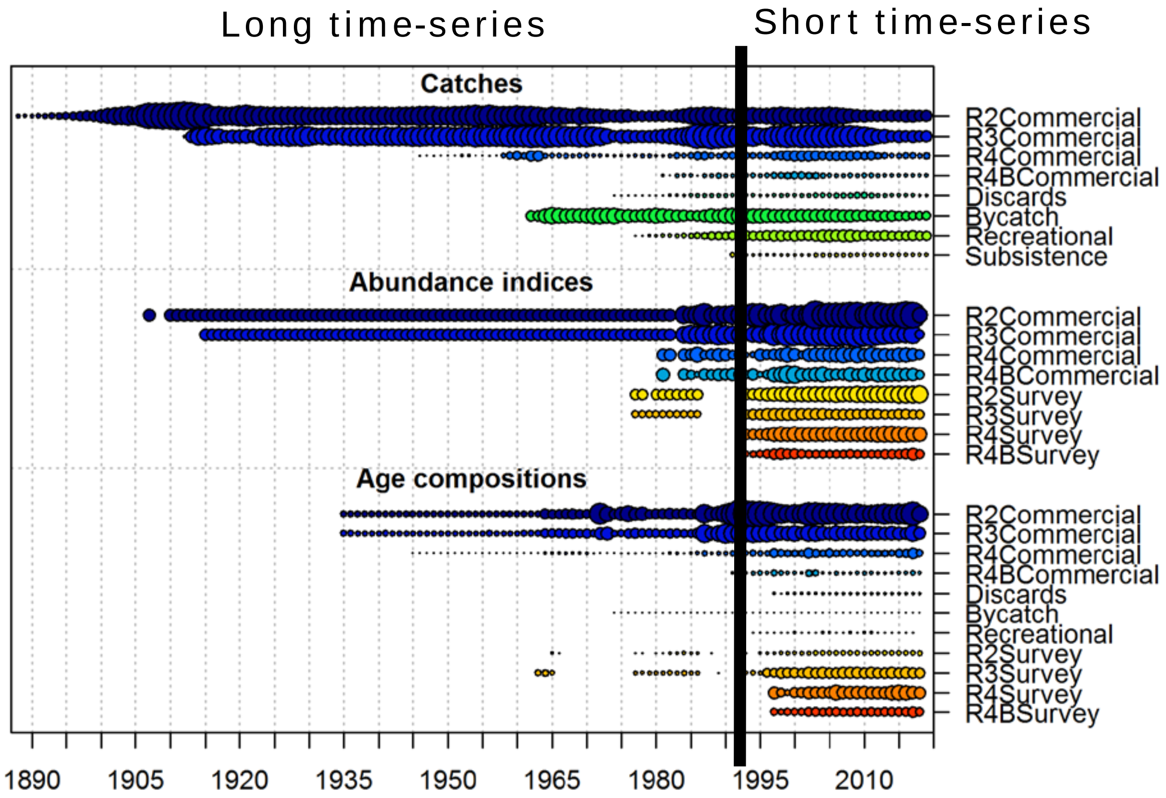
Mortality to 2018



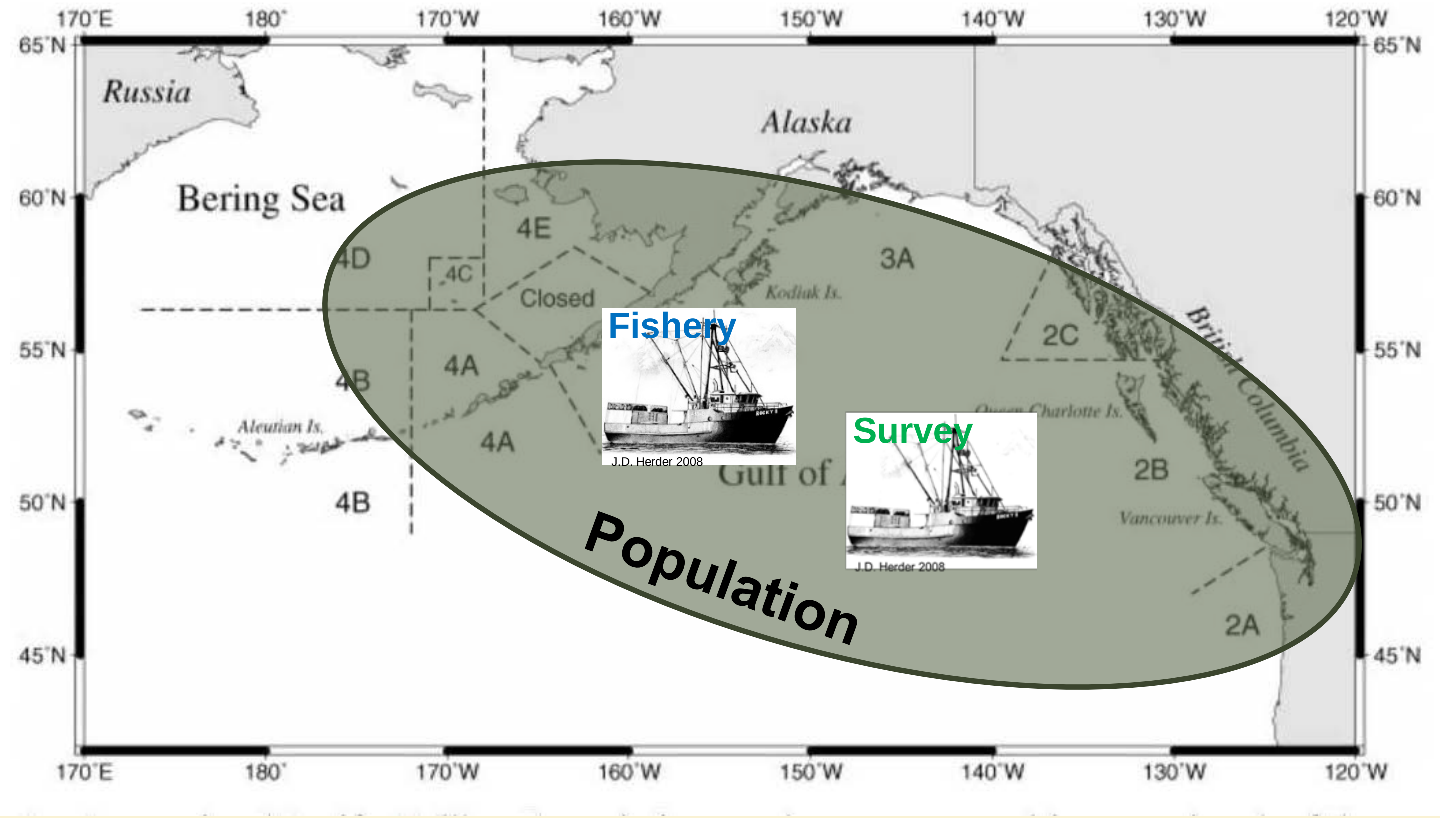
Data overview

	Model			
	Coastwide Short	Coastwide Long	AAF Short	AAF Long
Modelled period	1992-2019	1888-2019	1992-2019	1888-2019
Data partitions	N/A	N/A	Region 2, 3, 4, 4B	Region 2, 3, 4, 4B
Commercial Fishery fleets	1	1	4	4
Other fishing fleets	4	4	4	4
Survey fleets	1	1	4	4
Fishery CPUE (weight)	1992+	1907+	1992+	1907+, 1915+, 1981+, 1981+
Fishery age data years	1992+	1935+	1992+	1935+, 1935+, 1945+, 1991+
Survey CPUE (numbers)	1993+	1993+	1992+, 1992+, 1993+, 1993+	1977+, 1977+, 1993+, 1993+
Survey age data years	1993+	1963+	1992+, 1992+, 1997+, 1997+	1965+, 1963+, 1997+, 1997+
Weight-at-age	Aggregate	Aggregate	Region 2, 3, 4	Region 2, 3, 4

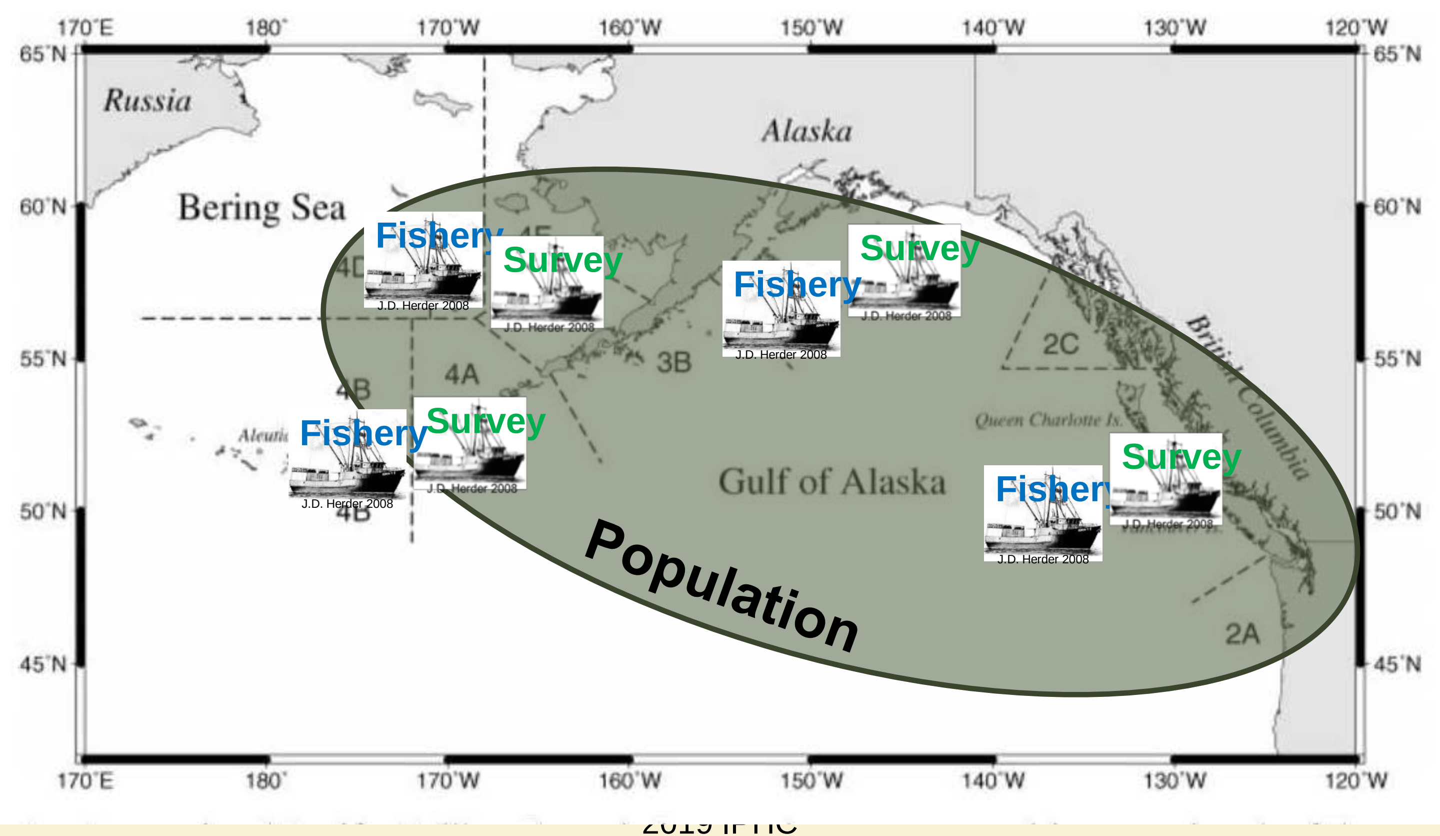
Data overview



Coastwide models



Areas-As-Fleets models



‘Other’ model inputs

(Table 8)

Input	Summary	Key assumptions
Pacific Decadal Oscillation index	Monthly values (http://jisao.washington.edu/pdo/) averaged and compiled into a binary index for each year based on assignment to ‘positive’ and ‘negative’ phases	Only used as a binary indicator rather than annually varying values.
Maturity	Trimmed logistic from Clark and Hare (2006); 50% female maturity at 11.6 years old.	Based on visual assessments, treated as age-based and time-invariant.
Fecundity	Assumed to be proportional to body weight.	Temporal variability only via changes in weight-at-age.
Weight-at-age	Reconstructed from survey and fishery information by Biological Region.	Temporal variability has been similar for female and male Pacific halibut.
Length-weight relationship	Not used directly in the assessment, most of the historical data relies on a constant average length-weight relationship.	Relationship has been shown to differ over space and time (Webster and Erikson 2017) and so may not provide an accurate translation from numbers to weight in some circumstances.
Ageing error	Pacific halibut are relatively easy to age accurately and with a high degree of precision using the break-and-bake method (Clark 2004a, 2004b; Clark and Hare 2006; Piner and Wischnioski 2004). Surface ages are biased and less precise (Stewart 2014).	Multi-decadal comparison suggest that accuracy and precision have not changed appreciably over the entire historical record (Forsberg and Stewart 2015).
Bycatch selectivity prior	Age-distributions are created from weighted and aggregated length frequencies from a variety of sources and age-length keys from trawl surveys.	Due to incomplete sampling, poor data quality in many years, and other uncertainties data are considered unreliable for estimation of recruitment.
Discard selectivity prior	Age-distributions of sub-legal (<32 inch) Pacific Halibut captured by the FISS are used as a proxy for poorly sampled directed commercial fishery discards.	Survey data may not be representative of commercial fishing behavior, but are currently the only source of information on the age range of discarded fish.
Recreational selectivity prior	Weighted age-frequency data from the IPHC Regulatory Area 3A recreational fishery are the only comprehensive source available.	These data may not be representative of all recreational mortality, but provide the best information currently available.

Outline

- Summary
- Data sources
- Model development
- Ensemble
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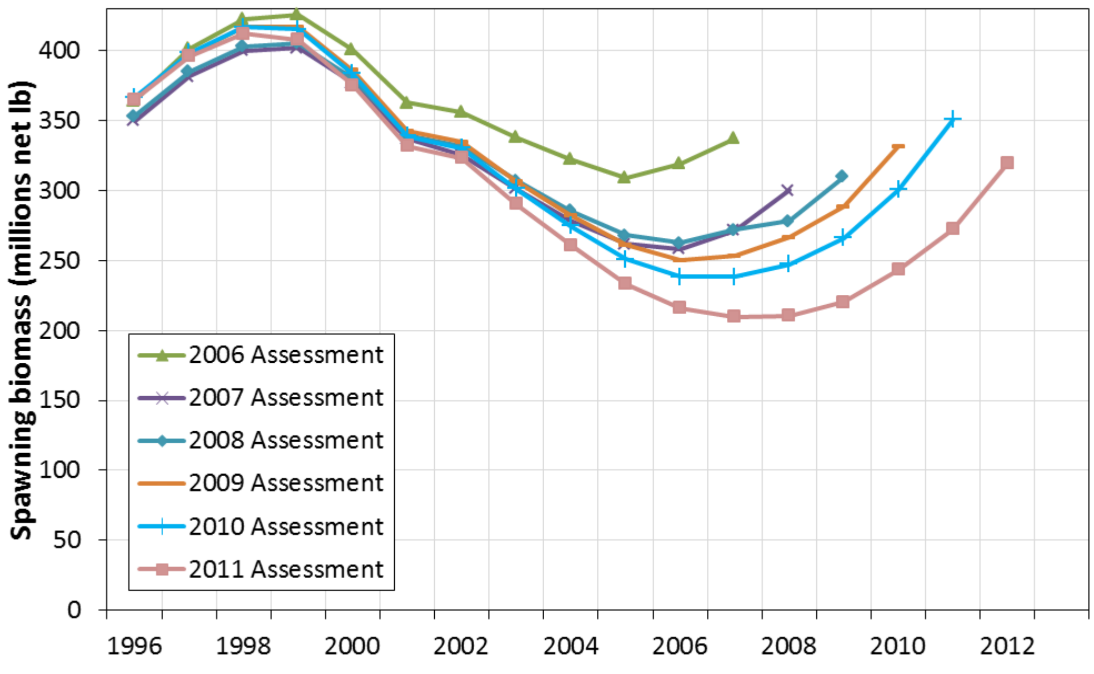
Assessment history

Years	Model	Issues
Pre-1977	Yield, yield-per-recruit, simple stock-production models	No growth or recruitment variability
1978-1981	Cohort analysis, coastwide, natural mortality (M)=0.2	Unstable estimates
1982-1983	Catch-AGE-ANalysis (CAGEAN; age-based availability), coastwide, M=0.2	Migratory dynamics not accounted for
1984-1988	CAGEAN, area-specific, migratory and coastwide, M=0.2	Trends differ by area
1989-1994	CAGEAN, area-specific, M=0.2, age-based selectivity	Retrospective pattern
1995-1997	Statistical Catch-Age (SCA), area-specific, length-based selectivity, M=0.2	M estimate imprecise
1998-1999	SCA, area-specific, length-based selectivity, M=0.15	Poor fit to data
2000-2002	New SCA, area-specific, constant age-based selectivity, M=0.15	Retrospective pattern
2003-2006	SCA, area-specific, constant length-based selectivity, M=0.15	Migratory dynamics created bias
2006-2011	SCA, coastwide, constant length-based availability, M=0.15	Retrospective pattern

Shifting dynamics – moving targets

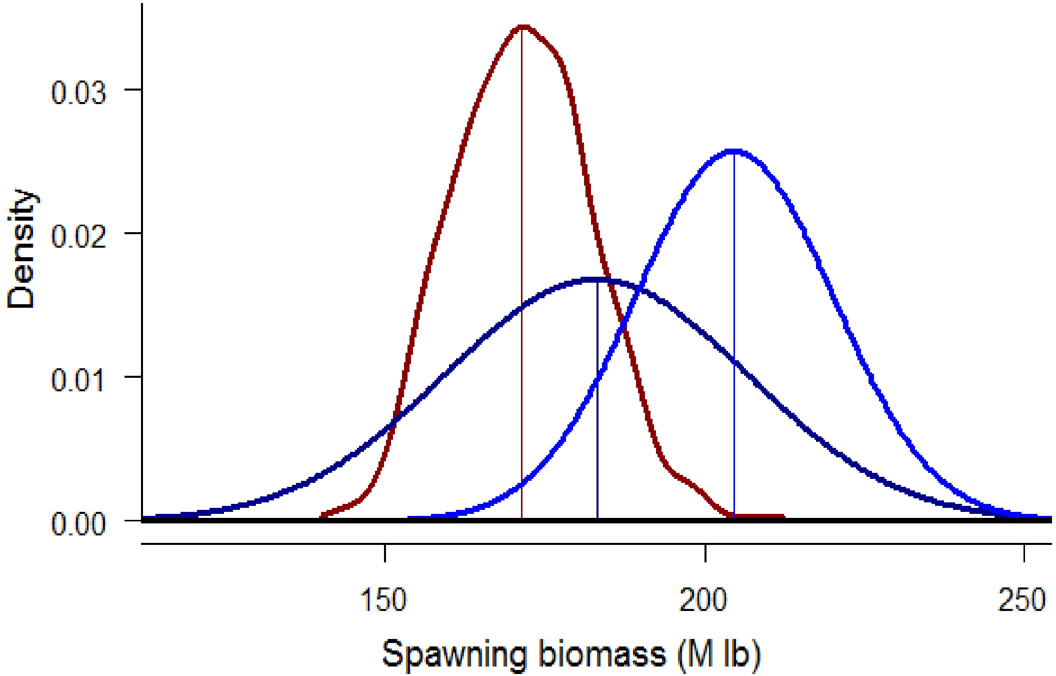


Stewart, I.J., and Martell, S.J.D. 2014. A historical review of selectivity approaches and retrospective patterns in the Pacific halibut stock assessment. Fish. Res. **158**: 40-49.

Ensemble evolution

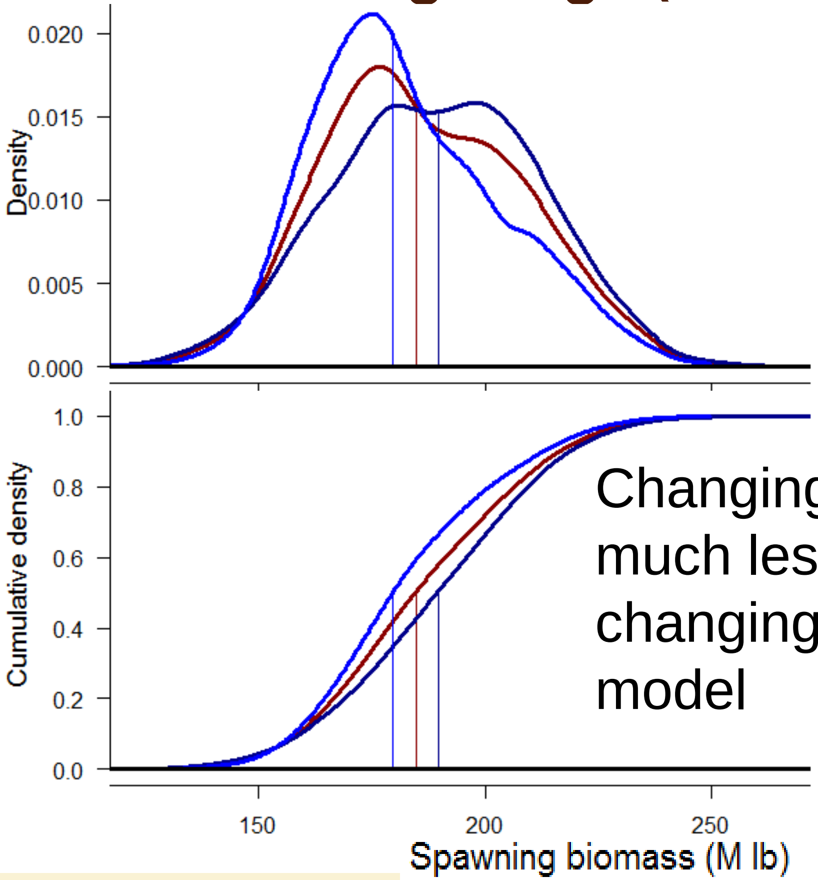
Year	Number of models	Factors included
2012	3	Natural mortality (*M*): 0.1, 0.15, 0.2
2013	3	+ time-series length (long and short), environmental effects on recruitment (PDO)
2014	4	+ level of data aggregation (AAF models)
2015	4	+ treatment of sex-ratio in catch, data weighting
2016-2018	4	Updates only
2019		*Full assessment*

Ensemble rationale



Stewart, I.J., and S.J.D. Martell. 2015. Reconciling stock assessment paradigms to better inform fisheries management. ICES J. Mar. Sci. 72(8): 2187-2196.

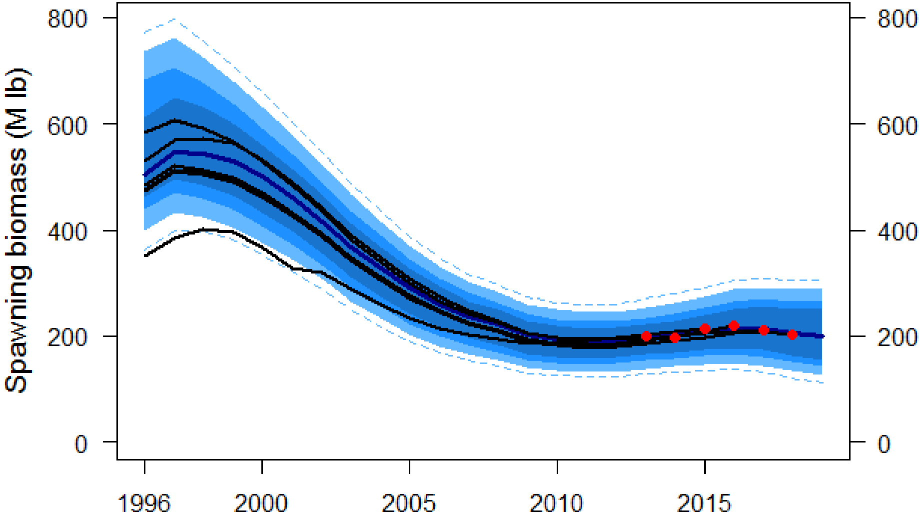
Alternative weightings (1-1-1, 0.5-0.5-1, 1-1-0.5)



Changing the weighting is much less volatile than changing the single "best" model

Interannual stability

- New data influence models in different ways
- An ensemble is stable as a function of:
  - The number of models included (more are better)
  - The correlations among models (low is better)

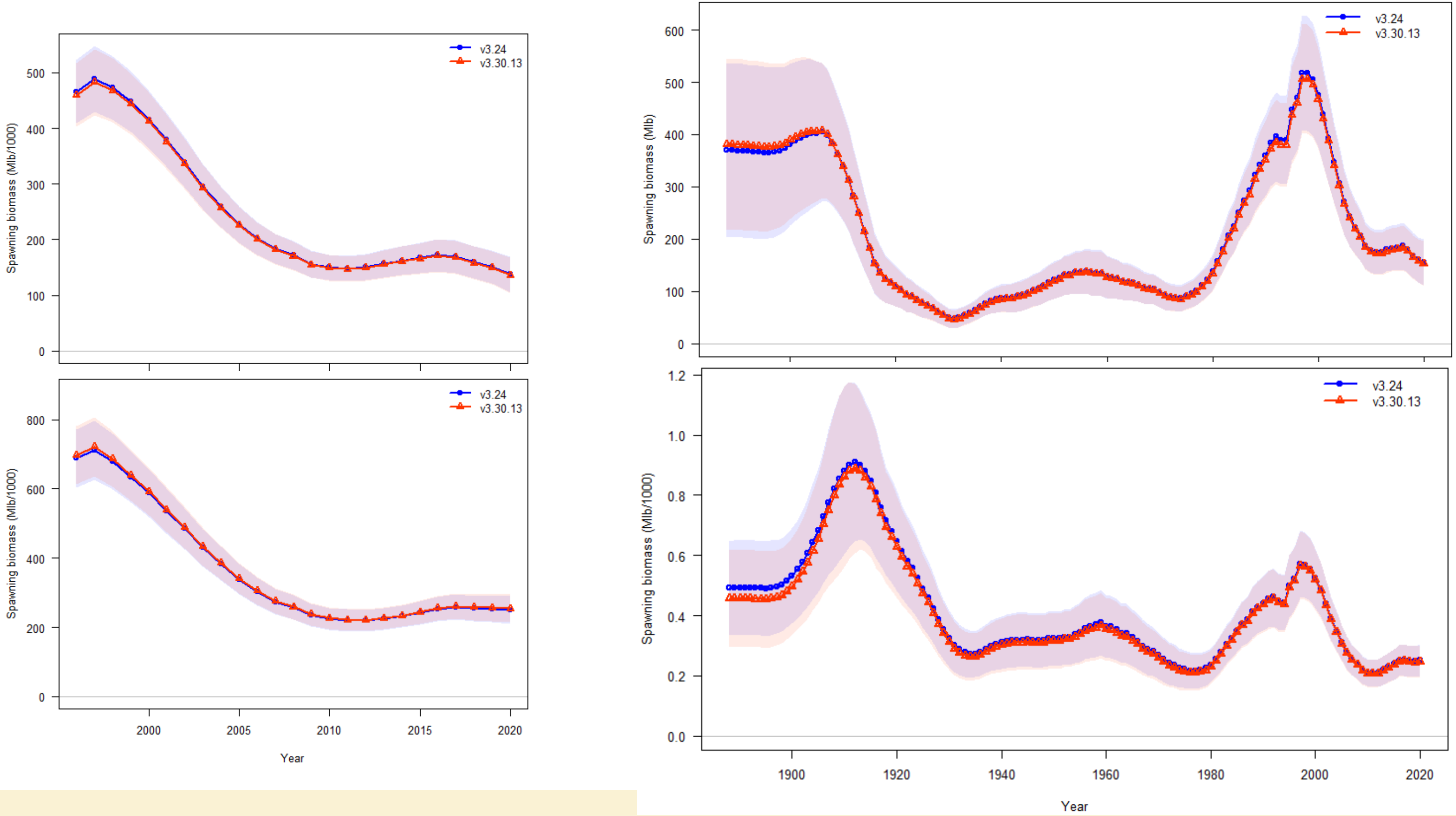


Stewart, I.J. and A.C. Hicks. 2018. Interannual stability from ensemble modelling. Can J Fish Aquat Sci. 75: 2109-2113.

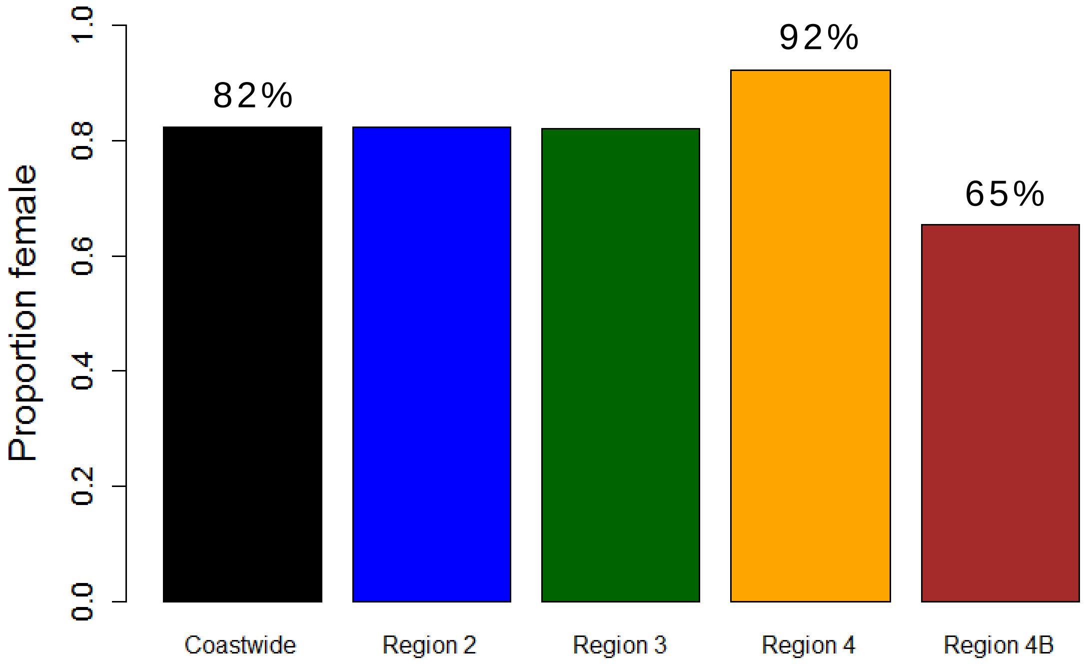
Bridge analysis 2019

– ss version (3.24 to 3.30)
– Sex-ratio at age data from 2017 (1st in 100 yrs!) and M:F selectivity parameters
– Short time-series models extended to 1992
– Revised survey time-series including improved whale depredation criteria
– Retuning each model for internal consistency
  - S-R function (σR, bias-correction)
  - Observation error (Francis method)
  - Process error (selectivity and catchability)

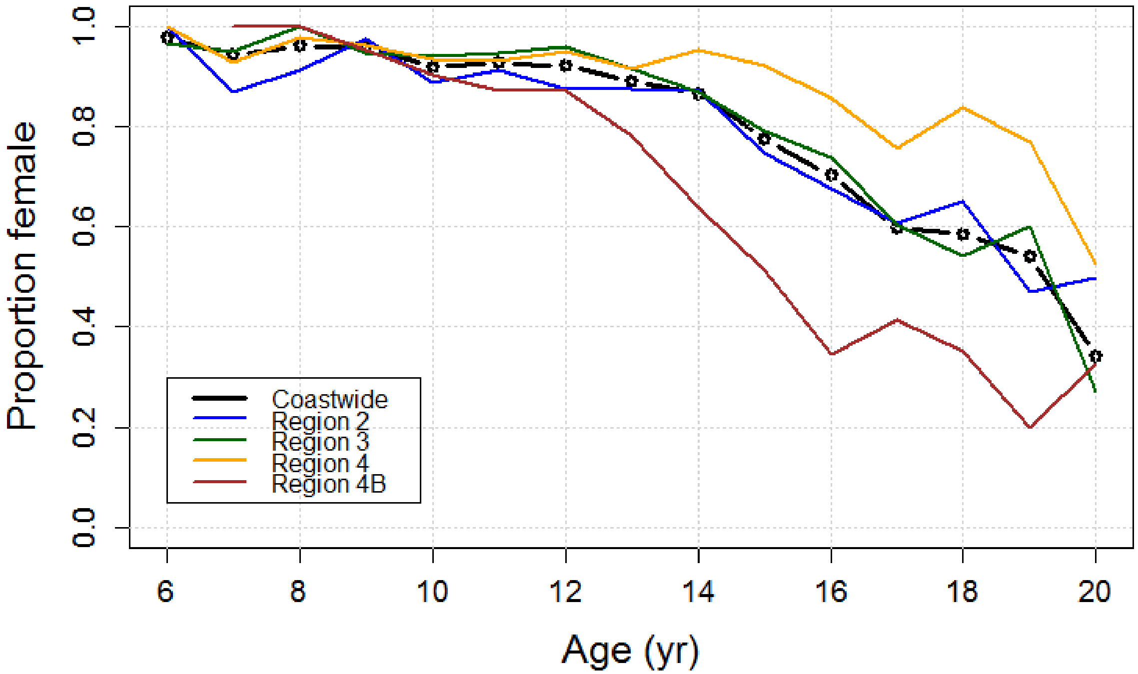
Bridge models – ss version



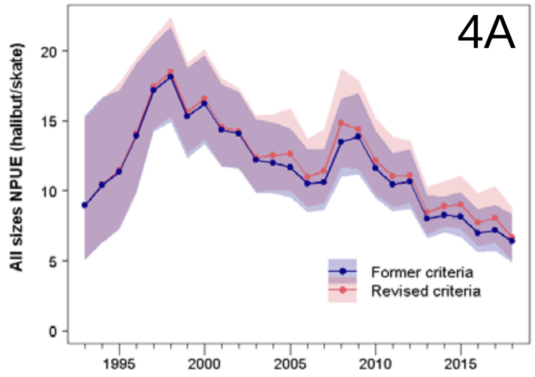
Sex ratios 2017 Commercial fishery

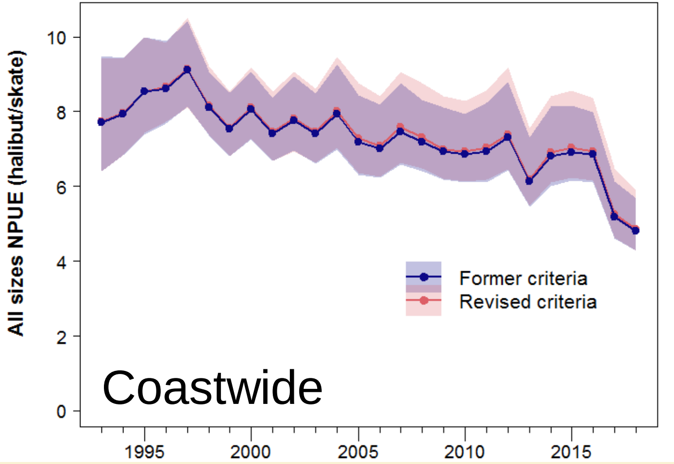


Sex ratios 2017 Commercial fishery



Whale depredation criteria





<u>Remove stations with</u>:

- Any sperm whale sighting during haul-back
- At least 2 lips (killer whales)
- Any other indication of depredation

→ 1.2% of stations in 2018

Extending the short time-series models

- Historical rationale: include all years with relatively ‘complete’ data (1996+)
- Subsequently, space-time model extended to 1993
- Model investigation (Monnahan et al. 2019) indicated initial conditions challenging for estimation without S-R function

Model tuning and regularizing process

- Incrementally add process error (recruitment, selectivity and fishery catchability)

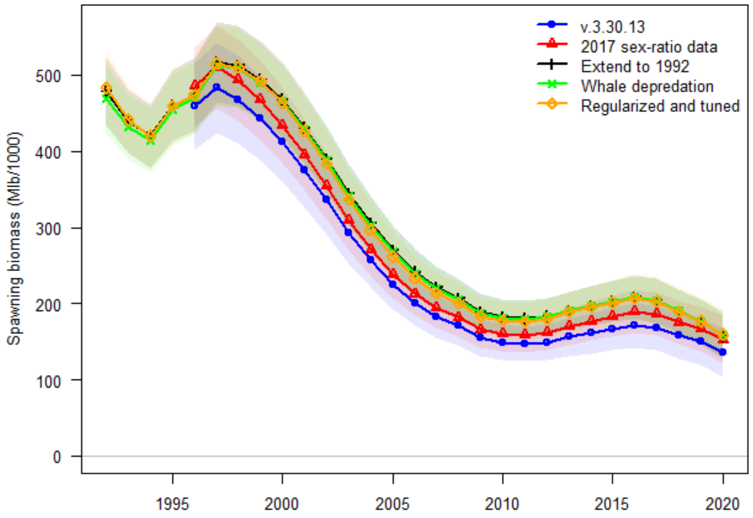
$$\sigma_{tuned} \sim \sqrt{SE^2_{devs} + \bar{\sigma}_{dev}{}^2}$$

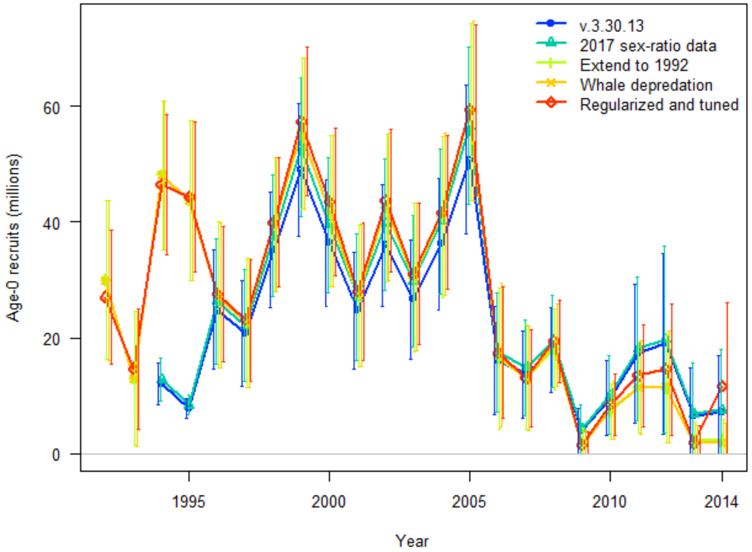
- Adjust input sample sizes: down as needed (not up) from number of trips/samples
- Fix selectivity parameters and/or deviations hitting bounds
- Iterate as needed:
  - process error generally converged quickly, regardless of observation error

Model tuning and regularizing process

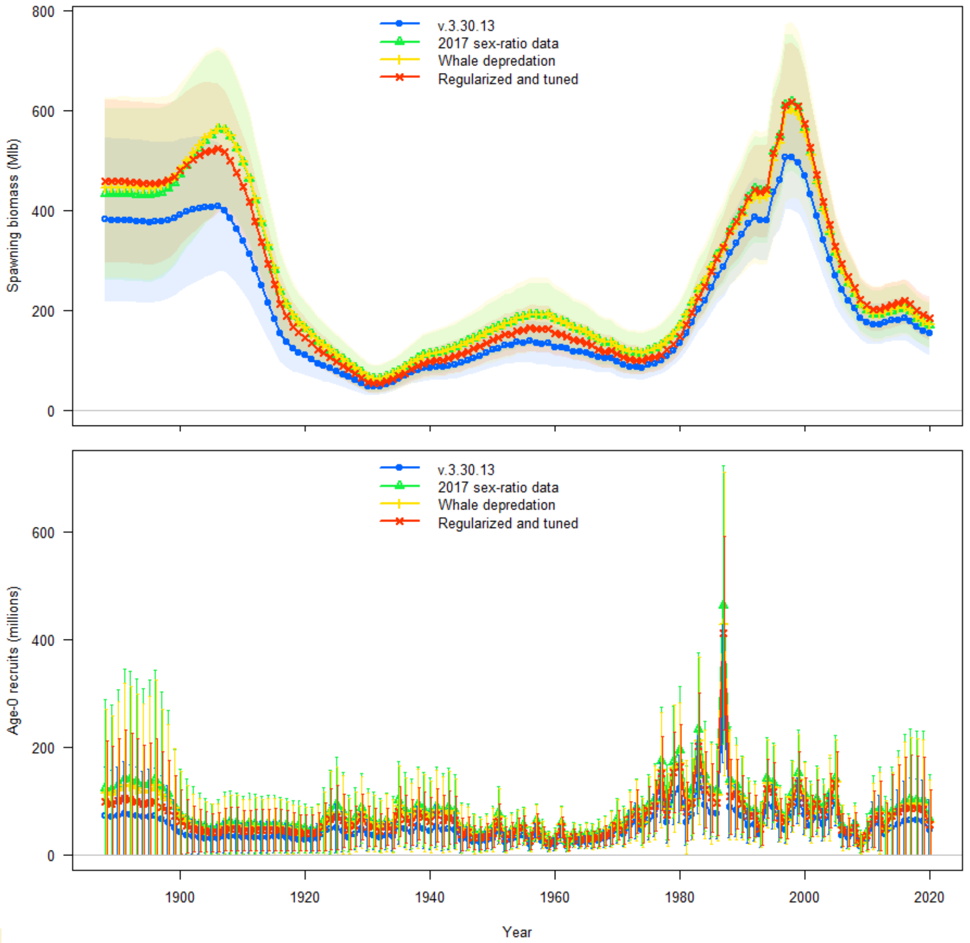
- Key points:
  - Each model represents an internally consistent representation of the data and population dynamics
  - Each model ‘clears the bar’ as a potential stand-alone for management decision-making, with it’s own set of pros and cons

Bridge: Coastwide short

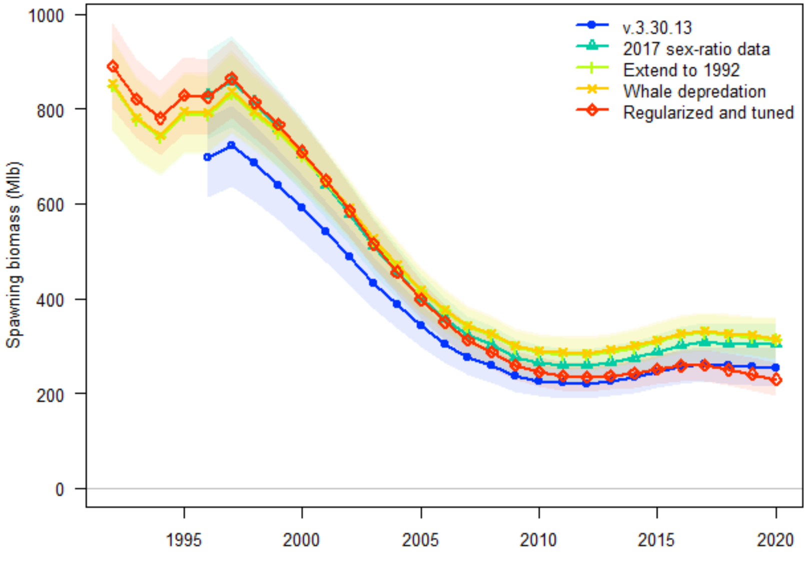


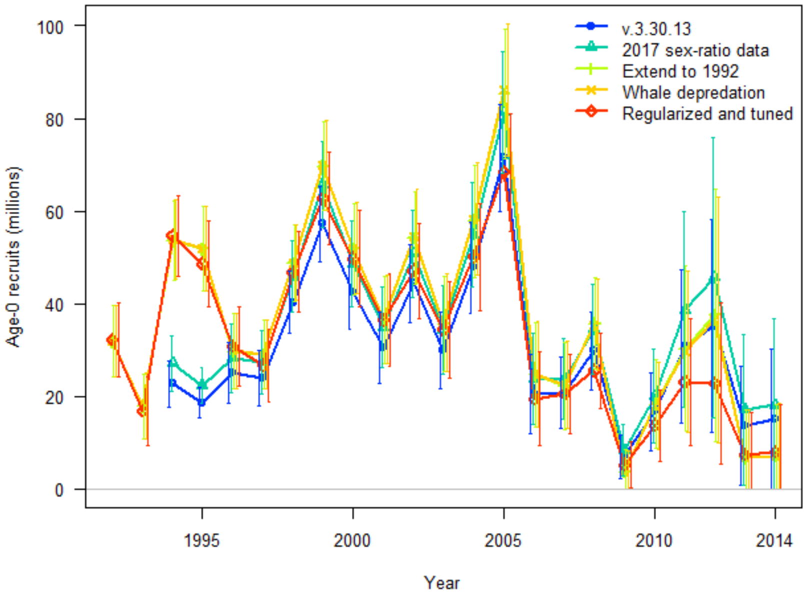


Bridge: Coastwide long

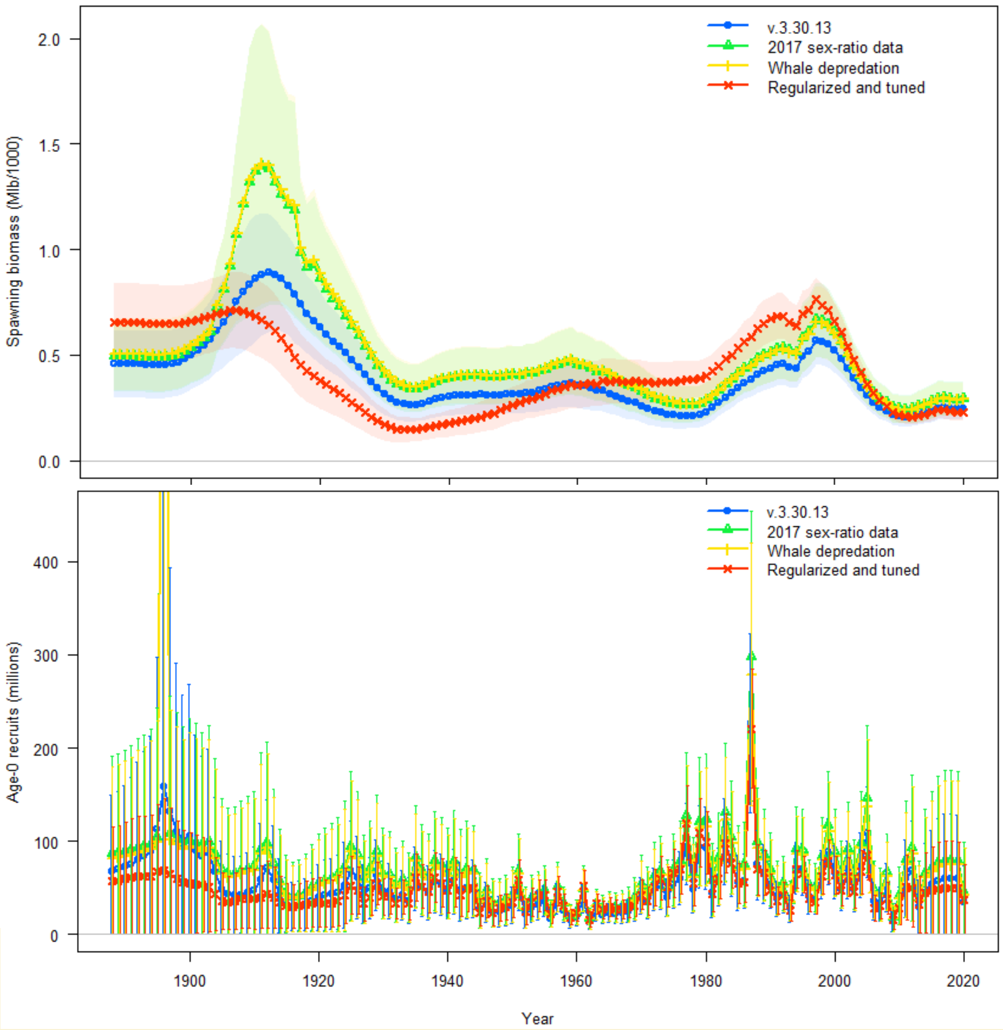


Bridge: AAF short





Bridge: AAF long



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Individual models: results and diagnostics

- Fit to index data:
  - All models fit survey time-series well
  - No process error (temporal variability in q) estimated for short fishery indices: coastwide, Region 4, Region 4B
  - Unconstrained process error estimated for geographical transitions (coastwide models), J to circle hook transitions (long models)

Individual models: results and diagnostics

- Fit to age data:
  - All fits commensurate with tuned sample sizes (Francis weighting)
  - Coastwide short: relatively less weight on fishery
  - AAF short: relatively less weight on Region 2 survey
  - AAF long: relatively less weight on Region 2 and 3 survey

Observation error diagnostics

	Average iterated input	Harmonic mean effective	Francis weight samples	Maximum Pearson residual
Coastwide short				
Fishery	37	244	37	1.58
Discards[1]	9	126	79	0.89
Bycatch[1]	5	56	49	1.65
Recreational[1]	5	109	35	0.93
Survey	372	724	372	2.48
Coastwide long				
Fishery	140	391	148	4.15
Discards[1]	6	234	118	0.58
Bycatch[1]	2.5	37	5	1.38
Recreational[1]	2.5	118	23	0.72
Survey	125	196	125	3.81

(Table 11)

Observation error diagnostics

	Average iterated input	Harmonic mean effective	Francis weight samples	Maximum Pearson residual
AAF short				
Region 2 Fishery[2]	136	591	218	3.97
Region 3 Fishery[2]	127	570	229	2.20
Region 4 Fishery	40	64	40	3.80
Region 4B Fishery[2]	23	114	55	1.69
Discards[1]	6	216	134	0.73
Bycatch[1]	5	51	65	1.10
Sport[1]	5	117	27	0.70
Region 2 Survey	185	411	187	1.14
Region 3 Survey	240	575	235	1.93
Region 4 Survey	87	195	90	2.98
Region 4B Survey	40	188	40	1.34
AAF long				
Region 2 Fishery[2]	270	347	513	3.72
Region 3 Fishery[2]	167	347	334	3.76
Region 4 Fishery	30	61	30	5.28
Region 4B Fishery[2]	22	104	57	1.81
Discards[1]	6	222	95	3.82
Bycatch[1]	2.5	45	7	1.26
Sport[1]	5	132	24	0.68
Region 2 Survey	9	101	9	1.30
Region 3 Survey	43	154	43	1.85
Region 4 Survey	82	198	87	3.45
Region 4B Survey	40	192	42	1.56

(Table 11)

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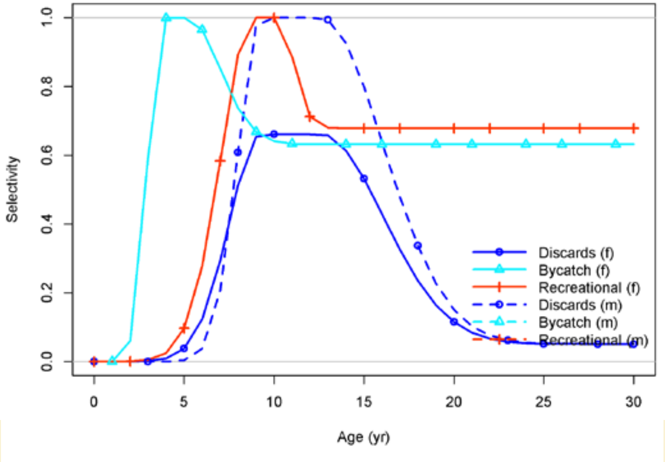
Individual models: results and diagnostics

- Key parameter estimates
  - Selectivity
  - Natural mortality
  - S-R

Bycatch, recreational, discard selectivity

- Some age data available
- Maybe not entirely representative

→ Estimate selectivity, but down-weight the age data such that is doesn't appreciably inform recruitment deviations.



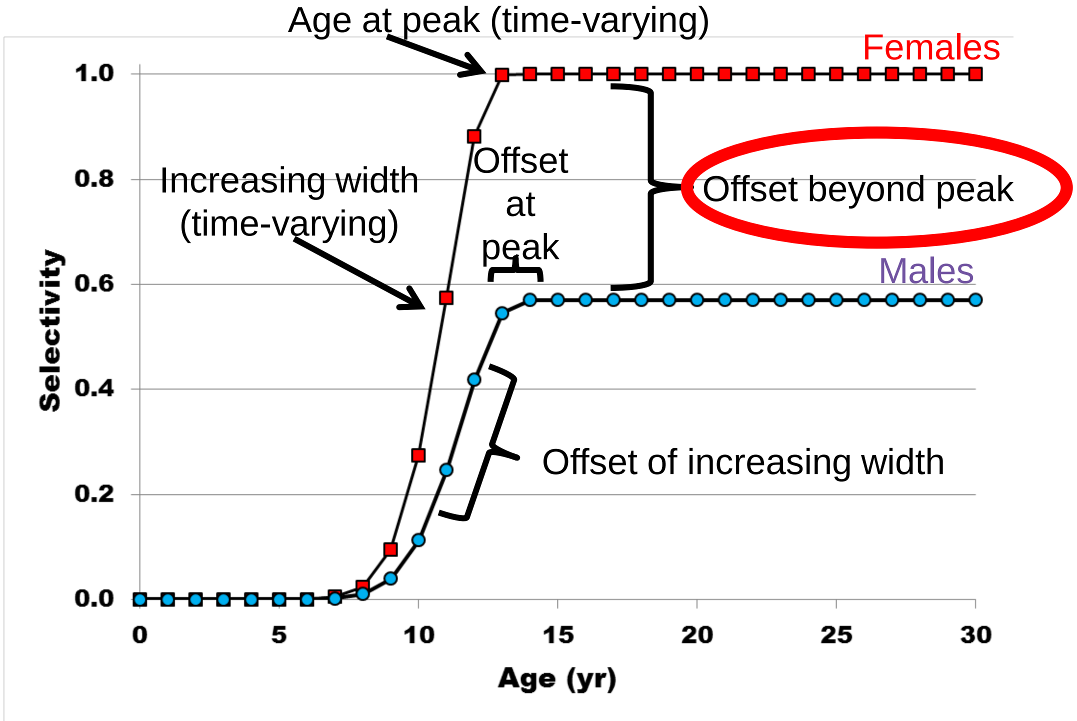
General model structure

	Model			
	Coastwide Short	Coastwide Long	AAF Short	AAF Long
Modelled period	1992-2019	1888-2019	1992-2019	1888-2019
Selectivity (fishery and survey)	Asymptotic, by sex	Asymptotic, by sex	Domed (A2, A3), Asymptotic (A4, A4B)	Domed (A2, A3), Asymptotic (A4, A4B)
Bycatch selectivity	Domed	Domed	Domed	Domed
Recreational selectivity	Domed	Domed	Domed	Domed
Discard selectivity	Domed, by sex	Domed, by sex	Domed, by sex	Domed, by sex
Subsistence selectivity	Mirrored to recreational	Mirrored to recreational	Mirrored to recreational	Mirrored to recreational

Reminder: Coastwide short allows for time-varying male selectivity. All others static peak but variable ascending parameters.

(Table 9)

Selectivity (resulting in sex-ratios)



Fishery no longer linked to survey.

Parameter summary

	Model			
	Coastwide Short	Coastwide Long	AAF Short	AAF Long
Static				
Female M	--	1	--	1
Male M	1	1	1	1
Log(R_0)	1	1	1	1
Initial R_0 offset	1	--	1	--
Environmental link coefficient	--	1	--	1
Fishery catchability	1	1	4	4
Survey catchability	1	4	--	4
Fishery selectivity	5	5	20	18
Discard selectivity	6	7	5	6
Bycatch selectivity	4	2	4	3
Recreational selectivity	4	3	3	4
Survey selectivity	5	5	21	18
Total static	29	31	60	61
Time-varying				
Recruitment deviations	51	165	51	165
Fishery catchability deviations	--	108	52	212
Fishery selectivity deviations	76	166	208	532
Survey selectivity deviations	75	84	182	236
Total deviations	202	523	493	1,145
Total	231	554	553	1,206

(Table 10)

General model structure

	Model			
	Coastwide Short	Coastwide Long	AAF Short	AAF Long
Modelled period	1992-2019	1888-2019	1992-2019	1888-2019
Fleets	6	6	12	12
Female M	Fixed at 0.15	Estimated	Fixed at 0.15	Estimated
Male M	Estimated	Estimated	Estimated	Estimated

M is a very strong assumption in the short time-series models (of course)

(Table 9)

Parameter estimates

	Model			
	Coastwide Short	Coastwide Long	AAF Short	AAF Long
Biological				
Female *M*	0.150 (Fixed)	0.213 (0.188-0.238)	0.150 (Fixed)	0.173 (0.157-0.189)
Male *M*	0.155 (0.143-0.167)	0.199 (0.184-0.214)	0.140 (0.134-0.147)	0.155 (0.145-0.165)
Log(R_0)	10.63 (10.45-10.81)	11.06 (10.72-11.40)	10.68 (10.53-10.82)	10.66 (10.35-10.96)
Initial R_0 offset	-1.274 (-1.474--1.075)	NA	-0.659 (-0.833--0.485)	NA
Environmental Link (β)	NA	0.398 (0.167-0.629)	NA	0.293 (0.078-0.508)

(Table 12)

General model structure

	Model			
	Coastwide Short	Coastwide Long	AAF Short	AAF Long
Modelled period	1992-2019	1888-2019	1992-2019	1888-2019
Stock-recruit relationship	B-H	B-H	B-H	B-H
Initial conditions estimated	R_0, R_0 offset, N-at-age: 1-19	R_0	R_0, R_0 offset, N-at-age: 1-19	R_0
Environmental regime effects on recruitment	No	Yes	No	Yes
Steepness (h)	0.75	0.75	0.75	0.75
$\sigma_{\text{recruitment deviations}}$	1.0	0.55	0.75	0.5

- Short models - flexible initial conditions
- Long models - PDO regimes
- All models – internally consistent S-R function

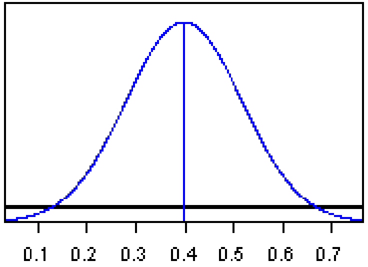
(bias-correction, tuned $\sigma_{recdevs}$)

(Table 9)

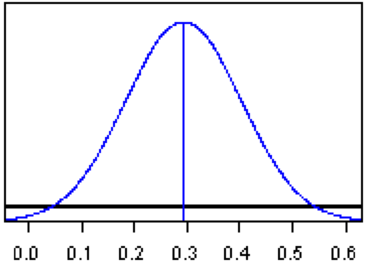
Link to PDO:

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

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

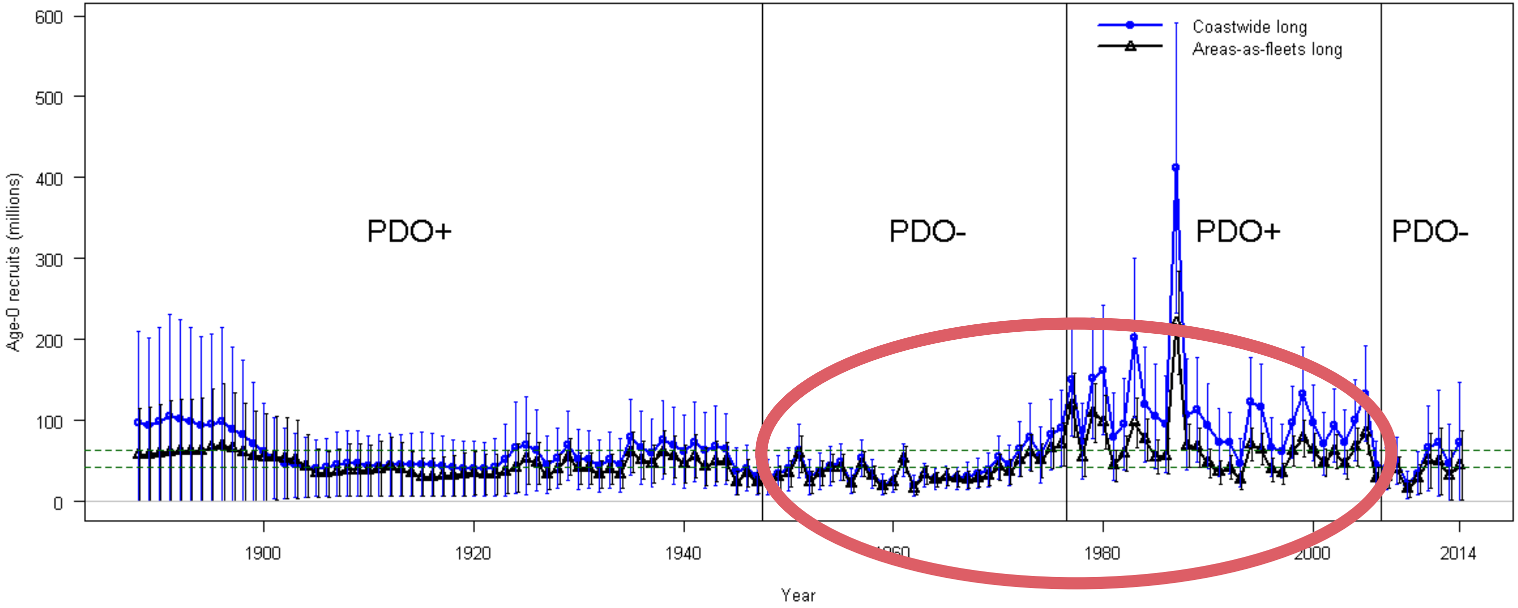


Model	
Coastwide Long	AAF Long
0.398 (0.167-0.629)	0.293 (0.078-0.508)

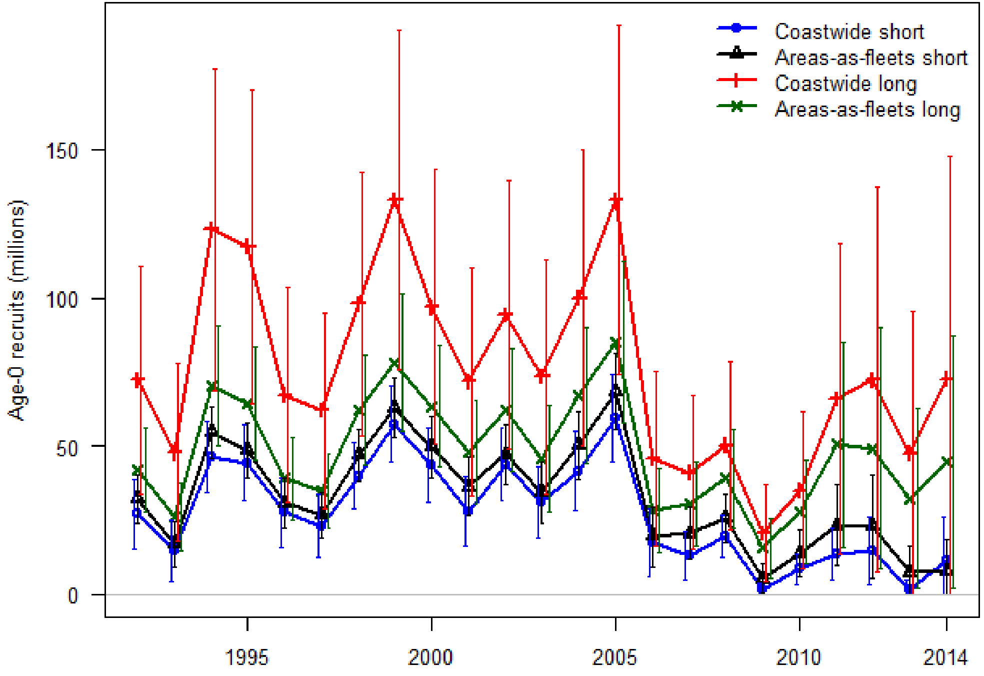


→ 34-49% scalar for positive PDO

Historical recruitment estimates



Individual models: recruitment

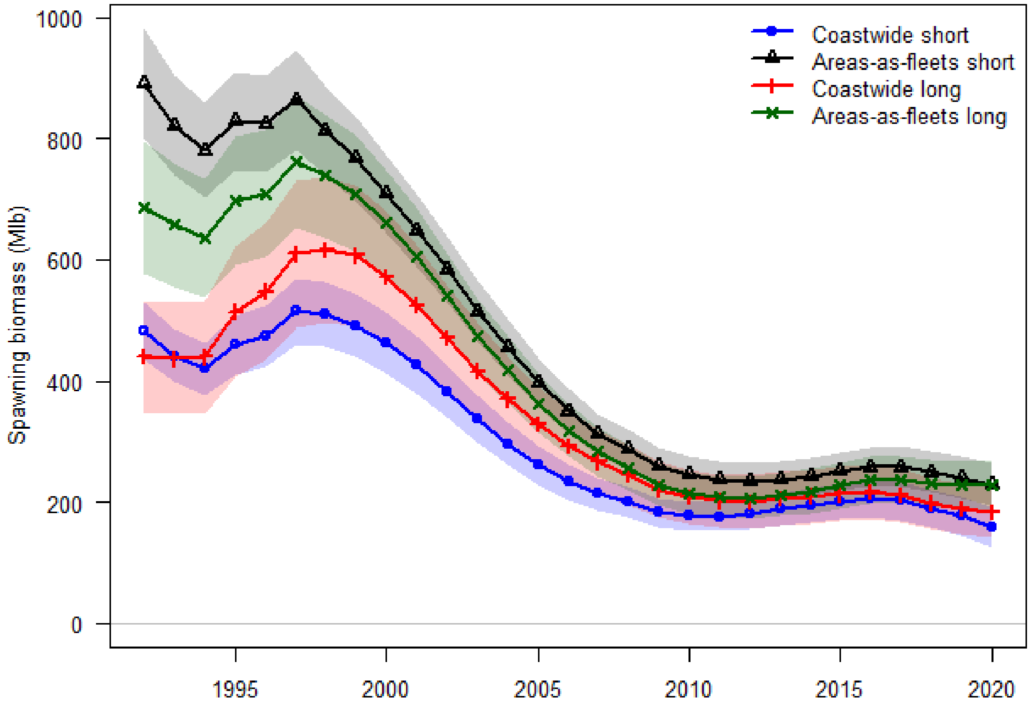


Natural mortality/scale differences

Relative strong/weak cohorts conserved

Late-series differences (2011+)

Individual models: spawning biomass

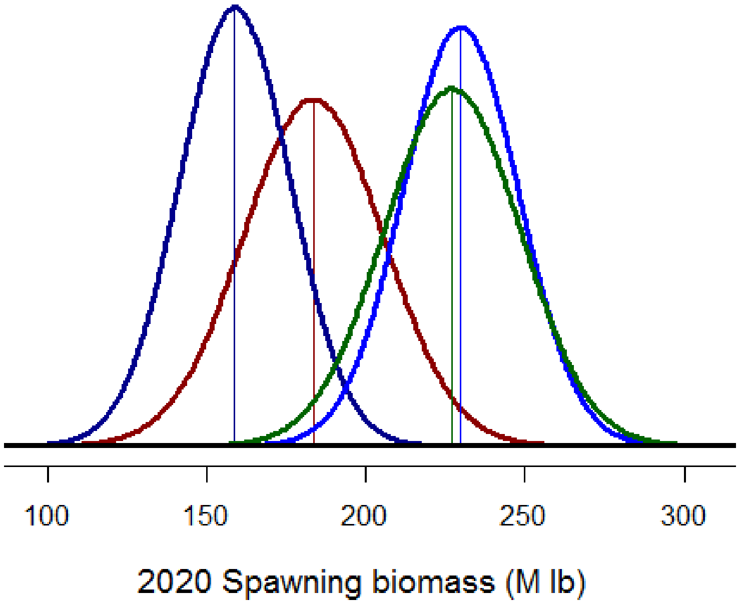


<u>Trend</u>
CW short ~ AAF short
CW long ~ AAF long

<u>Scale</u>
CW short ~ CW long
AAF short ~ AAF long

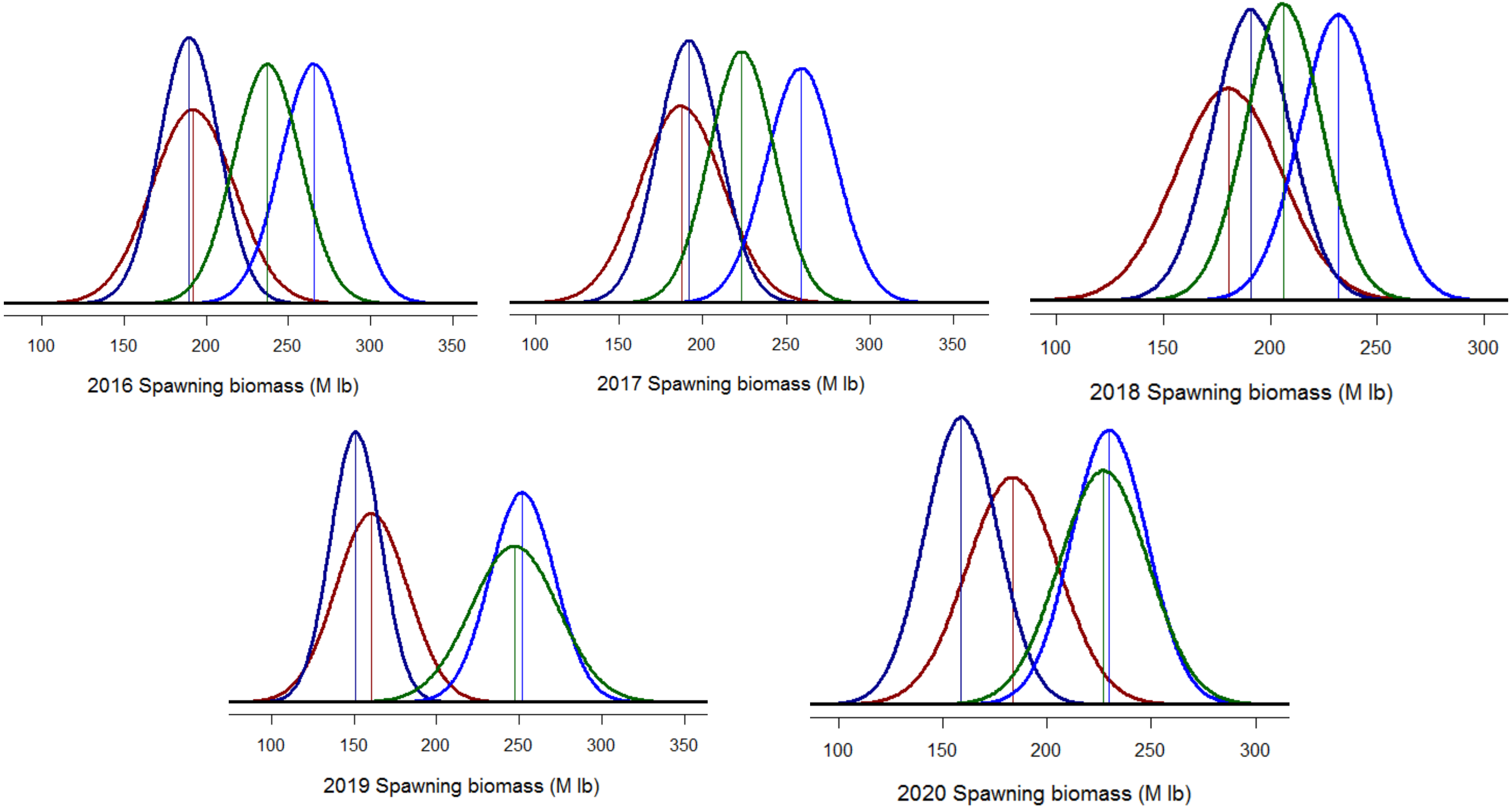
→ 2x2 cross necessary to capture both aspects

Individual models: spawning biomass



	Percentile		
Model	2.5%	50%	97.5%
Coastwide Long	141	184	227
Coastwide Short	125	159	193
AAF Long	185	227	269
AAF Short	194	230	265
Ensemble	135	203	261

Historical models: spawning biomass



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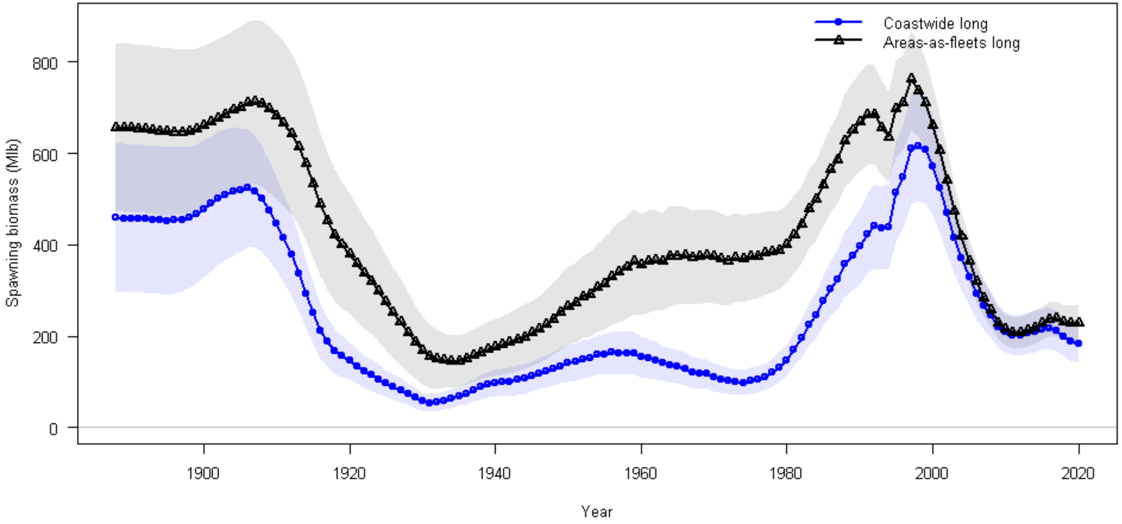
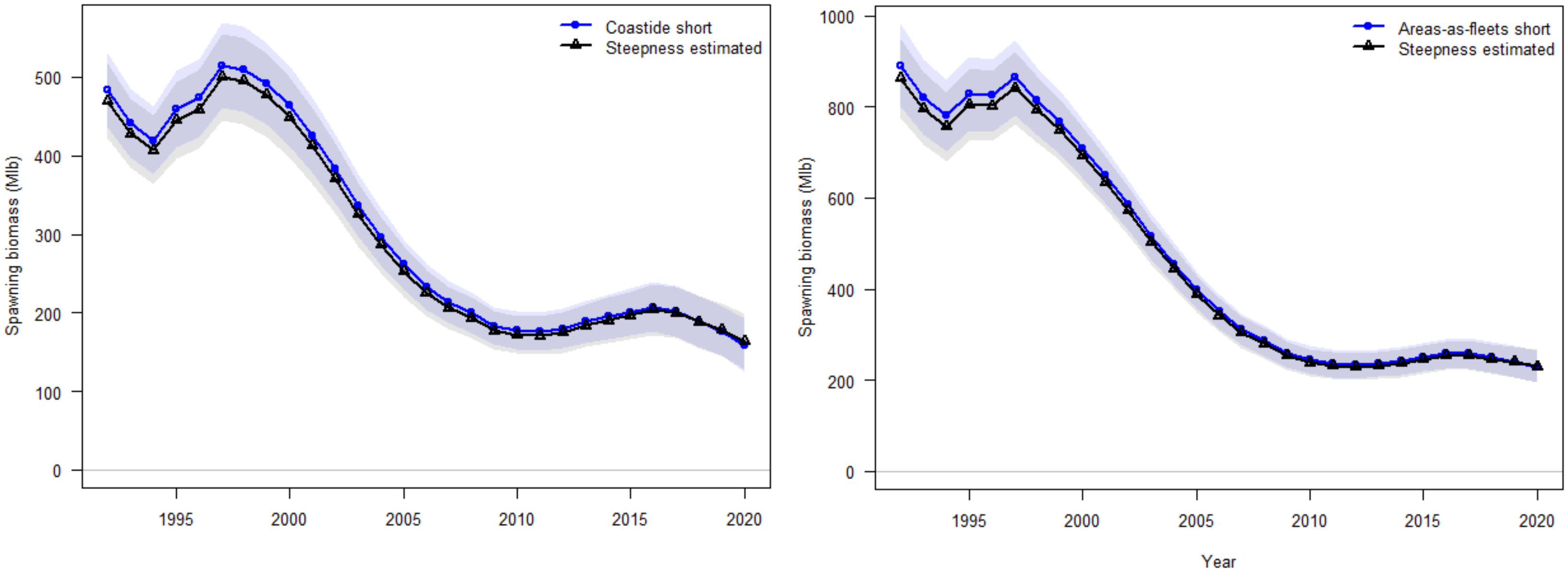
Historical sensitivity analyses

- 2015: *Ensemble*, fishery *q*, M:F selectivity, *M*, h, historical selectivity
- 2016: *Ensemble,* Maturity, M:F selectivity, Directed fishery DMRs
- 2017: *Ensemble,* Maturity, M:F selectivity, Unobserved mortality (e.g., whales or bycatch)
- 2018: *Ensemble,* Maturity, M:F selectivity, Unobserved mortality (e.g., whales or bycatch)
- 2019: *Ensemble, M, h, data weighting*

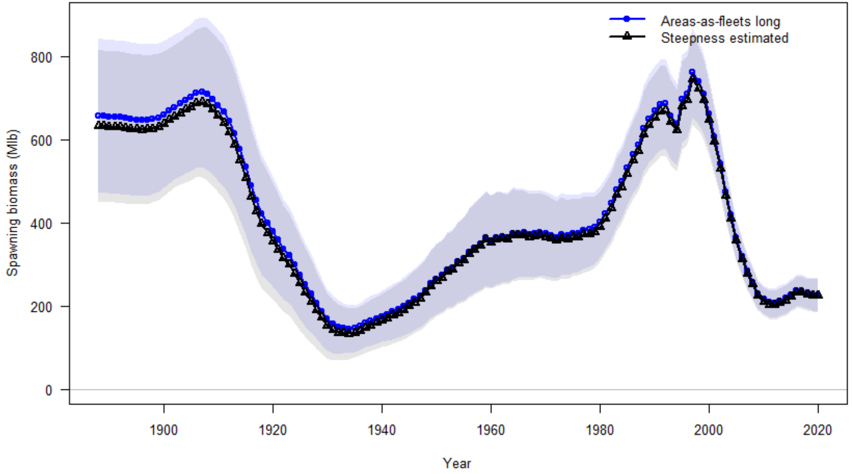
Long models: domed historical selectivity

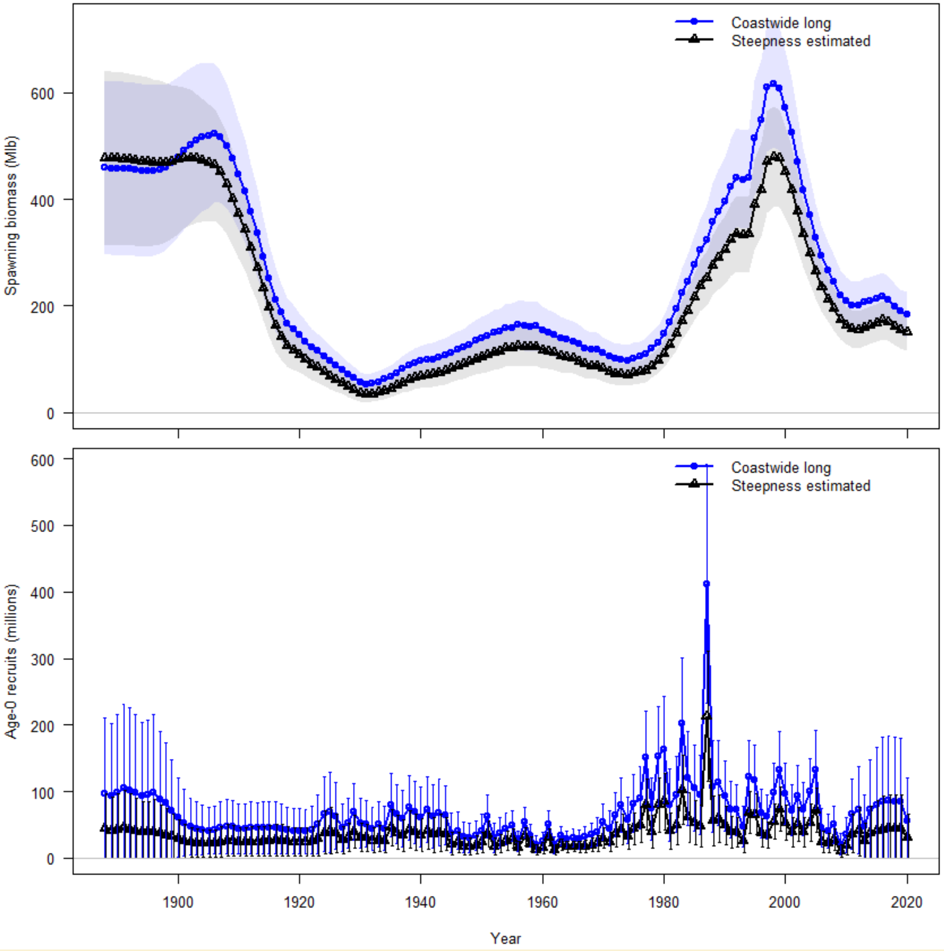


Steepness


Coastide short
Steepness estimated
Spawning biomass (Mlb)
0
100
200
300
400
500
1995
2000
2005
2010
2015
2020
Areas-as-fleets short
Steepness estimated
Spawning biomass (Mlb)
0
200
400
600
800
1000
1995
2000
2005
2010
2015
2020
Year

Steepness





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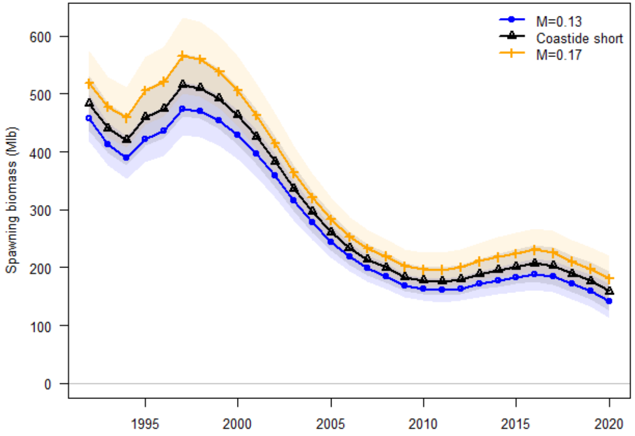
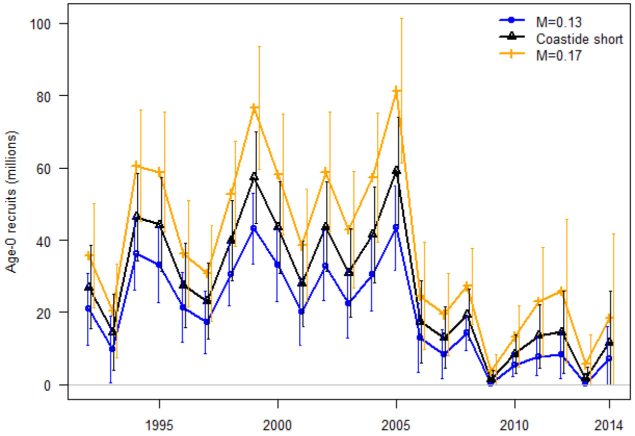
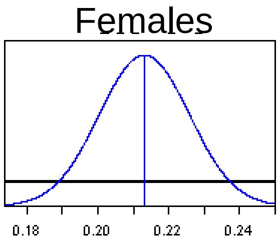
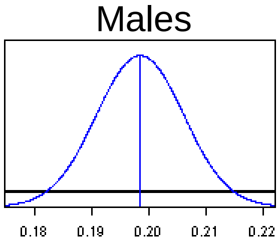
Natural mortality



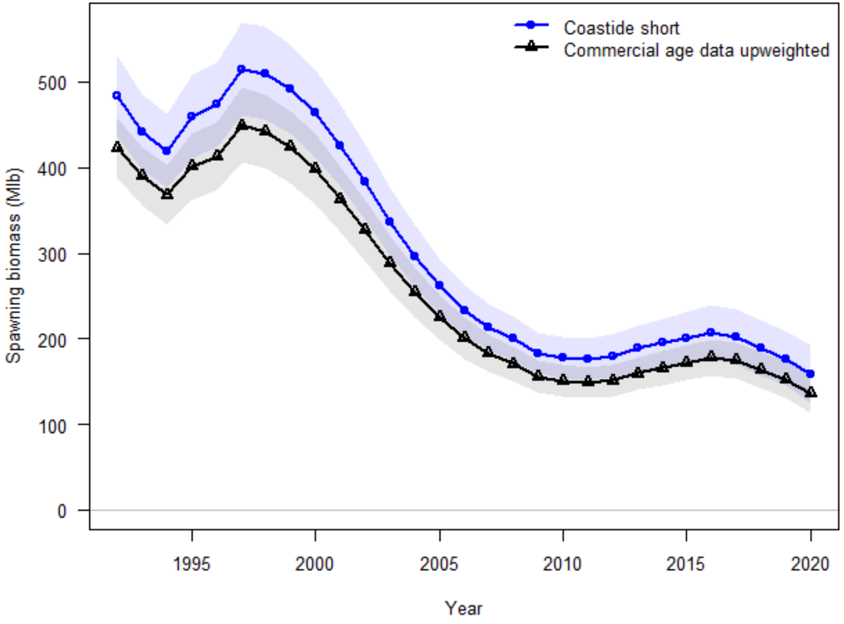


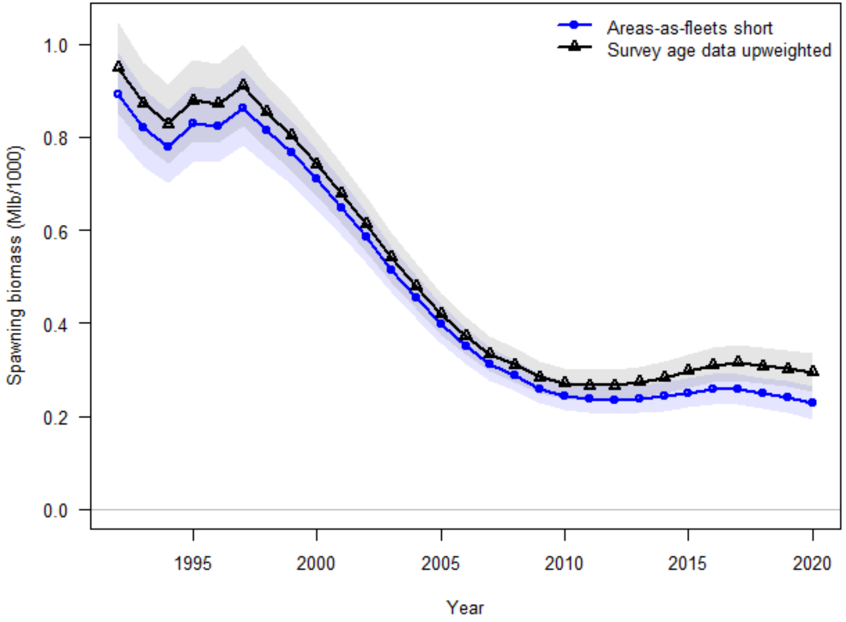
Coastwide long model



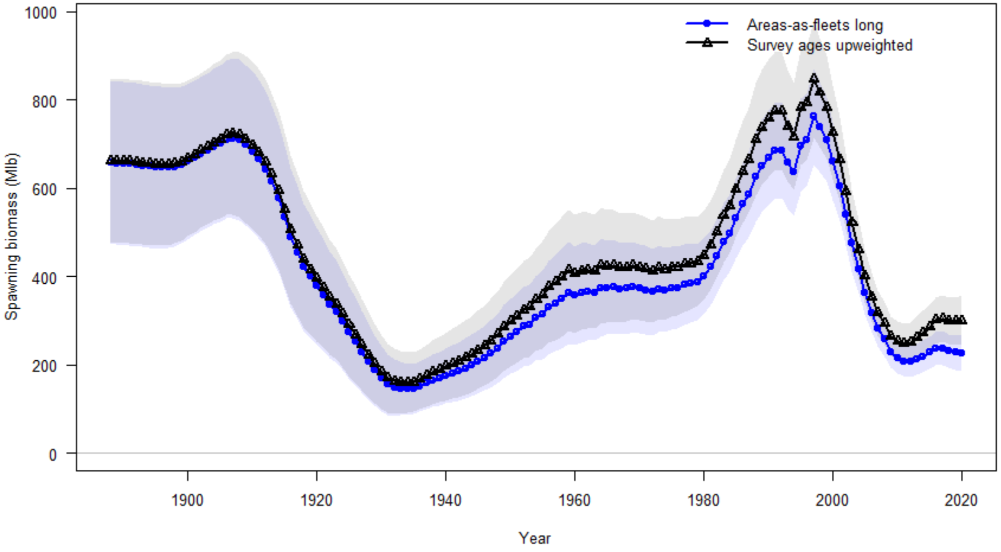


Upweighting specific data sets





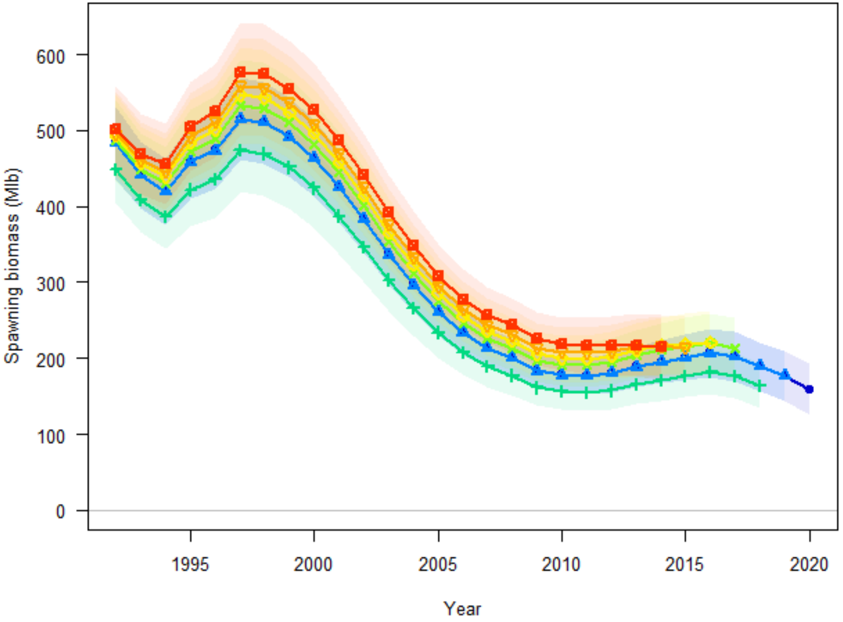
Upweighting specific data sets



Retrospective analyses

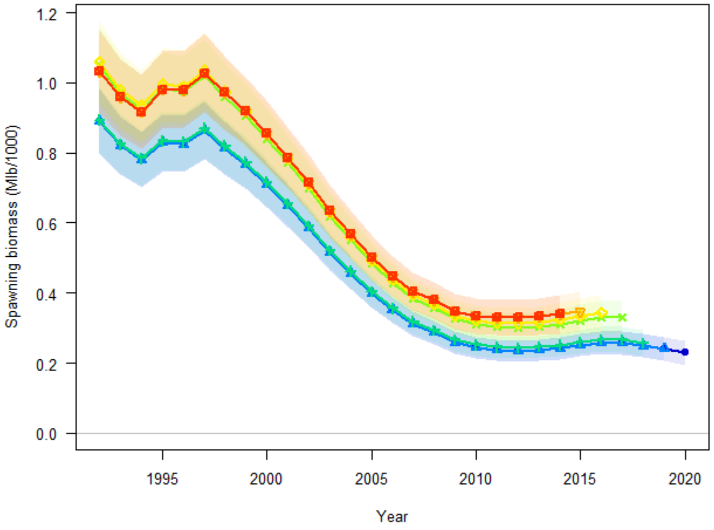
- Large effect of the 2017 sex-ratio data (as expected)
  - Two retrospectives: standard, fixing male selectivity peak

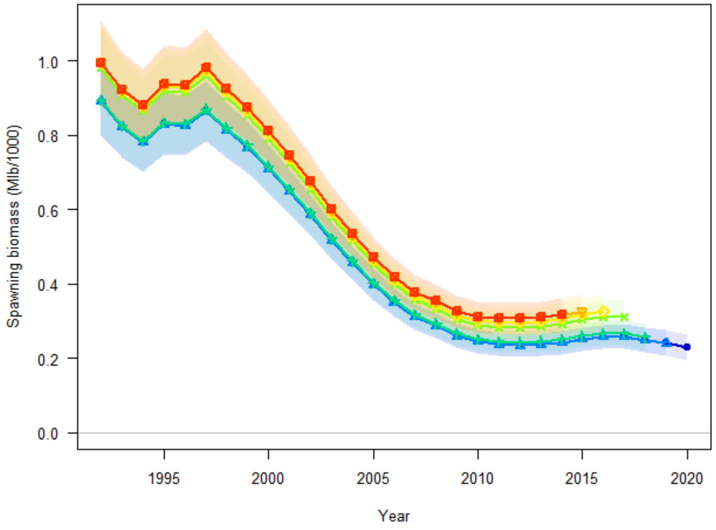
Retrospective analyses



Coastwide short: variable but no trend

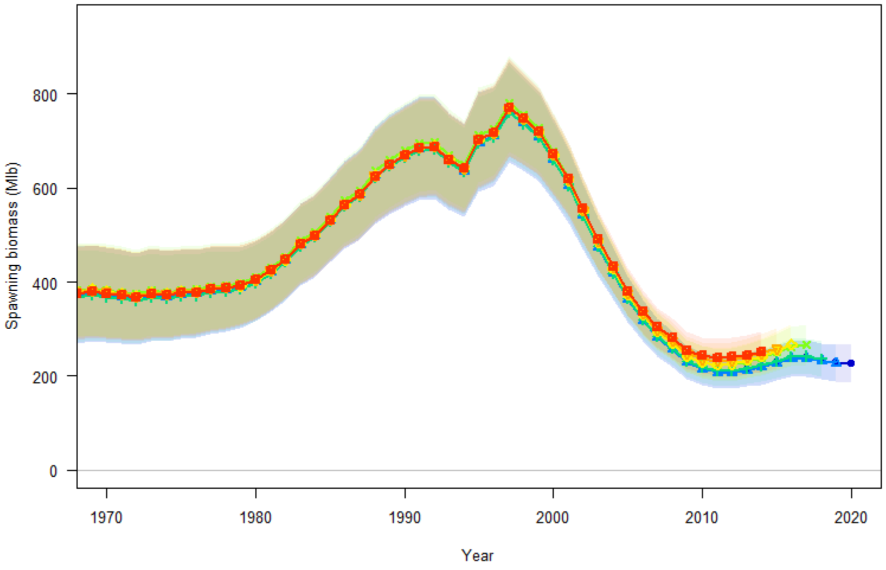
Retrospective analyses

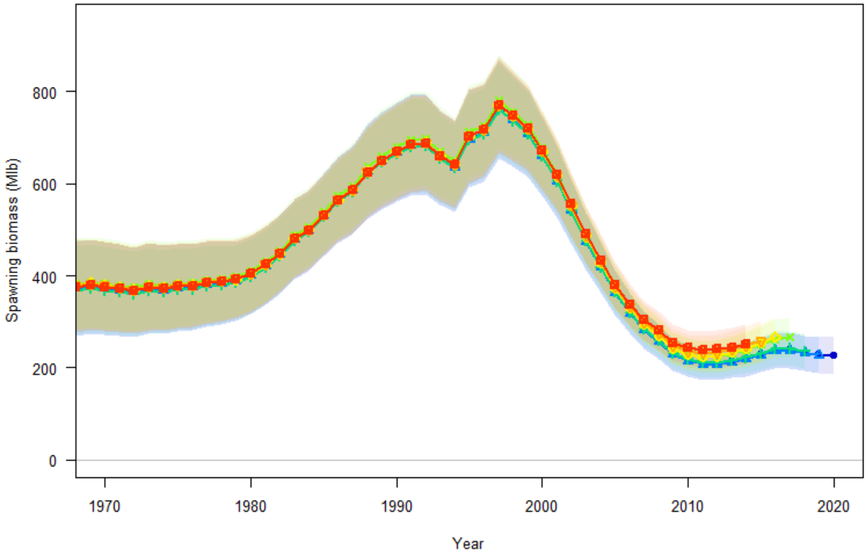




AAF short: worst trend, more pronounced without sex-ratio data

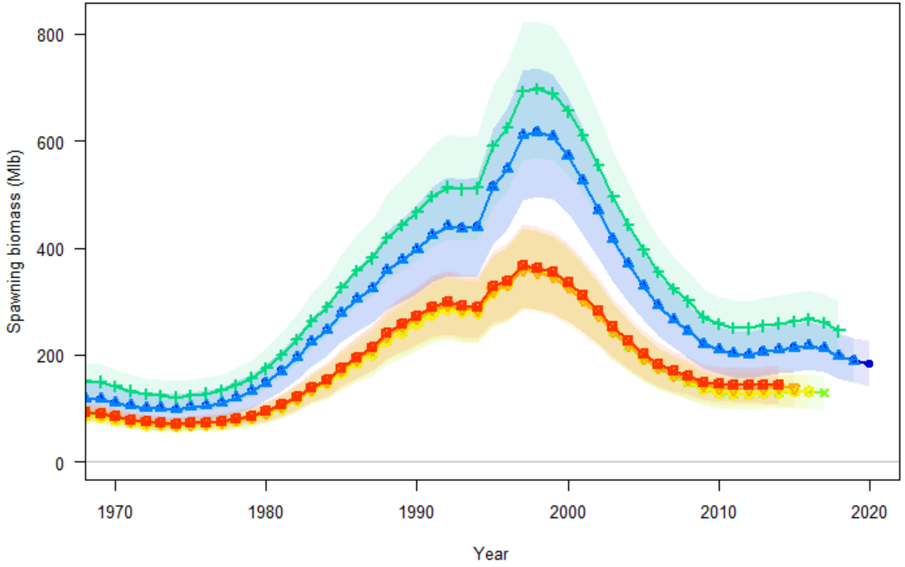
Retrospective analyses

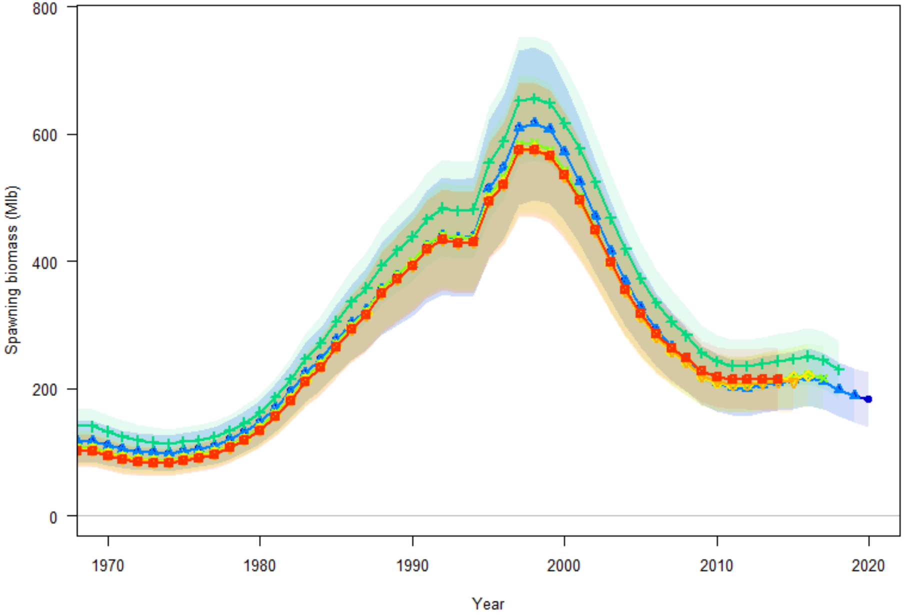




AAF long: trend inside 95% intervals

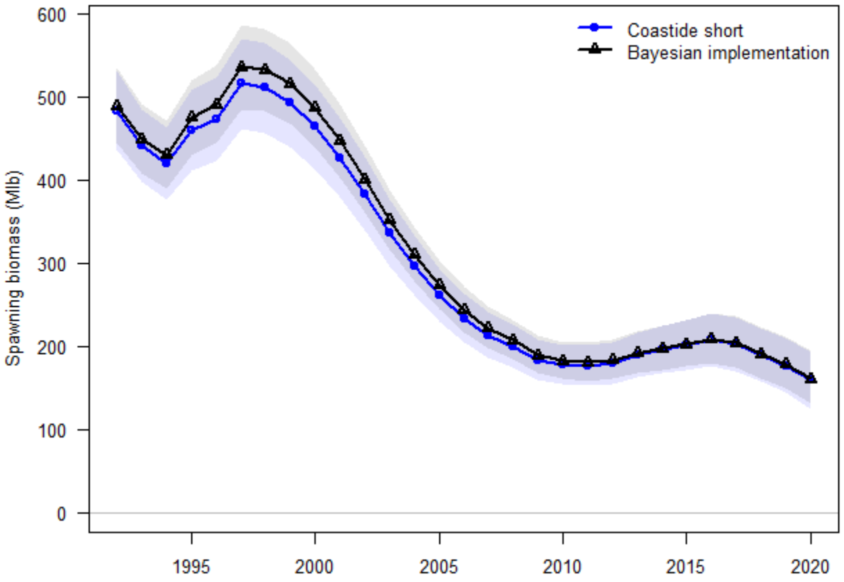
Retrospective analyses

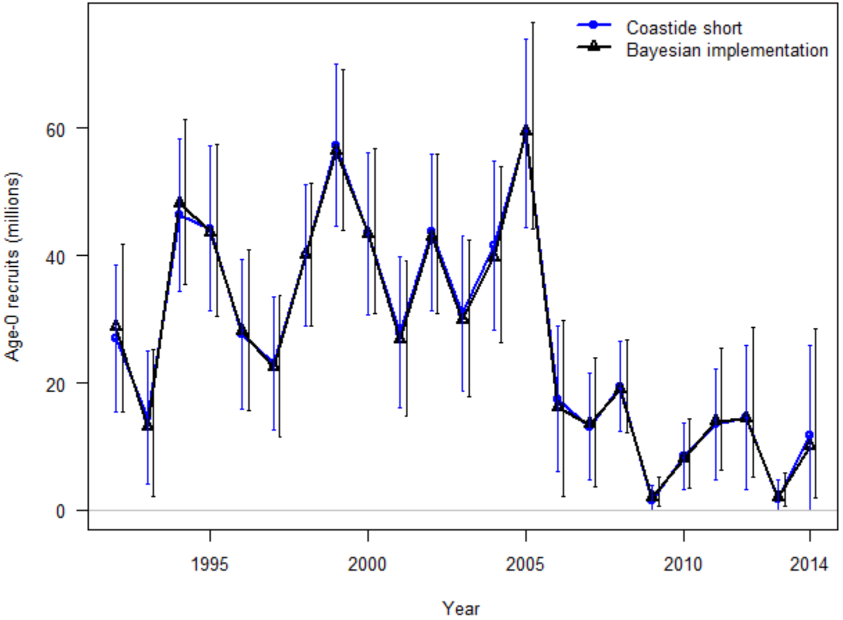




Coastwide long: sex-ratio data critically important

Bayesian version of CW short





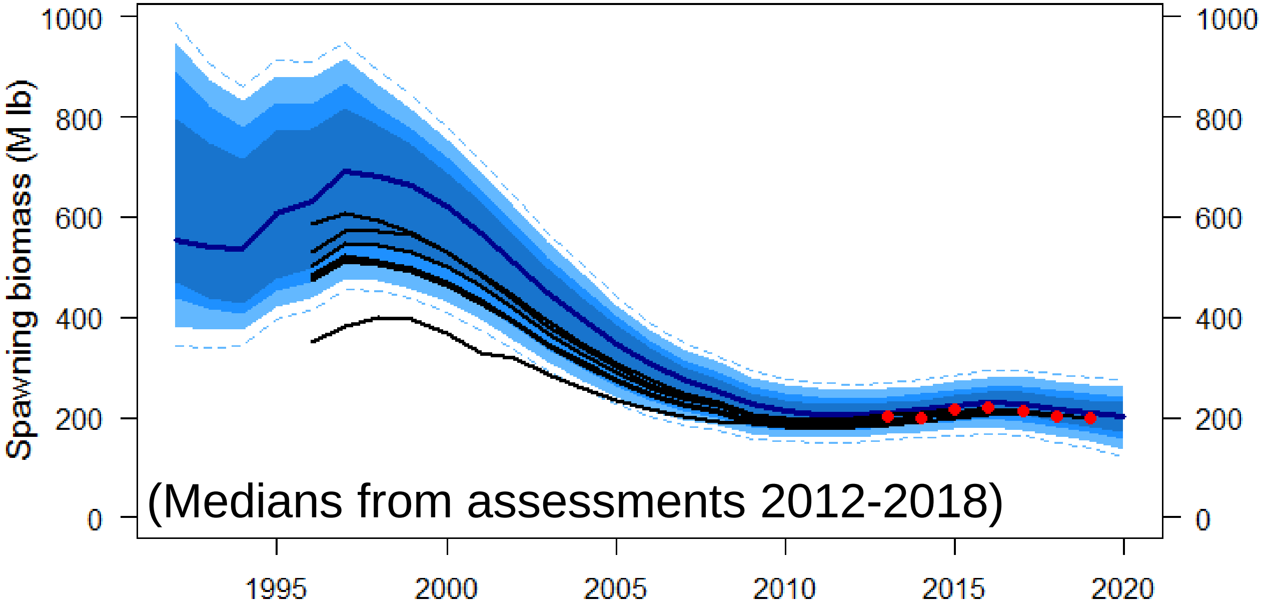
Outline

- Summary
- Data sources
- Model development
- Ensemble
- Research priorities

Ensemble

- Equally weighted models
  - Parametric bootstrap from asymptotic intervals (equal draws per model)

Comparison with previous results

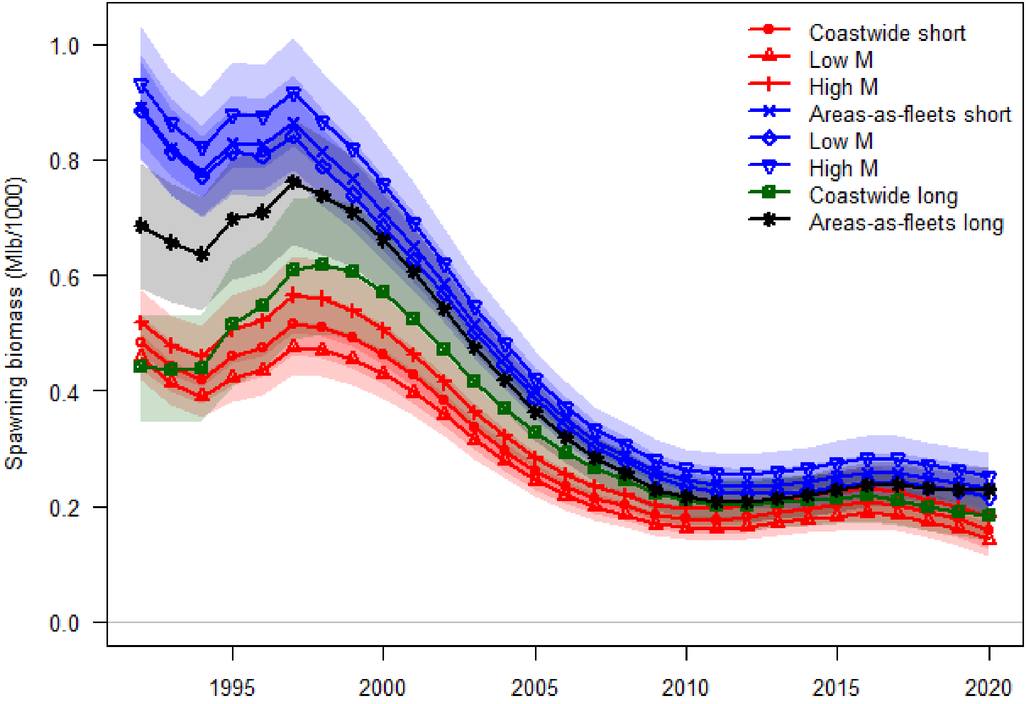


Reference point calculation

- Transition from static historical constants to dynamic SB_0 consistent with current harvest strategy and MSE-based management information

	2019	2020 (projected)
'Historical' SB ratio	43% (27-63) P<SB30% = 11% P<SB20% = <1%	38% (22-51) P<SB30% = 25% P<SB20% = <1%
Dynamic SB ratio	32% (23-44) P<SB30% = 38% P<SB20% = <1%	31% (20-44) P<SB30% = 44% P<SB20% = 2%

Potential extension (4 → 8 models): alternative fixed M values in short models



Moving toward 2019 final assessment

- Responses to SRB and external review
  - Additional bridge steps as necessary
- Sex-ratio of the 2018 commercial landings
- Standard data updates: 2018 revisions, 2019 observations
  - Mortality estimates
  - Survey, fishery CPUE
  - Age data

Outline

- Summary
- Data sources
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Research recommendations

- Biological understanding
  - Relate directly to Research Program
- Data-related
  - New and existing data analysis
- Technical
  - Modelling, methods, and other more conceptual issues (mostly for nerds)

Research recommendations

- (At least) two additions:
  - Whale depredation
  - Study of linkages with Russian waters
    - Life-history stages
    - Direct exchange

Research recommendations

- Biological understanding
  - Maturity, fecundity, skip spawning
  - Stock structure, i.e. 4B
  - Movement rates
  - Size-at-age (study of factors)
  - Recruitment processes
  - Discard mortality rates

Research recommendations

- Data-related
  - Sex-ratio monitoring
  - Fishery CPUE modelling
  - Hook spacing relationship
  - Length-weight relationship
  - Size-at-age (additional exploration of existing data)
  - Trawl survey data analysis
  - Historical data recovery
  - Subsistence harvest
  - NMFS observer data from directed fishery
  - Historical bycatch reanalysis
  - Variance analysis for mortality estimates
  - Model-based age-compositions

Research recommendations

- Technical
  - Consistency and coordination with MSE
  - Model refinement
    - Data weighting vs. process error
    - Composition weighting
    - Discard and bycatch uncertainty
    - Treatment of PDO index
    - Newly available model features
  - Ensemble refinement
    - Model weighting
    - Bayesian methods
    - Alternative model structures: growth- or movement-based

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