Assessment of Pacific cod in the eastern Bering Sea

NOAA FISHERIES
Alaska Fisheries Science Center

Grant Thompson

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Team and SSC comments

Comments on assessments in general (1 of 5)

- *SSC3: "The SSC reminds authors of the need to balance the desire to improve model fit with increased risk of model misspecification."* This recommendation was subsequently clarified in the minutes of the June 2018 SSC meeting as follows: *"In the absence of strict objective guidelines, the SSC recommends that thorough documentation of model evaluation and the logical basis for changes in model complexity be provided in all cases."*
  - Model evaluation is documented thoroughly in this assessment
  - Although a change from Model 16.6 to Model 16.6i is recommended here, this does not involve a change in model complexity
  - Model complexity is also addressed under "Choice of Final Model"

Comments on assessments in general (2 of 5)

- *SSC4: "Report a consistent metric (or set of metrics) to describe fish condition among assessments and ecosystem documents where possible."*
  - The index of fish condition used in this assessment is the same as that reported in this year's BSAI ESR, in conformity with the policy noted in response to this comment in Appendix 2.1

Comments on assessments in general (3 of 5)

- *SSC5: "Projections ... clearly illustrate the lack of uncertainty propagation in the 'proj' program used by assessment authors. The SSC encourages authors to investigate alternative methods for projection that incorporate uncertainty in model parameters in addition to recruitment deviations. Further, the SSC noted that projections made on the basis of fishing mortality rates (Fs) only will tend to underestimate the uncertainty (and perhaps introduce bias if the population distribution is skewed). Instead, a two-stage approach that first includes a projection using F to find the catch associated with that F and then a second projection using that fixed catch may produce differing results that may warrant consideration."*
  - Projections in this assessment are instead based on Stock Synthesis, thus allowing for incorporation of uncertainty in model parameters
  - The two-stage approach was used to create Figure 2.30

Comments on assessments in general (4 of 5)

- *SSC9 (follow-up on comment SSC1)*: *"A regression analysis of ecosystem indicators correlated with historical spawning biomass was presented in response to the SSCs request for a method to predict the likelihood of impending stock decline. The SSC cautions that testing a large number of indicators (as was done in this case) is likely to produce a statistically significant relationship even if one does not exist. Stock assessment authors are encouraged to work with ESR analysts to identify a small subset of indicators prior to analysis, and preferably based on mechanistic hypotheses."*
  - Because the analysis conducted in response to comment SSC1 in the preliminary assessment involved extensive cross-validation, the SSC's conclusion regarding the likelihood of finding a statistically significant result even if one does not exist may be debatable
  - Next year's analysis will conform to the new requested approach

Comments on assessments in general (5 of 5)

- *SSC10 (follow-up on comment SSC2): "The SSC recognized that because formal criteria for these categorizations have not been developed by the PT, they will not be presented in December 2018."*
  - In conformity with this comment, determinations regarding the "current and future condition" of the stock and its ecosystem are not presented here
- *SSC11: "The SSC supports the PT recommendation to make the use of model-based survey estimates at the individual author's discretion for 2018."*
  - Model-based survey estimates are not used in this assessment
    - VAST estimates for EBS Pacific cod are still under development
    - Given the number of models requested, there would not have been time to develop a VAST-based model anyway

Comments specific to this assessment (1 of 15)

- *BPT2: The Team recommends presenting in the next assessment document, the fishery CPUE for each of the separate sectors (pot, trawl, longline), as has been done in the past. This information would be useful to compare to estimated trends from the assessment.*
  - The requested data are presented in Table 2.2, along with an update of last year's analysis of longline fishery CPUE in Figure 2.1
- *BPT8: "The Plan Team recommends to not consider models with linkages to environmental covariates for further review in 2018 but encourages continued investigations in the future of the relationships between environmental covariates and various stock assessment parameters as well as the mechanisms behind those relationships."*
  - Models with such linkages are not included
  - Investigations of such models, as well as the mechanisms behind the modeled relationships, will continue in the future

Comments specific to this assessment (2 of 15)

- *BPT9: "The Plan Team recommends suspending the investigation of two-area models for Bering Sea Pacific cod in 2017 but encourages further development of the models in the future if data suggest that they are warranted."*
  - Investigation of two-area models has been suspended, but will resume in the future if data suggest that it is warranted
- *BPT10: "The Plan Team recommends not including Model 17.6 for 2018 runs for a number of reasons...."*
  - Model 17.6 is not included

Comments specific to this assessment (3 of 15)

- *BPT11: "Given recent and projected warm conditions and recent distributional trends, the Plan Team recommends that the NBS survey extension is conducted again in 2019 (and future years as needed) in order to support assessment estimates of fish biomass, to continue to monitor potential range expansion of Pacific cod, and to understand the dynamics and behavior of the Pacific cod stock in relation to environmental conditions. The ten-fold increase in the Pacific cod biomass in the Northern Bering Sea and distributional shifts between 2010 and 2017 is an important event to understand and monitor. Also, these observations led the Plan Team to recommend models that included data from northwestern EBS and Northern Bering Sea areas."*
  - The AFSC plans to conduct a survey of the NBS in 2019

Comments specific to this assessment (4 of 15)

- *BPT12: “The Plan Team requests that five models (described below) be brought back in November, with 2018 data included....*
  - A. *Model 16.6: the base model.*
  - B. *Model 16.6b, which includes the two northwestern EBS strata in the EBS survey index and is modeled with a change in Q from the early period without those northwestern strata.*
  - C. *A combination of Models 16.6b and 16.6g which includes the northwestern strata in the EBS survey index and modeled with time-varying Q, and the NBS survey observations with estimated selectivity and time-varying Q.*
  - D. *Model 17.2 as it was structured and parameterized in 2017....*
  - E. *Same as Model 17.2 but including the northwestern strata in the EBS survey index and modeled with time-varying Q, and the NBS survey observations with estimated selectivity and time-varying Q.”*
- See comment SSC13

Comments specific to this assessment (5 of 15)

- *BPT13: "Additionally, if time allows, the Plan Team recommends that the author consider the following two models.*
  - F. *Same as Model 16.6 but including the northwestern strata in the EBS survey index modeled with time-varying Q.*
  - G. *Same as Model 16.6 but adding the NBS survey estimates to the EBS survey estimates (with the NW strata) and model Q as time-varying. Size compositions should be combined by weighting by the abundance estimates from each area (if available)."*
- See comment SSC13

Comments specific to this assessment (6 of 15)

- *BPT14: "The final model in the above list (a potential model for consideration) simply adds the NBS survey estimates to the EBS survey estimates. This may not be statistically satisfactory. Therefore, the Plan Team encourages continued research on statistical methods (e.g., geospatial analysis) to combine the Bering Sea surveys into a single comprehensive biomass index, noting that it may be possible to include environmental covariates in this analysis, such as the cold pool and ice cover. Relatedly, the Plan Team recommends investigating model-based approaches to estimate a consistent time-series for the NBS survey given that the survey design changed in 2018."*
  - As noted under comment SSC11 above, model-based estimates for EBS Pacific cod are still under development
  - Some of the efforts to date have included the NBS survey data (Jim Thorson, AFSC, pers. commun.)

Comments specific to this assessment (7 of 15)

- *BPT15: "Finally, the Plan Team asks that the author provide a clear rationale for a reduction in the ABC from maxABC if one is proposed. For example, some concerns may be the possibility of an uncertain but potentially dramatic increase in mortality in the northern areas if ice cover returns quickly. An ensemble of models may not capture factors that are of concern, as the magnitude of this potential mortality is unknown."*
  - No reduction from maxABC is proposed

Comments specific to this assessment (8 of 15)

- *SSC12: "The author provided several entirely new models for 2018, including models with environmental covariates to growth and mortality, as well as a two-area model with migration. The SSC supports the PT recommendation to suspend development of these models (18.x) for 2018, but encourages future investigations. This choice was made pragmatically, to focus efforts on the treatment of the Northern Bering Sea data, and to reduce the workload on the assessment author, recognizing the importance of improved understanding of the environmental and ecosystem drivers on life history and movement. These models represent helpful exploratory analyses to identify linkages and how they might be included in stock assessment models. Some additional vetting of covariates using model output to refine mechanistic hypotheses might also be an avenue for future work."*
  - Development of such models has been suspended

Comments specific to this assessment (9 of 15)

- *SSC13: "The SSC requests that 6 models be prepared for presentation in November and December, 4 of those requested by the PT, one that was modified from the PT recommended model, and one additional model:*
  - A. *Model 16.6: the base model, including 2018 data (PT).*
  - B. *A variant of Model 16.6g, which includes the northwestern strata in the EBS survey index and models the 1982-2018 expanded survey series with time-varying catchability, and the Northern Bering Sea survey observations with estimated selectivity and time-varying catchability (modified from PT).*
  - C. *Model 17.2 as it was structured and parameterized in 2017, but with 2018 data included (PT)."*
- Continued on next slide

Comments specific to this assessment (10 of 15)

- *SSC13, continued: "The SSC requests that six models be prepared for presentation in November and December, four of those requested by the PT, one that was modified from the PT recommended model, and one additional model:*
    - D. *Model 17.2 but including the northwestern strata in the EBS survey index and modeled with time-varying catchability, and the Northern Bering Sea survey observations with estimated selectivity and time-varying catchability (PT).*
    - E. *Model 16.6 but adding the NBS survey estimates to the EBS survey estimates (with the northwestern strata) and model catchability as time-varying. Size compositions should be combined by weighting by the abundance estimates from each area (if available; PT)."*
- Continued on next slide

Comments specific to this assessment (11 of 15)

- SSC13, continued:
  F. "*Additional SSC request: Model 16.6 including the northwestern survey strata and the NBS biomass estimates added to the EBS estimates and treated as a single survey index without changes in selectivity or catchability.*
  - *The SSC acknowledges that there may be an additional model that seems important to bring forward identified during investigation of the requested model, and leaves this to the author's discretion, noting that this not specifically requested."*
- Post-meeting discussion with the SSC members who drafted this recommendation resulted in a determination that the model described under "B" above was really no different than the model described under "C" in comment BPT12
- All of the SSC's requested models are included, as are two additional new models

Comments specific to this assessment (12 of 15)

- *SSC14: "The SSC supports exploration of a geospatial model that includes all of the survey data (and perhaps environmental covariates), generating a single index that can be used in the assessment with little technical 'overhead' invested in time-varying catchability."*
  - See comment BPT14
- *SSC15: "The SSC requests that future presentations of a model ensemble include a preferred model set and weighting approach recommended by the author, including a rationale for these choices, rather than solely an array of alternatives. The SSC leaves the further development of an ensemble of Pacific cod models for 2018 to the author's discretion: if some or all of the requested models seems reasonable for use in an ensemble in December, and a weighting scheme is identified, the SSC will consider it in December. A set of base case results from a single model should also be presented."*
  - Response on next slide

Comments specific to this assessment (13 of 15)

- Response to SSC15:
  - Choosing which models to include in an ensemble and choosing an approach for weighting those models are both difficult problems
  - Last year's preliminary and final assessments and this year's preliminary assessment contained many alternative approaches to model weighting, none of which garnered enthusiastic support
  - Unfortunately, the number and nature of the models requested for inclusion in this year's final assessment precluded development of new approaches
  - Lacking a convincing rationale either for a preferred ensemble or approach to model weighting, model averaging was not pursued
  - If ensemble modeling is pursued in the future, both a preferred model set and a preferred weighting approach, including a rationale for each of those choices, will be included

Comments specific to this assessment (14 of 15)

- *SSC16: "Because stock structure and migratory connectivity between the U.S. waters of the Bering Sea and the western regions of the Bering Sea (Russian waters) are poorly understood, the SSC recommends not changing the name of this assessment to the 'Bering Sea' Pacific cod assessment, but retaining 'Eastern Bering Sea,' for the time being."*
  - The title of this assessment is the same as in previous years
- *SSC17: "If a migration-based model is pursued in the future, the SSC suggests that a more mechanistic approach to incorporating migration in the model would be fruitful. For example, migration is most likely linked to the size and location of the cold pool, which used to impede the northward migration of Pacific cod, as well as to the size of the cod stock."*
  - Response on next slide

Comments specific to this assessment (15 of 15)

- Response to SSC17*:*
  - This year's preliminary assessment included three migration models
  - Of those, Model 18.2 adopted an entirely mechanistic approach, where time-variability in the parameters governing the migration rates took the form of deterministic functions of environmental covariates
  - Although the size of the cold pool was not among the covariates considered, mean bottom temperature was among those considered (the two are almost perfectly correlated)
  - When compared to purely random deviations in the migration parameters, mean bottom temperature exhibited correlations that were 0.25, 0.35, and 0.42 lower than those exhibited by the covariates that were chosen for use in Model 18.2
  - Nevertheless, if migration-based models are pursued in the future, mechanistic linkages between the migration parameters and the size and location of the cold pool will be considered.

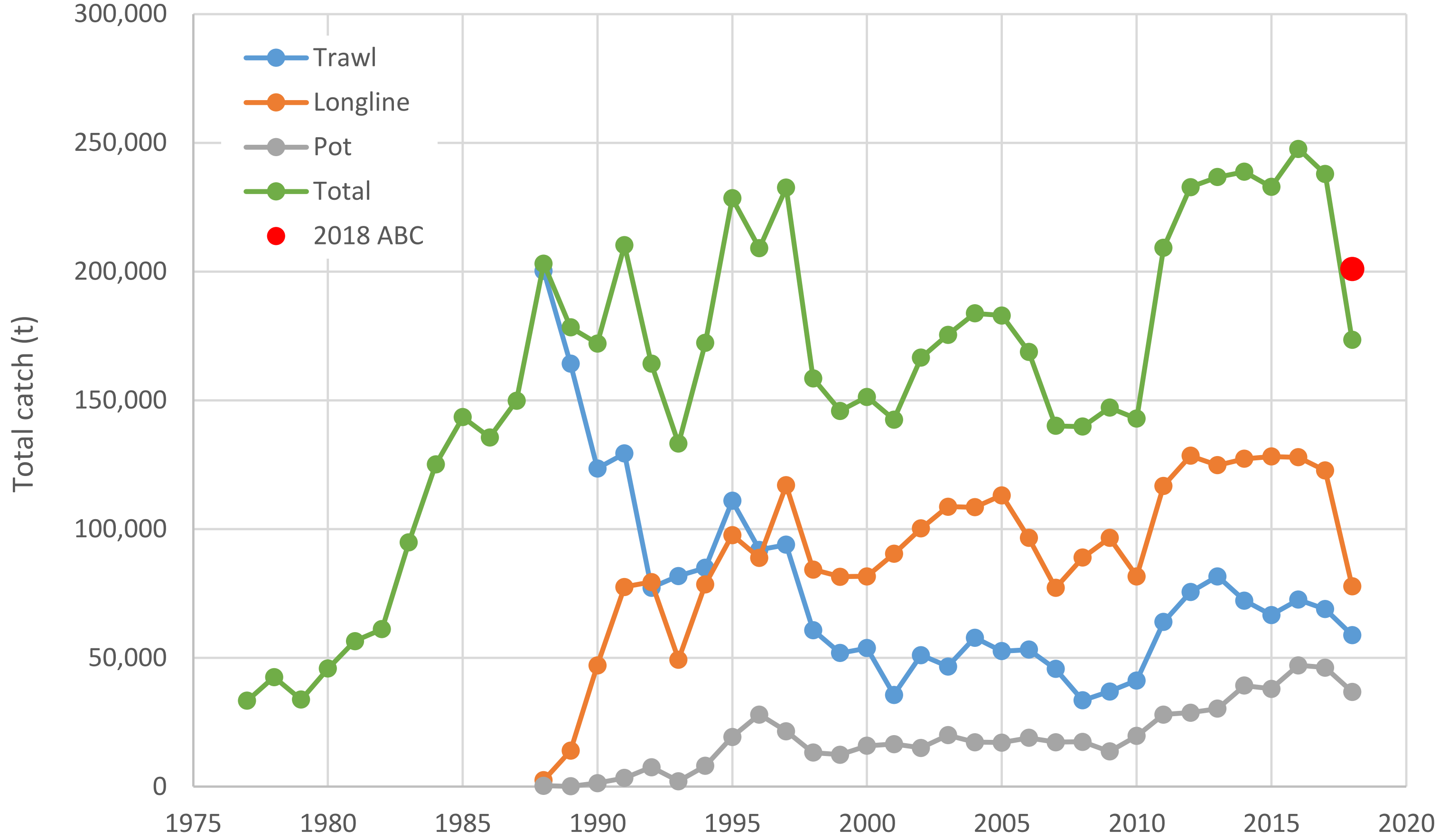
Data highlights

Economic performance report (Appendix 2.2)

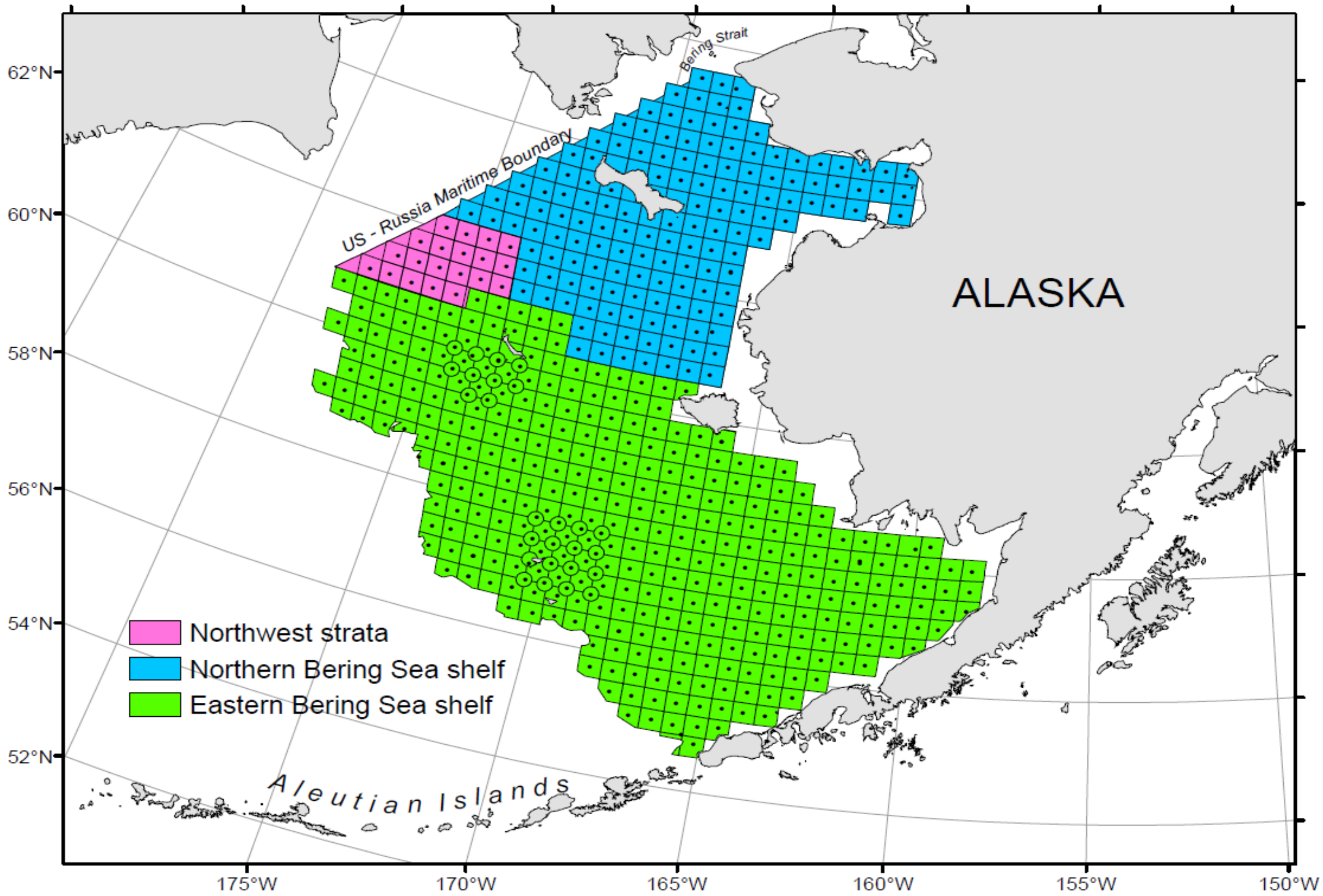
	Avg 08-12	2013	2014	2015	2016	2017
Total catch K mt	197.96	250.2	249.3	242.1	260.9	253
Retained catch K mt	194.8	243.5	244.4	238.9	257.6	249.8
Vessels #	180	175	156	149	162	170
CP H&L share of BSAI catch	54%	50%	50%	54%	49%	50%
CP trawl share of BSAI catch	15%	18%	14%	15%	14%	13%
Shoreside retained catch K mt	55.9	71.1	79.0	68.3	85.9	87.7
Shoreside catcher vessels #	124.4	125	109	100	110	125
CV pot gear share of BSAI catch	10%	11%	14%	12%	15%	17%
CV trawl share of BSAI catch	18%	18%	17%	16%	18%	18%
Shoreside ex-vessel value M $	$36.9	$36.8	$44.6	$34.0	$44.4	$53.8
Shoreside ex-vessel price lb $	$0.299	$0.243	$0.274	$0.248	$0.263	$0.316
Shoreside fixed gear ex-vessel price premium	$0.06	$0.01	$0.03	$0.03	$0.03	$0.04

Total catch

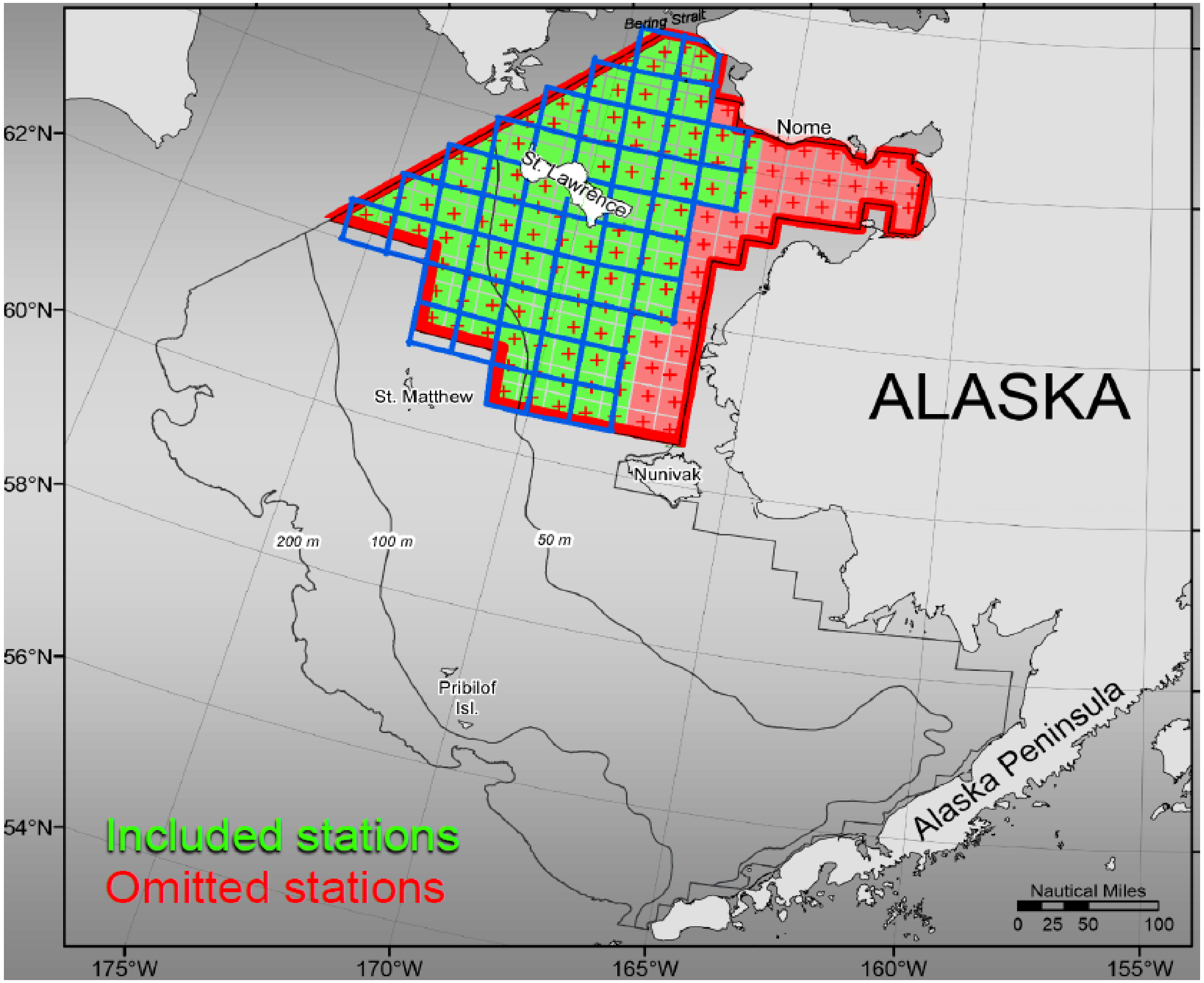
- 2018 current through October 23



AFSC bottom trawl survey areas

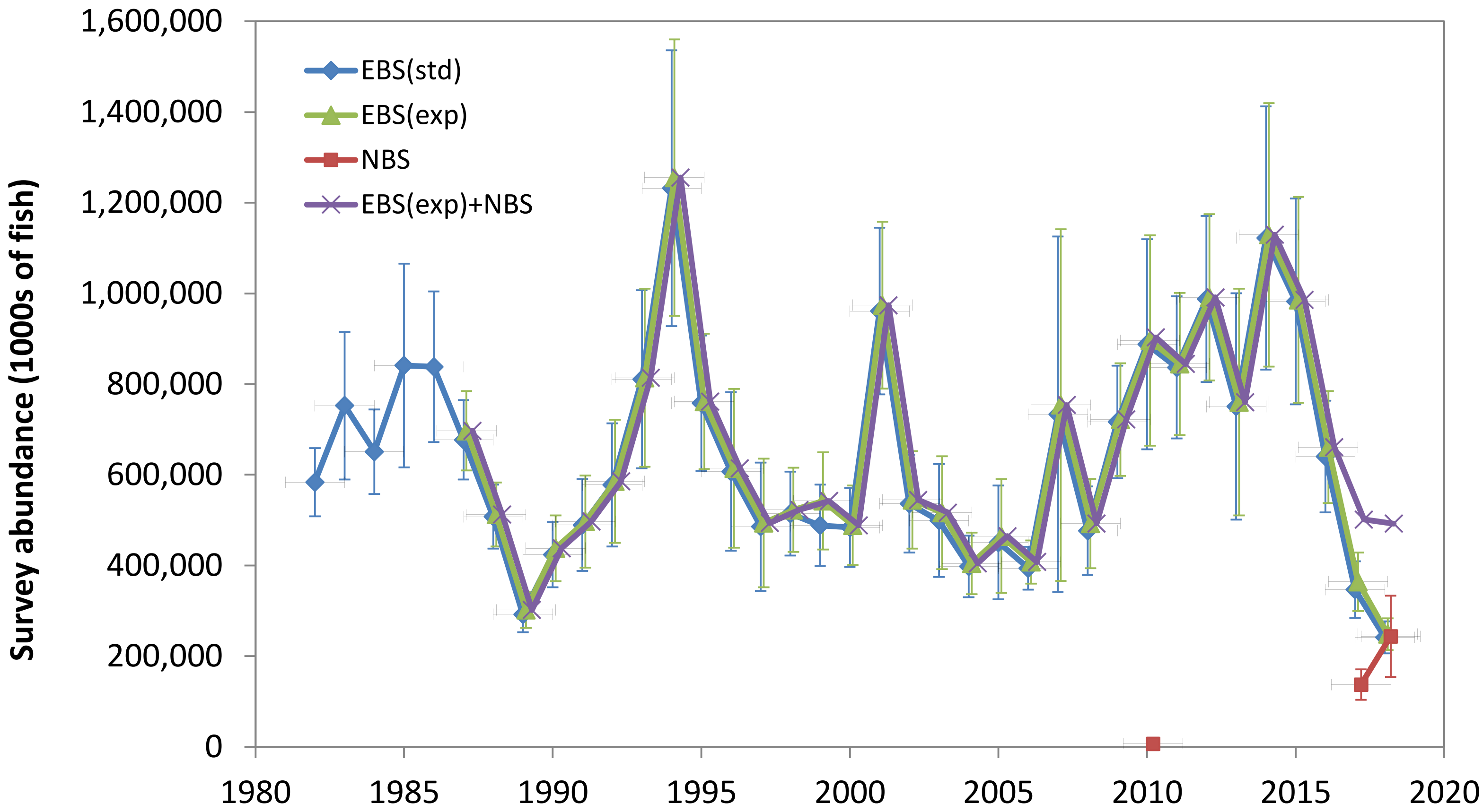


Truncated 2018 NBS survey area



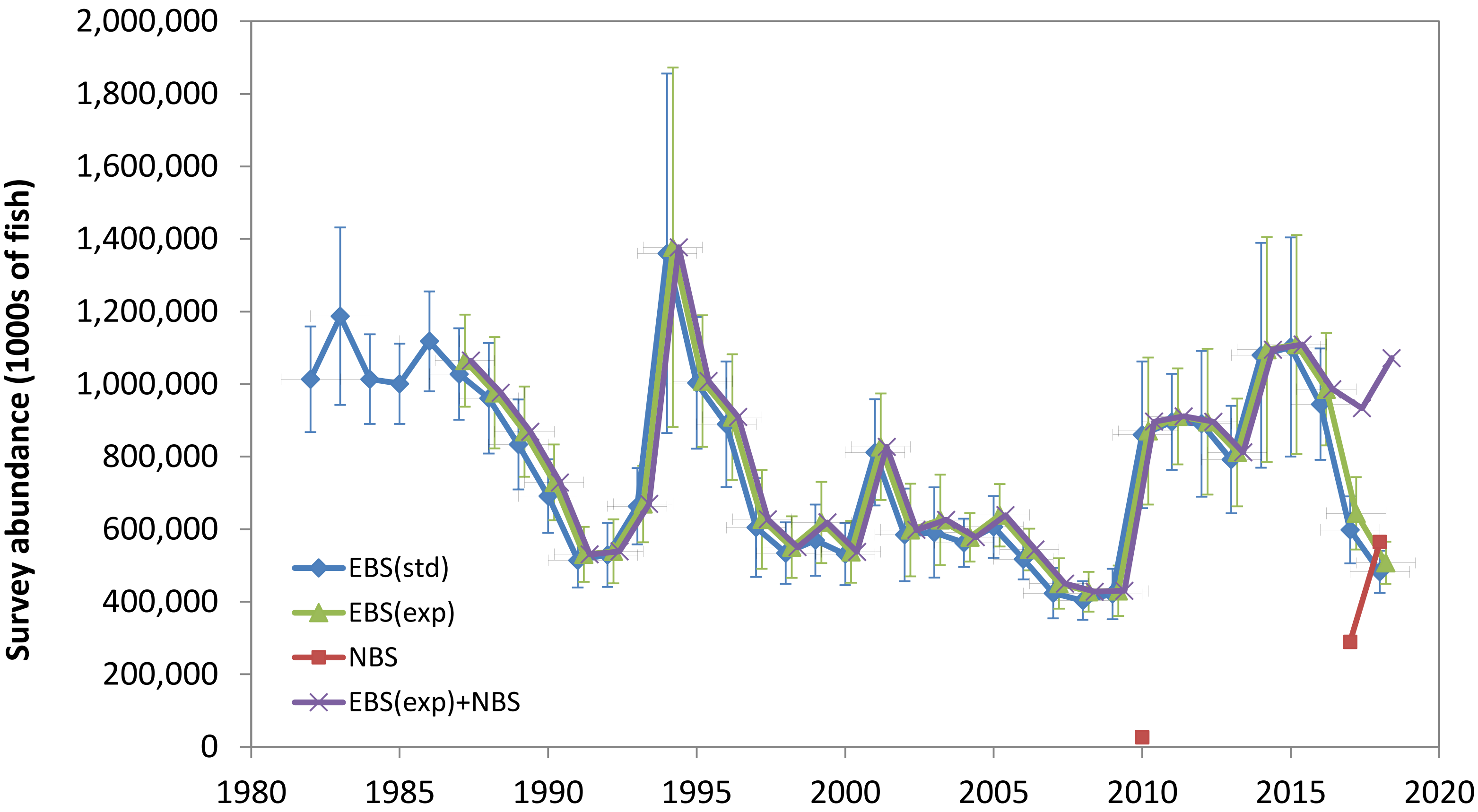
EBS, NBS shelf survey abundance (no. of fish)

- EBS has dropped 78% since 2014; 2018 EBS is all-time low



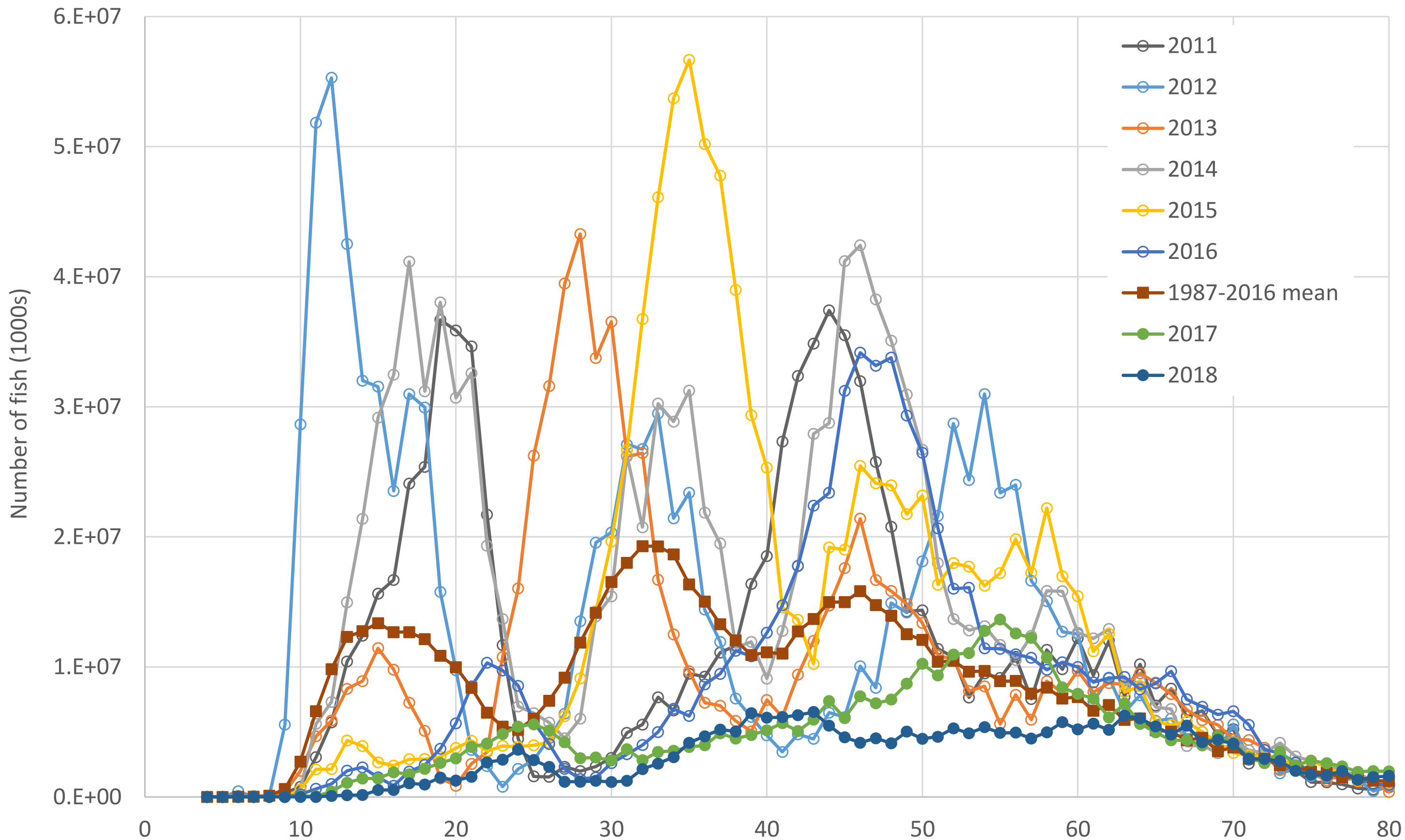
EBS, NBS shelf survey biomass

- EBS has dropped 54% since 2014



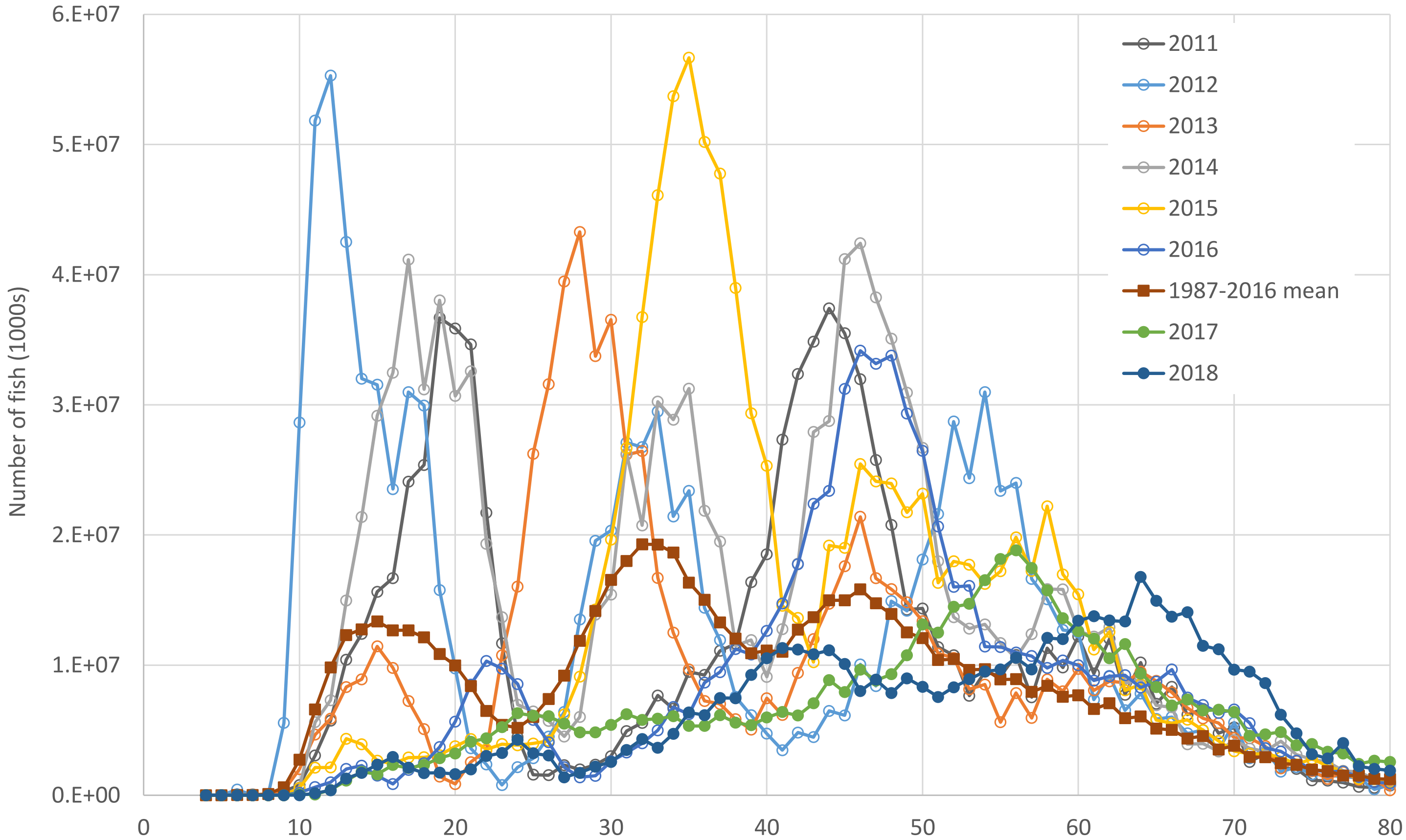
EBS shelf survey size composition

- 2017 below mean until 52 cm; 2018 below mean until 63 cm



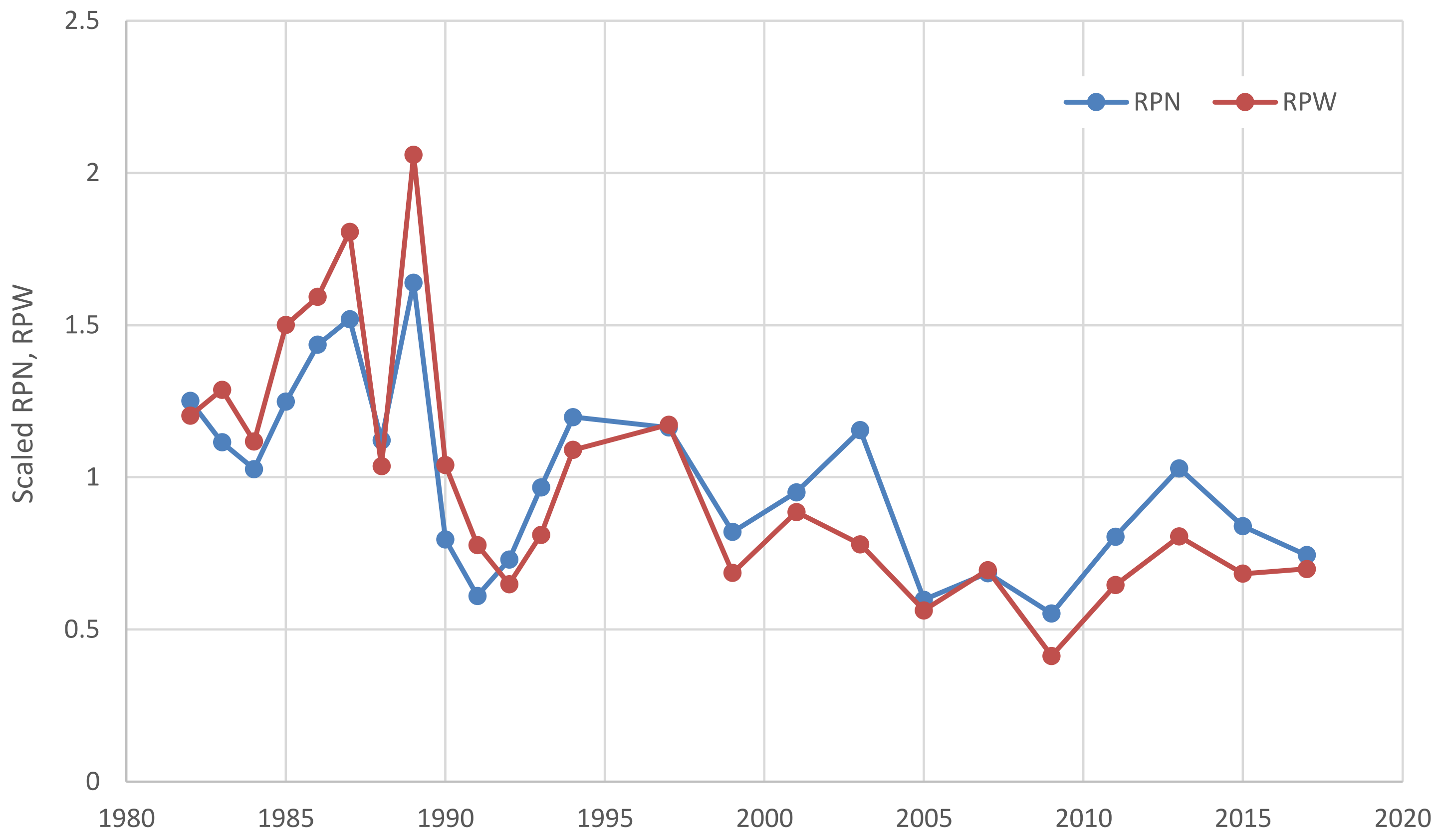
EBS+NBS shelf survey size composition

- 2017 below mean until 50 cm; 2018 below mean until 54 cm



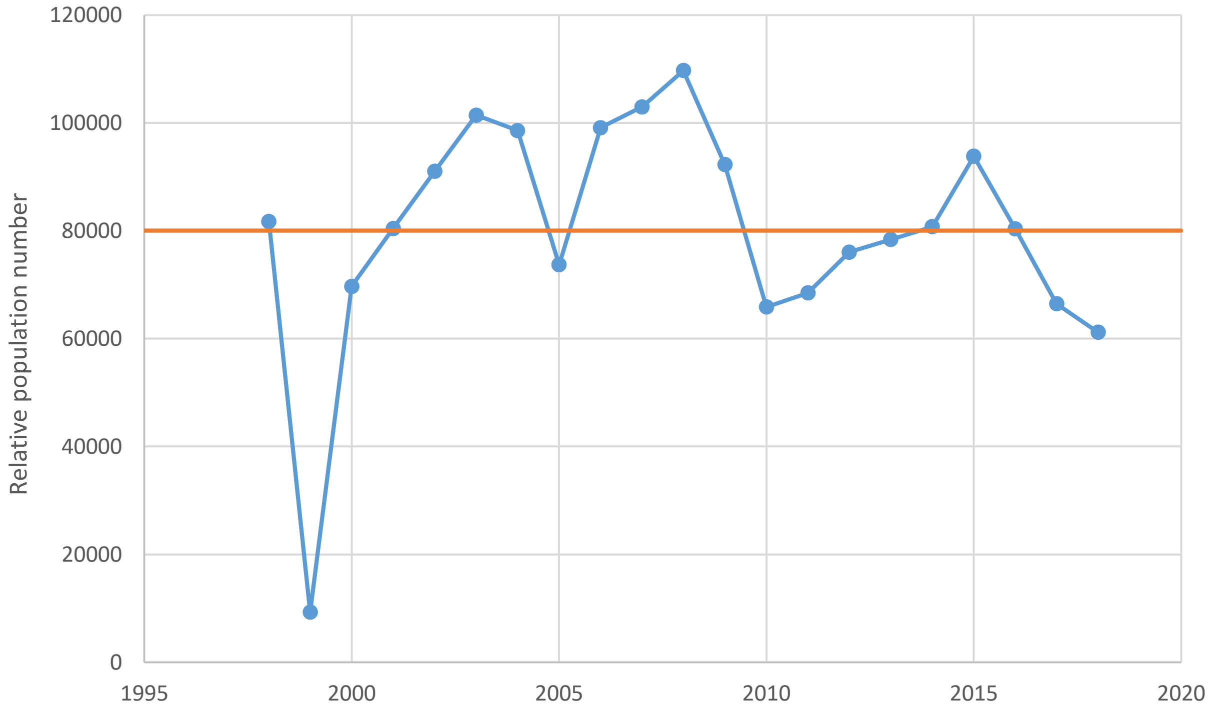
Other indices: NMFS longline survey

- RPN down 11% from 2015, RPW up 2%; no 2018 EBS survey



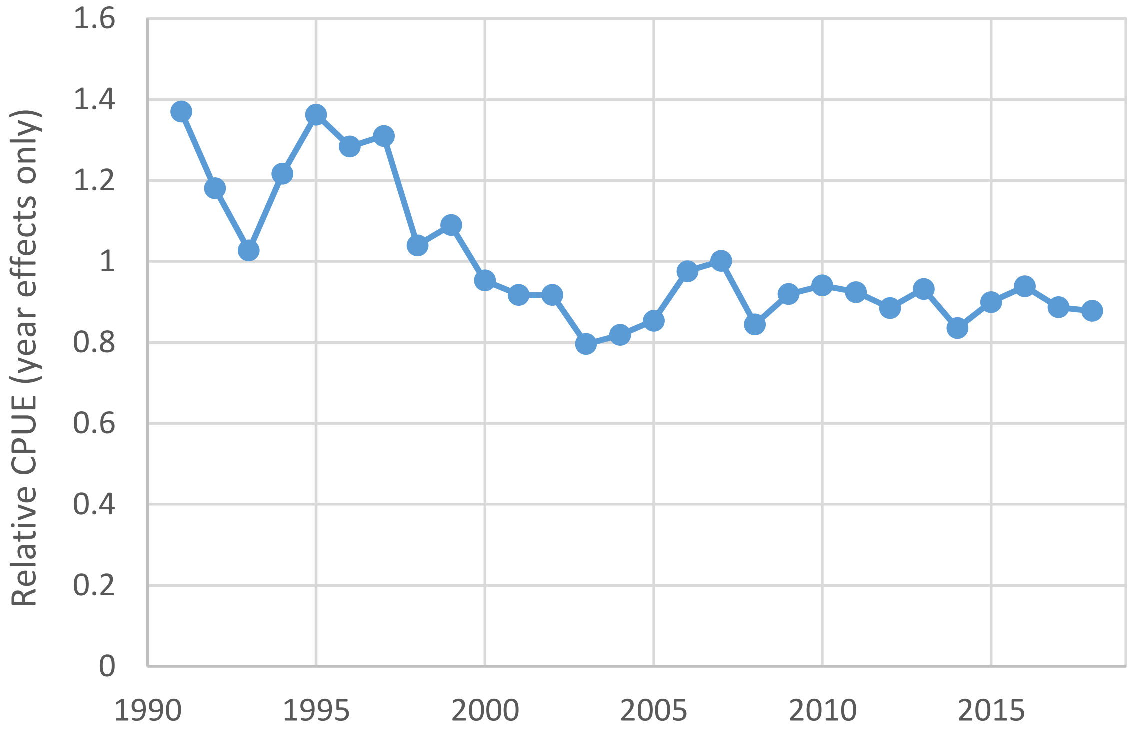
Other indices: IPHC longline survey

- RPN down 35% since 2015



Other indices: Longline fishery

- Fairly level since about 2000



Model structures

List of models (1 of x)

- Of the Team's 7 requested models A-G, all are included except B and F, which the SSC recommended omitting:
    B. *"Model 16.6b, which includes the two northwestern Eastern Bering Sea strata in the EBS survey index and is modeled with a change in catchability from the early period without those northwestern strata."*
    G. *"Same as Model 16.6 but including the northwestern strata in the EBS survey index modeled with time-varying catchability."*
- Of the SSC's 6 requested models A-F, all are included
- Two additional new models also included

List of models (2 of x)

- Following evaluation of the results, these model numbers were assigned:
  - Model 16.6 (previously numbered, requested by both Team and SSC)
  - Model 16.6i = SSC's "F"
  - Model 16.6j = Team's "G" and SSC's "E"
  - Model 16.6k = Team's "C" and SSC's "B"
  - Model 17.2 (previously numbered, requested by both Team and SSC)
  - Model 18.6 = Team's "E" and SSC's "D"
  - Model 18.7 (added by author)
  - Model 18.8 (added by author)

Model features (1 of 5)

- First rows list data sets that are included in the models
- Middle rows describe various ways in which *Q* is treated in the models
- Last rows describe miscellaneous features in three of the models

Feaure	16.6	16.6i	16.6j	16.6k	17.2	18.6	18.7	18.8
EBS survey strata 82 and 90		x	x	x		x	x	x
NBS survey as separate data set				x		x	x	x
Summed EBS and NBS data sets		x	x					
Fishery agecomps					x	x		x
EBS catchability estimated	x			x	x	x		
Annnually varying EBS catchability				x		x	x	x
NBS catchability estimated				x		x		
Annnually varying NBS catchability				x		x	x	x
EBS+NBS catchability estimated		x	x					
Annually varying EBS+NBS catchability			x					
Prior distribution for natural mortality					x	x		x
Flat-topped double normal selectivity					x	x		x
Annually varying fishery selectivity					x	x		x
Composition N = number of hauls					x	x		x
Harmonic mean composition weights					x	x		x

Model features (2 of 5)

- Model 16.6: The current base model, exhibiting the following features:
  - One fishery, one gear type, one season per year
  - Input N averages 300, with season×gear catch-weighted sizecomps
  - Logistic age-based selectivity for both the fishery and survey
  - External estimation of time-varying weight-at-length parameters and the standard deviations of ageing error at ages 1 and 20
  - All parameters constant over time except for recruitment and F
  - Internal estimation of M, F, length-at-age parameters (including ageing bias), recruitment (conditional on Beverton-Holt recruitment steepness fixed at 1.0), Q, and selectivity parameters

Model features (3 of 4)

- Model 16.6i: Same as Model 16.6, but with the following features added:
  - Include EBS survey strata 82 and 90 (i.e., use the 1987-2018 expanded EBS survey area)
  - Sum the EBS survey and NBS survey data sets into a single survey
- Model 16.6j: Same as Model 16.6i, but with the following feature added:
  - Allow randomly time-varying Q for the combined EBS+NBS survey
- Model 16.6k: Same as Model 16.6, but with the following feature added:
  - Include EBS survey strata 82 and 90 (i.e., use the 1987-2018 expanded EBS survey area)
  - Include the NBS survey as a separate data set
  - Allow randomly time-varying Q for the EBS survey
  - Estimate NBS survey Q internally
  - Allow randomly time-varying Q for the NBS survey

Model features (4 of 5)

- Model 17.2: Same as Model 16.6, but with the following features added:
    - Include fishery agecomps
    - Include a prior distribution for M based on previous estimates
    - Switch to age-based, flat-topped, double normal selectivity
    - Allow randomly time-varying fishery selectivity, with σs fixed at the restricted MLEs
    - Switch to haul-based input sample size and week×gear×area catch-weighted sizecomps
    - Use harmonic mean weighting of composition data

Model features (5 of 5)

- Model 18.6: Same as Model 17.2, but with the following features added:
  - Include EBS survey strata 82 and 90
  - Include the NBS survey as a separate data set
  - Allow randomly time-varying Q for the EBS survey
  - Estimate NBS survey Q internally
  - Allow randomly time-varying Q for the NBS survey
- Models 18.7 and 18.8: Same as Models 16.6k and 18.6, except:
  - Instead of estimating EBS survey Q internally, set it equal to the average EBS proportion of combined EBS+NBS survey abundance
  - Instead of estimating NBS survey Q internally, set it equal to the average NBS proportion of combined EBS+NBS survey abundance

Results

Objective function values, parameter counts

Aggregated components

Component	M16.6	M16.6i	M16.6j	M16.6k	M17.2	M18.6	M18.7	M18.8
Equil. catch	0.00	0.00	0.00	0.00	0.03	0.03	0.00	0.00
Survey indices	-20.66	-26.54	-70.09	-74.35	-9.27	-75.02	-76.21	-77.86
Sizecomps	1459.61	1427.42	1426.85	1550.13	1508.06	1543.16	1556.02	1542.63
Agecomps	267.75	271.94	270.10	276.85	99.12	98.83	282.14	102.70
Recruitment	1.27	-2.57	-2.52	-3.23	-3.50	-4.33	-3.09	-0.60
Initial recruitment	7.23	9.27	9.11	8.66	13.77	13.54	4.18	4.45
Priors					0.28	0.24		0.02
"Softbounds"	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.00
Parameter devs			-71.39	-60.89	-93.96	-149.95	-53.72	-138.81
Total	1715.20	1679.54	1562.07	1697.17	1514.53	1426.51	1709.32	1432.54

Parameter counts

Type	M16.6	M16.6i	M16.6j	M16.6k	M17.2	M18.6	M18.7	M18.8
Parameter devs	61	61	98	107	145	191	107	191
Parms with priors					1	1		1
Unconstrained	18	18	18	21	16	19	19	17
Total	79	79	116	128	162	211	126	209

Effective sample sizes: Models 16.6 and 16.6x

		Model 16.6						Model 16.6i					
Type	Fleet	Years	N	Mult.	Harm.	ΣNeff1	ΣNeff2	Years	N	Mult.	Harm.	ΣNeff1	ΣNeff2
Size	Fishery	42	300	1.0000	559	12599	23459	42	300	1.0000	583	12600	24502
Size	EBS(std) survey	37	300	1.0000	312	11098	11527	n/a	n/a	n/a	n/a	n/a	n/a
Size	EBS(exp) survey	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Size	NBS survey	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Size	EBS(exp)+NBS	n/a	n/a	n/a	n/a	n/a	n/a	37	300	1.0000	321	11101	11886
Age	Fishery	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Age	EBS(std) survey	24	300	1.0000	62	7203	1495	n/a	n/a	n/a	n/a	n/a	n/a
Age	EBS(exp) survey	n/a	n/a	n/a	n/a	n/a	n/a	24	300	1.0000	61	7200	1456
				SEave	RMSE					SEave	RMSE		
Index	EBS(std) survey	37	353	0.1065	0.1917	13061	4028	n/a	n/a	n/a	n/a	n/a	n/a
Index	EBS(exp) survey	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Index	NBS survey	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Index	EBS(exp)+NBS	n/a	n/a	n/a	n/a	n/a	n/a	37	378	0.1056	0.1819	13986	4717
					Sum:	43961	40509				Sum:	44887	42561

		Model 16.6j						Model 16.6k					
Type	Fleet	Years	N	Mult.	Harm.	ΣNeff1	ΣNeff2	Years	N	Mult.	Harm.	ΣNeff1	ΣNeff2
Size	Fishery	42	300	1.0000	581	12600	24404	42	300	1.0000	582	12600	24427
Size	EBS(std) survey	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Size	EBS(exp) survey	n/a	n/a	n/a	n/a	n/a	n/a	37	300	1.0000	317	11101	11724
Size	NBS survey	n/a	n/a	n/a	n/a	n/a	n/a	3	300	1.0000	82	900	246
Size	EBS(exp)+NBS	37	300	1.0000	321	11101	11869	n/a	n/a	n/a	n/a	n/a	n/a
Age	Fishery	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Age	EBS(std) survey	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Age	EBS(exp) survey	24	300	1.0000	61	7200	1468	24	300	1.0000	60	7200	1429
				SEave	RMSE					SEave	RMSE		
Index	EBS(std) survey	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Index	EBS(exp) survey	n/a	n/a	n/a	n/a	n/a	n/a	37	371	0.1054	0.1053	13727	13734
Index	NBS survey	n/a	n/a	n/a	n/a	n/a	n/a	3	89	0.1623	0.1624	267	267
Index	EBS(exp)+NBS	37	378	0.1056	0.1056	13986	13989	n/a	n/a	n/a	n/a	n/a	n/a
					Sum:	44887	51730				Sum:	45795	51828

Effective sample sizes: Models 17.2 and 18.x

		Model 17.2						Model 18.6					
Type	Fleet	Years	N	Mult.	Harm.	ΣNeff1	ΣNeff2	Years	N	Mult.	Harm.	ΣNeff1	ΣNeff2
Size	Fishery	34	5225	0.2517	1315	44713	44724	34	5225	0.2549	1332	45283	45278
Size	EBS(std) survey	37	332	0.8871	295	10904	10904	n/a	n/a	n/a	n/a	n/a	n/a
Size	EBS(exp) survey	n/a	n/a	n/a	n/a	n/a	n/a	37	346	0.8701	301	11139	11144
Size	NBS survey	n/a	n/a	n/a	n/a	n/a	n/a	3	68	1.3015	89	266	266
Size	EBS(exp)+NBS	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Age	Fishery	8	9516	0.0273	260	2078	2082	8	9516	0.0292	279	2223	2230
Age	EBS(std) survey	24	342	0.1402	48	1151	1151	n/a	n/a	n/a	n/a	n/a	n/a
Age	EBS(exp) survey	n/a	n/a	n/a	n/a	n/a	n/a	24	359	0.1281	46	1104	1104
				SEave	RMSE					SEave	RMSE		
Index	EBS(std) survey	37	353	0.1065	0.2065	13061	3474	n/a	n/a	n/a	n/a	n/a	n/a
Index	EBS(exp) survey	n/a	n/a	n/a	n/a	n/a	n/a	37	371	0.1054	0.1054	13727	13719
Index	NBS survey	n/a	n/a	n/a	n/a	n/a	n/a	3	89	0.1623	0.1624	267	267
Index	EBS(exp)+NBS	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
					Sum:	71907	62336				Sum:	74008	74007

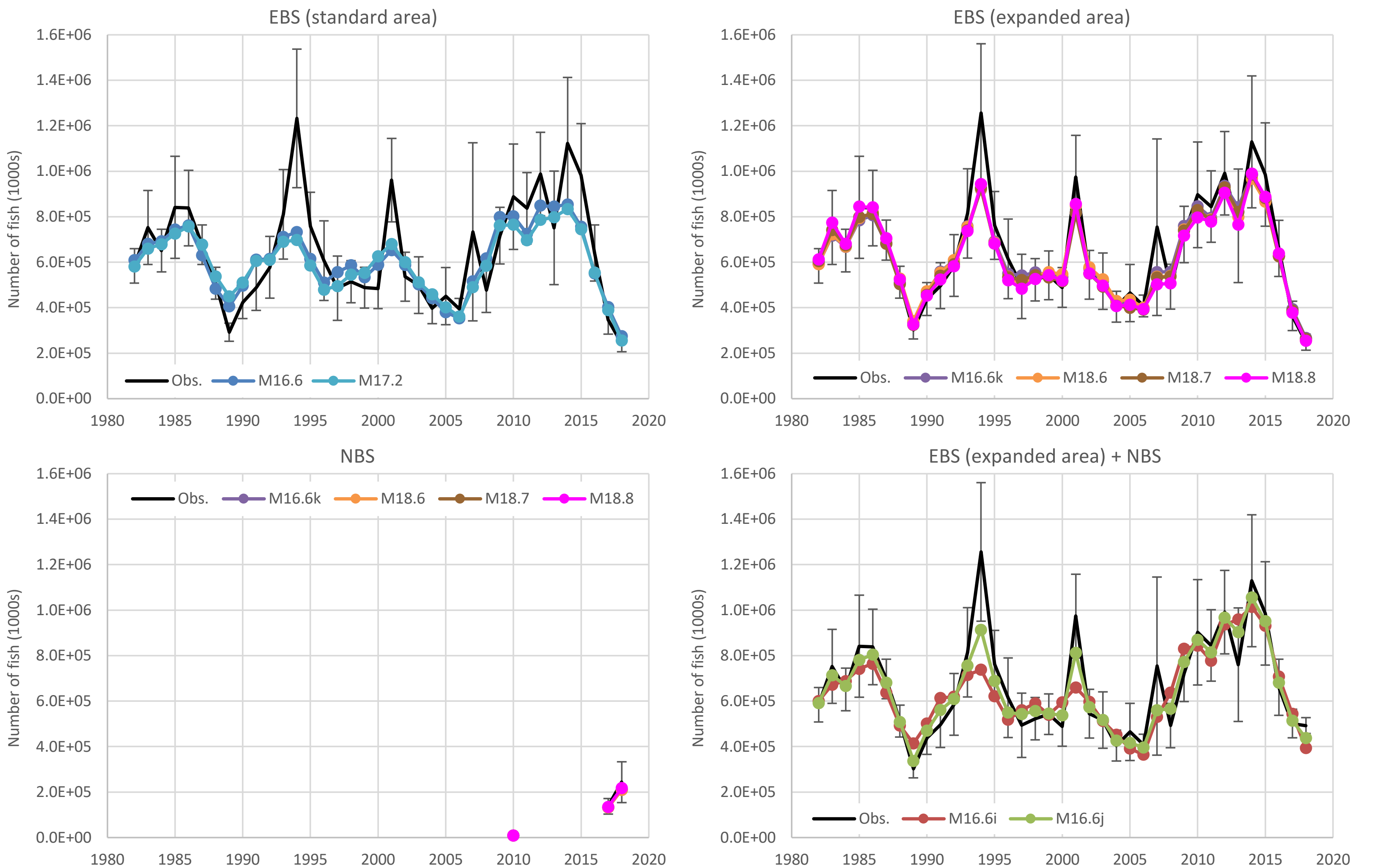
		Model 18.7						Model 18.8					
Type	Fleet	Years	N	Mult.	Harm.	ΣNeff1	ΣNeff2	Years	N	Mult.	Harm.	ΣNeff1	ΣNeff2
Size	Fishery	42	300	1.0000	569	12600	23917	34	5225	0.2398	1253	42600	42605
Size	EBS(std) survey	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Size	EBS(exp) survey	37	300	1.0000	317	11100	11728	37	346	0.8841	306	11318	11324
Size	NBS survey	3	300	1.0000	81	900	244	3	68	1.2940	88	264	264
Size	EBS(exp)+NBS	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Age	Fishery	n/a	n/a	n/a	n/a	n/a	n/a	8	9516	0.0324	309	2467	2470
Age	EBS(std) survey	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Age	EBS(exp) survey	24	300	1.0000	59	7200	1416	24	359	0.1239	45	1068	1068
				SEave	RMSE					SEave	RMSE		
Index	EBS(std) survey	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Index	EBS(exp) survey	37	371	0.1054	0.1054	13727	13720	37	371	0.1054	0.1053	13727	13729
Index	NBS survey	3	89	0.1623	0.1623	267	267	3	89	0.1623	0.1624	267	267
Index	EBS(exp)+NBS	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
					Sum:	45794	51292				Sum:	71711	71727

Common parameters

Quantity	Model 16.6		Model 16.6i		Model 16.6j		Model 16.6k		Model 17.2		Model 18.6		Model 18.7		Model 18.8	
	Est.	StD.	Est.	StD.	Est.	StD.	Est.	StD.	Est.	StD.	Est.	StD.	Est.	StD.	Est.	StD.
Natural mortality (M)	0.354	0.012	0.340	0.012	0.340	0.013	0.345	0.013	0.356	0.020	0.364	0.023	0.398	0.007	0.471	0.011
Length at age 1.5 (cm)	16.358	0.087	16.377	0.088	16.378	0.089	16.423	0.088	16.458	0.091	16.479	0.091	16.418	0.088	16.468	0.090
Asymptotic length (cm)	100.60	1.952	100.62	1.955	100.71	1.986	100.09	1.850	109.05	1.923	108.79	1.915	98.444	1.666	106.34	1.629
Brody growth coefficient (K)	0.196	0.012	0.195	0.012	0.194	0.012	0.202	0.012	0.175	0.009	0.176	0.009	0.201	0.011	0.182	0.009
Richards growth coefficient	1.036	0.047	1.039	0.047	1.043	0.047	1.008	0.045	1.041	0.038	1.036	0.038	1.046	0.044	1.032	0.037
SD of length at age 1 (cm)	3.447	0.057	3.456	0.058	3.457	0.058	3.468	0.058	3.488	0.058	3.495	0.058	3.474	0.058	3.496	0.057
SD of length at age 20 (cm)	9.622	0.272	9.532	0.272	9.509	0.274	9.250	0.259	9.037	0.234	8.907	0.230	9.169	0.252	8.773	0.220
Ageing bias at age 1	0.337	0.012	0.335	0.012	0.335	0.013	0.335	0.013	0.340	0.029	0.334	0.031	0.347	0.011	0.347	0.028
Ageing bias at age 20	0.198	0.143	0.157	0.145	0.133	0.146	0.166	0.145	-0.491	0.191	-0.547	0.197	0.126	0.140	-0.793	0.200
ln(mean post-1976 recruits)	13.047	0.099	12.984	0.097	12.986	0.106	12.972	0.104	12.948	0.136	13.006	0.160	13.413	0.056	13.848	0.070
SD of ln(recruitment) devs	0.684	0.072	0.656	0.067	0.655	0.067	0.637	0.063	0.645	_	0.634	_	0.604	0.059	0.661	_
ln(pre-1977 recruits offset)	-1.120	0.216	-1.158	0.201	-1.147	0.203	-1.106	0.200	-1.465	0.053	-1.467	0.068	-0.867	0.214	-1.215	0.232
Initial fishing mortality rate	0.107	0.033	0.190	0.075	0.186	0.073	0.186	0.071	0.866	0.706	0.738	0.582	0.120	0.037	0.212	0.097

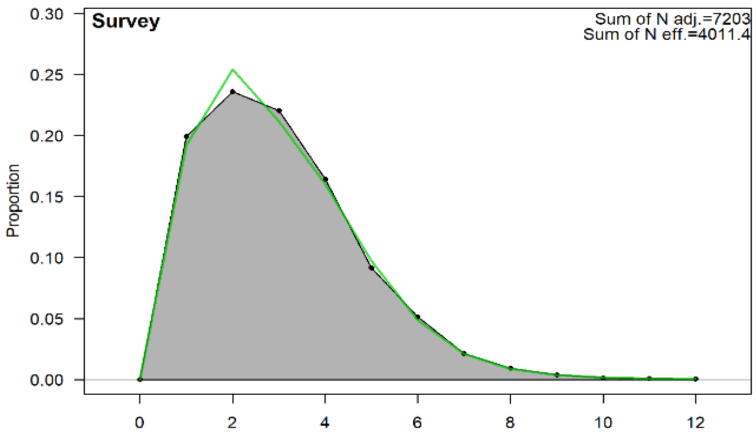
- Parameters with notably wide ranges:
  - M: ratio of max to min = 1.38
  - ln(mean post-1976 R): back-transformed ratio of max to min = 2.46
  - ln(pre-1977 R offset): back-transformed ratio of max to min = 1.82
  - Initial F: ratio of max to min = 8.07

Fit to survey abundance index

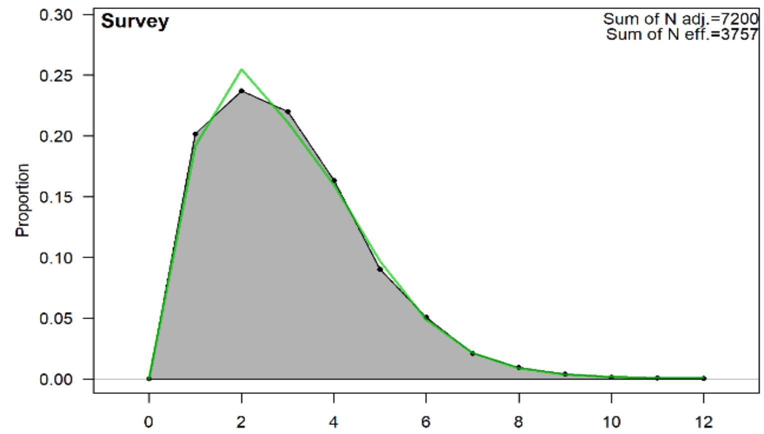


Time-aggregated agecomp fits: M16.6, M16.6x

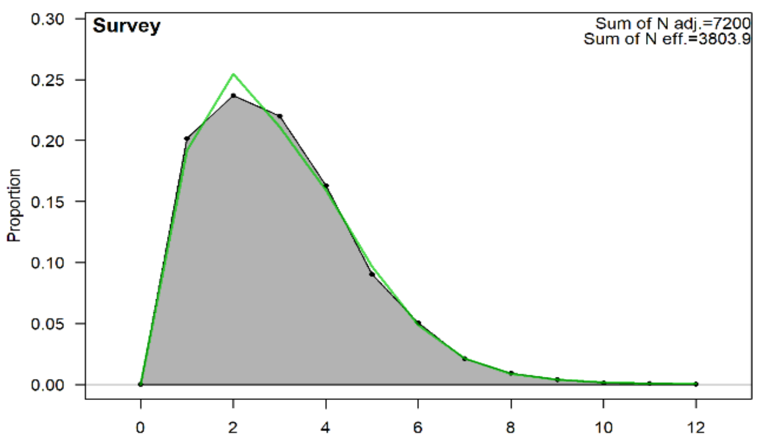
Model 16.6



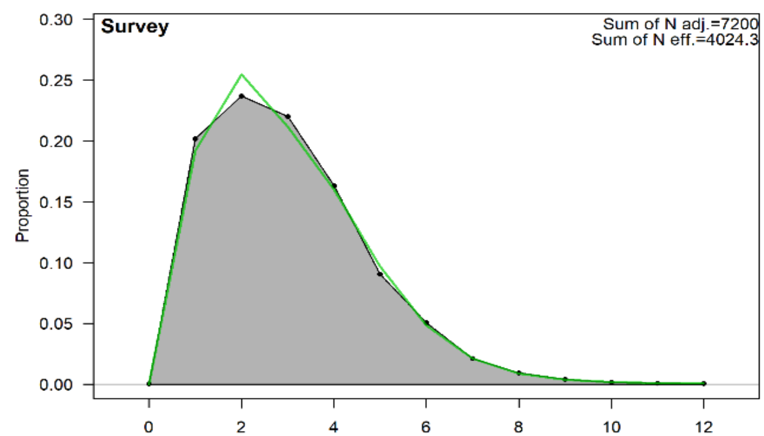
Model 16.6i



Model 16.6j

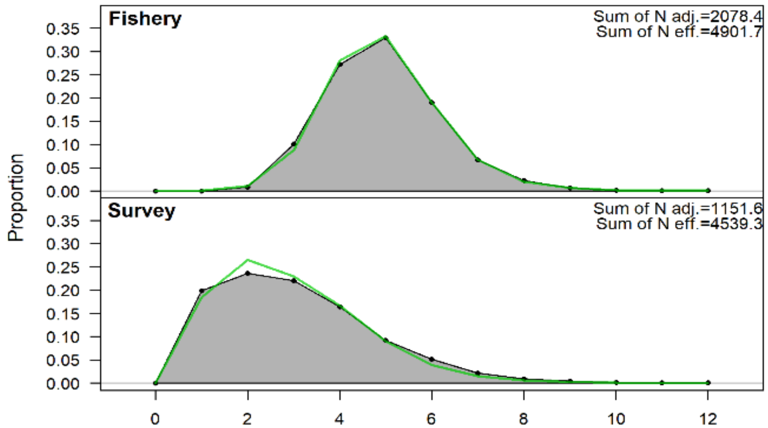


Model 16.6k

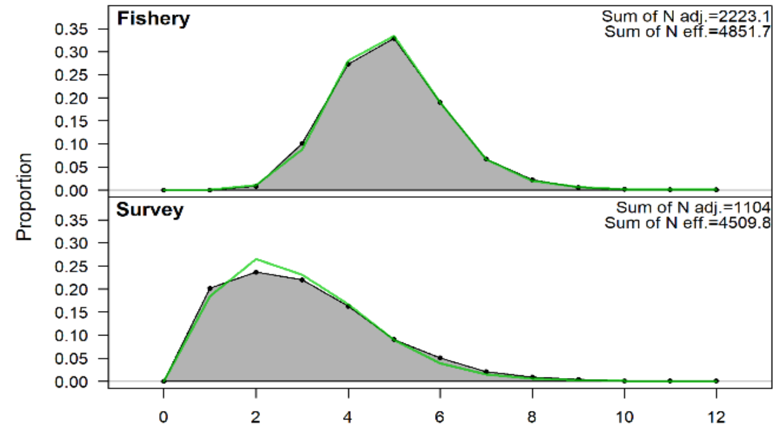


Time-aggregated agecomp fits: M17.2, M18.x

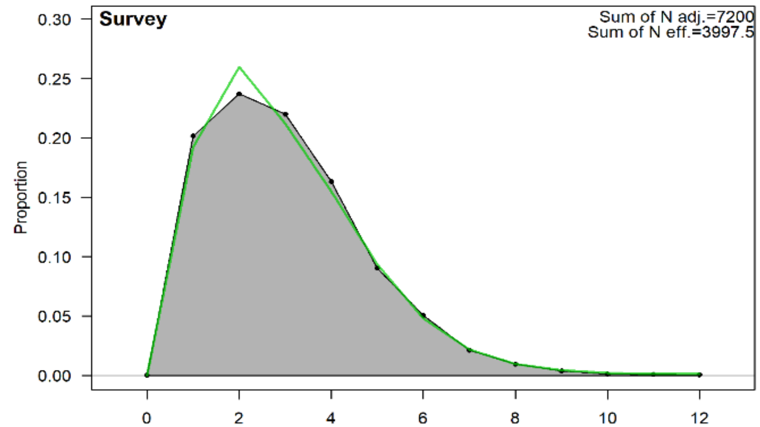
Model 17.2



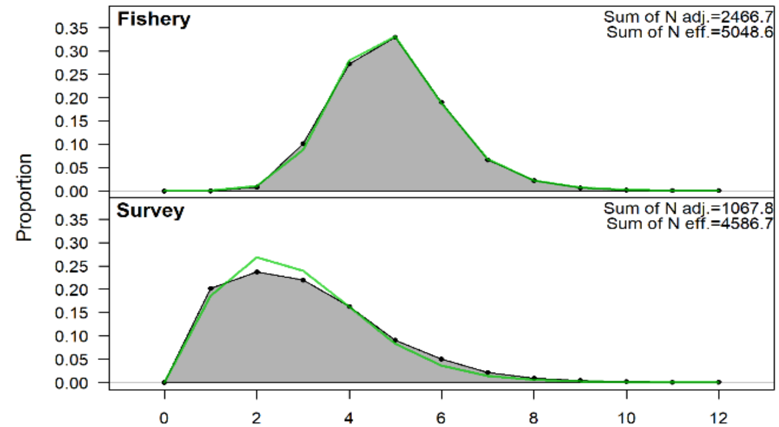
Model 18.6



Model 18.7

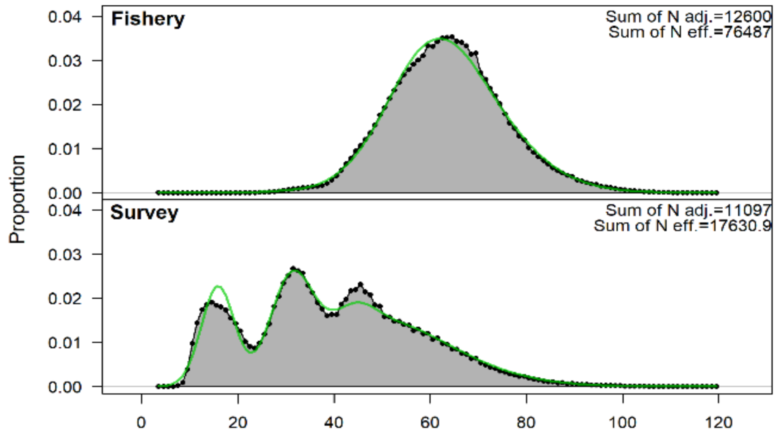


Model 18.8

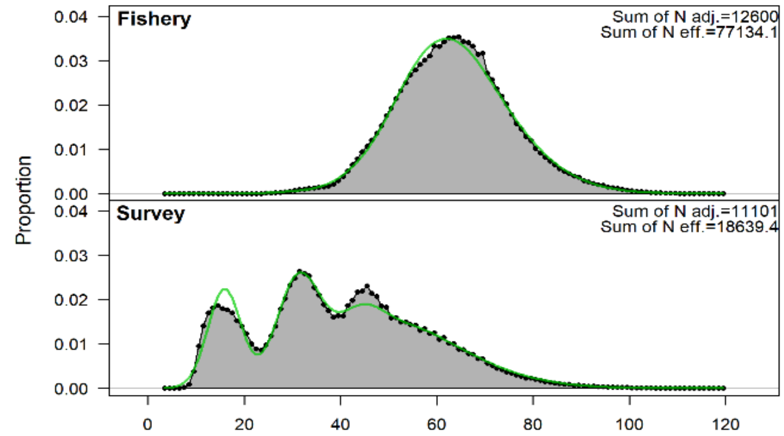


Time-aggregated sizecomp fits: M16.6, M16.6x

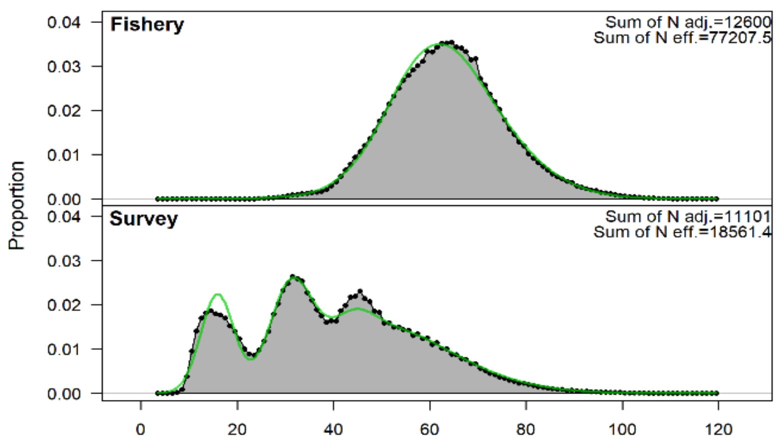
Model 16.6



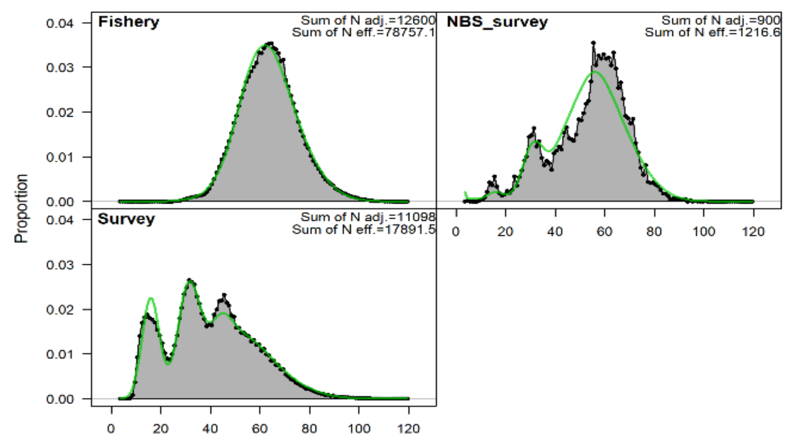
Model 16.6i



Model 16.6j

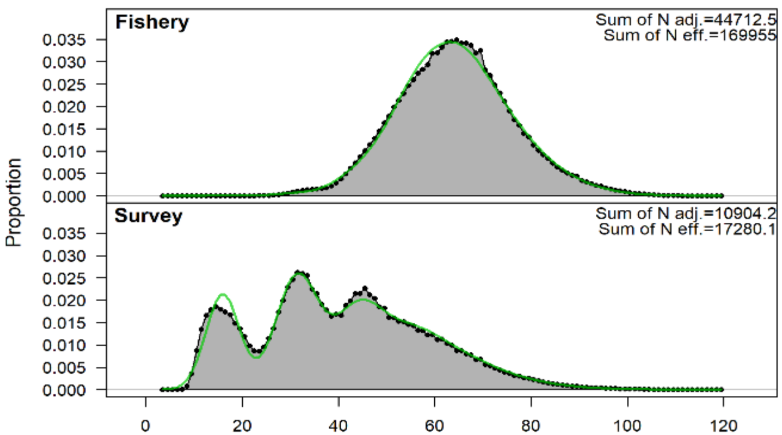


Model 16.6k

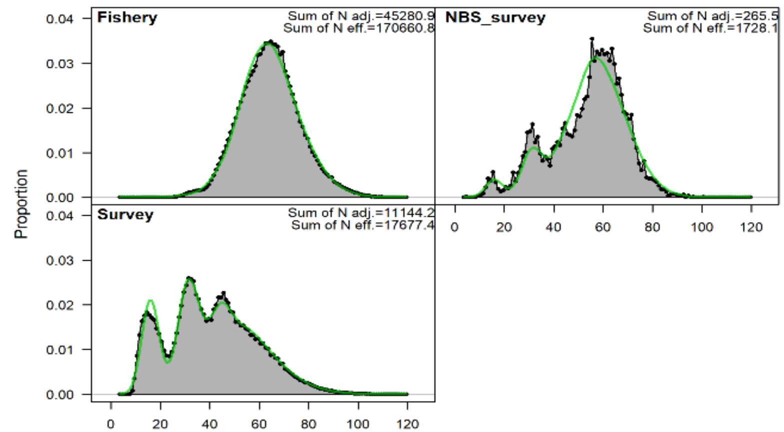


Time-aggregated sizecomp fits: M17.2, M18.x

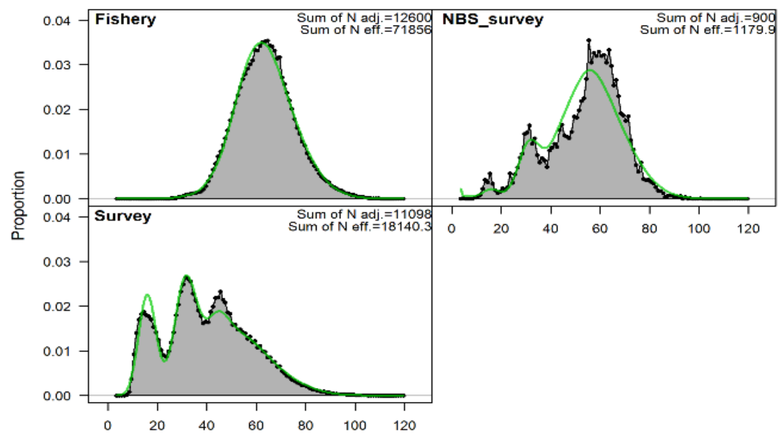
Model 17.2



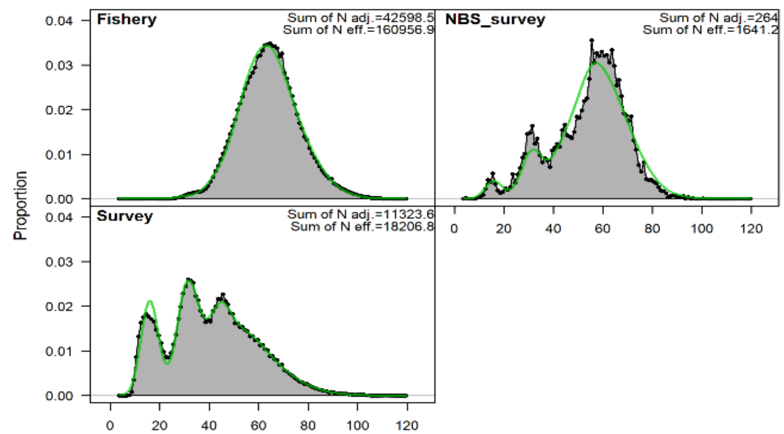
Model 18.6



Model 18.7

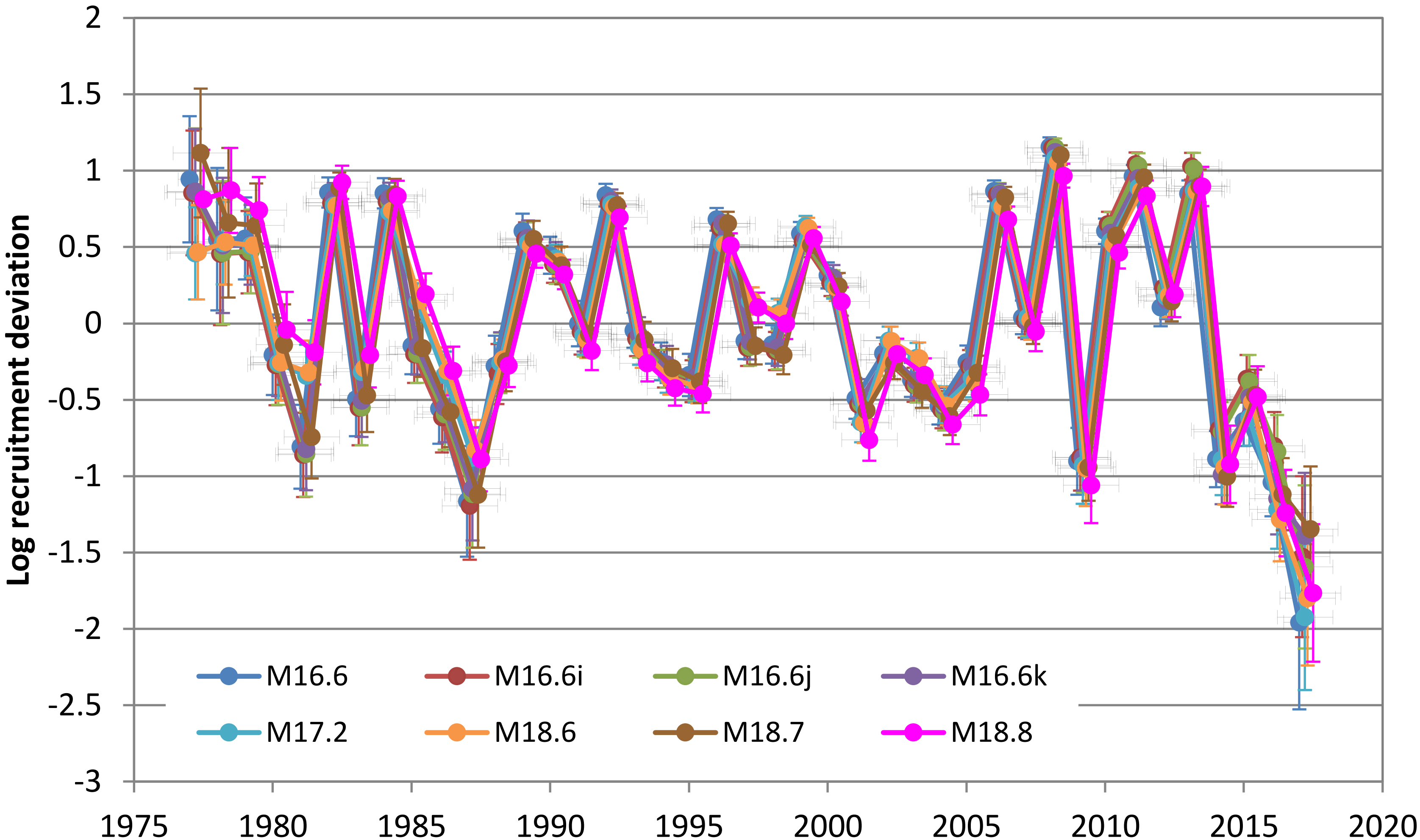


Model 18.8

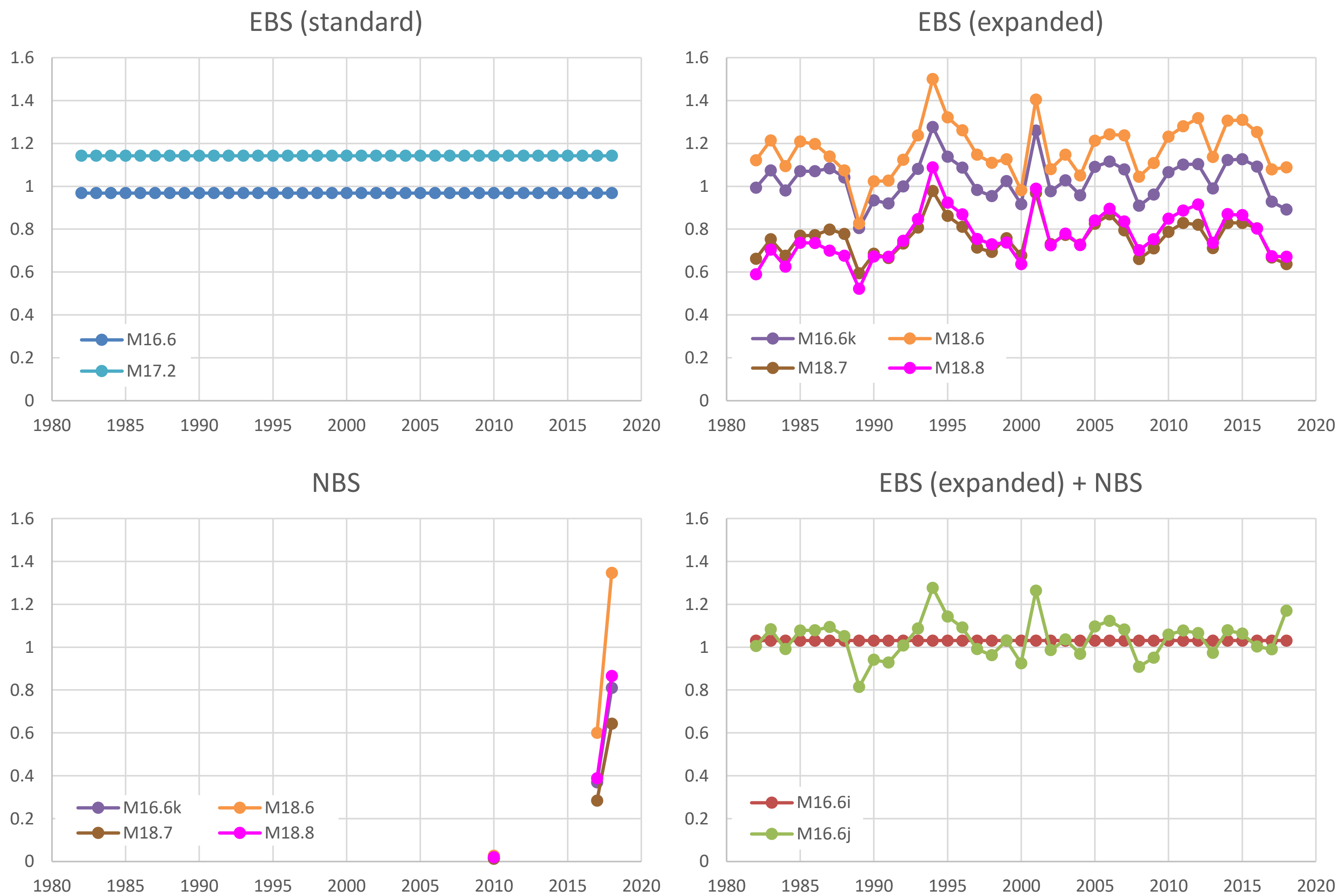


NOAA FISHERIES

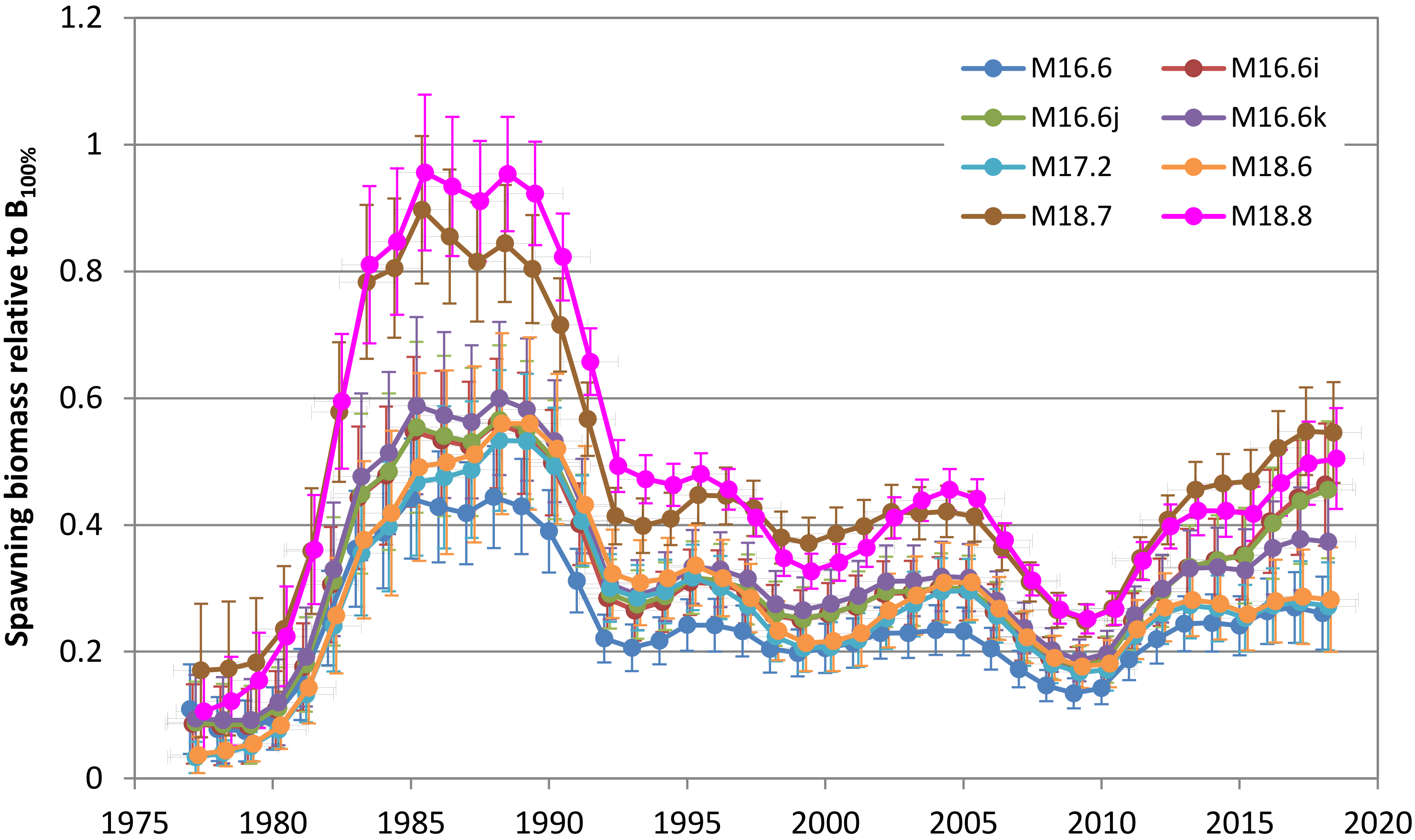
Age 0 recruitment deviations



Catchability

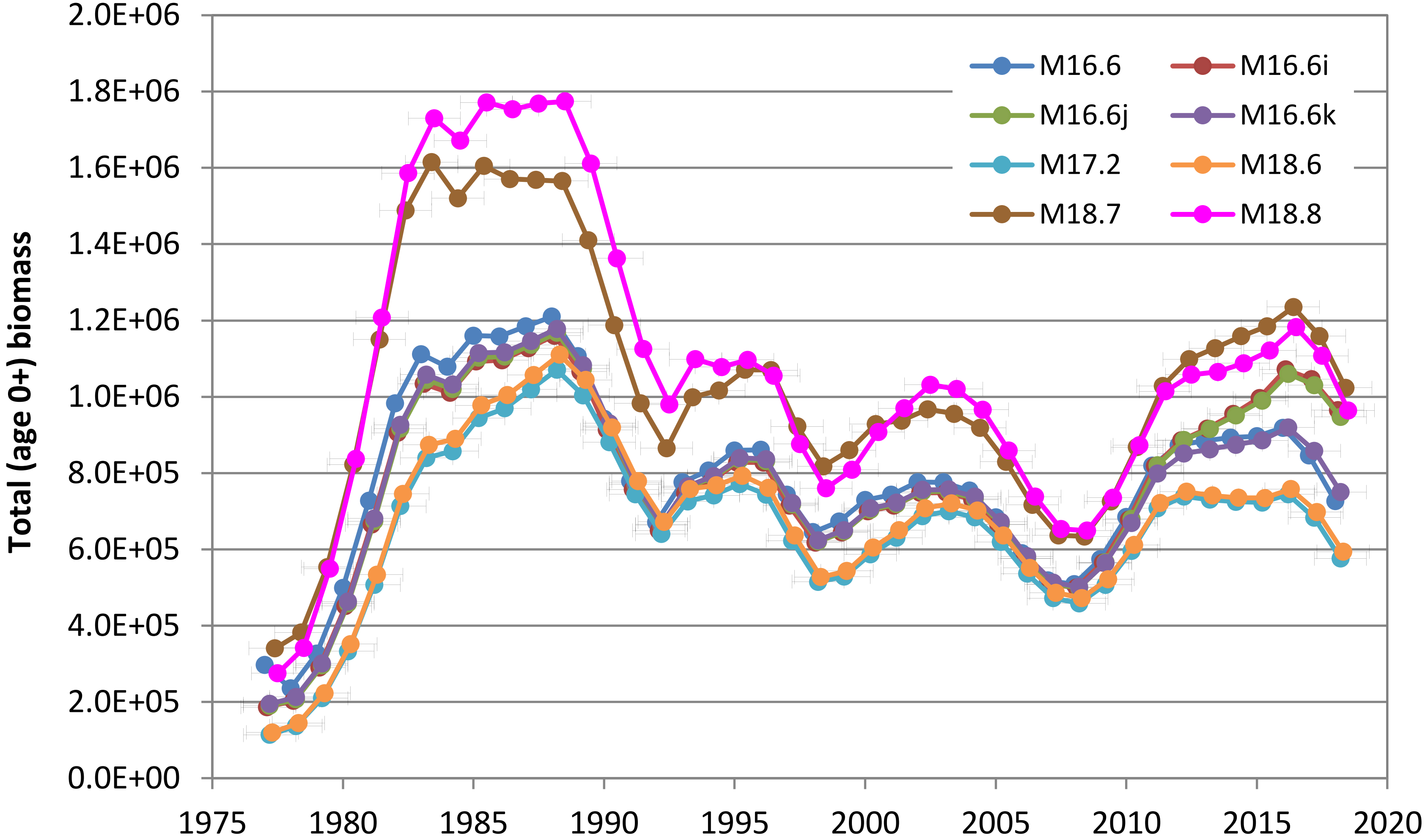


Depletion



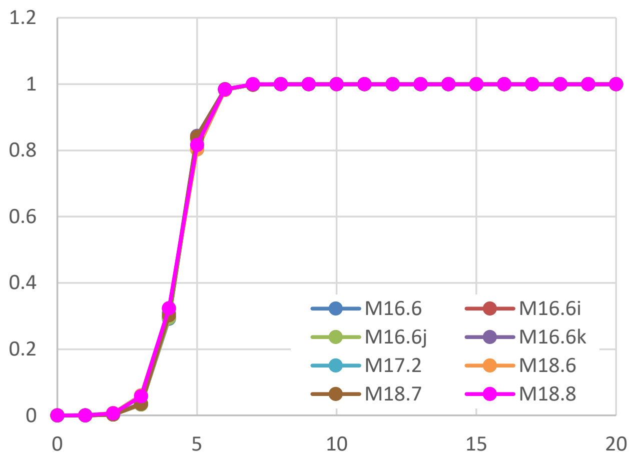
Spawning biomass relative to B100%
1.2
1
0.8
0.6
0.4
0.2
0
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
M16.6
M16.6i
M16.6j
M16.6k
M17.2
M18.6
M18.7
M18.8

Total (age 0+) biomass

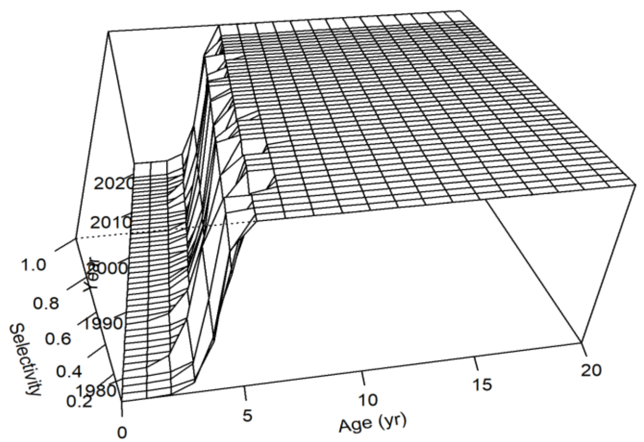


Fishery selectivity

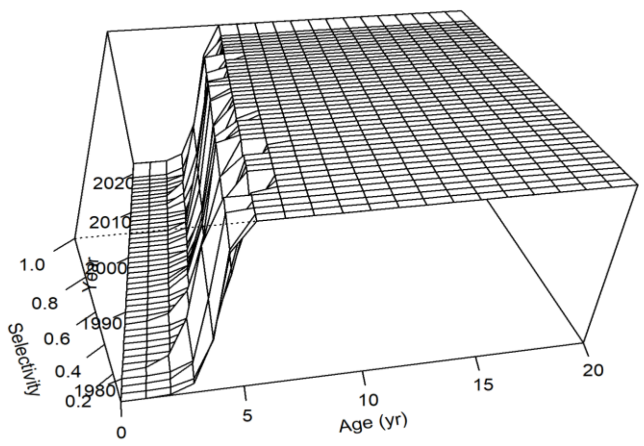
Base values (all models)



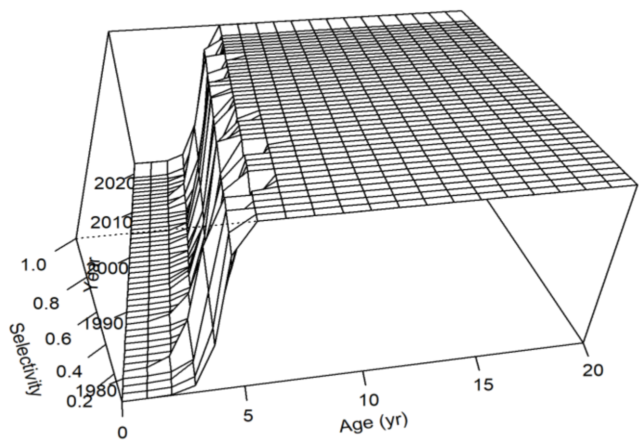
Model 17.2 time-varying



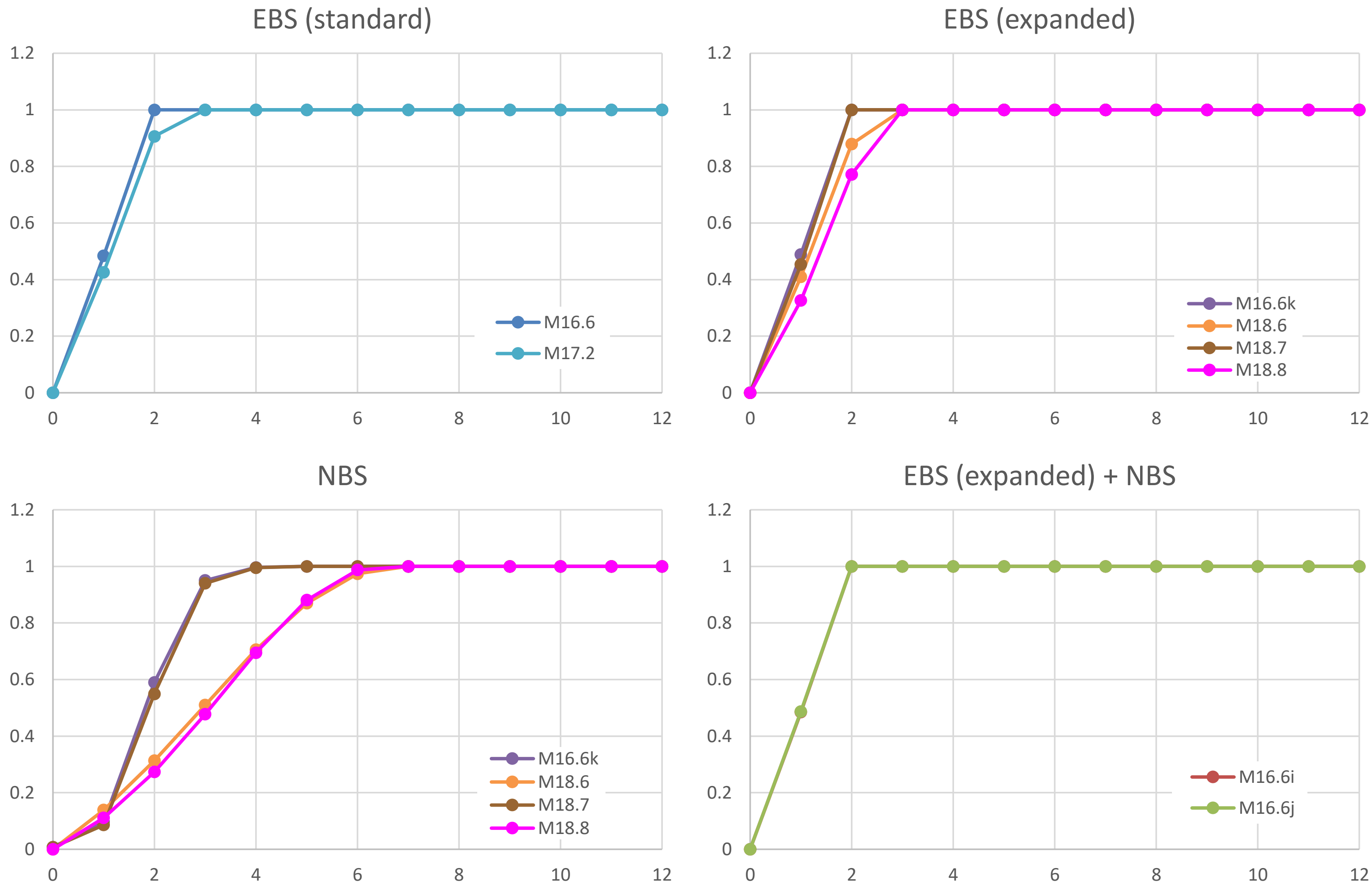
Model 18.6 time-varying



Model 18.8 time-varying

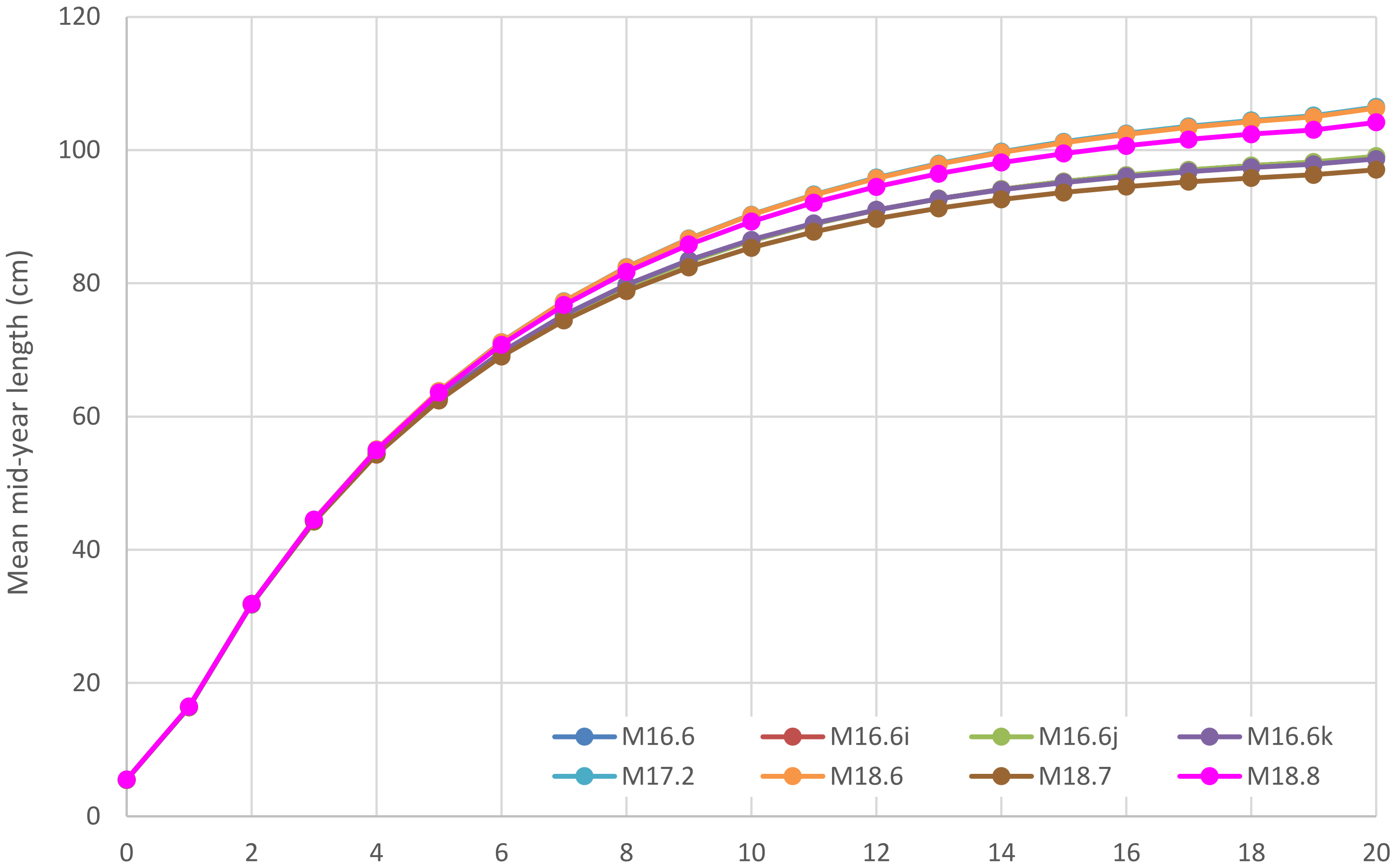


Survey selectivity



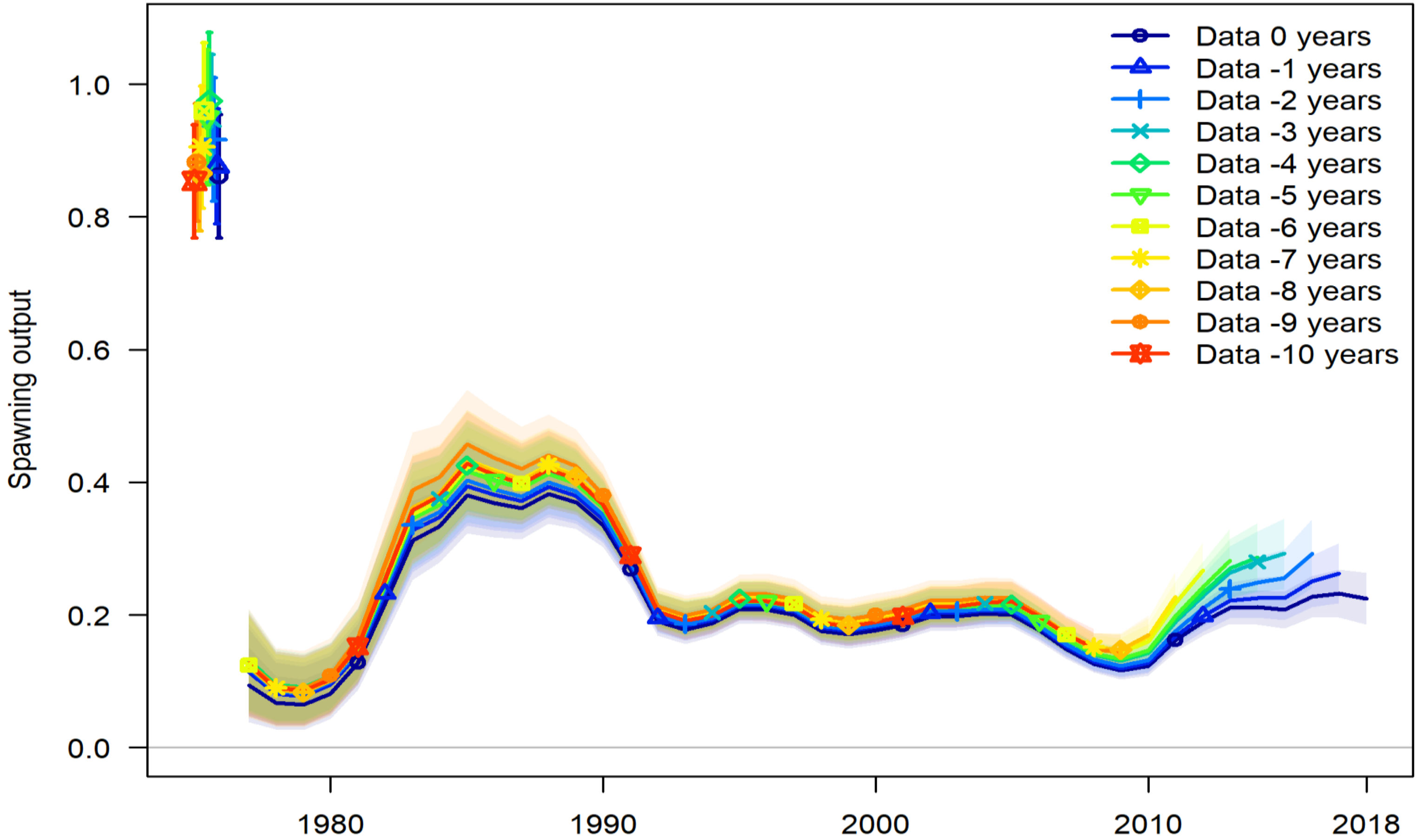
Mean length at age

- Models 17.2, 18.6, and 18.8 estimate lower mean lengths at age



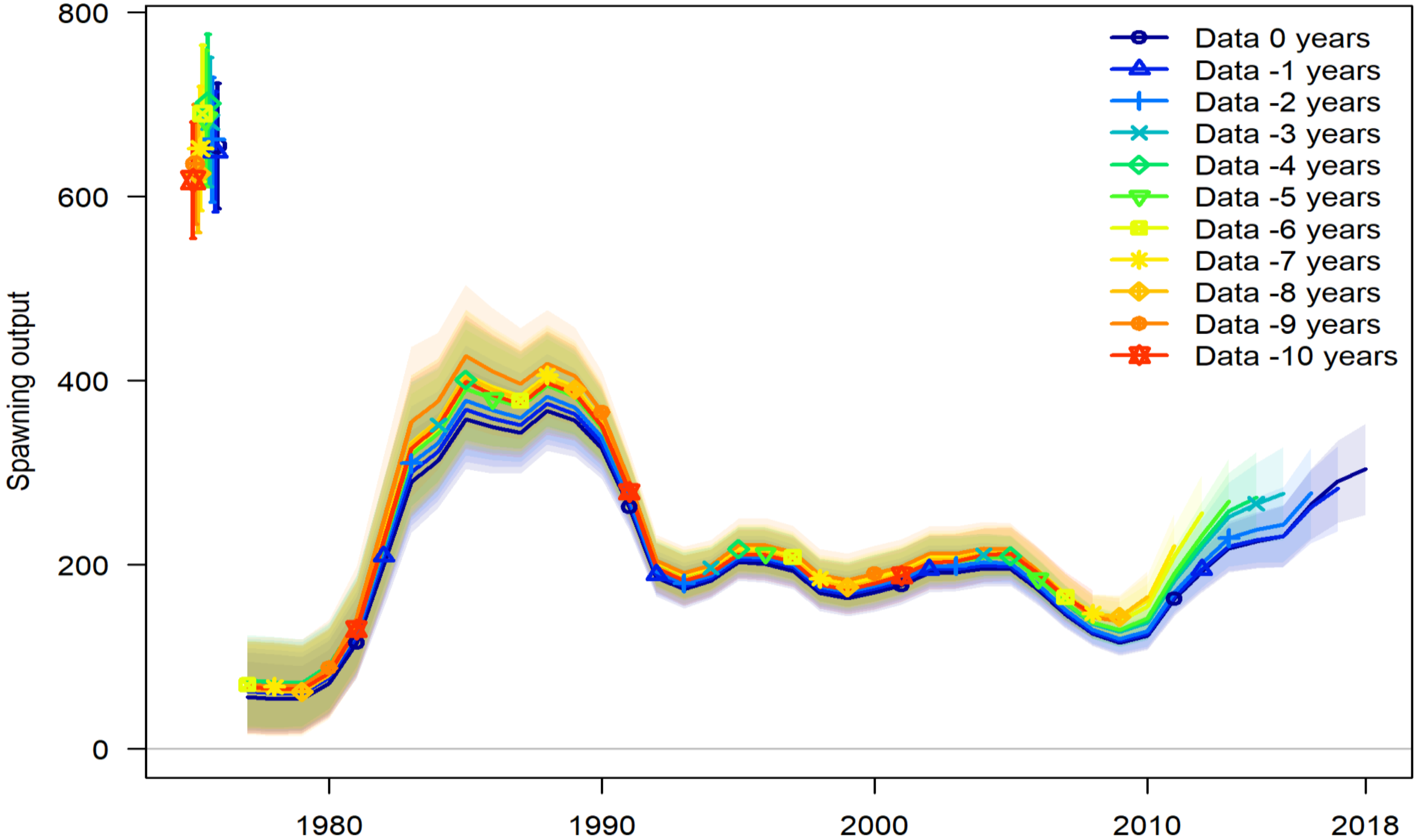
Retrospective analysis: Model 16.6

- Mohn's $\rho = 0.315$



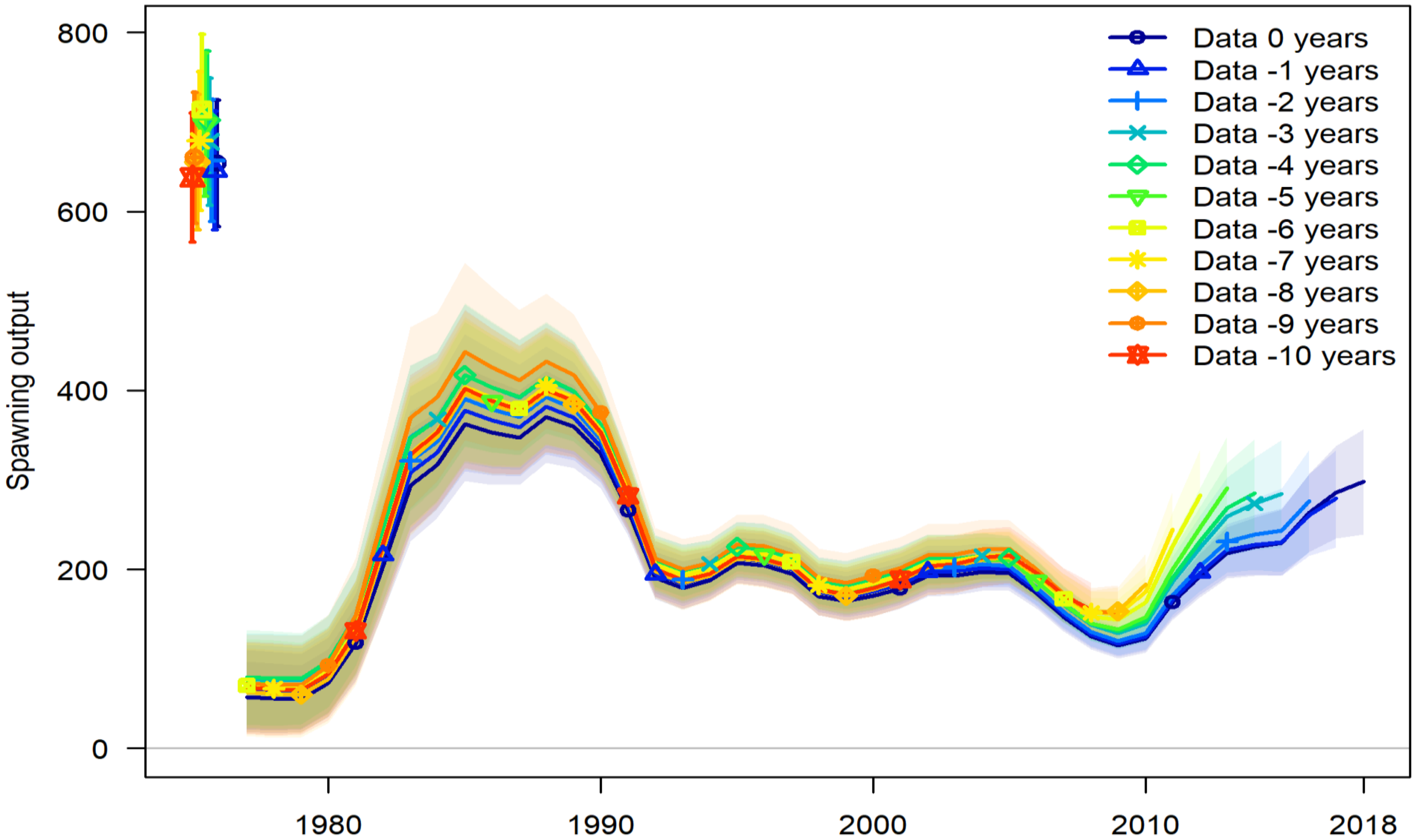
Retrospective analysis: Model 16.6i

- Mohn's ρ = 0.207



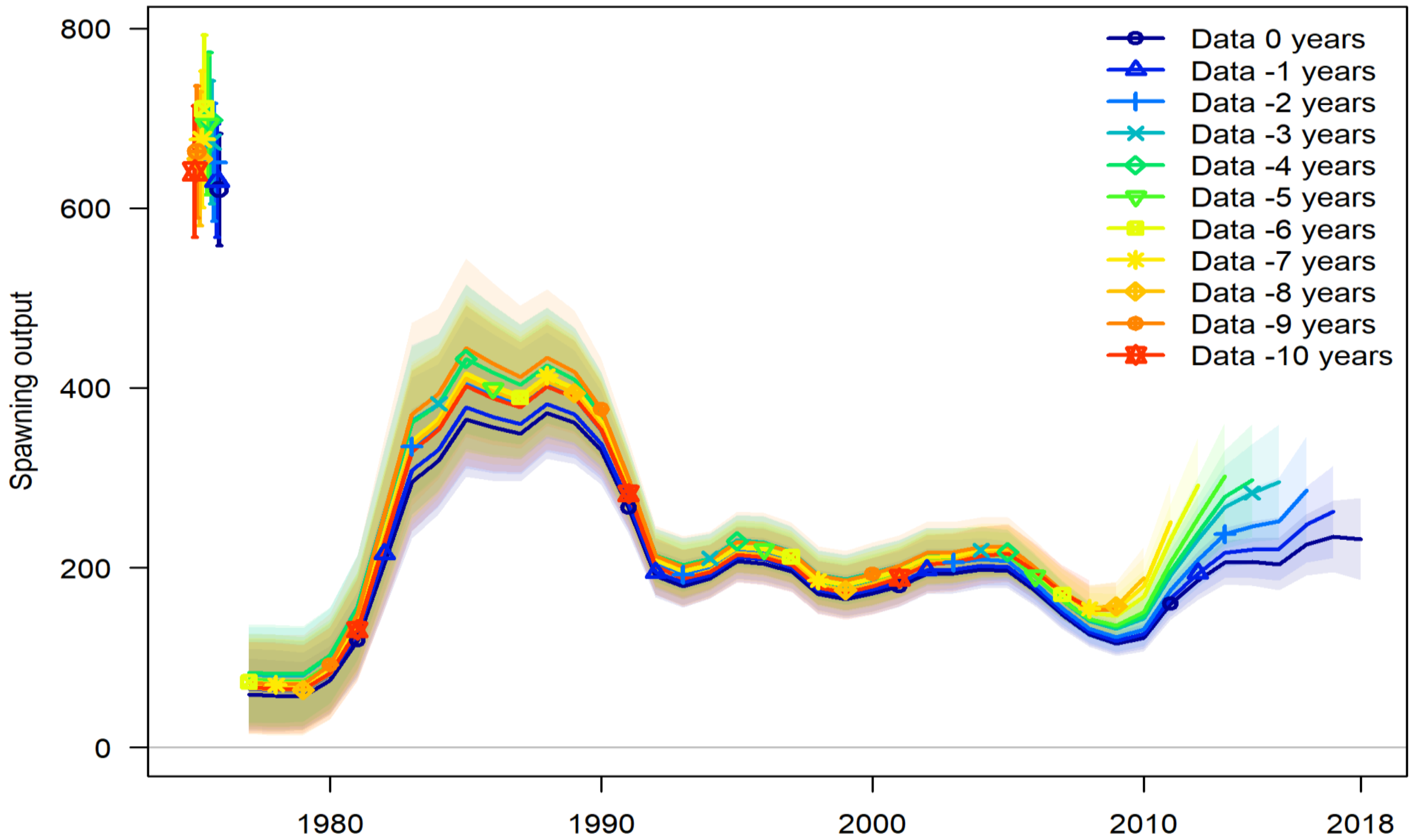
Retrospective analysis: Model 16.6j

- Mohn's ρ = 0.288



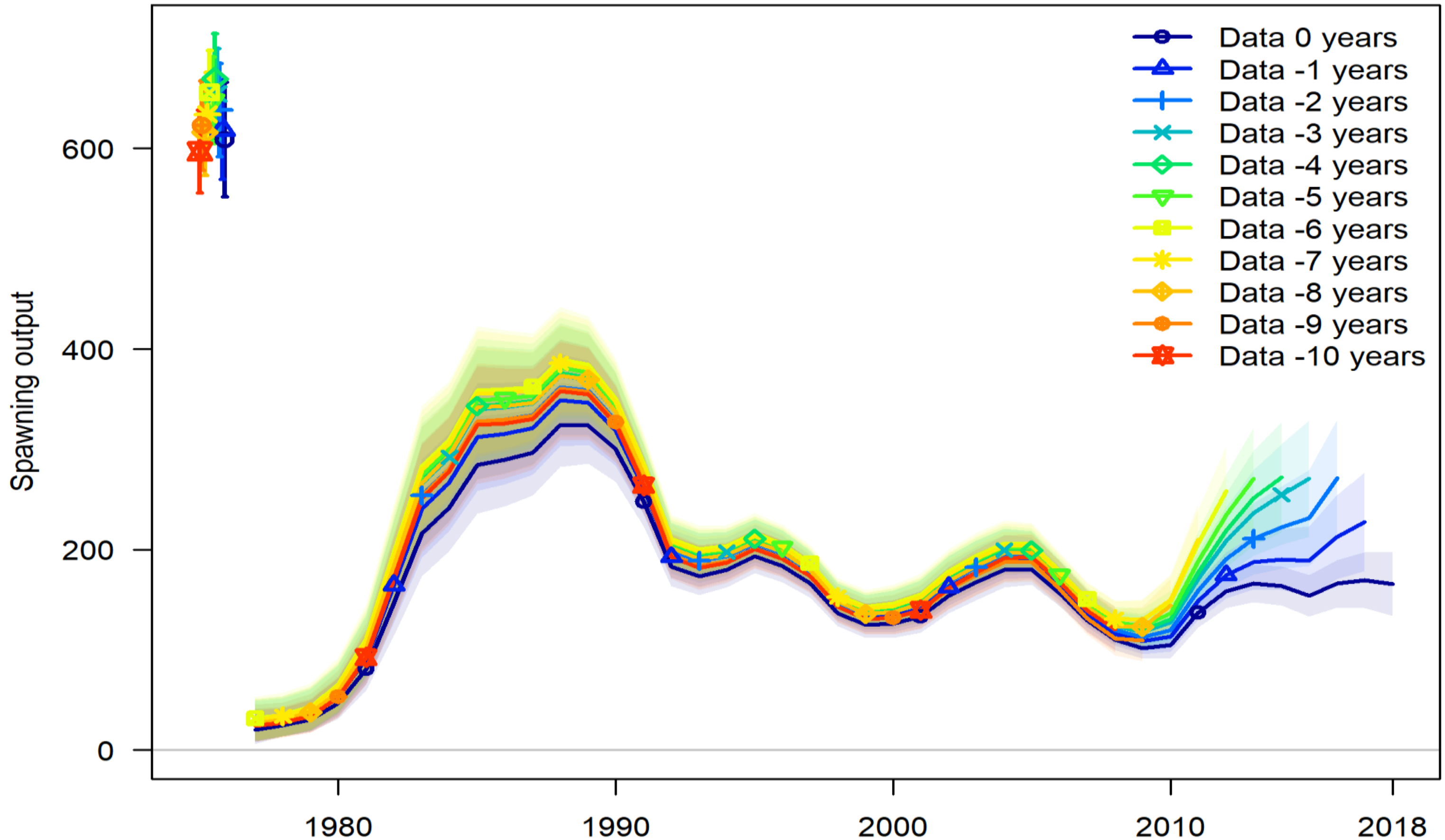
Retrospective analysis: Model 16.6k

- Mohn's ρ = 0.397



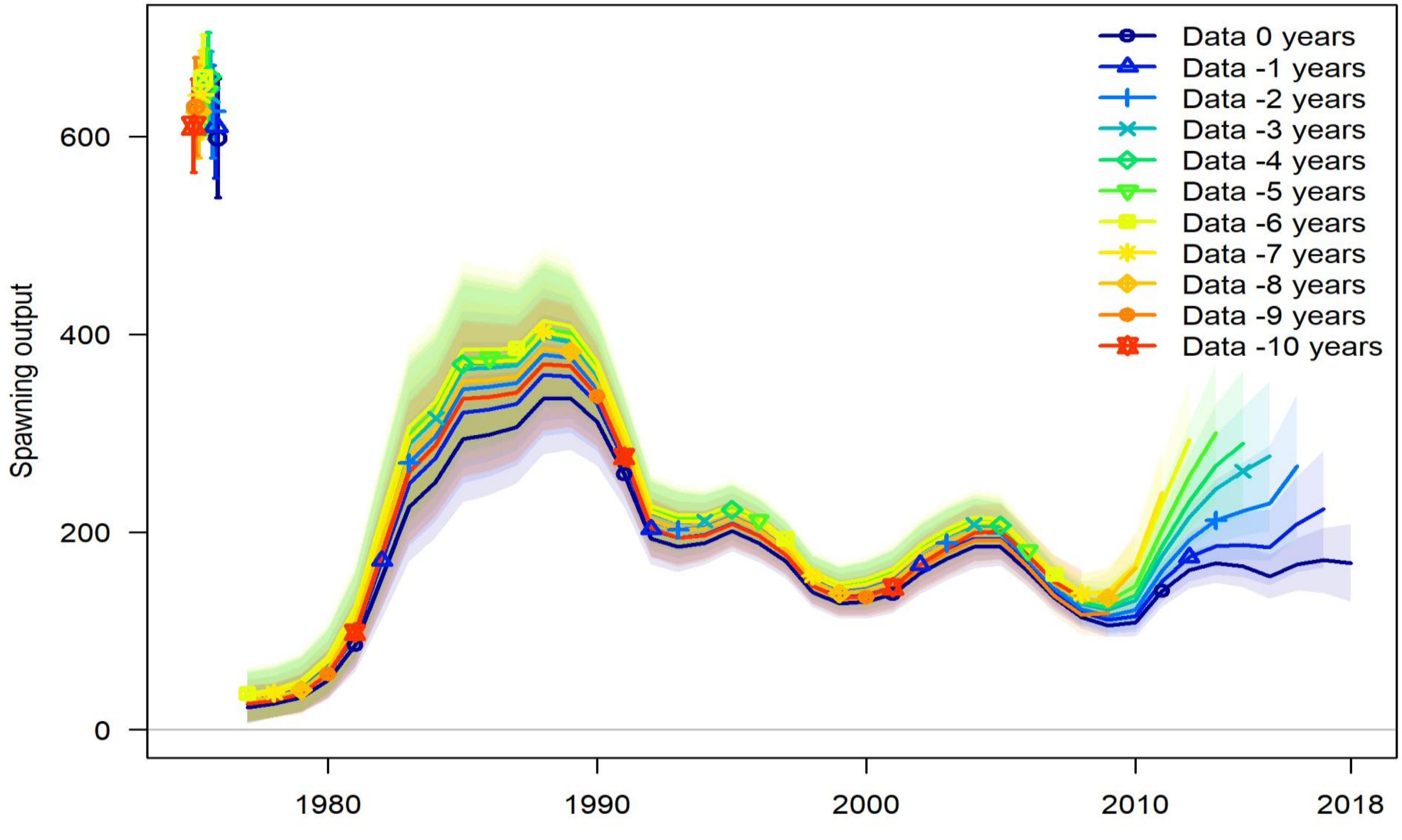
Retrospective analysis: Model 17.2

- Mohn's ρ = 0.475



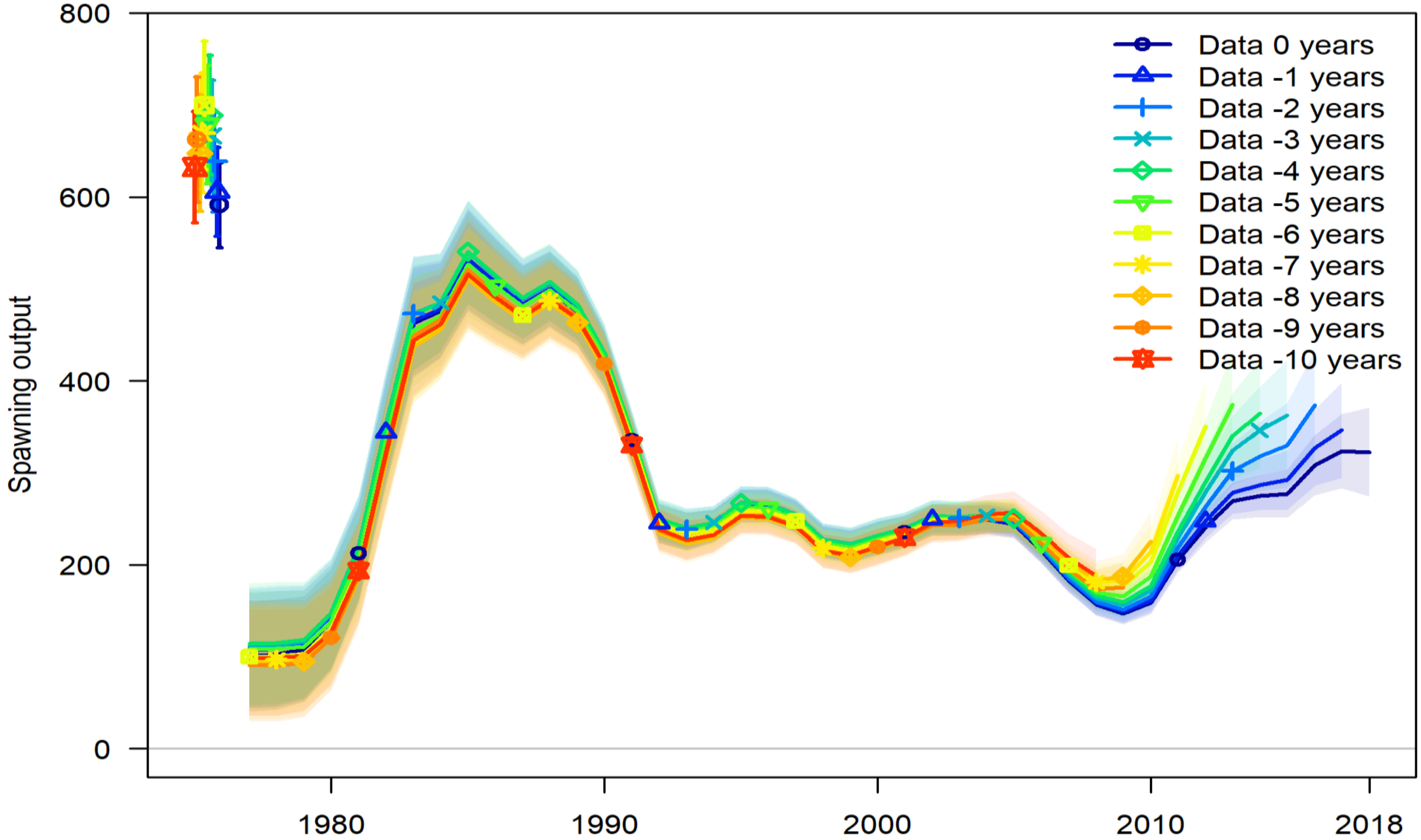
Retrospective analysis: Model 18.6

- Mohn's $\rho = 0.555$



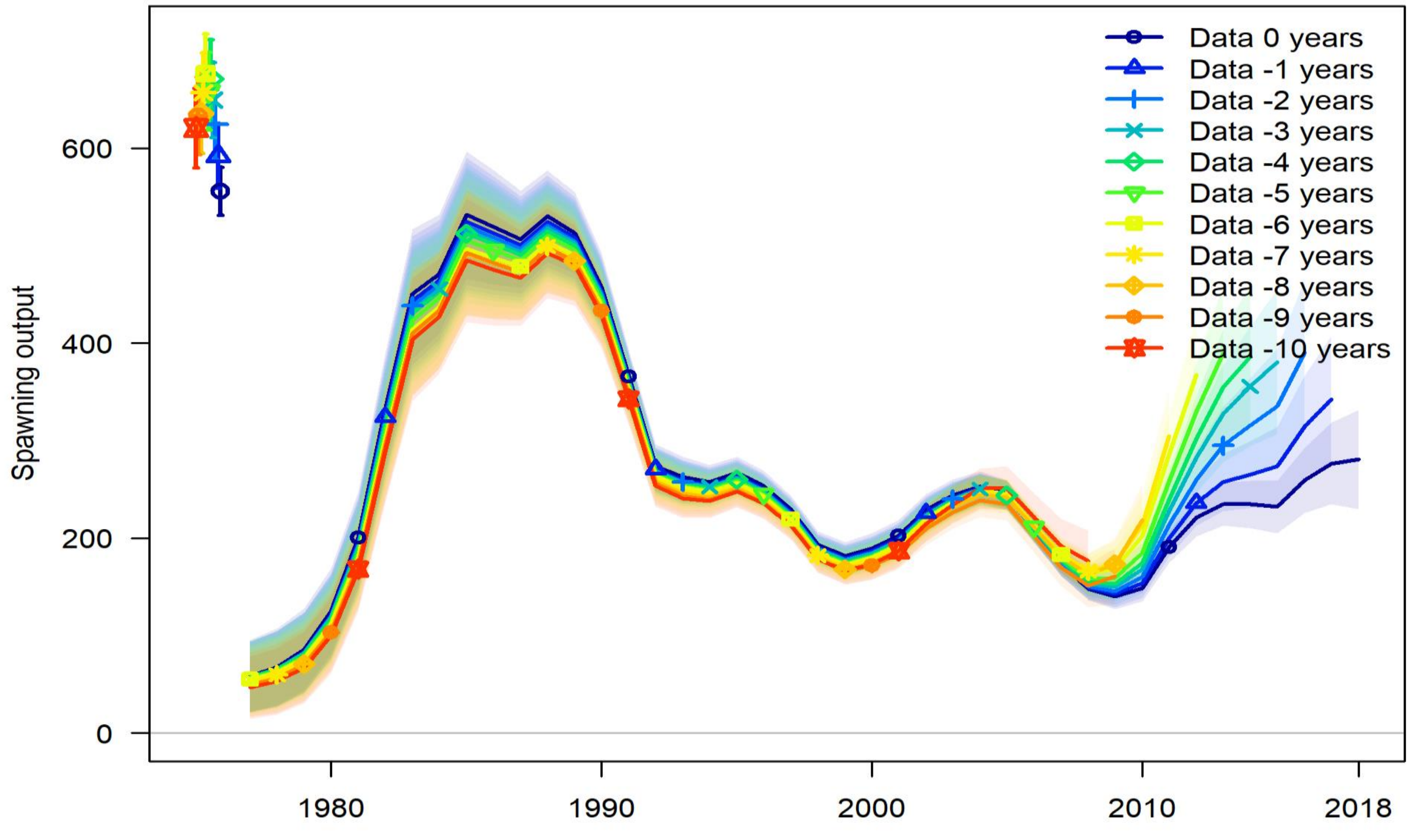
Retrospective analysis: Model 18.7

- Mohn's ρ = 0.301



Retrospective analysis: Model 18.8

- Mohn's ρ = 0.477



Choice of final model

Criteria and choice of final model

- The following criteria were used to choose the final model:
  - Are catchability estimates plausible?
  - Is retrospective performance acceptable?
  - Are changes in the complexity of model structure justified?
  - Are changes in model structure appropriately incremental?
- Evaluation of the eight models with respect to the above criteria resulted in a choice of Model 16.6i as the final model, as described on the following slides

Evaluation with respect to criterion #1 (1 of 3)

- Field studies have indicated that bottom trawl survey catchability of EBS Pacific cod is unlikely to be much greater than unity (Somerton 2004)
- Because the EBS and NBS surveys take place at nearly the same time and in disjoint areas, it is therefore reasonable to prefer models with catchability estimates exhibiting the following characteristics:
  - For models that use the EBS(std) survey data and exclude the NBS survey data, the estimate of Q should approximate the ratio of the EBS(std) survey abundance to the combined EBS(exp) and NBS survey abundances
  - For models the use the EBS(exp) survey data and NBS survey data separately, the estimate of Q for each survey should approximate the ratio of the survey abundance in the respective area to the combined EBS(exp) and NBS survey abundances
  - For models that combine the EBS(exp) survey data and NBS survey data into 1 index, the estimate of Q should approximate unity

Evaluation with respect to criterion #1 (2 of 3)

- Because the NBS surveys took place only in 2010, 2017, and 2018, the above comparisons need to be made only in those years

		EBS(std)		EBS(exp)				NBS				EBS+NBS	
Year	Quantity	16.6	17.2	16.6k	18.6	18.7	18.8	16.6k	18.6	18.7	18.8	16.6i	16.6j
2010	Rel. Abund.	0.98	0.98	0.99	0.99	0.99	0.99	0.01	0.01	0.01	0.01	1.00	1.00
2010	Catchability	0.97	1.14	1.07	1.23	0.79	0.85	0.01	0.03	0.01	0.02	1.03	1.06
2010	Abs. Diff.	0.01	0.16	0.07	0.24	0.21	0.14	0.01	0.02	0.00	0.01	0.03	0.06
2017	Rel. Abund.	0.69	0.69	0.73	0.73	0.73	0.73	0.27	0.27	0.27	0.27	1.00	1.00
2017	Catchability	0.97	1.14	0.93	1.08	0.67	0.67	0.37	0.60	0.28	0.39	1.03	0.99
2017	Abs. Diff.	0.28	0.45	0.20	0.35	0.06	0.05	0.10	0.33	0.01	0.11	0.03	0.01
2018	Rel. Abund.	0.49	0.49	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	1.00	1.00
2018	Catchability	0.97	1.14	0.89	1.09	0.64	0.67	0.81	1.35	0.64	0.87	1.03	1.17
2018	Abs. Diff.	0.48	0.65	0.39	0.58	0.13	0.17	0.32	0.85	0.15	0.37	0.03	0.17
All	RMSD	0.32	0.47	0.26	0.42	0.14	0.13	0.19	0.53	0.09	0.22	0.03	0.10

Evaluation with respect to criterion #1 (3 of 3)

- The table on the preceding slide illustrates why Models 18.7 and 18.8 were added to the set of models for this assessment:
  - Their closest counterparts, Models 16.6k and 18.6 respectively, tended not to satisfy the desired approximations
  - More specifically, Models 16.6k and 18.6 tended to estimate area-specific Qs much larger than the respective area-specific relative abundances, particularly in 2017 and 2018 when EBS survey abundances were smallest and NBS survey abundances were largest
- The lowest RMSD is obtained by Model 16.6i (0.03 for the combined areas), followed by Model 16.6j (0.10 for the combined areas) and Model 18.7 (0.14 for the EBS expanded area and 0.09 for the NBS)

Evaluation with respect to criterion #2

- Comparing realized values of Mohn's ρ to the "acceptable" range implied by Hurtado-Ferro et al. (2015):

Model:	16.6	16.6i	16.6j	16.6k	17.2	18.6	18.7	18.8
ρ:	0.315	0.207	0.288	0.397	0.475	0.555	0.301	0.477
M:	0.354	0.340	0.340	0.345	0.356	0.364	0.398	0.471
Min:	-0.204	-0.199	-0.199	-0.201	-0.205	-0.207	-0.219	-0.245
Max:	0.277	0.270	0.270	0.273	0.278	0.282	0.299	0.335

- Model 16.6i exhibits the lowest value among all the models
- Model 16.6i also exhibits the only value that falls within the acceptable range implied by Hurtado-Ferro et al. (2015)
  - Although the value exhibited by Model 18.7 is extremely close to the upper end of the range

Evaluation with respect to criterion #3 (1 of 2)

- Although the alternative models include many changes from the base model, not all of them constitute changes in structural complexity
- For example, the only difference between Models 16.6 and 16.6i is that the latter uses the combined EBS expanded area and NBS surveys in lieu of the EBS standard area survey used in the former
- The features that would most likely qualify as changes in structural complexity are:
  a. Addition of a second survey, with concomitant need to estimate an additional Q and selectivity parameters (16.6k, 18.6-18.8)
  b. Addition of randomly time-varying Q (16.6j, 16.6k, 18.6-18.8)
  c. Addition of randomly time-varying fishery selectivity (17.2, 18.6/8)

Evaluation with respect to criterion #3 (2 of 2)

- The SSC minutes from June 2018 offer this guidance on justifying additional complexity: *"Existing assessments should be periodically evaluated for 'complexity creep' and consistency with similar assessments"*
  - Assume that "similar assessments" means "Tier 3 BSAI assessments"
- Features "a" through "c" on the previous slide can be evaluated with respect to similar assessments as follows:
  a. Some similar assessments include multiple surveys (typically bottom trawl surveys of the EBS shelf, EBS slope, or Aleutian Islands)
  b. Few, if any, similar assessments include randomly time-varying Q
  c. Some similar assessments include randomly time-varying fishery selectivity
- Given the above evaluation, the only models that have levels of complexity consistent with similar assessments are Models 16.6, 16.6i, and 17.2

Evaluation with respect to criterion #4 (1 of 2)

- The SSC has often expressed a preference for incremental changes in model structure:
  - SSC minutes, 6/12: "…The SSC encourages the authors to evaluate changes in one or a few structural elements at a time."
  - SSC minutes, 6/13: "...The SSC recommends that model changes be kept to a minimum to ensure that we can track model sensitivities to specific changes in model structure."
  - SSC minutes, 12/13: "…The SSC discussed the need for a more incremental approach to implementing changes to the model.…"
  - SSC minutes, 12/15: "...The SSC has repeatedly stressed the need to incrementally evaluate model changes...."

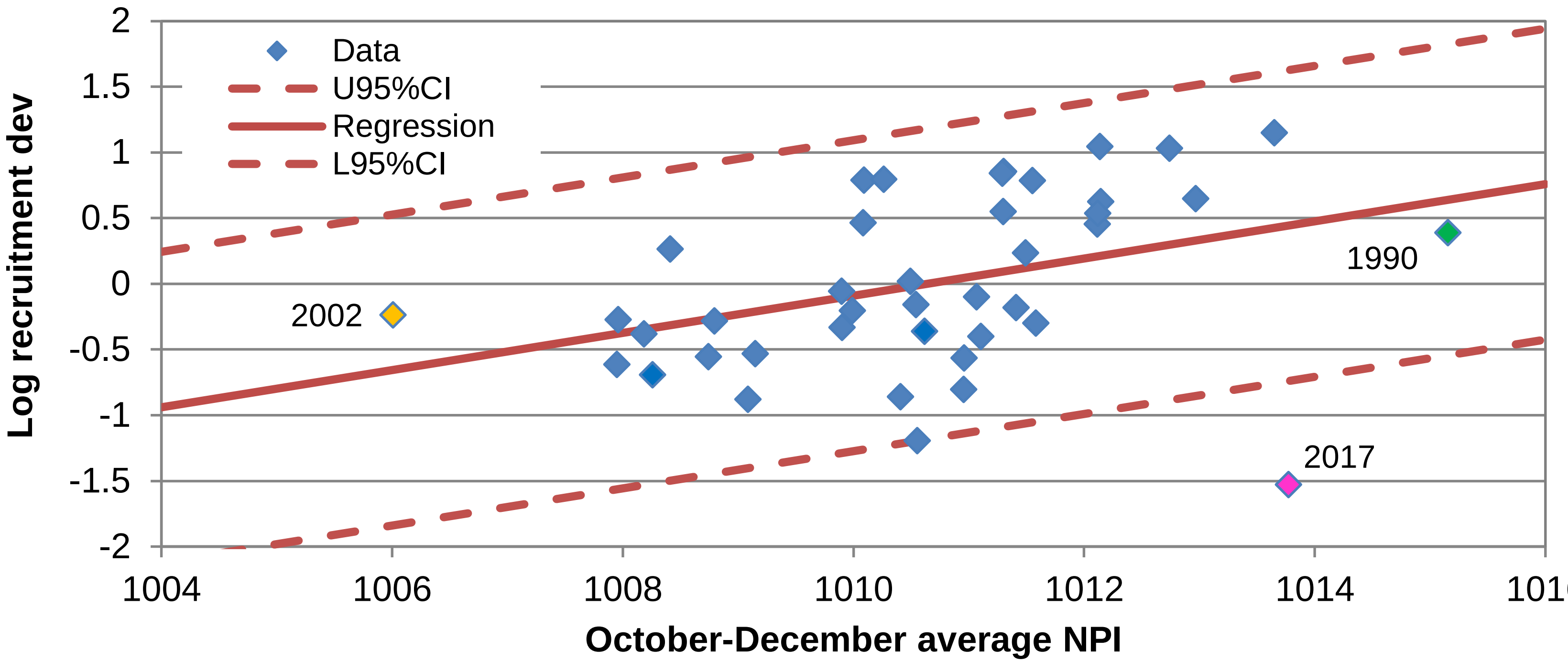
Evaluation with respect to criterion #4 (2 of 2)

- Given the relatively stable level of the combined EBS and NBS survey biomass over the last few years (Figure 2.6), the stock does not appear to be in an emergency situation that might render an incremental approach inappropriate
- On the contrary, given the uncertain effects of the large and potentially unprecedented movements of Pacific cod from the EBS and NBS that appear to have taken place in the last few years, an incremental approach to changes in model structure might be especially important at this particular time, with the understanding that additional changes might be called for in the future as more information becomes available
- While it is difficult to determine exactly which of the eight candidate models in this assessment qualify as involving only incremental changes in model structure, it is clear that Model 16.6 would qualify by definition, and Model 16.6i would likely qualify also

Ecosystem considerations

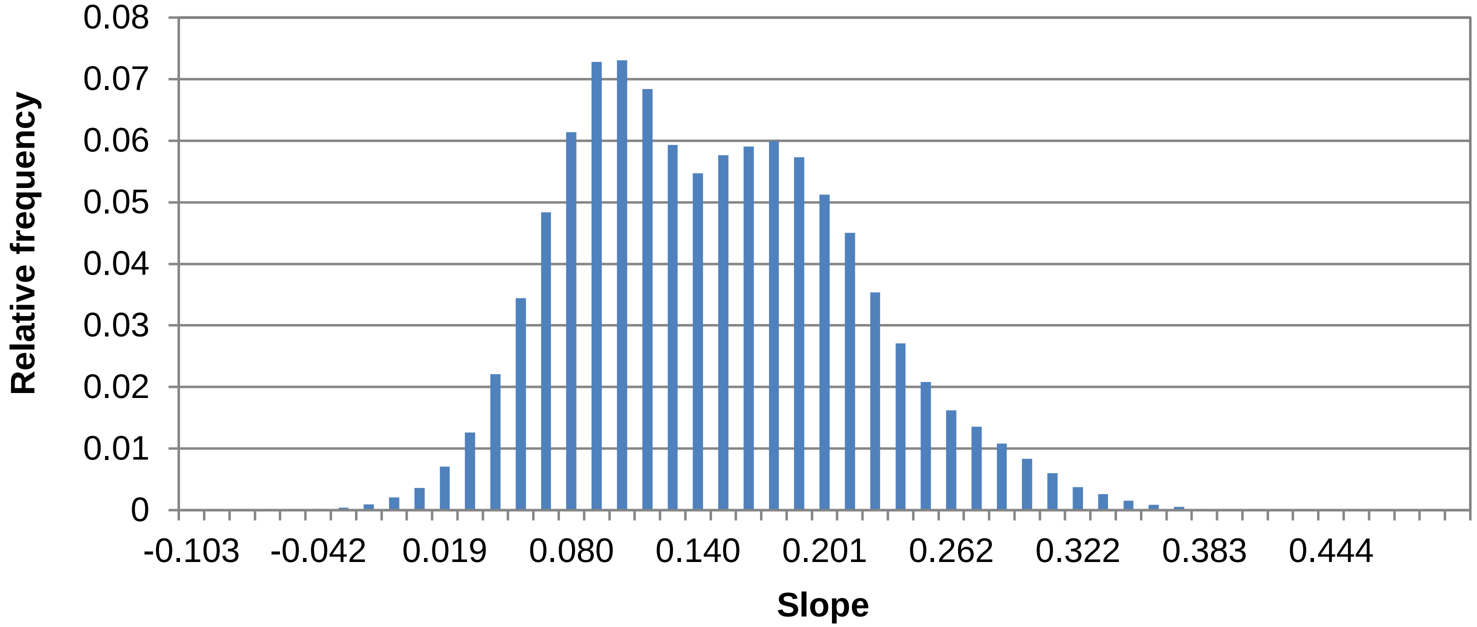
An environmental predictor of recruitment

- Every assessment since 2012 has evaluated a possible relationship between recruitment and the October-December average NPI
  - Last year: correlation = 0.53, $R^2 = 0.28$
  - This year: correlation = 0.38, $R^2 = 0.15$



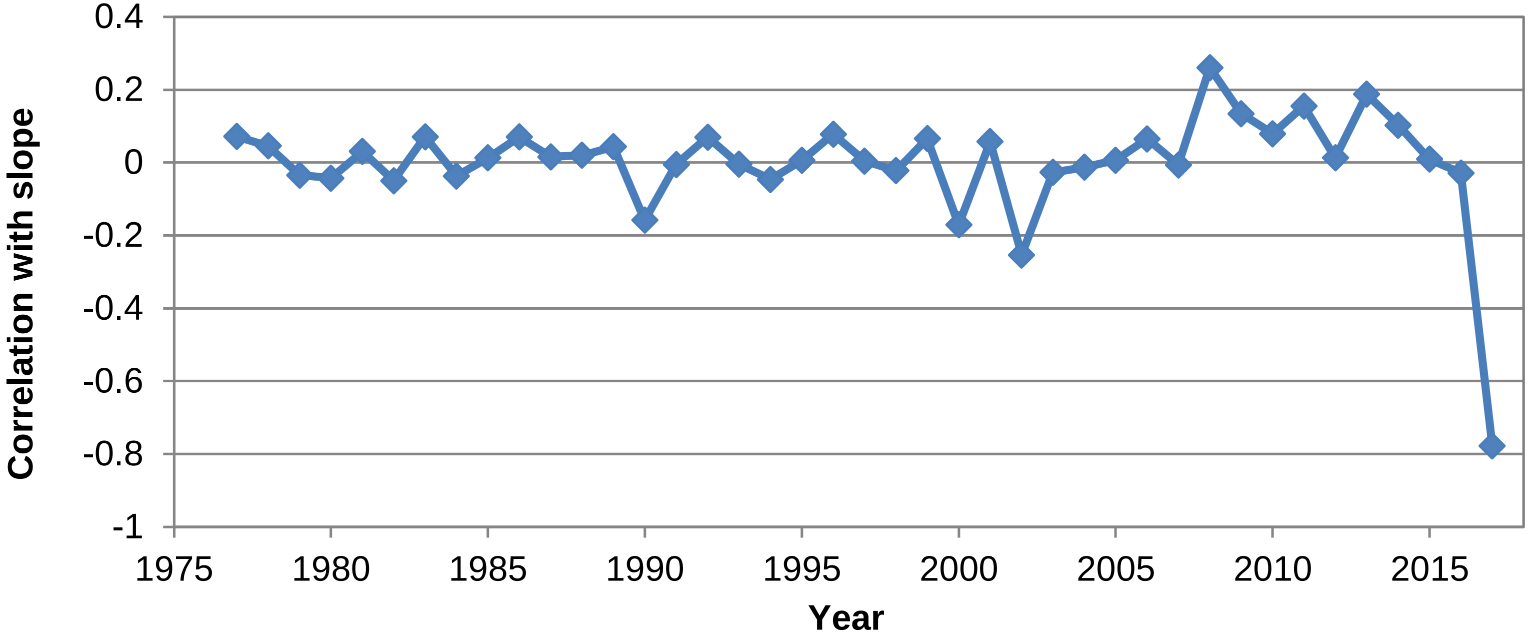
Cross validation (50% random samples)

- RMSE from *test* sets:
  - Last year: 0.59 without NPI, 0.52 with NPI
  - This year: 0.68 without NPI, 0.66 with NPI
- Distribution of slope estimates from *training* sets:



Impact of individual years on slope estimate

- Last year: 1990 and 2002 had strongest impact on slope
- This year: 2016 has strongest impact on slope, by far

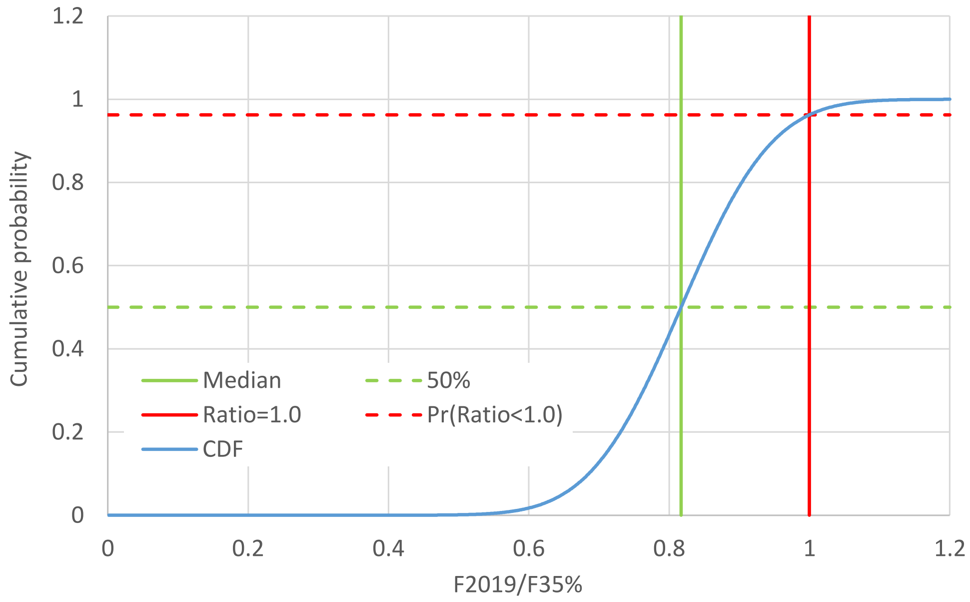


- Next year's assessment may discontinue this analysis

Final recommendations

Projections

- This year's assessment used SS to make all projections, rather than the formerly standard AFSC software
- This change allowed, among other things, estimating the distribution of F2019/F35%, conditional on the choice of final model and the assumption that 2019 catch will equal the point estimate of maxABC



Reasons for not setting ABC<maxABC

- SSC guidance
  - Last year, when the SSC concluded that no reduction was warranted:
    - Combined EBS+NBS survey biomass was down 5%
    - Persistence of NBS biomass was unknown
    - Genetic relationship between EBS and NBS fish was unknown
  - This year:
    - Combined EBS+NBS survey biomass is up 15%
    - Persistence of NBS biomass has been corroborated
    - EBS and NBS fish have been shown to be genetically similar
- 2019 maxABC already down from 2018 ABC, with further drop in 2020
  - Given $F=maxF_{ABC}$, biomass projected to decrease through 2022
  - Given $F=F_{60\%}$, biomass projected to decrease through 2022

Management reference points

Year	Quantity	M16.6	M16.6i	M16.6j	M16.6k	M17.2	M18.6	M18.7	M18.8
n/a	B100%	623,000	658,000	656,000	623,000	609,000	598,000	594,000	556,000
n/a	B40%	249,000	263,000	263,000	249,000	244,000	239,000	238,000	222,000
n/a	B35%	218,000	230,000	230,000	218,000	213,000	209,000	208,000	195,000
n/a	F40%	0.32	0.31	0.31	0.31	0.31	0.32	0.38	0.46
n/a	F35%	0.40	0.38	0.38	0.38	0.37	0.39	0.47	0.58
2019	Female spawning biomass	195,000	290,000	283,000	206,000	141,000	145,000	290,000	249,000
2019	Relative spawning biomass	0.23	0.44	0.43	0.33	0.23	0.24	0.49	0.45
2019	Pr(B/B100%<0.2)	0.17	0.00	0.00	0.00	0.19	0.16	0.00	0.00
2019	maxFABC	0.25	0.31	0.31	0.25	0.17	0.18	0.38	0.46
2019	maxABC	103,000	181,000	177,000	111,000	53,900	59,900	212,000	216,000
2019	Catch	103,000	181,000	177,000	111,000	53,900	59,900	206,000	208,000
2019	FOFL	0.31	0.38	0.38	0.31	0.21	0.22	0.47	0.58
2019	OFL	123,000	216,000	211,000	132,000	60,900	72,000	253,000	257,000
2019	Pr(maxABC>truOFL)	0.24	0.07	0.11	0.26	0.30	0.32	0.03	0.07
2020	Female spawning biomass	176,000	246,000	240,000	187,000	146,000	148,000	221,000	180,000
2020	Relative spawning biomass	0.20	0.38	0.37	0.30	0.24	0.25	0.37	0.32
2020	Pr(B/B100%<0.2)	0.38	0.00	0.00	0.00	0.04	0.04	0.00	0.00
2020	maxFABC	0.22	0.29	0.28	0.23	0.18	0.19	0.35	0.37
2020	maxABC	78,900	137,000	131,000	86,100	53,800	58,600	144,000	123,000
2020	Catch	78,900	137,000	131,000	86,100	53,800	58,600	144,000	123,000
2020	FOFL	0.28	0.35	0.34	0.28	0.21	0.23	0.44	0.46
2020	OFL	94,800	164,000	157,000	103,000	64,600	70,400	173,000	147,000
2020	Pr(maxABC>truOFL)	0.25	0.23	0.27	0.28	0.28	0.34	0.22	0.31