2019 Gulf of Alaska Pacific cod

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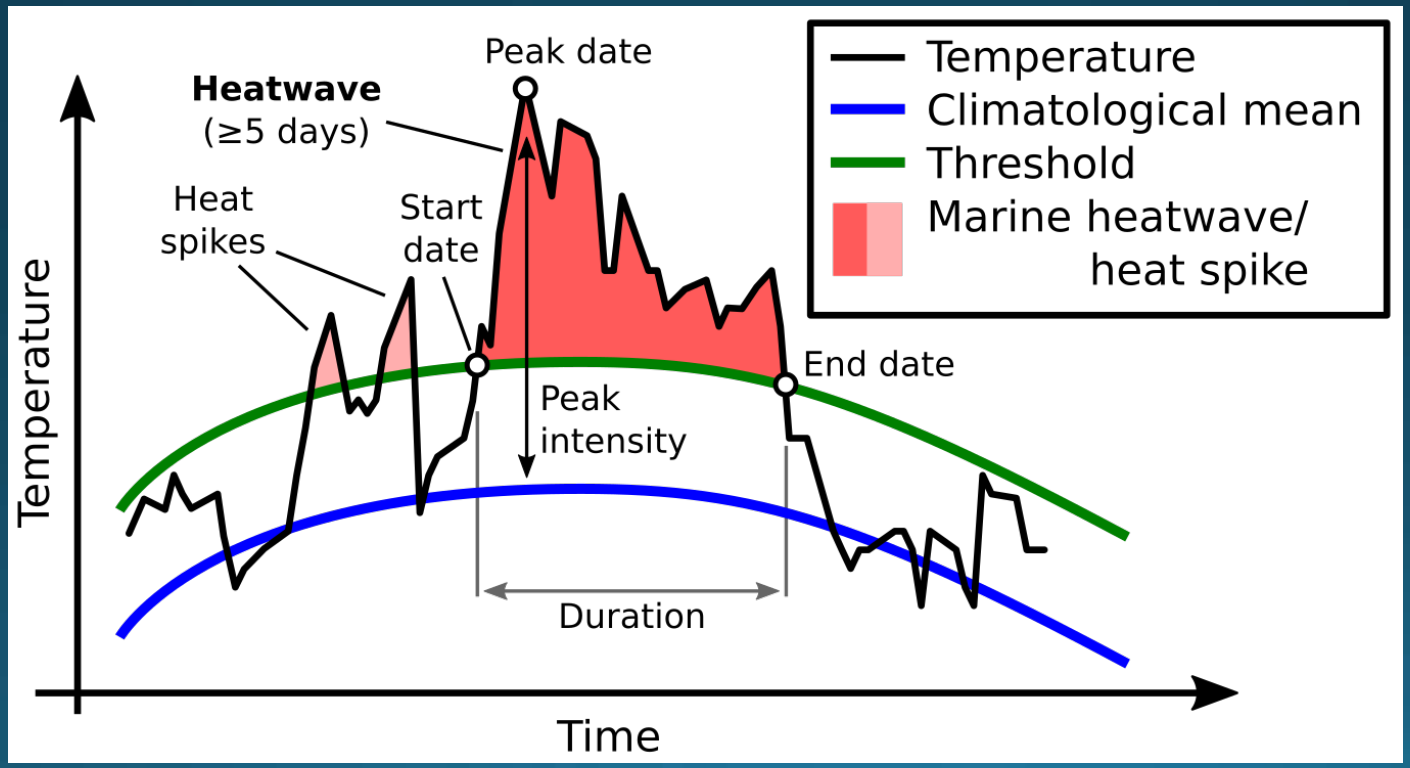
What is a marine heatwave?

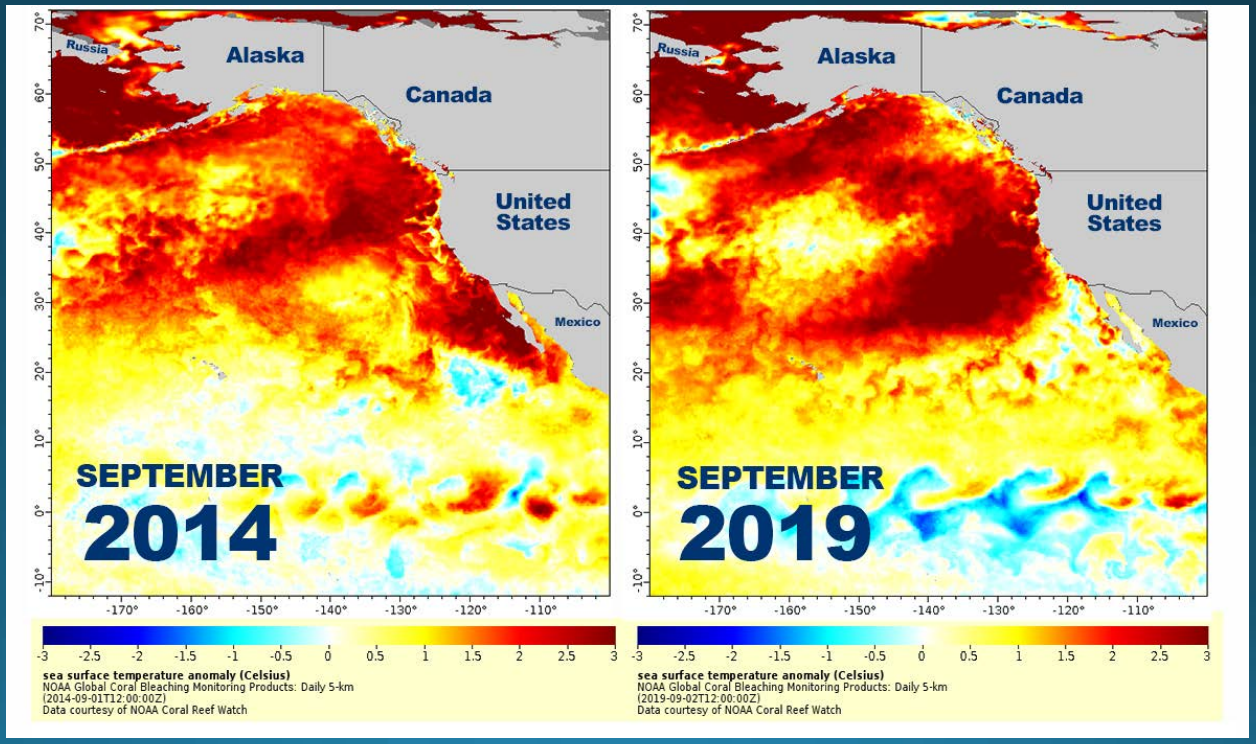
When seawater temperatures exceed a seasonally-varying threshold (usually the 90th percentile) for at least 5 consecutive days. Successive heatwaves with gaps of 2 days or less are considered part of the same event (Hobday et al. 2016).



Hobday, A. J. et al. (2016), *A hierarchical approach to defining marine heatwaves*, Prog. Ocean., 141, pp. 227-238, 10.1016/j.pocean.2015.12.014

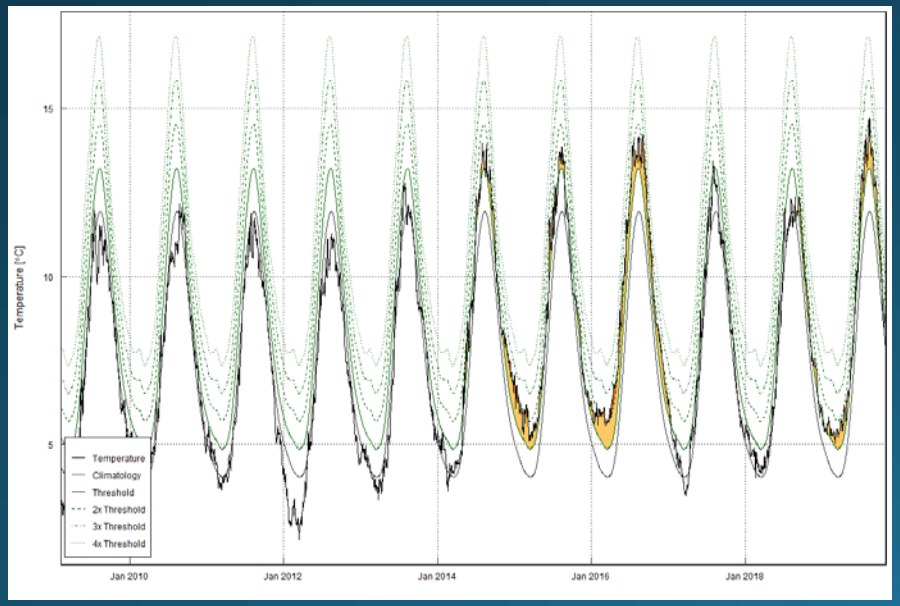
Anomalously warm waters 2018-2019

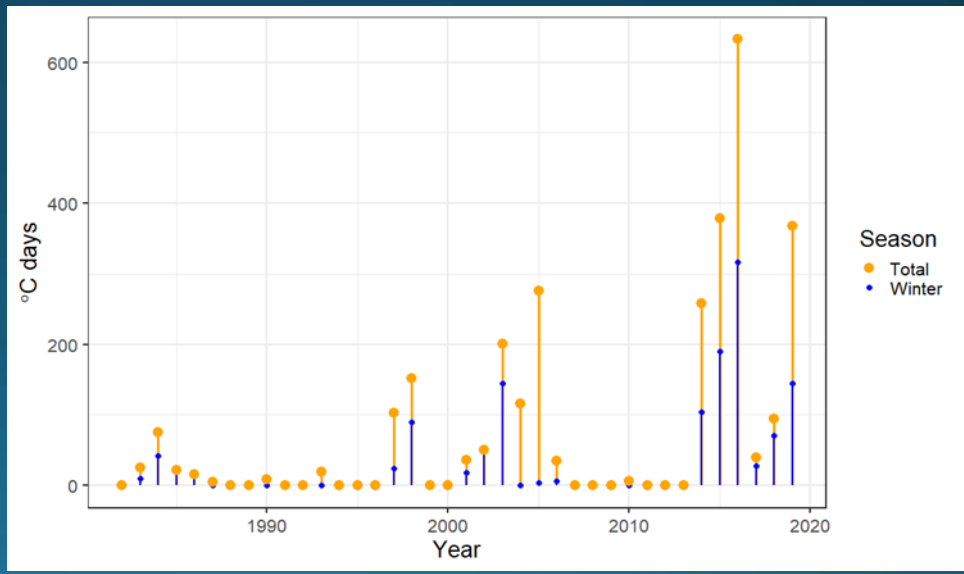
- New heatwave began September 10,2018
- Summer of 2019 surface temps were warmer than “blob” years.



Marine heatwave index

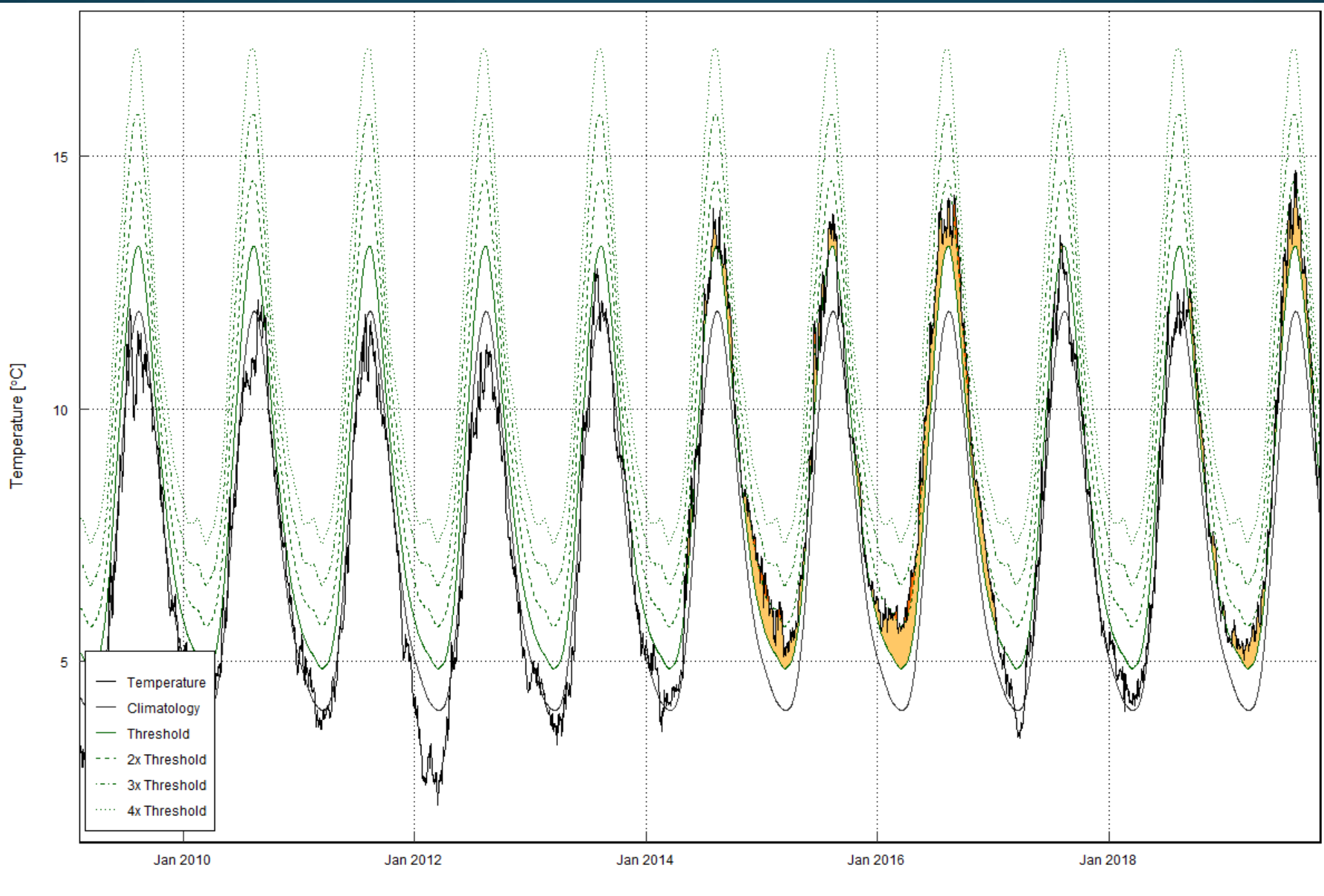
- NOAA high resolution blended analysis data for the Central GOA
  - Daily mean SST (1 September 1981 - 4 November 2019)
- Sum of the annual marine heatwave cumulative intensity (°C days)
  - 1982-2012 baseline
  - Above 90th percentile for more than 5 days
  - "Winter" defined as Jan-Mar and Nov-Dec for a given year





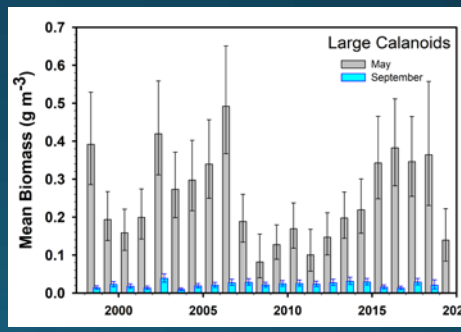
Hobday et al. (2018)

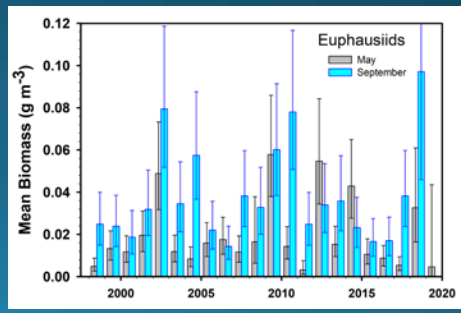
SST data through 11/4/2019


Temperature [°C]
15
10
5
Jan 2010
Jan 2012
Jan 2014
Jan 2016
Jan 2018
Temperature
Climatology
Threshold
2x Threshold
3x Threshold
4x Threshold

Other indicators 2019

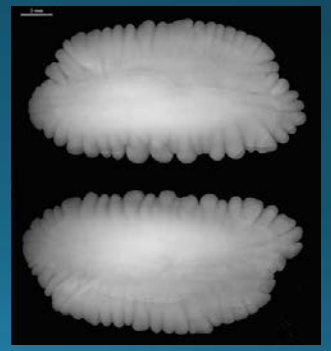
- Juvenile forage
  - Copepod community size anomalies were larger for the Alaskan Shelf and oceanic habitats in 2017
  - Euphausiids were at record abundance during the September 2018 Seward Line sampling
  - Euphausiids abundance estimates were low in May 2019.
  - Acoustically-derived estimates of euphausiid abundance during summer 2019 were moderate to low.
  - The reproductive success of planktivorous auklets at the Semedi Islands was average
- Foraging conditions for adult cod
  - Forage fish indicators suggest mixed signals for abundance during 2019.
    - Spring and late summer surveys for young-of-year groundfish found very few.
    - Forage-fish eating seabirds at the Semidis had strong reproductive success, although observations indicated that diets were unusual relative to other years.





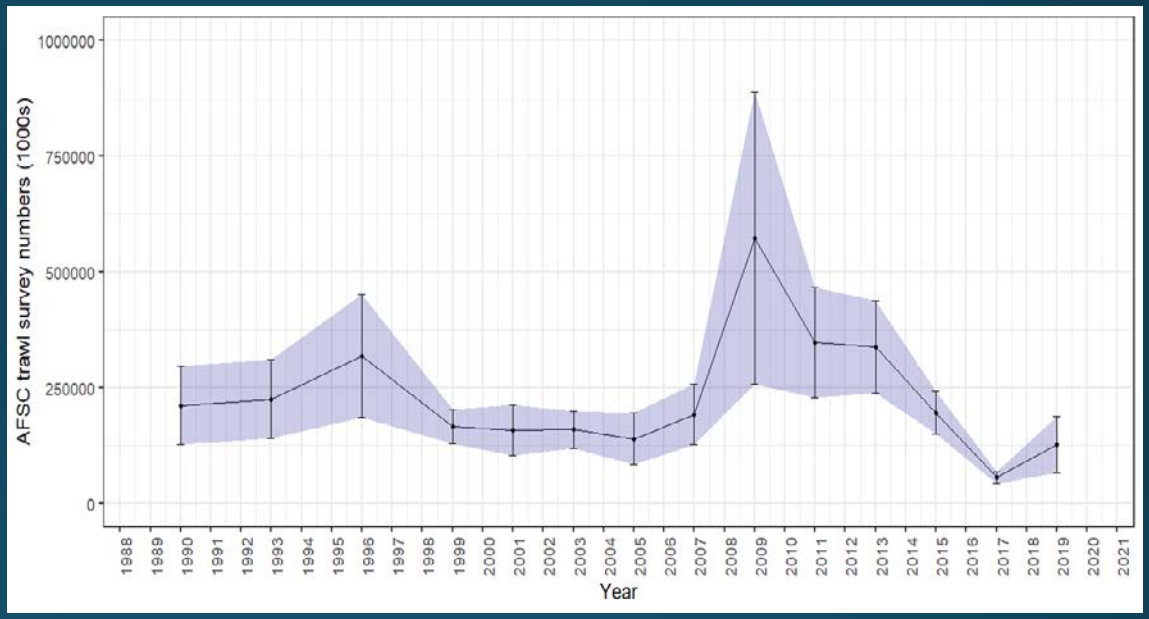
New data for 2019 in assessment model

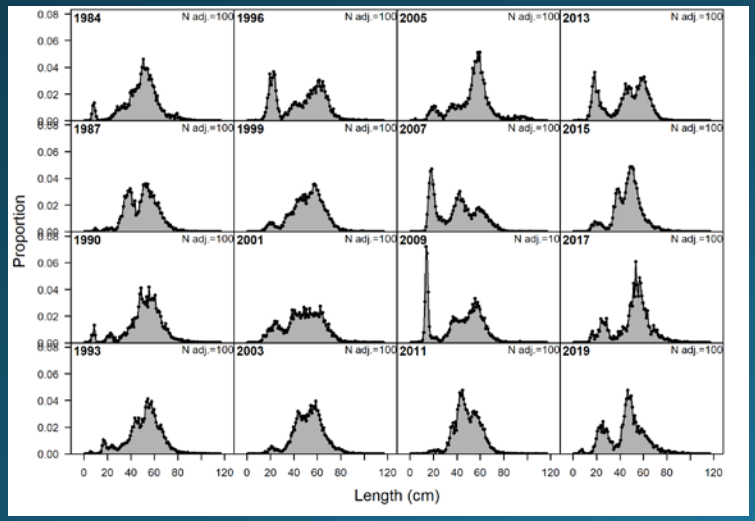
- 2019 AFSC bottom trawl survey
  - Abundance Index 1990-2019
  - Length composition
- 2019 AFSC longline survey
  - RPN Index 1990-2019
  - Length composition
- 2010-2011 and 2018 fishery conditional age at length
- 2018-2019 Fishery catch and length composition

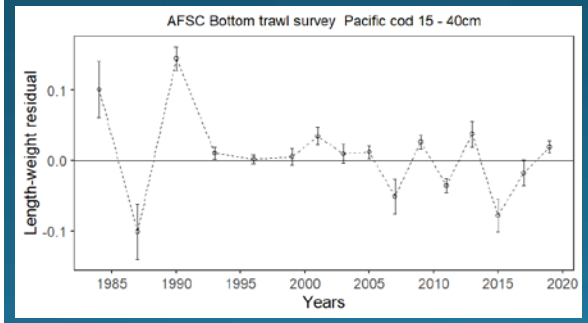


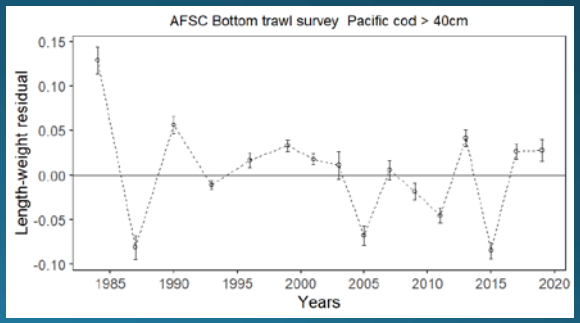
GOA Pacific cod
2019 AFSC Bottom trawl survey

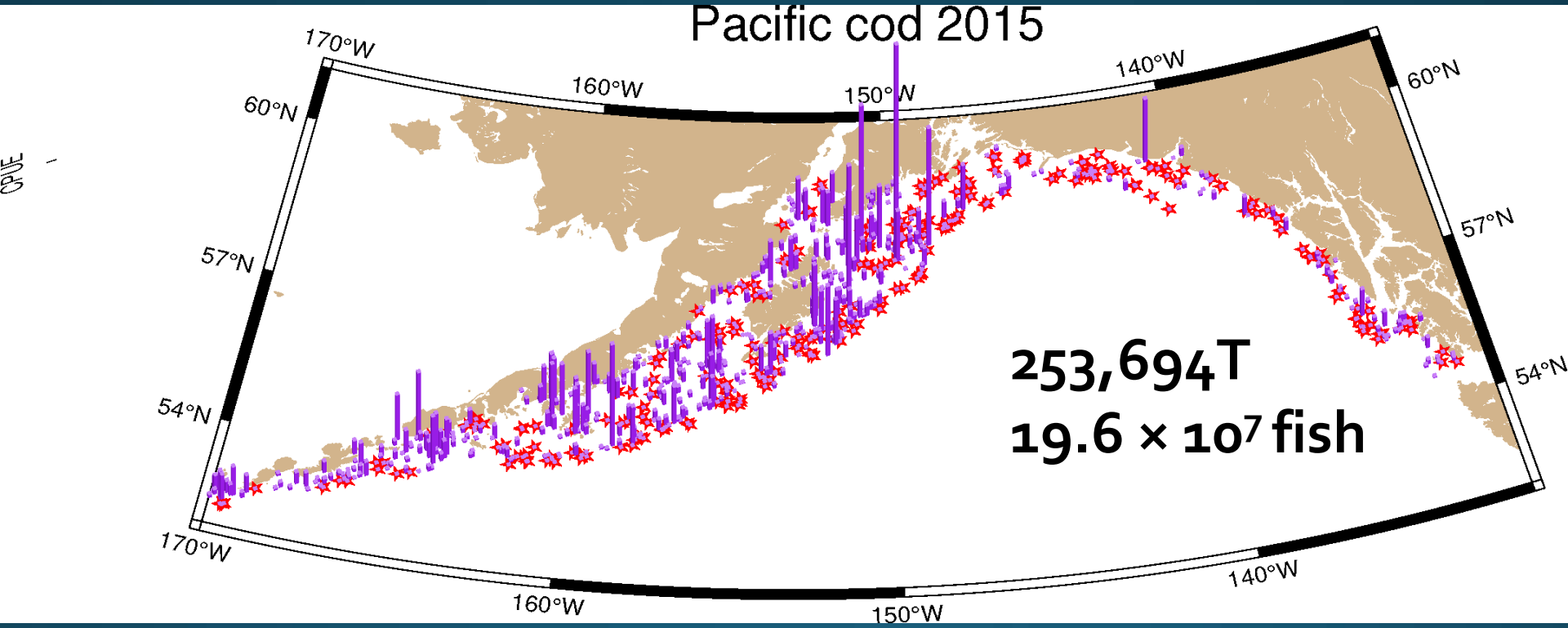
- 126% increase in abundance from 2017
  - 5.6×10^7 to 12.7×10^7 fish
- Second lowest biomass estimate in time series
  - 69% increase to 181,581 t
  - Highest CV in time series (0.243)

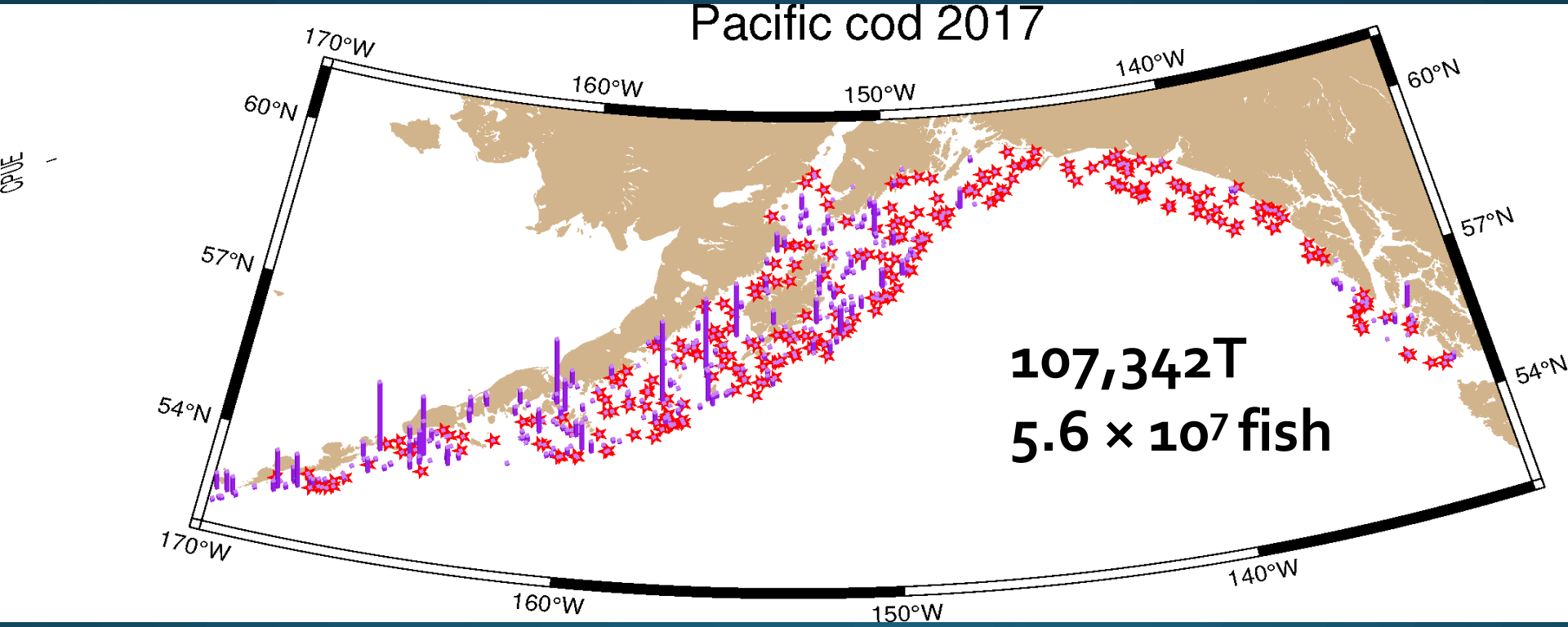


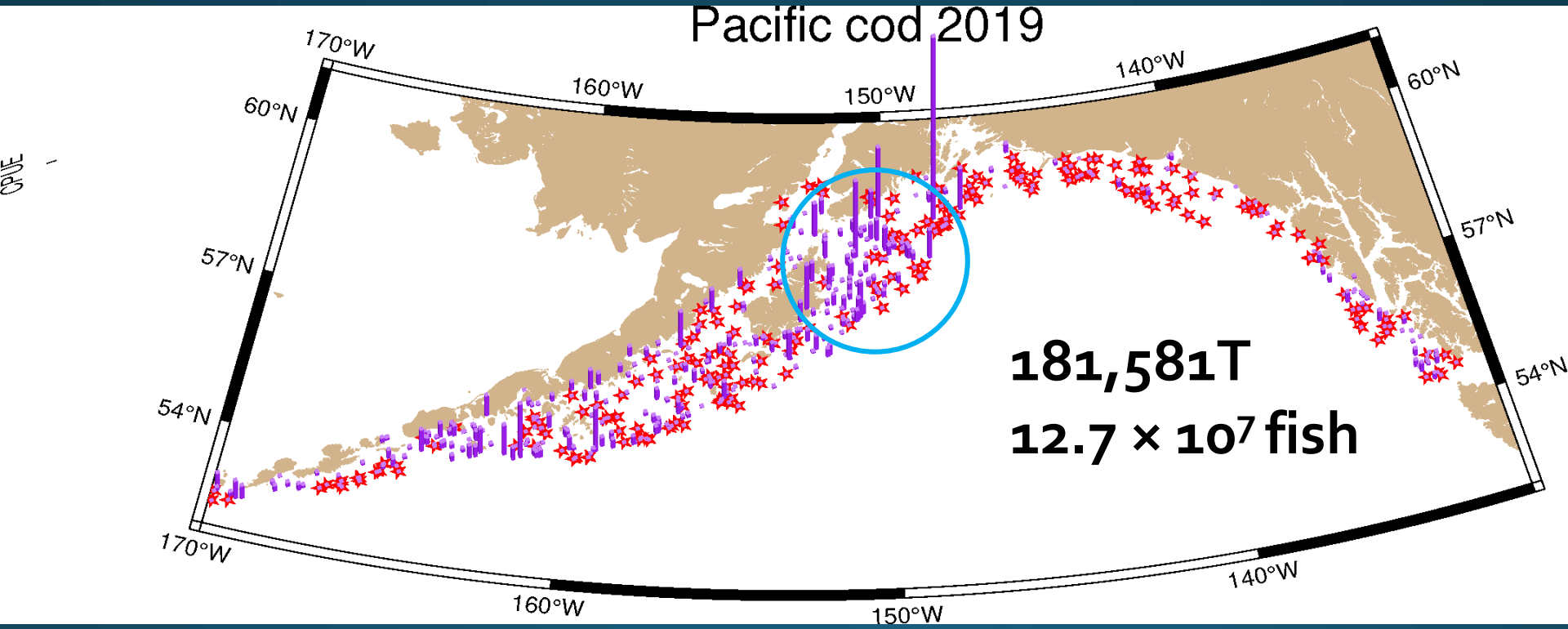






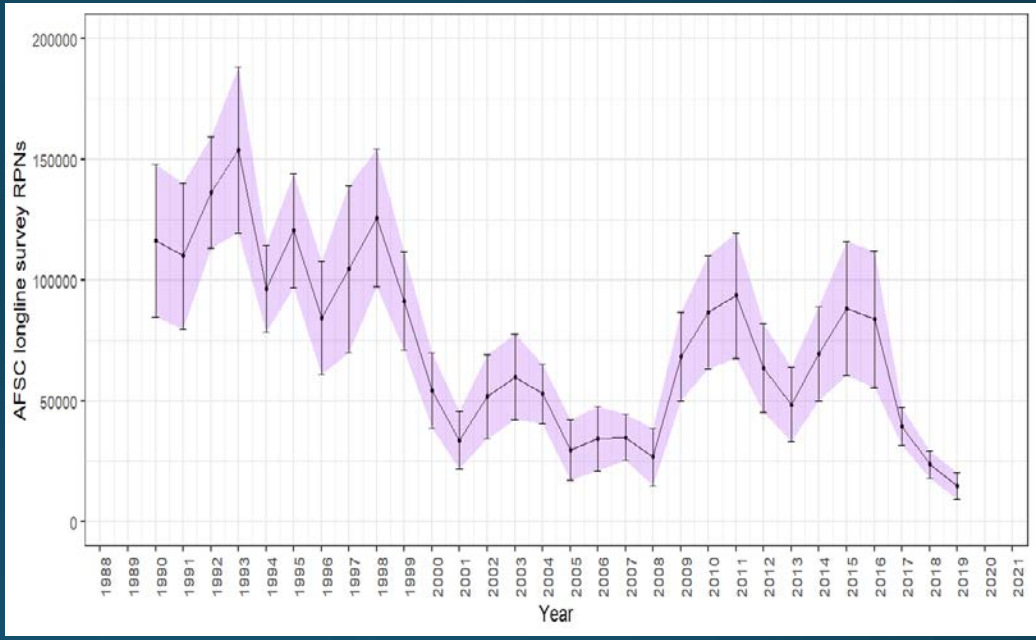

Pacific cod 2015
CPUE
170°W
160°W
150°W
140°W
60°N
57°N
54°N
253,694T
19.6 × 10⁷ fish

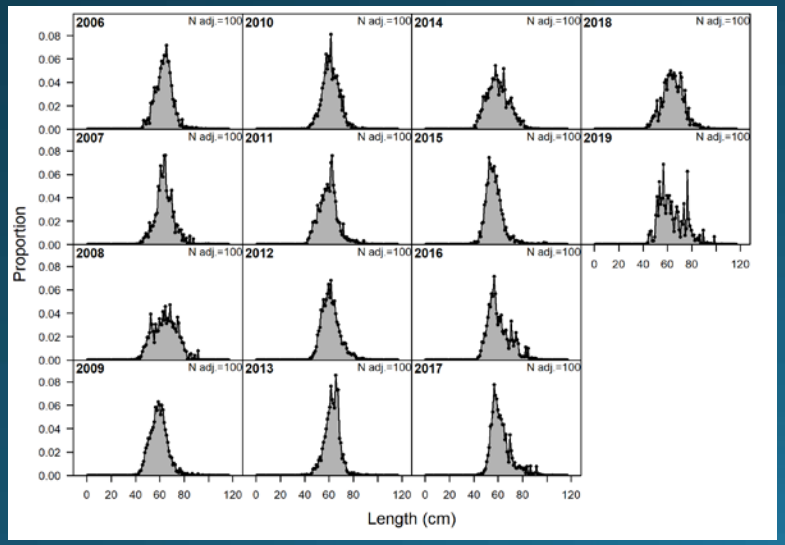

Pacific cod 2017
170°W
160°W
150°W
140°W
60°N
57°N
54°N
107,342T
5.6 × 10⁷ fish

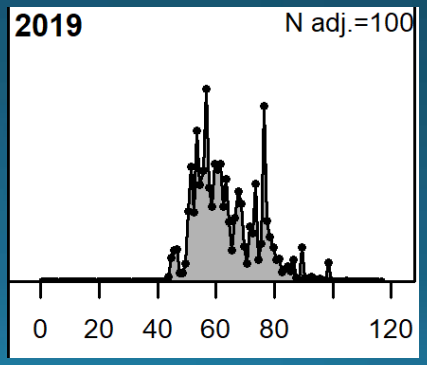

Pacific cod 2019
CPUE
170°W
160°W
150°W
140°W
60°N
57°N
54°N
181,581T
12.7 × 10⁷ fish

AFSC longline survey

- 2019 Lowest index value in series
  - 19,933 RPN
  - 37% decline from 2018
  - 83% decline since 2015
- Survey of large cod
  - Deep > 150 m depth
  - > ~40 cm





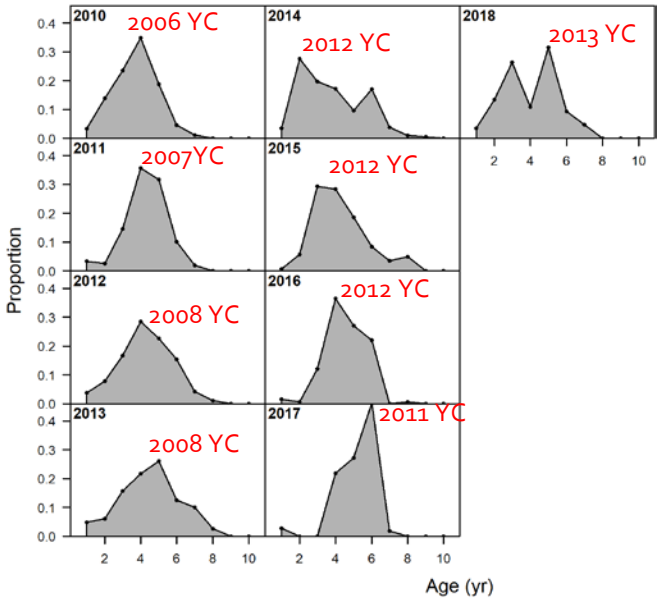


Fishery age composition data

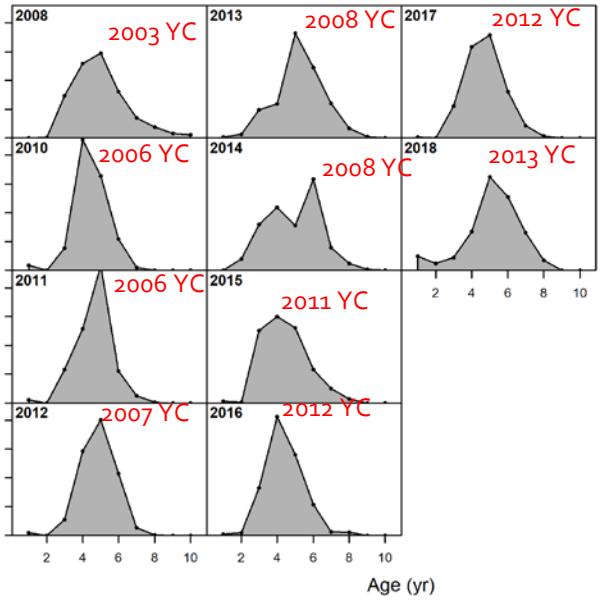
- Based on annual fishery-specific age-length key

Note that in the Bering Sea large year classes are 2011 and 2013

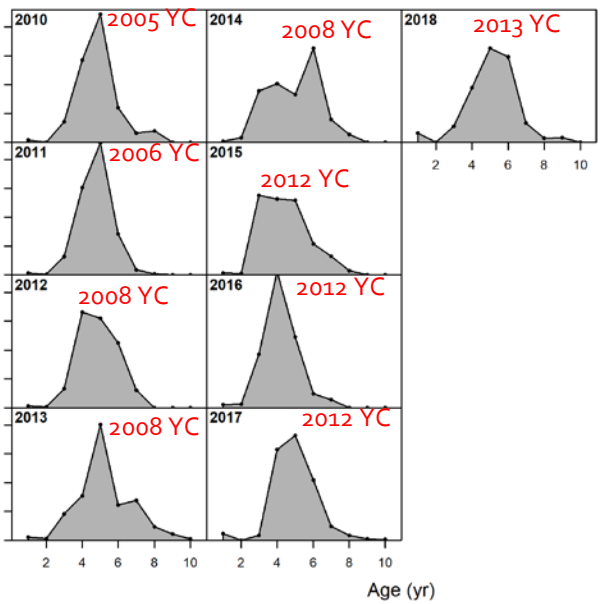
Trawl



Longline



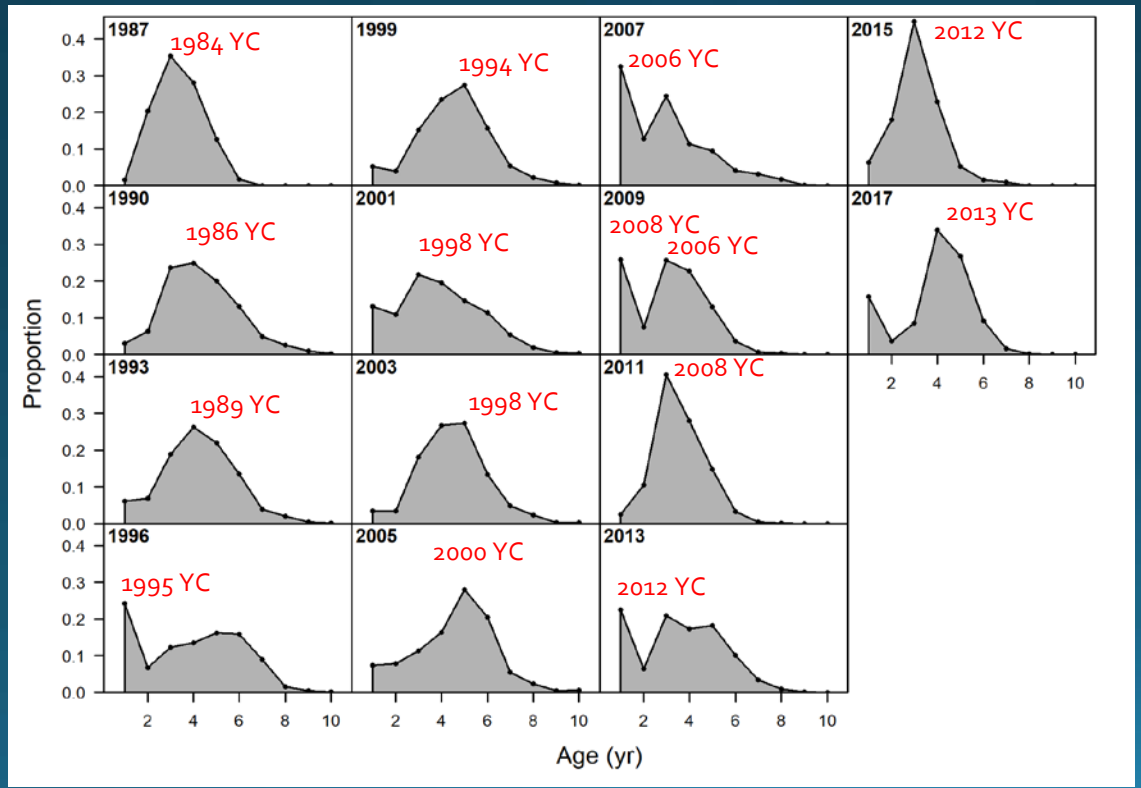
Pot



Survey age composition 1990-2017

- Change from dominant 2012 to 2013 year classes between 2015 and 2017
- 2019 age data not yet available.

Note that in the Bering Sea large year classes are 2011 and 2013



New ancillary data for 2018

- 2019 IPHC longline survey
  - RPN Index
  - No length composition data available yet
- 2019 ADF&G large-mesh trawl survey
  - Random effects model biomass Index
  - Length composition
- Fishery CPUEs
- Bycatch rates
  - Encounter rate in GOA pollock fishery
  - Catch rate in GOA shallow water flatfish fishery
- Pacific cod body condition
- Larval surveys
  - 2019 Ichthyoplankton survey
  - 2019 GOA beach seine studies

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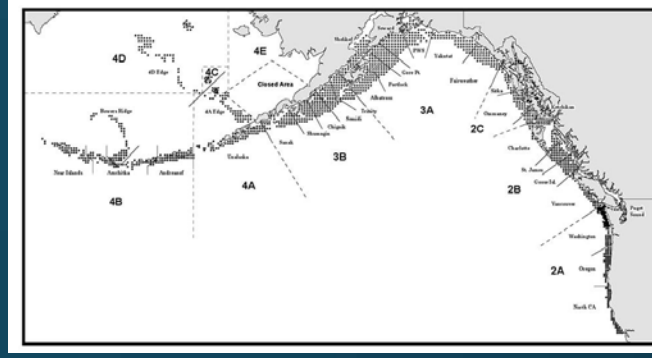
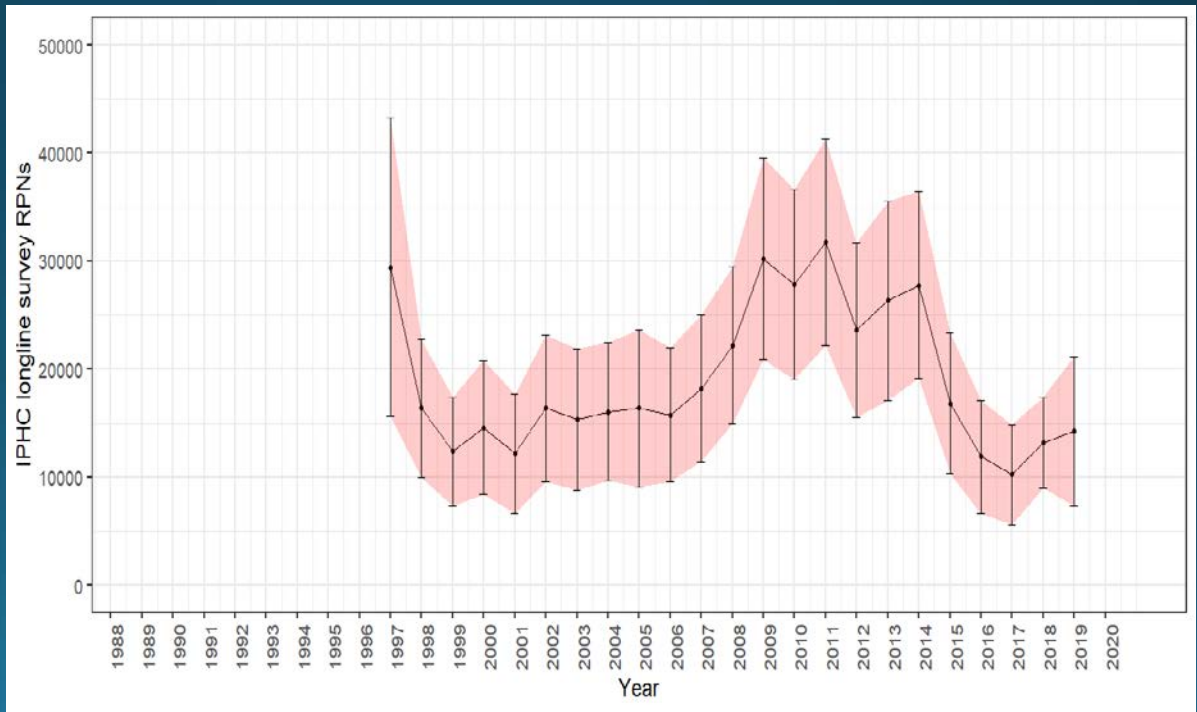
IPHC longline survey 1997-2019

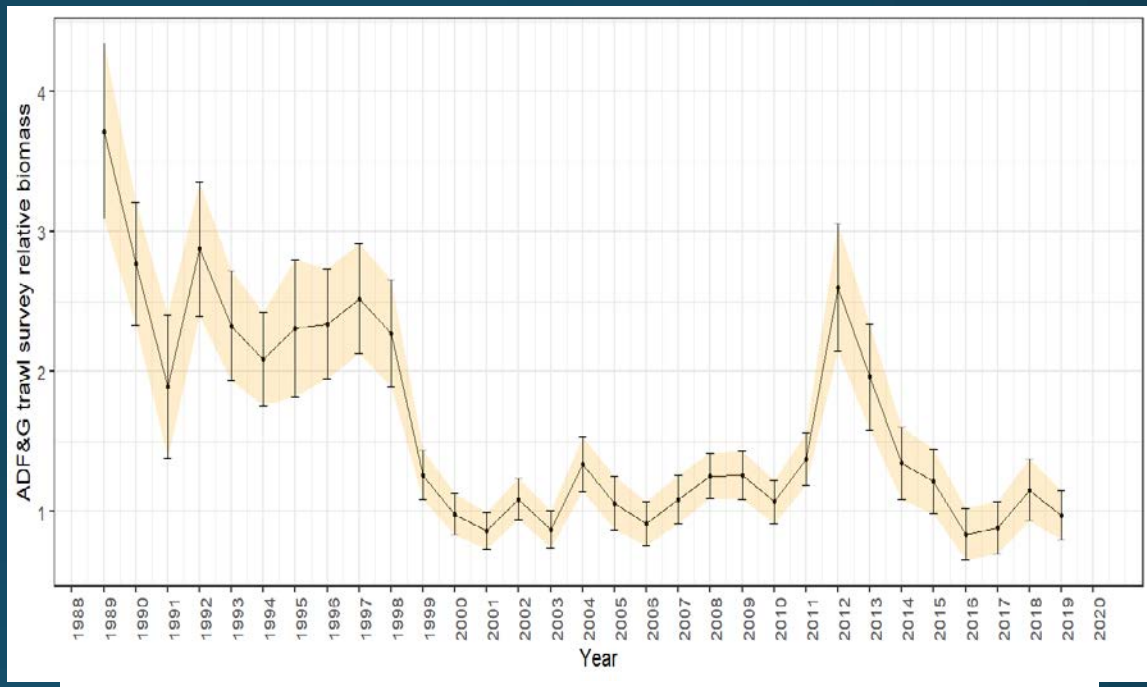


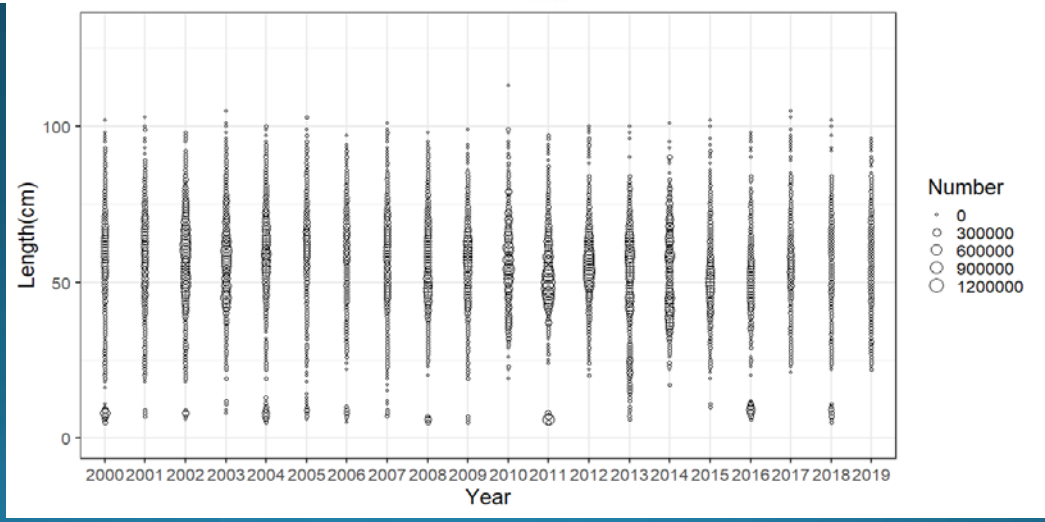
- Surveys GOA shelf area
  - Comparable to AFSC bottom trawl survey
  - 2017 lowest in time series
  - 7.9% increase from 2018 to 2019
  - Highest cv of time series (0.25)



ADF&G large-mesh trawl survey 1990-2018

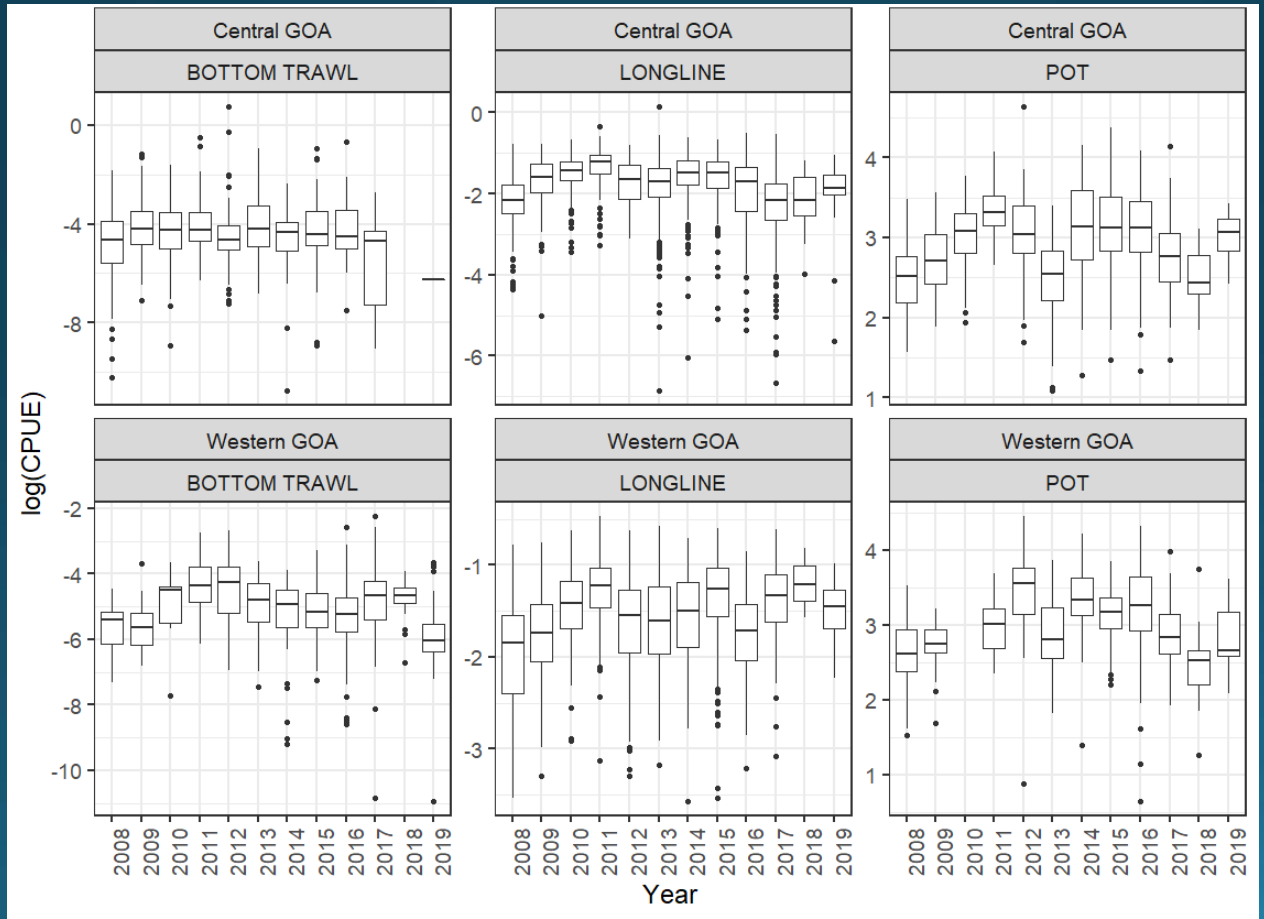
- Generally near-shore
- Random-effects model used for index
- 2016 lowest relative biomass estimate in series
- 16.4% decrease from 2018 to 2019



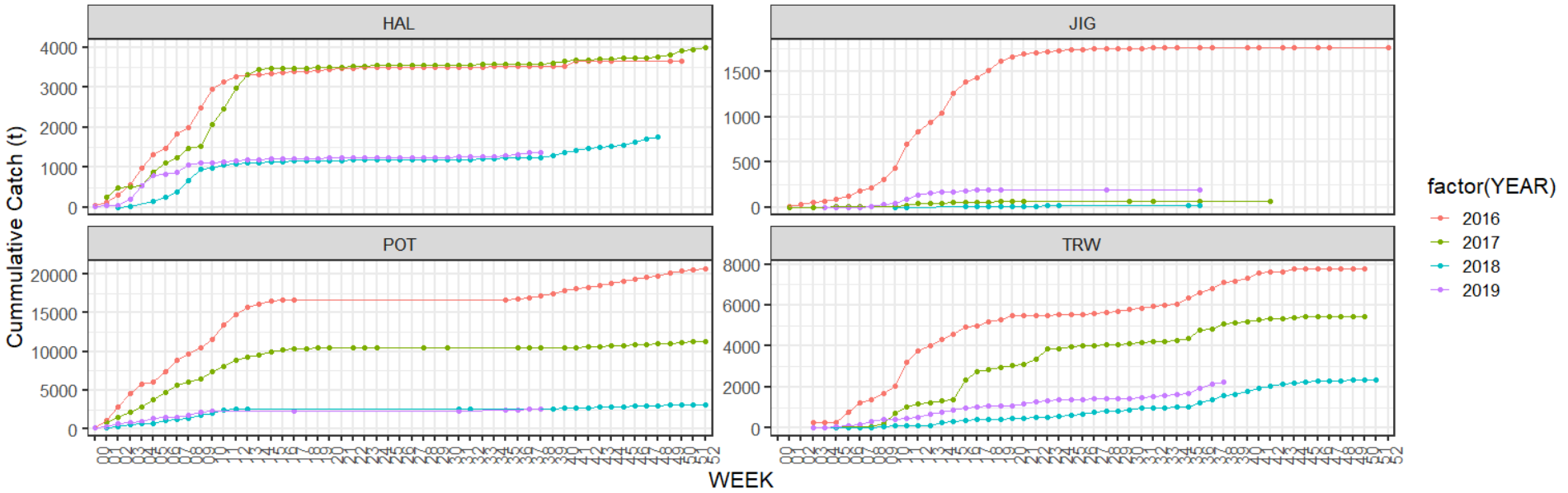


Directed fishery CPUE

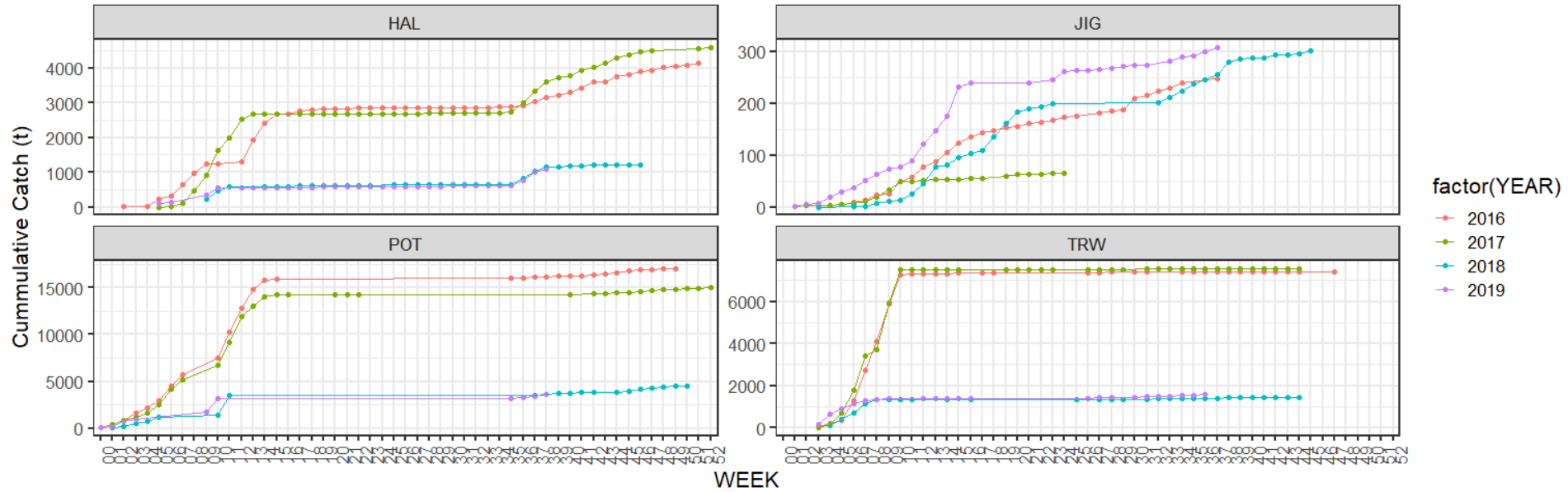
- 2019 mixed signals
  - Pot CPUE up in both regions, longline up in Central GOA
  - Trawl CPUE down in Western GOA, not measurable in Central
  - Longline CPUE down in Western GOA



Central GOA

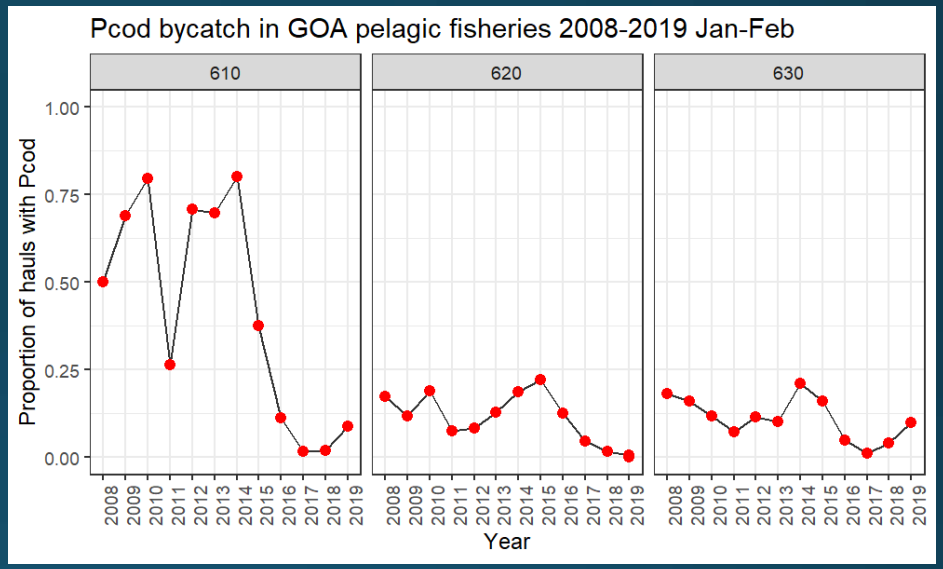


Western GOA

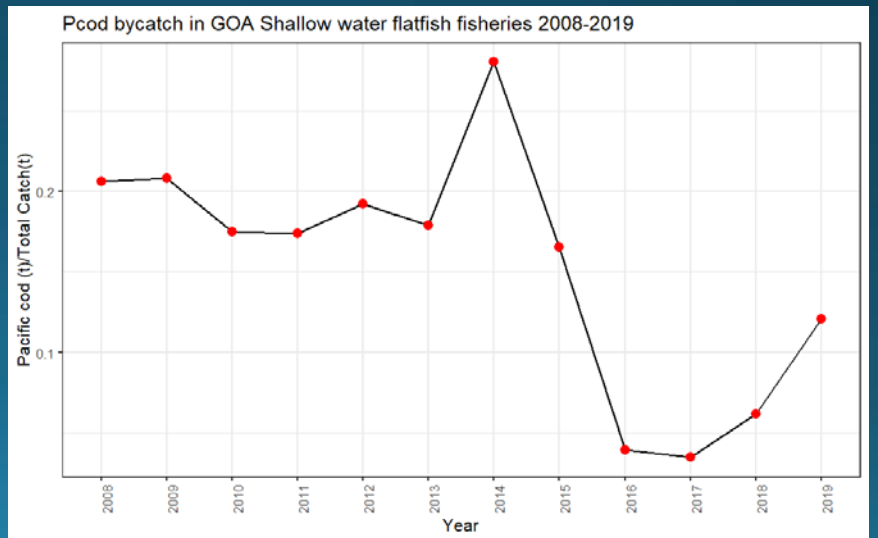


Bycatch rates in pollock and shallow-water flat fisheries

- Encounter rate in pelagic pollock fishery is a mixed signal depending on area
- Up in 610 and 630, down in 620



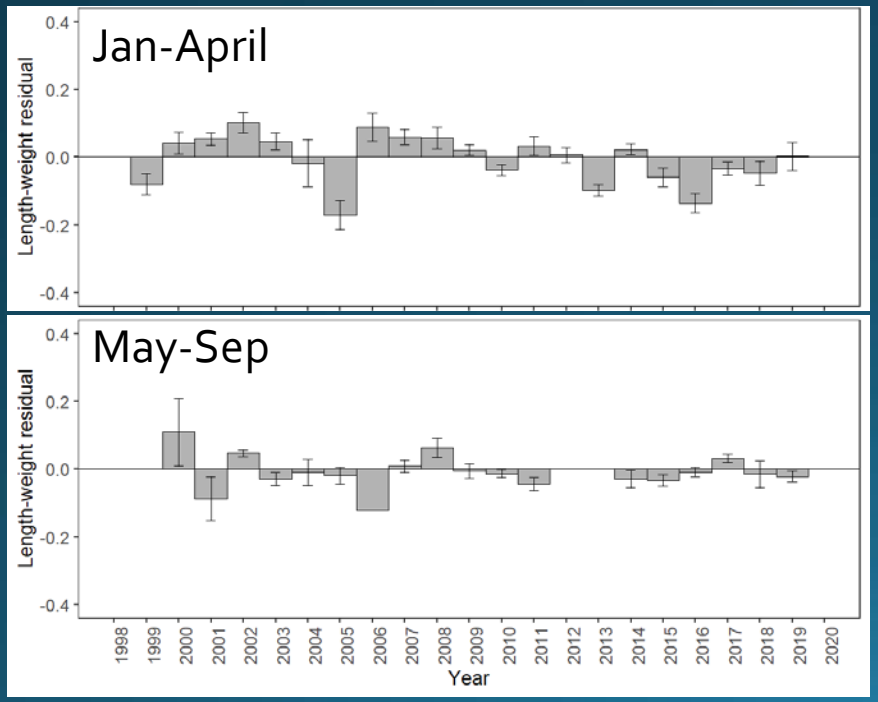
- Bycatch rate in shallow water flatfish fishery appears higher in 2019 compared to 2016 through 2018
- Remains low compared to prior years



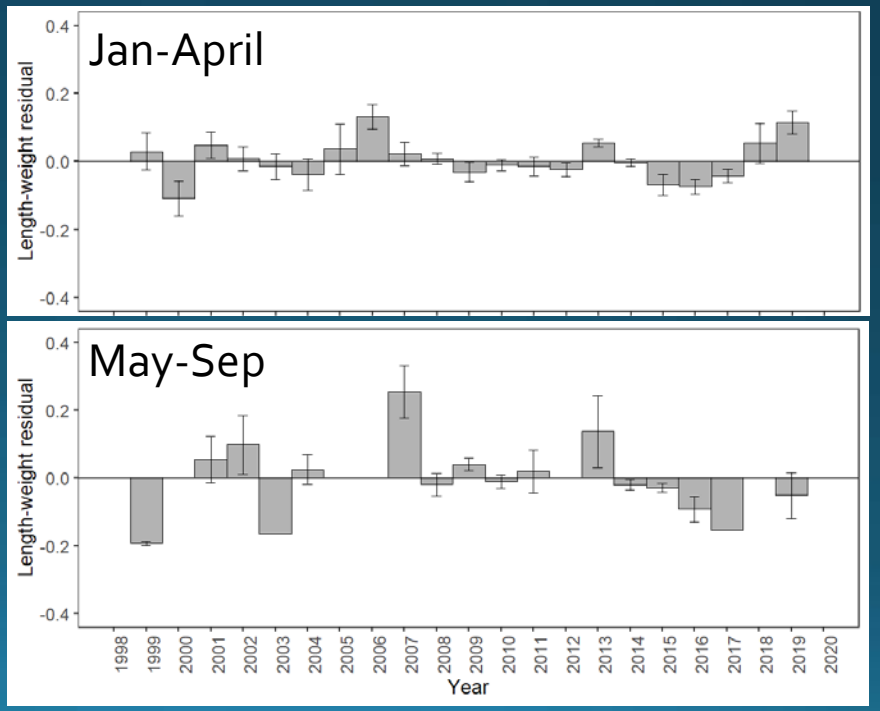
Pacific cod weight at length in fisheries

- Mixed seasonal signals
  - Good to average condition in the Winter/ early Spring
  - Poorer condition in the late Spring/Summer

Western GOA Longline

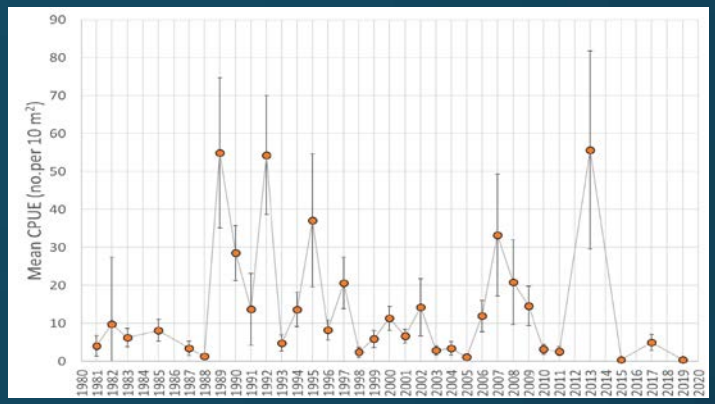


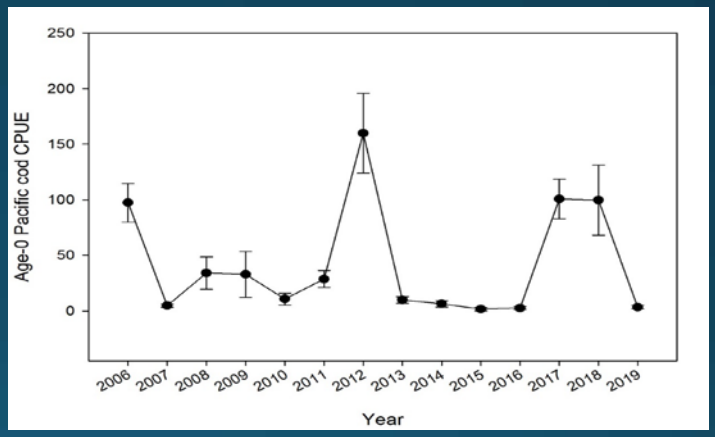
Central GOA Longline

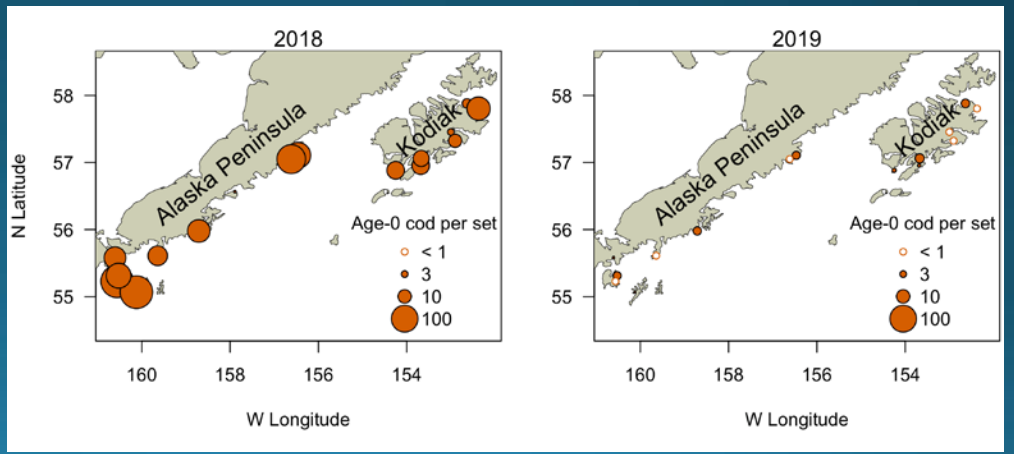


Larval surveys

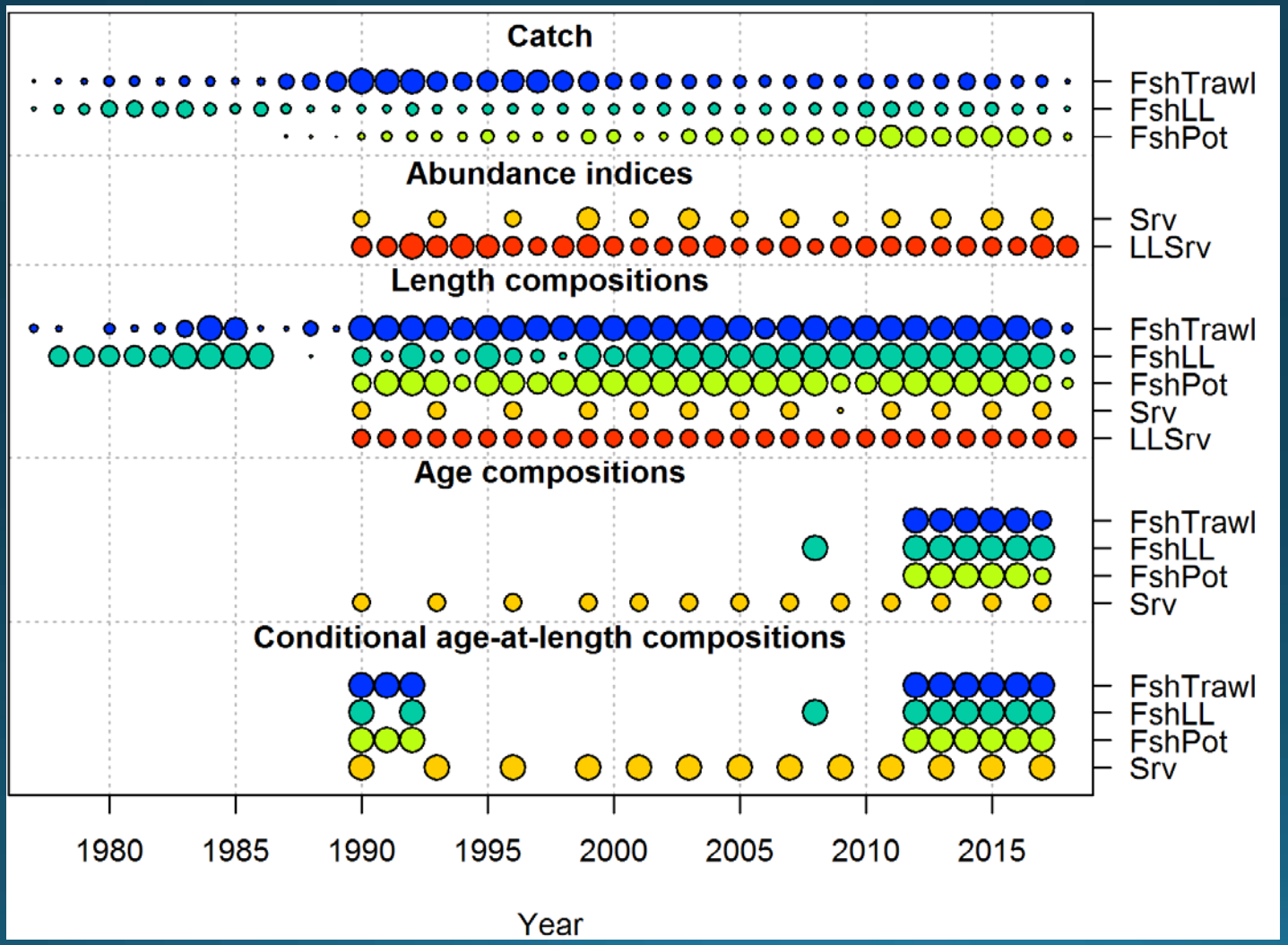
- Icthyoplankton survey (1981-2019)
  - 2019 very low
- Age-0 Kodiak beach seine survey (2006-2019)
  - 2019 very low
- Age-0 western GOA beach seine survey (2018-2019)
  - 2019 order of magnitude lower than 2018





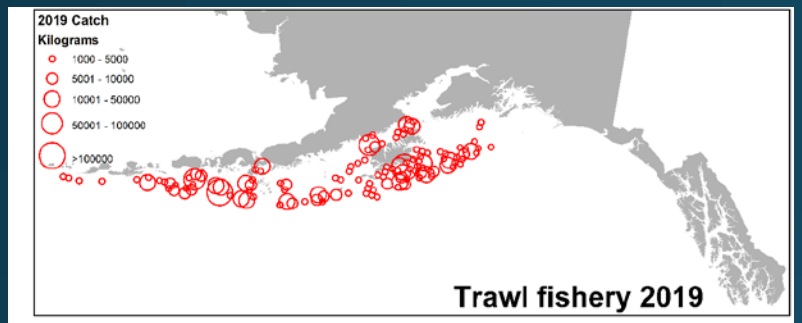


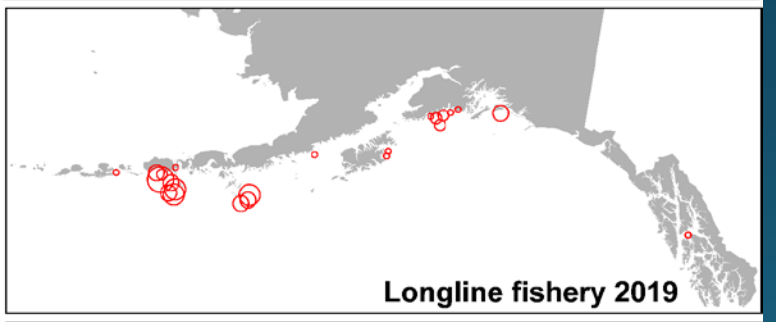
Data used in assessments

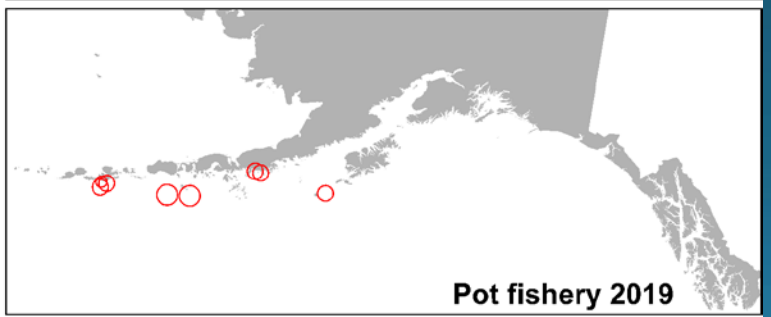


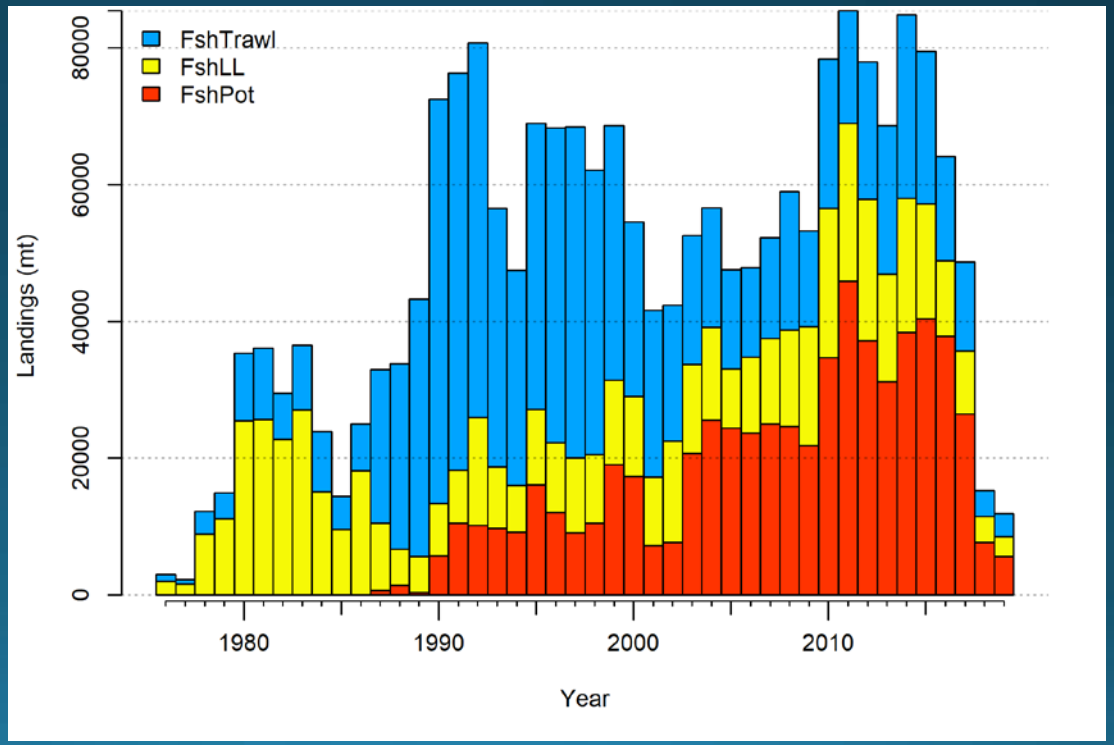
Catch

- ABC for 2019 remained low at 17,000 t reduced from 18,000t in 2018
- Total catch in 2019 at < ABC_{2019} ~15,000t



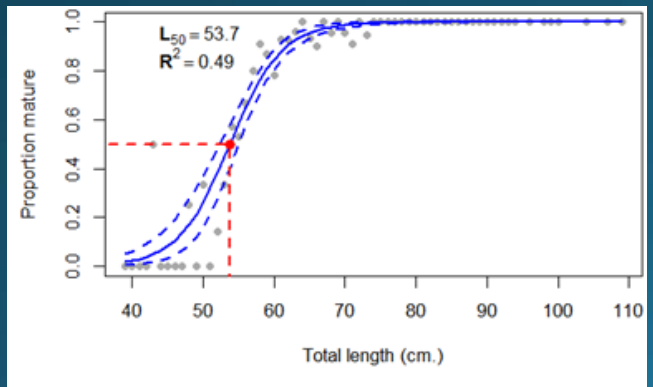


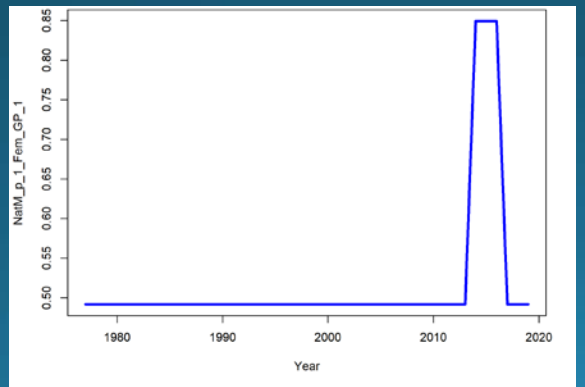


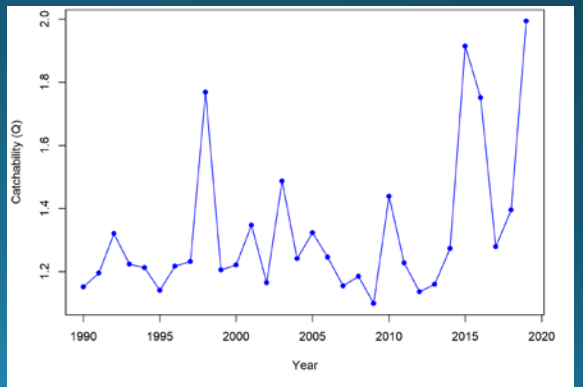


Base Model – Model18.10.44

- Developed in Stock Synthesis
  - von Bertalanffy growth
  - $L_{50\%}$ at 53.7cm slope = -0.273657 using Stark (2007) maturity data
  - Beverton-Holt with steepness = 1.0, sigma R = 0.44
  - Heatwave block on natural mortality 2014-2016
    - Fit with lognormal μ =-0.81 and SD = 0.1
  - All selectivity double normal on length composition
    - Blocks on fishery and trawl survey
      - Annual devs on pre-1989 longline and trawl fishery selectivity parameters
    - Longline survey single selectivity curve
  - Catchability on AFSC longline survey scaled to CFSR temperatures (at 10cm fish mean depth)
  - No age data prior to 2007 due to aging bias

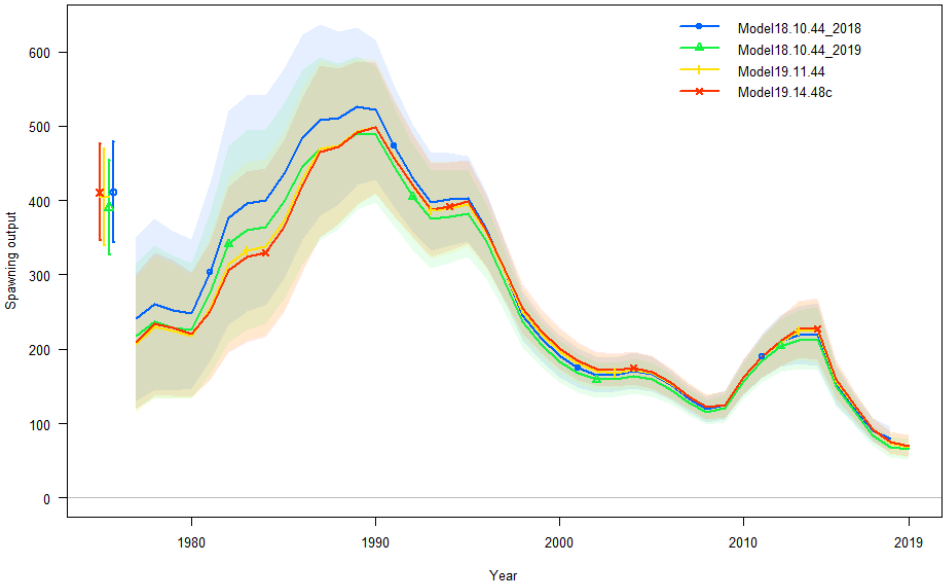


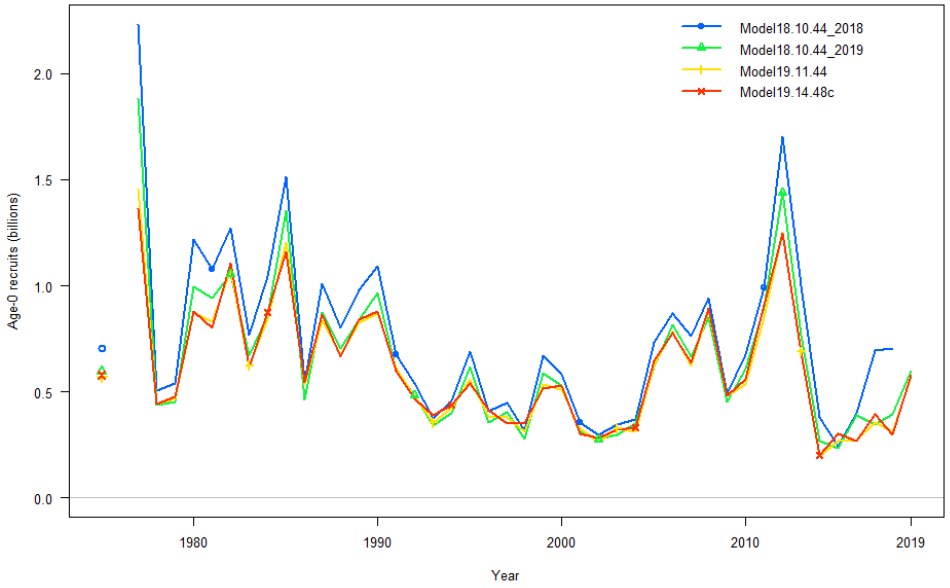




Models reviewed in 2019

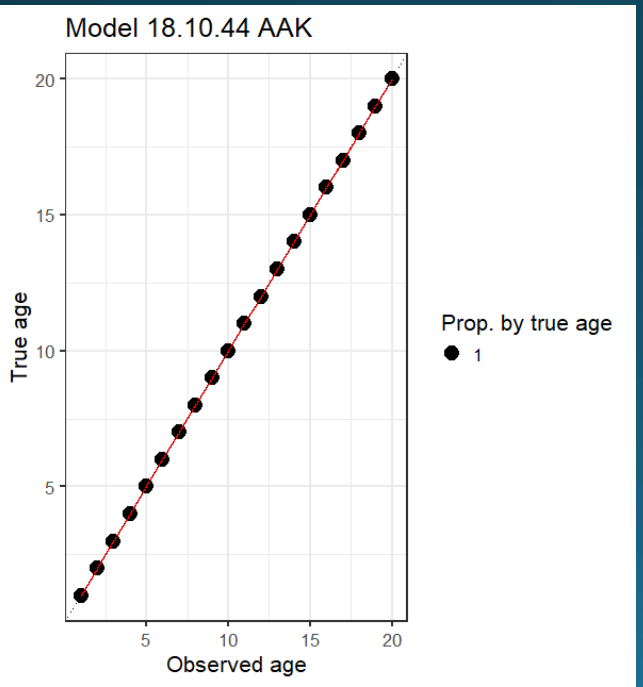
Model	Data	Plus group	Aging error	Aging bias
18.10.44	No age data pre-2007	20+	No	No
19.11.44	No age data pre-2007	10+	Yes	No
19.14.48c	All Cond. length at age	10+	Yes	Pre-2007 fit, 2007+ fixed at 0

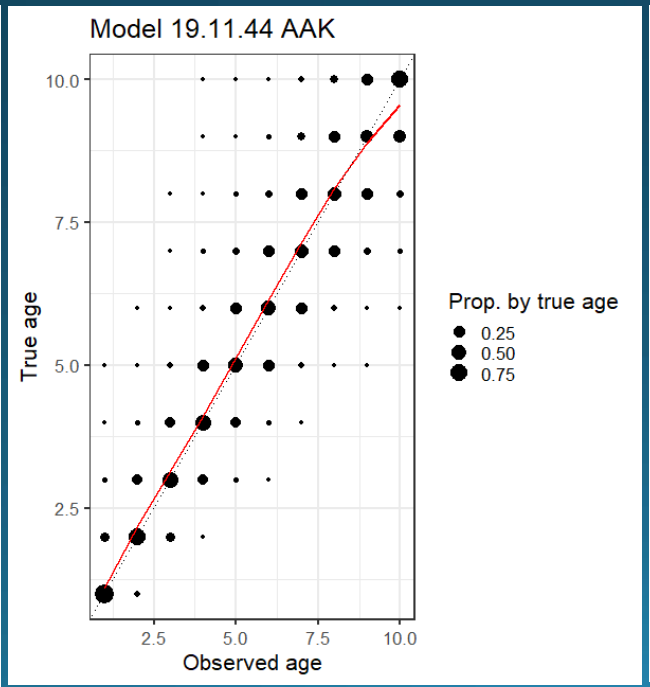


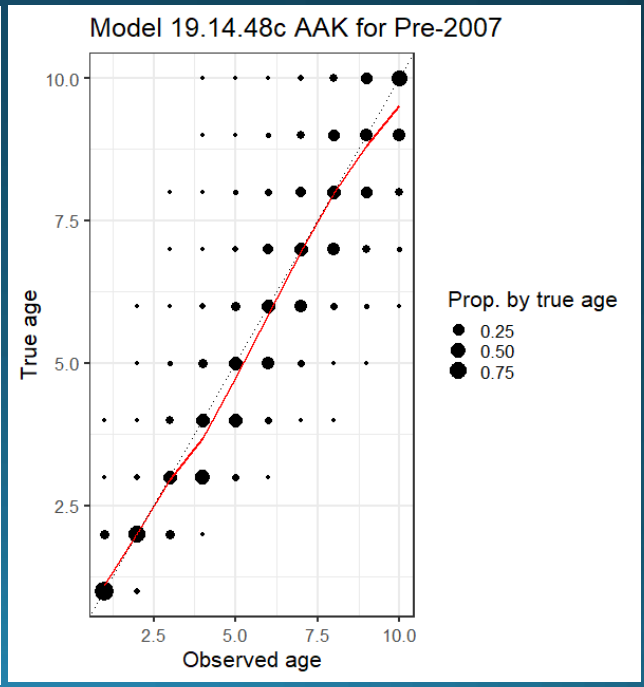


Aging error and bias

- Model 19.11.44 adds aging error without bias for all age data
  - Aging error derived from age reader validation test for 2007-2017 survey data
- Model 19.14.48c adds aging error for all age data and aging bias for pre-2007 age data
  - Aging bias fit within the model





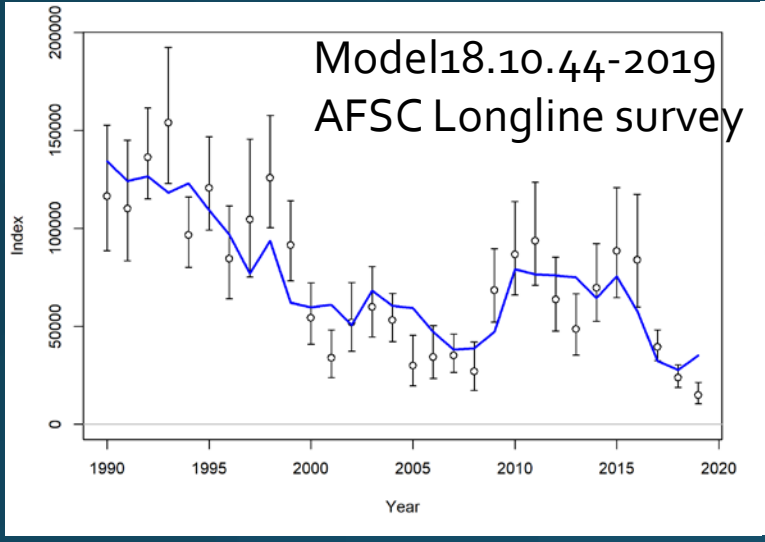


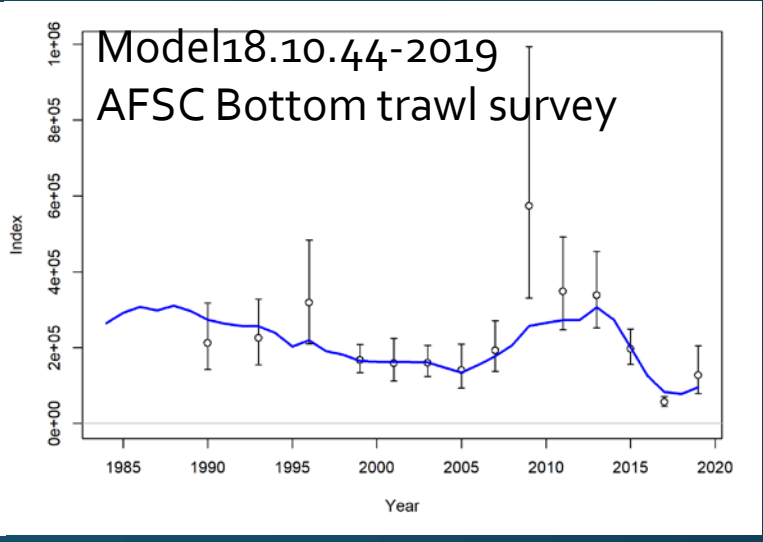
Model selection

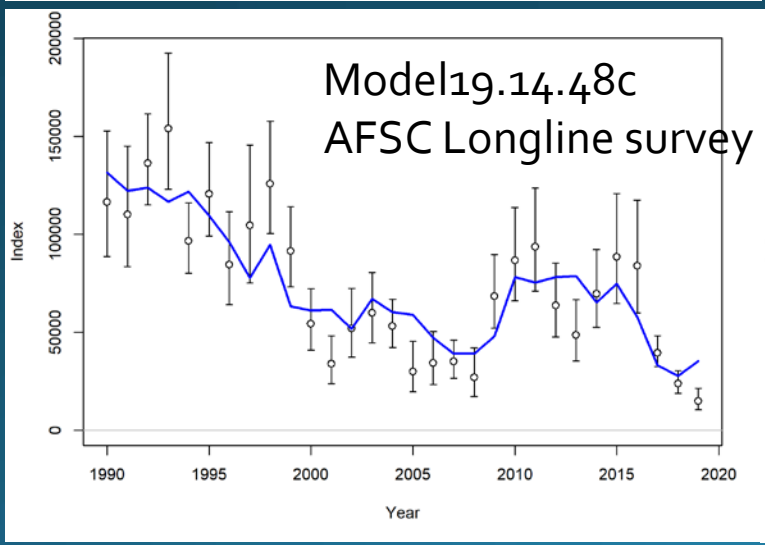
- Direct comparisons of likelihood not possible as data and error structure change
- Adding aging error adjust weighting in model to fit survey estimates better and composition worse
- Visual inspection of fits to data show very little difference

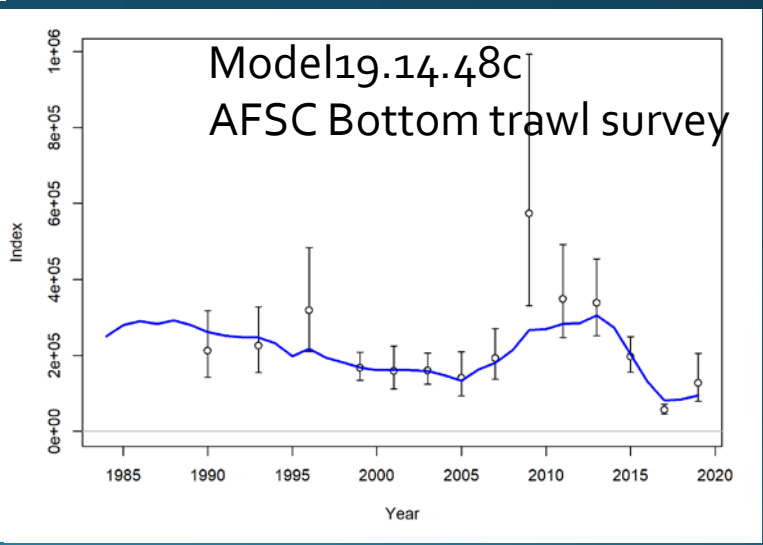
	M18.10.44	M19.11.44	M19.14.48c
Likelihoods Total	2297.59	2349.20	2714.86
Survey	-9.59	-11.79	-11.38
Length Comp.	1337.18	1342.63	1360.43
Age Comp.	963.36	1013.33	1362.03
Recruitment	-6.34	-8.04	-9.00
Parameter priors	1.58	1.19	1.18
Parameter Devs.	5.83	6.09	6.10

Index fits


Model18.10.44-2019
AFSC Longline survey
Index
Year


Model18.10.44-2019
AFSC Bottom trawl survey
Index
Year

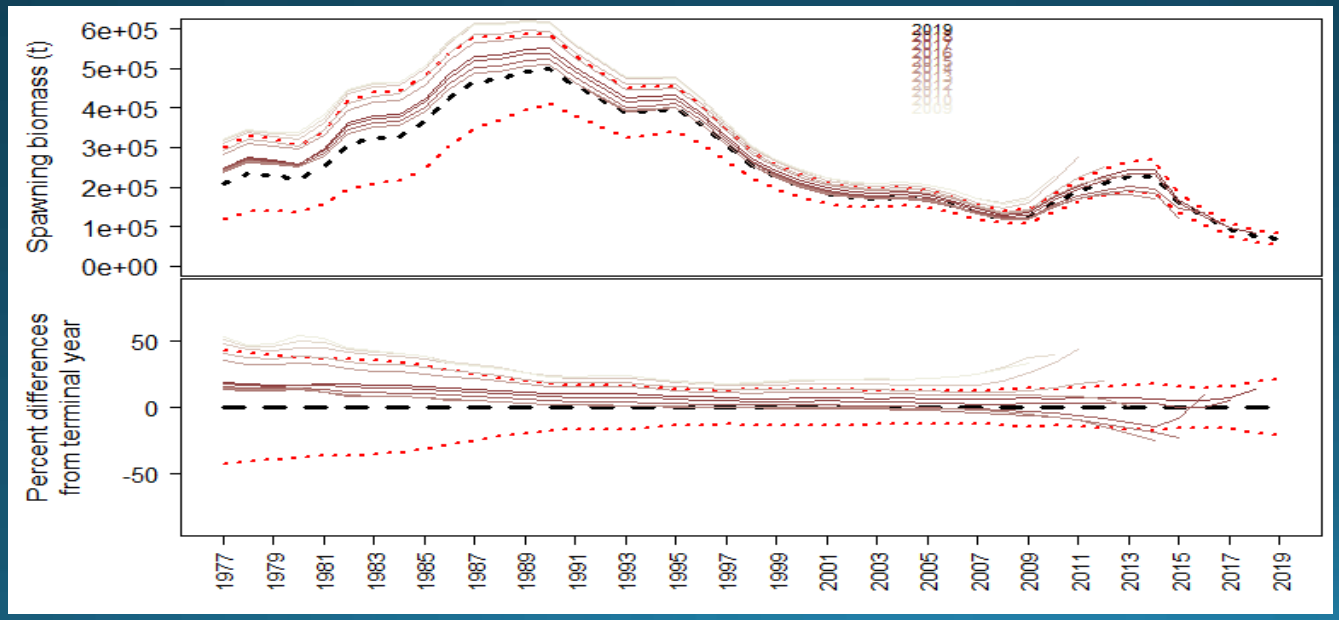

Model19.14.48c
AFSC Longline survey
Index
Year


Model19.14.48c
AFSC Bottom trawl survey
Index
Year

Retrospectives

- Model19.14.48c
  - Lowest for all measures examined
  - Final year retrospective SSB and R peals diverge with slight positive bias

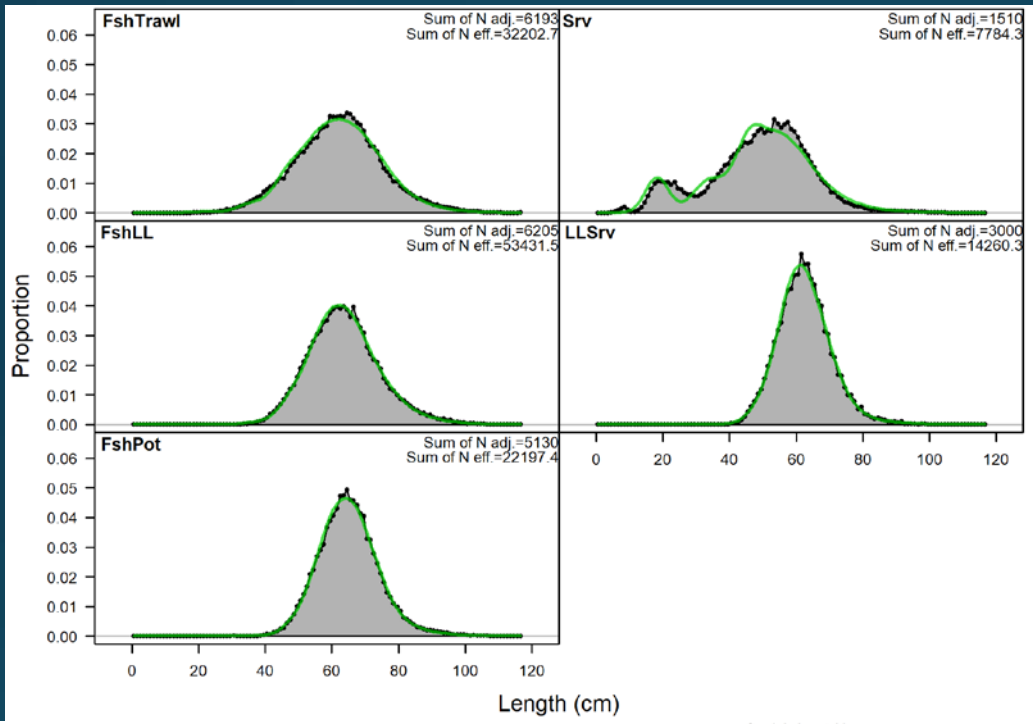
	M18.10.44	M19.11.44	M19.14.48c
Spawning biomass Mohn's ρ	0.182	0.155	0.118
Woods Hole ρ	0.190	0.177	0.148
RMSE	0.195	0.185	0.174
Recruit. (age-0) Mohn's ρ	0.347	0.246	0.197
Woods Hole ρ	0.338	0.295	0.217
RMSE	0.307	0.276	0.233

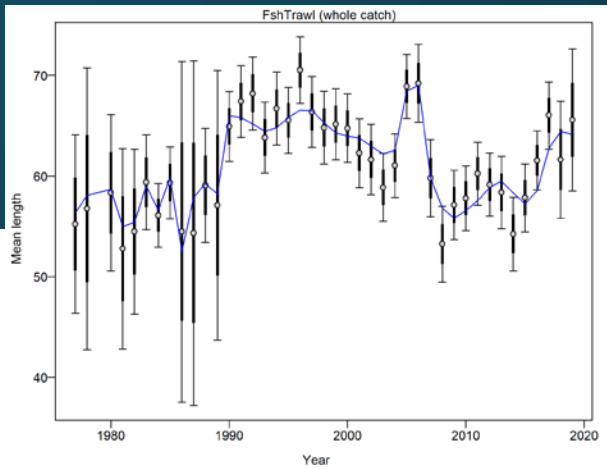


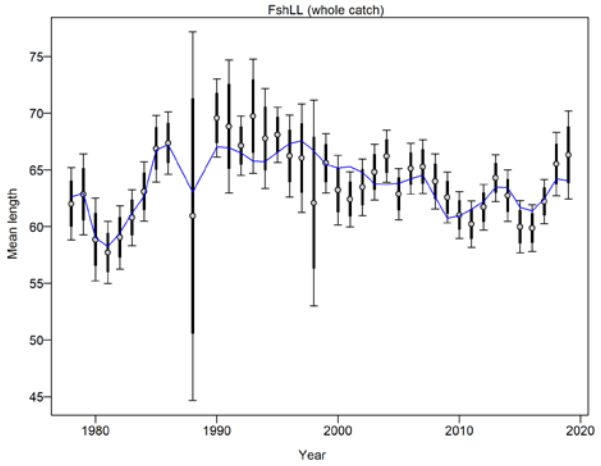
Minor changes in results with major management implications

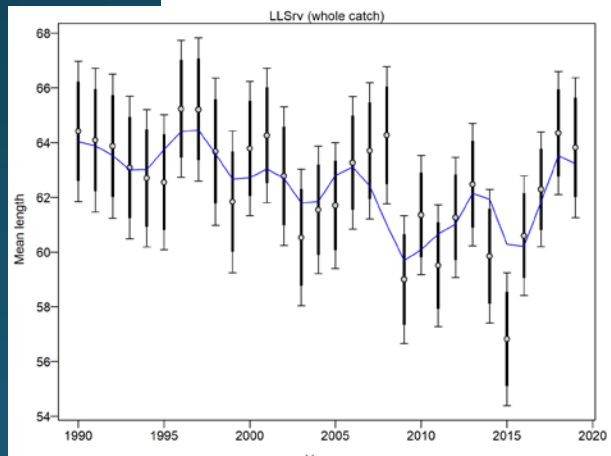
	M18.10.44	M19.11.44	M19.14.48c
Parameters			
R_0 billions	0.598	0.571	0.579
Steepness	1.0	1.0	1.0
Natural Mortality	0.49	0.49	0.49
$M_{14\text{-}16}$	0.85	0.81	0.81
q_{Shelf}	1.16	1.10	1.08
$q_{longline}$	1.23	1.16	1.15
L_{min}	5.29	3.49	2.30
L_{max}	99.46	99.46	99.46
Von Bert K	0.17	0.18	0.19
Results			
SSB_{1978} (t)	118,283	115,078	117,113
$SSB_{100\%}$ (t)	173,544	185,651	187,780
SSB_{2019} (t)	29,386	32,387	33,274
$SSB_{2019\%}$	16.9	17.4	17.7
SSB_{2020} (t)	29,782	31,840	32,958
$SSB_{2020\%}$	17.2	17.2	17.6
SSB_{2021} (t)	38,841	40,403	42,026
$SSB_{2021\%}$	22.4	21.8	22.4
$F_{35\%}$	0.750	0.676	0.668
$F_{40\%}$	0.603	0.546	0.540

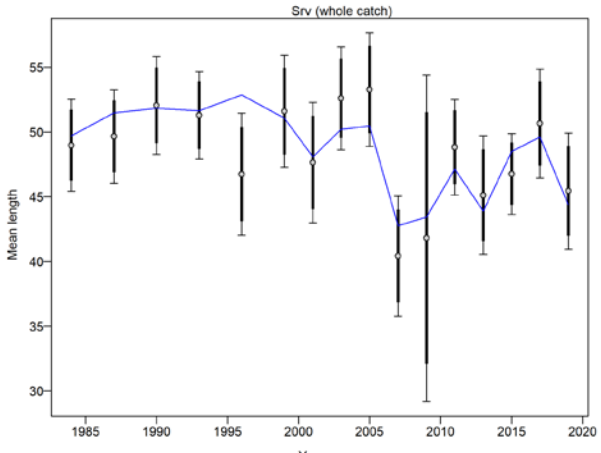
Model19.14.48c
Length composition fits

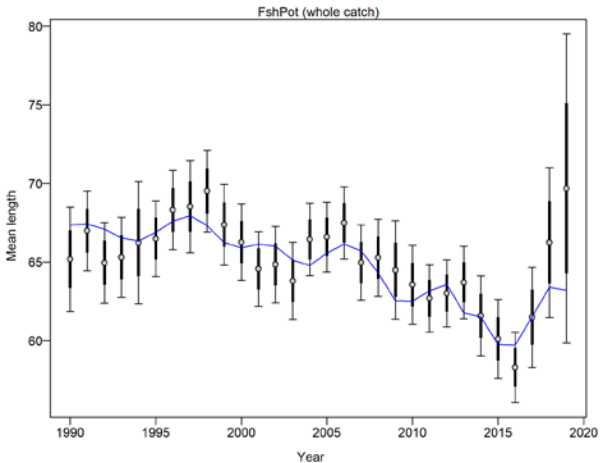




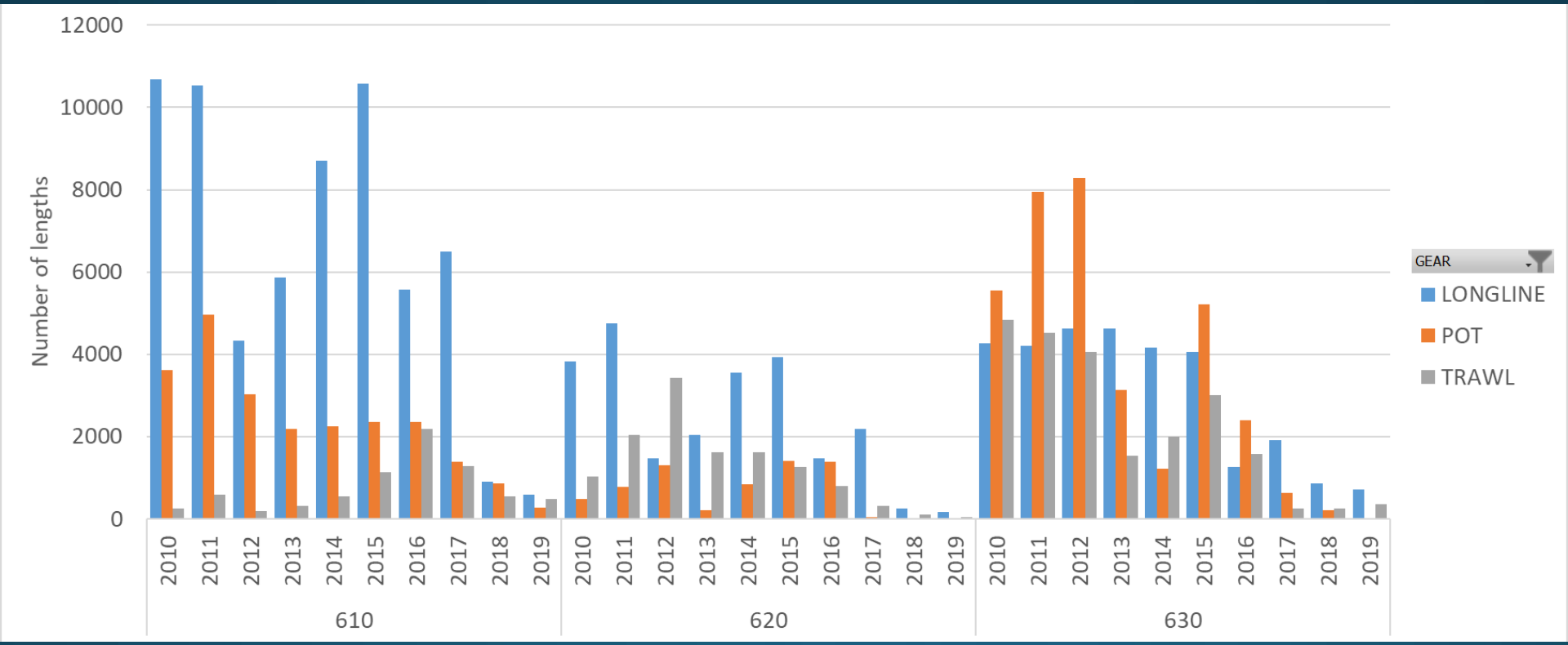






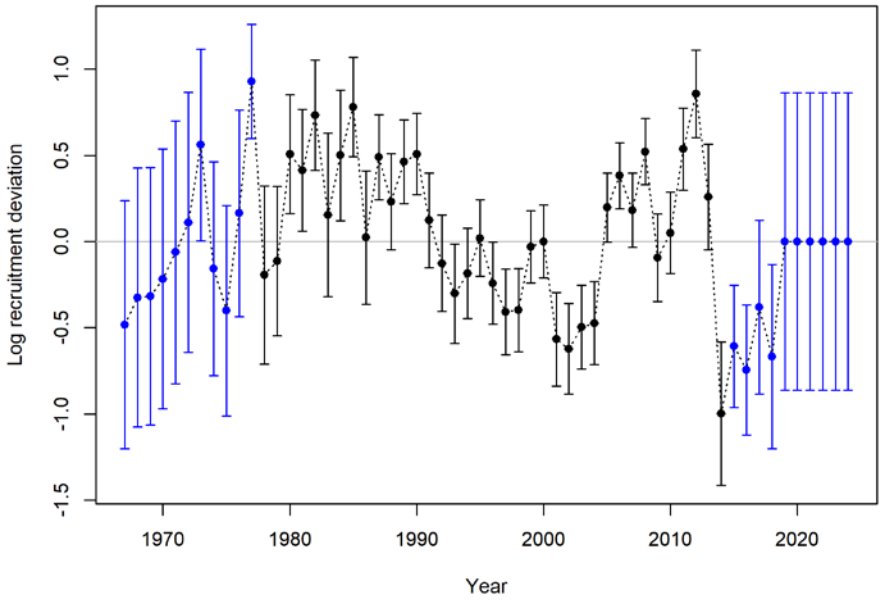


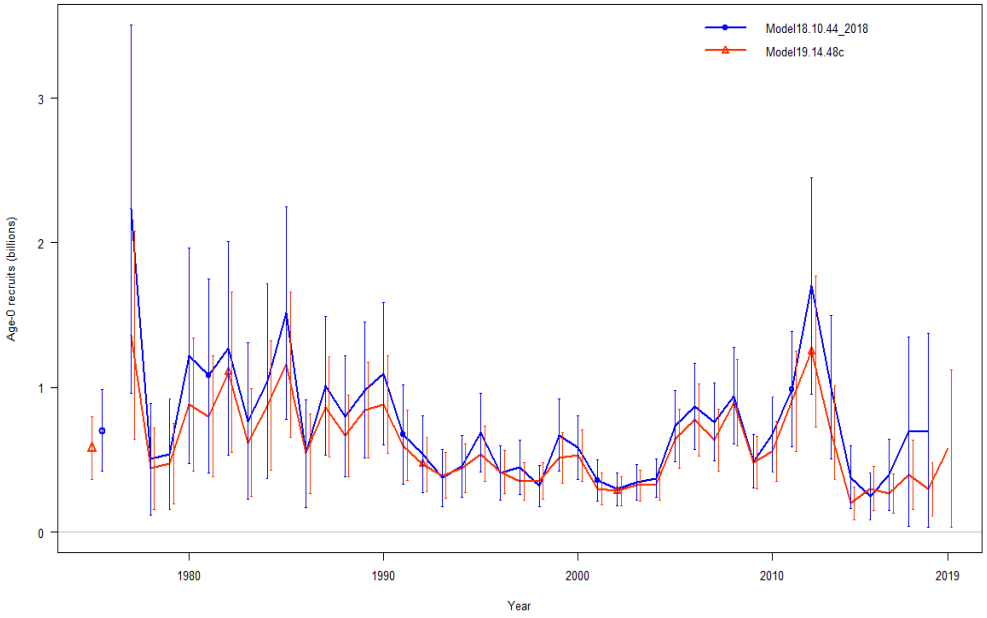
EM is impacting data availability



GOA Pacific cod Assessment Model Recruitment

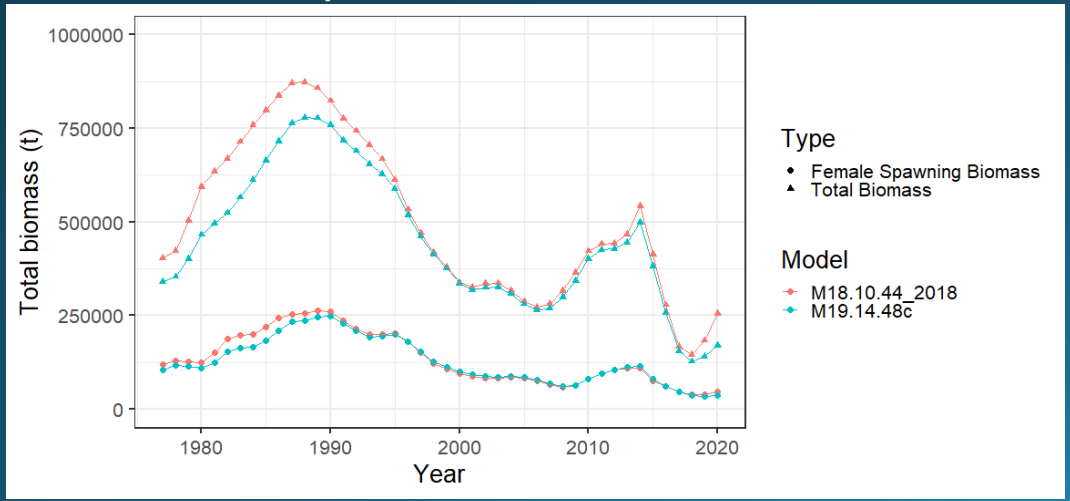
- Low recruitment in 2014-2018
  - 2014 lowest recruitment estimate in time series at 0.2×10^9
  - 2014 and 2016 through 2018 decreased in relative strength compared to last year's base model
  - 2015 increased in relative strength compared to last year's model

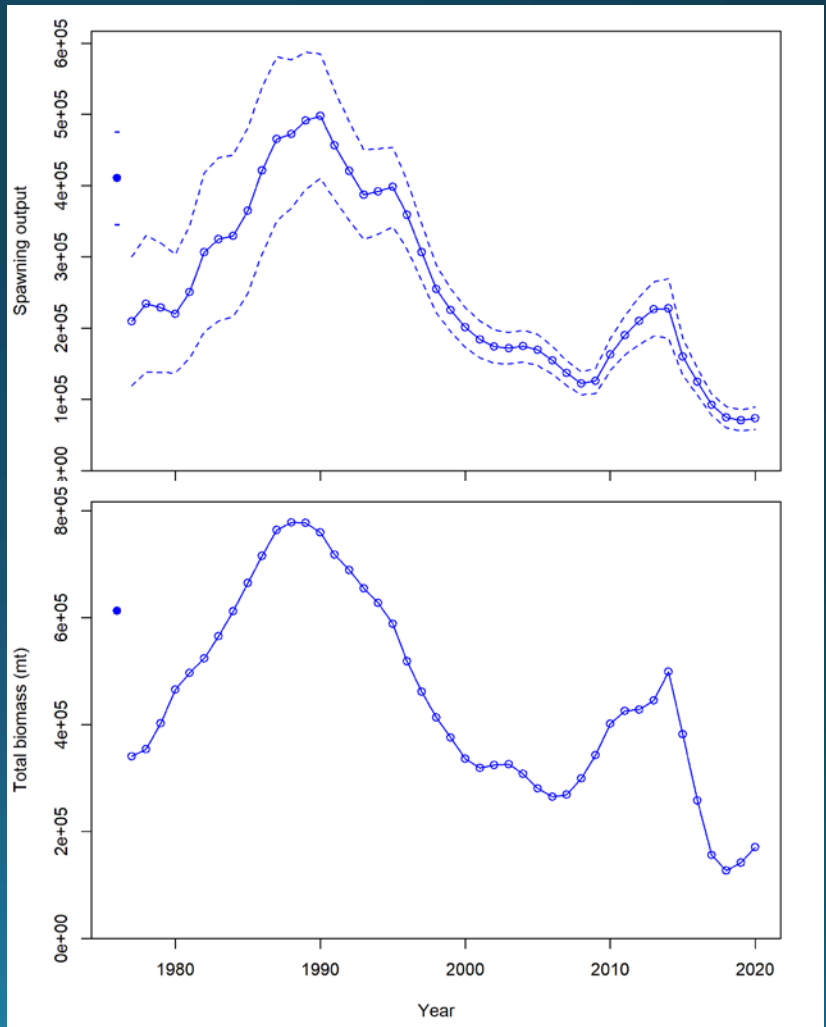




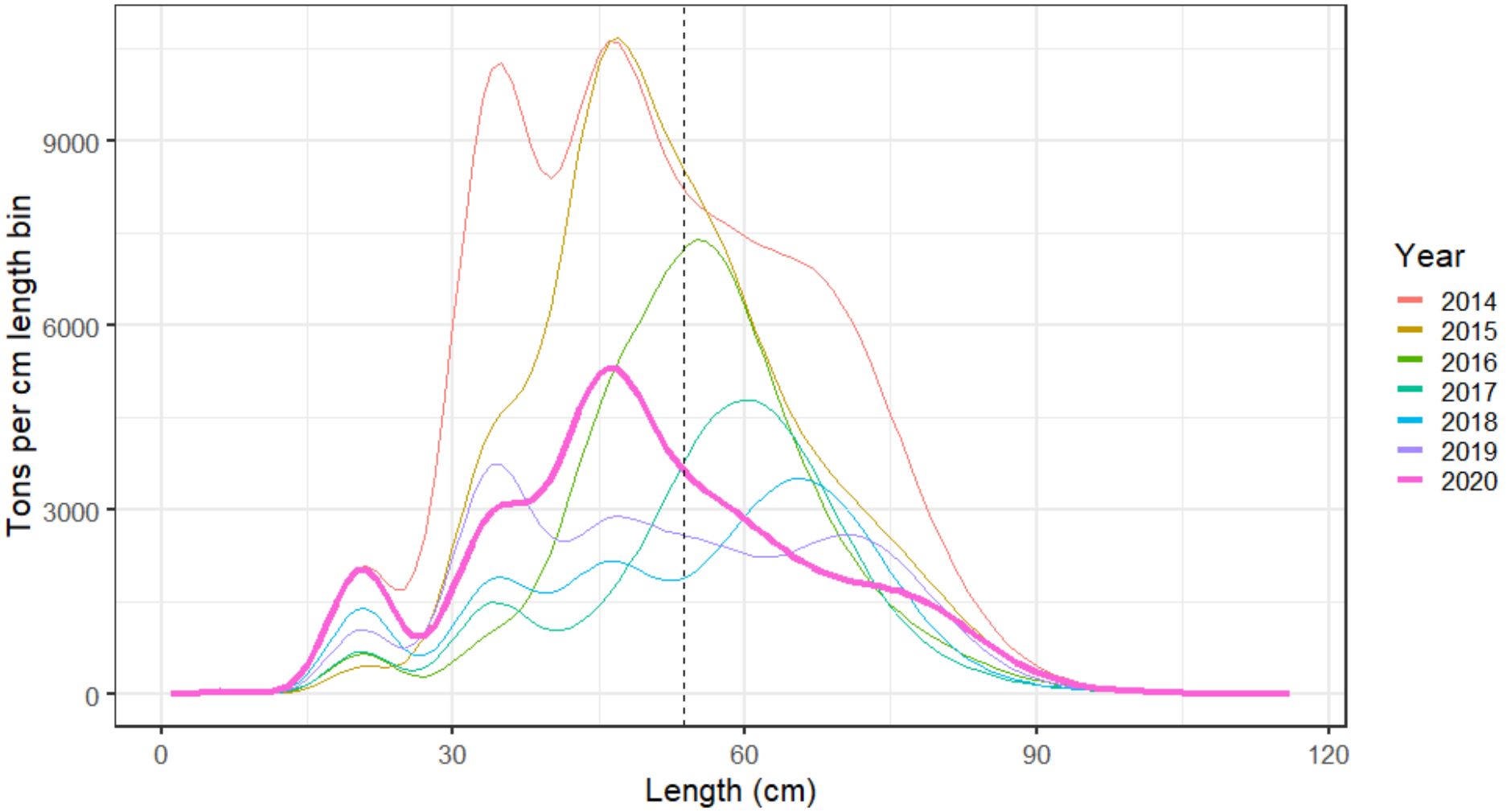
GOA Pacific cod
Assessment Model Spawning Biomass

- Lowest female spawning biomass in 2019 (32,231 t)
- Peak female spawning biomass in 1990 (248,915 t)
- 2018 previous low at 37,369 t
- Dipped to a low of 61,215 in previous low period in 2008
- Build up in 2009-2013 based on large 2005-2008 year classes
- Peak in 2014 total biomass due to large 2011-2012 year classes



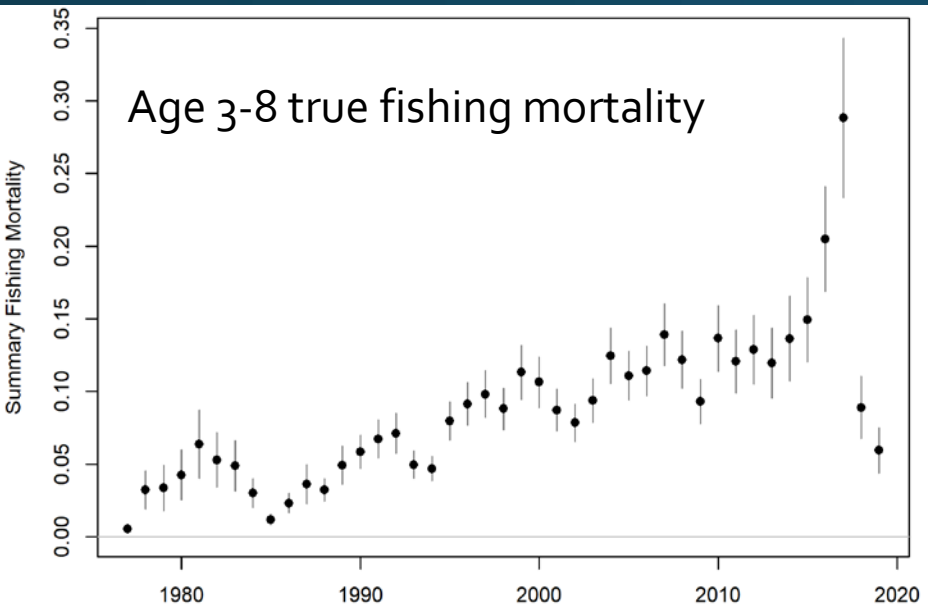


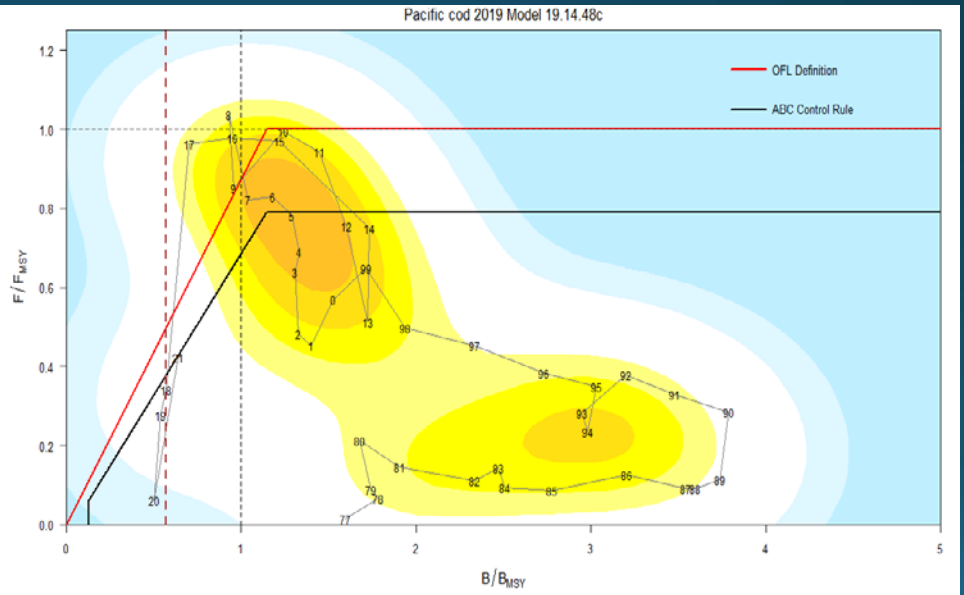
Total biomass by length



GOA Pacific cod
Model 19.14.48c Fishing mortality

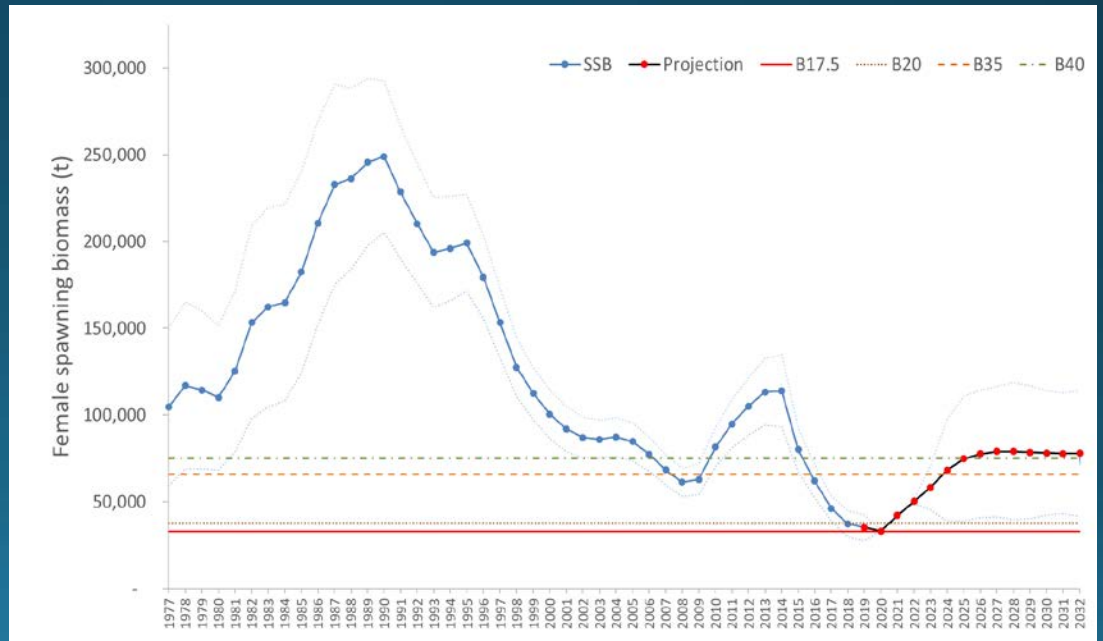
- Increasing trend in F over time until 2018
- Relatively high F 2016-2017
- Below $B_{20\%}$ for 2018-2020
- Projected to be above $B_{20\%}$ in 2021 under average conditions





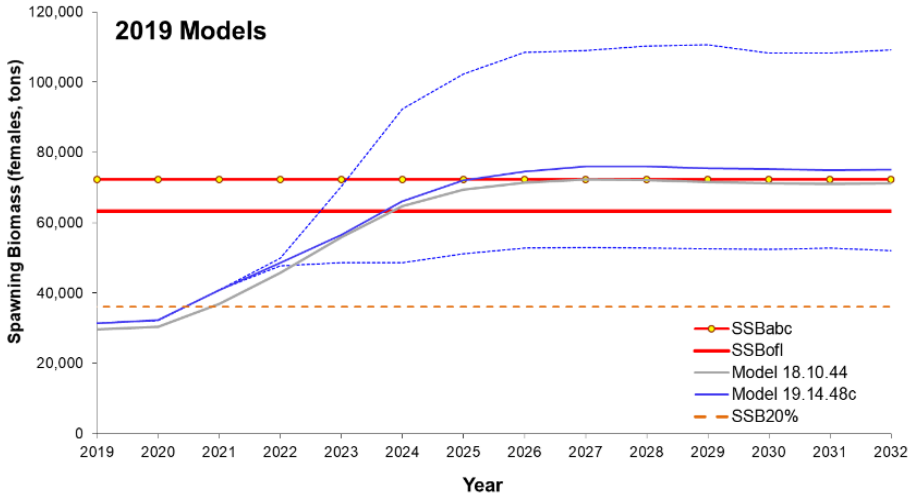
GOA Pacific cod Assessment Model Projections

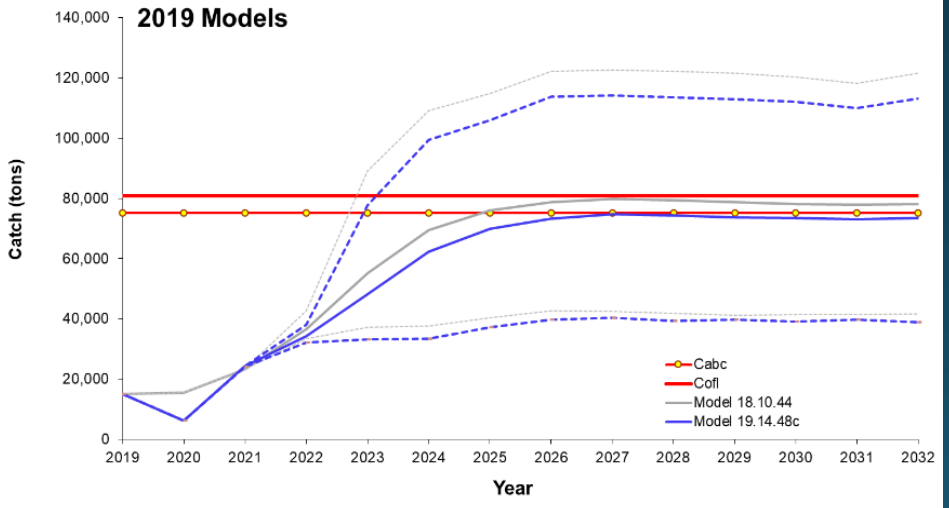
- Spawning biomass projected to reach all-time low in 2020
- Due to high mortality of the 2011 and 2012 age classes and expected poor recruitment 2014-2018
- First increase expected in 2021 given low fishing pressure
- Projection based on average recruitment after 2018



GOA Pacific cod Model 19.14.48c Projections

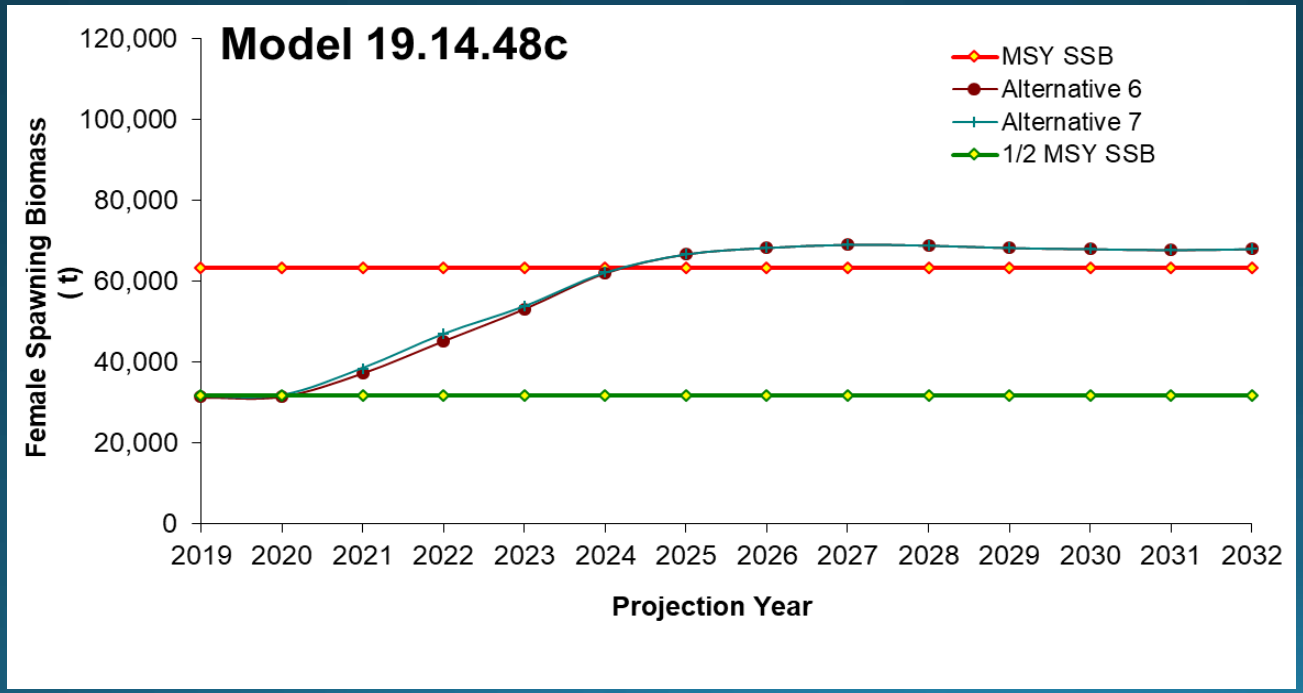
- Below $B_{20\%}$ in 2020
- Adjusted catch to 6,300 t in 2020
  - 3,300t state fishery and
  - 3,000 t as bycatch in other fisheries



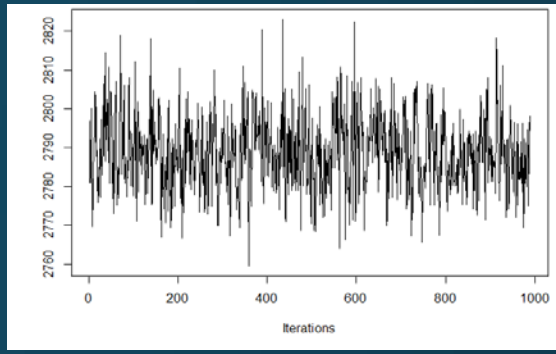


GOA Pacific cod Model 19.14.48c Projections

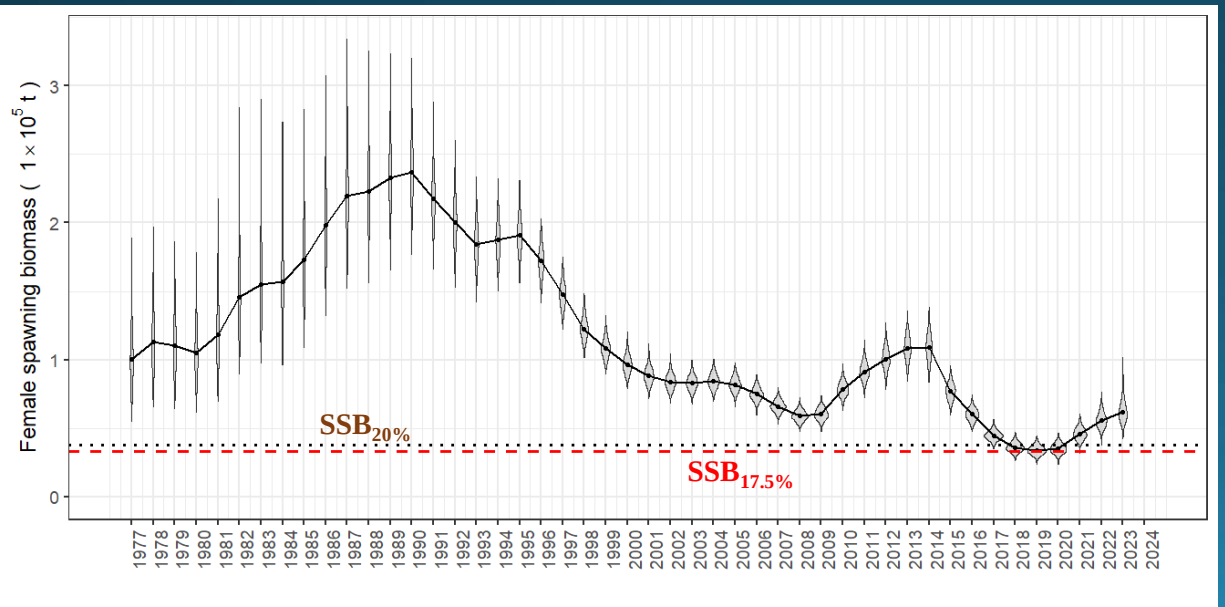
- Above $B_{17.5\%}$ in 2019 and 2020
- Above $B_{35\%}$ by 2029 and 2031
- Not overfished, not overfishing…

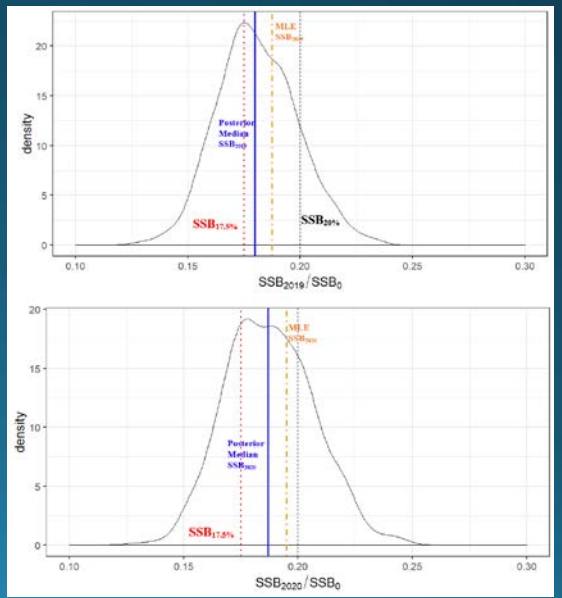


M19.14.48c- MCMC



- Well behaved posteriors
  - 1,000,000 iterations (150,000 burn in and thinned by 1,000)
- Results
  - 85.3% probability of being ≤ $B_{20\%}$ in 2019
  - 39.8% probability of being ≤ $B_{17.5\%}$ in 2019
  - 73.3% probability of being ≤ $B_{20\%}$ in 2020
  - 27.7% probability of being ≤ $B_{17.5\%}$ in 2020





GOA Pacific cod Dorn risk matrix

Assessment-related considerations	Population dynamics considerations	Environmental/ ecosystem considerations	Fishery Performance	Overall score (highest of the individual scores)
Level 2: Substantially increased	Level 2: Substantially increased	Level 2: Substantially increased	Level 1: Normal	Level 2: Substantially increased

Assessment - Level 2:

- Modeling uncertainty in the early recruitment estimates and model sensitivity relative to other North Pacific assessments where this is not an issue.

Population dynamics – Level 2:

- With average recruitment it is expected that the stock status will improve, however there are indications that 2019 recruitment is well below average.

Environment – Level 2:

- Conditions in 2017 and early 2018 appeared to have improved
- Currently experiencing heatwave (10 Sept 2018 – present)

- Fishery Performance – Level 1:
  - Mixed signals

GOA Pacific cod Status

- $B_{2020} = B_{17.6\%}$
- $B_{2021} = B_{22.4\%}$

- Below $B_{20\%}$ requires shutting down of directed fisheries for SSL concerns in 2020

- MaxABC recommendation at 14,621 t for 2020
- MaxABC recommendation at 24,820 for 2021

- All projections here assume 6,300t of catch in 2020
  - (3,300 t state fishery and 3,000 t bycatch in other fisheries)

- Area apportionment based on random effects model

Authors' recommended Model 19.14.48c

Quantity	As estimated or *specified last* year for: 2019	2020	As estimated or *specified this* year for: 2020	2021
M (natural mortality rate)	0.50	0.50	0.49	0.49
Tier	3b	3b	3b	3b
Projected total (age 0+) biomass (t)	207,198	266,066	203,373	261,484
Female spawning biomass (t)				
Projected	34,701	34,774	32,958	42,026
$B_{100\%}$	172,240	172,240	187,780	187,780
$B_{40\%}$	68,896	68,896	75,112	75,112
$B_{35\%}$	60,284	60,284	65,723	65,723
F_{OFL}	0.36	0.36	0.27	0.36
$maxF_{ABC}$	0.29	0.29	0.22	0.29
F_{ABC}	0.25	0.29	0.22	0.29
OFL (t)	23,669	26,078	17,794	30,099
maxABC (t)	19,665	21,592	14,621	24,820
ABC (t)	*17,000	21,592	**14,621	**24,820

	Western	Central	Eastern	Total
Random effects area apportionment (last year)	22.7% (44.9%)	70.6% (45.1%)	6.7% (10.0%)	100%
2020 ABC	3,319	10,322	980	14,621
2021 ABC	5,634	17,523	1,663	24,820