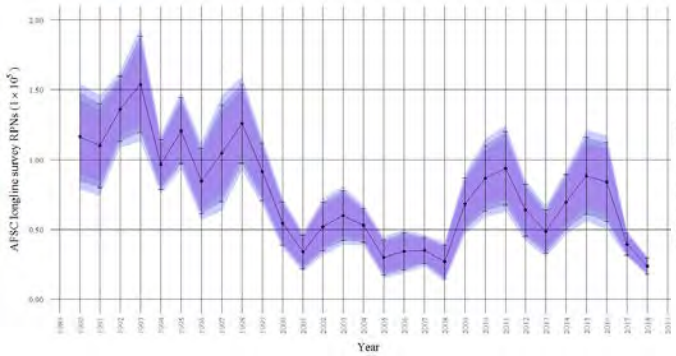
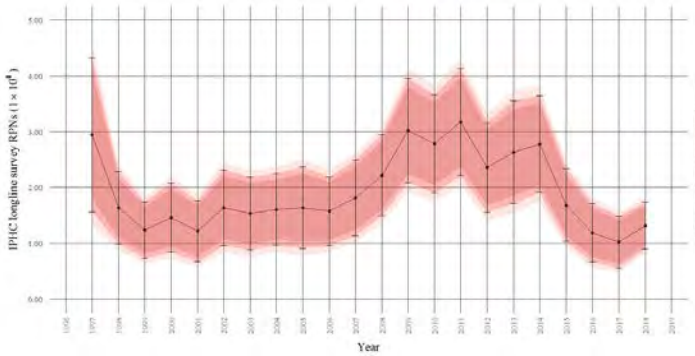
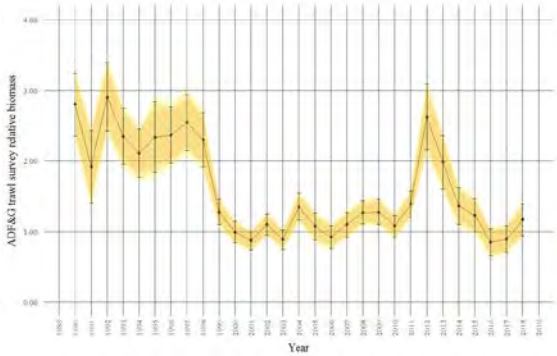
NOAA FISHERIES

2018 Gulf of Alaska Pacific cod

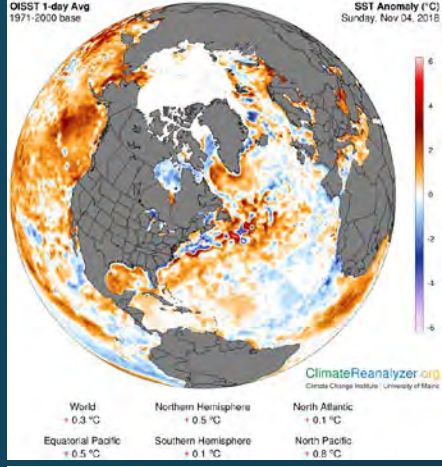
Steve Barbeaux, Kerim Aydin, Ben Fissel, Kirstin Holsman, Ben Laurel, Wayne Palsson, Laei Shotwell, Qiong Yang, and Stephani Zador

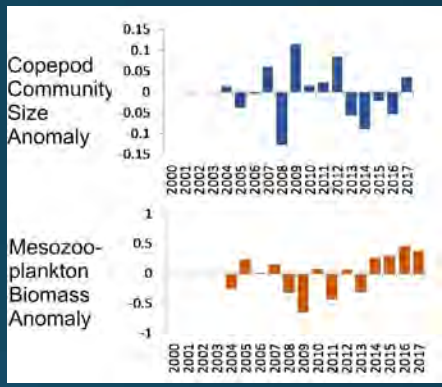




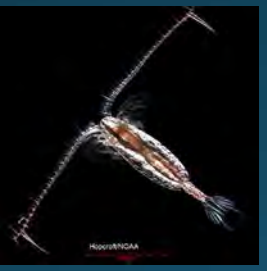


The environment 2018





- Two temperature indices
  - CFSR temperatures at depth
  - Marine Heatwave index
- Other indicators
  - Juvenile forage
    - Copepod community size anomalies were larger for the Alaskan Shelf and oceanic habitats in 2017
    - Biomass of copepods and euphausiids were above the long-term mean

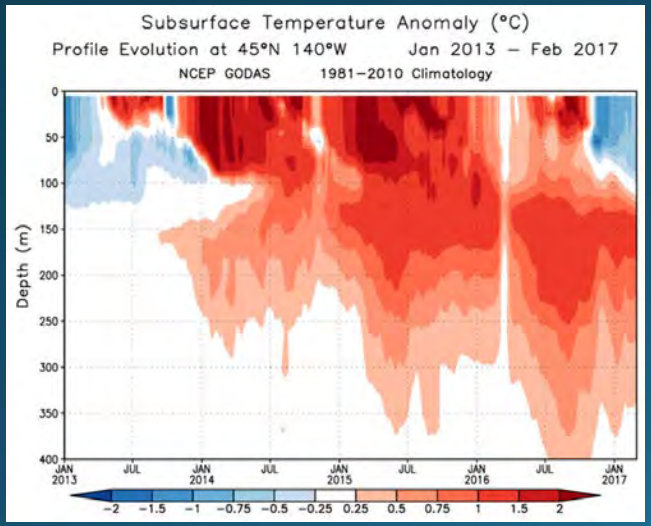


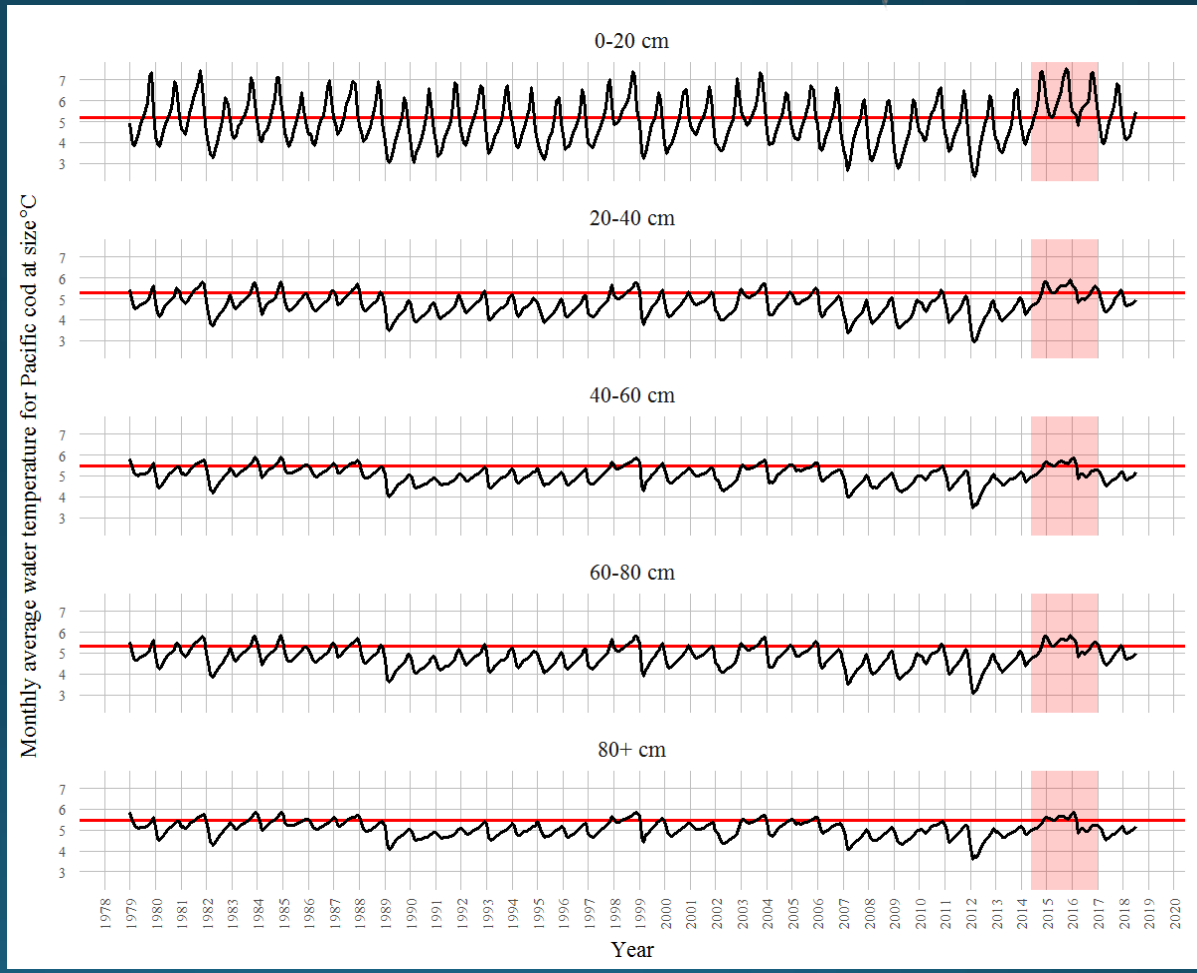
  - Foraging conditions for adult cod
    - Fish-eating seabirds in the Gulf of Alaska had generally normal reproductive success at monitored colonies in 2018.
    - Timing of breeding was normal for most species at Chowiet (Semidi Islands), late for murres at East Amatuli (Barren Islands), and late for murres and gulls at St. Lazaria (Southeast Alaska).

Anomalously warm waters 2014-2016

- Anomalously warm waters 2014-2016
- "Endless summer"
- Deep and continued throughout the year

- Cooler in 2017 and first half of 2018

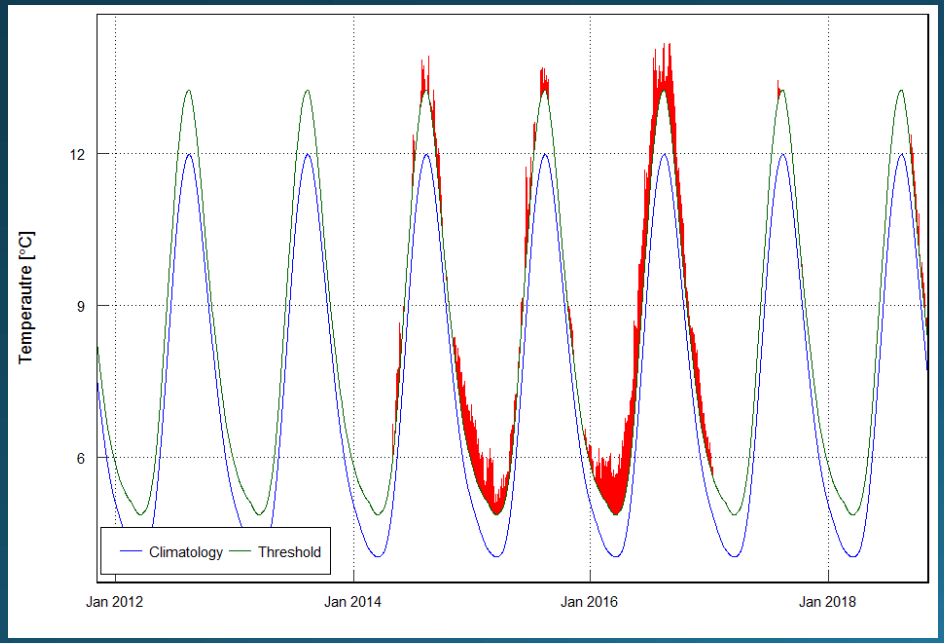


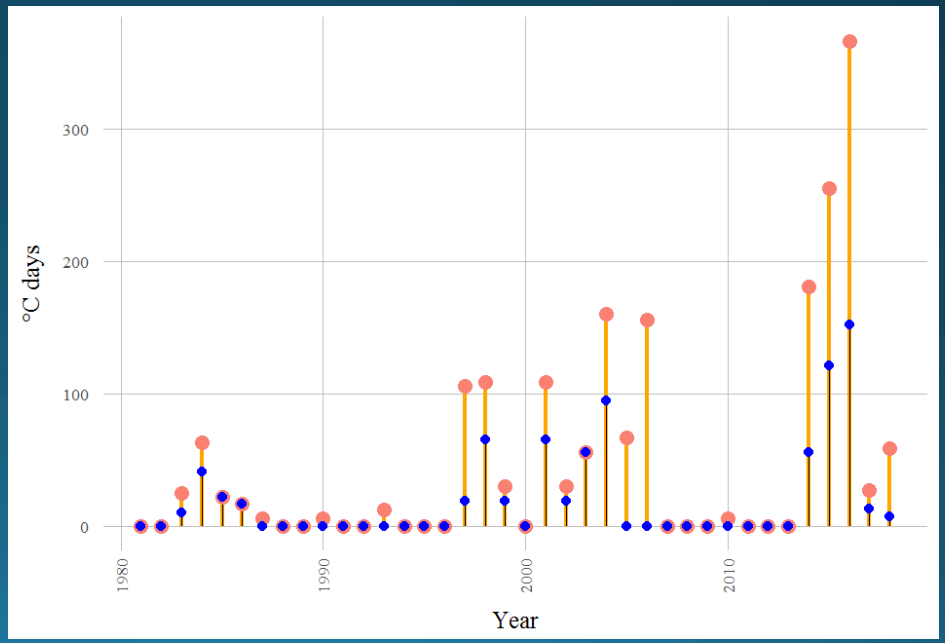


CFSR analysis by Qiong Yang, NPRB project 1509

Marine heatwave index

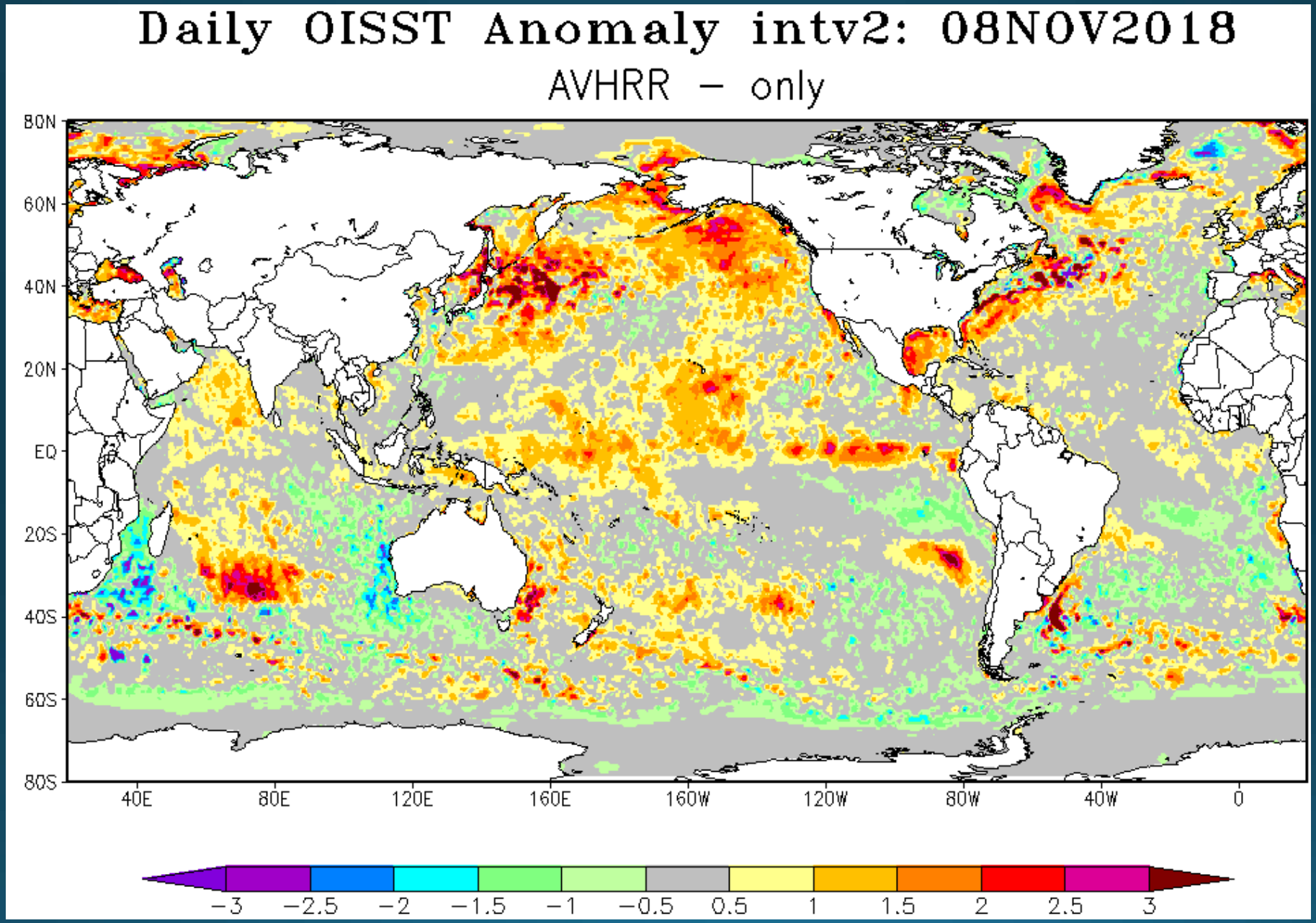
- NOAA high resolution blended analysis data for the Central GOA
  - Daily mean SST (1 September 1981 - 7 November 2018)
- Sum of the annual marine heatwave cumulative intensity (°C days)
  - 1983-2012 baseline
  - Above 90th percentile for more than 5 days
  - "Winter" defined as Jan-Mar and Nov-Dec for a given year





Hobday et al. (2018)

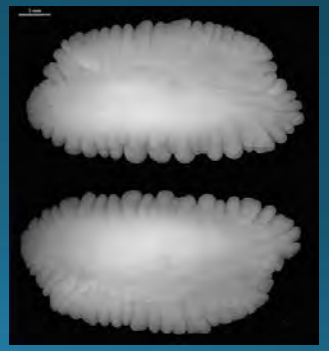
SST data through 11/7/2018



- **Heatwave in central GOA since September 10, 2018**
- **70-75% chance of El Niño in winter 2018-2019**

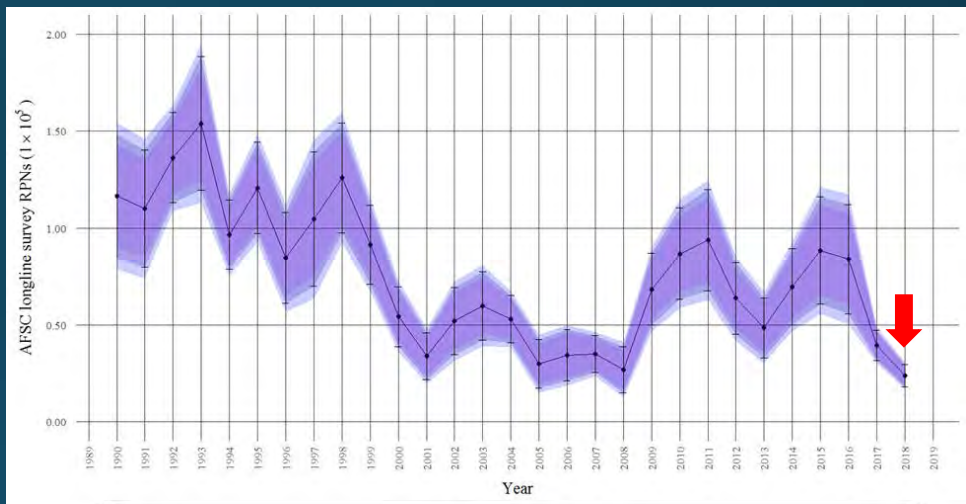
New data for 2018 in assessment model

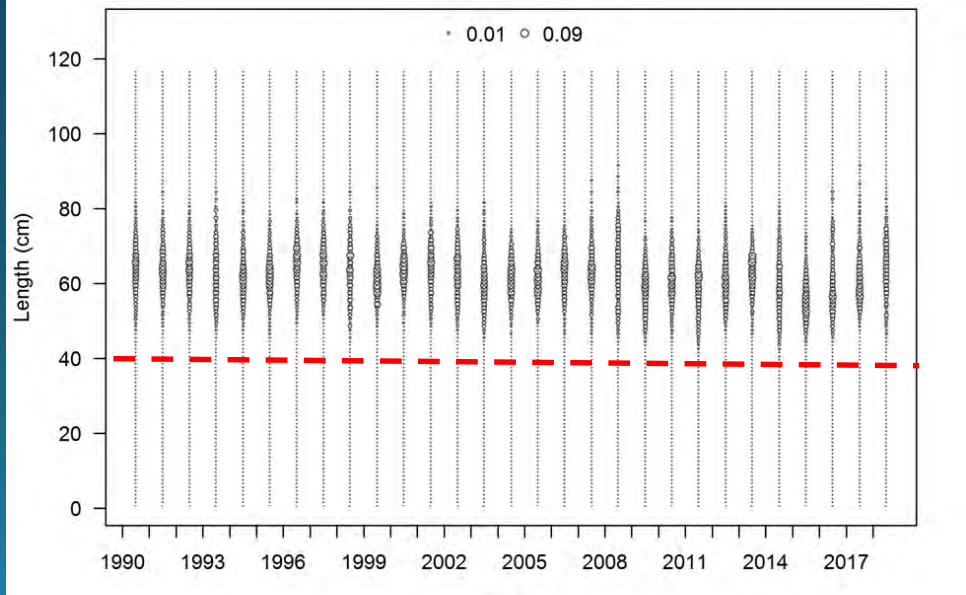
- 2018 AFSC longline survey
  - RPN Index 1990-2018
  - Length composition
- 2012-2017 Fishery age composition and length at age
- 2017-2018 Fishery catch and length composition
- 2017 AFSC bottom trawl survey age composition and length at age



AFSC longline survey

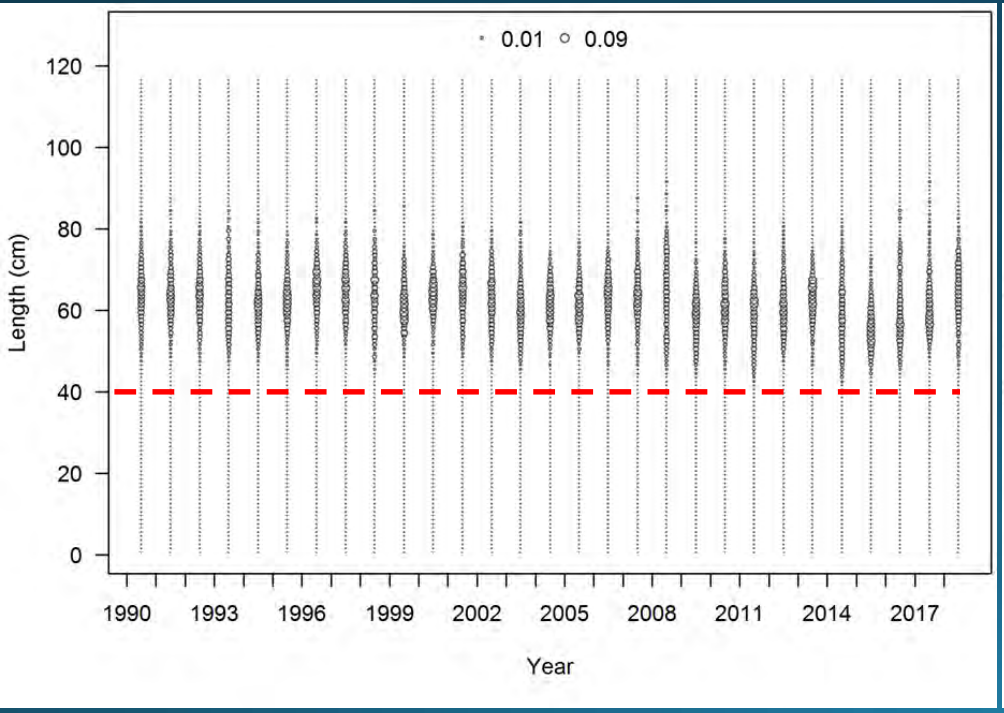
- 2018 Lowest index value in series
  - 23,853 RPN
  - 40% decline from 2017
- Survey of large cod
  - Deep > 150 m depth
  - > ~40 cm

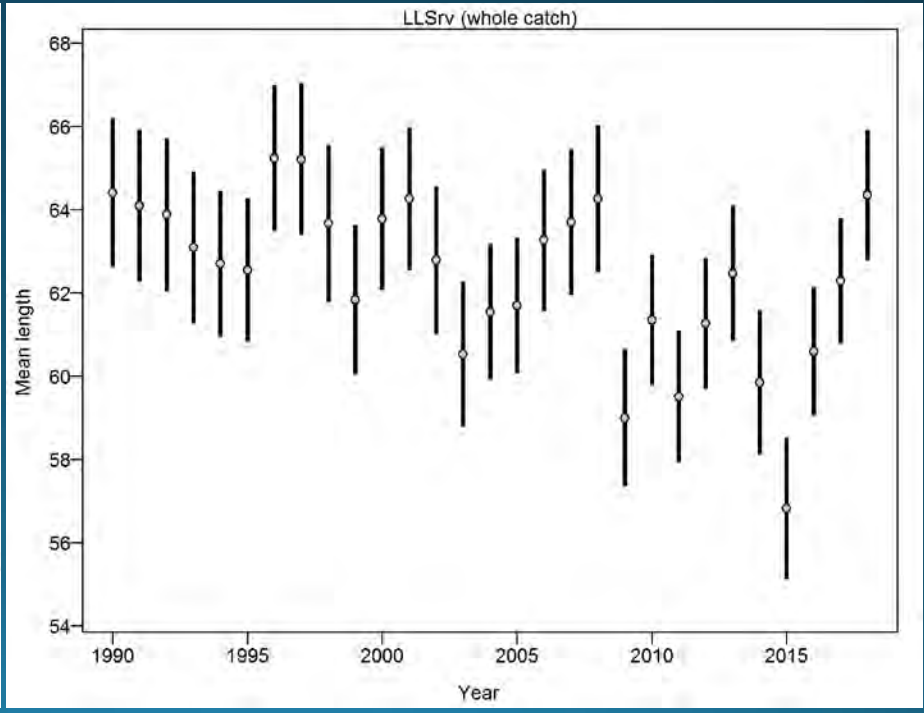




AFSC longline survey – Length composition

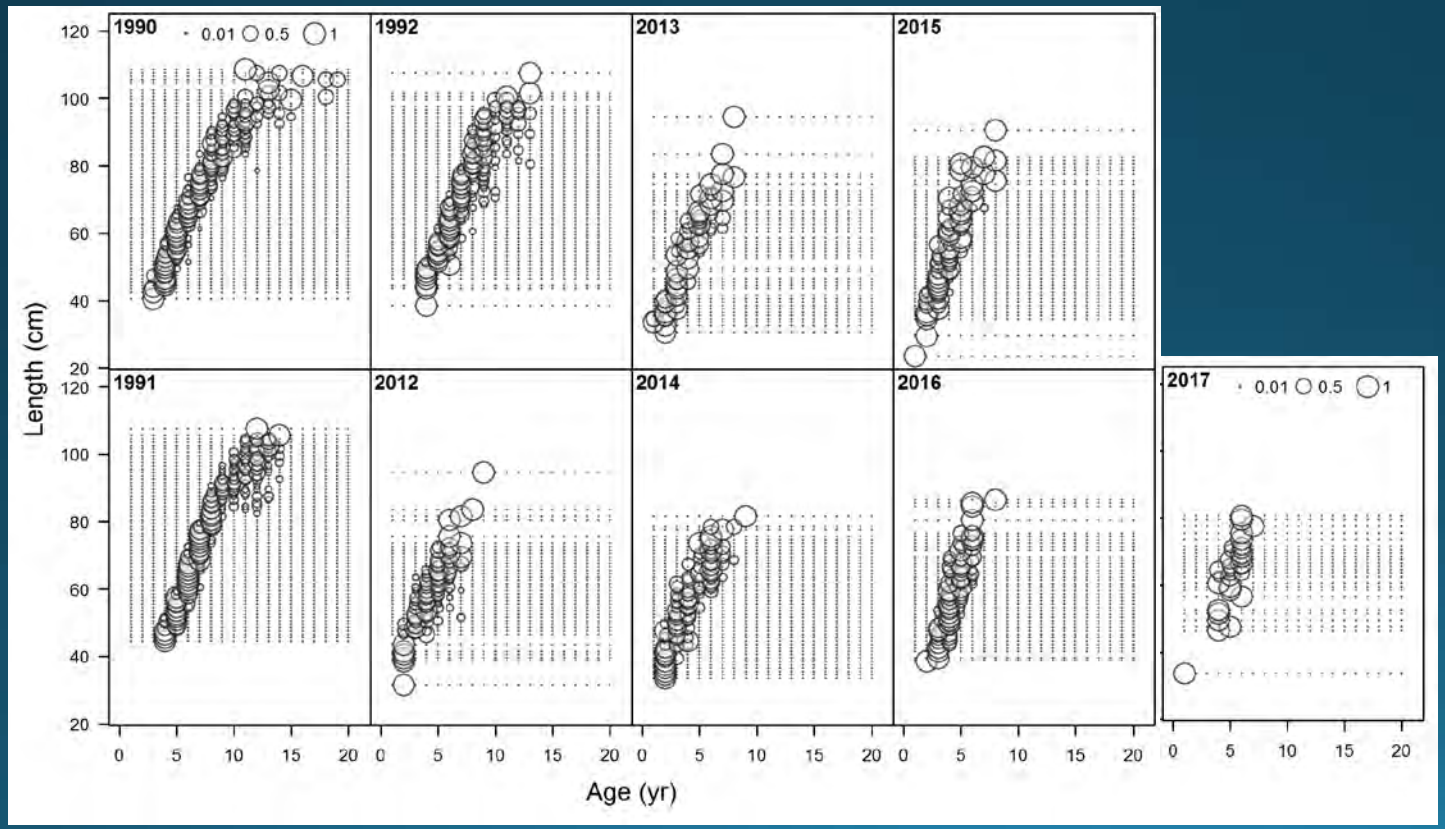
- Sharp increase in mean length post heatwave





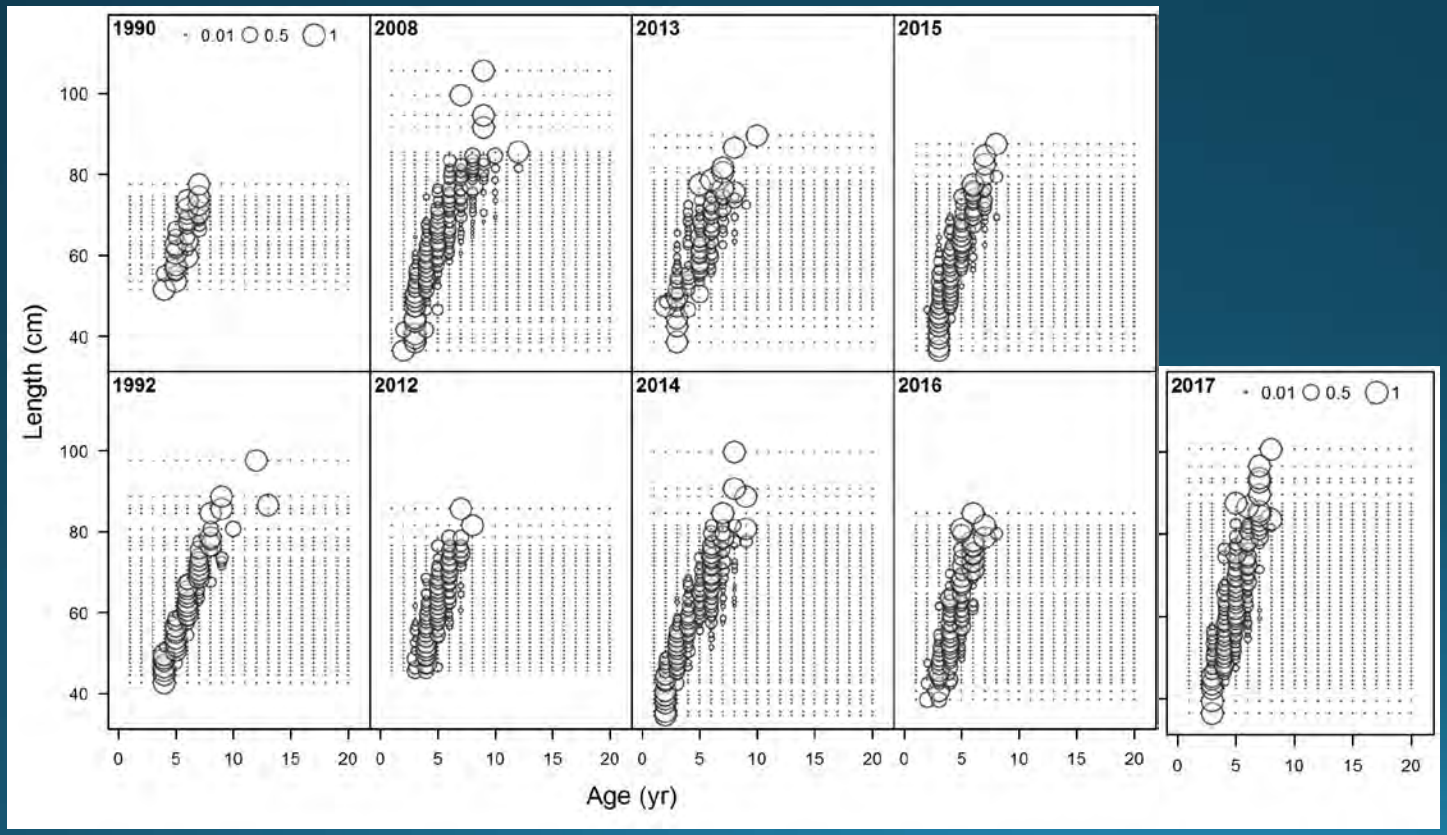
Fishery age data – Trawl fishery

- 1990-1992 were length stratified samples, resulting in more large fish, aged older.
- No fish older than 10 in new collections/age methods



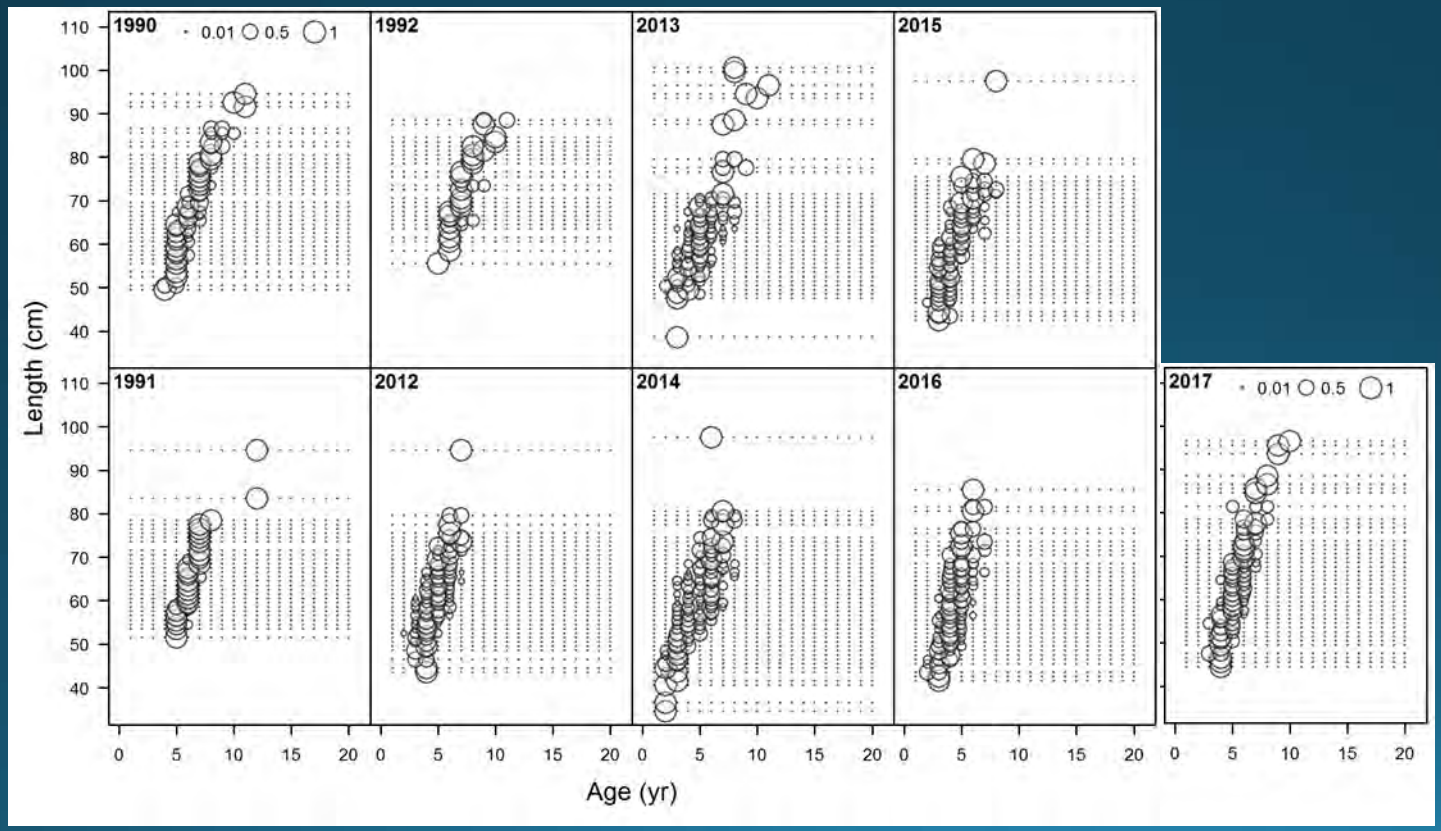
Fishery age data – Longline fishery

- Larger fish than trawl fishery
- Few fish older than 10



Fishery age data – Pot fishery

- Broader age-at-length in general than other fisheries

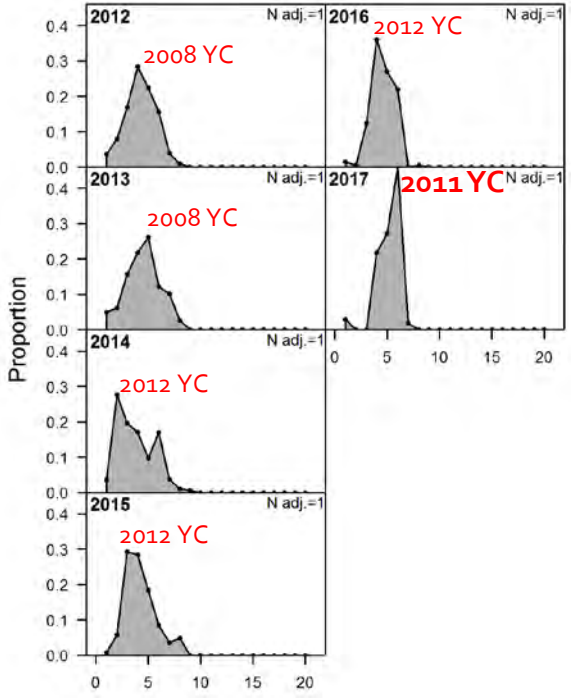


Fishery age composition data

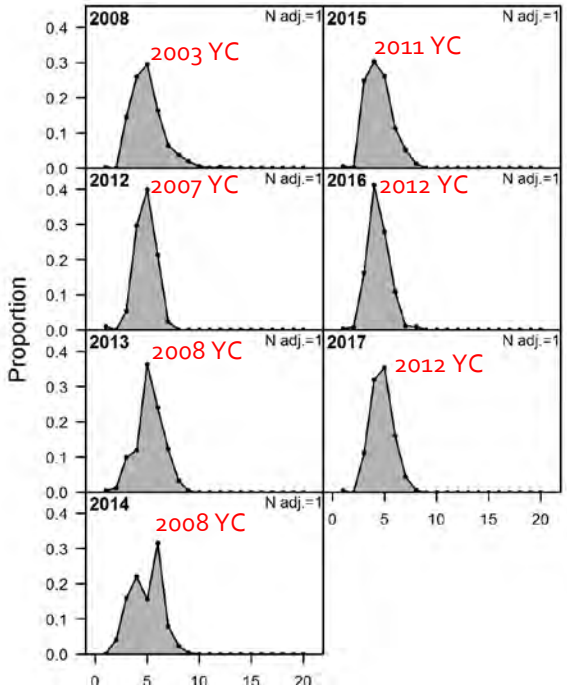
- Based on annual fishery-specific age-length key

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

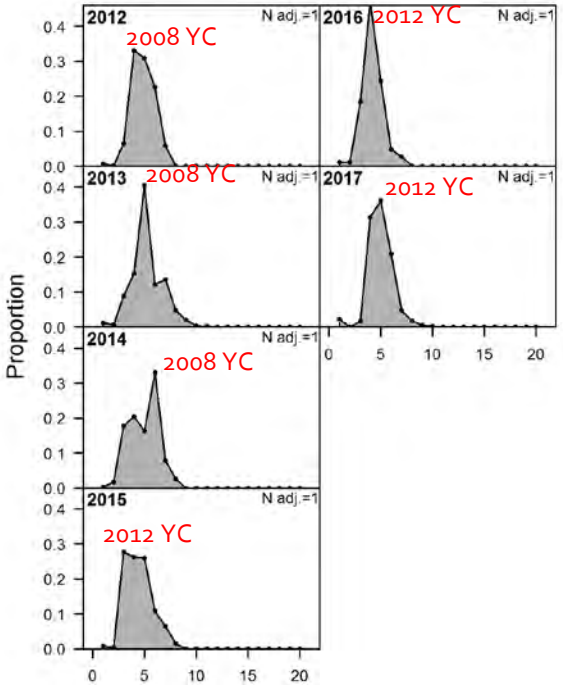
Trawl



Longline



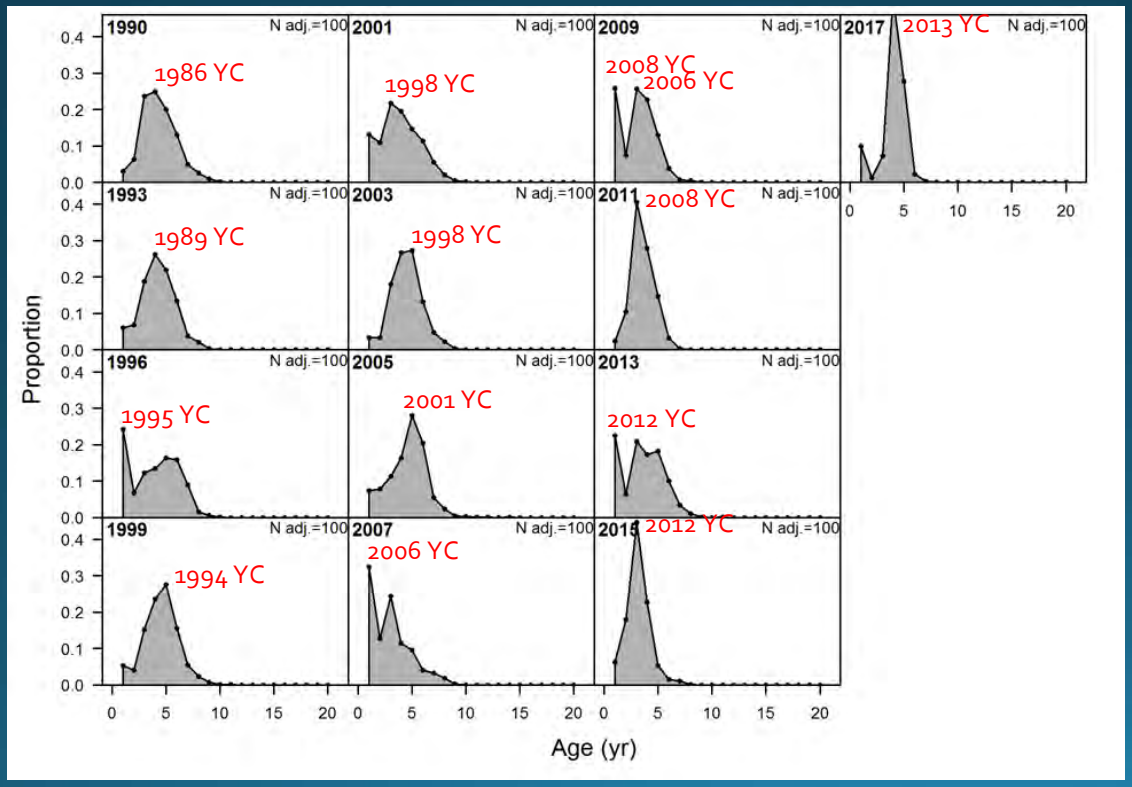
Pot



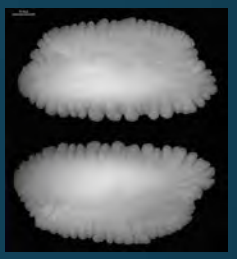
Survey age composition 1990-2017

- 2017 new to this assessment
  - Large 2013 and 2012 year classes
  - 2016 year class apparent

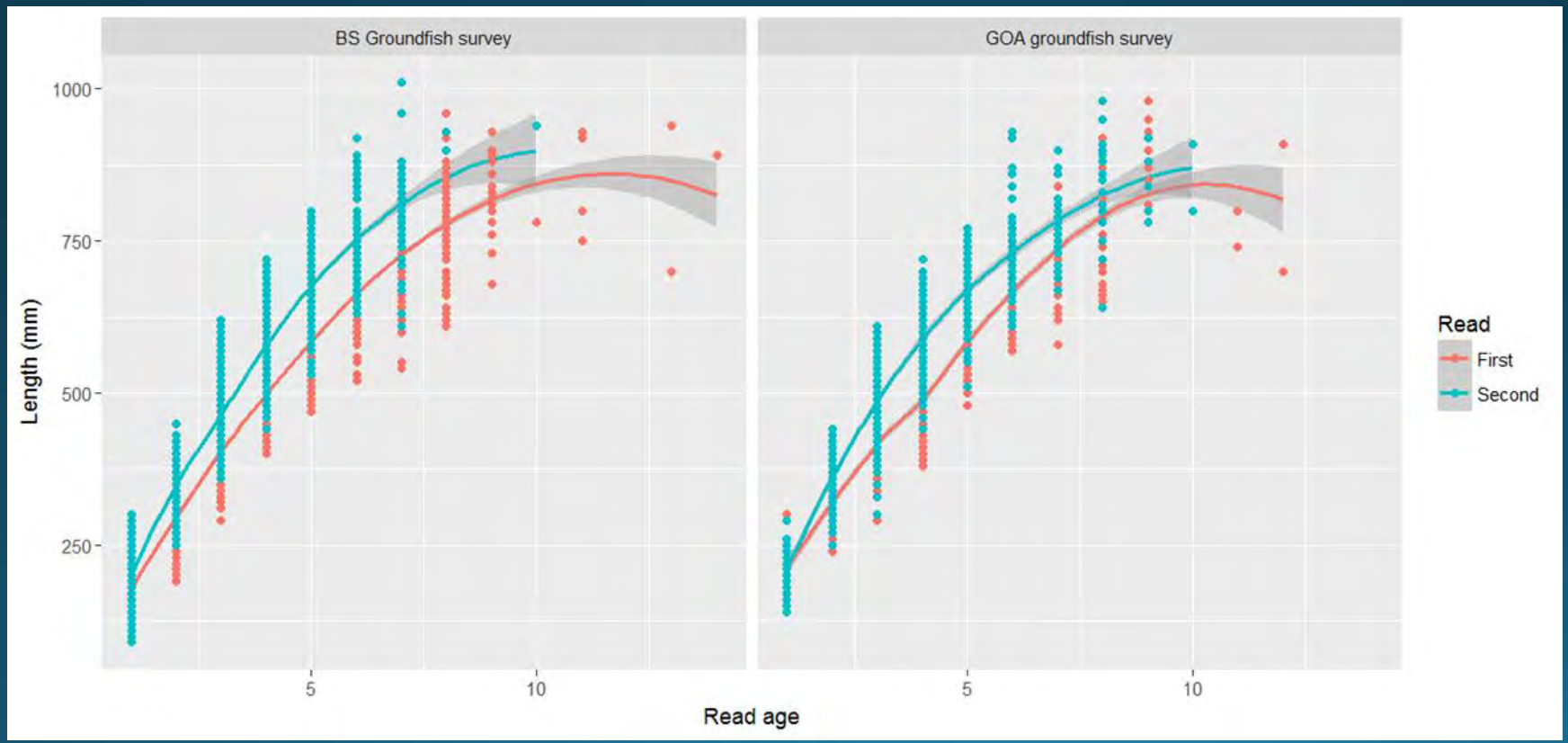
Note that in the Bering Sea large year classes are 2011 and 2013



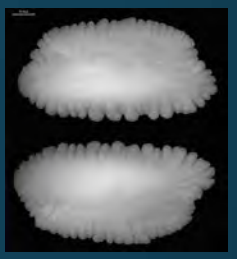
Aging Bias



- Reread of Stark (2007) ages
  - Consistent and significant change in age for ages 2-9
  - No fish aged greater than 10 in new aging methods
  - Consistent with bias found by Kastelle *et al.* (2017)

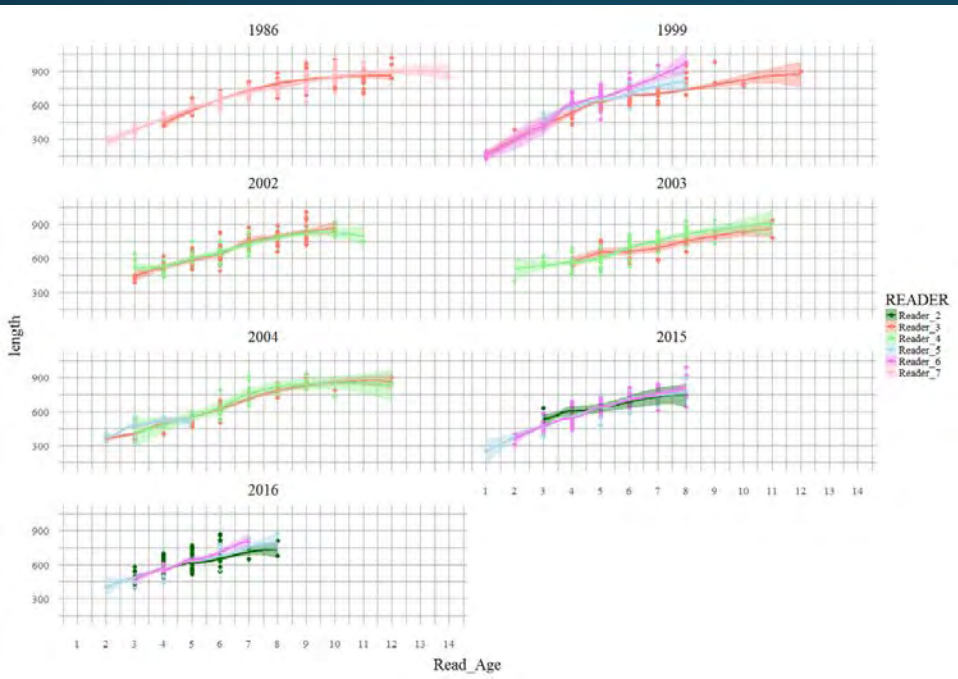


Aging bias - GOA specific

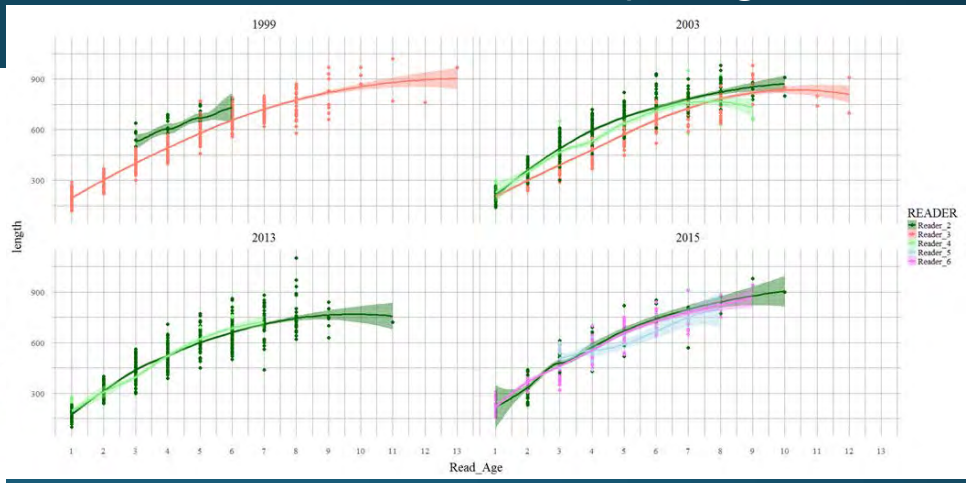


- Reader comparison where there were more than one reader for a single collection
  - Apparent age reader effect
  - Potential seasonal effect on bias

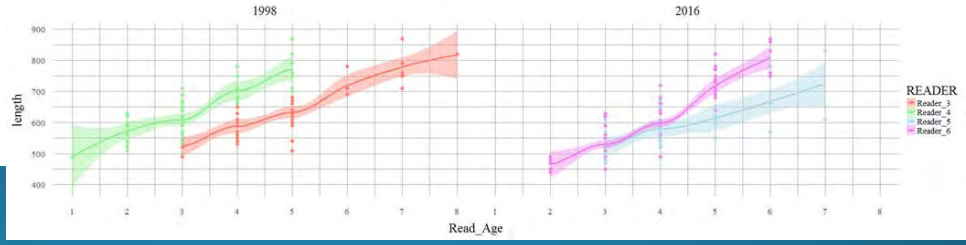
1st Trimester Jan-April



2nd Trimester May - Aug



3rd Trimester Sep - Dec



New ancillary data for 2018

- 2018 IPHC longline survey
  - RPN Index
  - Length composition
- 2018 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 at length
- Laval surveys
  - 2017 Icthyoplankton survey
  - 2018 GOA beach seine studies
- Genetics and tagging

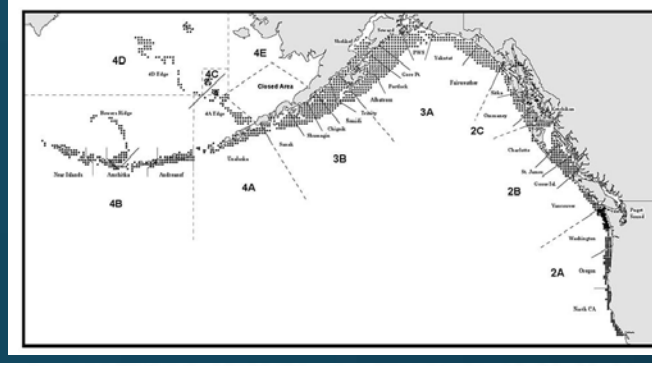
INTERNATIONAL PACIFIC HALIBUT COMMISSION

ALASKA DEPARTMENT OF FISH AND GAME

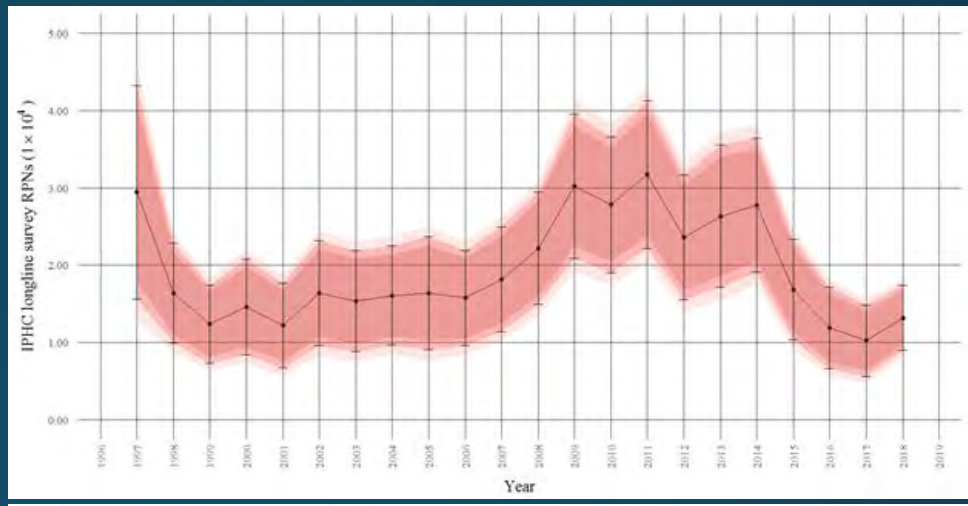
EcoFOCI
Ecosystems & Fisheries-Oceanography Coordinated Investigations

NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION U.S. DEPARTMENT OF COMMERCE

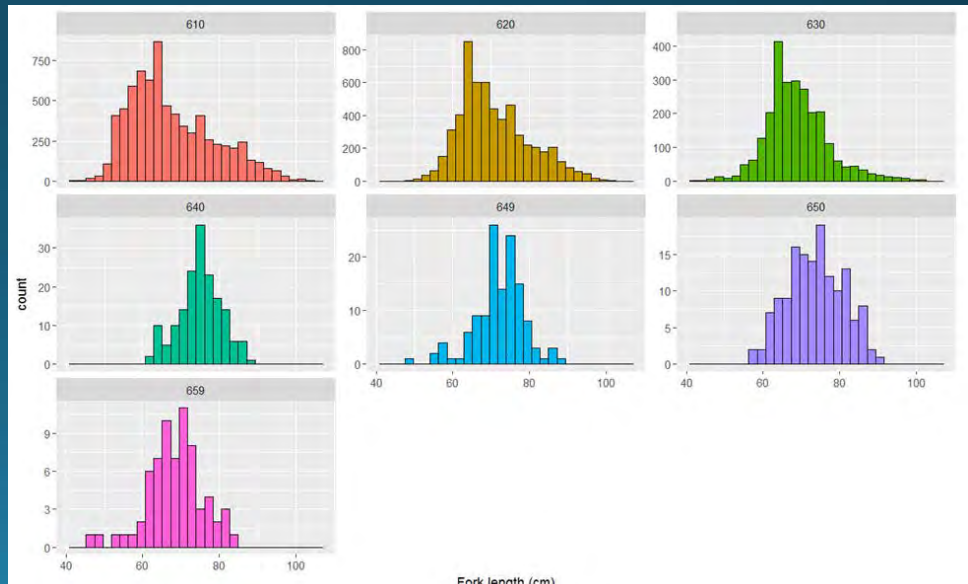
IPHC longline survey 1997-2018



- Surveys GOA shelf area
  - Comparable to AFSC bottom trawl survey
  - 2017 lowest in time series
  - 29% increase from 2017 to 2018

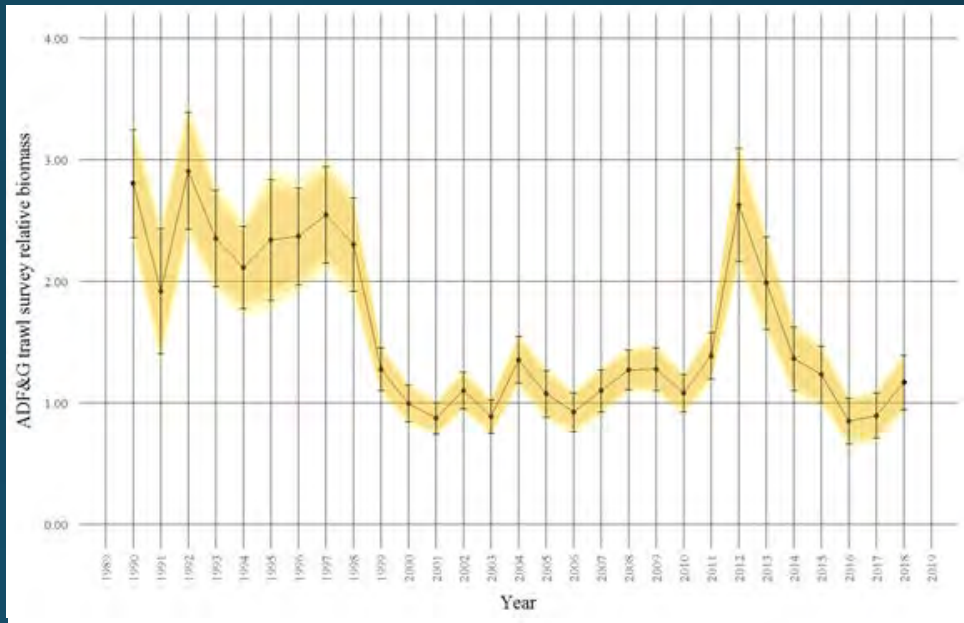


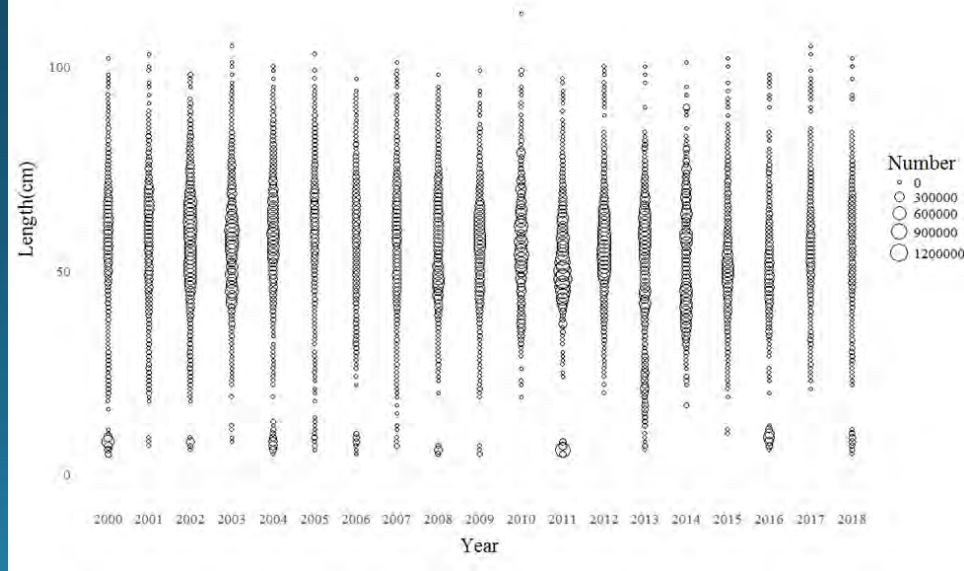
- Size composition for cod not collected until 2018



ADF&G large-mesh trawl survey 1990-2018

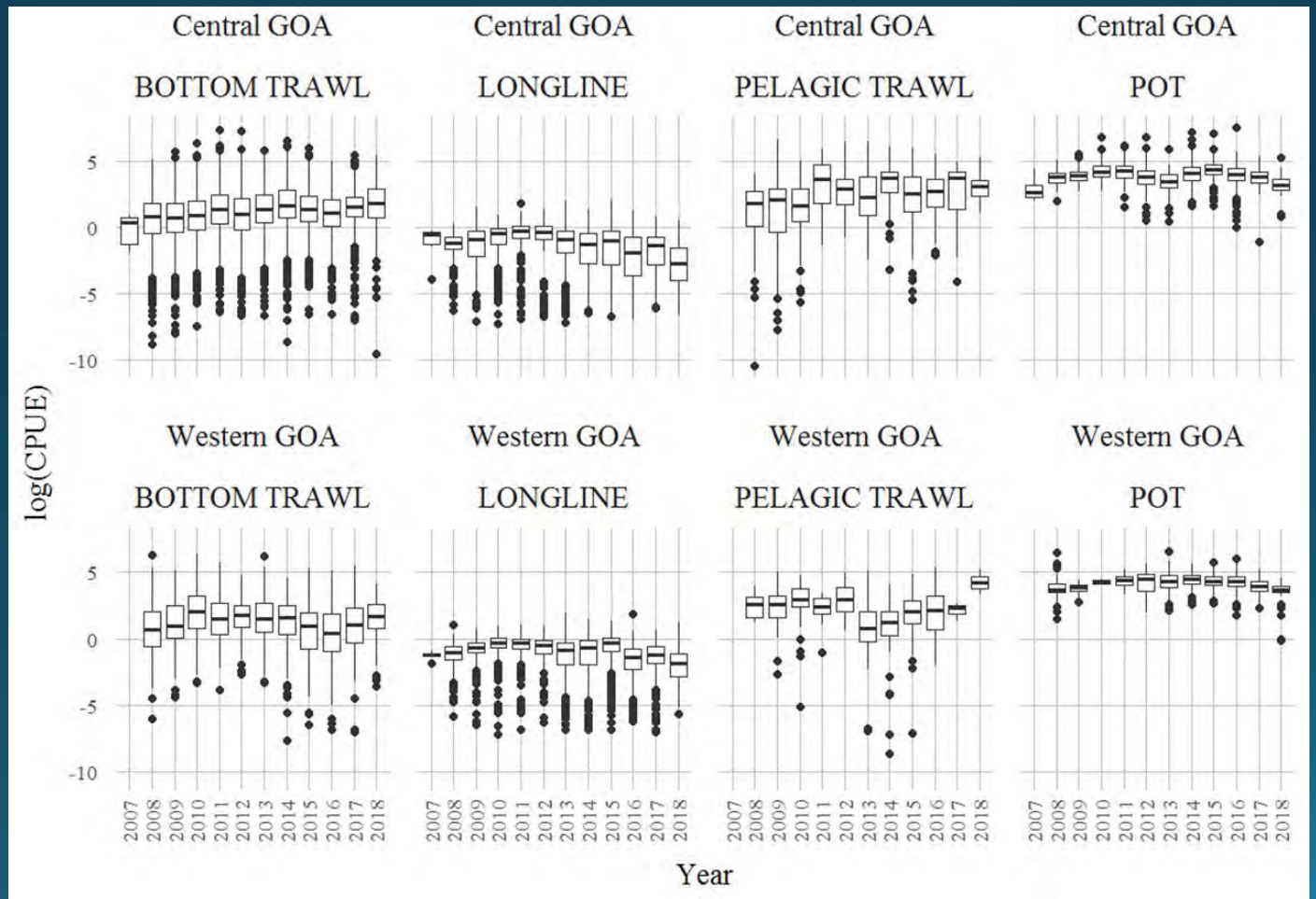
- Generally near-shore
- Random-effects model used for index
- 2016 lowest relative biomass estimate in series
- 30% increase from 2017 to 2018





Directed fishery CPUE

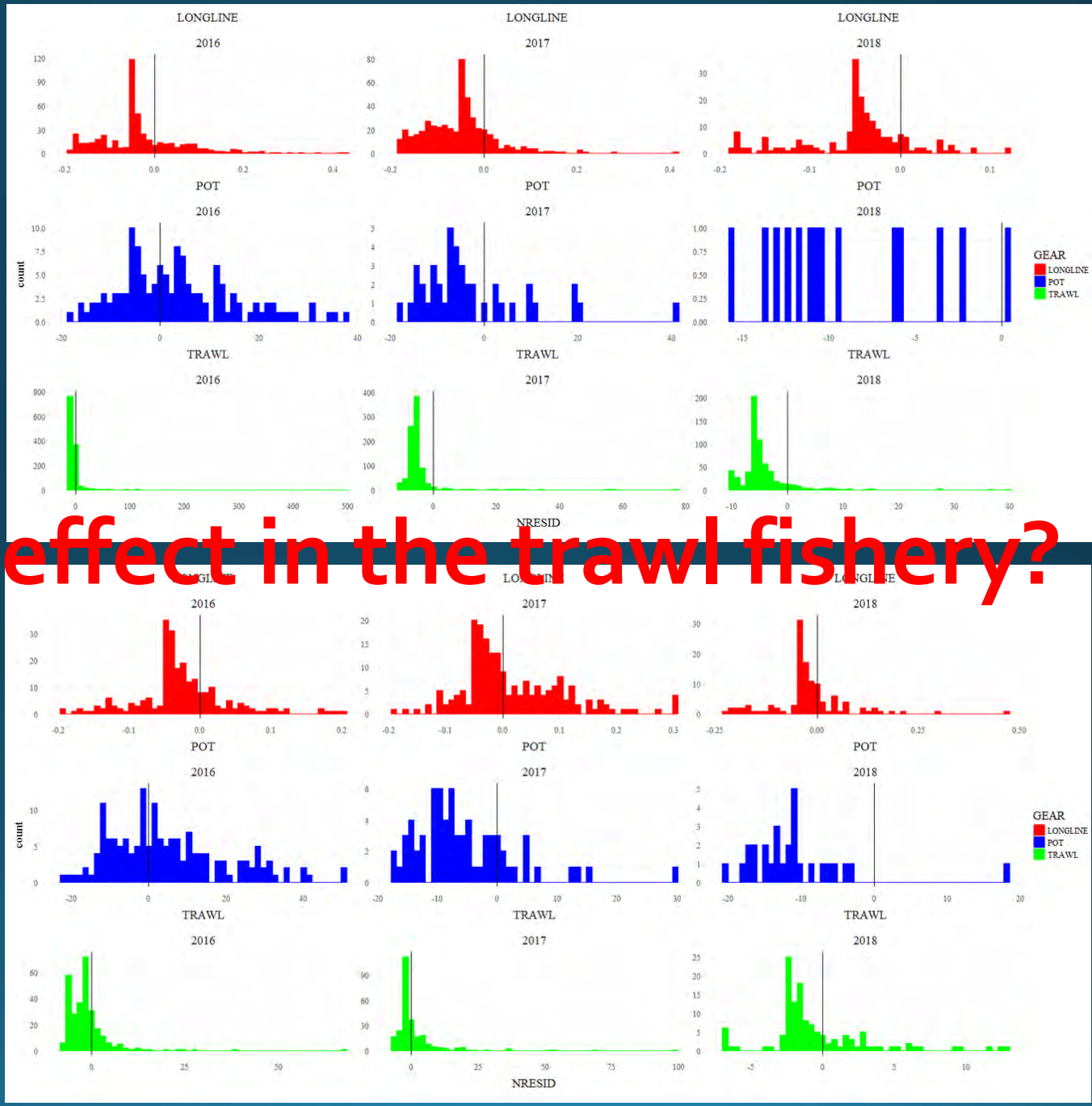
- 2018 mixed signals
  - Longline and Pot CPUE down
  - Trawl CPUE good to best ever…



- Central GOA CPUE
  - Bulk of hauls are below the long-term mean
  - Long tail on trawl fishery pulls median higher

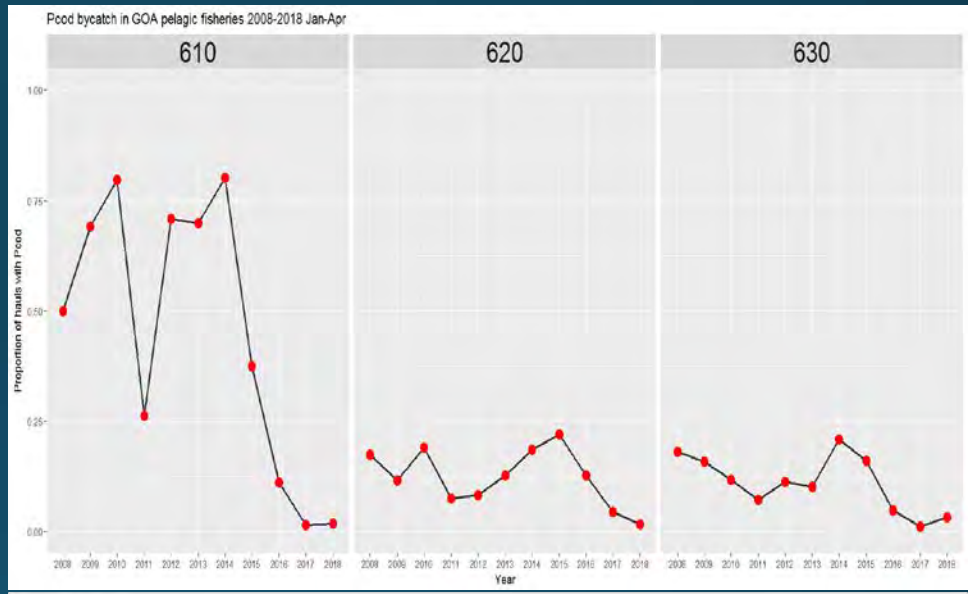
Highliner effect in the trawl fishery?

- Western GOA CPUE
  - Similar to Central GOA

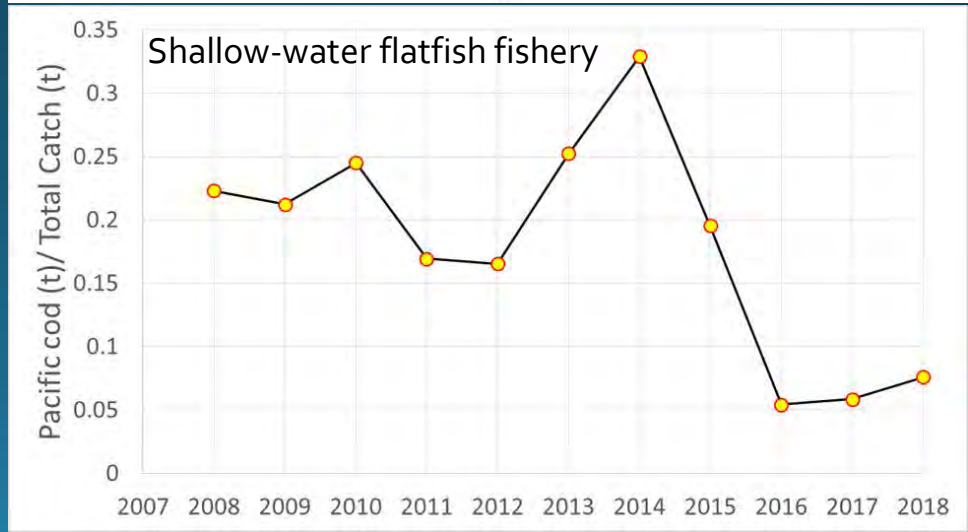


Bycatch rates in pollock and shallow-water flat fisheries

- Encounter rate in pelagic pollock fishery is a mixed signal depending on area

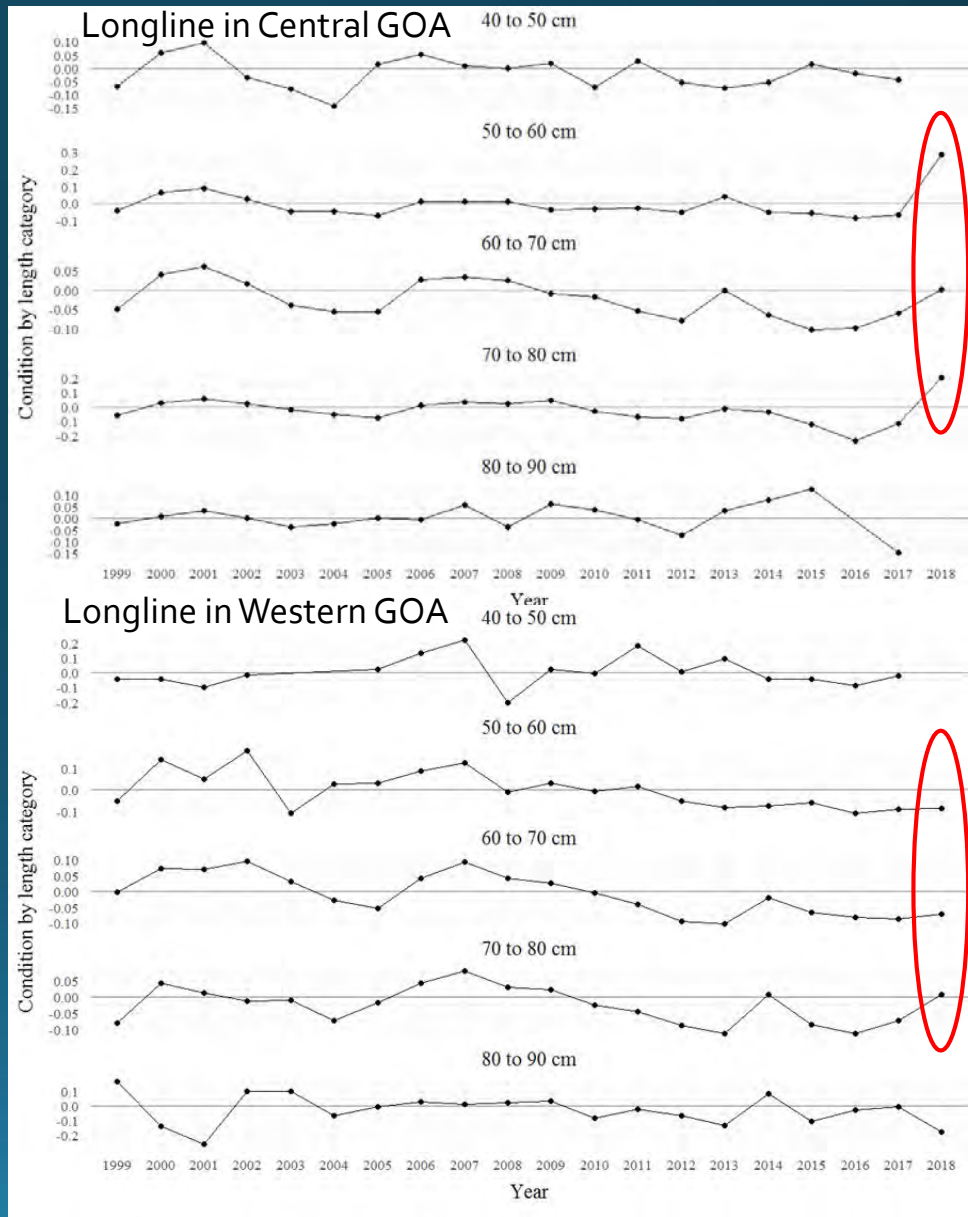


- Bycatch rate in shallow water flatfish fishery appears slightly higher in 2018 compared to 2016 and 2017
- Remains low compared to other years



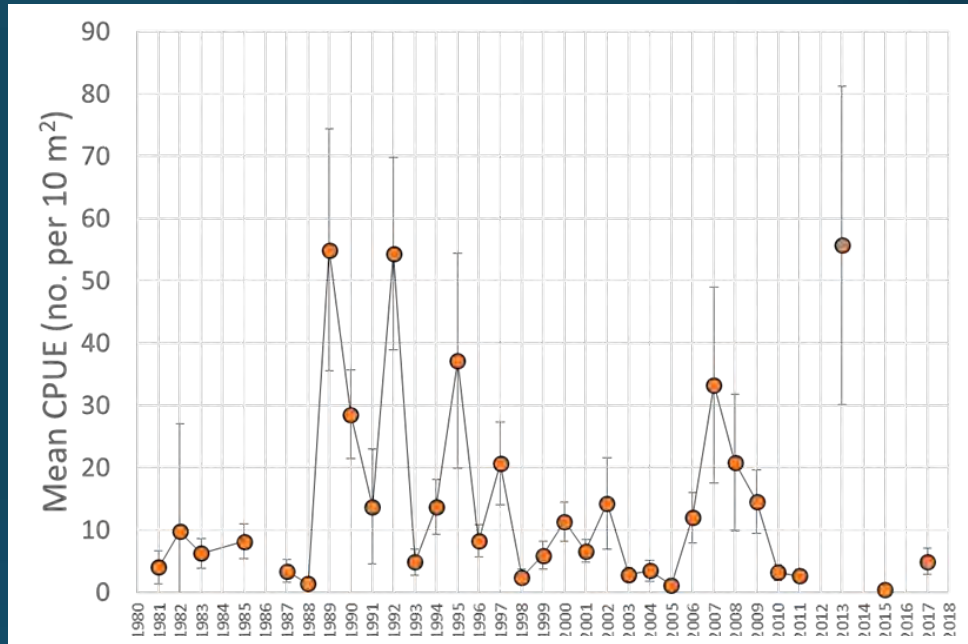
Pacific cod weight at length in fisheries

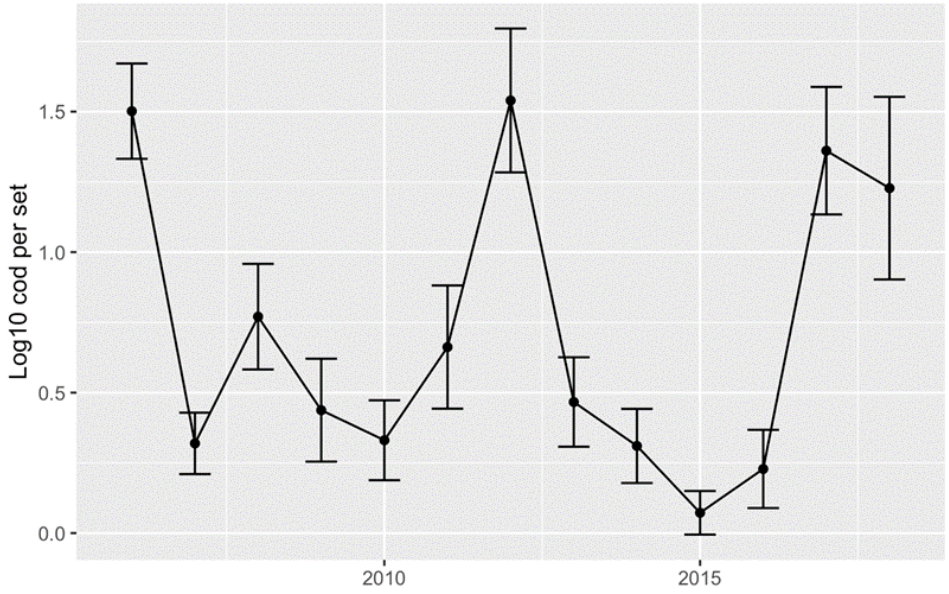
- Mixed signals
  - Better than average condition for fish between 50 and 80 cm in Central GOA
  - Continued poor condition for fish between 50 and 70 cm in the western GOA
- Longline and pot show similar patterns in fish condition



Larval surveys

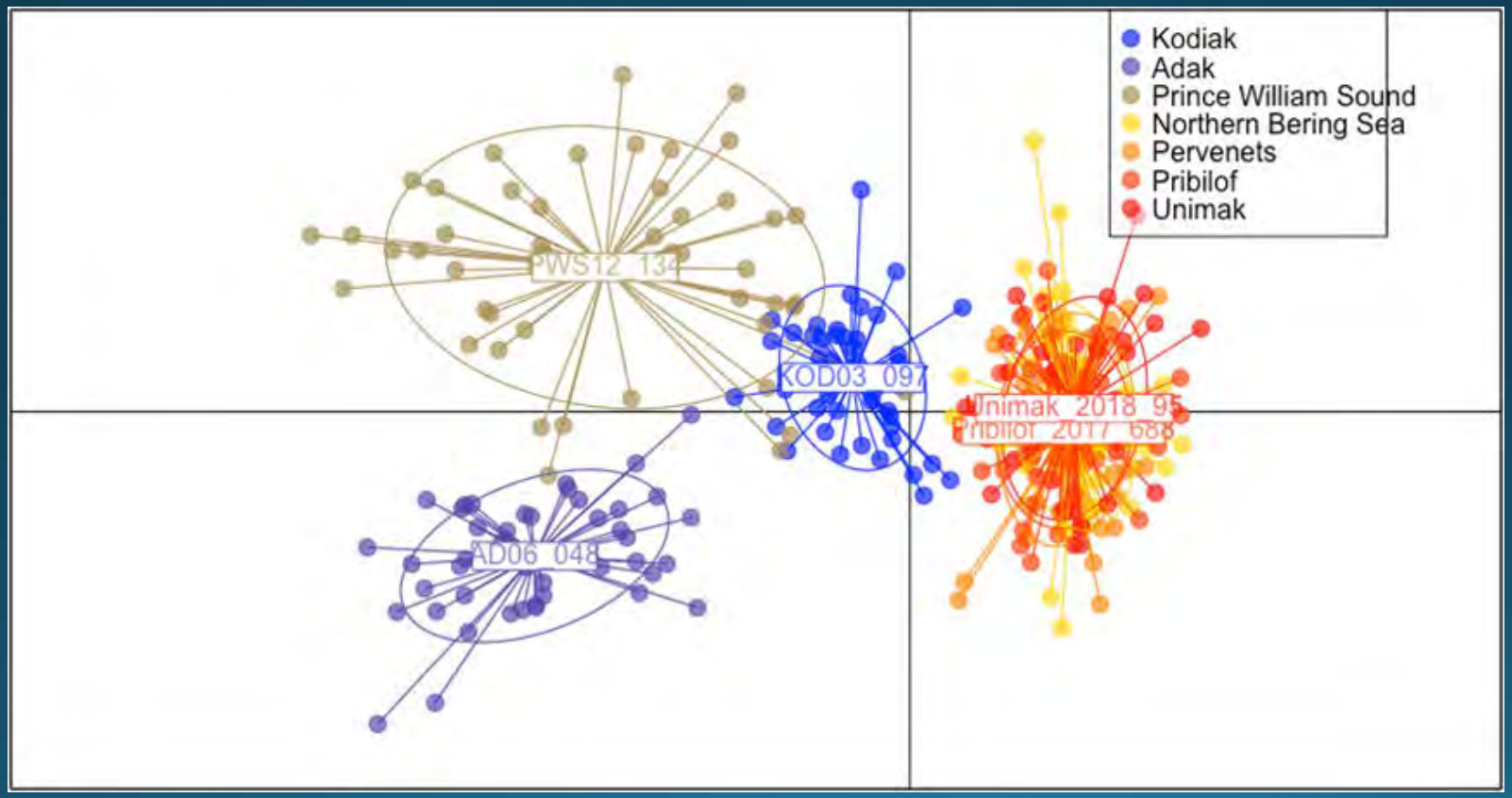
- Icthyoplankton survey
  - 1981-2017
  - 2017 below average but up from 2015
- Age-0 Kodiak beach seine survey
  - 2006-2018
  - 2017 and 2018 well above average.





Genetics

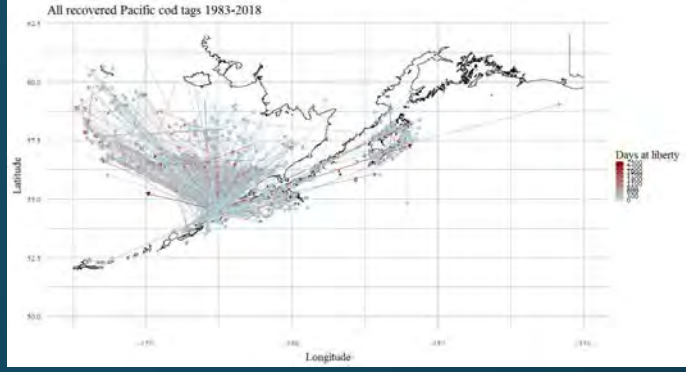
- Kodiak area and Prince William Sound Pacific cod genetically distinct from other samples

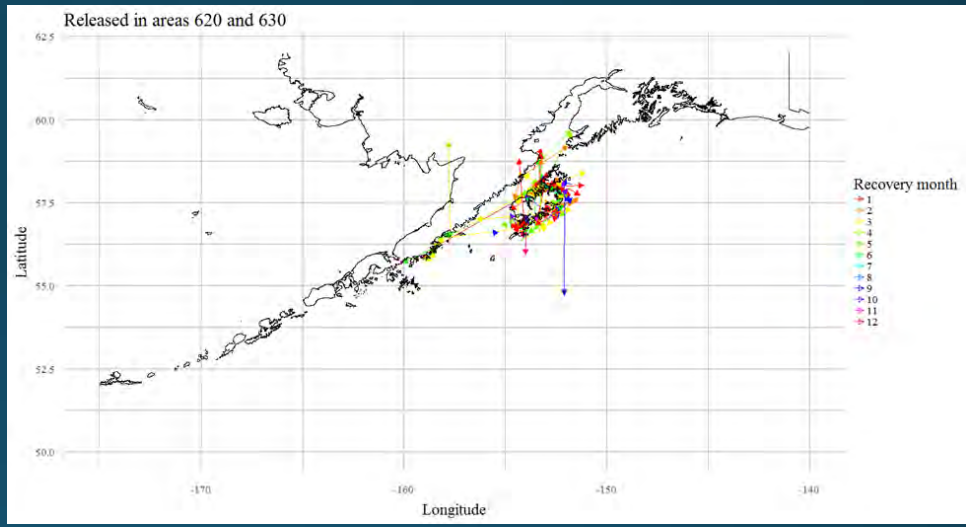


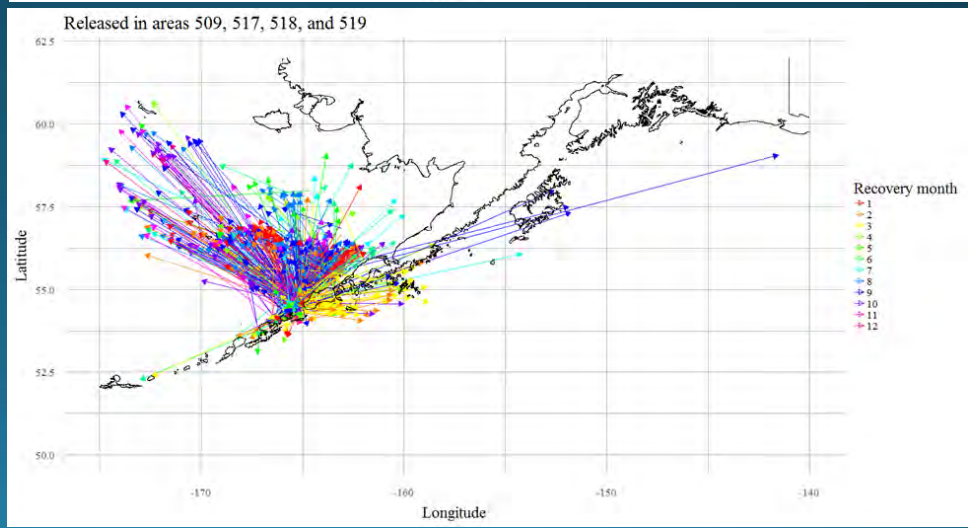
Spies et al.(in prep.)

"New" tagging data

- 1982-2009 tag returns being analyzed (3,180 returns)
- Tagging shows substantial movement between Bering Sea and western Gulf of Alaska
- Not much movement from Kodiak or Central GOA westward

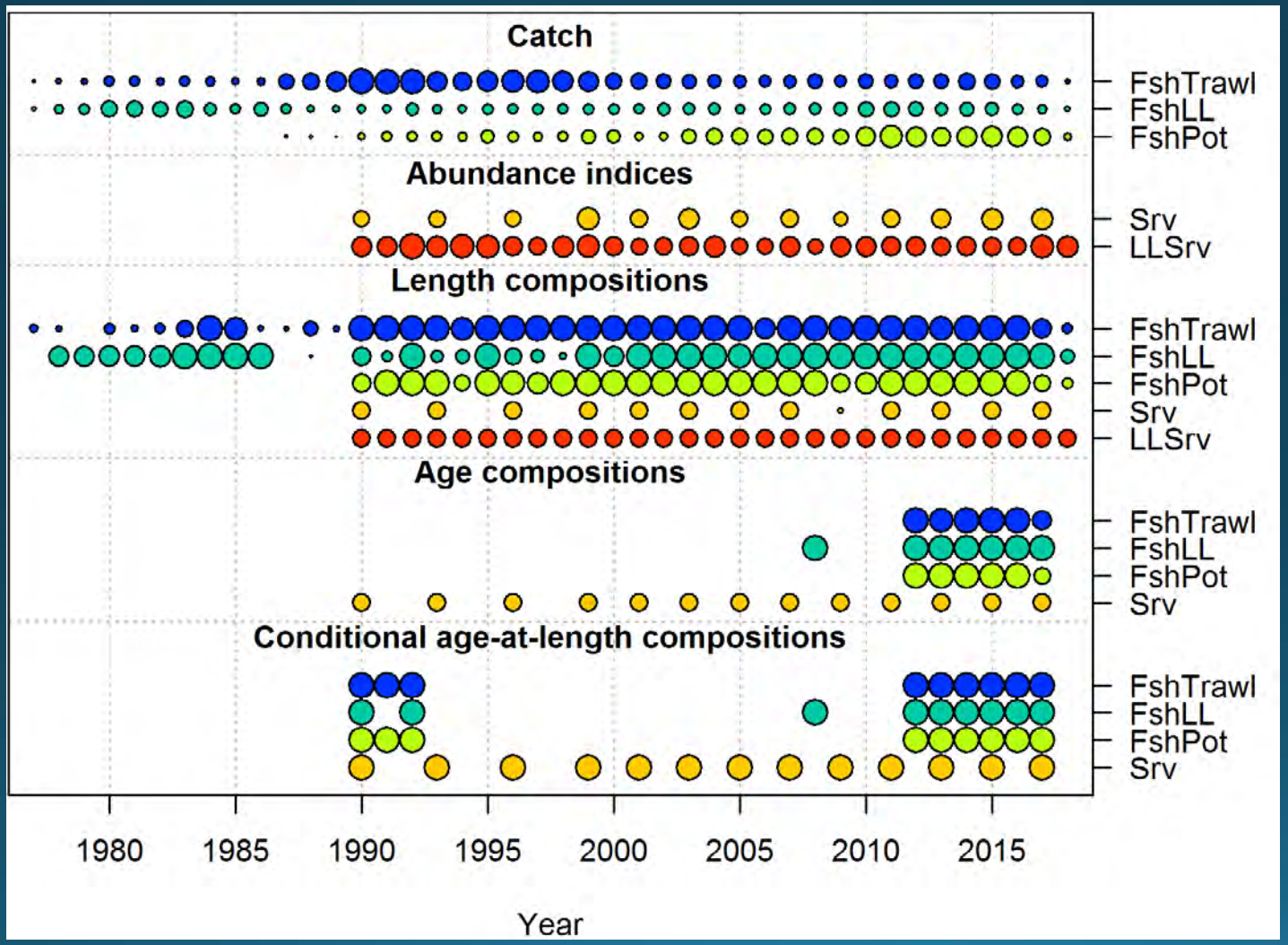






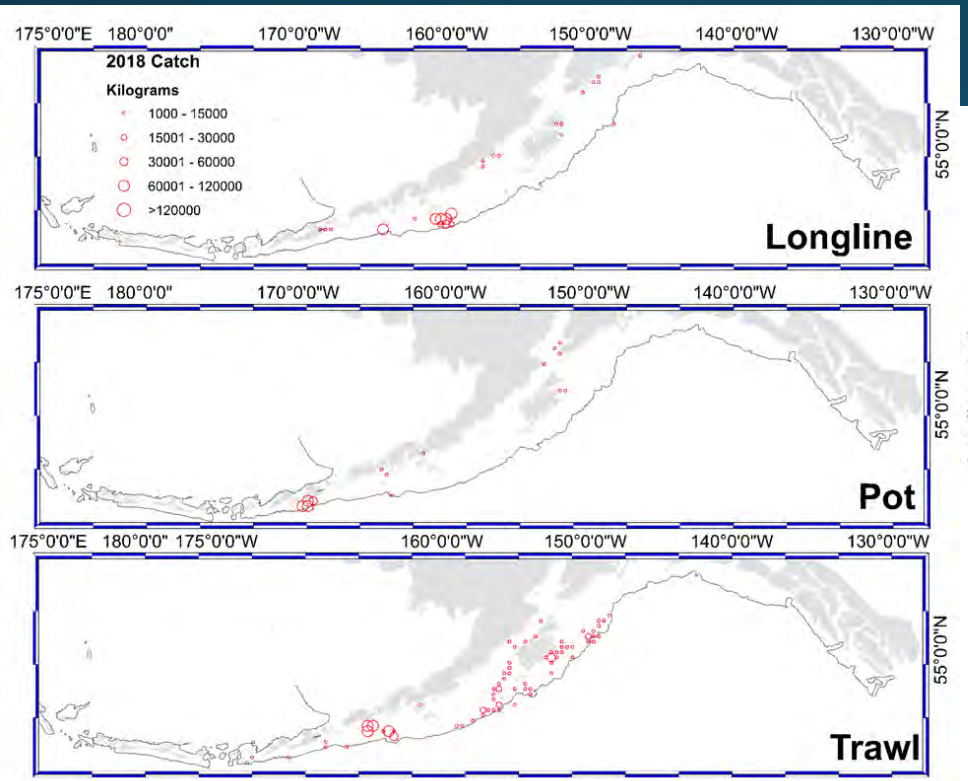
Note: Tagging data not in assessment

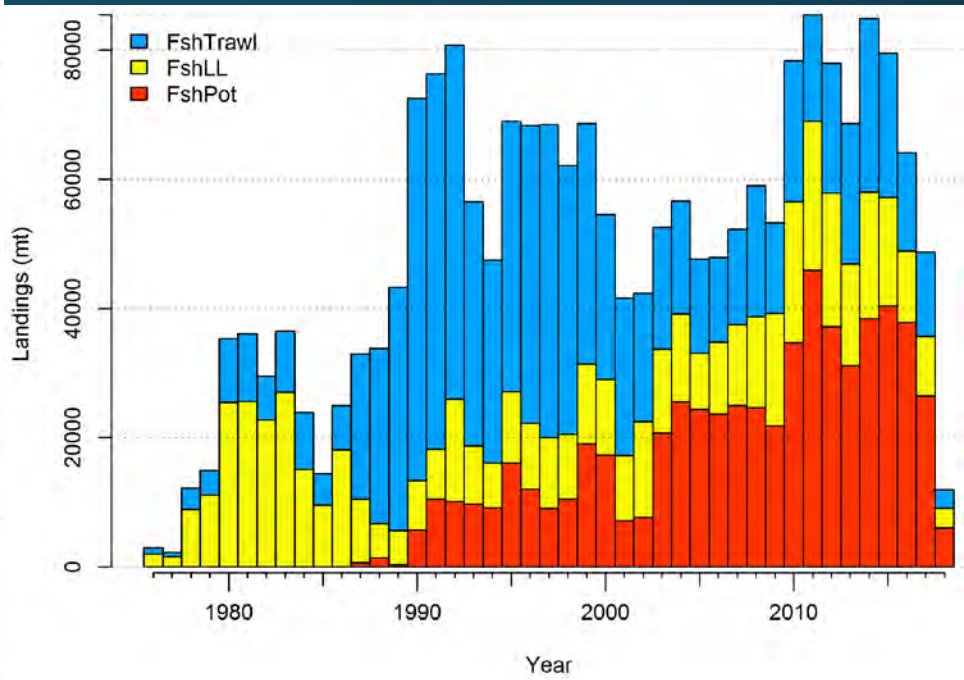
Data used in assessments



Catch

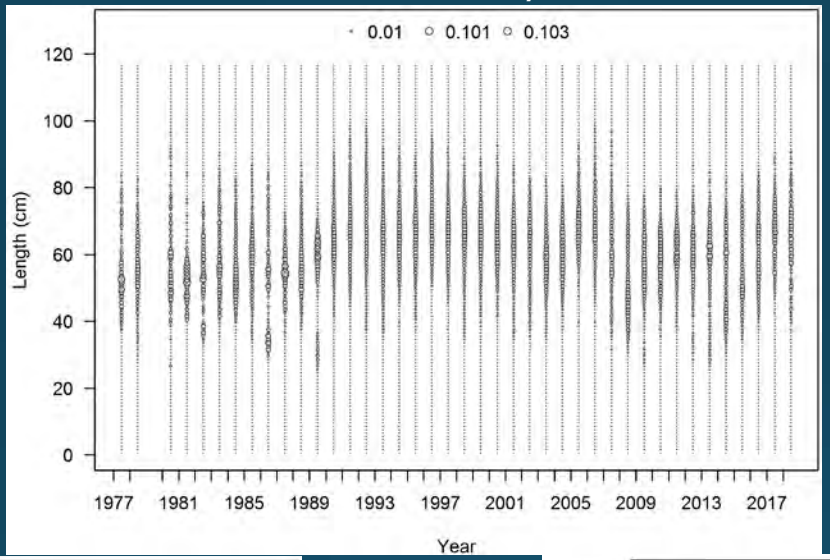
- ABC reduced from 88,342t in 2017 to 18,000t in 2018
- Total catch in 2018 at < ABC_{2018} ~130000t



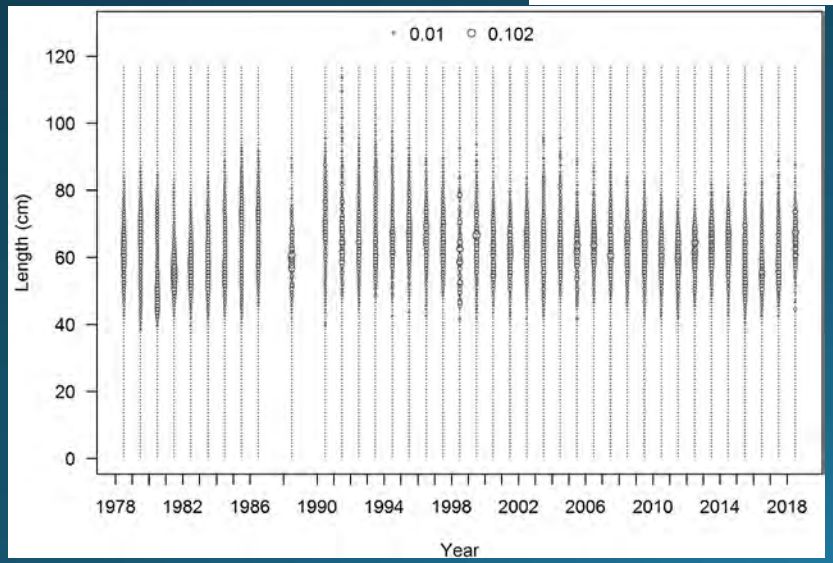


Fishery length composition

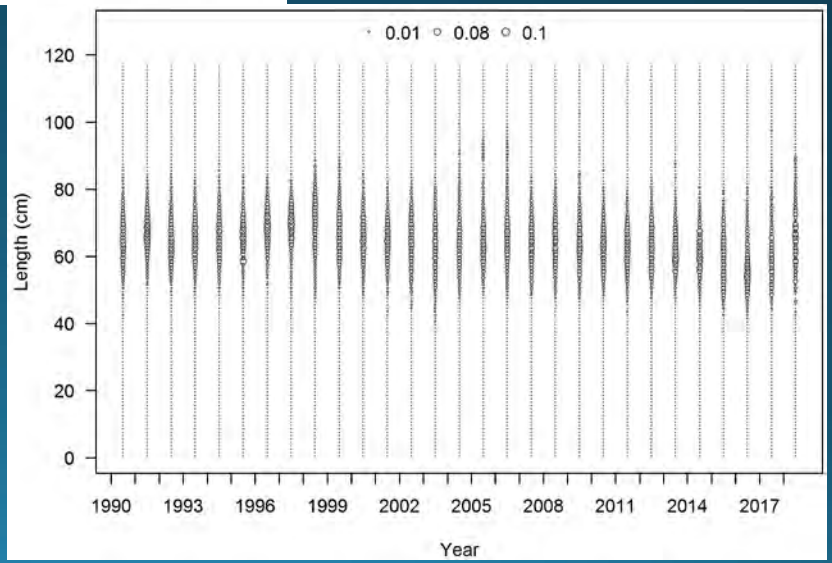
Trawl Fishery



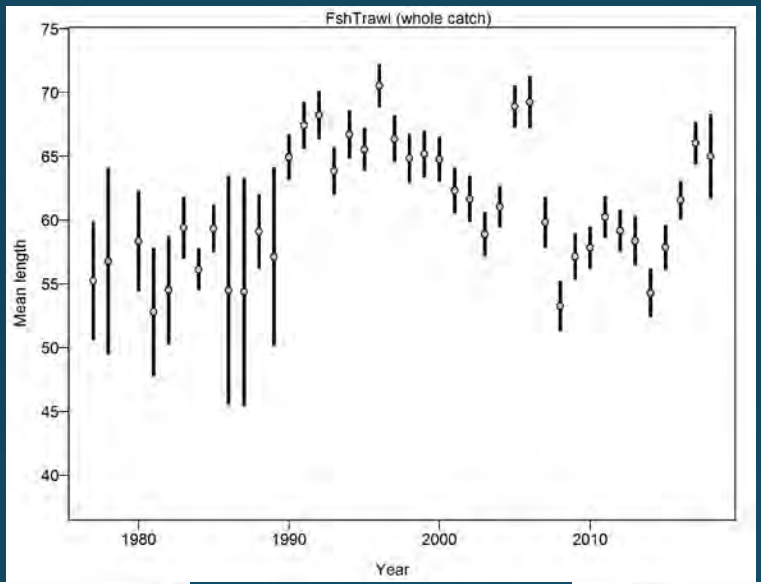
Longline Fishery

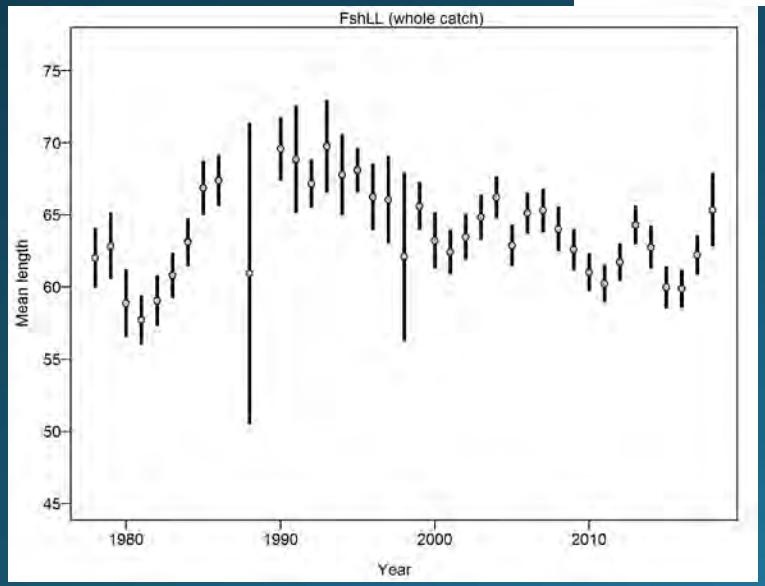


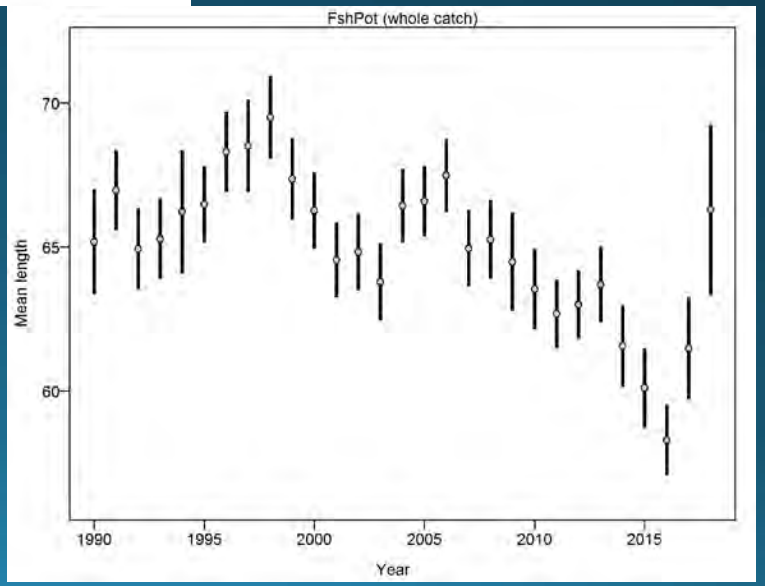
Pot Fishery



Fishery length composition



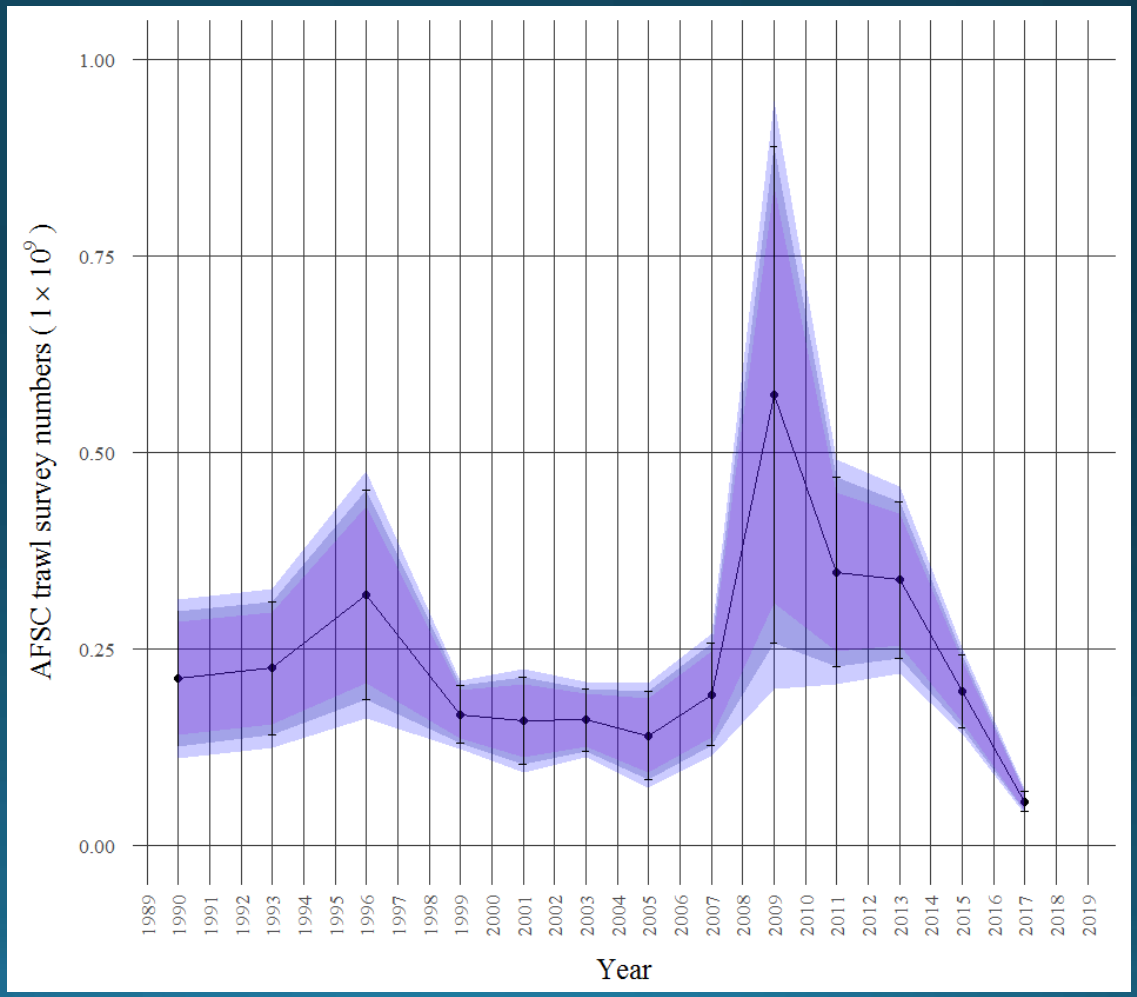




GOA Pacific cod
2017 Bottom trawl survey

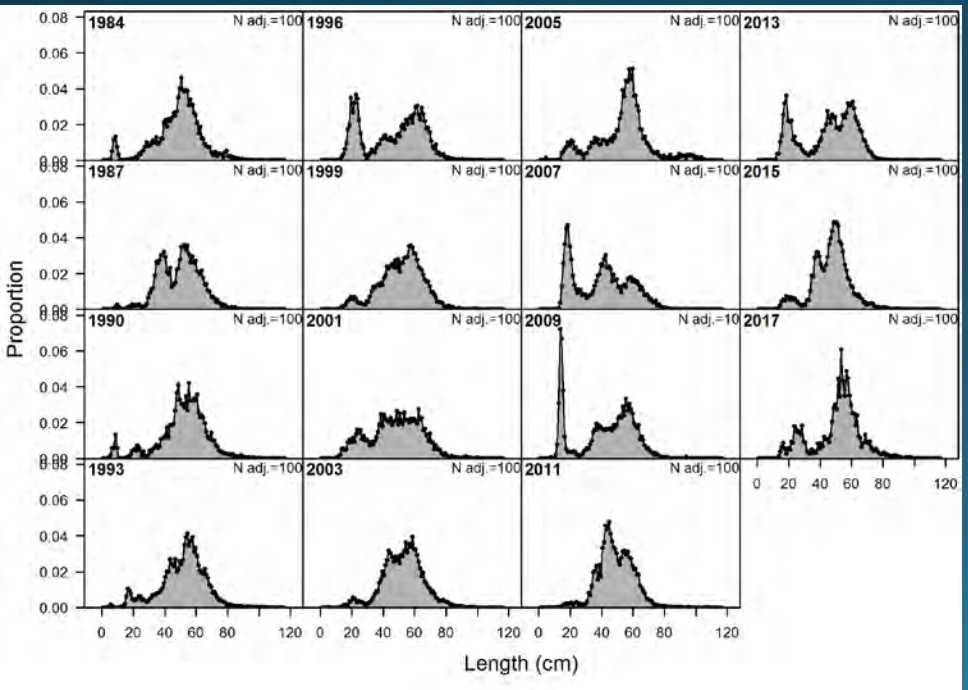
- Lowest estimate ever
  1.96×10^8 fish and 107,324 t
- Precise estimate (0.117 CV)

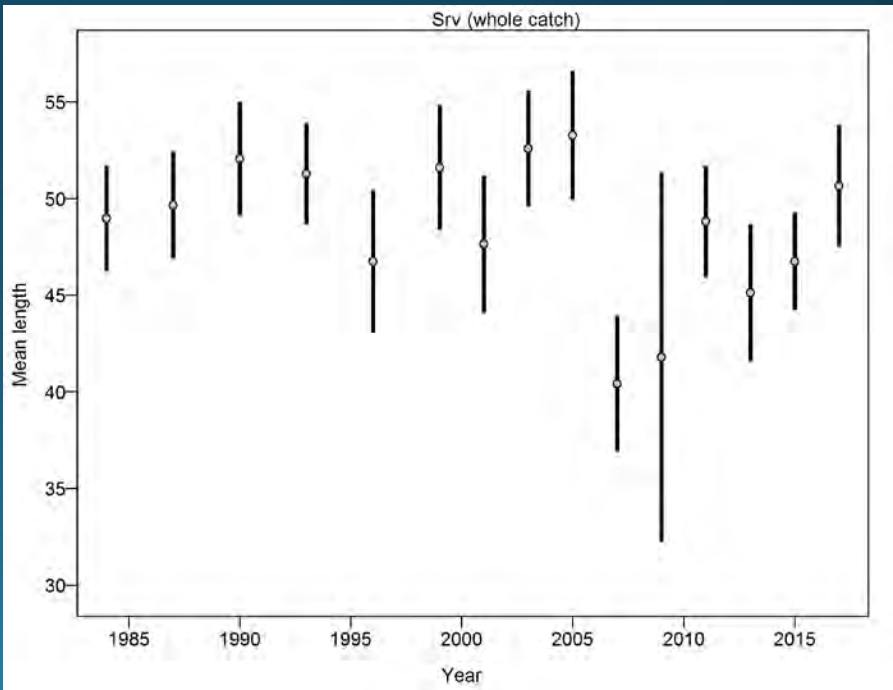
- 71% decline in abundance since 2015 (83% since 2013)
- 58% decline in biomass since 2015 (78% since 2013)



Bottom trawl survey Length composition

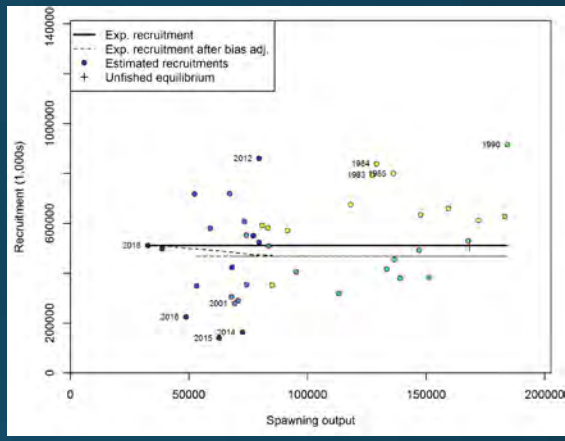
- 2017 bimodal with 20-30 cm and 50-65cm modes
- Increase in mean length

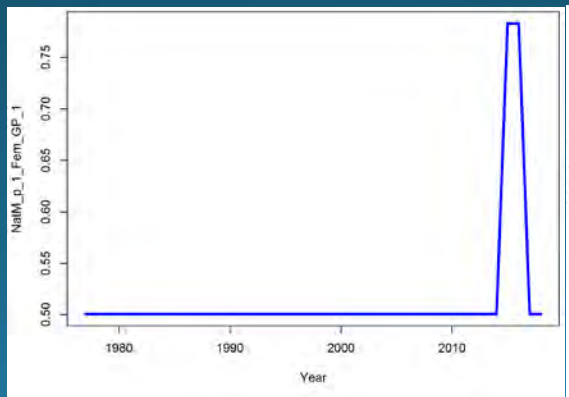


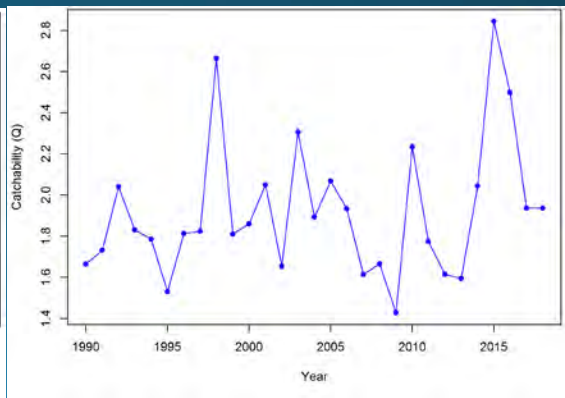


Base Model – Model17.09.35

- Developed in Stock Synthesis
  - von Bertalanffy growth
  - $A_{50\%}$ at 4.3499 slope = -1.9632 from Stark (2007)
  - Beverton-Holt with steepness = 1.0, sigma R = 0.44
  - Heatwave block on natural mortality 2015-2016
    - 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)

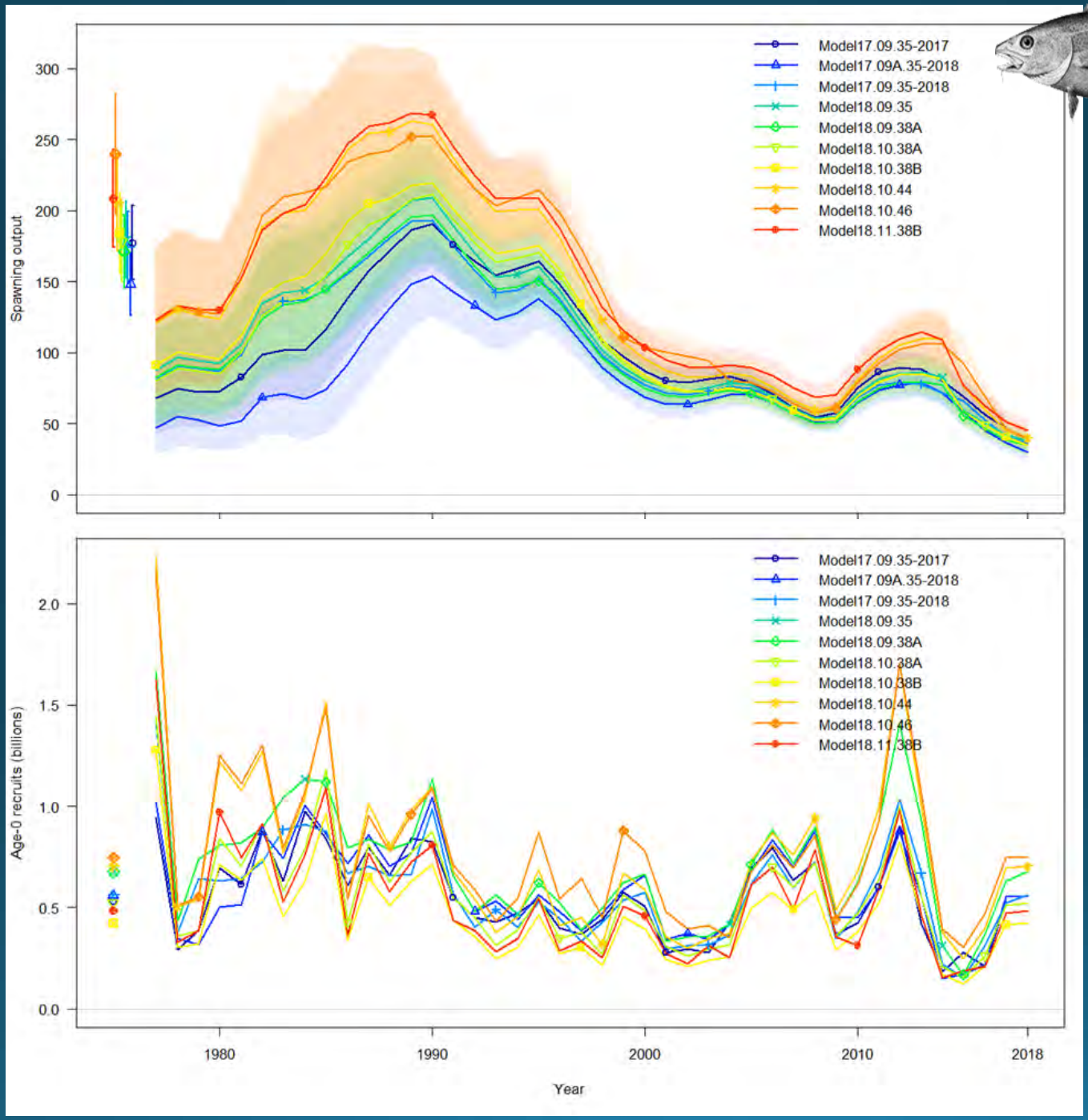






Models reviewed in 2018

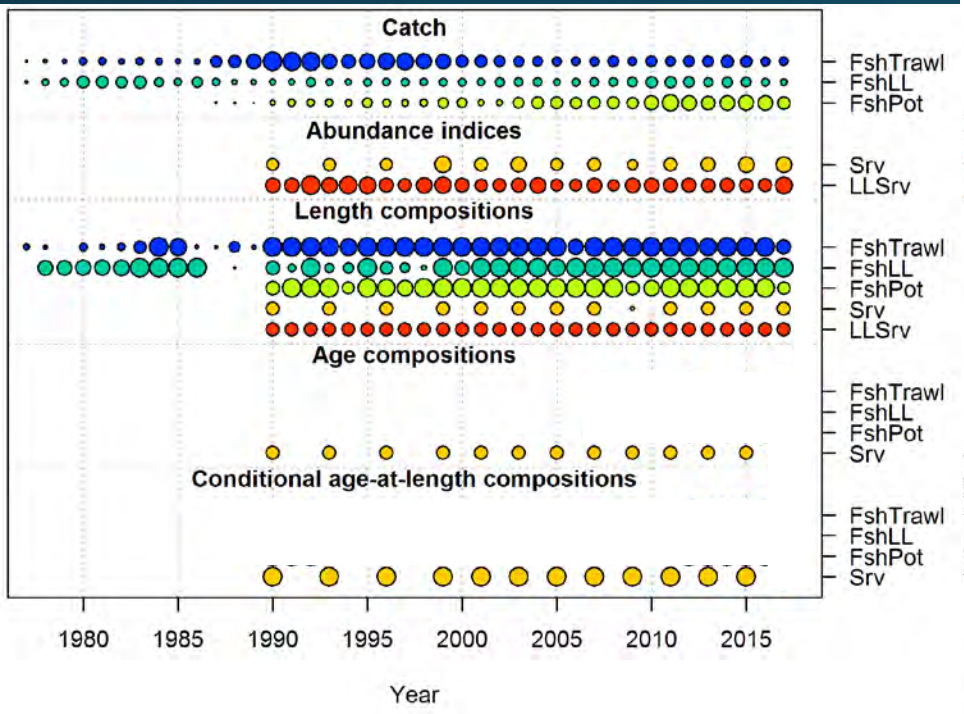
Model	Data	SS version	M- block	Maturity	Marine heatwave index	Selectivity	Prior CV on M	VB prior (l_{inf}/K)
17.09.35	Same as 2017	2.24	15-16	Age-based		Length-based	0.10	Uniform
18.09.35	Same as 2017	3.30	14-16	Age-based		Length-based	0.10	Uniform
18.09.38A	Same as 2017	3.30	14-16	Length-based		Length-based	0.10	Uniform
18.10.38A	No age data pre-2007	3.30	14-16	Length-based		Length-based	0.10	Uniform
18.10.38B	No age data pre-2007	3.30	14-16	Length-based		Length-based	0.10	Normal 99.46/0.197
18.10.44	No age data pre-2007	3.30	14-16	Length-based		Length-based	0.41	Normal 99.46/0.197
18.10.46	No age data pre-2007	3.30	NA	Length-based	✓	Length-based	0.41	Normal 99.46/0.197
18.11.38B	No age data	3.30	14-16	Length-based		Length-based	0.10	Normal 99.46/0.197

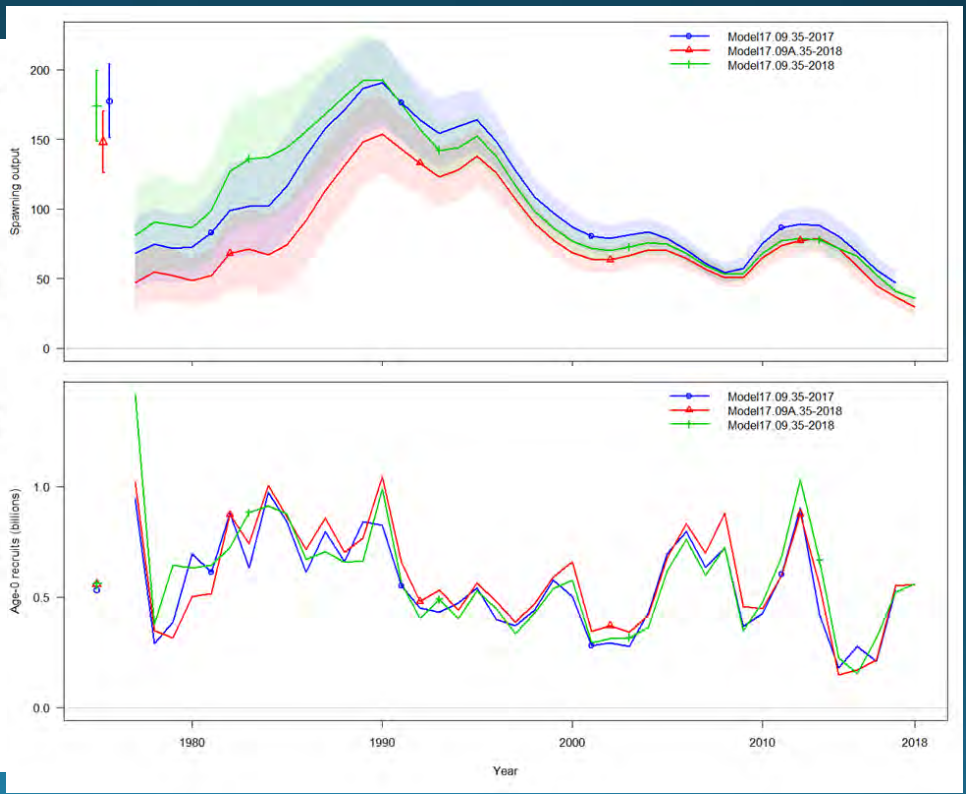

Spawning output
300
250
200
150
100
50
0
Model17.09.35-2017
Model17.09A.35-2018
Model17.09.35-2018
Model18.09.35
Model18.09.38A
Model18.10.38A
Model18.10.38B
Model18.10.44
Model18.10.46
Model18.11.38B
Age-0 recruits (billions)
2.0
1.5
1.0
0.5
0.0
1980
1990
2000
2010
2018
Year

Model17.09.35

- Data changes from last year
  - **Model17.09A.38-2018** is the same data components as last year
  - **Model17.09.35-2018** adds fishery age composition and conditional length at age

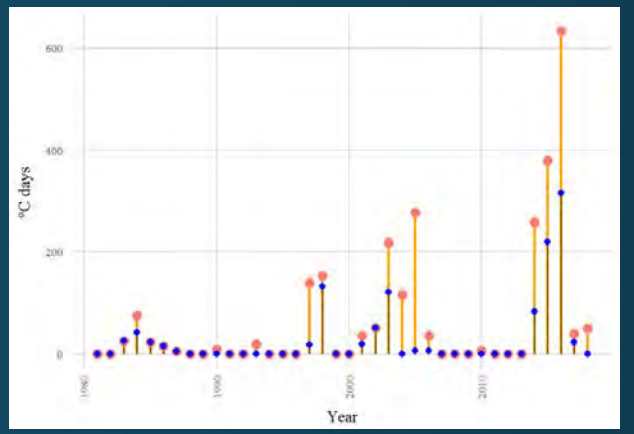
Model17.09.35-2018



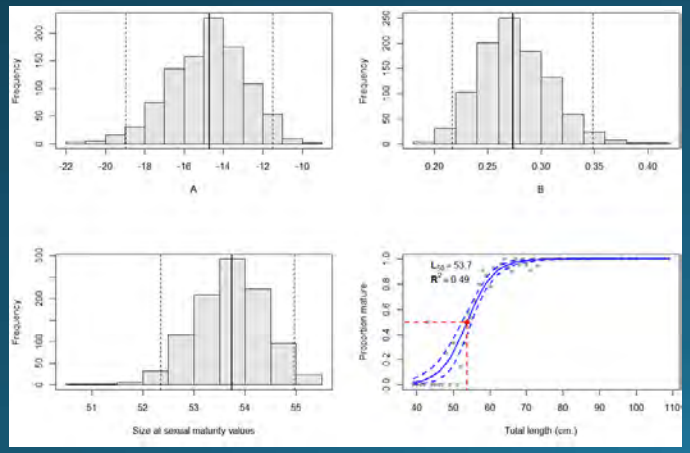


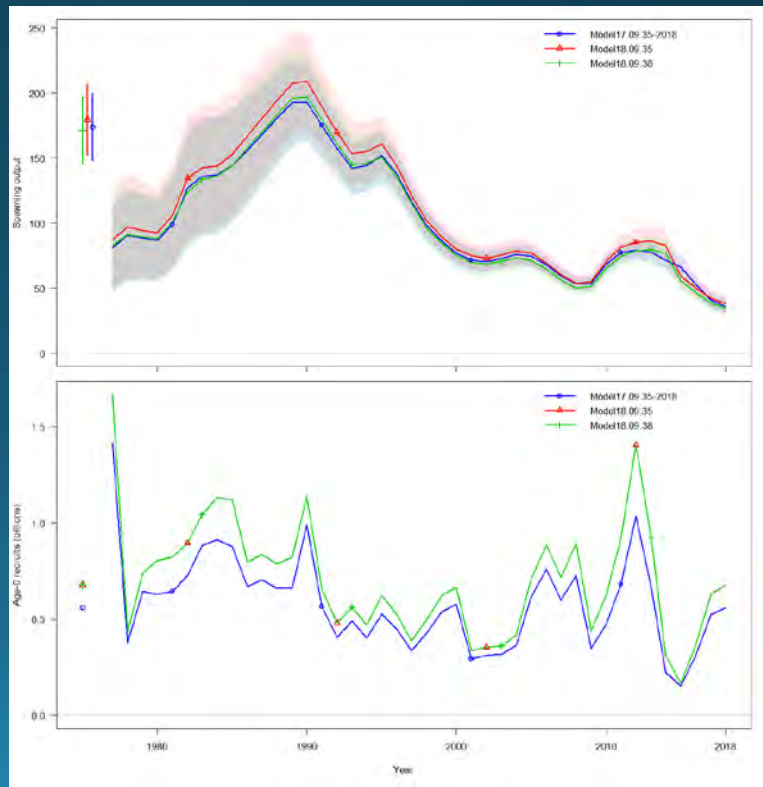
Model18.09.35 - 38

- Switch to Stock Synthesis 3.30.12 from 2.24U
  - Changes how annual deviations are handled in selectivity
  - Adding 2014 to heatwave M block
  - Places more weight on size composition
  - Increase in M, decrease in Q



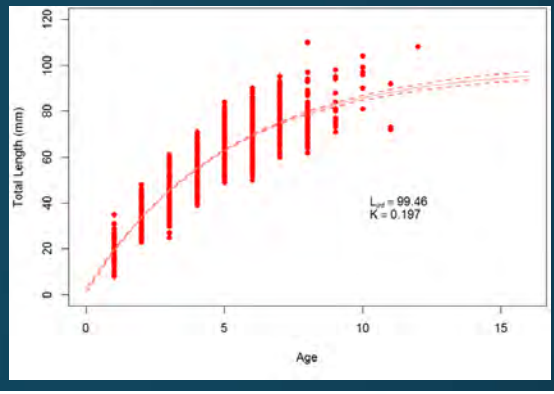
- Change from age-based to size-based maturity
  - Size-based using Stark (2007) maturity data
  - No change in model fit
  - Decrease in spawning biomass



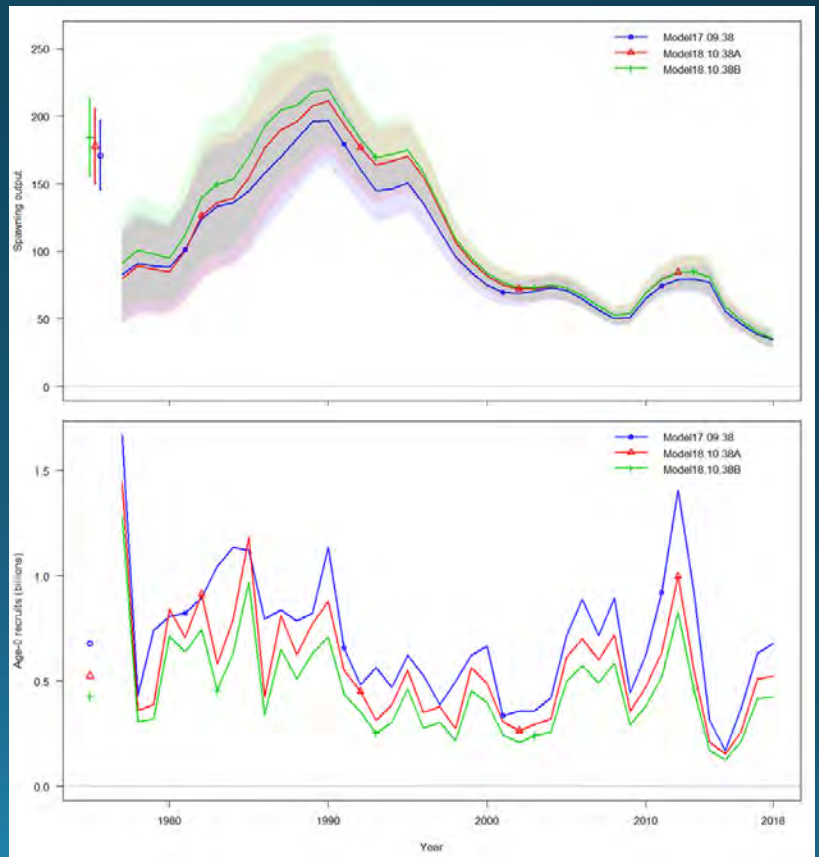


Model18.10.38A and B

- Model18.10.38A – Remove all age composition and pre-2007 conditional length at age data
  - Decrease in Ms and Qs (M=0.49, Q_{BT}=1.27)
  - Decrease in L_{inf}, increase in K
  - Better fit to surveys and length composition for all fleets
  - Minor shift in selectivity to left for all components post-1990

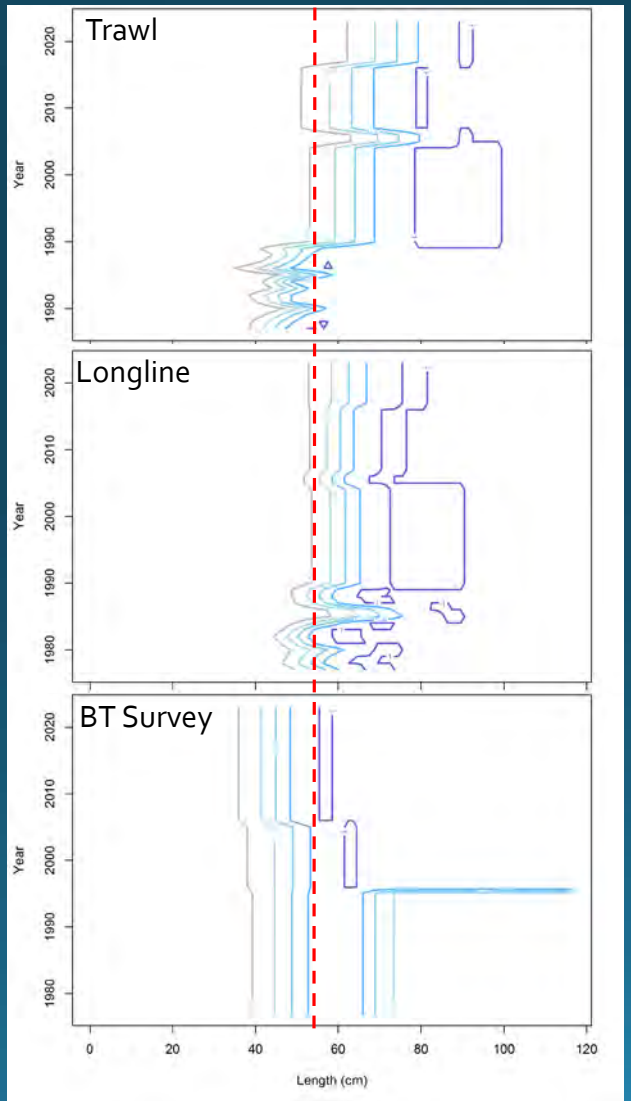


- Model18.10.38B uses the growth model parameters from post-2007 survey data (L_{inf}=99.46, K=0.197)
  - Decrease in Ms and Qs (M=0.45, Q_{BT}=1.25)
  - Improved survey fits
  - Degraded length and age composition fits

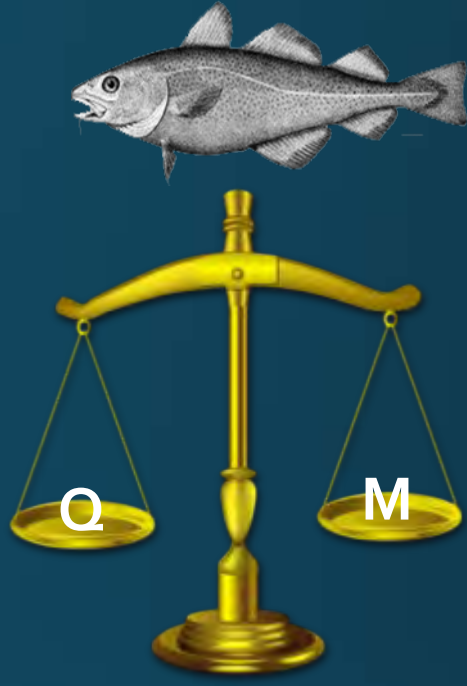


Selectivity change

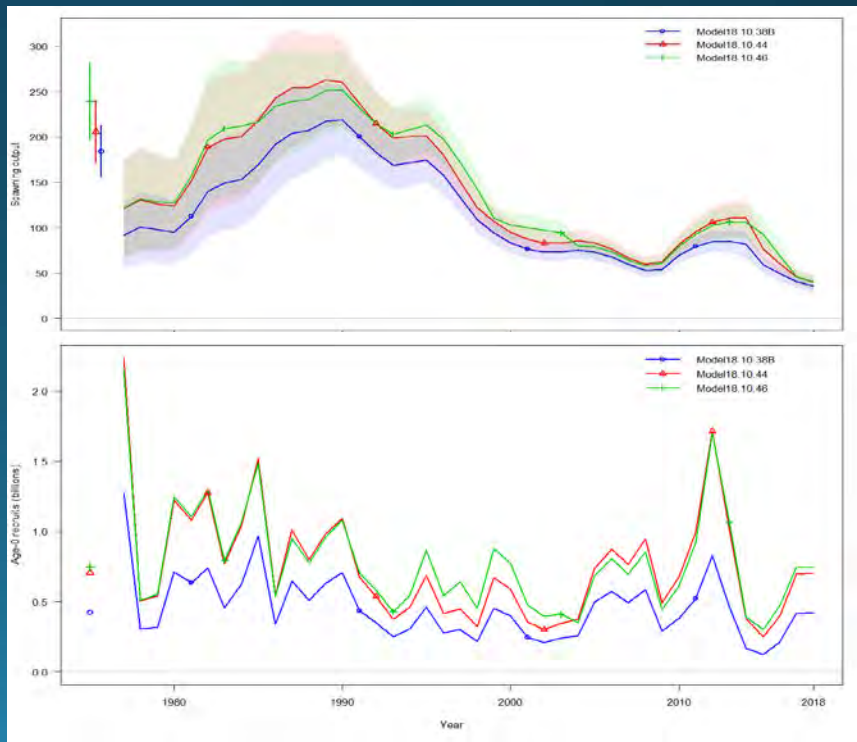
Model18.09.38A



Model 18.10.44

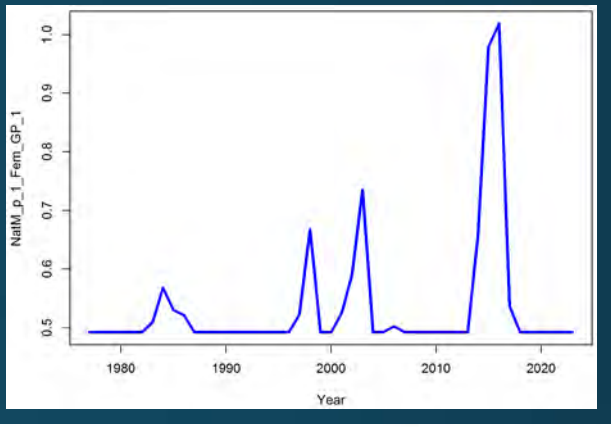


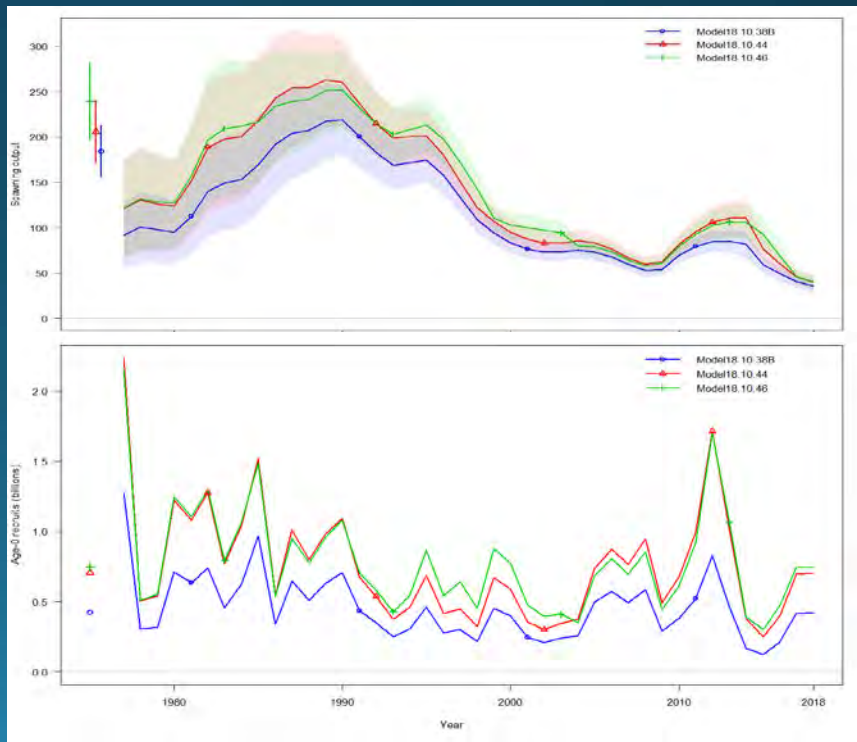
- Loosen cv prior from 0.1 to 0.41 on both natural mortalities
- Better overall fit
  - Improvements in fit to indices
  - Degradation of fit to length composition
  - Lower parameter priors
- Results
  - Increase M to 0.5
  - Increase heatwave M to 0.87
  - Decrease both survey catchabilities
    - 1.07 for AFSC bottom trawl survey
    - 1.22 for AFSC longline survey



Model 18.10.46

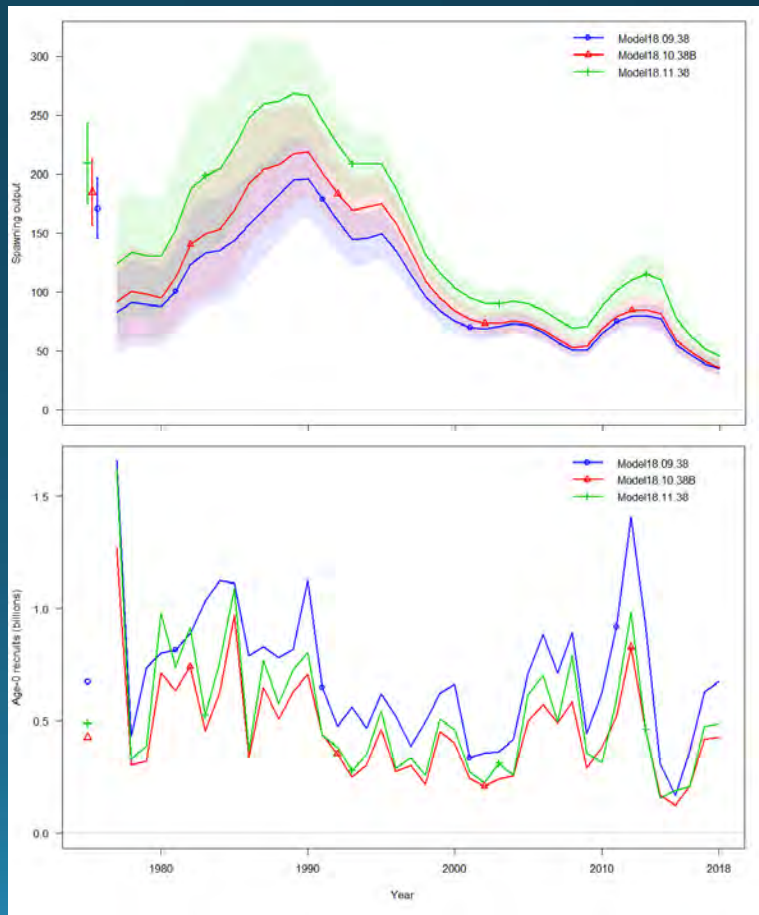
- M fit to Winter heatwave intensity index
  - Mean M of 0.54
  - Decrease in Qs
- Best fit overall
  - Best fit to length composition
  - Slightly degraded fit to indices
- Results
  - Increases in recruitment 1995-2005
  - Increase spawning biomass 1995-2005
  - Less steep decline during heatwave





Model18.11.38B

- Same as model 18.10.38B except no age data
  - Lower catchability for both indices (Q_{BT}=1.00, Q_{LL}= 1.14)
- Improved model fits
  - Improved fit to indices over 18.10.38B
  - Best fit to length composition
- Results
  - Increase in overall biomass estimates
  - Increase in reference points



Model selection

- Changing SS version changed treatment of selectivity devs and model fit to early fishery data
- Of series Model 18.10.xx
  - Model 18.10.46 best overall fit – least influential priors
  - Model 18.10.44 best fit to indices and retrospective

	M17.09.38-2017	M17.09A.35 - 2018	M17.09.35-2018	M18.09.35	M18.09.38A	M18.10.38A	M18.10.38B	M18.10.44	M18.10.46	M18.11.38B
AIC	3526.78	4138.26	6719.86	6552.38	6552.38	4155.96	4167.58	4150.66	4133.38	2682.4
Likelihoods Total	1559.39	1866.13	3155.93	3073.19	3073.19	1874.98	1880.79	1872.33	1863.69	1138.2
Survey	0.8	-2	0.42	-4.98	-4.98	-14.06	-15.77	-19.19	-17.02	-17.7
Length Comp.	1005.46	1260.09	1272.6	1299.8	1299.8	1255.04	1257.24	1259.08	1252.94	1240.74
Age Comp.	531.37	588.8	1862.66	1861.39	1861.39	719.97	725.98	727.61	728.64	0
Recruitment	-4.14	-7.77	-11.23	-10.94	-10.94	-6.38	-5.1	-4.54	-9.14	-2.29
Parameter priors	11.64	16.6	22.25	19.26	19.26	11.72	9.29	1.7	0.35	9.19
Parameter Devs.	4.8	4.74	4.33	-96.92	-96.92	-96.14	-95.68	-95.72	-94.52	-95.68

Model selection

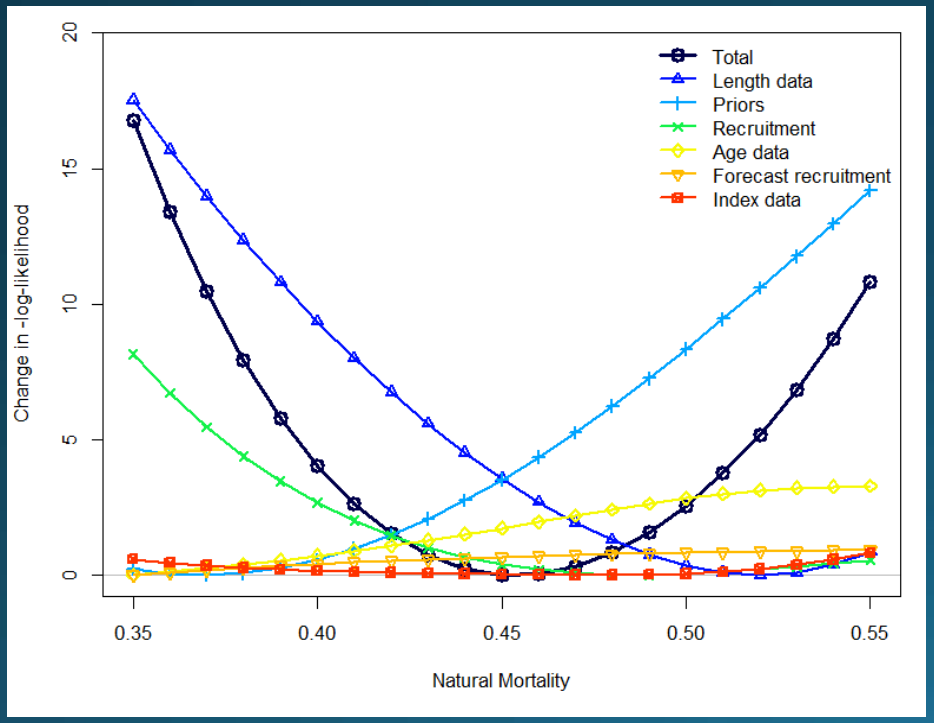
- Removal of age data substantially impacts estimates
  - Shift in selectivity to smaller fish
  - Drop in reference point Fs
  - Drop in catchability
- Loosening of the priors on M (0.1 to 0.41)
  - Increases in M, lower catchabilities

	M17.09.35-2017	M17.09.35-2018	M17.09A.35	M18.09.35/38	M18.10.38A	M18.10.38B	M18.10.44	M18.10.46	M18.11.38B
R0 billions	0.470	0.560	0.559	0.674	0.523	0.424	0.703	0.747	0.487
Natural Mortality	0.49	0.51	0.54	0.53	0.49	0.45	0.5	0.54	0.45
M heatwave	0.71	0.86	0.77	0.81	0.72	0.68	0.87	0.88	0.67
Q_{BT}	1.47	1.63	1.87	1.42	1.27	1.25	1.07	1.03	1.00
Q_{LL} - base	1.4	1.86	2.08	1.62	1.48	1.43	1.22	1.19	1.14
L_{min}	7.08	7.2	5.53	6.9	6.27	5.09	4.91	4.94	7.16
L_{inf}	123.98	115.76	121.07	116.11	107.86	99.46	99.46	99.46	99.46
Von Bert K	0.11	0.13	0.13	0.13	0.15	0.17	0.17	0.17	0.16
SSB1978 (t)	74,472	66,025	85,133	96,577/90,714	88,751	100,707	130,267	131,898	133,325
SSB100% (t)	168,583	155,842	154,554	155,325/147,748	160,525	169,252	172,240	172,326	192,072
$F_{35\%}$	1.02	1.04	0.92	0.92/0.87	0.68	0.63	0.76	0.84	0.61
$F_{40\%}$	0.80	0.82	0.73	0.73/0.70	0.55	0.51	0.62	0.68	0.50

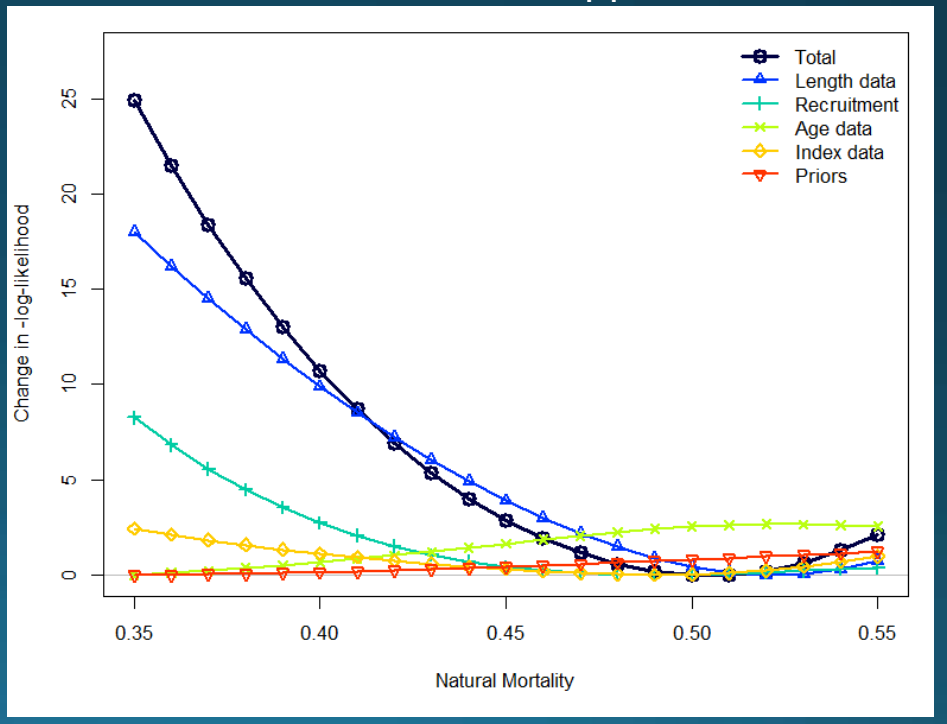
Profiles on natural mortality

- Prior on M less influential in Model 18.10.44

Model18.10.38B

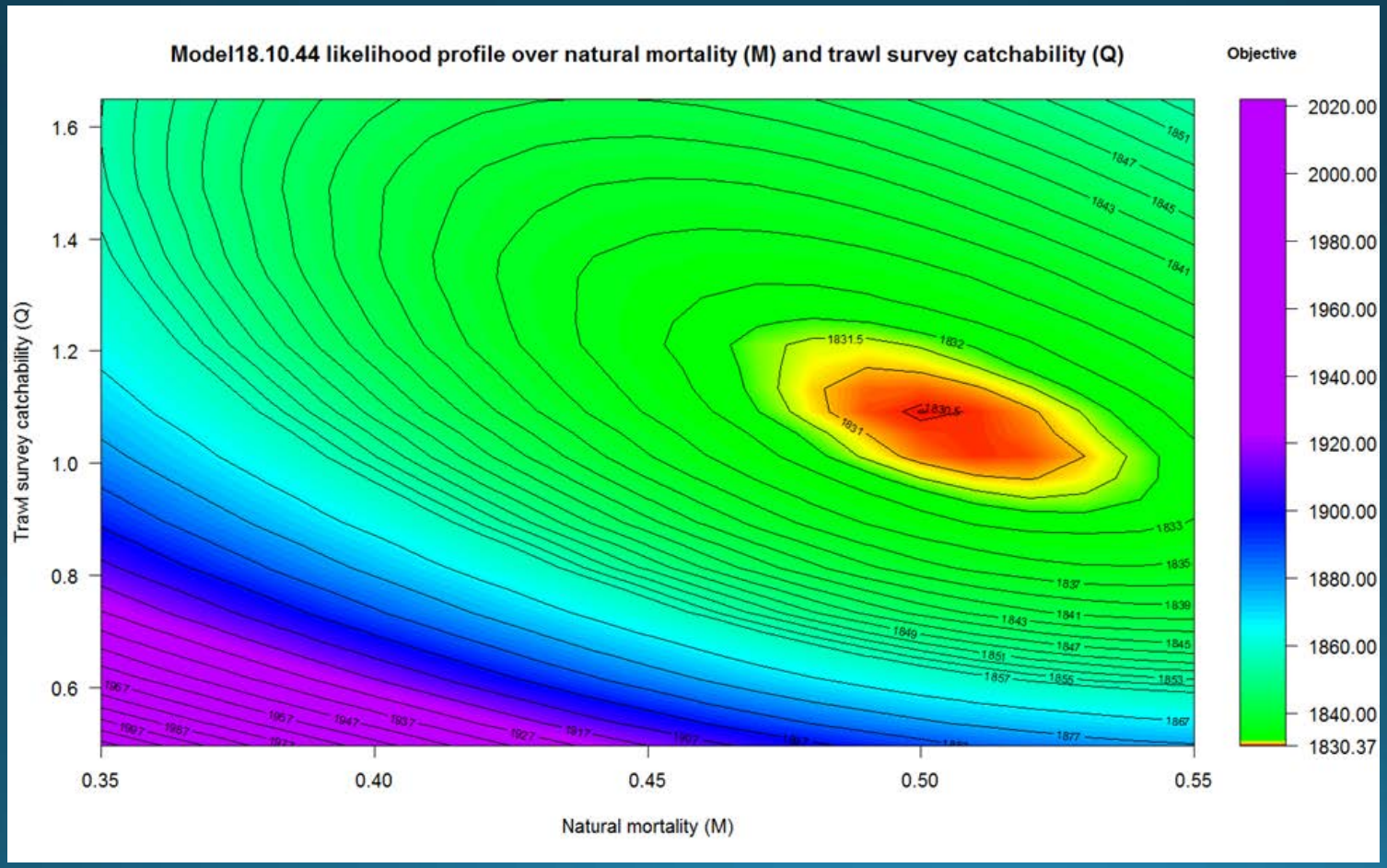


Model18.10.44



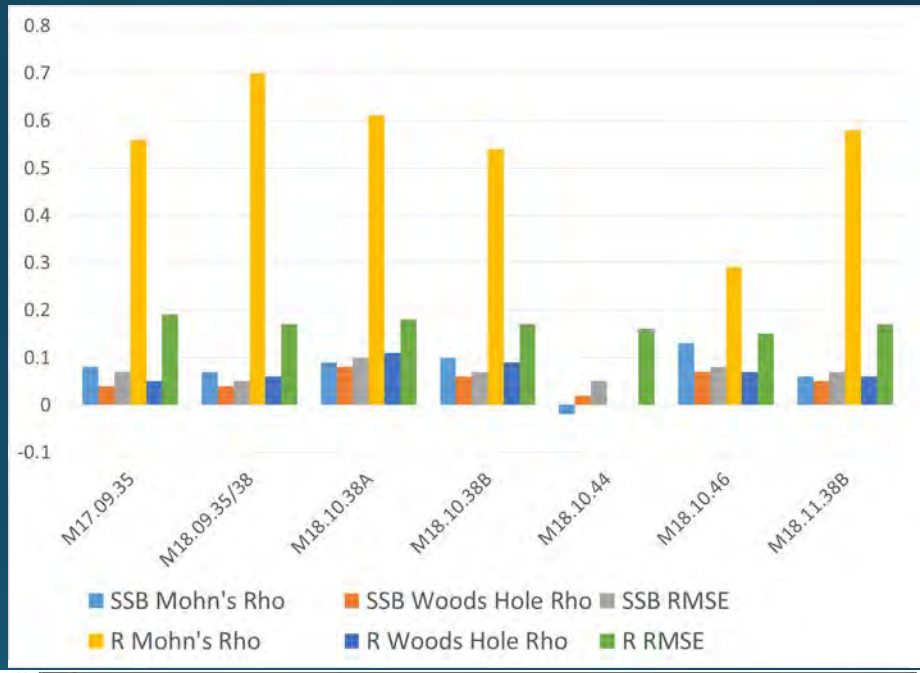
Model18.10.44 profile on M and Q

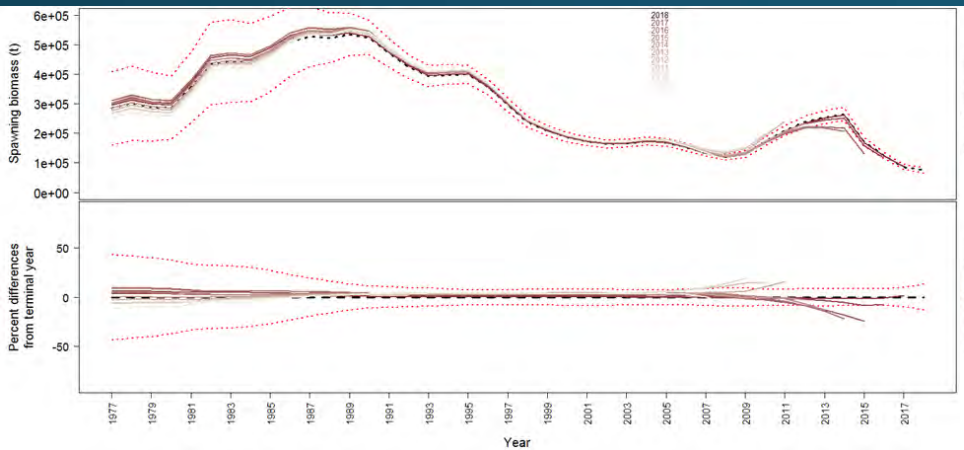
- Well defined likelihood profile

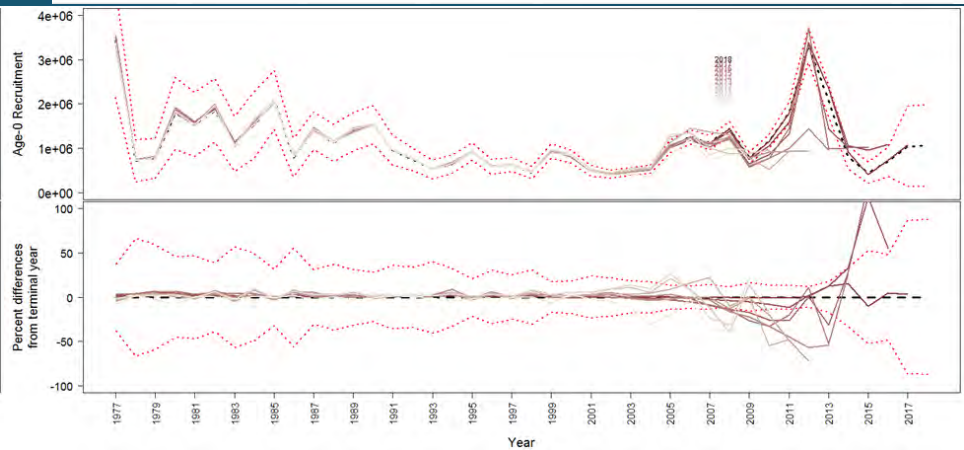


Retrospective – Model18.10.44

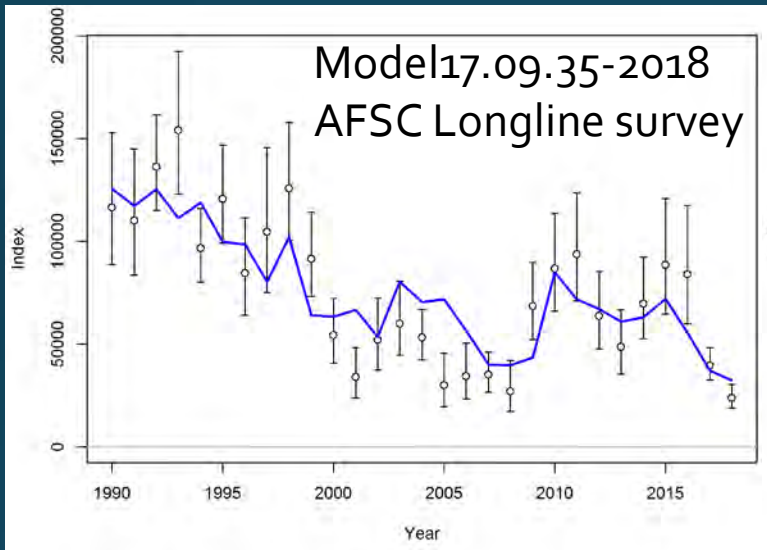
- Model18.10.44
  - Lowest for all measures examined
  - Final year retrospective SSB and R peals diverge but unbiased

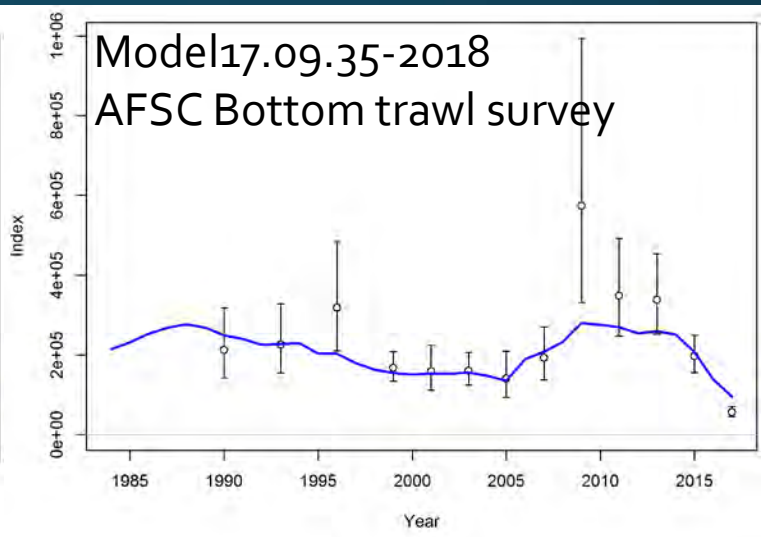


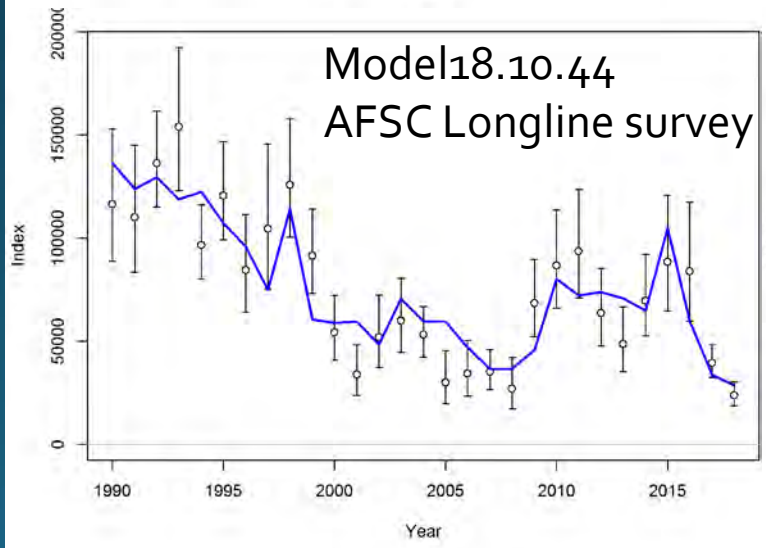


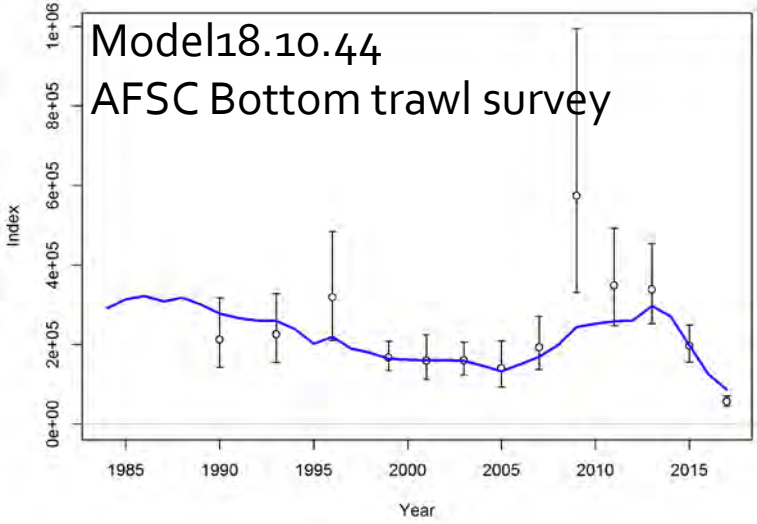


Model18.10.44
Index fits

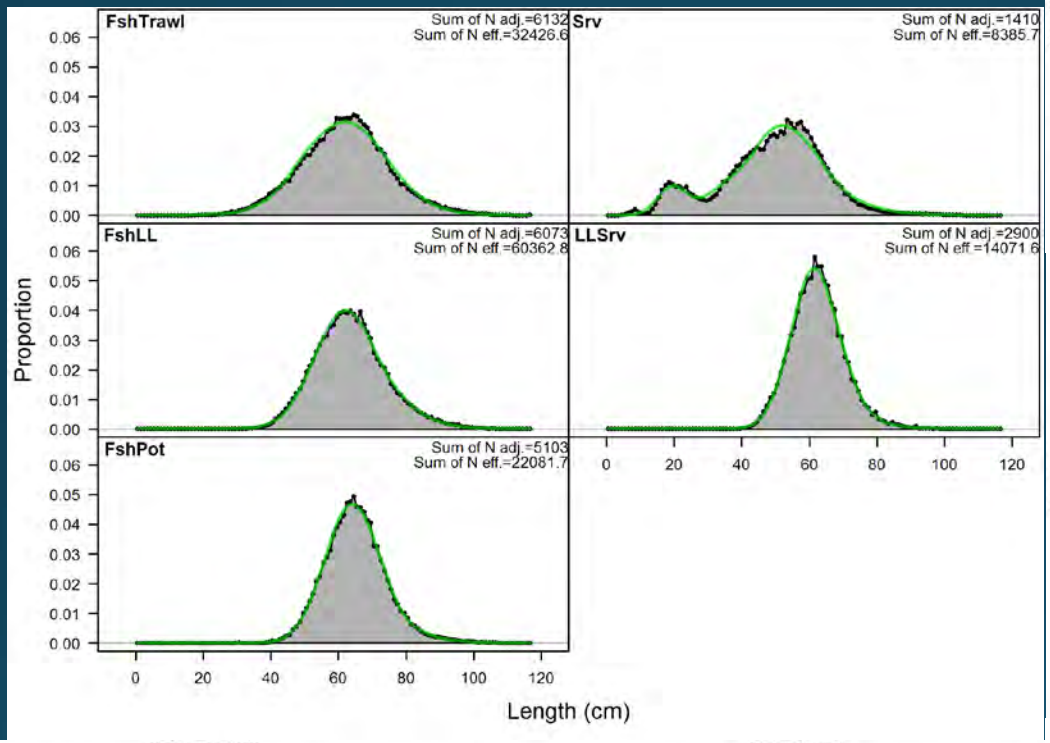


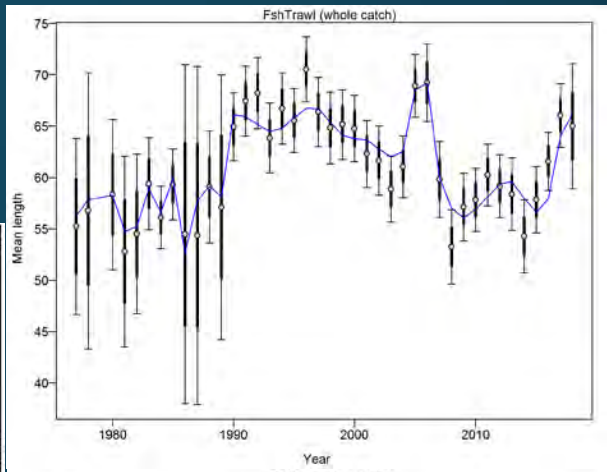


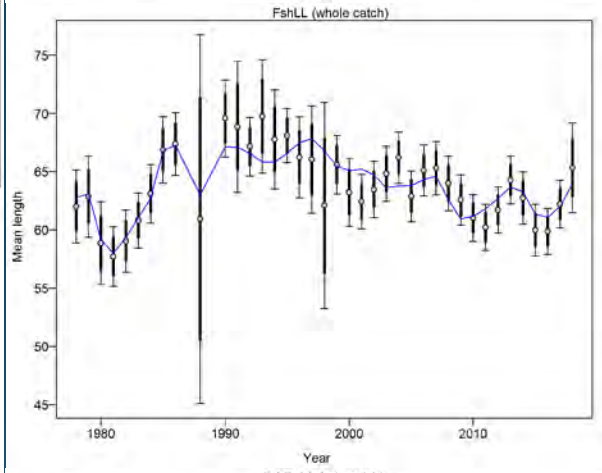


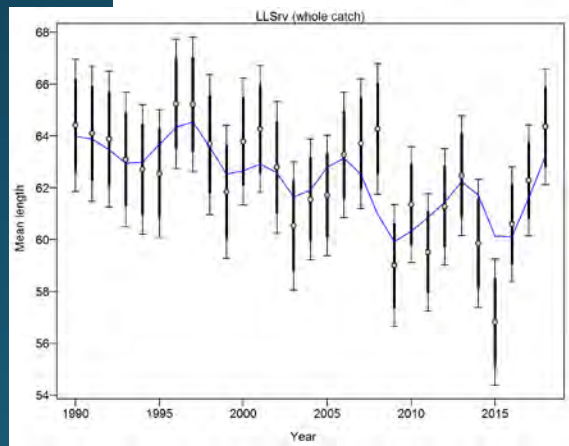


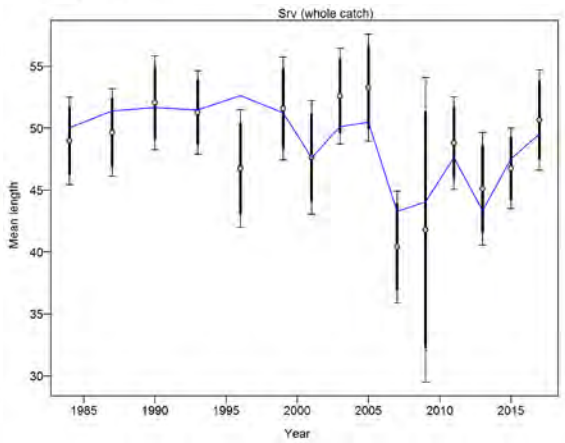
Model18.10.44
Length composition fits

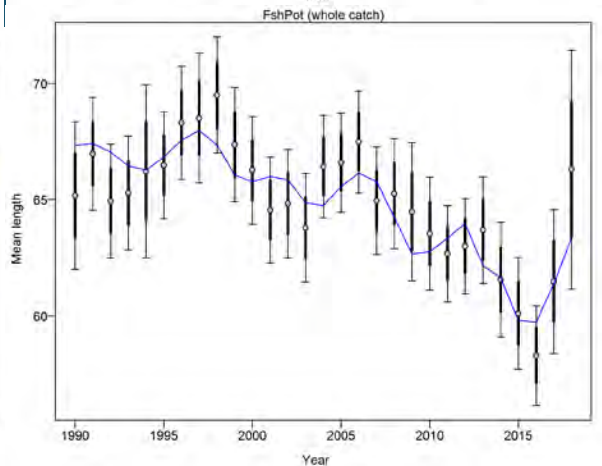






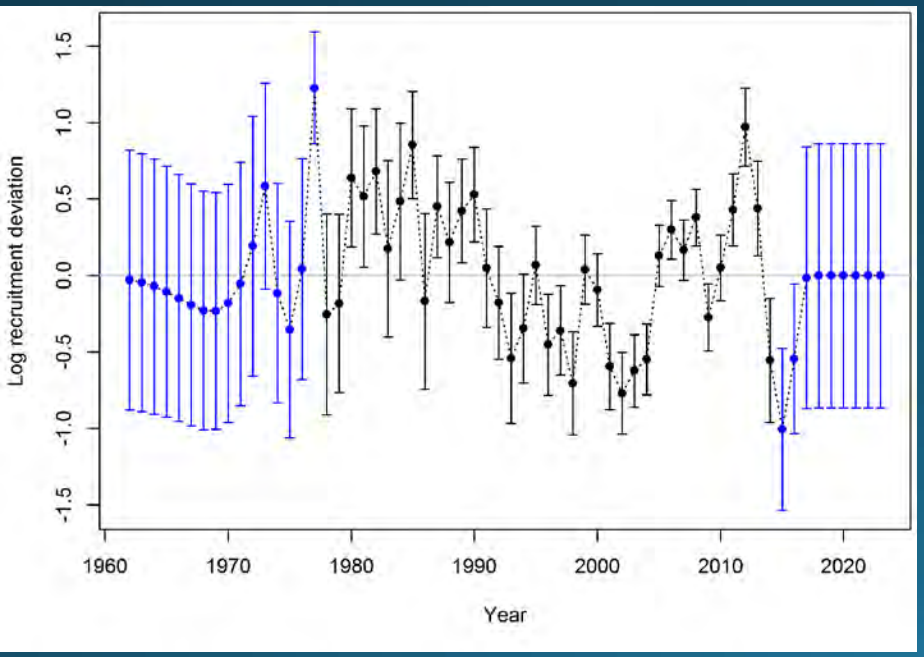


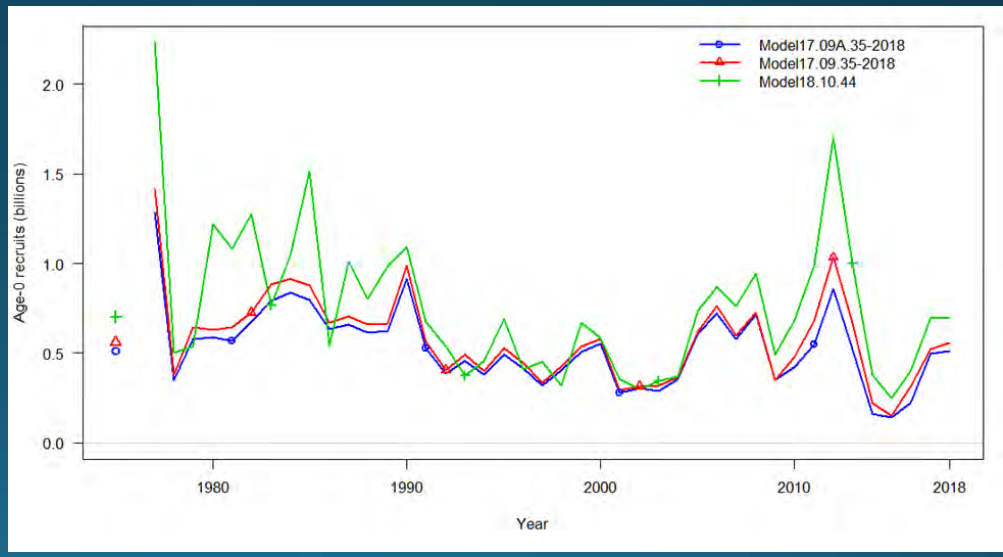




GOA Pacific cod
Assessment Model Recruitment

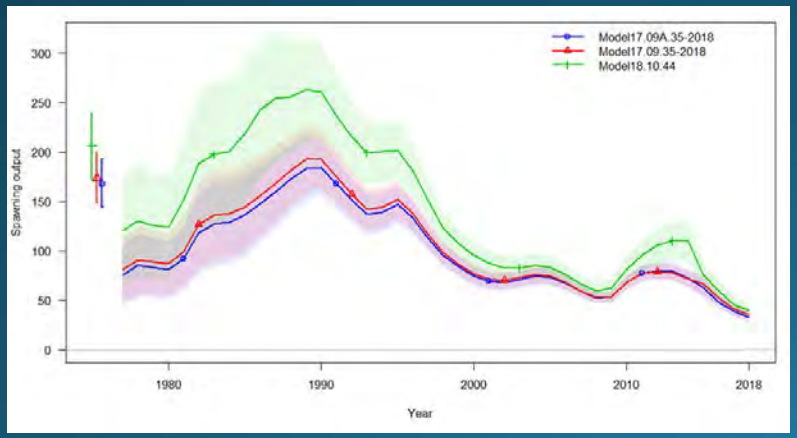
- Low recruitment in the 2014-2016
  - 2015 lowest recruitment estimate in time series at 0.25×10^9
  - 2013, 2014, and 2016 increased in relative strength compared to last year's base model with increase in heatwave M

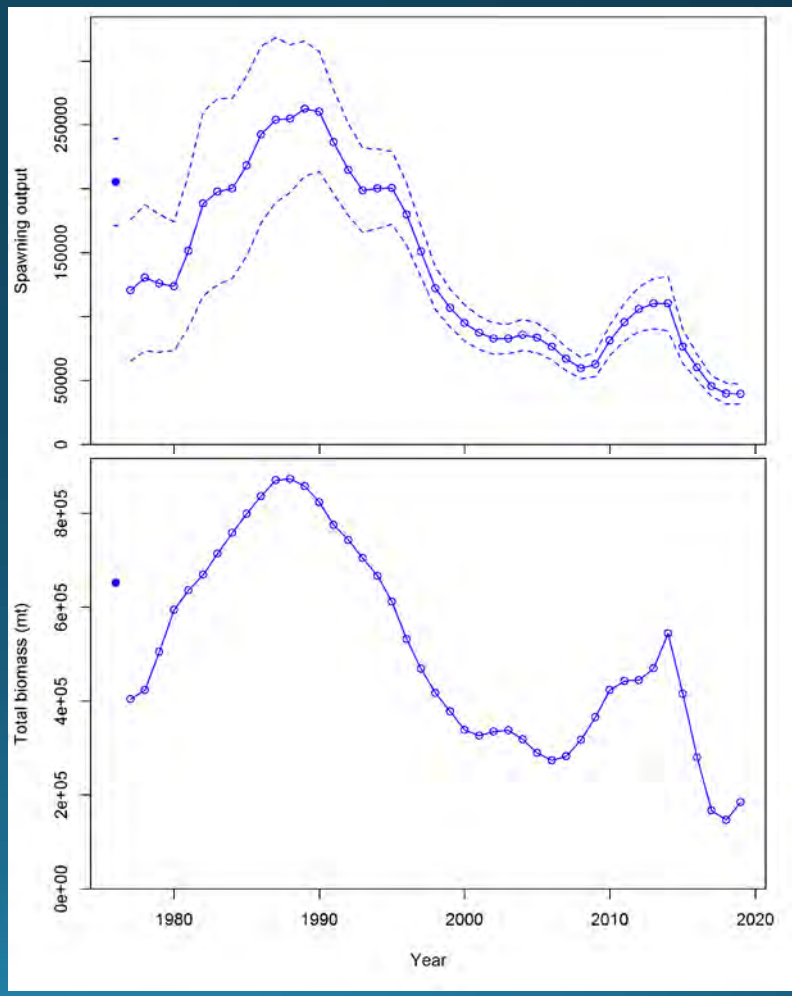




GOA Pacific cod
Assessment Model Spawning Biomass

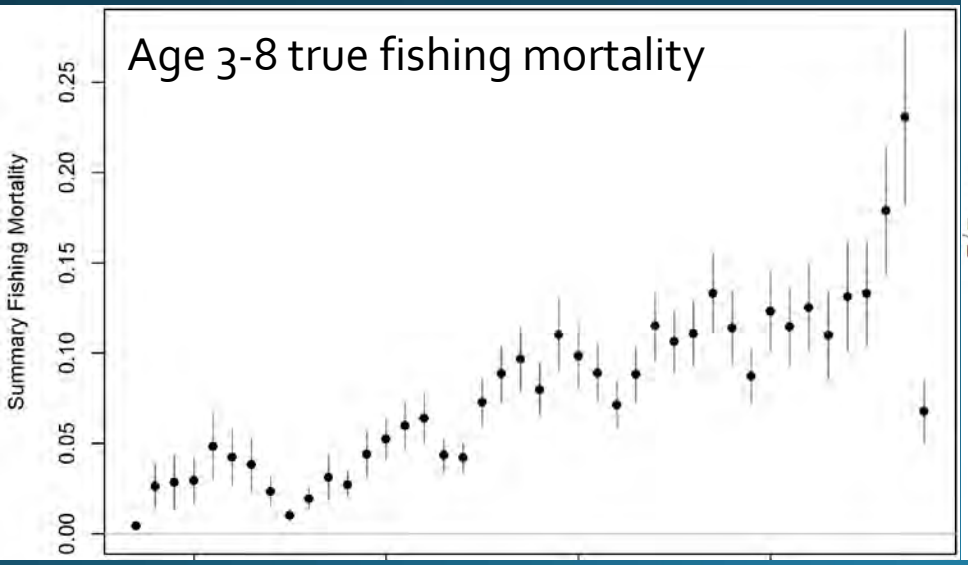
- Lowest female spawning biomass in 2018 (39,723 t)
- Peak female spawning biomass in 1989 (263,180 t)
- 2008 previous low at 59,467 t
- Build up in 2009-2012 based on large 2006-2008 year classes
- Peak in 2014 total biomass due to large 2011-2012 year classes

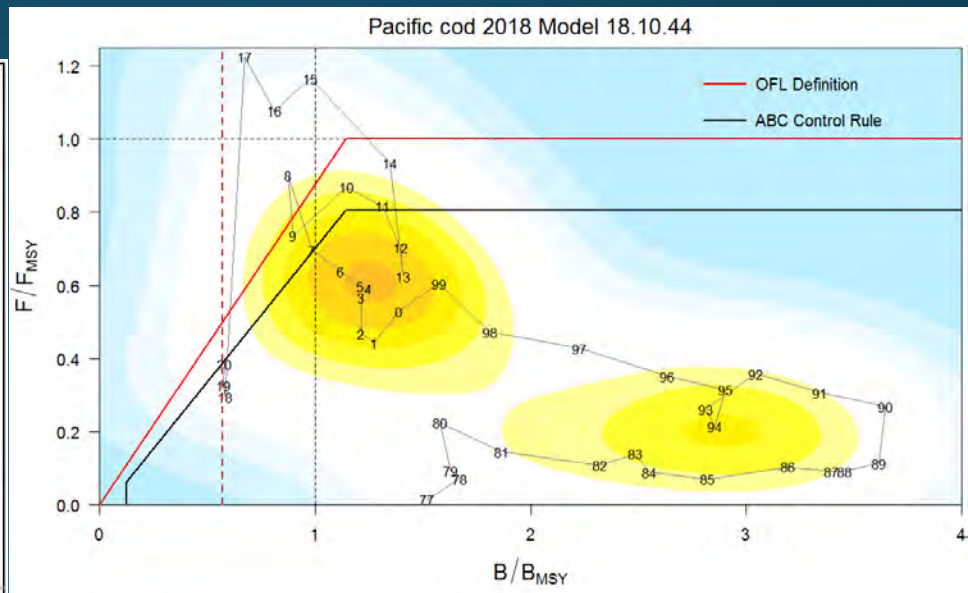




GOA Pacific cod
Model 18.10.44 Fishing mortality

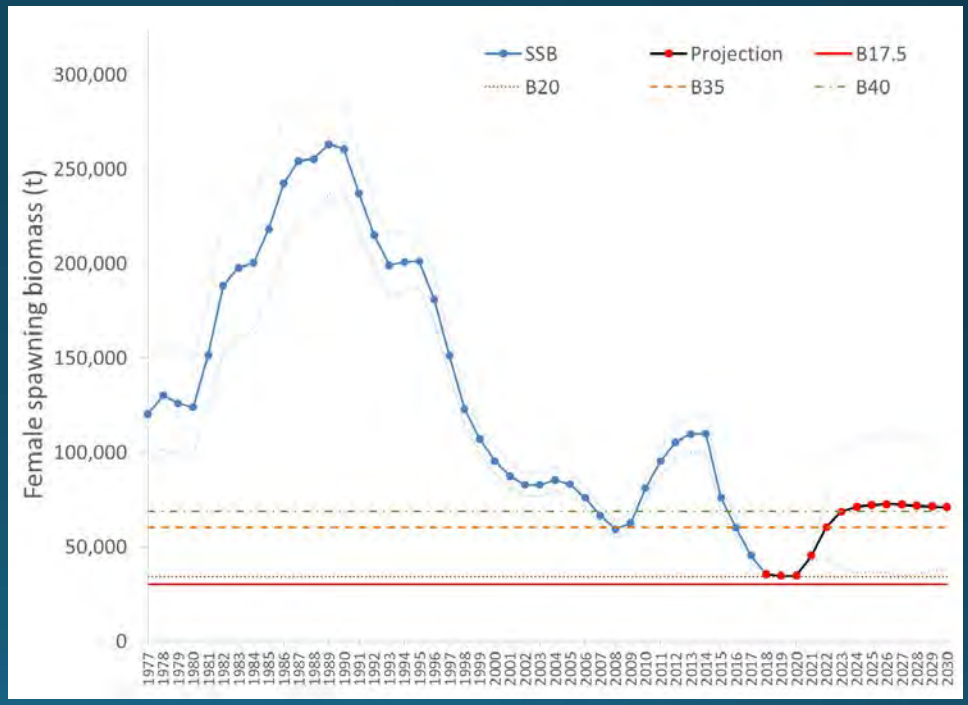
- Relatively high F
  - 2008-2011 and 2014-2017
- Highest F in 2017
- Near B20% for 2018-2019 and projected for 2020



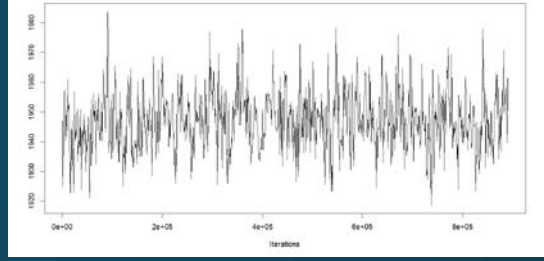


GOA Pacific cod Assessment Model Projections

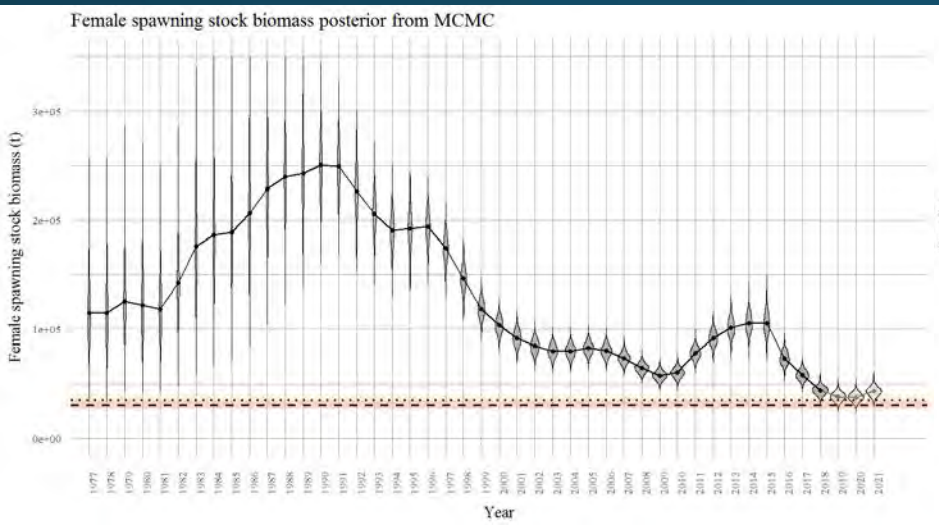
- Spawning biomass projected to reach all-time low in 2020
- Due to high mortality of the 2011 and 2012 age classes and expected poor recruitment 2014-2016
- First increase expected in 2021 given mean recruitment post-2016

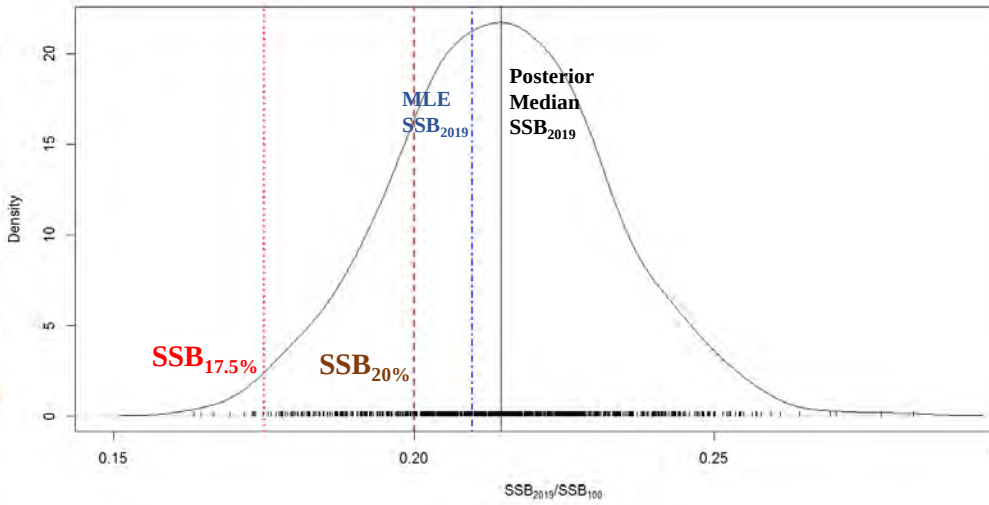


M18.10.44 - MCMC



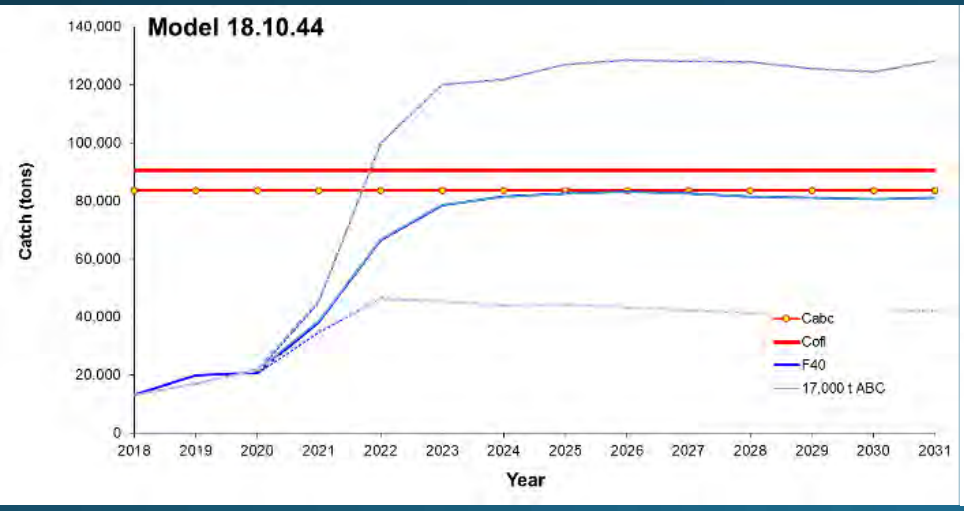
- Well behaved posteriors
  - 1,000,000 iterations (150,000 burn in and thinned by 1,000)
- Results
  - 20.3% probability of being < $B_{20\%}$ in 2019
  - 1.1% probability of being <$B_{17.5\%}$ in 2019

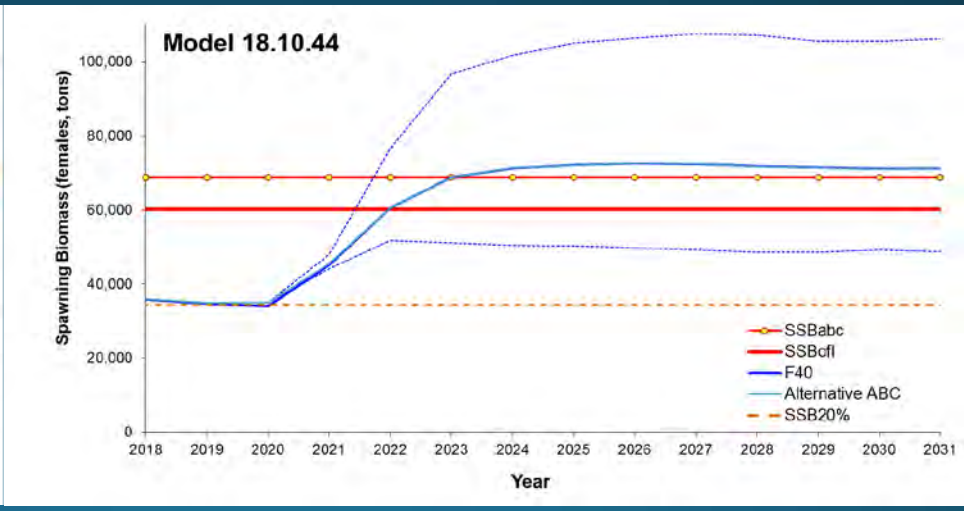




GOA Pacific cod Model 18.10.44 Projections

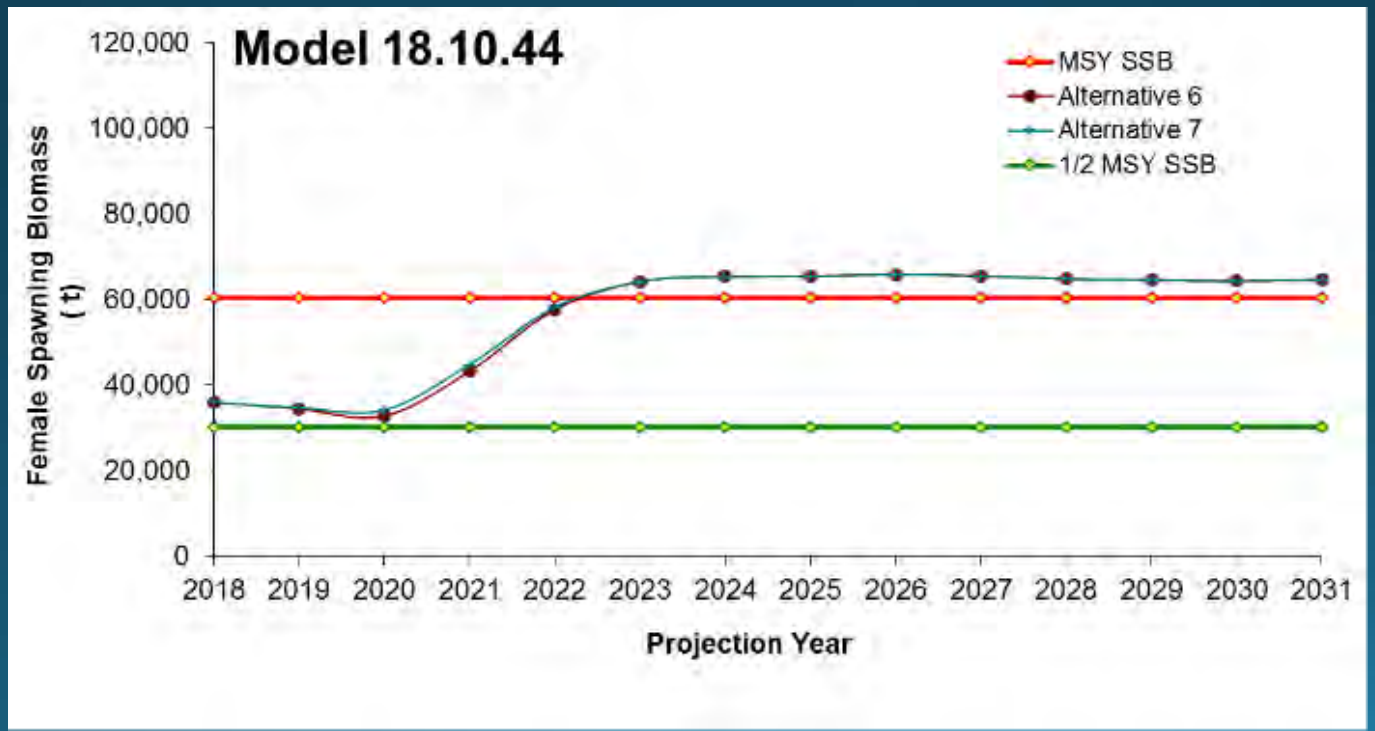
- Expected to go below $B_{20\%}$ in 2020 under Max ABC
- Adjustment of 2019 catch from 19,665 t to 17,000t expected to keep B_{2020} to above $B_{20\%}$





GOA Pacific cod Model 18.10.44 Projections

- Above $B_{17.5\%}$ in 2018 and 2020
- Above $B_{35\%}$ by 2028 and 2030
- Not overfished, not overfishing…



GOA Pacific cod Dorn risk matrix

Assessment-related considerations	Population dynamics considerations	Environmental/ecosystem considerations	Overall score (highest of the individual scores)
Level 2: Substantially increased	Level 4: Extreme concern	Level 2: Substantially increased	Level 4: Extreme concern

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 4:

- Female spawning biomass is currently estimated to be at its lowest point in the 41-year time series considered in this assessment
- three years of poor recruitment in 2014-2016 and increased natural mortality during the 2014-2016 GOA marine heat wave
- With average recruitment it is expected that the stock status will improve, however there are no data to inform Pacific cod recruitment for these years

Environment – Level 2:

- Conditions in 2017 and early 2018 appeared to be substantially improved
- Currently experiencing heatwave (10 Sept – present)
- High probability of el Niño condition in winter 2018-19

GOA Pacific cod Status

- Tier 3b ($B_{2019} = B_{20.0\%}$)
- Same recommendation for 2019 (17,000t)
  - 13% reduction from max ABC
- Increase to max ABC in 2020
  - Relies on 2017 recruits entering spawning biomass

Authors' recommended Model 18.10.44

Quantity	As estimated or *specified last* year for: 2018	2019	As estimated or *specified this* year for: 2019	2020
M (natural mortality rate)	0.49	0.49	0.50	0.50
Tier	3b	3b	3b	3b
Projected total (age 0+) biomass (t)	170,005	199,239	266,066	329,133
Female spawning biomass (t)				
Projected	35,973	34,444	34,701	34,774
$B_{100\%}$	168,583	168,583	172,240	172,240
$B_{40\%}$	67,433	67,433	68,896	68,896
$B_{35\%}$	59,004	59,004	60,284	60,284
F_{OFL}	0.51	0.49	0.36	0.36
$maxF_{ABC}$	0.39	0.39	0.29	0.29
F_{ABC}	0.36	0.37	0.25	0.29
OFL (t)	23,204	21,767	23,669	26,078
maxABC (t)	18,972	17,821	19,665	21,592
ABC (t)	18,000	17,000	*17,000	21,592
Status	As determined *this* year for: 2016	2017	2017	2018
Overfishing	no	n/a	No	n/a
Overfished	n/a	no	n/a	No
Approaching overfished	n/a	no	n/a	No

*Reduction from max to 17,000t to maintain stock above $B_{20\%}$ in 2020 based on estimated end of year catch in 2018 of 13,096 t.

- Area apportionment based on random effects model

	Western	Central	Eastern	Total
Random effects area apportionment	44.9%	45.1%	10.0%	100%
2019 ABC	7,633	7,667	1,700	17,000
2020 ABC	9,695	9,738	2,159	21,592

Aleutian Islands pollock

- Addition of 2018 AI bottom trawl survey data
  - 99.5% increase from 2016
- No change in model
  - 15.1 AMAK (age-based)
- Low catch
  - < 3000 t/year since 1998
  - 2018 Limited directed fishery
    - 188t
    - High POP bycatch
- Proposed EFP for 2019
  - Change limits of POP bycatch to 500t total
  - Instead of 5% bycatch limit per delivery