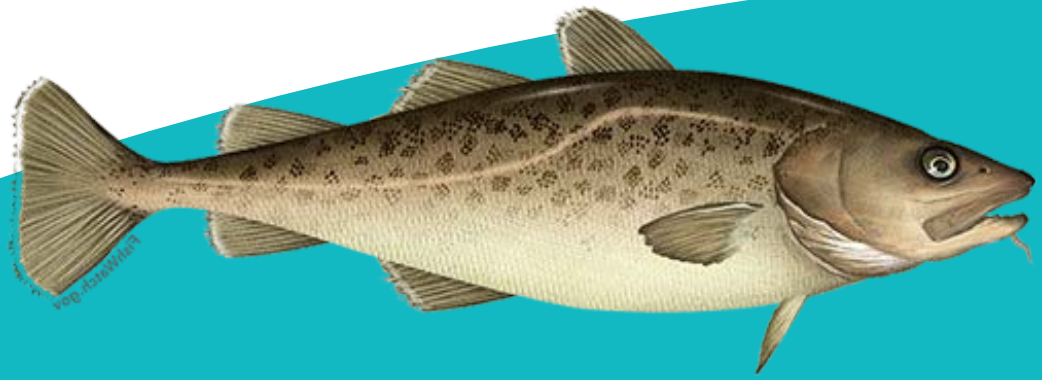

Gulf of Alaska Pacific cod

Steven Barbeaux, Bridget Ferriss, Wayne Palsson, Kelei Shotwell, Ingrid Spies, Muyin Wang, and Stephani Zador

Quantity	As estimated or *specified last* year for: 2020	2021	As estimated or *specified this* year for: 2021	2022
M (natural mortality rate)	0.49	0.49	0.47	0.47
Tier	3b	3b	3b	3b
Projected total (age 0+) biomass (t)	203,373	261,484	265,661	312,783
Female spawning biomass (t)				
Projected	32,958	42,026	39,977	50,813
$B_{100\%}$	187,780	187,780	180,111	180,111
$B_{40\%}$	75,112	75,112	72,045	72,045
$B_{35\%}$	65,723	65,723	63,039	63,039
F_{OFL}	0.27	0.36	0.41	0.54
$maxF_{ABC}$	0.22	0.29	0.33	0.43
F_{ABC}	0.22	0.29	0.33	0.43
OFL (t)	17,794	30,099	28,977	46,587
maxABC (t)	14,621	24,820	23,627	38,141
ABC (t)	*14,621	*24,820	23,627	38,141

- **2021 above $B_{20\%}$**
- 2021 maxABC 23,627t
- 2022 maxABC 38,141t
- 2021 OFL 28,977t
- 2022 OFL 46,587t

Summary of results

Tier 3b stock status in 2021 estimated to be at $B_{22\%}$ and in 2022 at $B_{28\%}$. No overfishing, not overfished, and not approaching overfished.

NOAA FISHERIES

Response to Plan Team and SSC

Plan Team Comments - November 2019

The Team recommended that the author coordinate with IPHC to obtain and evaluate length compositions so that the IPHC RPN index can be investigated within the assessment model.

- Authors coordinated with IPHC for collection of lengths however due to changes in IPHC policy on data collection and COVID-19 pandemic no cod lengths were collected during the 2020 survey.

The Team recommended that the author work with the AFSC FMA Division (Observer Program) to identify alternative ways to collect information on cod for 2019 and beyond given the likelihood of a reduced fishery and expanding displacement of observers with EM and that these efforts should complement ADFG data collection efforts.

- The authors coordinated with the FMA division and data are being collected in non-target fisheries. As there wasn't a directed federal fishery in 2020, there was not opportunity to increases sampling effort for EM fisheries. However lack of biological data from the EM fleet will be a continuing issue in the future when the fishery reopens. Currently ADFG port sampling data are being used to support the assessment model when at-sea federal observer data are not available for a specific time, gear, and area.

NOAA FISHERIES

Response to Plan Team and SSC

Plan Team Comments - November 2019

The Team proposed apportionment percentages that are an average between the apportionments estimated in 2017 and 2019 as an alternative to the 2019 random effects model results. The Team also recommended that the author investigate alternatives of the random effects model that integrates multiple population indices.

- The authors were planning on using IPHC survey results to inform apportionment. Since these data became unavailable for the western GOA, this method will not be considered for this year. We did investigate using the AFSC longline survey results. However using the RPNs from this survey for allocation would result in a substantial shift of ABC to the eastern GOA as 47% and 49% of the total RPN were estimated to be in eastern GOA strata in 2019 and 2020. On average over the full time series, the eastern GOA accounts for 30% of the total Pacific cod RPN for the AFSC longline survey.

NOAA FISHERIES

Response to Plan Team and SSC

SSC Comments - December 2019

The SSC requests the authors compare results from the standard projection model with results from projections generated within the SS model under different assumptions about natural mortality (perhaps time or age-varying) and recruitment.

- Projections using the stock synthesis were conducted and presented here. Model 20.1 is presented as an experimental model with growth modeled as a function of temperature and recruitment as a function of the spawning marine heatwave cumulative index. Other models were explored with natural mortality impacted by the MHWI, however relationships between temperature and natural mortality appeared to be largely driven by the 2014-2016 heatwave event. These models were judged to not provide adequate mechanisms for explaining natural mortality during less extreme conditions.

The SSC recommends that the authors in 2020 choose a model nomenclature of their new models that is more in line with SAFE guidelines, such as Model 19.3, if the base model from 2019 is chosen.

- The authors changed to a simpler model naming convention in line with SAFE guidelines. Model 19.14.48c is not named Model 19.1, this year's experimental model is names Model 20.1 as it has substantial changes from Model 19.1 and is new in 2020.

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Changes in the input data

- Federal and state catch data for 2019 were updated and preliminary federal and state catch data for 2020 were included;
- Commercial federal and state fishery size composition data for 2019 were updated, and preliminary commercial federal and state fishery size composition data for 2020 were included;
- AFSC bottom trawl survey Pacific cod conditional length-at-age data for the GOA for 2019 were included;
- AFSC longline survey Pacific cod abundance index and length composition data for the GOA for 2020 were included;
- All length composition samples with less than 30 fish for a particular area, year, quarter, and gear type were excluded from the dataset. This made up 2% of the data representing < 1% of the overall catch.

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Model changes

- Model 19.1 is Model 19.14.48c, last year's accepted management model with new data
- Model 20.1 is a climate-enhanced Model 19.1
  - Growth – temperature influenced von Bertananffy growth
    - L_∞ and K scaled to mean June SST anomaly
    - L_0 scaled to temperature dependent juvenile growth rate from Laurel *et al.* 2015
  - Recruitment
    - R_0 scaled to the cube of the spawning marine heatwave cumulative index (Feb-Mar HWCI)

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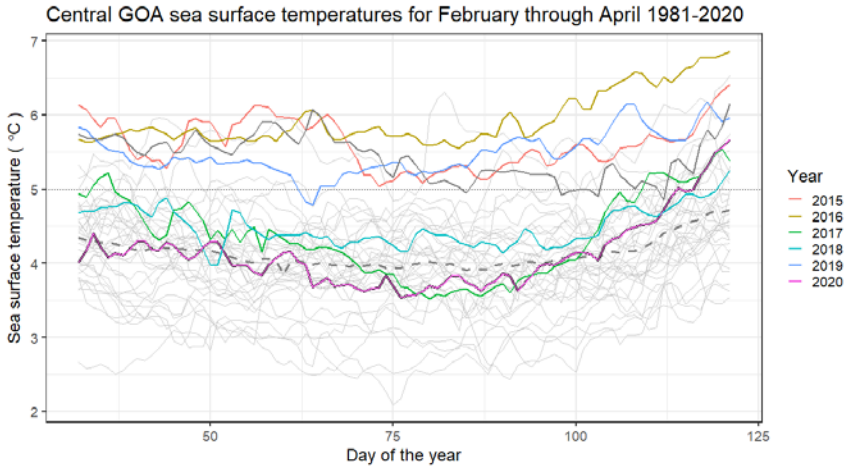
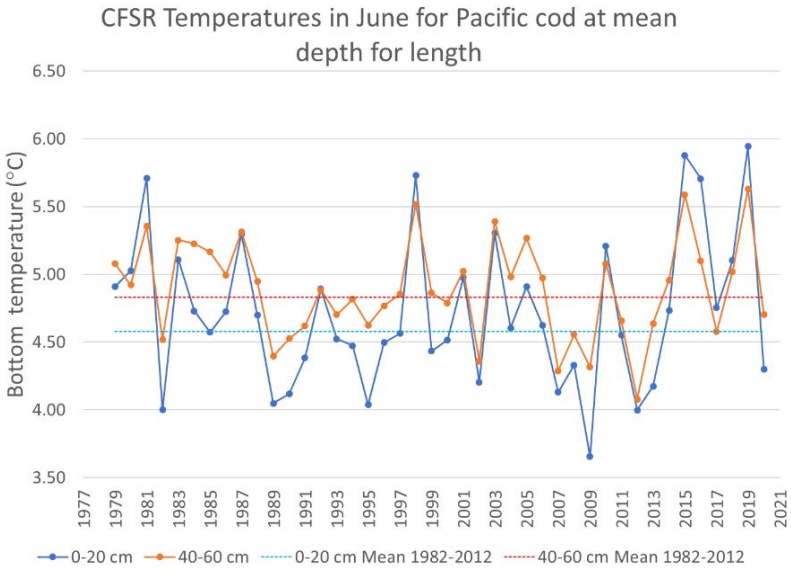


2019 heatwave conditions during spawning

2020 cooler SST during spawning season



2019 warmest June bottom temperatures

2020 cooler June bottom temperatures to below the 1982-2012 mean

Ecosystem data

Sea surface and bottom temperatures were cooler in 2020 Winter and Spring

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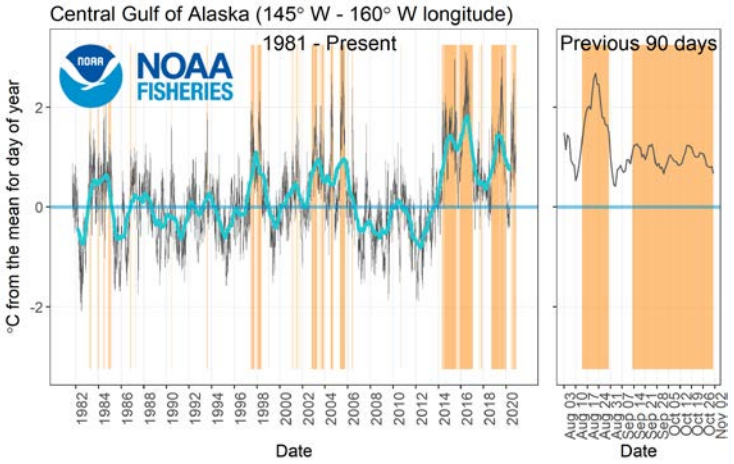
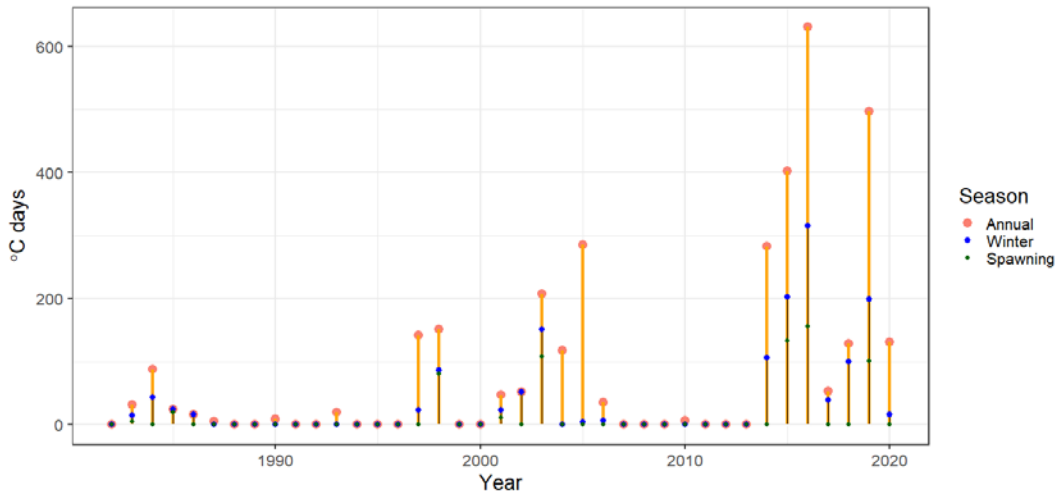
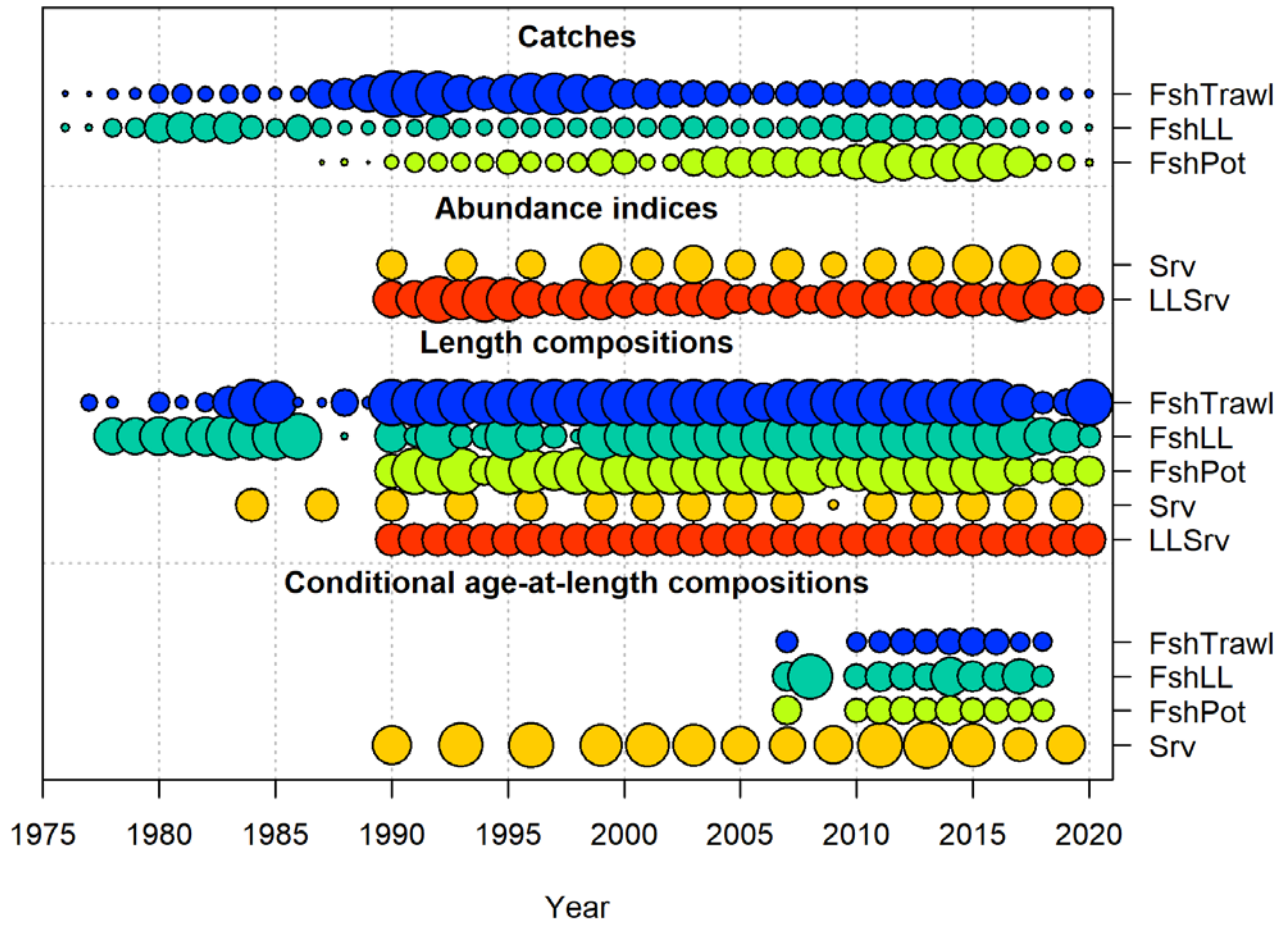




- 2019 heatwave conditions throughout the year
- 2020 heatwave conditions during summer and into fall

Ecosystem data

Temperatures and heatwave indices show a warm 2020 summer and fall



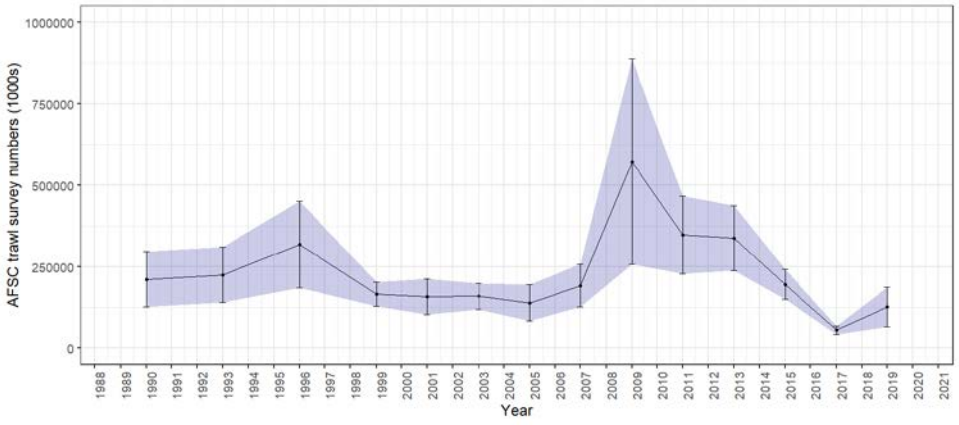
Same as 2019

- Three fisheries
- Two survey indices
- Length composition
- Conditional age-at-length

Data in the models

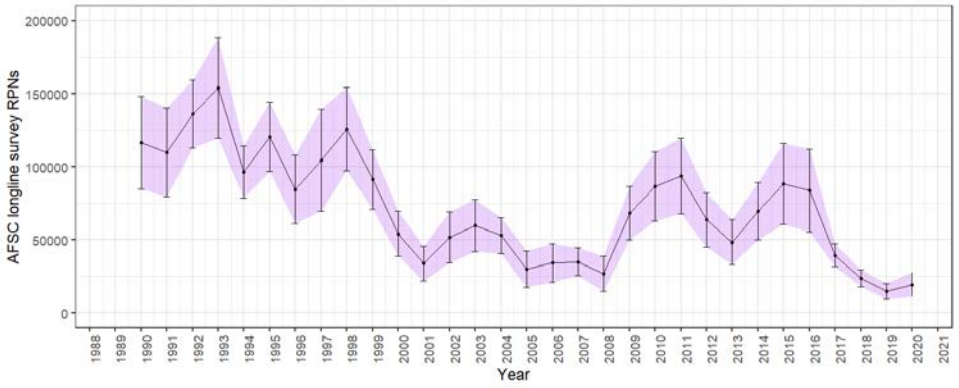
Three fisheries, two surveys, length composition from all, conditional age-at-length composition for Bottom trawl survey and three fisheries.

NOAA FISHERIES



2019 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)



2020 Longline survey

- 30% increase in abundance from 2019
  - Second lowest RPN in time series
  - 2019 lowest estimate in time series

Survey indices: used in model

AFSC bottom trawl and AFSC longline surveys still at low values

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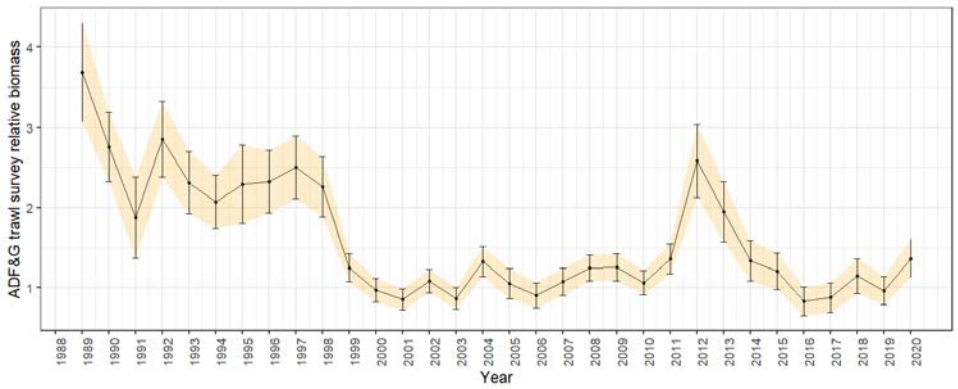
IPHC longline survey

- 2020 reduced survey area not including western GOA strata
  - Data not yet available
  - No Pacific cod lengths measured
- 2019 survey 4% decrease from 2018



2020 ADFG trawl survey

- 2020 survey 41% increase in abundance from 2019

Survey indices: not used in assessment

Some mixed signals, but continued lower abundance for both surveys

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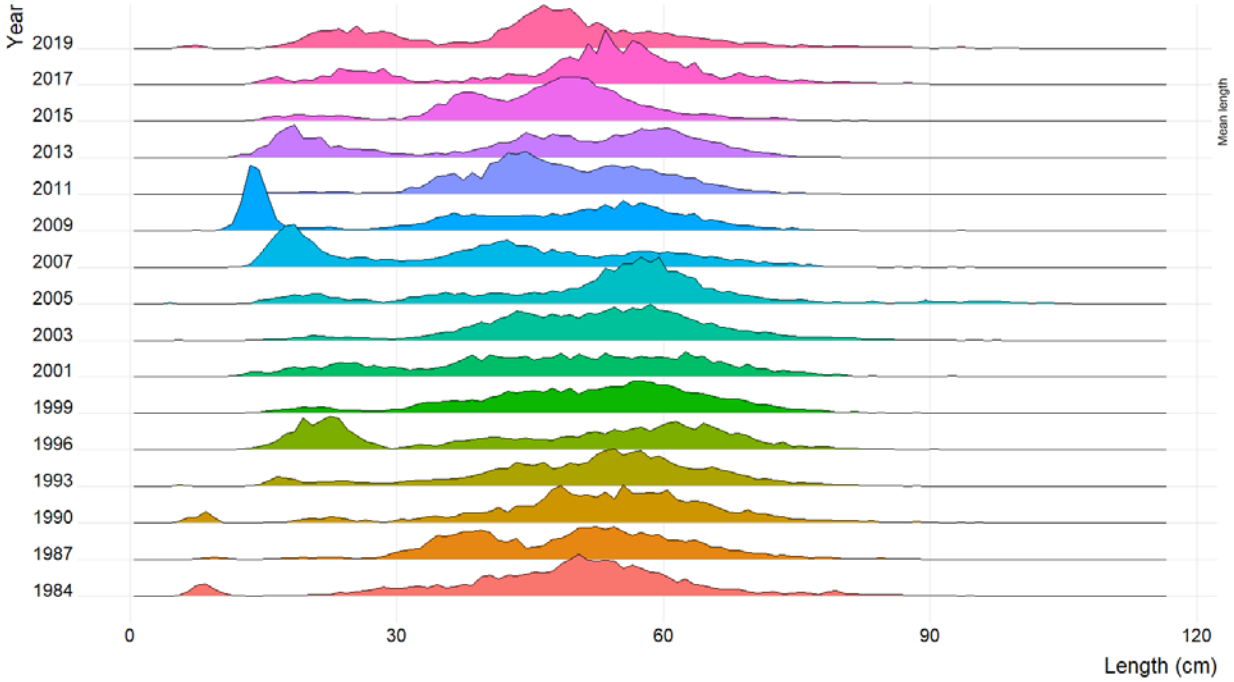
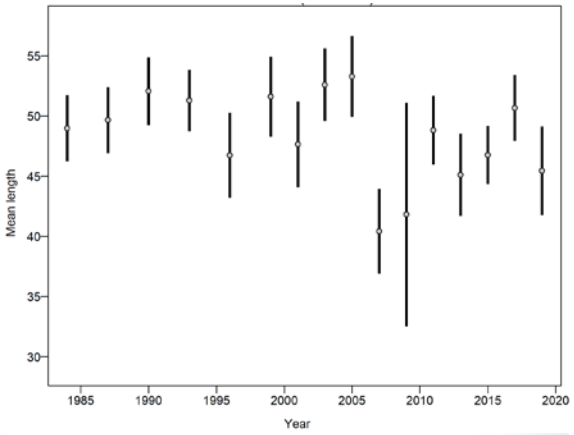
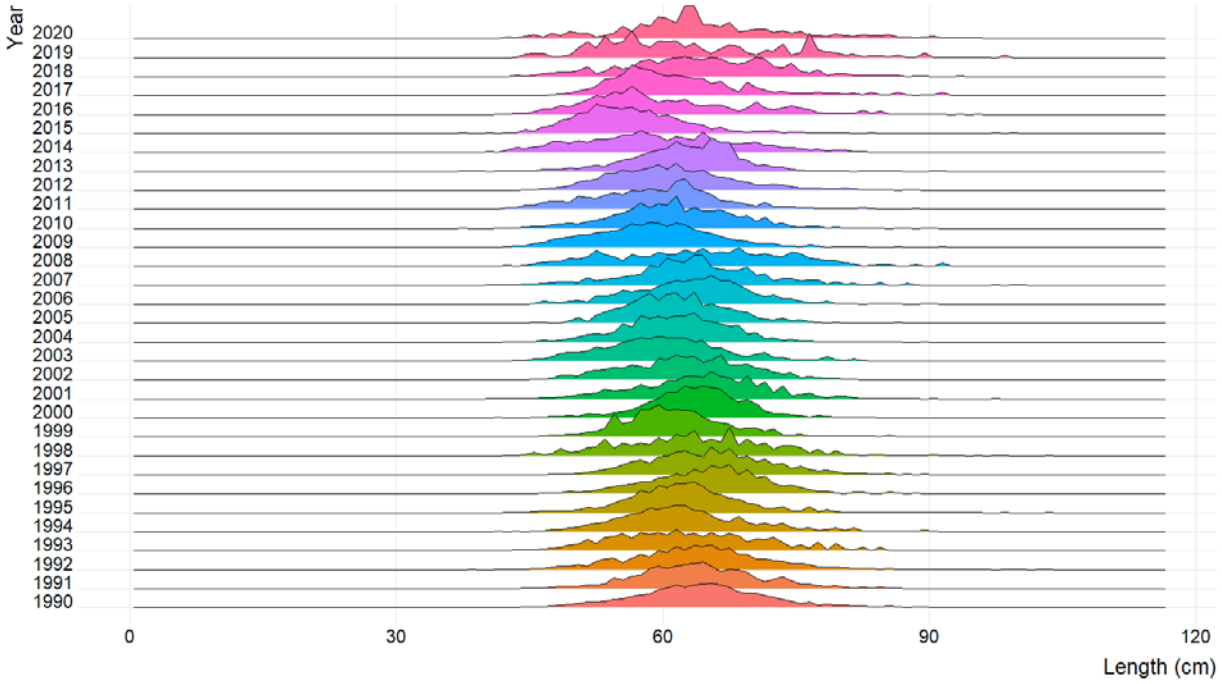


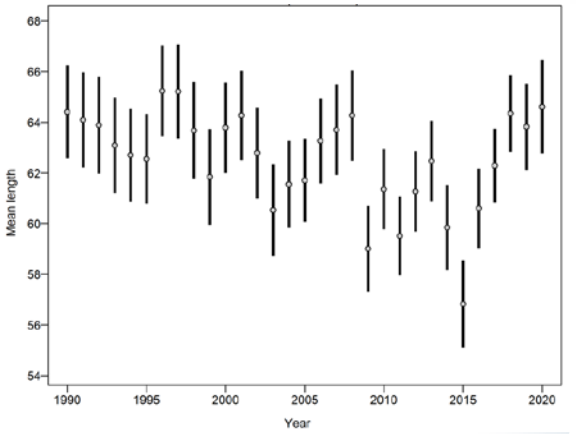


AFSC bottom trawl survey lengths

2019 AFSC bottom trawl survey length composition shows wide distribution with apparent incoming 2017 and 2018 year classes.

NOAA FISHERIES

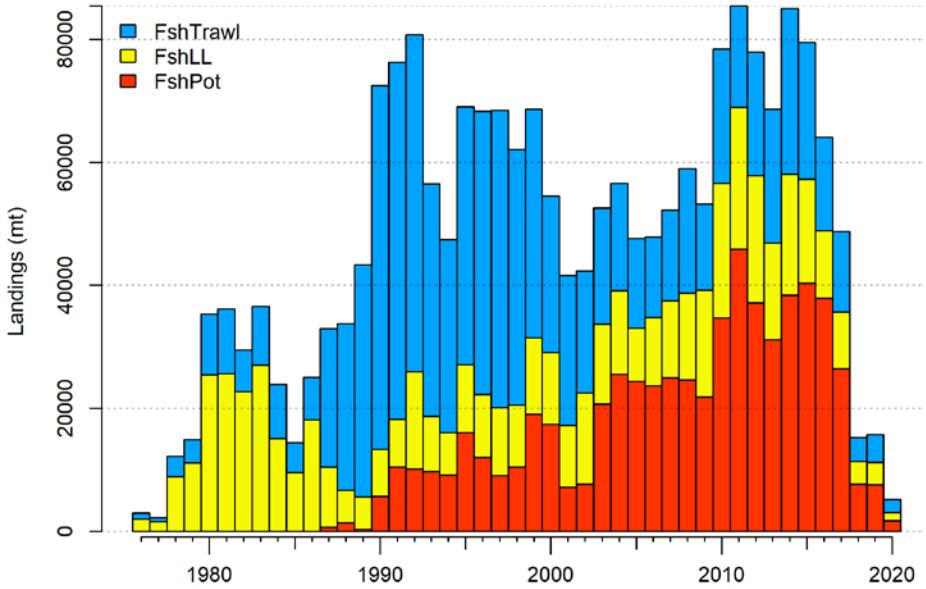


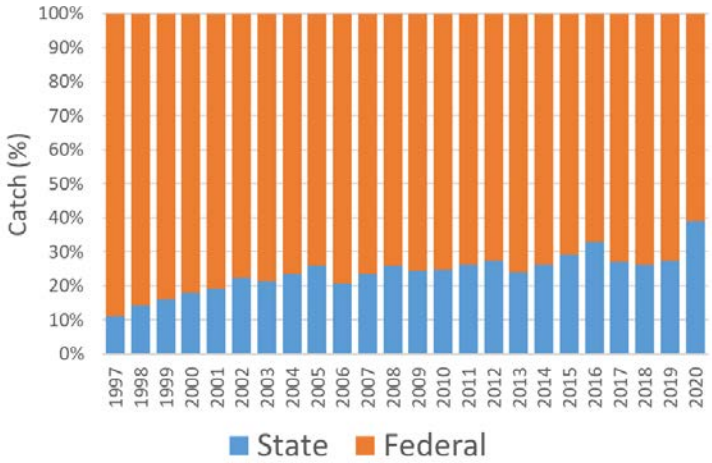


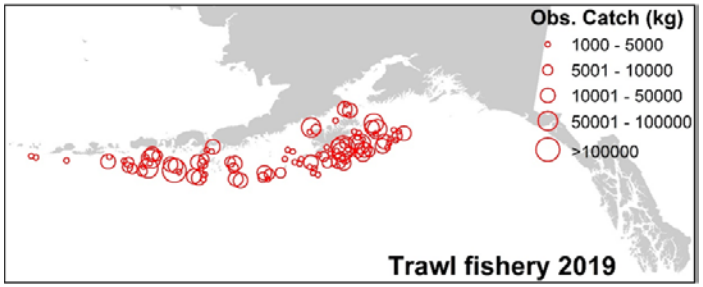
AFSC longline survey lengths

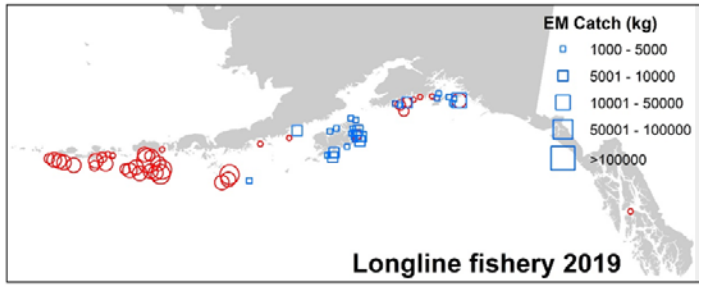
AFSC longline survey length composition larger fish with an increasing mean length in last three years

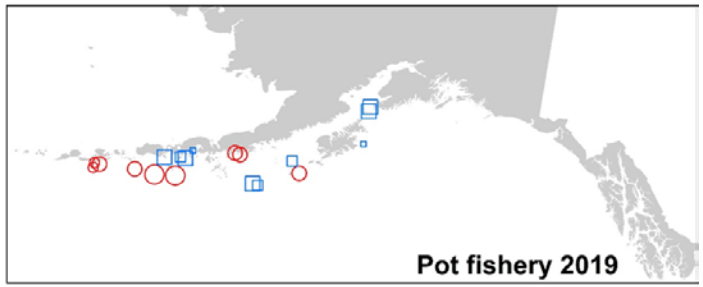
NOAA FISHERIES









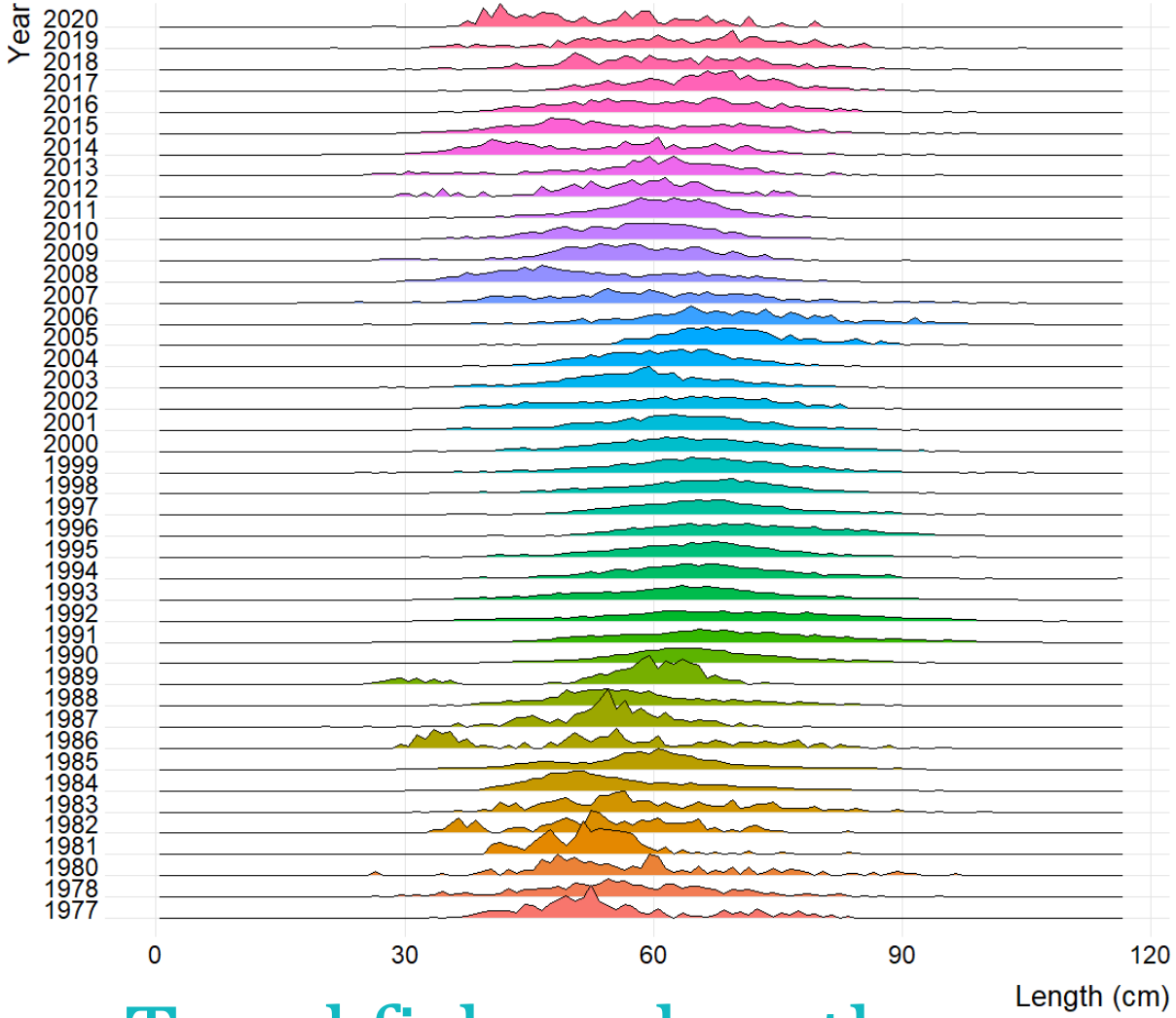


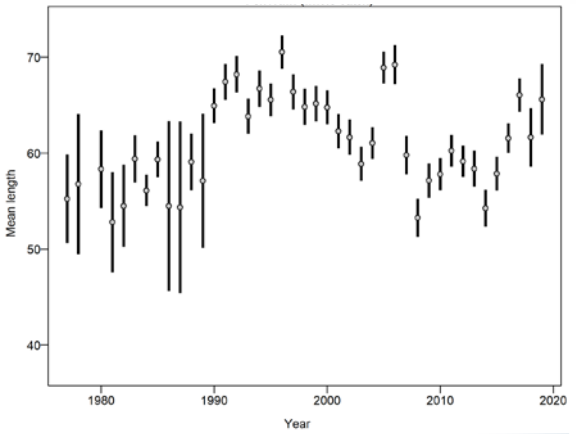
Fishery catch

5,742 t as of 10/14/2020

Drastically reduced catch starting in 2017. Larger proportion of longline and pot fishery monitored electronically. Increasing proportion of catch taken by the state.

NOAA FISHERIES

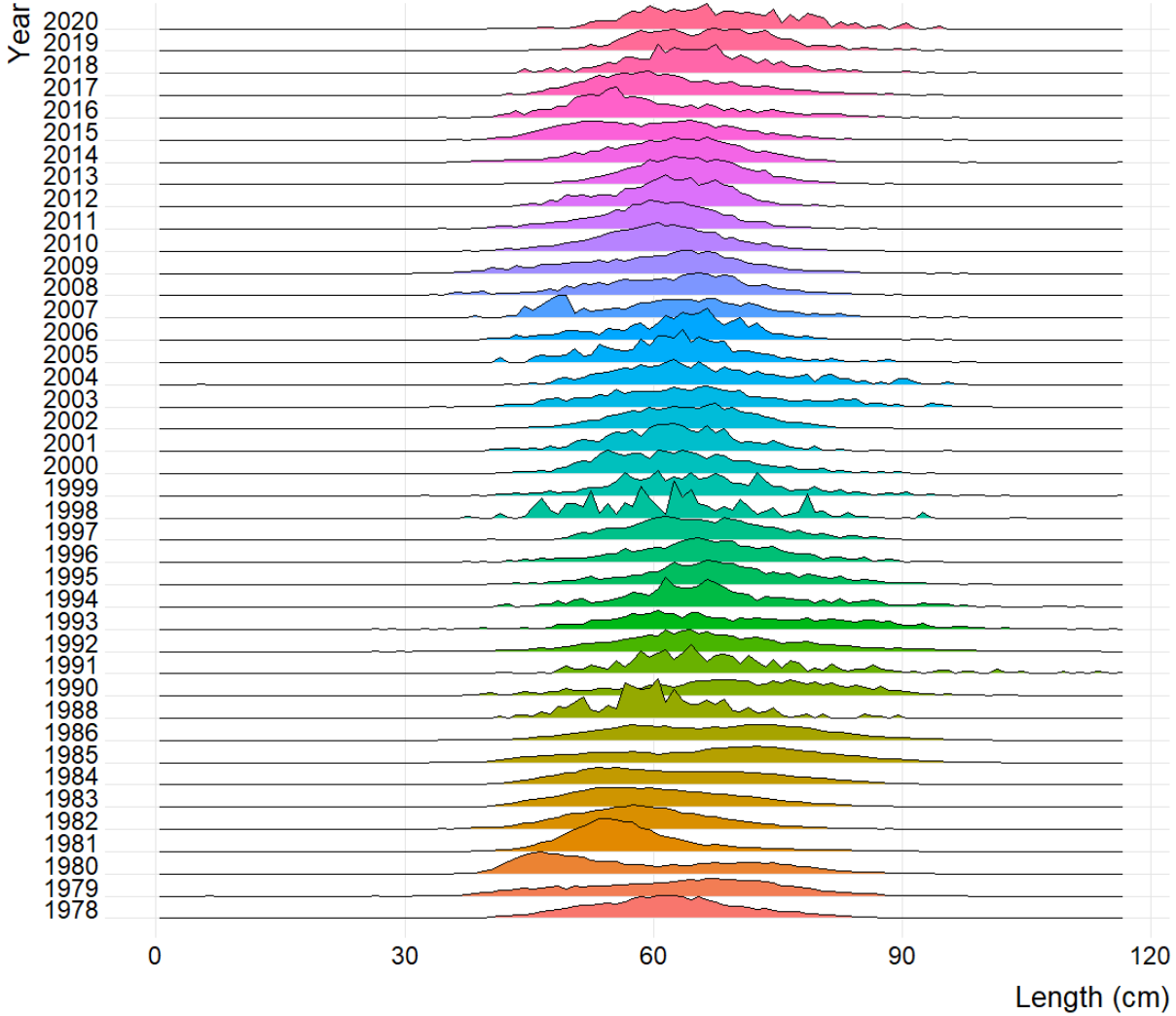


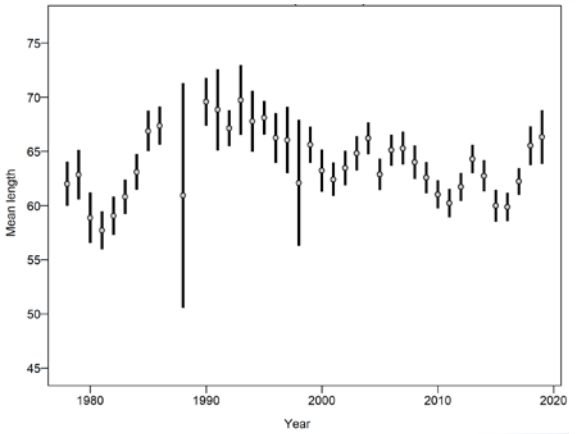


Trawl fishery length composition

Increasing mean size since 2016 with lower recruitment and increased proportion of lengths from non-directed fishery.

NOAA FISHERIES

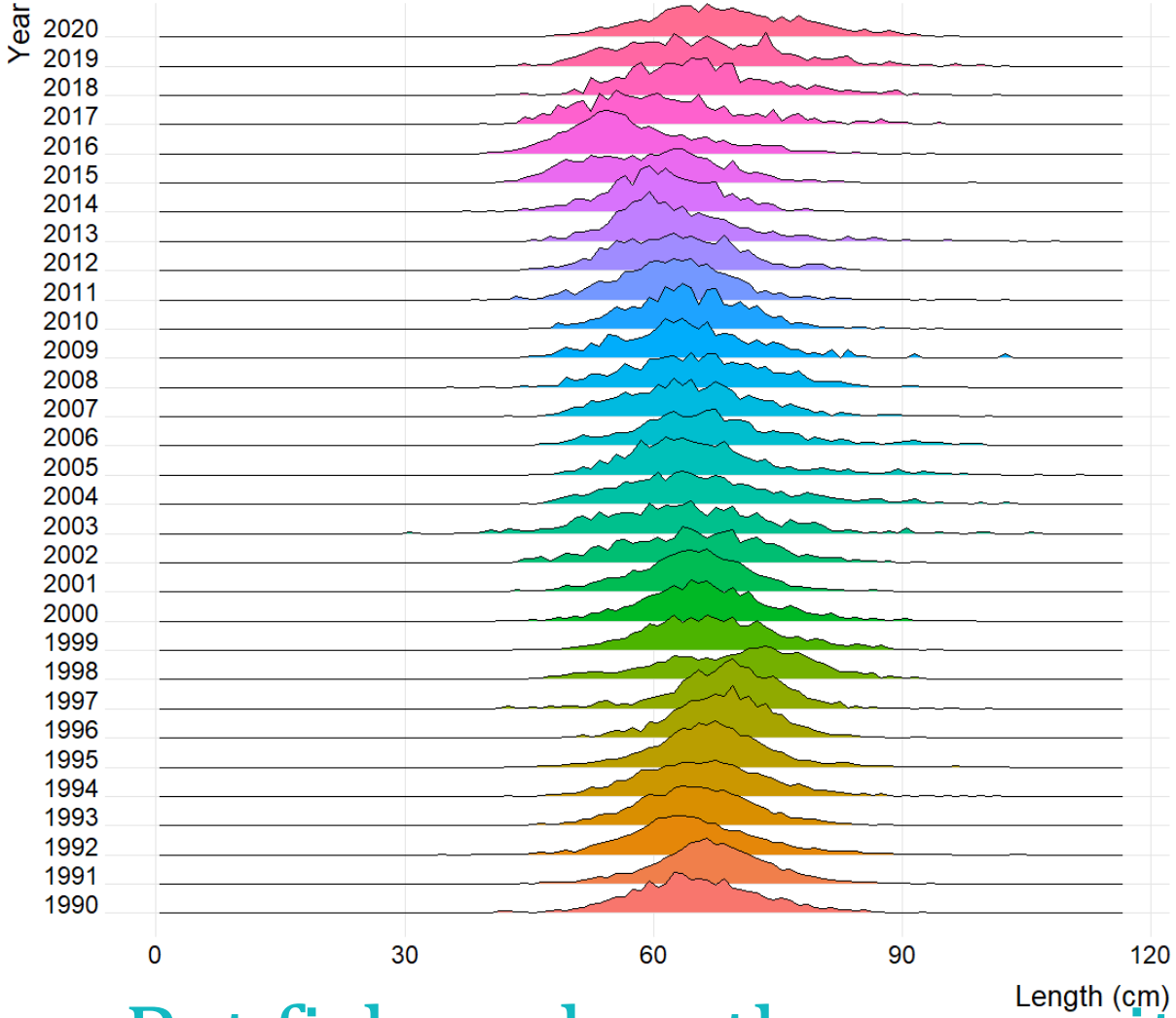


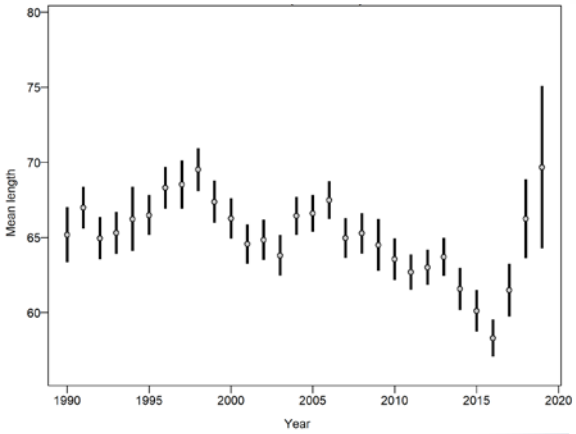


Longline fishery length composition

Increasing mean length in 2019 and 2020 with fewer smaller fish and larger proportion from state port sampling.

NOAA FISHERIES





Pot fishery length composition

Increase in mean length in 2019 and 2020 with fewer small fish also larger proportion from ADF&G port sampling.

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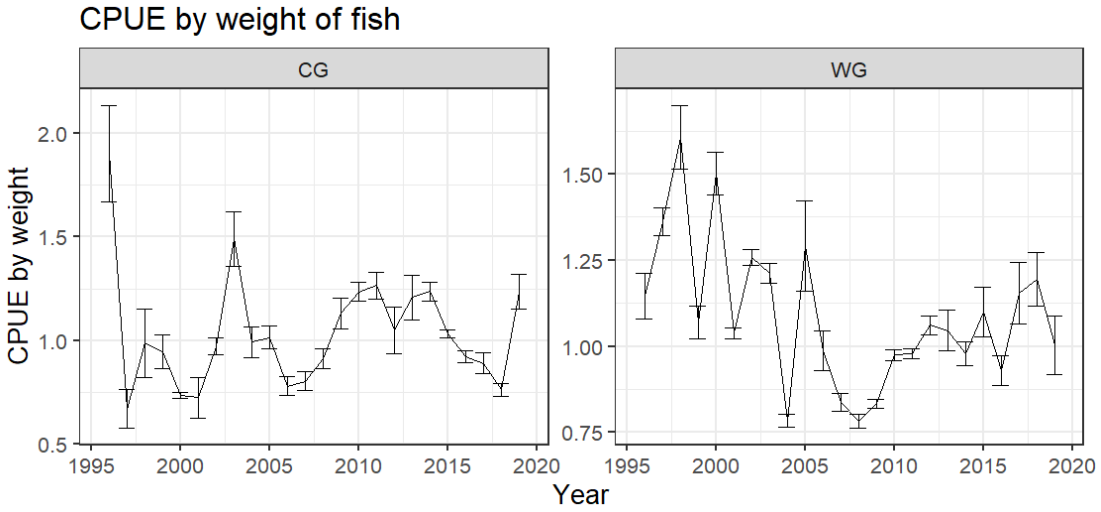
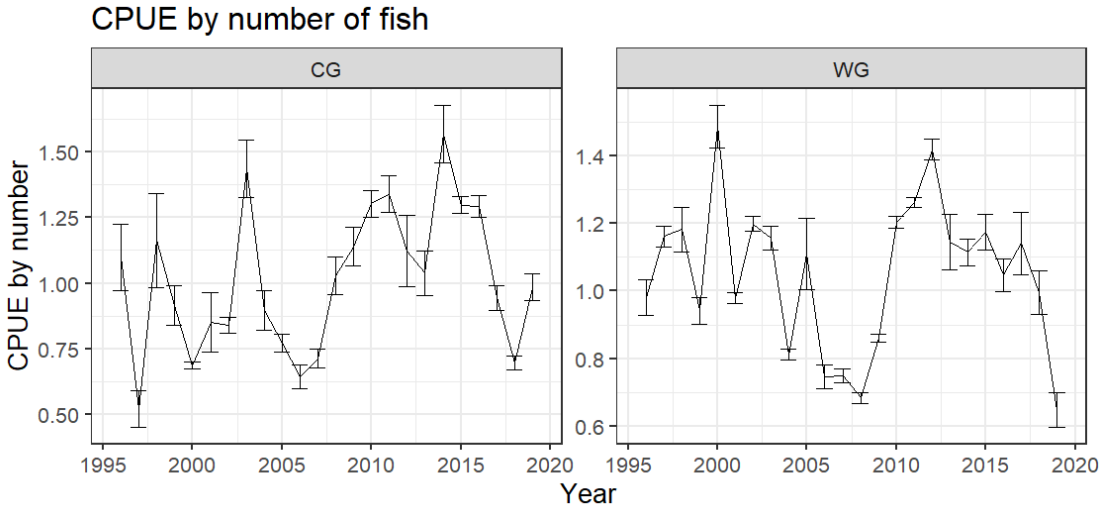


Catch weighted standardized combined gear CPUE



2019 has few longline and pot data in central GOA due to electronic monitoring coverage

Fishery CPUE through 2019

Mixed signal on CPUE but overall drop in CPUE from 2015-2018 in central GOA and variable signal in the western GOA.

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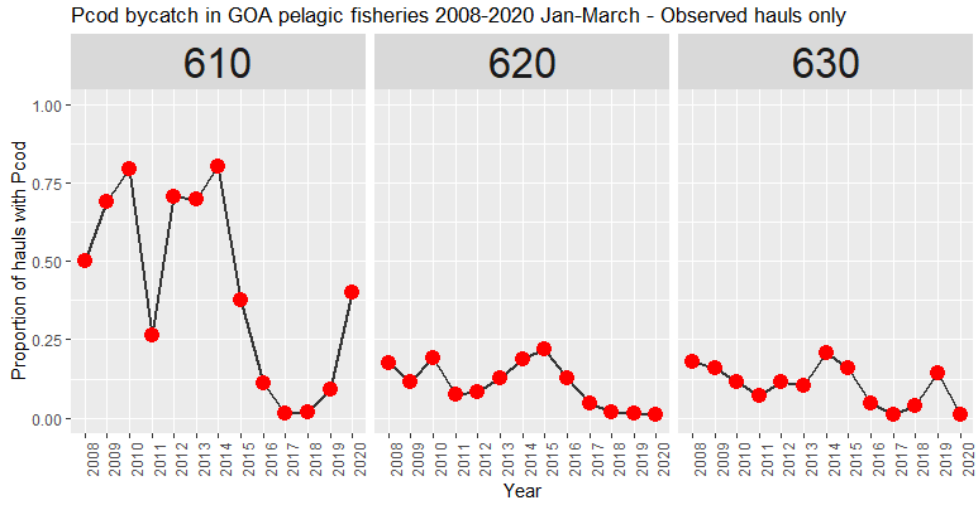
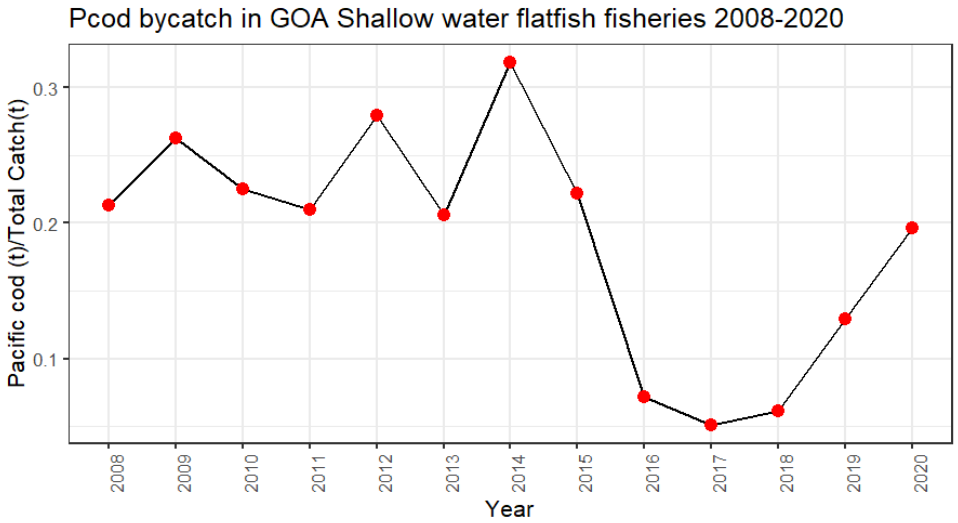


Encounter rate of Pacific cod in the pollock fishery indicates increases in the western GOA, but decreases in central GOA



Shallow water flatfish show a steady increase in bycatch of Pacific cod since 2017 low

Pacific cod bycatch indices

Mixed signals in Pacific cod bycatch

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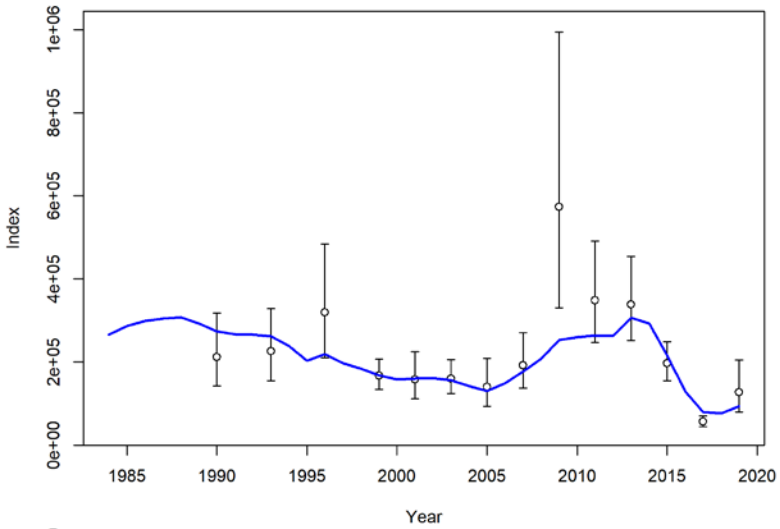

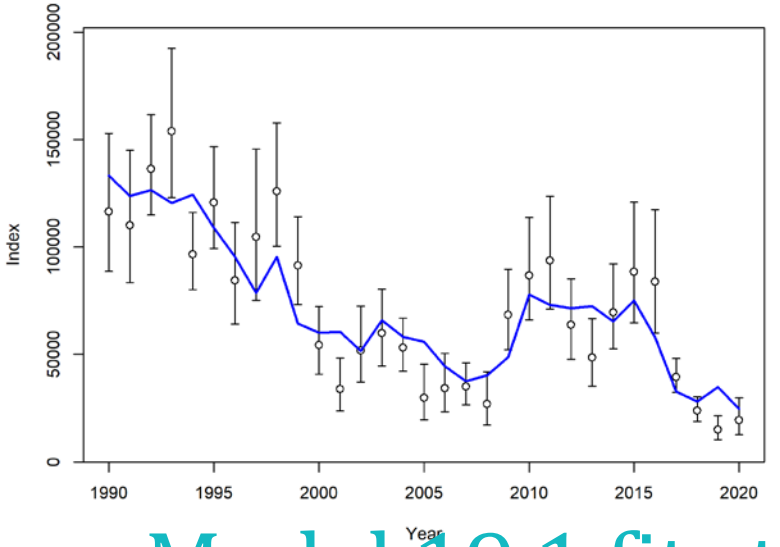

AFSC bottom trawl survey

- Poor fit to high 2009 estimate.

AFSC longline survey

- Catchability scaled to June CFSR temperatures
- Poor fit to low 2019 estimate

Model 19.1 fits to survey indices

Generally good fit to surveys, trawl survey difficulty fitting 2009 survey estimate, the longline survey has difficulty fitting 2019 estimate.

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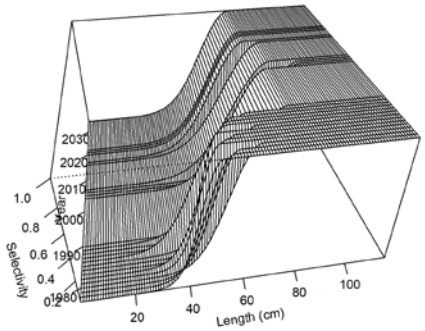
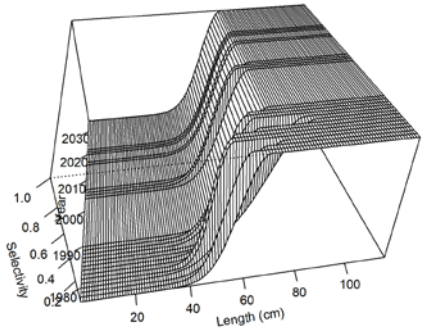
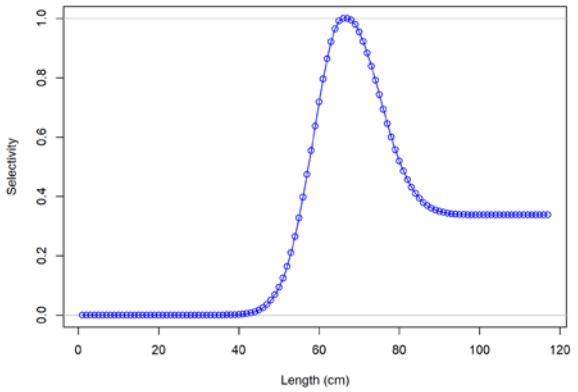
Trawl Fishery



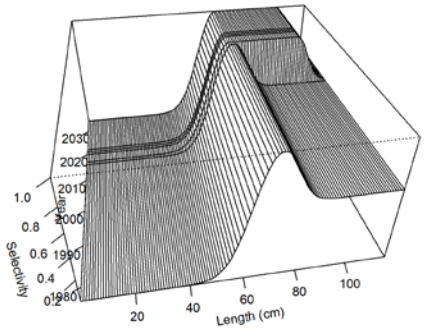
Longline Fishery



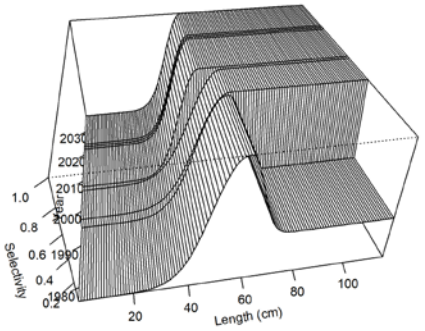
AFSC longline survey



Pot Fishery



AFSC bottom trawl survey



Model 19.1 selectivity

Annual varying and blocks for the AFSC bottom trawl survey and all fisheries, single selectivity for the AFSC longline survey.

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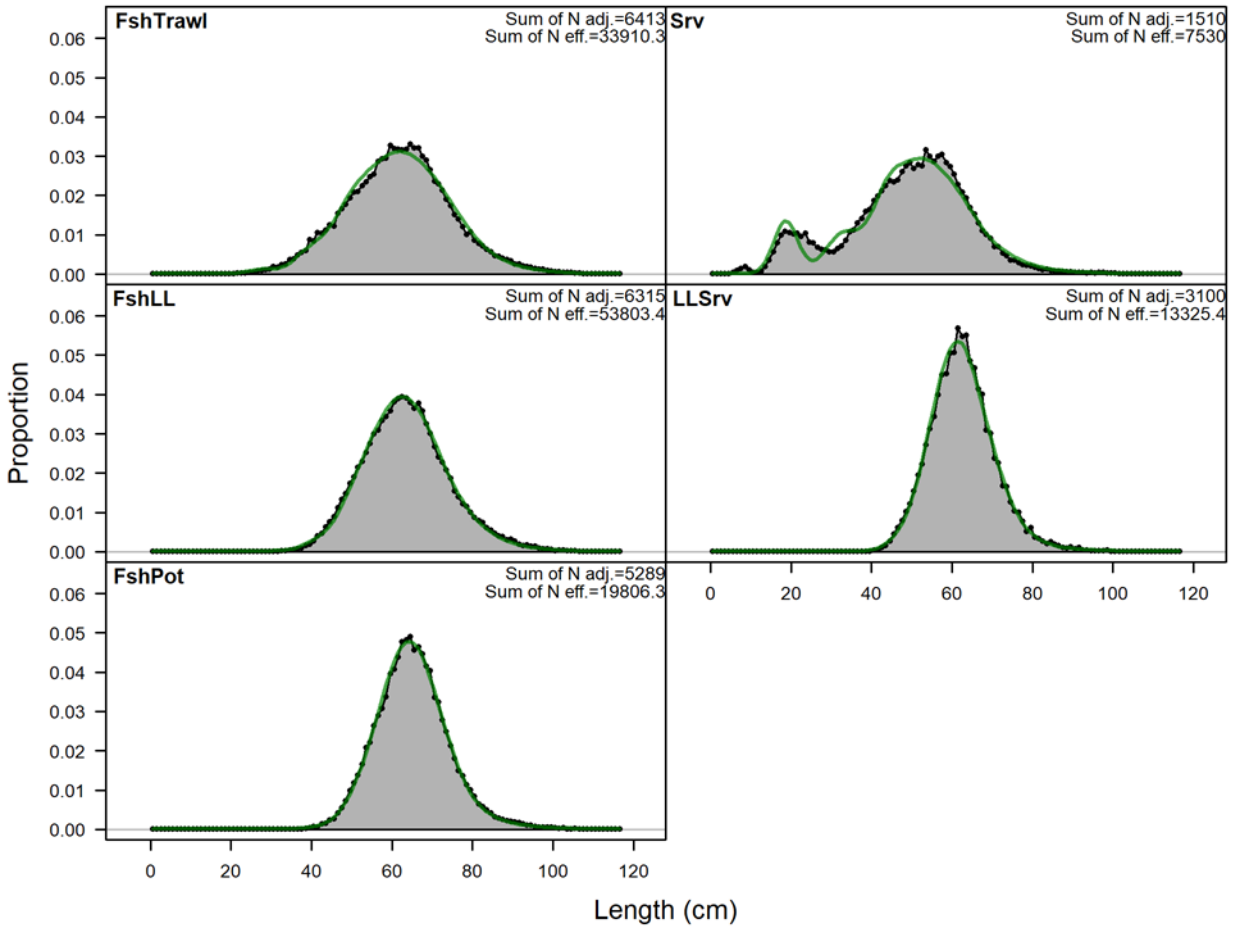

Model 19.1 fit to length composition

Overall good fit to length composition.

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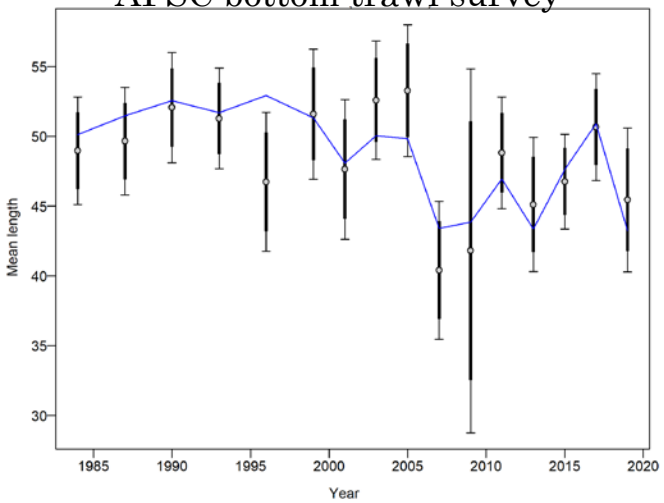
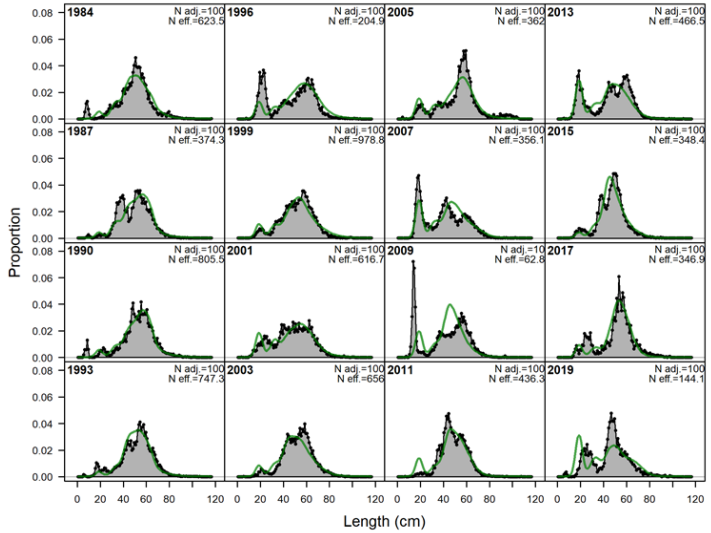
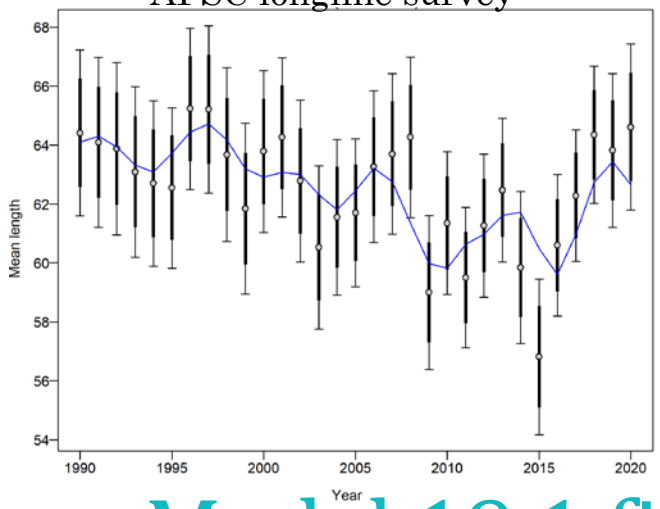
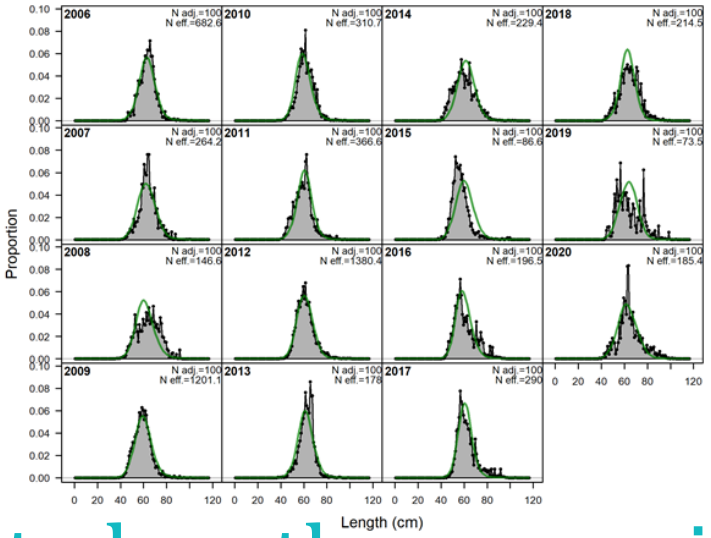
AFSC bottom trawl survey





AFSC longline survey





Model 19.1 fit to length composition

Poorer fits to 2020 survey length composition data as mean length trend diverges between trawl and longline survey data.

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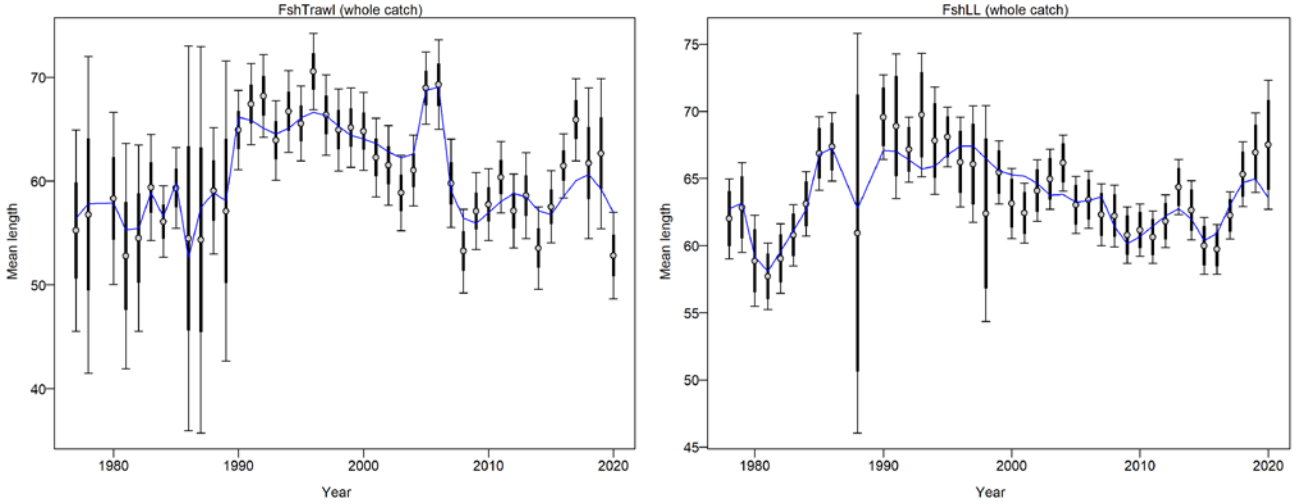

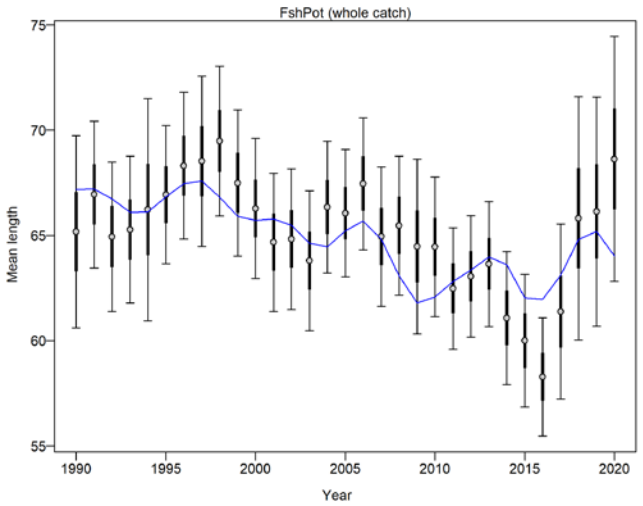

Model 19.1 fit to length composition

Poor fit to 2019 and 2020 length composition data as mean length trend diverges between trawl length composition data and pot and longline length composition data.

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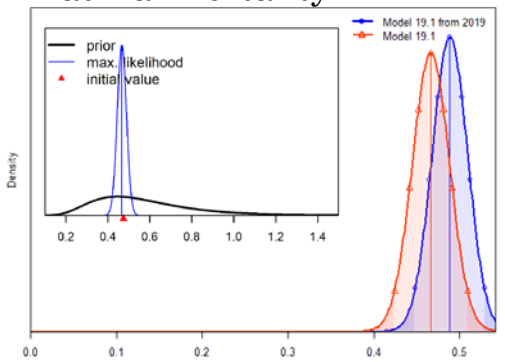
Main model results

- Model 19.1 from last year
  - Natural mortality
    - General estimate to 0.47 (from 0.49)
    - 2014-2016 block to 0.82 (from 0.81)
  - Survey catchability
    - Q_{BTS} to 1.16 (from 1.08) effective Q of 0.94
    - Q_{LL} between 1.1 and 1.9 (little difference from 2019)
      - Fit to 0-20cm CFSR temps
  - Recruitment
    - Lower recruitment 1977-2013 and 2019-2020 due to lower M
    - Lower 2015-2017 recruitment estimates
    - Higher 2018 estimate

Natural mortality



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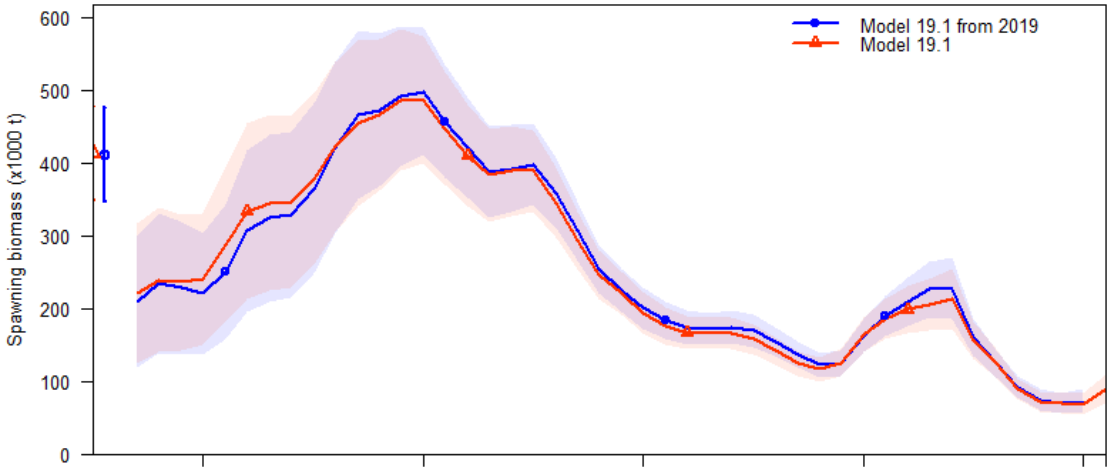

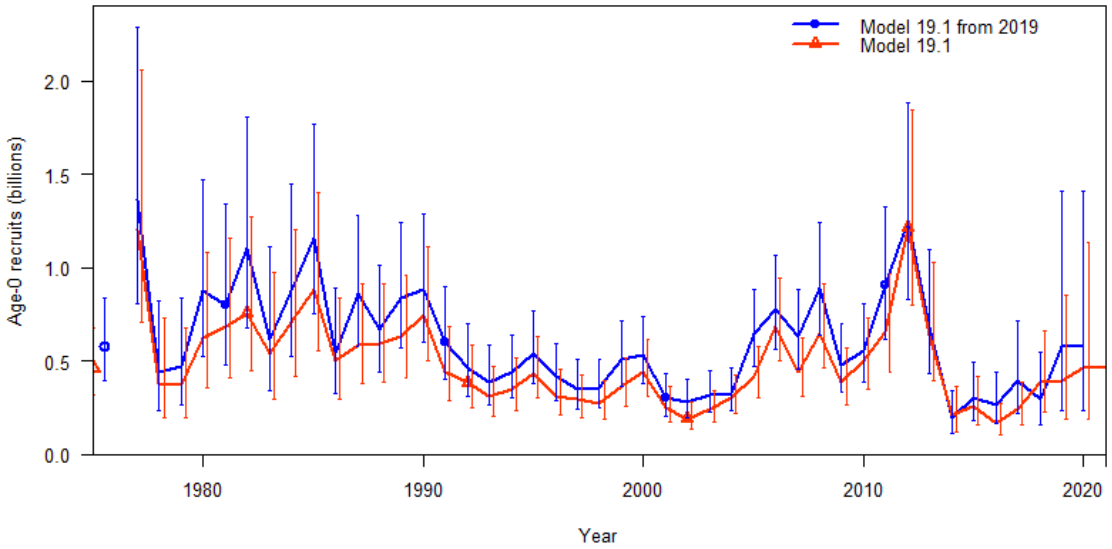

- Model 19.1 results in similar SSB to 2019 reference model

- Scale of recruitment differs for this years models due to change in natural mortality estimate.

Model 19.1 comparison with previous year

Slight reduction in peak SSB in 2012-2015 with lower natural mortality.

Lower recruitment with lower natural mortality estimate.

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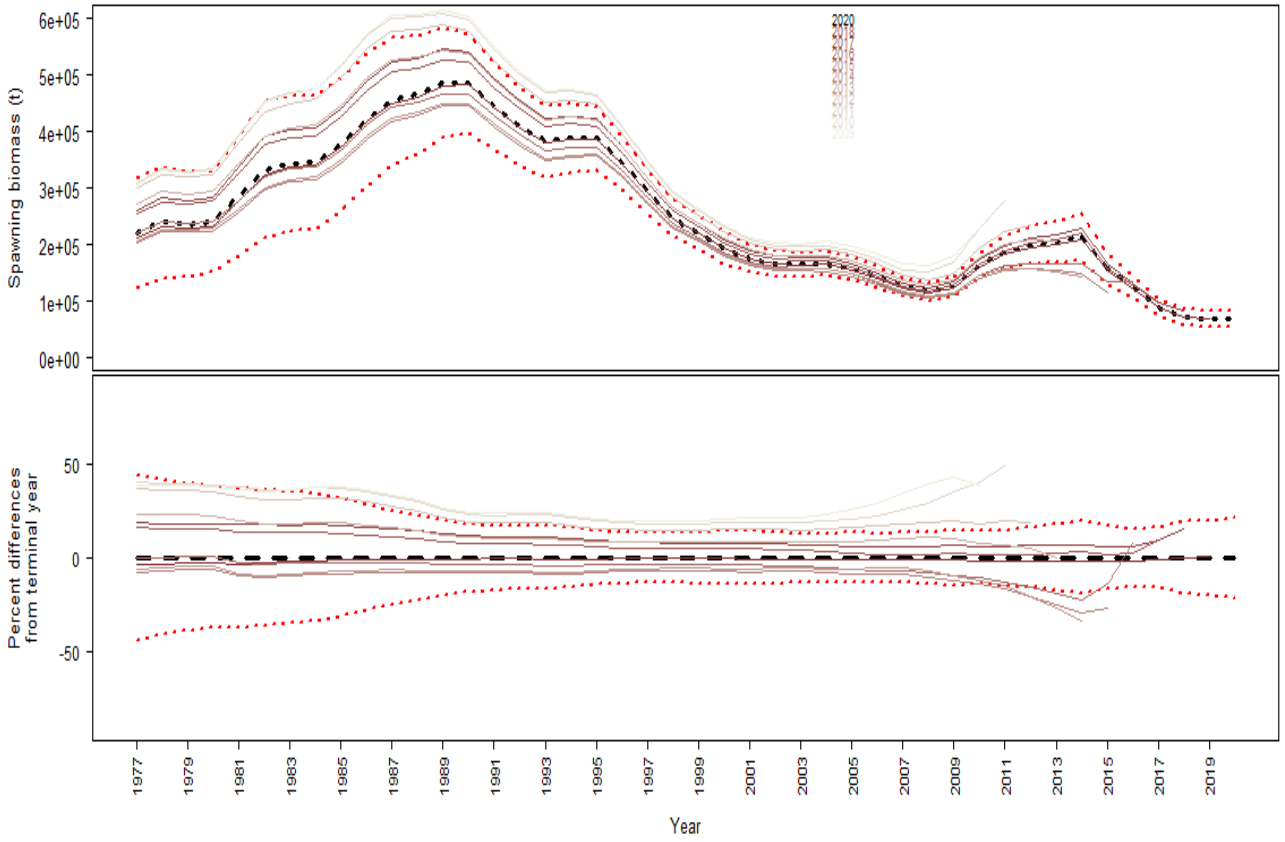

- SSB
  - Mohn's ρ = 0.08
  - WH ρ = 0.08
  - RMSE = 0.15
- Recruitment
  - Mohn's ρ = -0.06
  - WH ρ = 0.04
  - RMSE = 0.22

Model 19.1 retrospective bias

Low retrospective bias in both spawning biomass and recruitment

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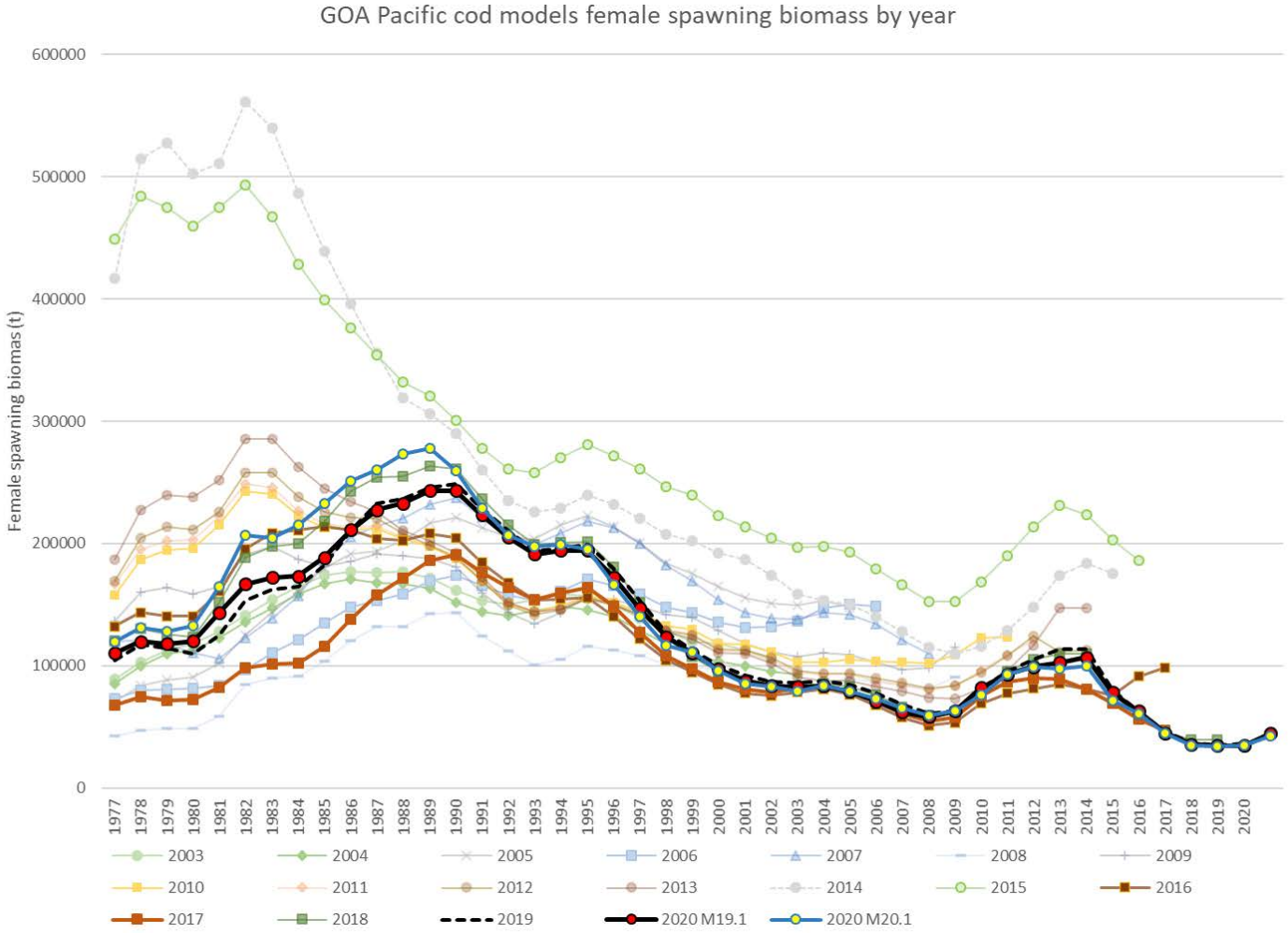

Model 19.1 compared to previous years

Model 19.1 similar results to previous 3 models.

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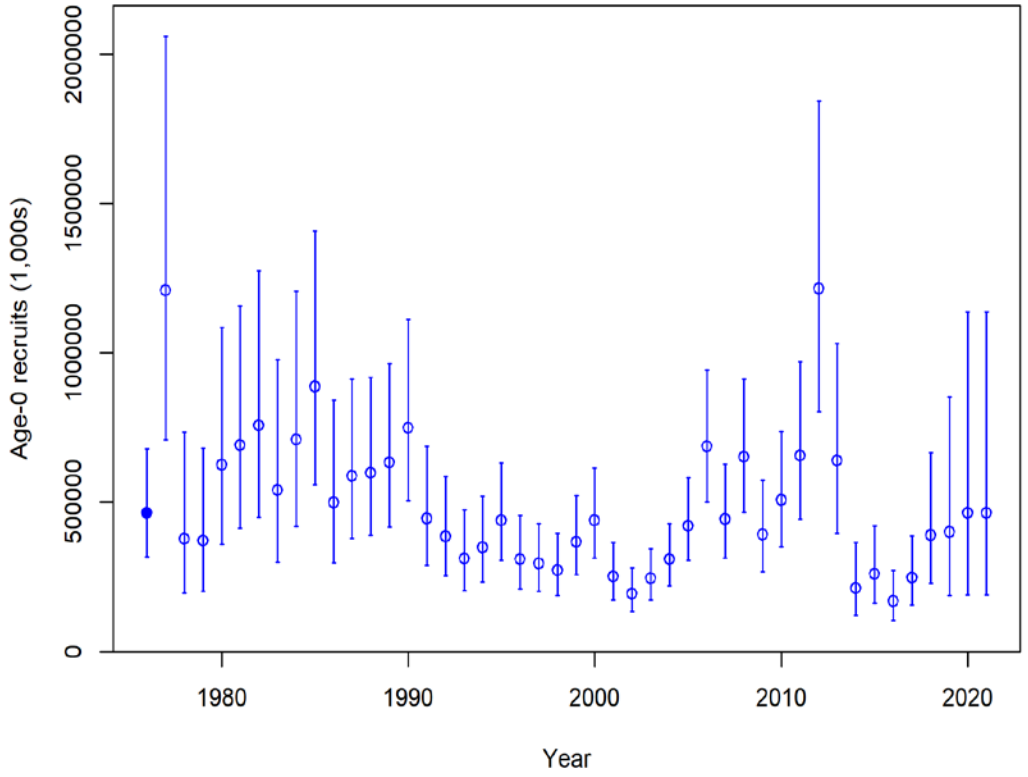

- Poor recruitment since 2014
- Recent fishery carried on 2010-2013 year classes
- 2018 recruitment better, but still projected to be below average recruitment
- 2019 recruitment modeled as near average even though most indicators suggest it is much lower
- Although modeled as average we have no data on 2020

Model 19.1 recruitment

Poor recent recruitment post-2013. 2018 better recruitment, but little data to inform 2019. Post-2019 is average recruitment.

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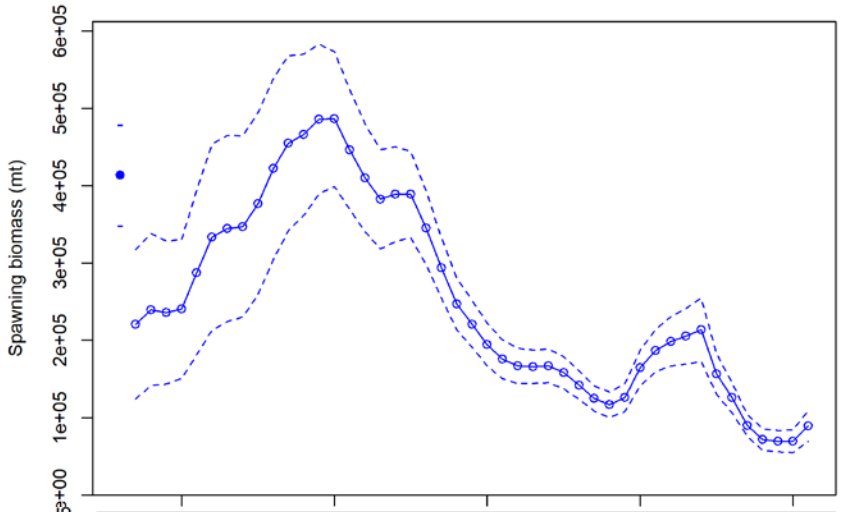

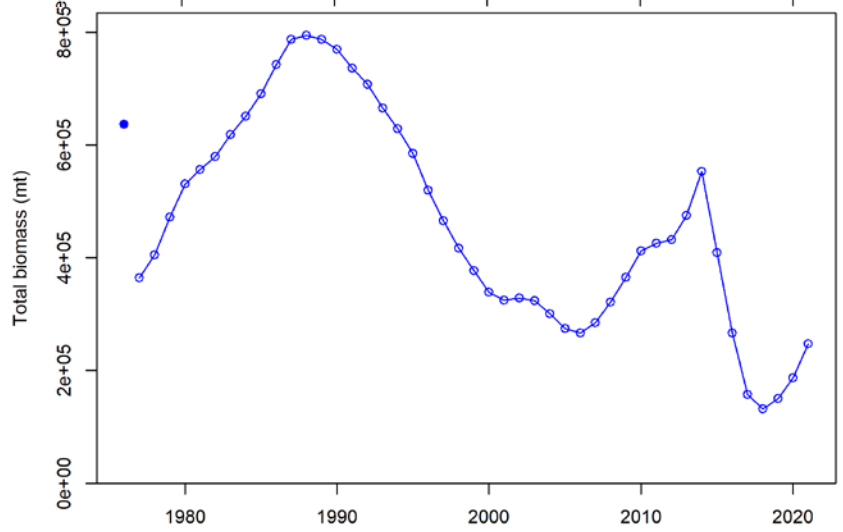

- 2020 lowest female spawning biomass at 34,631 t ($B_{19.2\%}$)
- 2021 15% increase in female spawning biomass to 39,977 t ($B_{22.2\%}$)
- Lowest total biomass in 2018 131,650 t
- 2021 biomass up 88% from 2018 to 247,415 t

Model 19.1 biomass trends

Caption caption caption caption caption caption caption caption caption caption caption caption caption caption caption caption caption.

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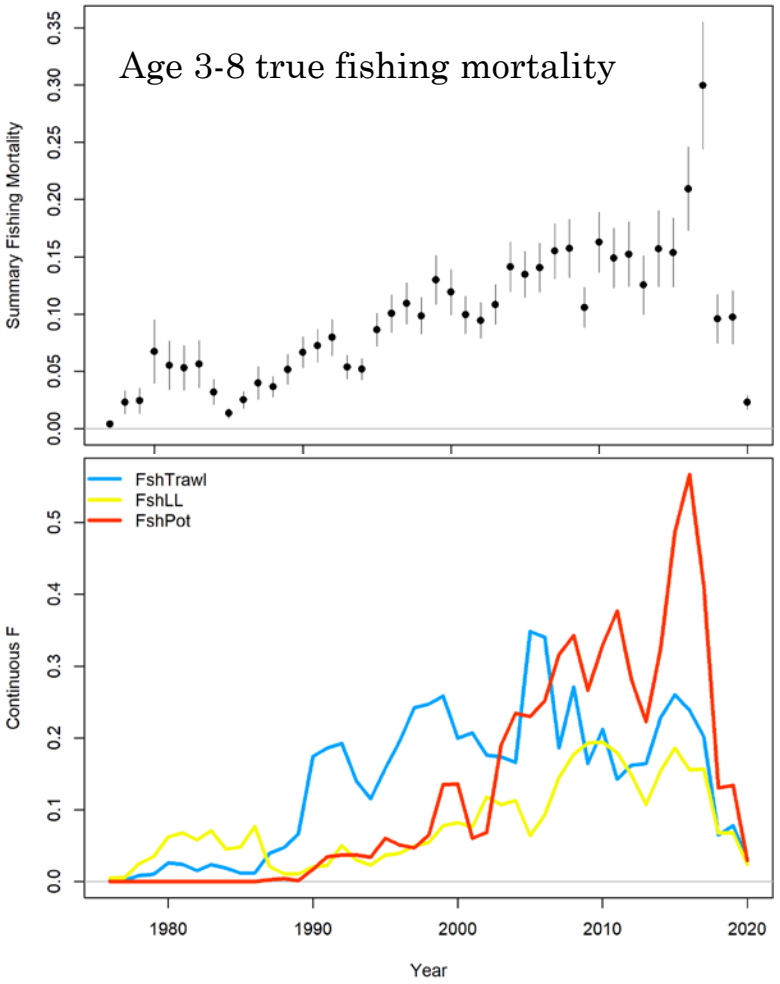

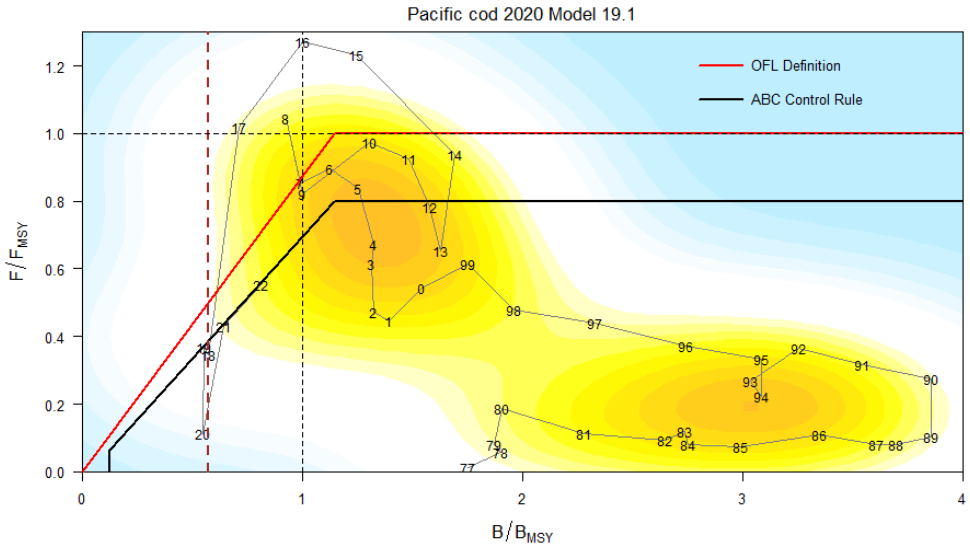

- Increasing F over time
- Highest F 2016-2017
- Below $B_{20\%}$ 2018-2020

Model 19.1 fishing mortality

Increasing trend in F over time until 2018 with relatively high F for 2016-2017. Below B20% for 2018-2020. Above $B_{20\%}$ in 2021.

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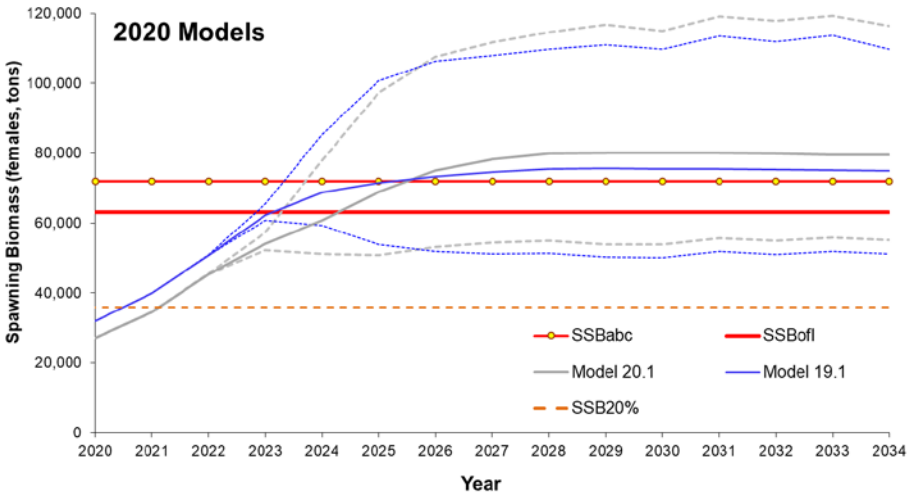

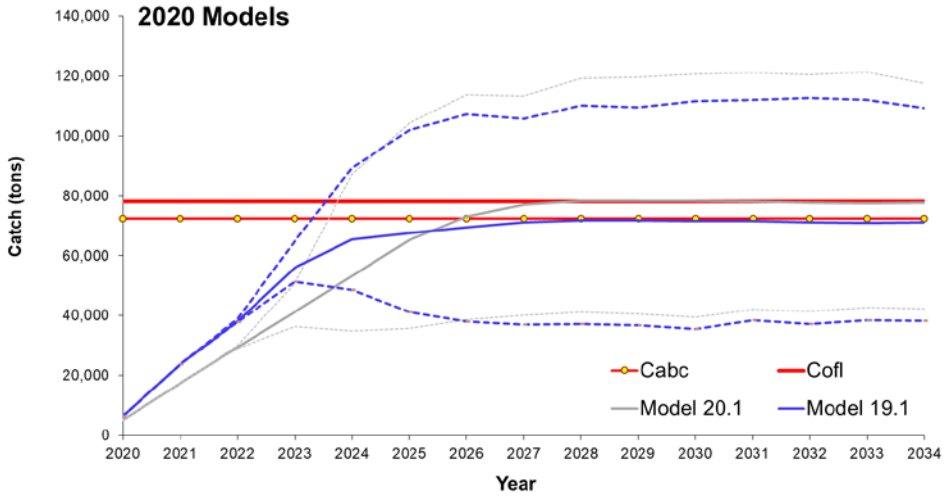

- Assuming average recruitment expect to reach $B_{40\%}$ by 2026 while fishing at maxABC

- Assuming average recruitment expect steady rise in catch to 2026

Projections using standard bootstrap method

Above $B_{20\%}$ after 2021, assumes maxABC after 2021, also assumes average recruitment after 2019 and near average recruitment in 2019.

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Quantity	As estimated or *specified last* year for: 2020	2021	As estimated or *specified this* year for: 2021	2022
M (natural mortality rate)	0.49	0.49	0.47	0.47
Tier	3b	3b	3b	3b
Projected total (age 0+) biomass (t)	203,373	261,484	265,661	312,783
Female spawning biomass (t)				
Projected	32,958	42,026	39,977	50,813
$B_{100\%}$	187,780	187,780	180,111	180,111
$B_{40\%}$	75,112	75,112	72,045	72,045
$B_{35\%}$	65,723	65,723	63,039	63,039
F_{OFL}	0.27	0.36	0.41	0.54
$maxF_{ABC}$	0.22	0.29	0.33	0.43
F_{ABC}	0.22	0.29	0.33	0.43
OFL (t)	17,794	30,099	28,977	46,587
maxABC (t)	14,621	24,820	23,627	38,141
ABC (t)	*14,621	*24,820	23,627	38,141

- **2021 above $B_{20\%}$**
- 2021 maxABC 23,627t
- 2022 maxABC 38,141t
- 2021 OFL 28,977t
- 2022 OFL 46,587t

- 2021 ABC is 5% lower than projected for 2021 last year
- 2021 OFL id 4% lower than projected for 2021 last year

Summary of results

Tier 3b stock status in 2021 estimated to be at $B_{22\%}$ and in 2022 at $B_{28\%}$.
No overfishing, not overfished, and not approaching overfished.

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Assessment-related considerations	Population dynamics considerations	Environmental /ecosystem considerations	Fishery Performance
Level 2: Substantially increased	Level 2: Substantially increased	Level 1: Normal	Level 1: Normal

- Assessment-related concerns
  - High uncertainty in 1977-1989 recruitment and SSB subject to assumptions on selectivity
  - Sub-27cm fish not well fit for AFSC bottom trawl survey

- Population dynamics considerations
  - 2019 year class appears much lower in ancillary data and ecosystem-linked model than projected in the reference model

Risk Table

No reduction in maxABC recommended for 2021 and 2022.

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Assessment-related considerations	Population dynamics considerations	Environmental /ecosystem considerations	Fishery Performance
Level 2: Substantially increased	Level 2: Substantially increased	Level 1: Normal	Level 1: Normal

- Environmental/ecosystem
  - Cooler spring
  - Warm summer and fall
  - Mixed signals in prey, predators, and competition

- Fishery performance
  - No federal fishery in 2020
  - Mixed signals by area and fishery
  - Appears to have some indications of increasing bycatch in other target fisheries

Risk Table

No reduction in maxABC recommended for 2021 and 2022

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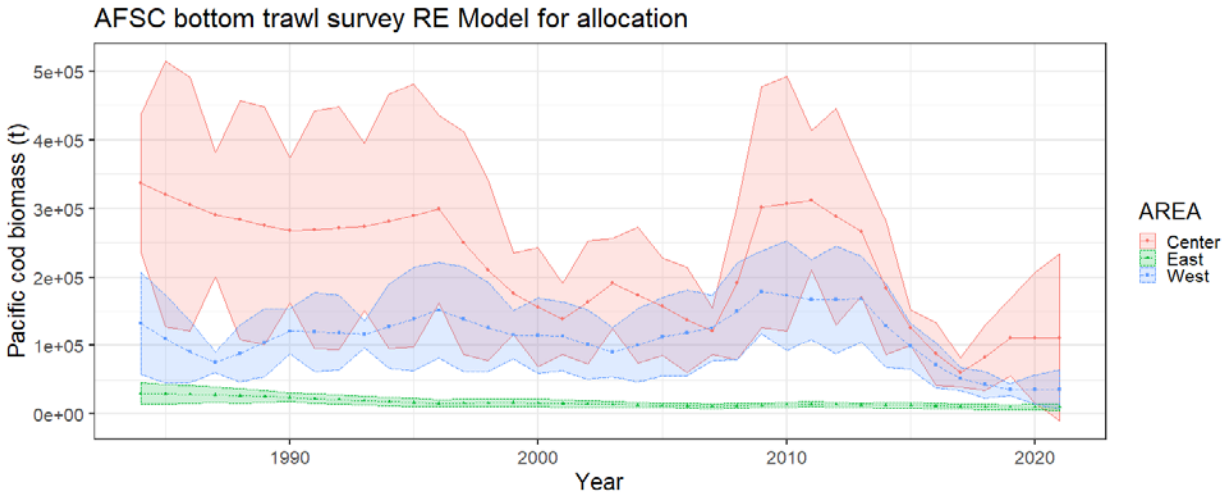

- In 2019 the SSC chose a stair-step approach as the mean between 2018 and 2019 random effects model apportionment proportions

Random Effects model apportionment

	Western	Central	Eastern	Total
Random effects area apportionment	22.7%	70.6%	6.7%	100%
2021 ABC	5,363	16,681	1,583	23,627
2022 ABC	8,658	26,928	2,555	38,141

Stair-step apportionment

	Western	Central	Eastern	Total
Stair-step area apportionment	33.8%	57.8%	8.4%	100%
2021 ABC	7,986	13,656	1,985	23,627
2022 ABC	12,892	22,045	3,204	38,141

Apportionment

Random effects model used 2013-2018, in 2019 SSC recommended a stair-step approach due to the large change from 2018.

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Model 20.1

- Ecosystem-linked model

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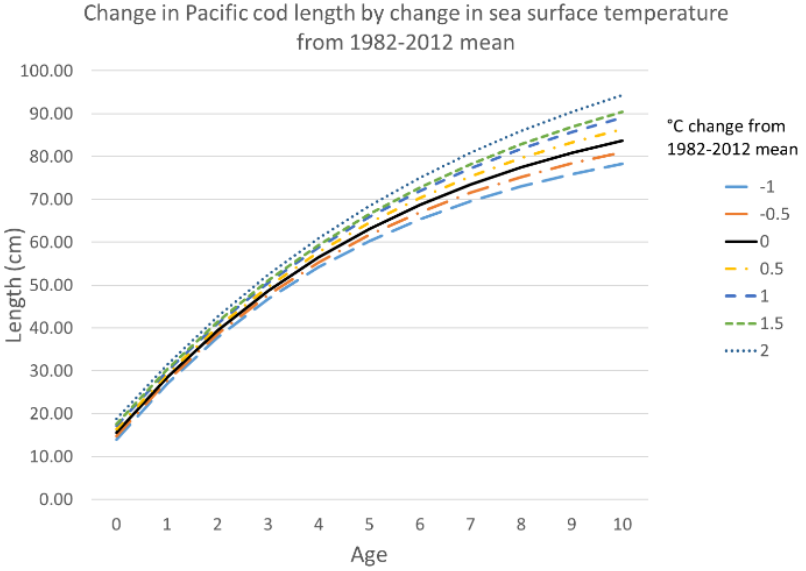

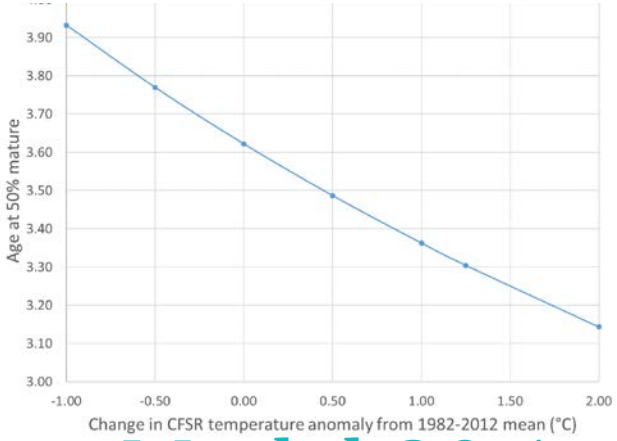

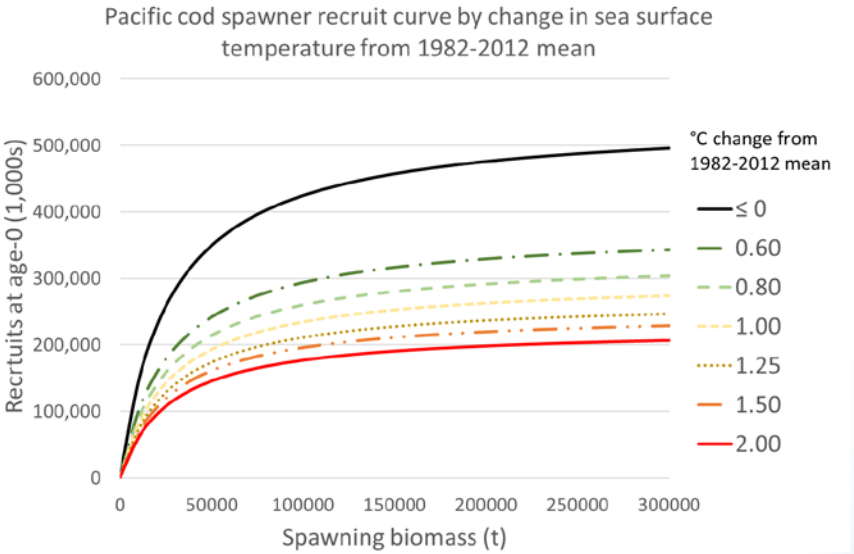

Model 20.1

Ecosystem-linked growth and recruitment shows increased growth with increased temperature and lower recruitment with increased spawning season marine heatwave conditions.

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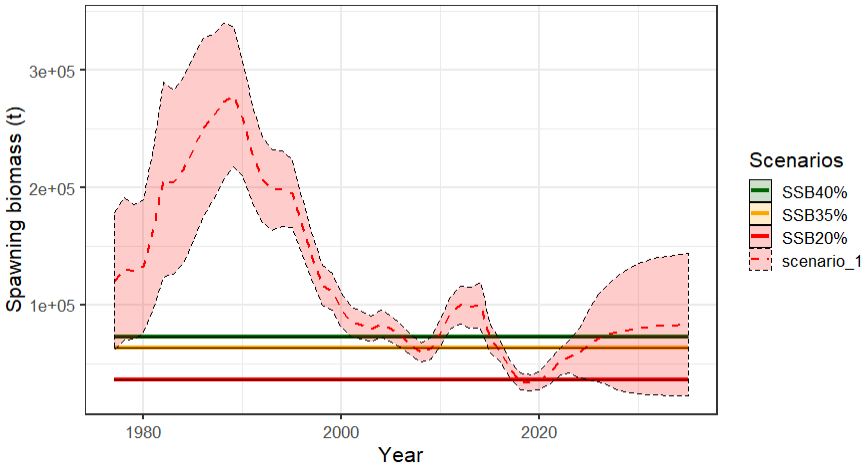

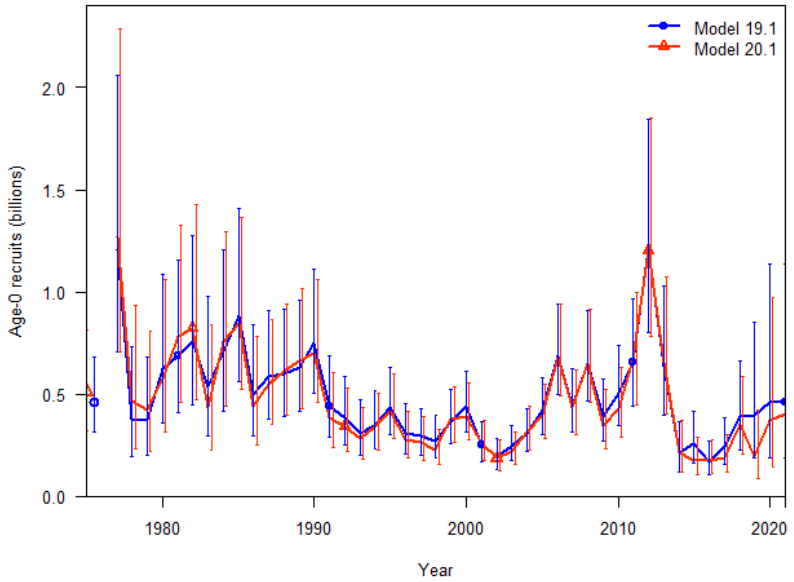

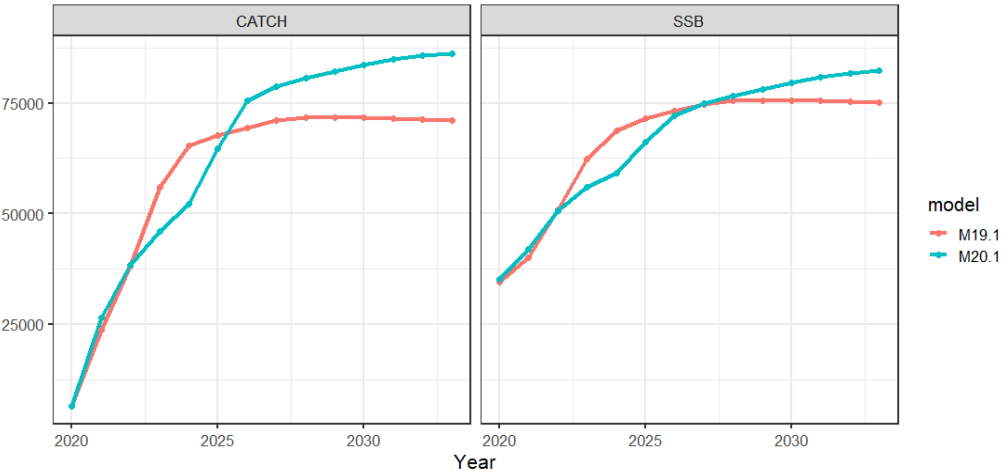

Model 20.1 Projections

Short-term projections shows difference due to difference in estimated 2019 recruitment.

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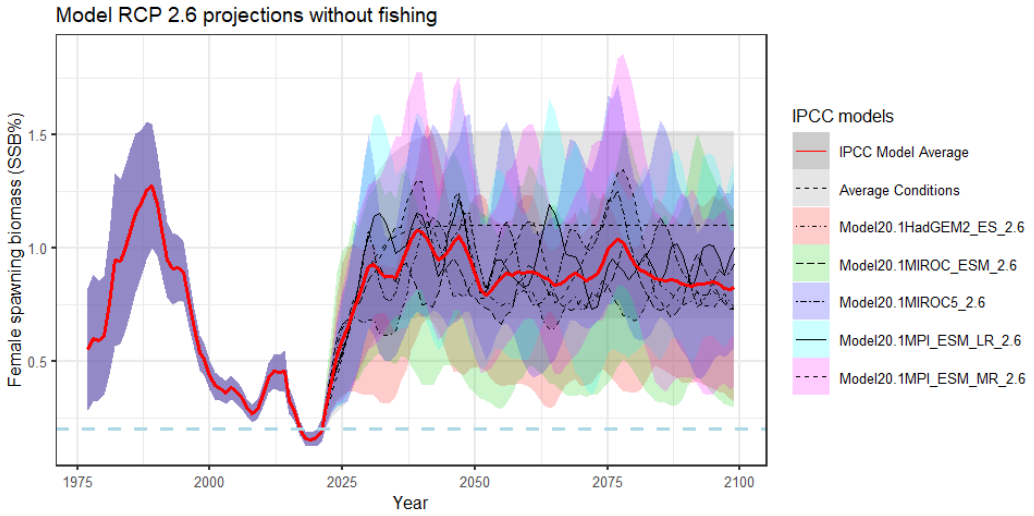

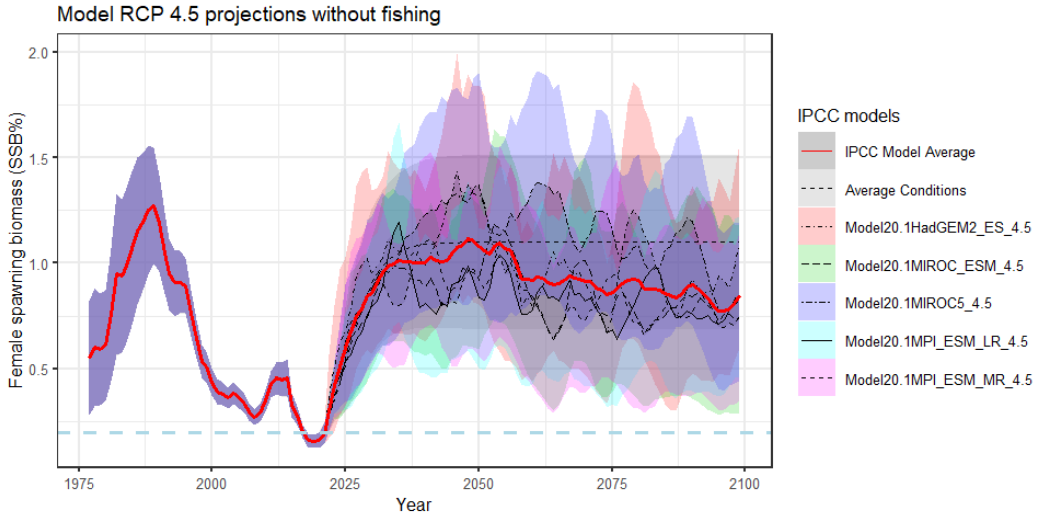

Model 20.1 IPCC model projections

Five IPCC models under RCP 2.6 and RCP 4.5, the most optimistic IPCC scenarios. Both scenarios result in reduction in productivity.

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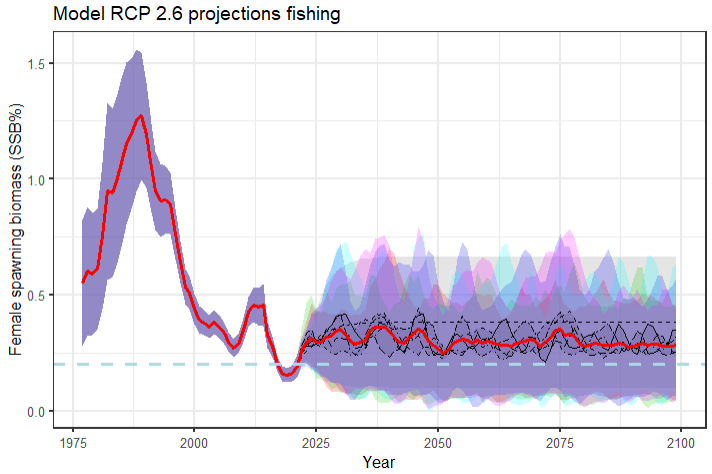

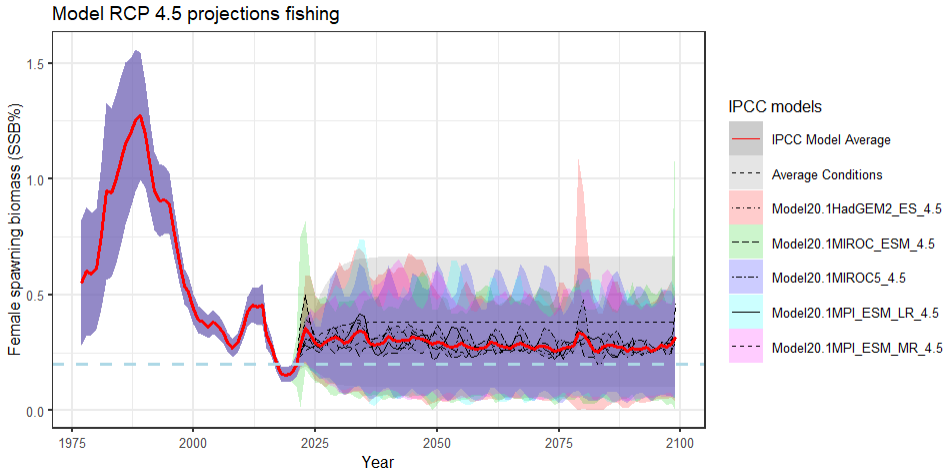

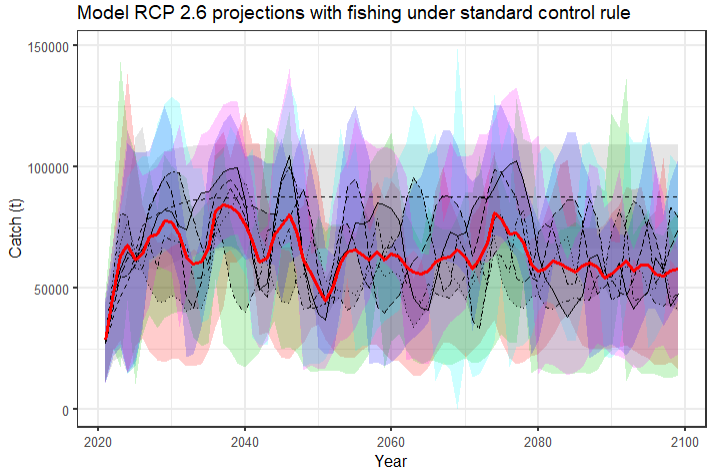

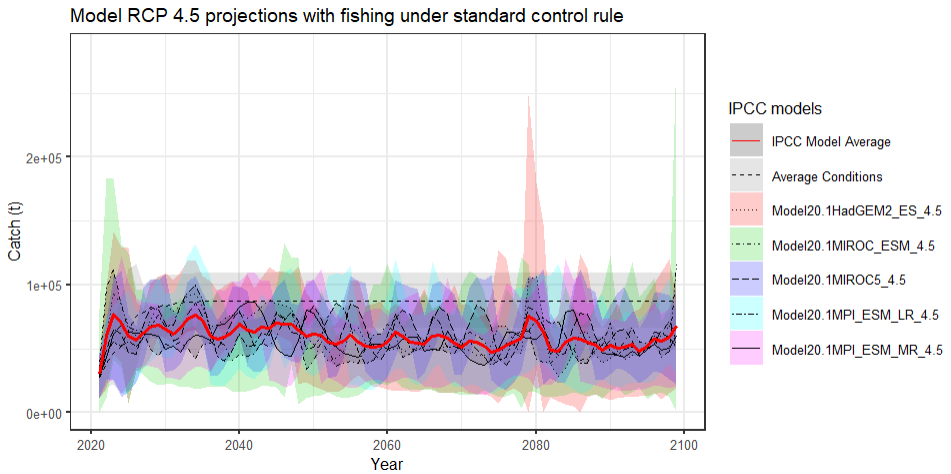

Model 20.1 IPCC model projections

23-27% reduction in spawning biomass with fishing

30-36% reduction in catch 2050-2099

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Quantity	As estimated or *specified last* year for: 2020	2021	As estimated or *specified this* year for: 2021	2022
M (natural mortality rate)	0.49	0.49	0.47	0.47
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F_{ABC}	0.22	0.29	0.33	0.43
OFL (t)	17,794	30,099	**28,977**	**46,587**
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ABC (t)	*14,621	*24,820	**23,627**	**38,141**

	Western	Central	Eastern	Total
Stair-step area apportionment	33.8%	57.8%	8.4%	100%
2021 ABC	7,986	13,656	1,985	23,627
2022 ABC	12,892	22,045	3,204	38,141

Summary of results/recommendations

Recommending Model 19.1 OFL and maxABC with no reduction from risk table adjustments and continued use of the stair-step area apportionment for 2021 and 2022.

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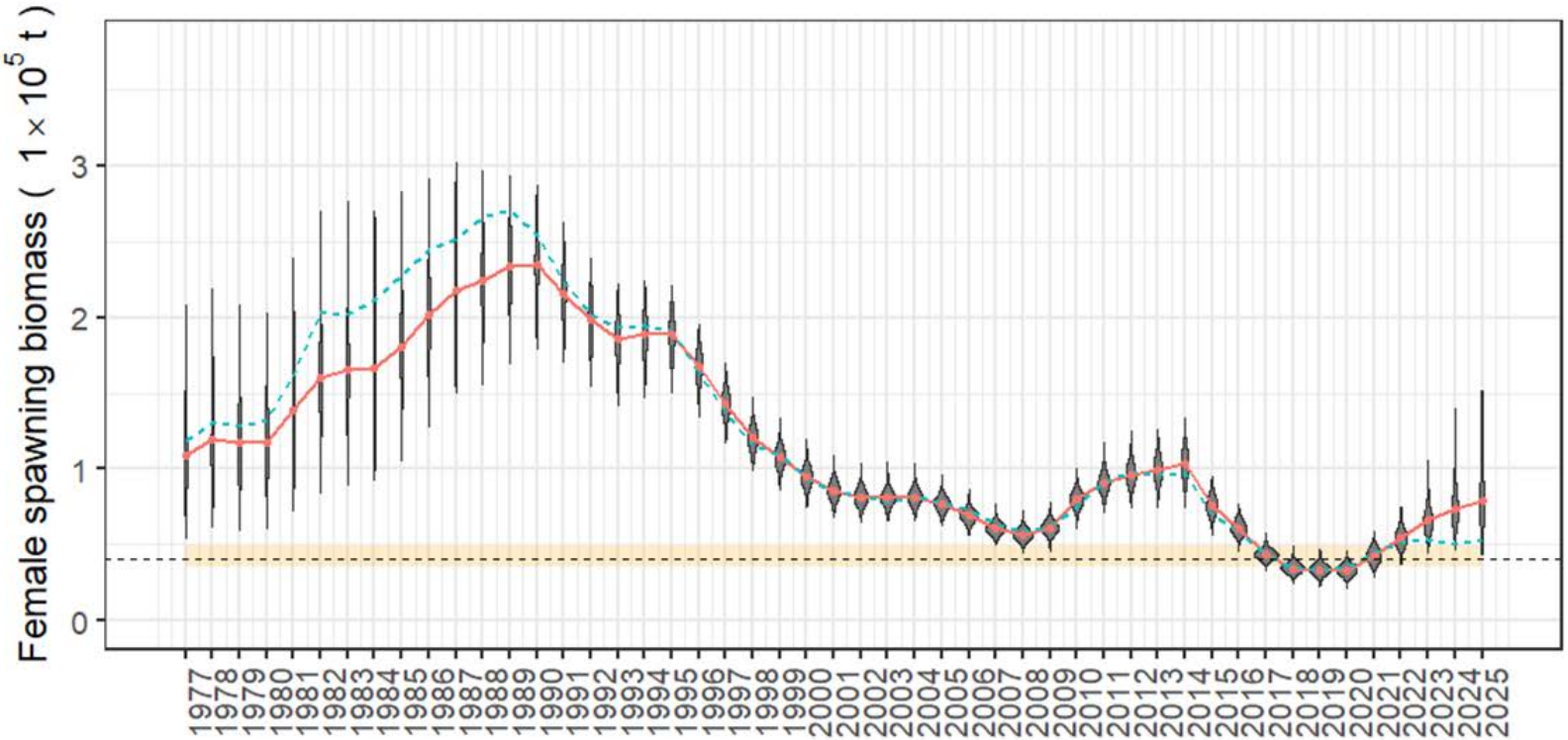

Model 19.1 MCMC

Low probability of ever being below $B_{17.5\%}$, 74.2% probability of being below $B_{20\%}$ in 2020 and 7.1% probability in 2021

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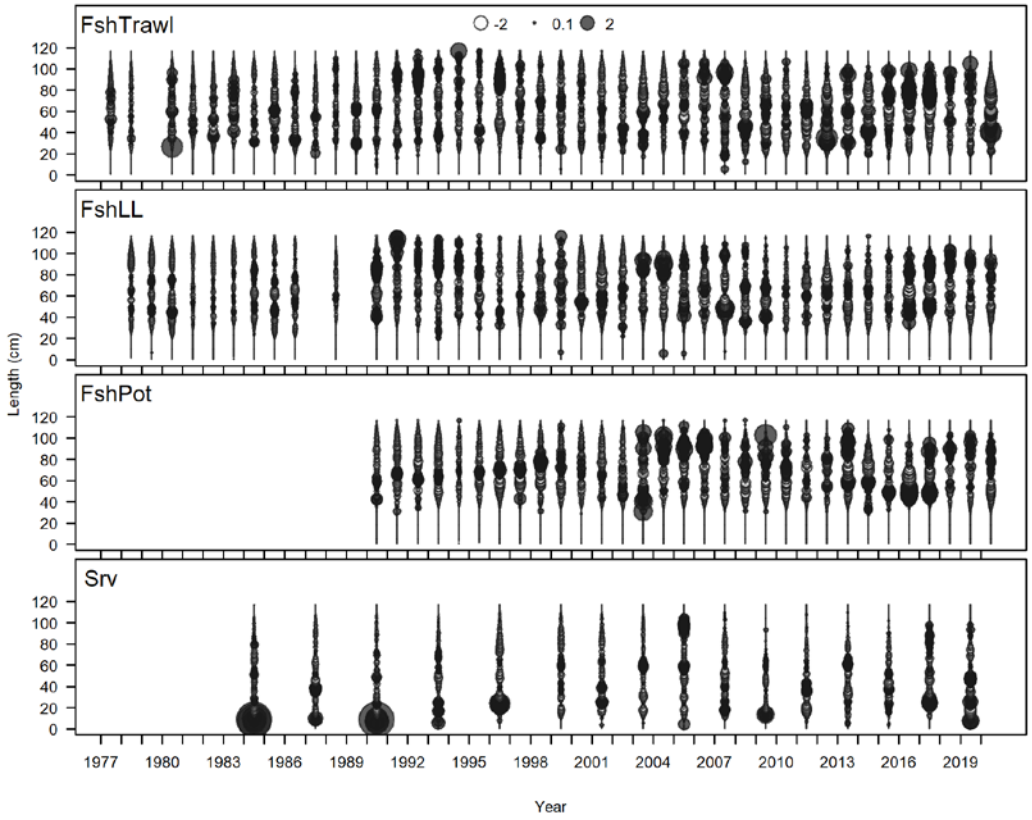

Model 19.1 length comp. residuals

No consistent pattern in residuals, poor fitting of Longline survey

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