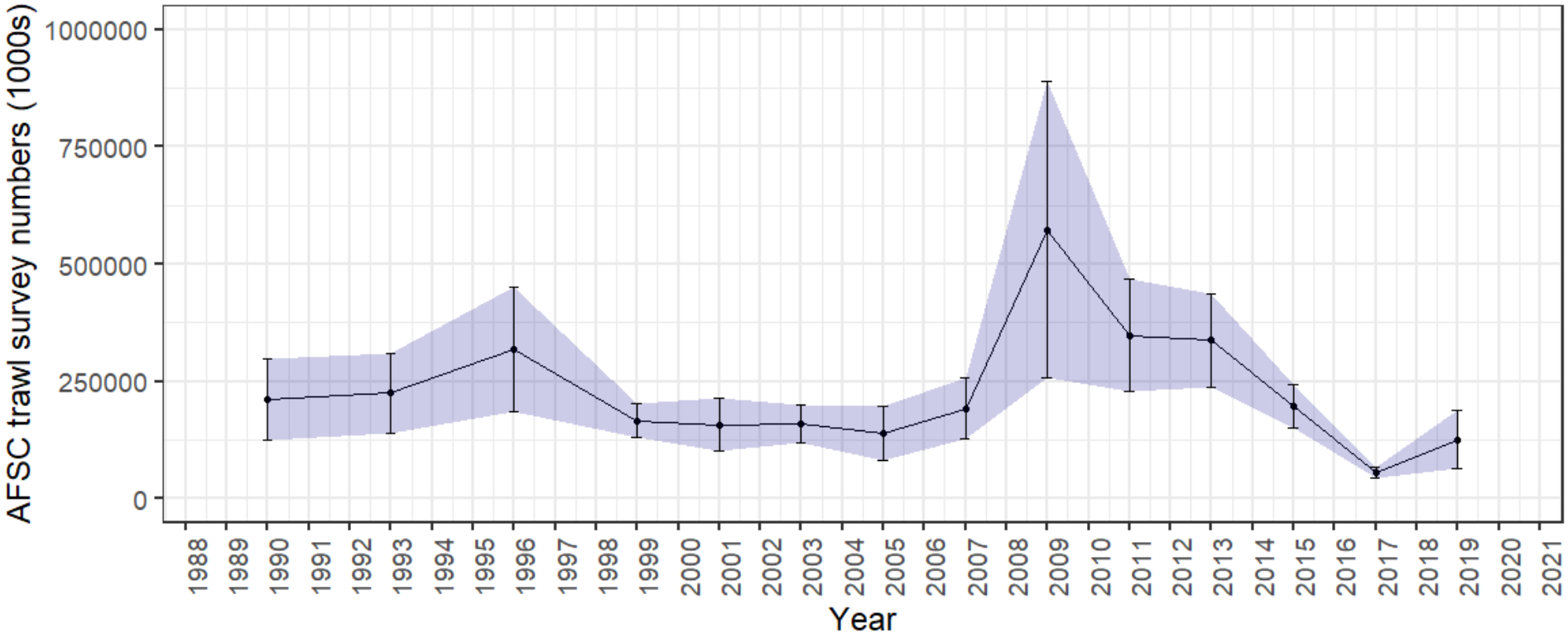
# 2019 Gulf of Alaska Pacific cod

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

## September Plan Team Edition

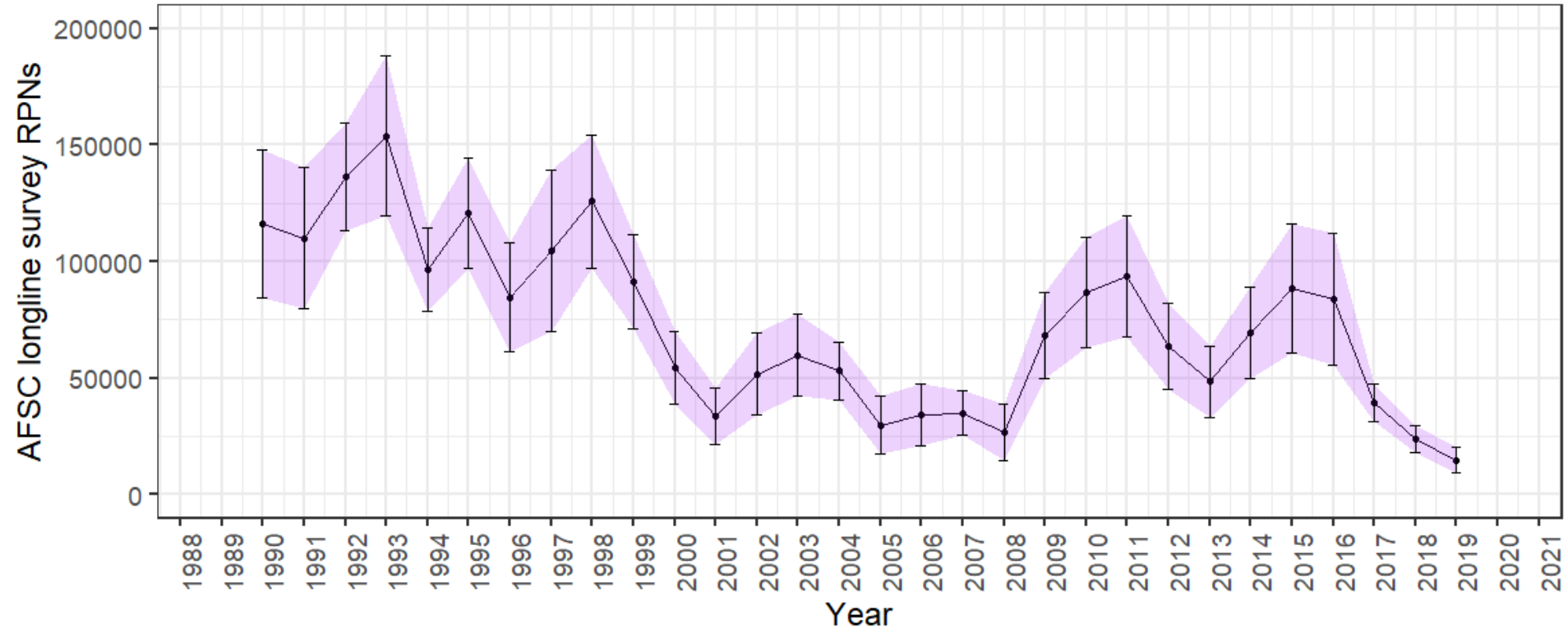
# AFSC bottom trawl survey

- 126% Increase from 2017 (56 KT to 127 KT)
- Second lowest abundance estimate of time series
- High uncertainty and no length composition data available yet



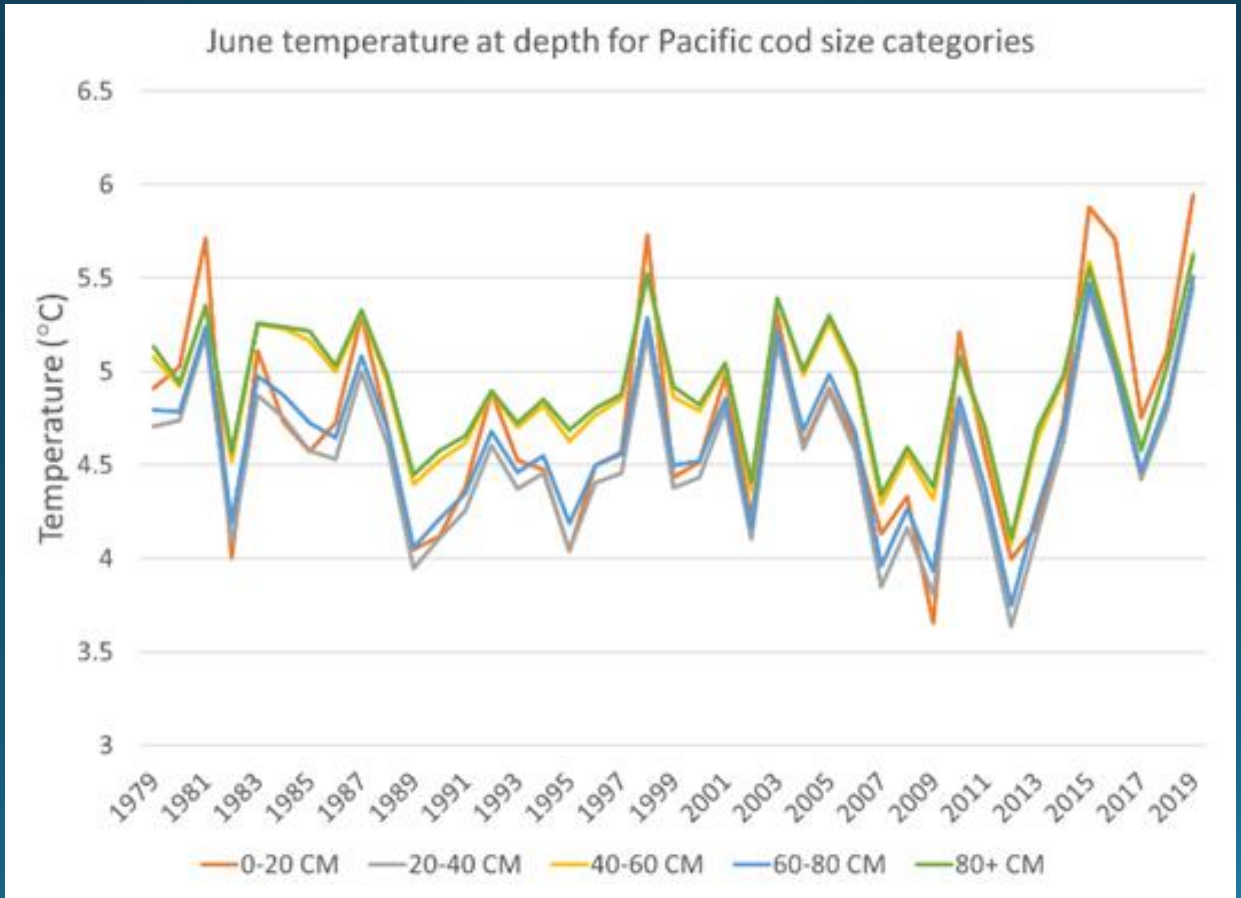
# AFSC longline survey

- Historic low (37% decrease from 2018)
- Surveys larger fish in deeper waters



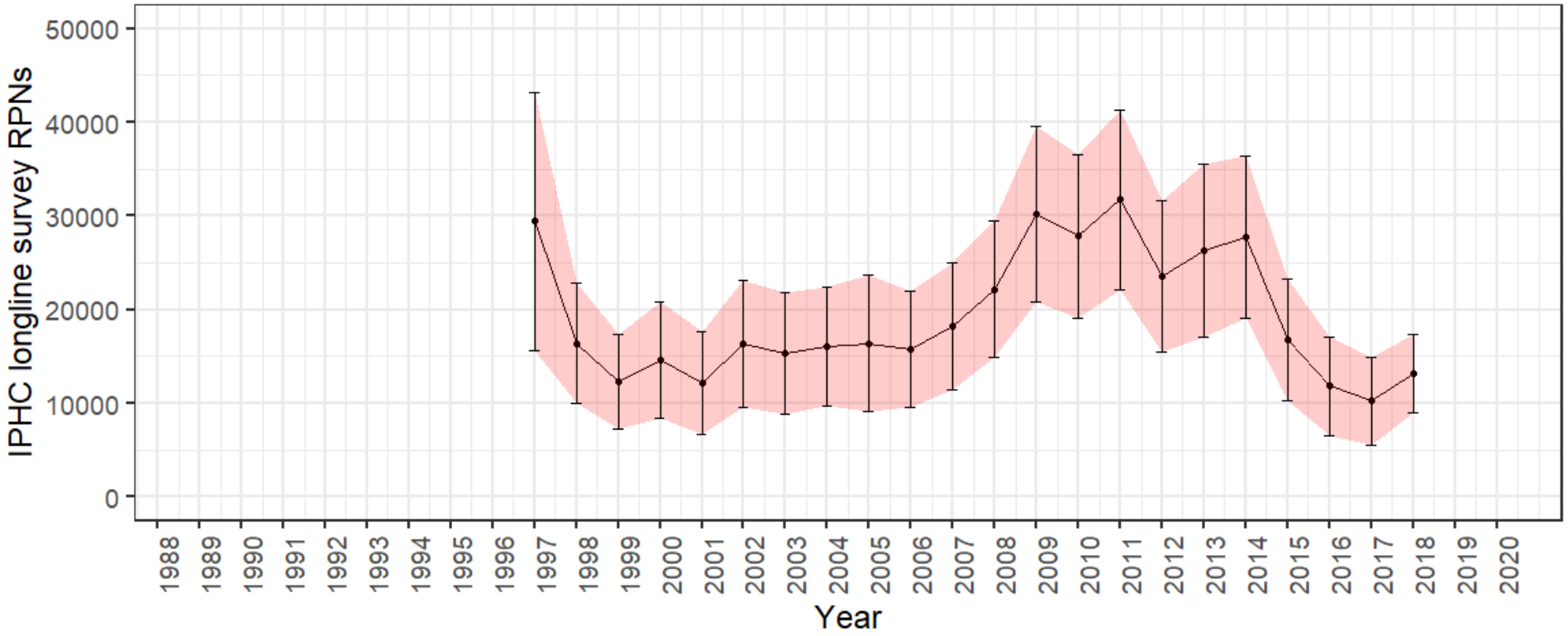
# Climate Forecast System Reanalysis data for Central GOA Pacific cod

- Temperatures at depth for centroid of Pacific cod at different lengths

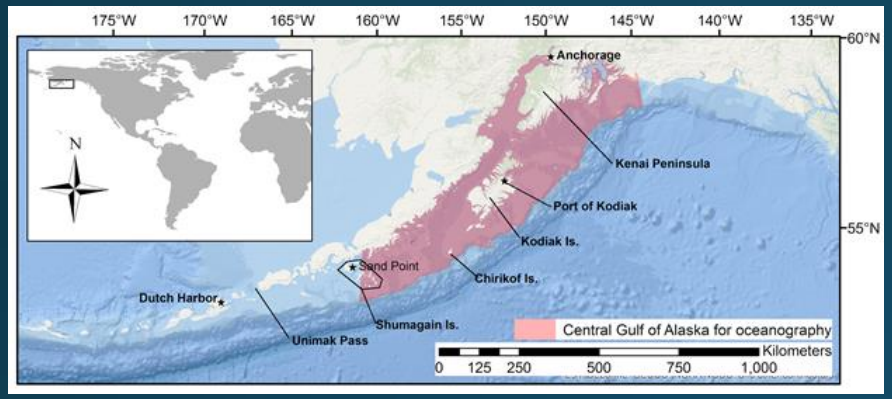


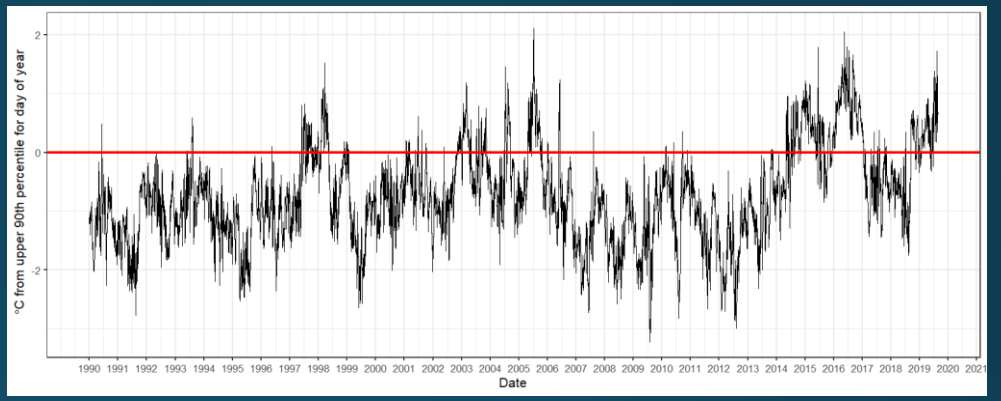
# IPHC longline survey

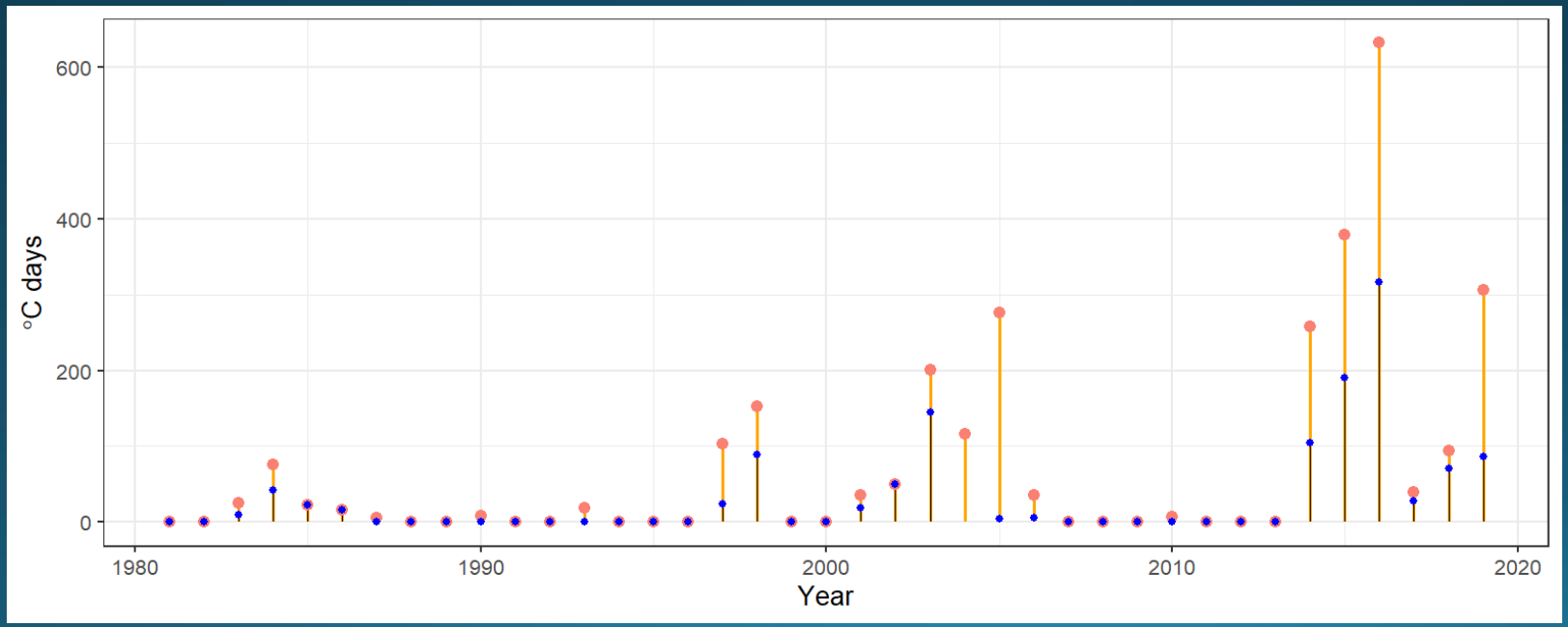
- 2018 up from 2017 historic low
- 2019 survey data will not be available until after October 15
- Length composition data starting in 2018



# Marine heatwave analysis from NOAA high-resolution blended analysis data for central GOA



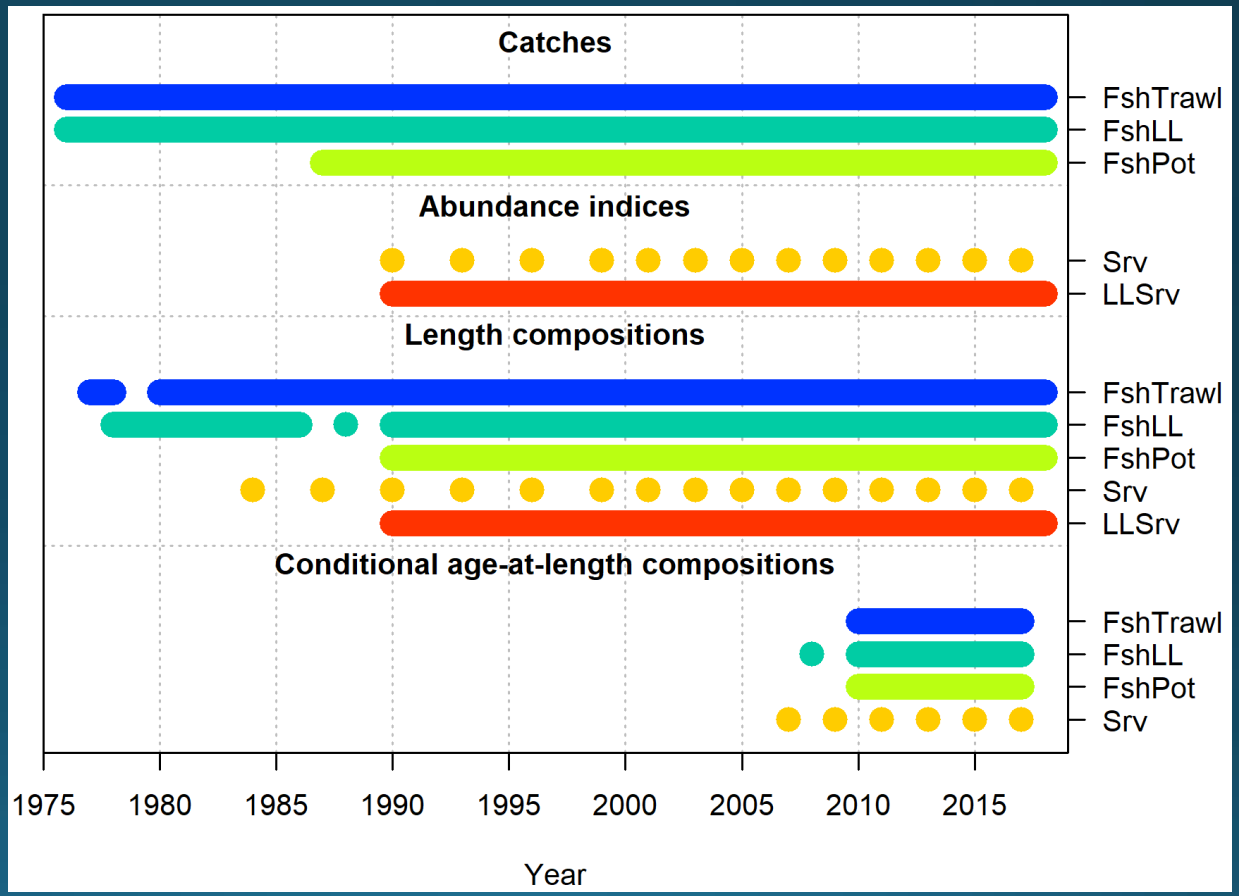
# 2019 Model Development

- First document addresses simple refinements from 2018 base model
  - **Plan team review of refinements for use in single model in November**

- Second document introduces climate-enhanced Model 19.14.51
  - **Plan team consideration of new methods and recommendations for model development/validation**

# 2019 Model 18.10.44

- Indices – AFSC Longline and AFSC bottom trawl
- Fisheries – Longline, Pot, Trawl
- Size composition
  - All fisheries and indices
- Age data
  - 2007+ survey and Fishery conditional length at age



# 2019 Model 18.10.44

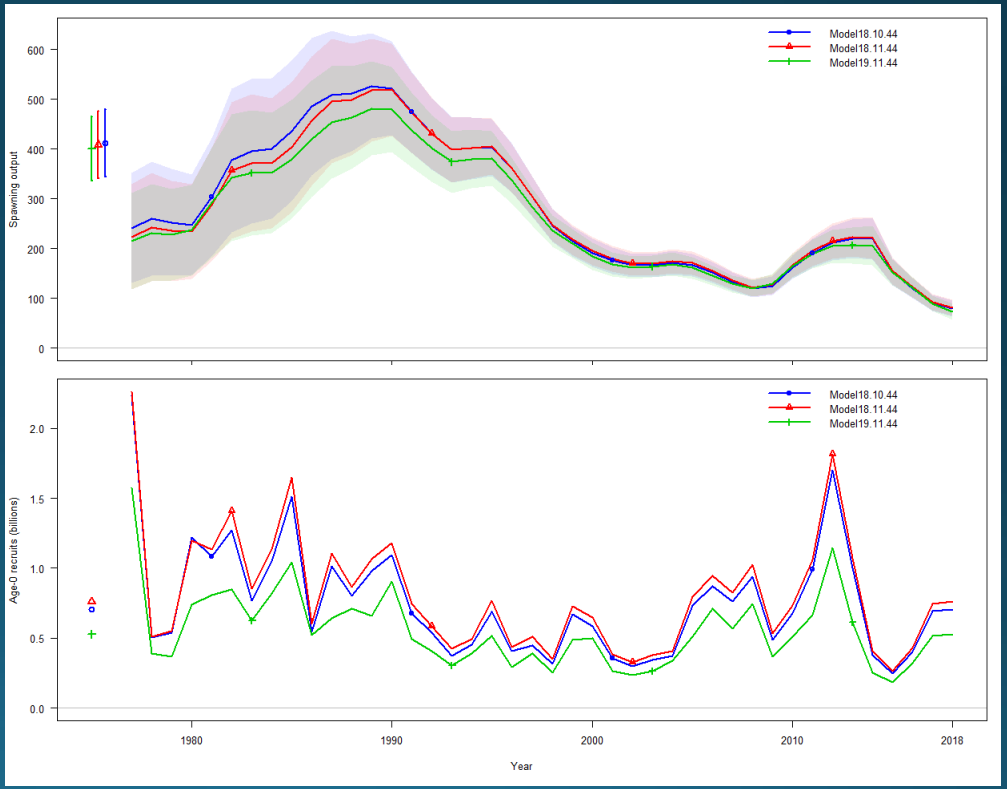
- 1-20+ age bins,  1-117+cm length bins
- M (lognormal prior) and Qs (uninformative prior) fit in model
- M fit separately for 2014-2016 block
- Beverton-Holt ($\sigma_R$ = 0.44, Steepness = 1.0)
- Three-parameter von Bertalanffy growth (informative priors based on 2007-2018 survey age composition data)
- Double normal length-based size selectivity for all size composition
  - Blocks for bottom trawl survey
  - longline and trawl
    - pre-1990 annual varying
    - Blocks for post-1990
- Longline survey catchability scaled to CFSR temperatures for 0-10 cm Pacific cod mean depth

# New data and models

| Model | Description |
|---|---|
| Model 18.10.44 | 2018 Author's recommended model |
| Model 18.11.44 | Same as 18.10.44 except plus group at age 10 |
| Model 19.11.44 | Same as 18.11.44 except data updated and all recent data included |
| Model 19.12.44 | Same as 19.11.44 except 10cm CFSR June temperatures are updated to latest with anomaly defined by 1982-2012 average |
| Model 19.14.44a | 19.12.44 with IPHC longline survey index and length data |
| Model 19.14.44b | 19.14.44a with aging error |
| Model 19.14.47 | 19.14.44b with all available age data included and aging error - without bias |
| Model 19.14.48a | 19.14.47 with age-based selectivity and growth parameters fit freely |
| Model 19.14.48b | 19.14.48a with the model aging bias for data prior to 2007 based on Stark (2007) re-aging and 2007+ fit freely with uninformative priors |
| Model 19.14.48c | 19.14.48a with the model aging bias fit freely for pre-2007 with uninformative priors and 2007 to present bias set to 0 |
| Model 19.14.48d | 19.14.48c with 2007 to present aging bias parameters fit freely |
| Model 19.14.49 | 19.14.48d with recruitment scaled to the fourth root of the MHWI |
| Model 19.14.50 | 19.14.48d with Natural mortality by age and time scaled to the MHWI |

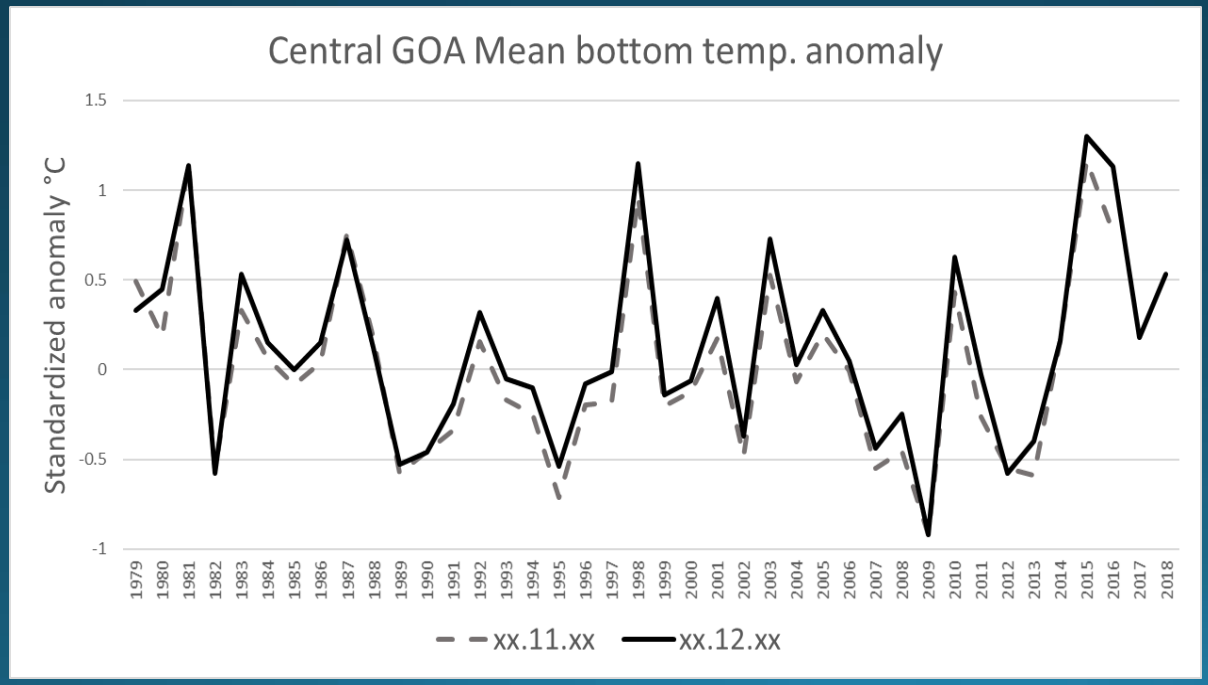
# Reducing the age plus group from 20+ to 10+ and new composition data (Models 18.10.44,18.11.44, and 19.11.44)

- Reducing age plus group had little impact in model results.
- Inclusion of older survey length composition changed recruitment estimates and decreased the estimate of M
- Addition of new 2010-2011 fishery age data had little impact in model results



# Sea surface temperature estimation change (Model 19.11.44 vs. Model 19.12.44)

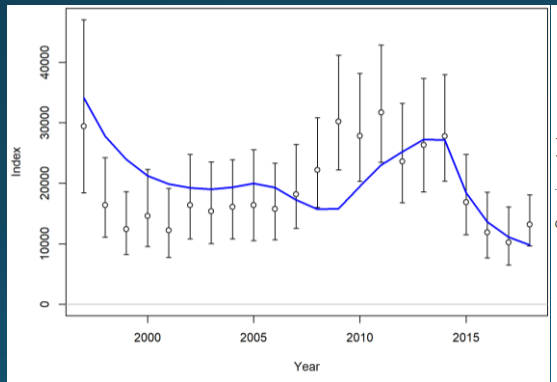
- Changed the CFSR surface temperature anomaly to a new baseline of 1982-2012 instead of full time series to be consistent with other uses of these indices.
- Used to scale AFSC longline catchability.
- Overall better fit, small change to model results.

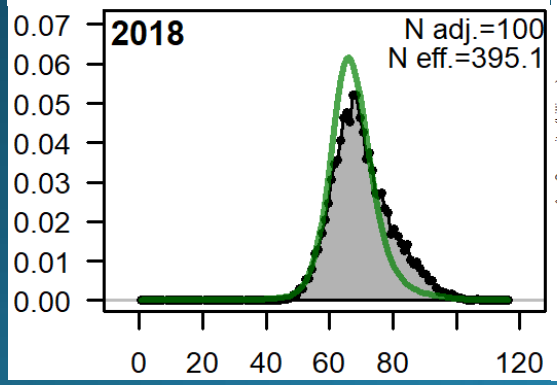


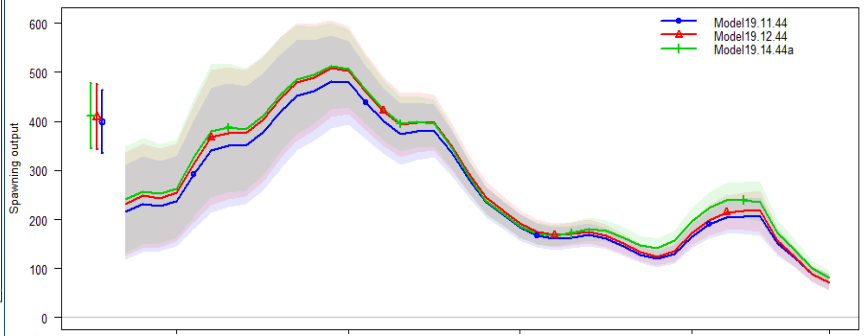
# Addition of IPHC survey index and size composition (Model 19.12.44 vs Model19.14.44a)

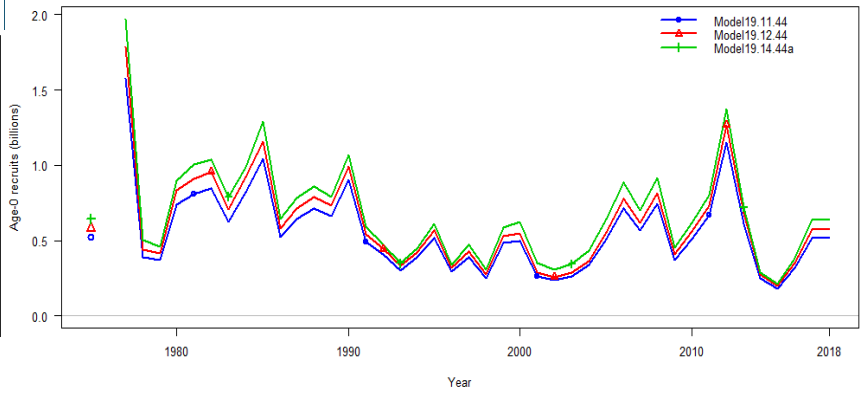
- Surveys GOA shelf area comparable to AFSC bottom trawl survey
  - 2017 lowest in time series
  - 29% increase from 2017 to 2018

- Not a great fit
- Makes little change in results



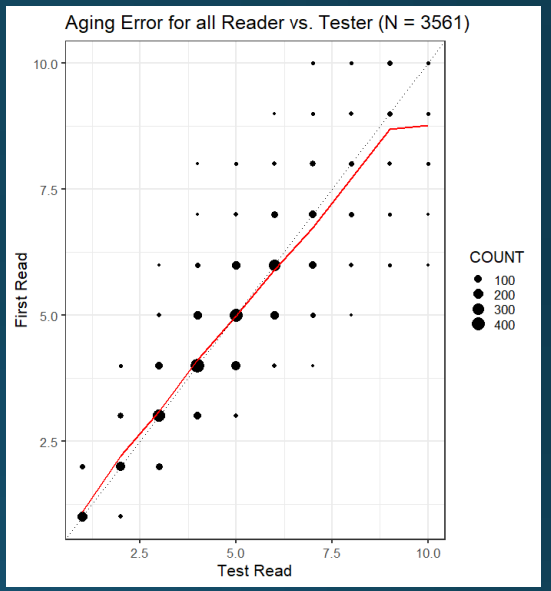



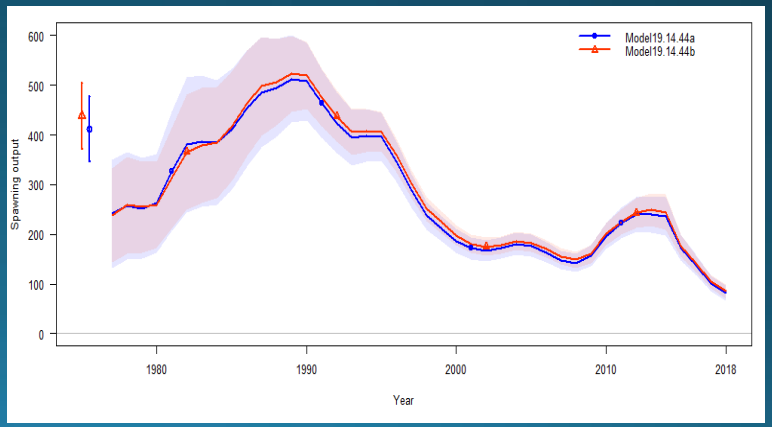



# Addition of aging error (Model 19.14.44a vs Model19.14.44b)

- Added aging error based on test reading results from 2007-2018 bottom trawl survey otoliths
- Shifts to a slightly better fit to the indices (-0.44 LL) with the decrease in weighting of age data.
- Decrease in M (0.51 to 0.48) and bottom trawl Q (1.01 to 0.98)
- Overall minor changes to model results.

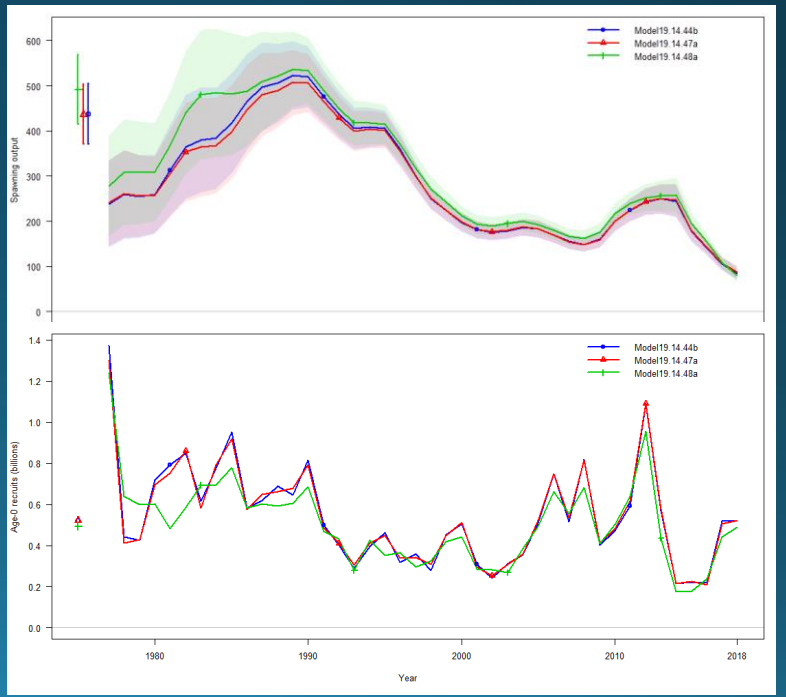


# Addition of Pre-2007 age data (Model 19.14.44b vs Model 19.14.47)

- Added the pre-2007 survey conditional age-at-length data back into model.

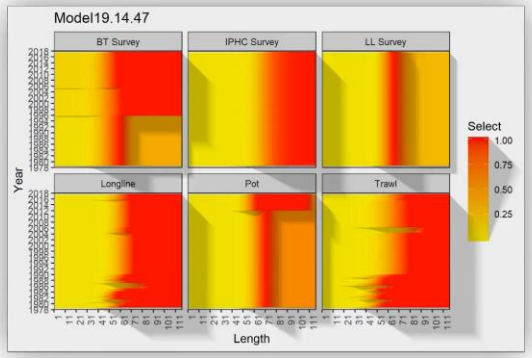
- Minor changes in model results.

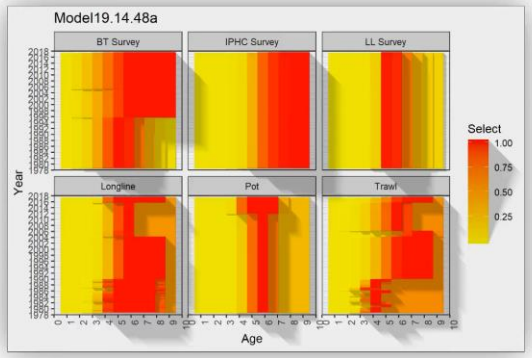


# Addition of age-based selectivity and freeing of growth parameters (Model 19.14.47 vs Model 19.14.48a)

- Switched selectivity for all surveys and fisheries to be age-based instead of size based to match Bering Sea Model and to prepare for inclusion of aging bias

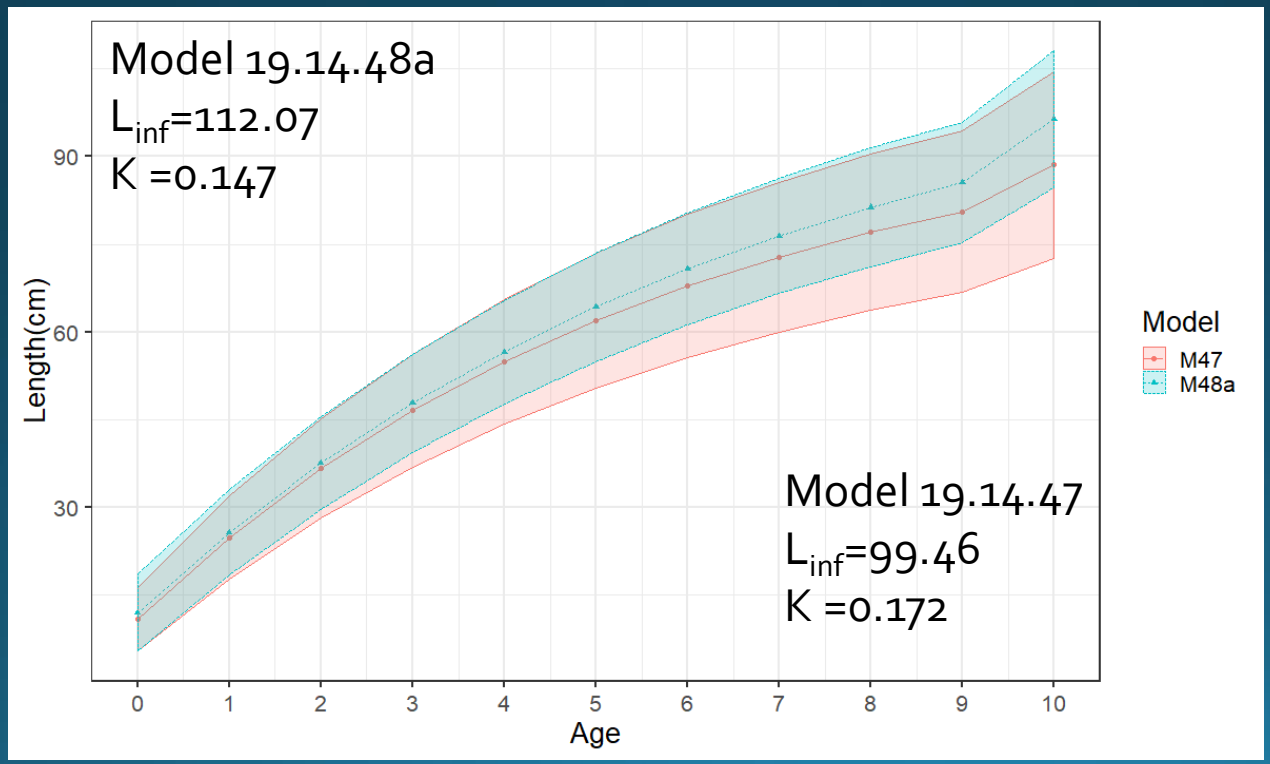
- Similar patterns except pre-1990 longline and trawl fishery selectivities become dome-shaped instead of asymptotic



# Addition of age-based selectivity and freeing of growth parameters (Model 19.14.47 vs Model 19.14.48a)

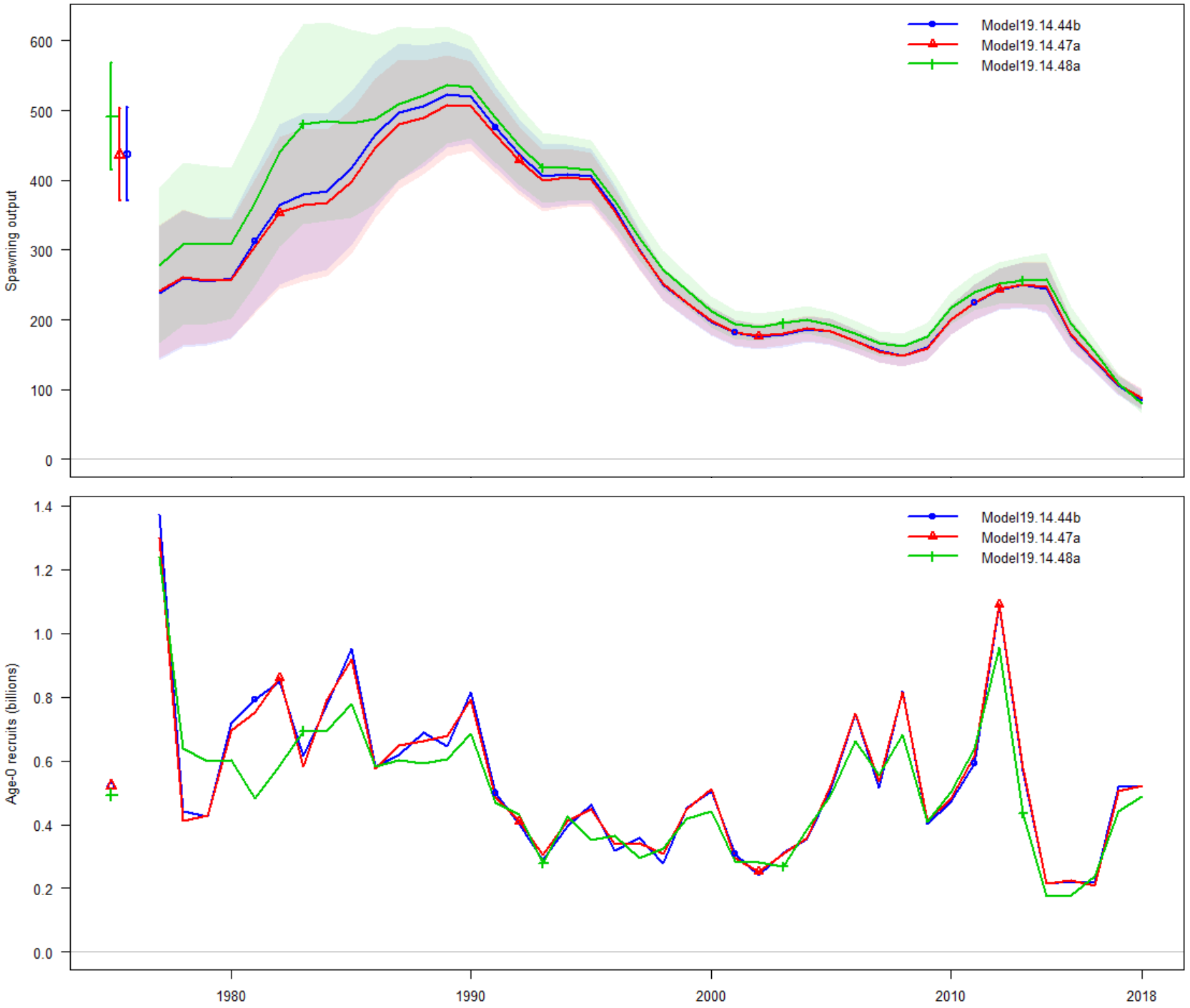
- Model 19.14.48a removed tight priors on $L_{inf}$ and K
- Small adjustment to maximum size and growth rate



# Addition of age-based selectivity and freeing of growth parameters (Model 19.14.47 vs Model 19.14.48a)

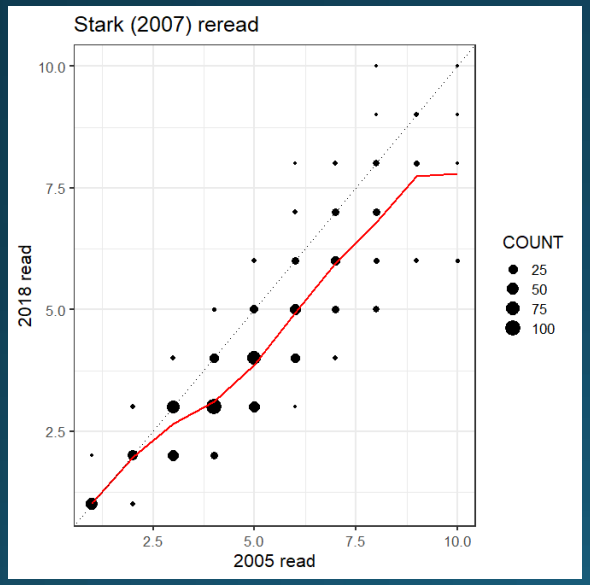
- Overall improvement to model fit (-80 LL) with a decrease in the number of parameters (200 vs 182)
- Poorer fit to length composition (+80.3), but improved fit to age composition (-153.98)

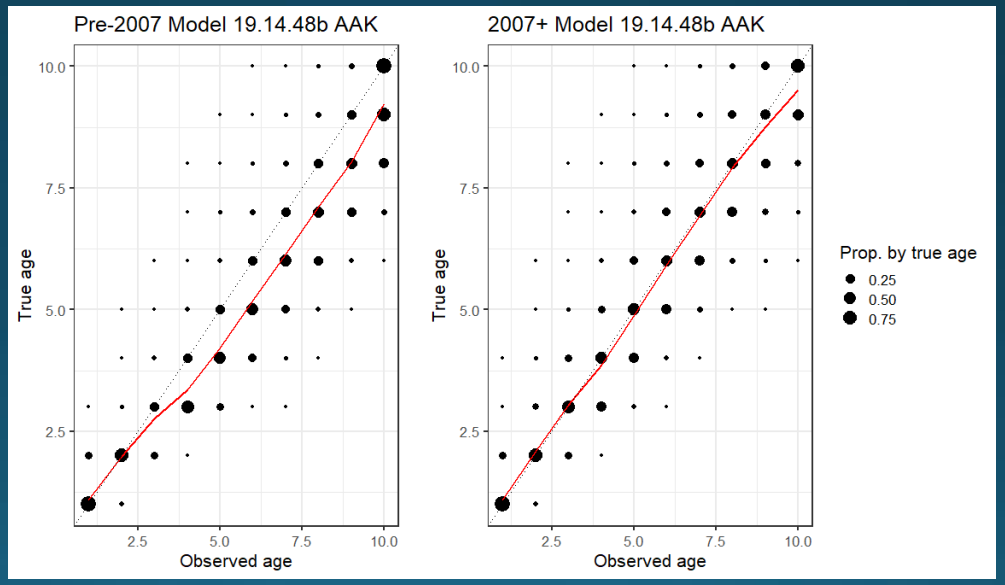
- Dome-shaped selectivity in older fishery data results in change in estimates of early spawning biomass and selectivity substantially impacting reference point estimates


Model19.14.44b
Model19.14.47a
Model19.14.48a
Spawning output
0
100
200
300
400
500
600
Model19.14.44b
Model19.14.47a
Model19.14.48a
Age-0 recruits (billions)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1980
1990
2000
2010
2018

# Aging bias (Models 19.14.48a, 48b, 48c, and 48d)

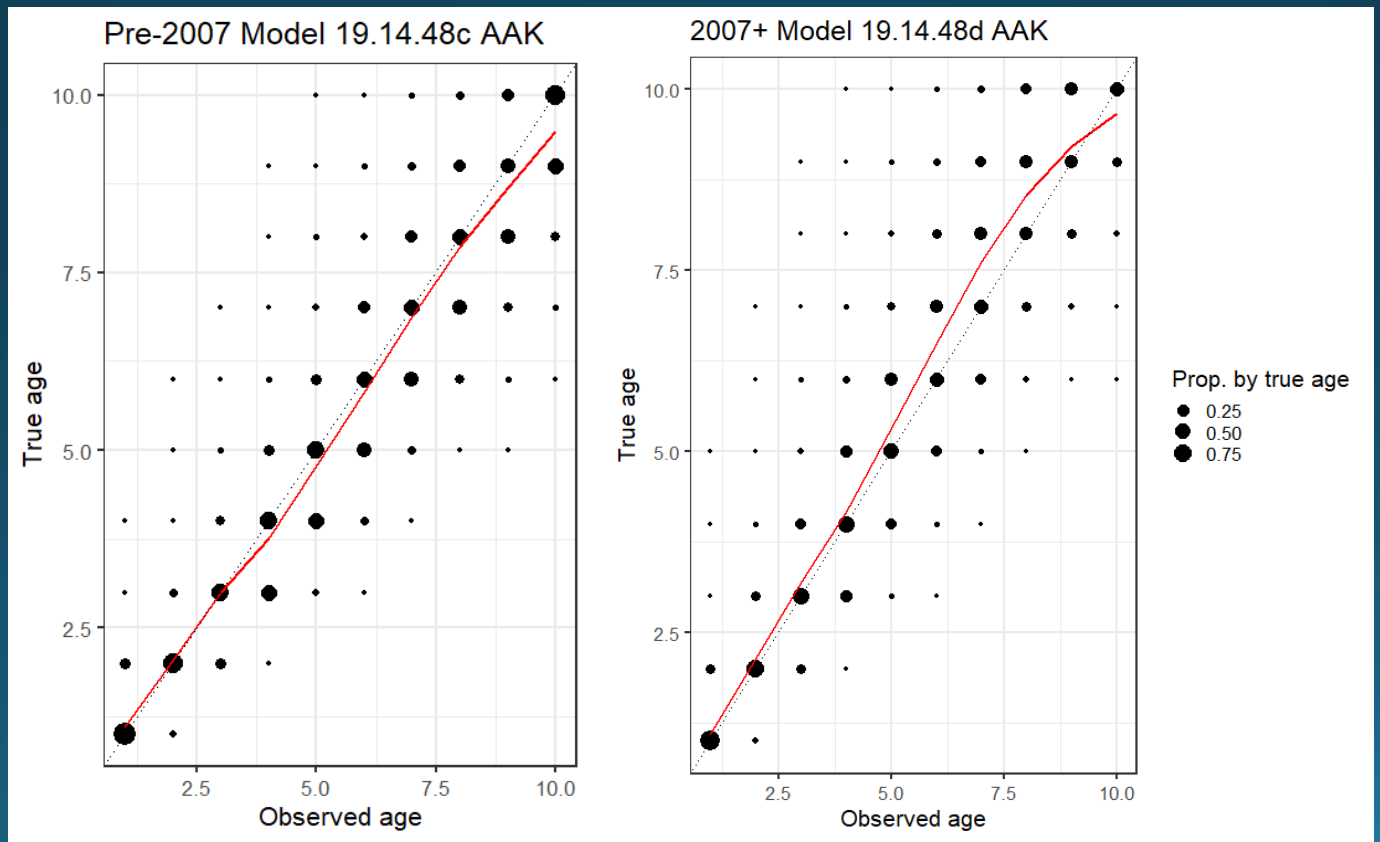
- 48b – Pre-2007 bias based on Stark (2007) and 2007+ fit freely



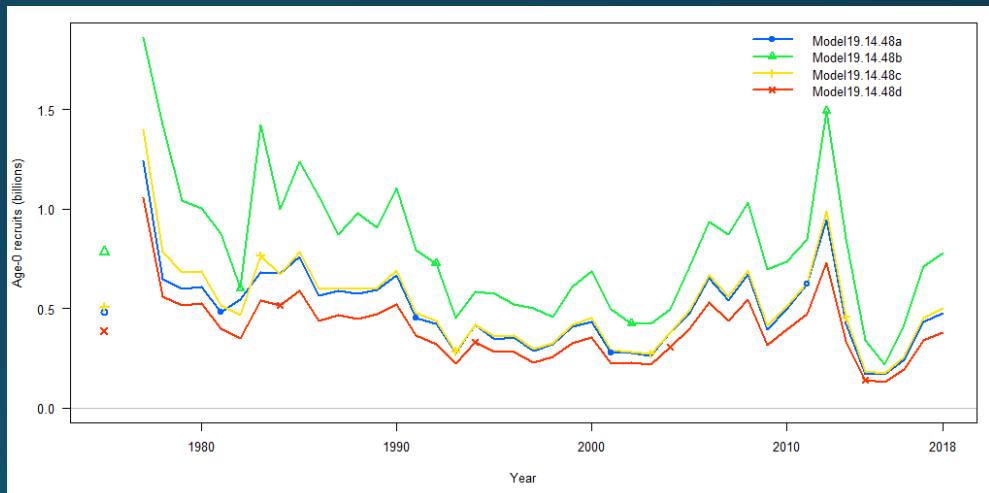
# Aging bias (Models 19.14.48a, 48b, 48c, and 48d)

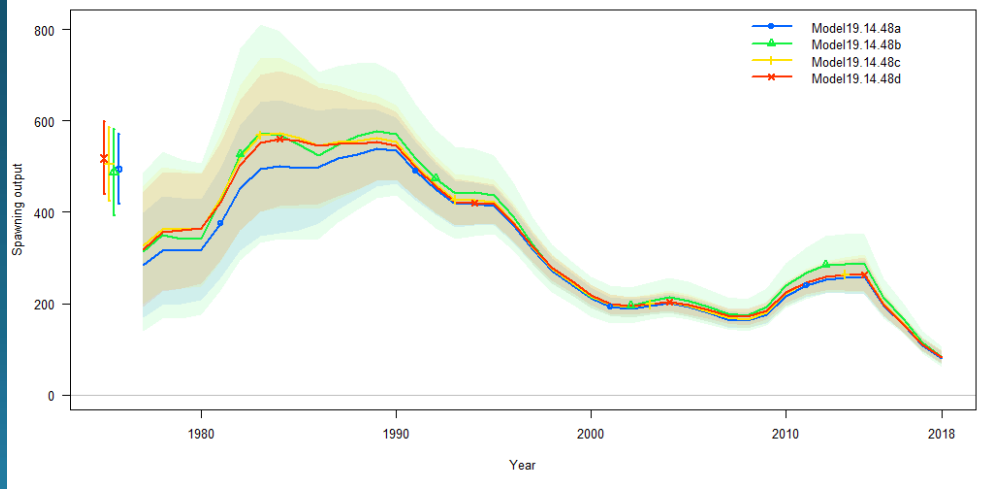
- 48c – Pre-2007 fit freely with 2007+ fixed at 0
- 48d – Pre-2007 fixed at 48c values, 2007+ fit freely



# Aging bias (Models 19.14.48a, 48b, 48c, and 48d)

- 48b – Forcing age bias as specified in the Stark (2007) re-read resulted in a much poorer model fit and implausible results (M=0.57).
- 48c – Provided a much better fit to the data and plausible results
- 48d – Provided an even better fit to the model and parameter estimates that appear plausible



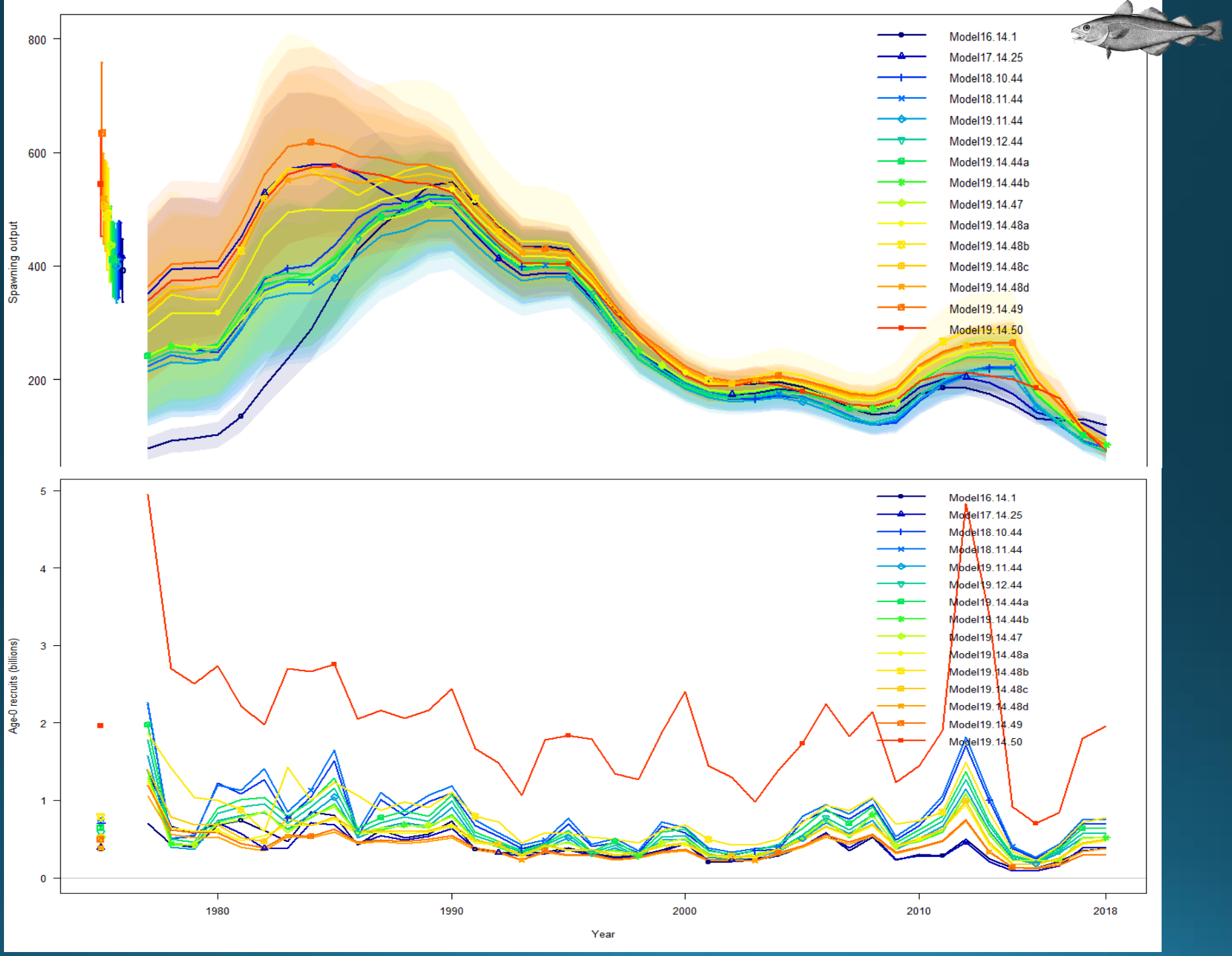
# Summary aging bias analysis

- If model is parameterized correctly it suggests that the re-aging of the Stark (2007) data may not be a good representation of aging error in data.
- Best model fits suggest a slight over-aging pre-2007 and slight under-aging 2007+

| | Model19.14.48a | Model19.14.48b | Model 19.14.48c | Model 19.14.48d |
|---|---|---|---|---|
| Starting age | 3 | 3 | 3 | 3 |
| Bias at start age pre-2007 | 0 | 0.95 (σ = NA ) | 0.387 (σ = 0.055) | 0.387 (σ = NA ) |
| Bias at maxage pre-2007 | 0 | 1.25 (σ = NA ) | 0.177 (σ = 0.159) | 0.177 (σ = NA ) |
| Bias at start age 2007+ | 0 | 0.263 (σ = 0.041) | 0 | 0.135 (σ = 0.038) |
| Bias at maxage 2007+ | 0 | 0.193 (σ = 0.189) | 0 | -0.792 (σ = 0.114) |
| Standard deviation at start age | 0.57 | 0.57 | 0.57 | 0.57 |
| Standard deviation at maxage | 1.16 | 1.16 | 1.16 | 1.16 |
| -Loglikelihood | 2727.45 | 2790.24 | 2694.87 | 2673.72 |

# Model results

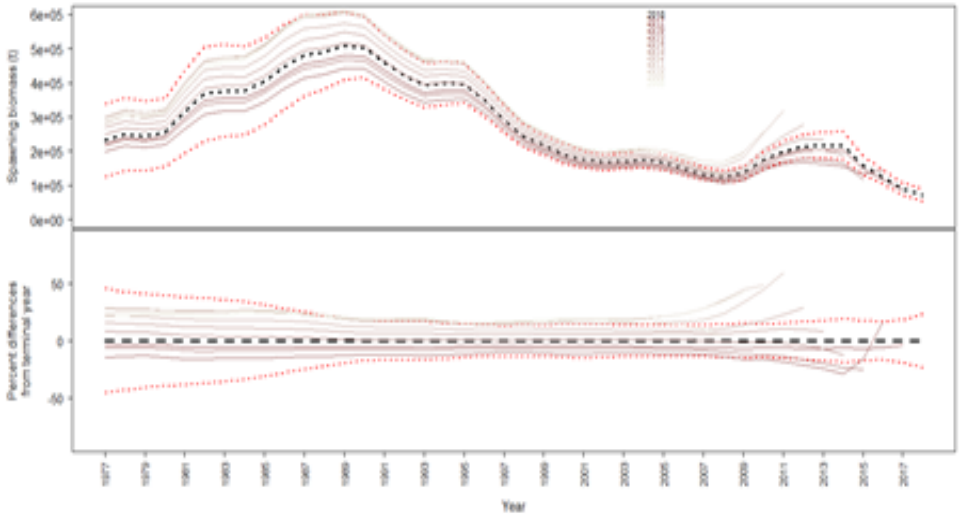
| Label | Model 19.11.44 | Model 19.12.44 | Model 19.14.44a | Model 19.14.44b | Model 19.14.47 | Model 19.14.48a | Model 19.14.48b | Model 19.14.48c | Model 19.14.48d |
|---|---|---|---|---|---|---|---|---|---|
| #parameters | 197 | 197 | 200 | 200 | 200 | 182 | 184 | 184 | 186 |
| Likelihoods | | | | | | | | | |
| TOTAL | 2081.02 | 2080.71 | 2192.08 | 2418.49 | 2807.98 | 2727.30 | 2790.11 | 2694.69 | 2673.72 |
| Survey | -13.76 | -15.54 | -17.99 | -18.43 | -17.53 | -17.20 | -17.61 | -17.65 | -17.17 |
| Length_comp | 1314.55 | 1314.55 | 1322.12 | 1327.88 | 1337.29 | 1417.59 | 1429.37 | 1414.17 | 1408.78 |
| Age_comp | 879.12 | 879.12 | 884.80 | 1108.29 | 1488.31 | 1334.33 | 1383.80 | 1304.89 | 1289.51 |
| Parm_priors | 1.68 | 1.81 | 1.78 | 1.20 | 1.19 | 0.81 | 1.53 | 0.87 | 0.57 |
| Parameters | | | | | | | | | |
| LN($R_0$) | 13.174 | 13.274 | 13.38 | 13.164 | 13.166 | 13.089 | 13.574 | 13.136 | 12.862 |
| M | 0.480 | 0.490 | 0.506 | 0.477 | 0.476 | 0.473 | **0.571** | 0.479 | 0.432 |
| $M_{2014\text{-}2016}$ | 0.783 | 0.811 | 0.808 | 0.756 | 0.754 | 0.746 | **0.871** | 0.760 | 0.690 |
| $Q_{AFSC\ trawl}$ | 1.096 | 1.057 | 1.008 | 0.976 | 0.966 | 1.011 | **0.896** | 0.969 | 0.966 |
| $L_{inf}$ | 99.46 | 99.461 | 99.461 | 99.461 | 99.462 | 112.070 | 115.745 | 111.810 | 107.639 |
| VonBert K | 0.161 | 0.161 | 0.162 | 0.171 | 0.172 | 0.147 | 0.150 | 0.150 | 0.157 |
| $SSB_0$ ($10^3$t) | 199.737 | 204.195 | 205.729 | 218.710 | 218.242 | 247.078 | 243.354 | 252.574 | 259.000 |


Spawning output
800
600
400
200
Model16.14.1
Model17.14.25
Model18.10.44
Model18.11.44
Model19.11.44
Model19.12.44
Model19.14.44a
Model19.14.44b
Model19.14.47
Model19.14.48a
Model19.14.48b
Model19.14.48c
Model19.14.48d
Model19.14.49
Model19.14.50
Age-0 recruits (billions)
5
4
3
2
1
0
1980
1990
2000
2010
2018
Year

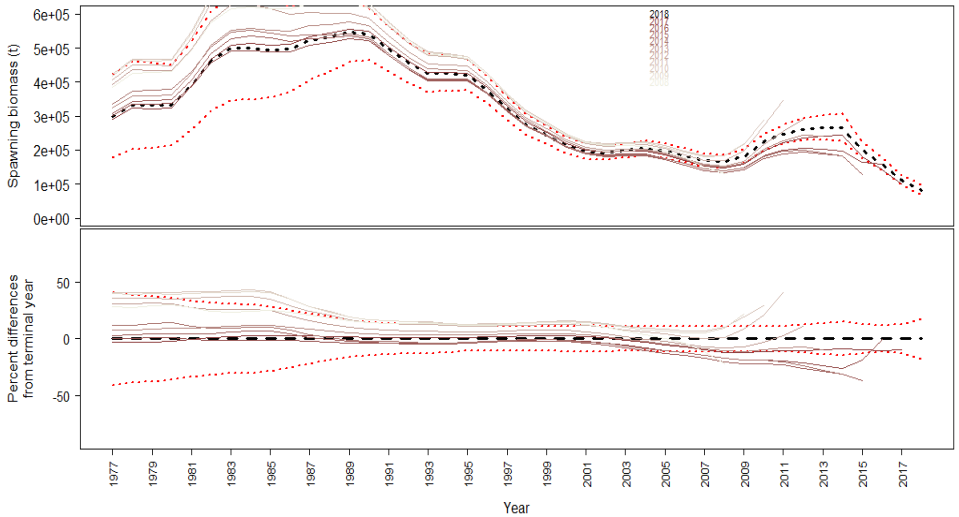
# Retrospective analysis

| Model | ρ | Woods Hole ρ | RMSE |
|---|---|---|---|
| Model19.12.44 | 0.166 | 0.083 | 0.150 |
| Model19.14.44a | -0.051 | -0.015 | 0.236 |
| Model19.14.44b | 0.037 | 0.062 | 0.126 |
| Model19.14.47 | 0.022 | 0.063 | 0.125 |
| Model19.14.48a | -0.013 | 0.080 | 0.147 |
| Model19.14.48b | -0.048 | -0.112 | 0.332 |
| Model19.14.48c | -0.006 | 0.072 | 0.155 |
| Model19.14.48d | -0.007 | 0.088 | 0.153 |

Model19.12.44




Model19.14.48b

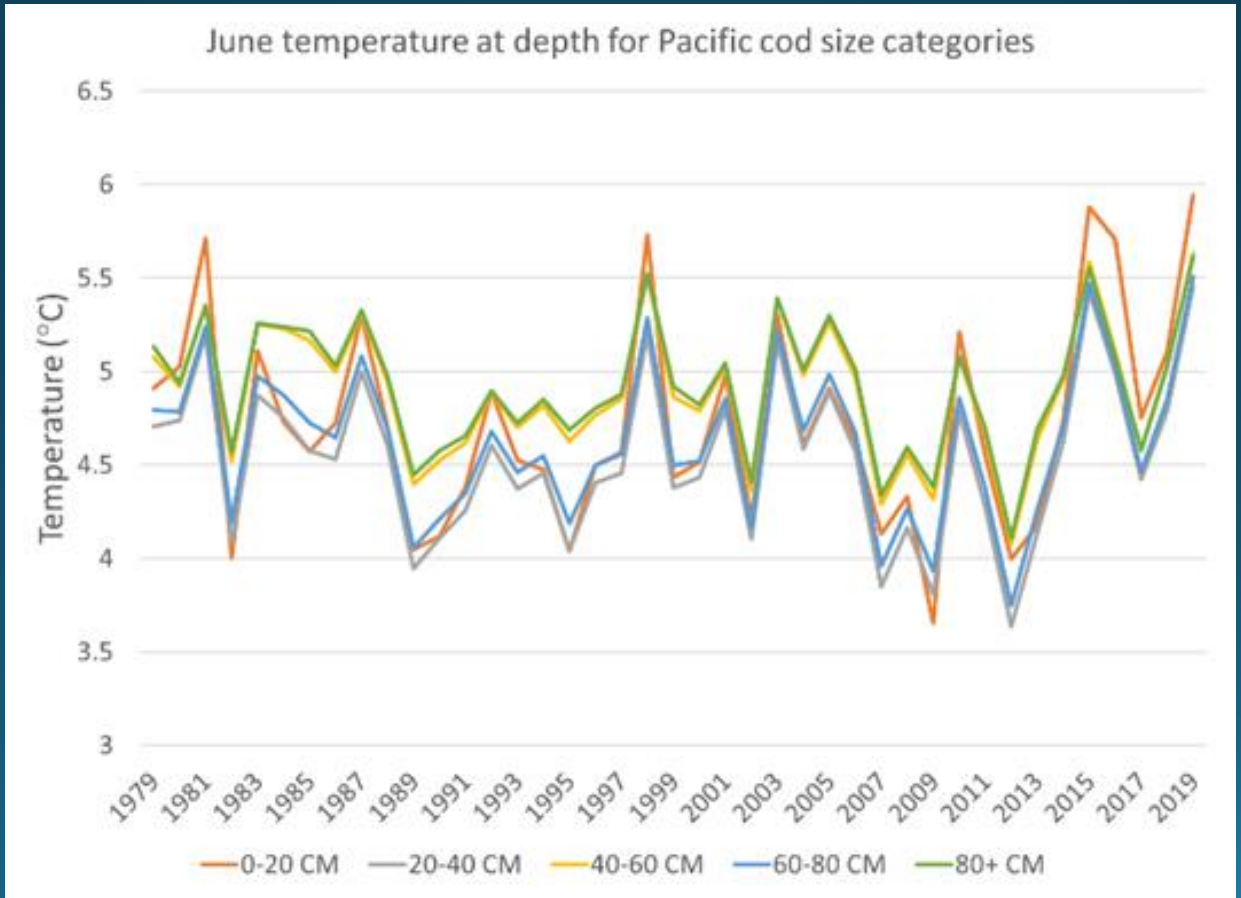


# Model 19.14.51

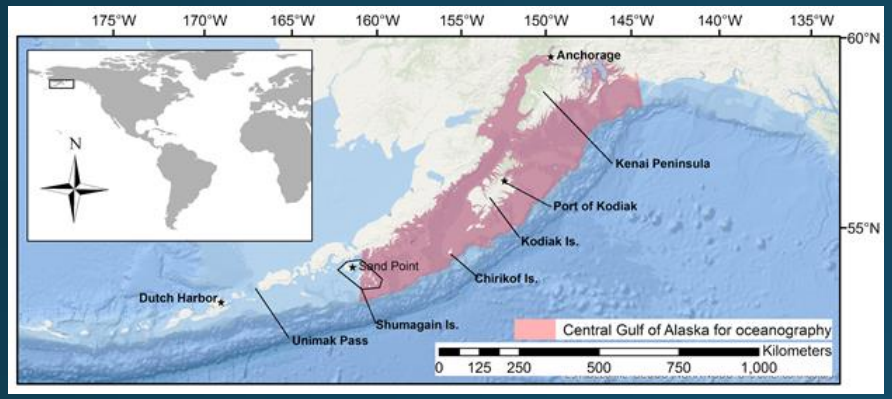
- Model 19.14.48d with addition of:
  - Age varying natural mortality scaled to the winter MHCI
  - $R_0$ scaled to the winter MHCI
  - $L_\infty$ and K scaled to CFSR water temperatures
- Addresses the need for a climate-enhanced single species Pacific cod model if rebuilding becomes necessary
- Allows forecasting of likely climate change impacts on stock

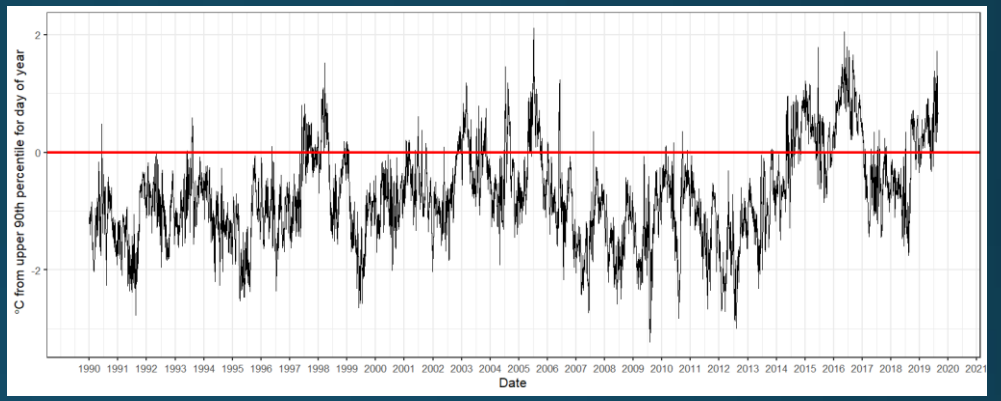
# Climate Forecast System Reanalysis data for Central GOA Pacific cod

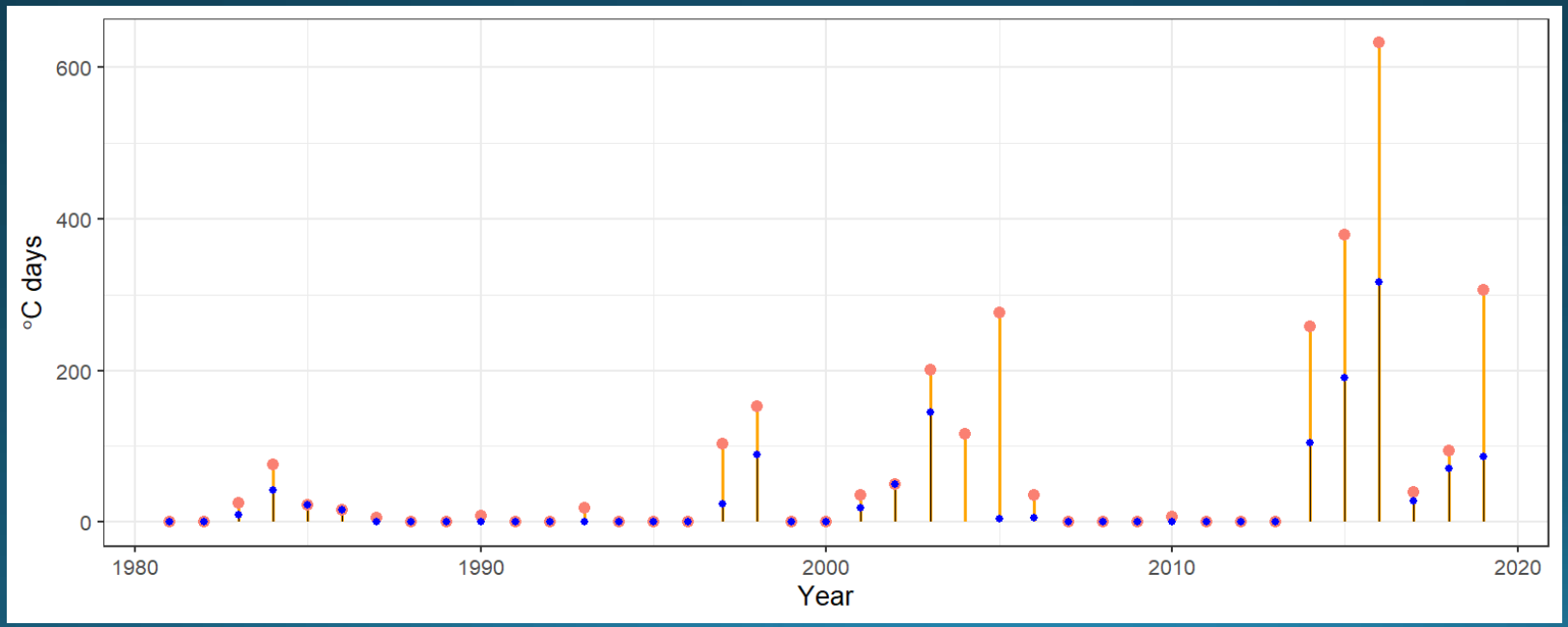
- Temperatures at depth for centroid of Pacific cod at different lengths



# Marine heatwave analysis from NOAA high-resolution blended analysis data for central GOA

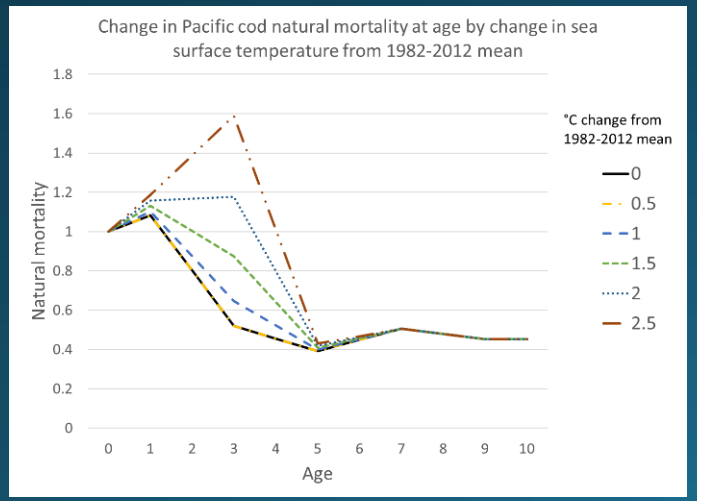


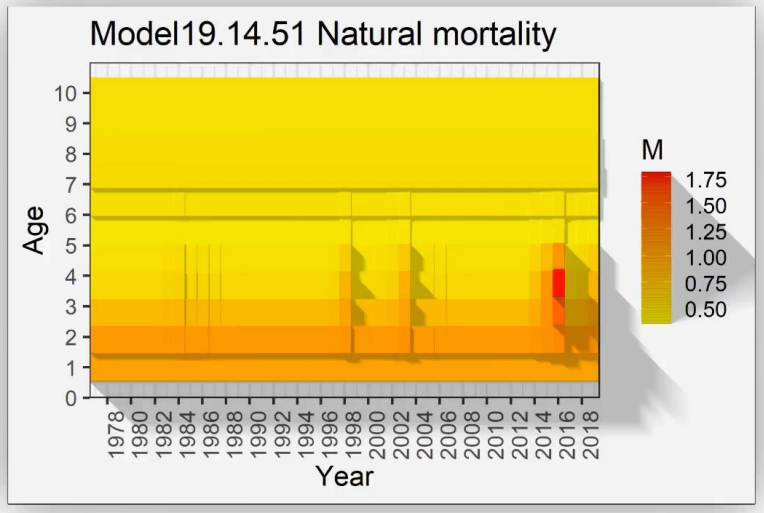



# Natural mortality

- Only changes during heatwaves, with most extreme in 2016
- Anchored at age 1 with 1.0
- No annual changes after age 7
- High gradients on age specific natural mortality environmental parameters (-0.005 to -0.001)

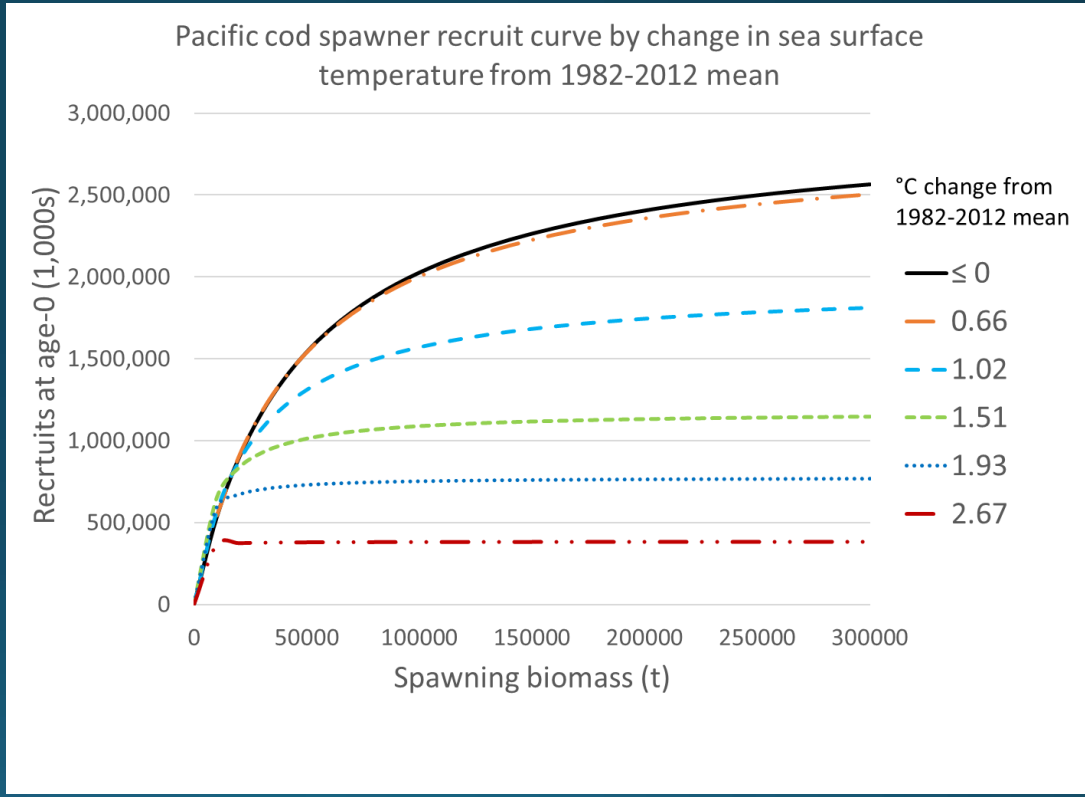


# Beverton-Holt recruitment

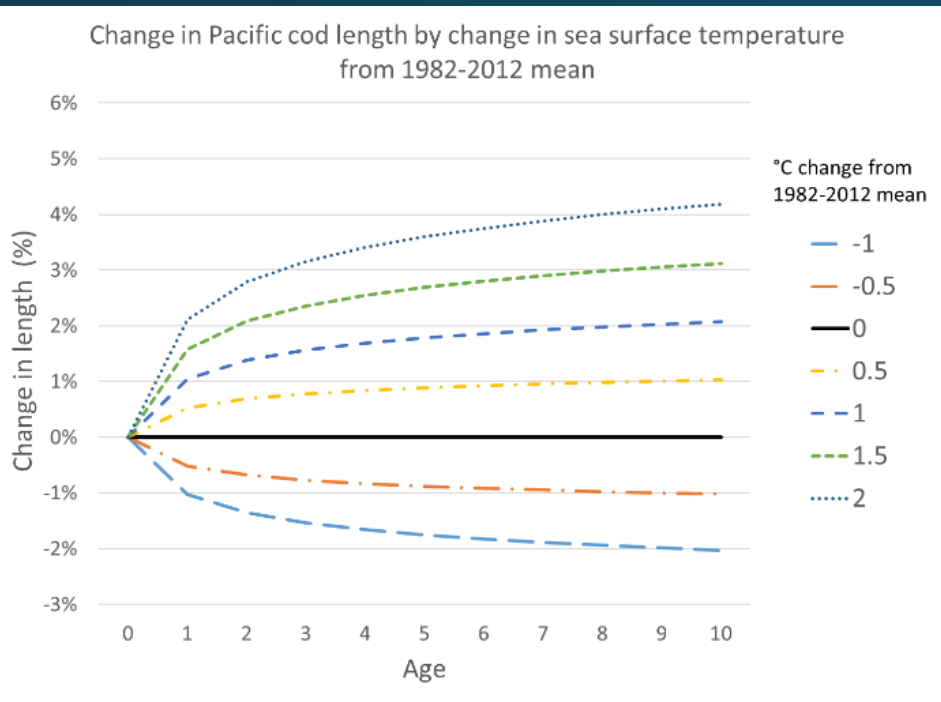
- Steepness fit at 0.80
- $R_0$ scaled to winter MHWCI
- Lowest recruitment at highest MHWCI

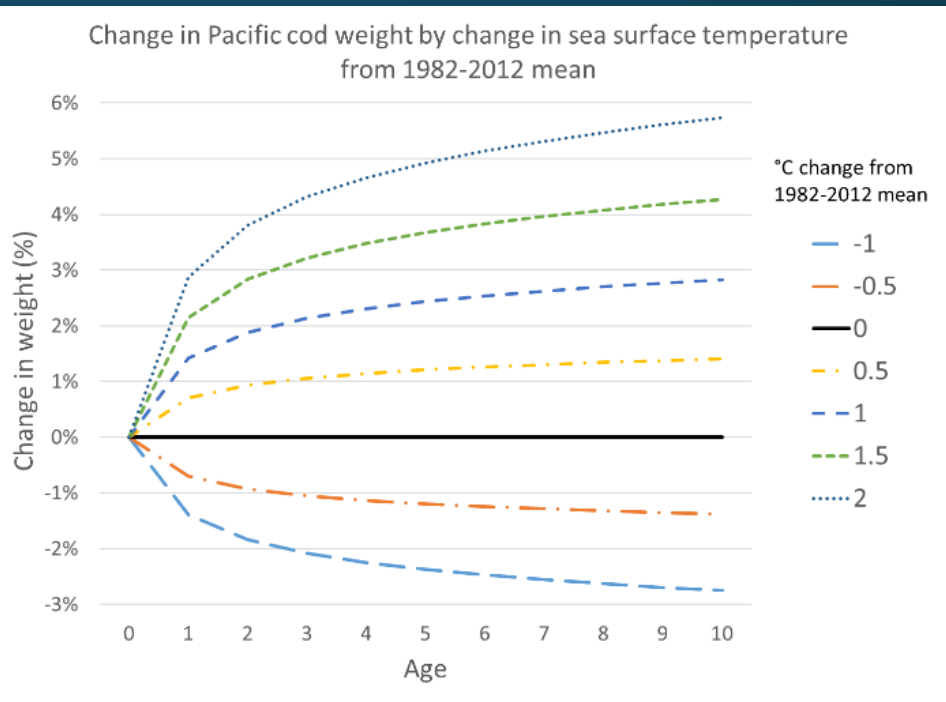
- Low precision on steepness ($\sigma = 0.22$)
- High gradient on $R_0$ environmental parameter (0.119)



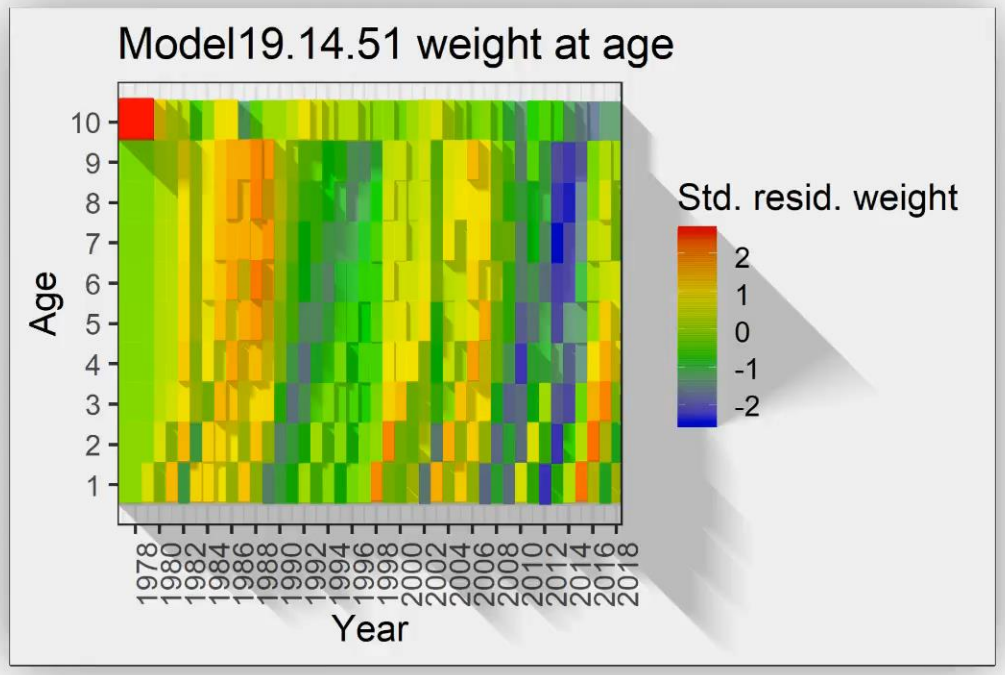
# von Bertalanffy growth

- $L_\infty$ and K scaled to 0-20 cm Pacific cod CFSR water temperature anomalies
- Warmer waters resulted in longer and heavier fish
- Modeled as a cohort effect



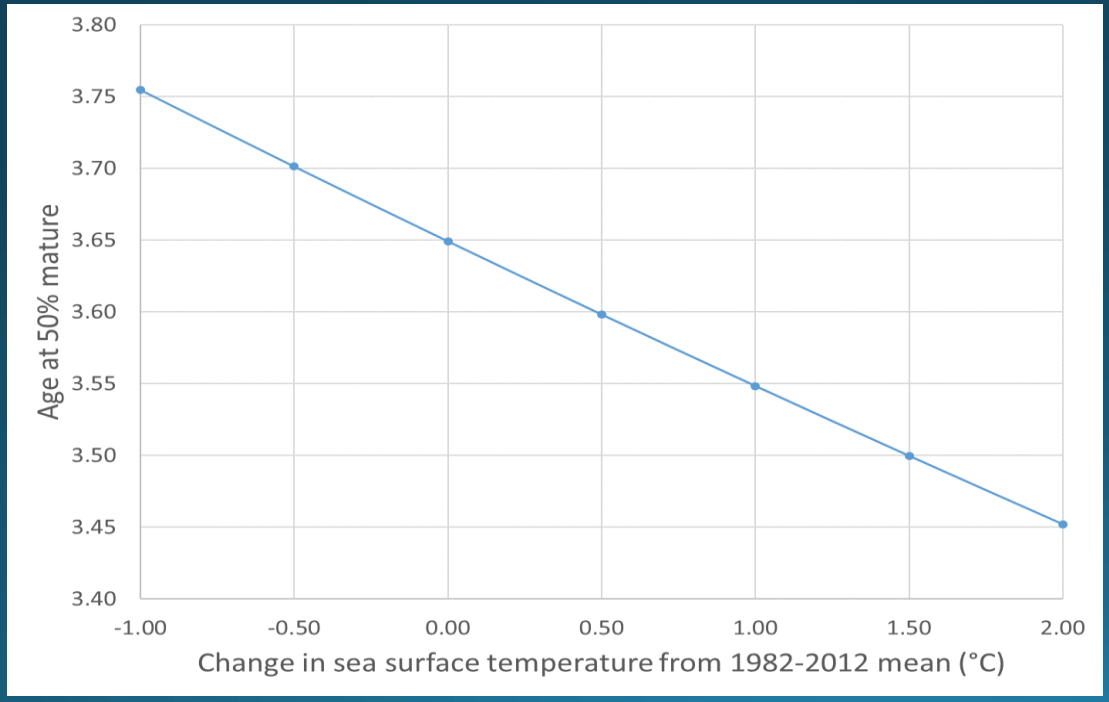



# von Bertalanffy growth –weight by age stand. residuals



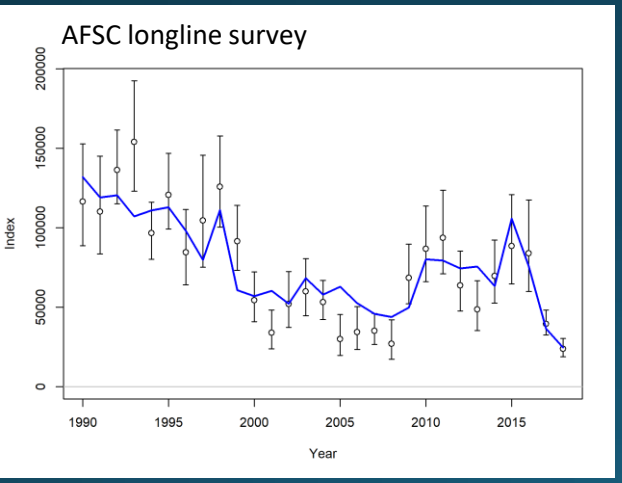
# Maturity

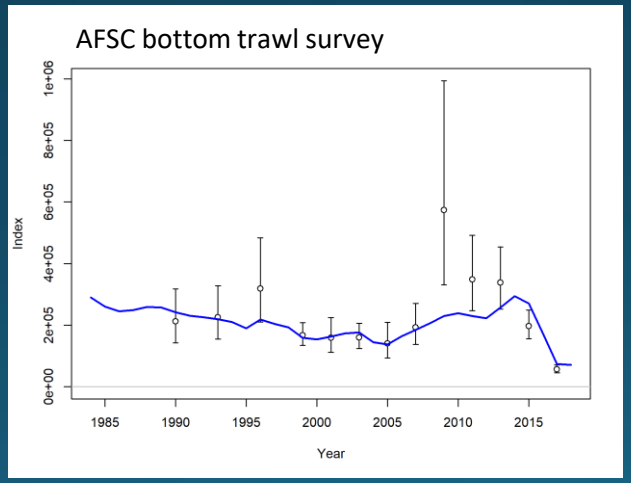
- Maturity is fixed as a function of length in the model with $L_{50}$ at 53.7cm
- Age at maturity goes down with higher temperatures

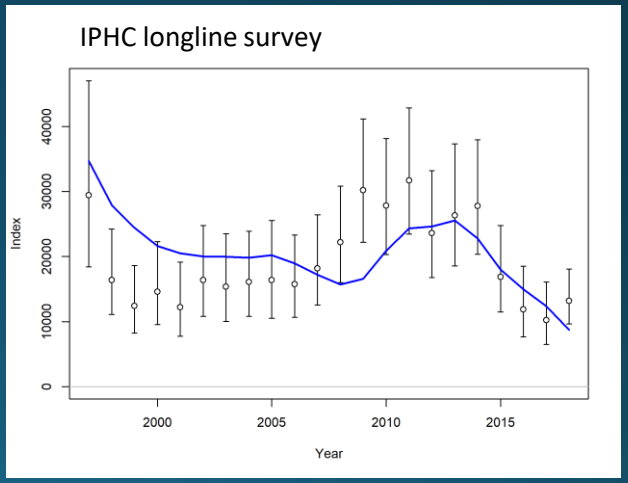


# Index fits model 19.14.48d vs .51

- Model 19.14.51 has best fit to AFSC longline survey
- Poorer fits to AFSC bottom trawl and IPHC longline surveys

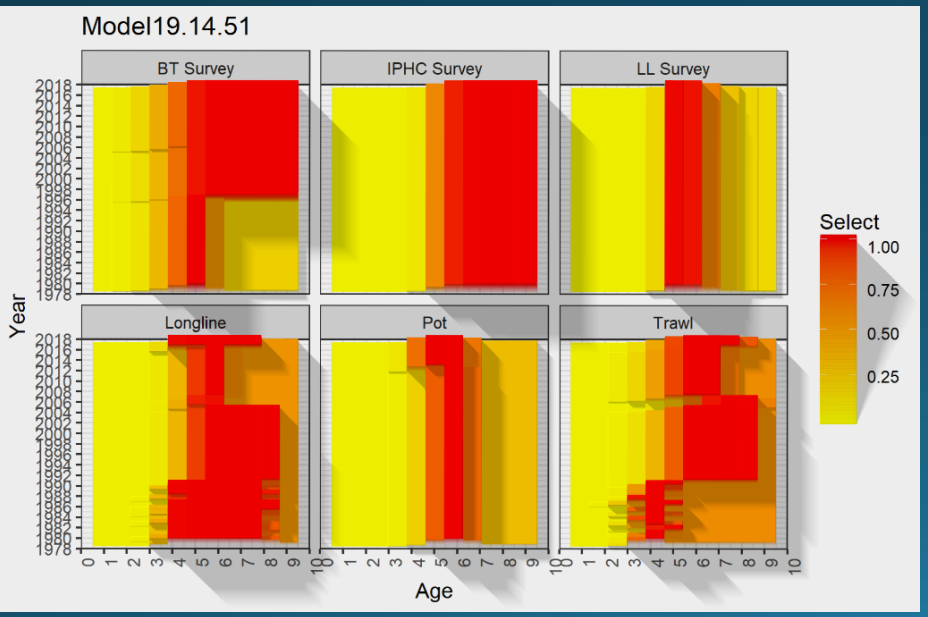


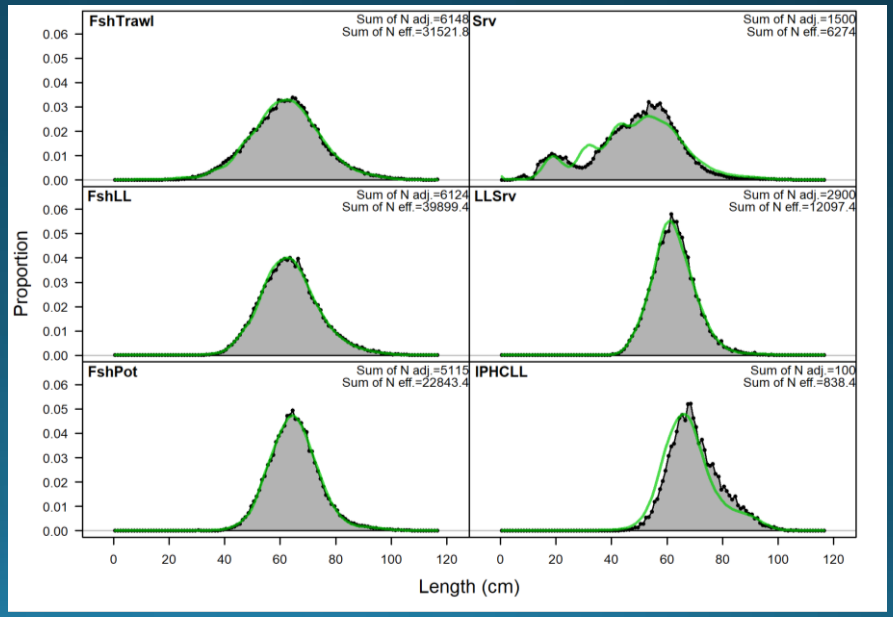



# Selectivity and fit to length comps

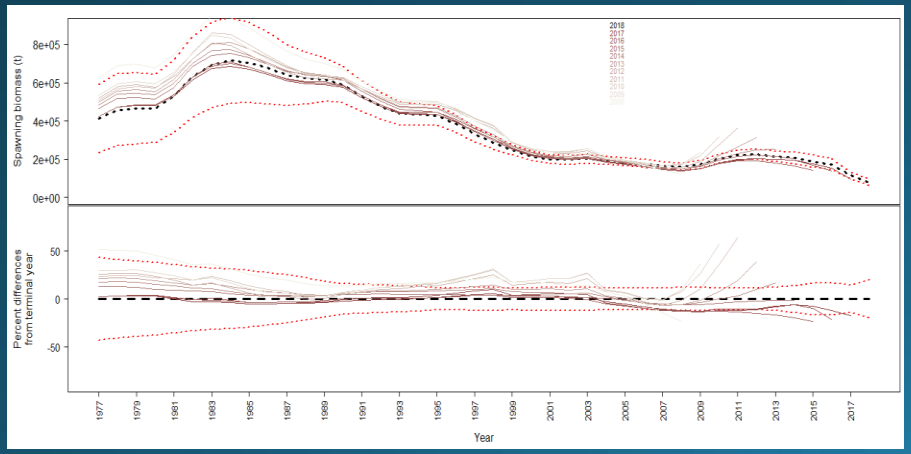
- Age-based with double normal for all but the IPHC longline which is fit using a logistic
- Little difference from Model 19.14.48d
- Good fit to all components



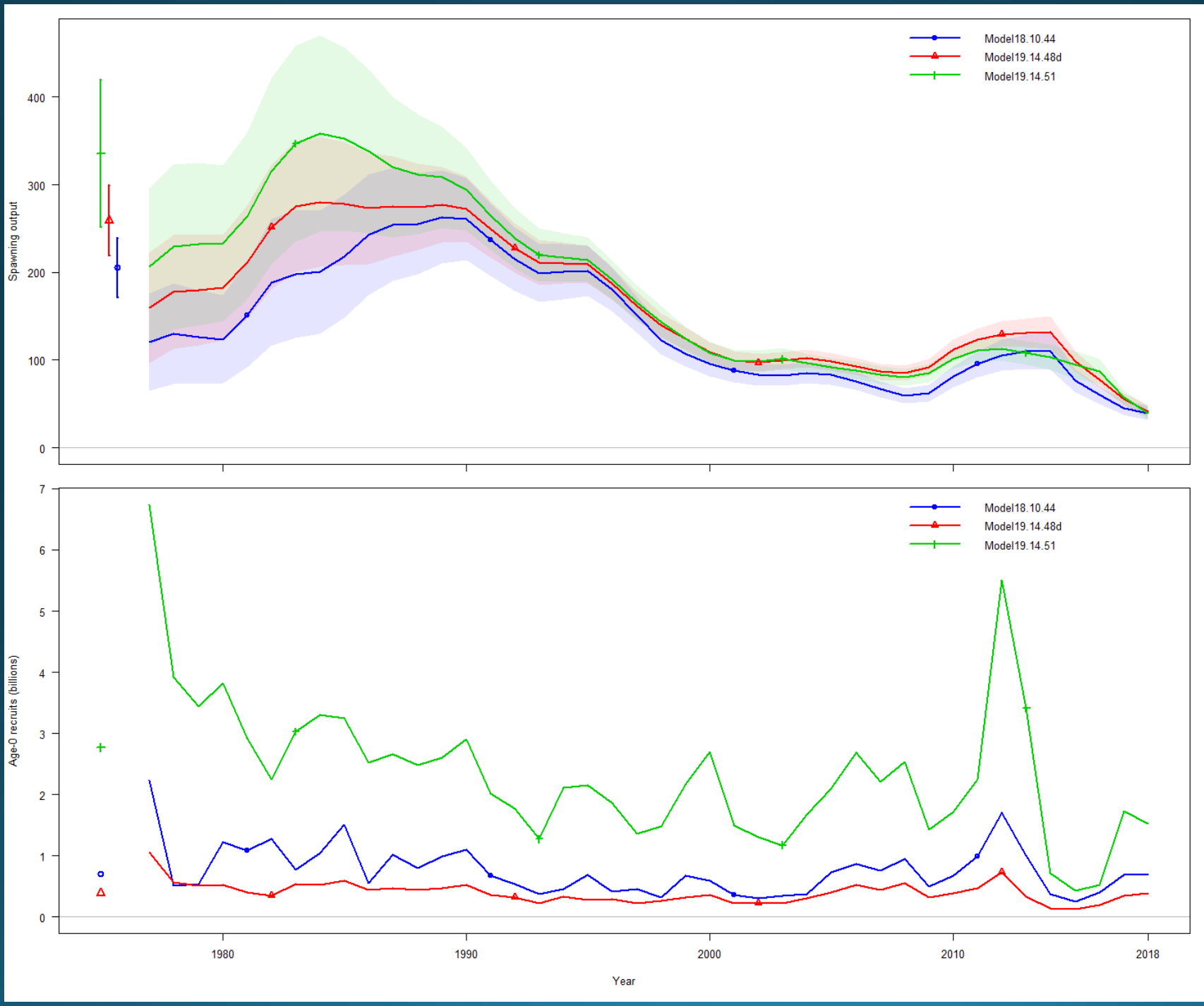



# Model fit

- Better overall fit to data than Model 19.14.48d
- Retrospective worse, but within acceptable bounds.
- Higher unfished female spawning biomass

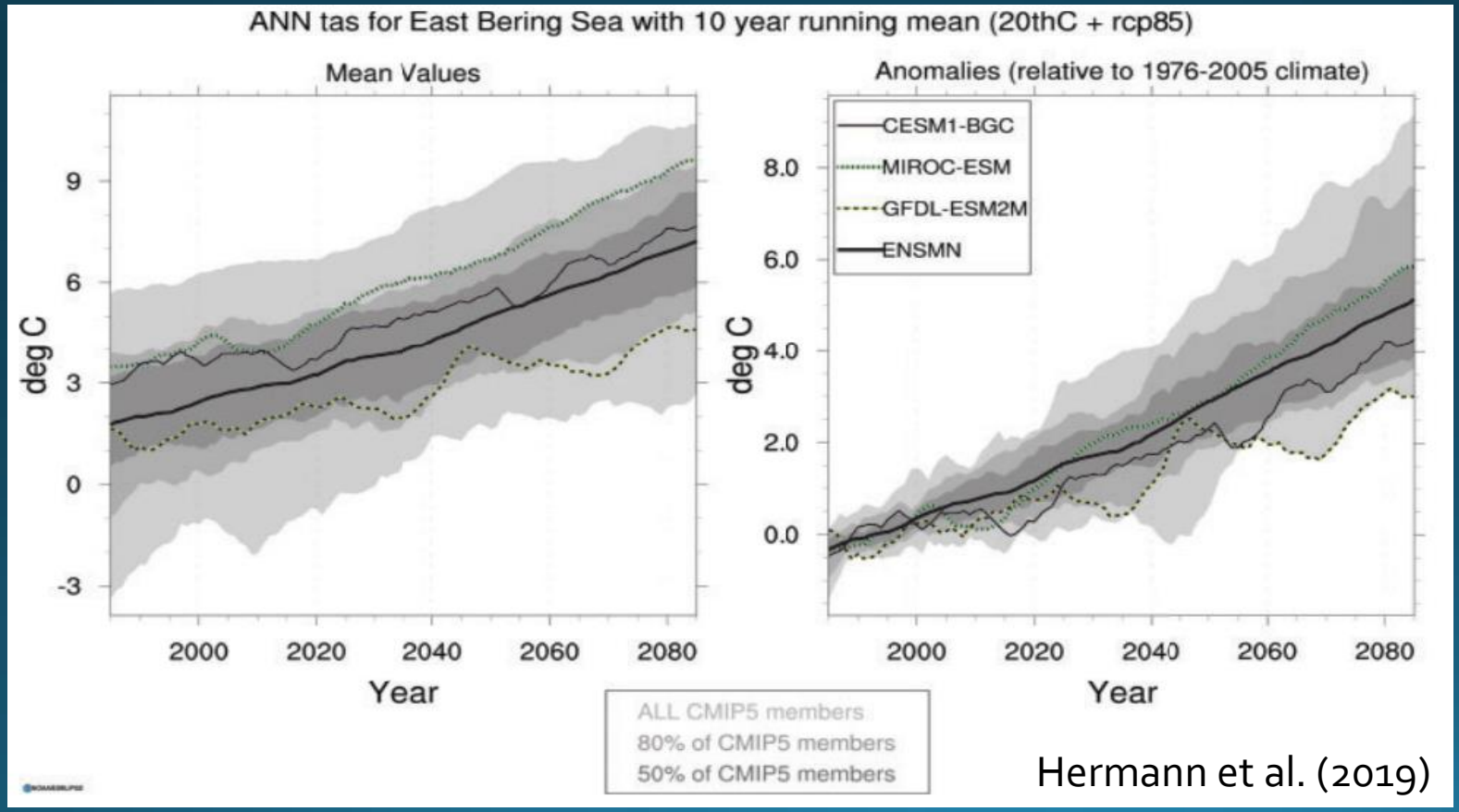



| | M19.14.48d | Model19.14.51 |
|---|---|---|
| AIC | 5715.44 | 5653.26 |
| # Parameters | 184 | 212 |
| Likelihoods | | |
| Total | 2673.72 | 2614.63 |
| Surveys | -17.1732 | -20.20 |
| Length Composition | 1408.78 | 1347.70 |
| Cond. Age at length | 1289.51 | 1297.76 |
| Parameter Priors | 0.57643 | 2.52 |
| Results | | |
| Rvirgin | 385.423 | 2766.04 |
| LN(Ro) | 12.8621 | 14.83 |
| LN(Ro)_ENV parameter | NA | -4.03E-04 |
| BH steepness | 1.000 | 0.796 |
| M or Mat age 0 | 0.432 | 1.000 |
| M 2014-2016 | 0.690 | NA |
| M age 1 | NA | 1.08 |
| M age 3 | NA | 0.52 |
| M age 5 | NA | 0.39 |
| M age 7 | NA | 0.51 |
| M age 9 | NA | 0.45 |
| M age 1 env. parameter | NA | 2.72E-04 |
| M age 3 env. Parameter | NA | 3.31E-03 |
| M age 5 env. Parameter | NA | 2.71E-04 |
| $L_\infty$ | 107.639 | 111.608 |
| L∞ env. Parameter | NA | 2.43E-02 |
| VonBert K | 0.157 | 0.147 |
| VonBert K env. Parameter | NA | -8.01E-03 |
| SSB_Virgin_thousand_mt | 259.000 | 275.876 |
| Retrospectives | | |
| Mohn's ρ | -0.007 | 0.127 |
| Woods Hole ρ | 0.088 | 0.078 |
| RMSE | 0.153 | 0.132 |


Model18.10.44
Model19.14.48d
Model19.14.51
Spawning output
0
100
200
300
400
Model18.10.44
Model19.14.48d
Model19.14.51
Age-0 recruits (billions)
0
1
2
3
4
5
6
7
1980
1990
2000
2010
2018
Year

# Climate change and GOA Pacific cod

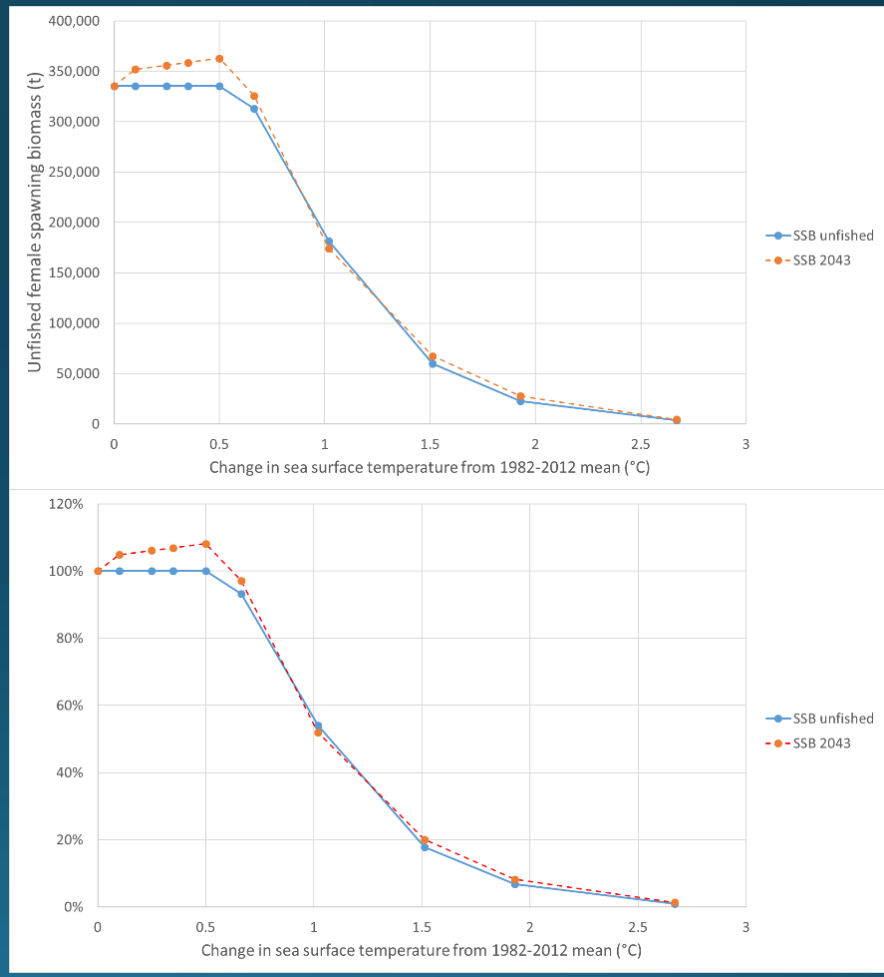
- Sea temperatures are expected to rise and marine heatwaves become more common



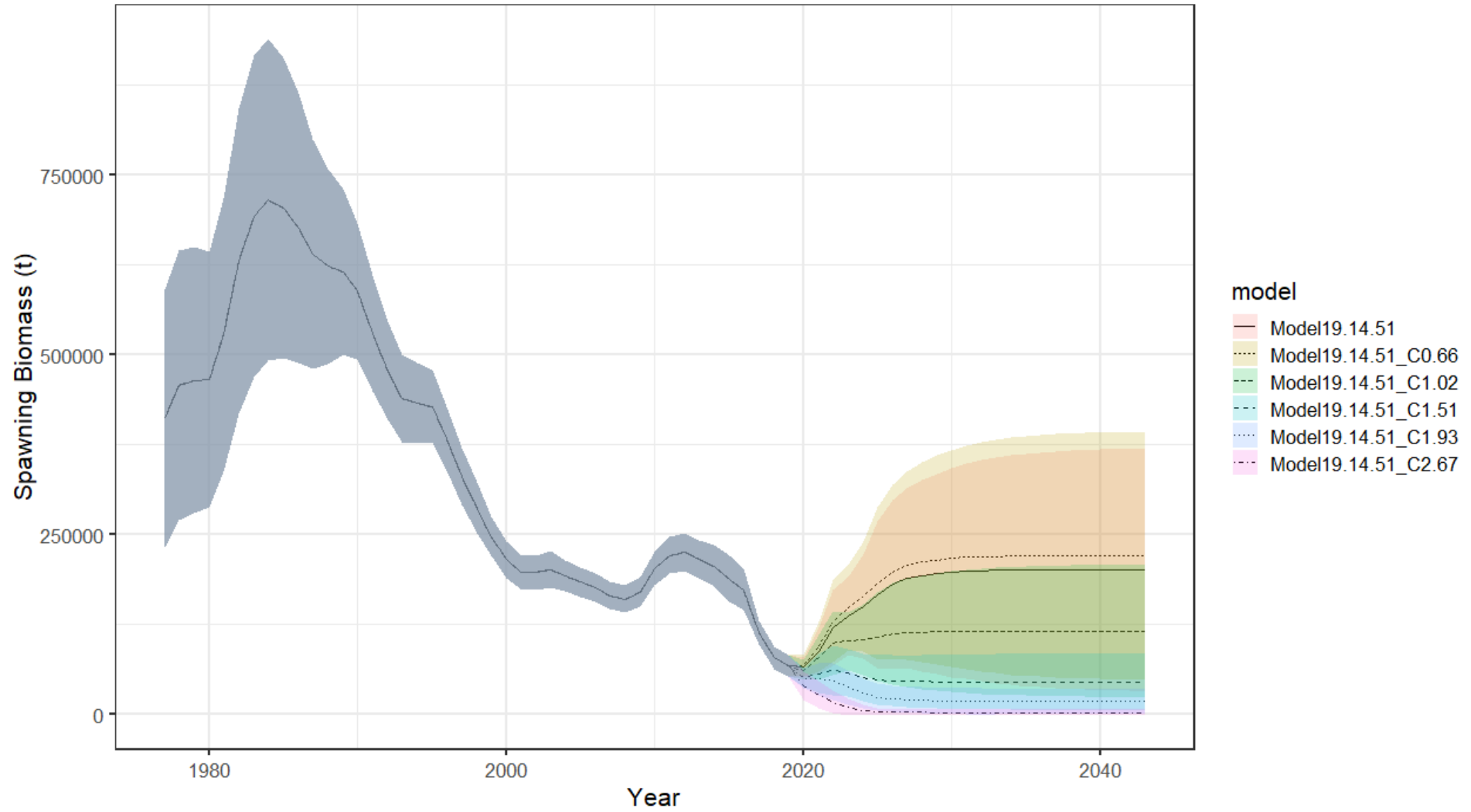

Hermann et al. (2019)

# Sea temperature impacts on reference points

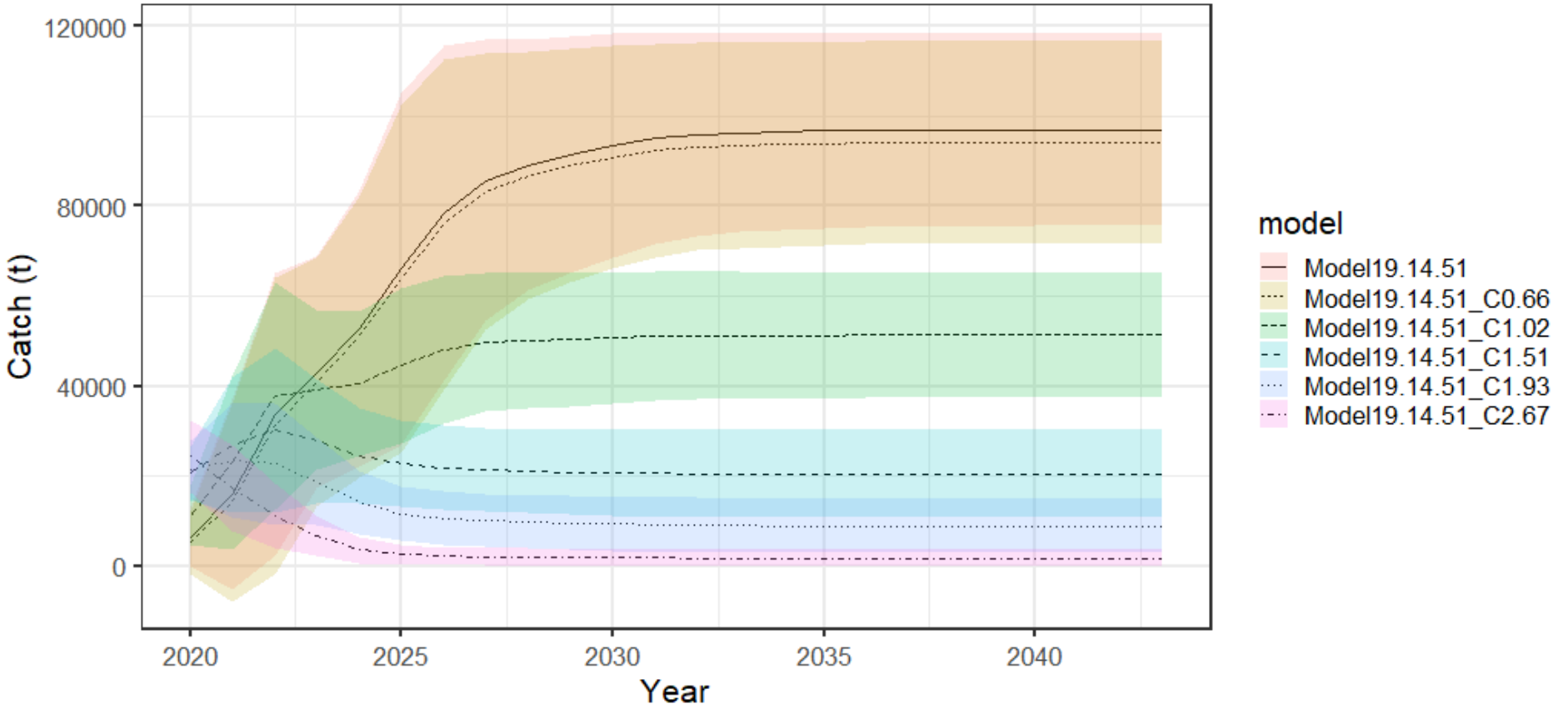
- Model projected forward to 2043 with no fishing at increasing temperatures
- $B_{20\%}$ of current unfished at 1.5 °C
- 2015 was on average 2.67°C greater than the 1982-2012 mean



# Projected spawning biomass at $F_{35\%}$



# Projected catch at $F_{35\%}$



# Summary

- Without rapid adaptation increased temperature in the GOA will impact cod
  - Reduced recruitment
  - Increased natural mortality
  - Increase growth
- A 1.5°C increase in temperature from 1982-2012 mean reduced potential unfished biomass to 20% of current $B_{100\%}$
- 2019 sea temperatures currently exceed this level
- Any rebuilding plan that might be required in the near future should take these factors into account

# 2020 and beyond

- Further sensitivity testing and validation of the climate-enhanced model
- Addition of Rogers and Laurel Pacific cod habitat index and/or age-0 estimates from spring icthyoplankton surveys as data source
- Multispecies model: GOA CEATTLE (Grant Adams and Kirstin Holsman)
- Exploration of use of bioenergetics and multispecies model outputs (e.g. Relative Forage Requirement index) for model inputs driving M and growth from Adams and Holsman (GOA CEATTLE)