Spatiotemporal model-based indices for BSAI crab stocks

Update for Crab Plan Team

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Goals

1. Develop spatiotemporal model-based indices for:
   - Bering Sea Tanner crab
   - Bering Sea snow crab
   - St. Matthew Island blue king crab (*see* January modeling workshop)
   - Norton Sound red king crab
2. Develop a transparent process for evaluating and selecting models

Approach

Fit models using the *sdmTMB* R package

sdmTMB estimates spatial and spatiotemporal generalized linear mixed effects models

Allows for index standardization when the set of stations surveyed is inconsistent across years

Comparison with VAST

- VAST models also accomplish index standardization, but are often criticized for:
  - A difficult user interface
  - Slower fitting times
  - Less flexible model specification
- We compared model-indices generated using sdmTMB and VAST (when available) using the best sdmTMB model specification
- The equivalence of VAST and sdmTMB models has been demonstrated in direct comparisons for groundfish stocks:
  https://github.com/afsc-gap-products/model-based-indices/blob/main/species_specific_code/GOA/sdmTMB_VAST_index_comparison_goa.Rmd

Model-fitting decision points

Resolution of spatial mesh used to fit model

- more knots = higher resolution

Spatiotemporal random fields estimation

- IID: RF independent from one time step to next
- AR1: RF correlated from one time step to next
- random walk: difference in spatiotemporal deviations from one time step to the next are IID

Observation model family

- Tweedie, delta-gamma, delta-lognormal

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```
m.smbkc.rw.tw.90kn <- sdmTMB(
  data = bkc_kgkm_utm,
  formula = kg.km ~ 0 + year_f,
  spatial = "on",
  time = "SURVEY_YEAR",
  mesh = BK_spde_90kn,
  spatiotemporal = "rw",
  extra_time = c(2020),
  silent = FALSE,
  anisotropy = TRUE,
  family = tweedie(link = "log"))
```

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Model diagnostics: sanity checks

sdmTMB::sanity()

- ✓ Non-linear minimizer suggests successful convergence
- ✓ Hessian matrix is positive definite
- ✓ No extreme or very small eigenvalues detected
- ✓ No gradients with respect to fixed effects are >= 0.001
- ✓ No fixed-effect standard errors are NA
- ✓ No standard errors look unreasonably large
- ✓ No sigma parameters are < 0.01
- ✓ No sigma parameters are > 100
- ✓ Range parameter doesn't look unreasonably large

Model diagnostics: DHARMa residuals

- Calculated residuals using the *DHARMa* R package
- Tested for quantile deviations, over- or underdispersion, outliers, and zero-inflation using *DHARMa*
- Plotted *DHARMa* residuals spatially to evaluate potential spatiotemporal autocorrelation

Model diagnostics: predictive skill

- Used cross validation to estimate log-likelihood values across models
  - Larger log-likelihood, better predictive skill

The shadow model: how and why small choices in spatially explicit species distribution models affect predictions

Christian J. C. Commander[1,2], Lewis A. K. Barnett[3], Eric J. Ward[4], Sean C. Anderson[5] and Timothy E. Essington[2]

- Evaluated model spatial predictions over time
- Plotted model-predicted indices against observed values

Tanner crab

Specific methods for Tanner crab

- Fit models for abundance and biomass
- Fit models for all males, mature females, immature females
- Fit separate models for survey data <1982 and ≥1982 due to gear change
- Fit EBS-wide models, predict Tanners east and west of 166°
- Model family: delta-gamma, Tweedie, delta-lognormal
- Random field: IID, AR1, random walk

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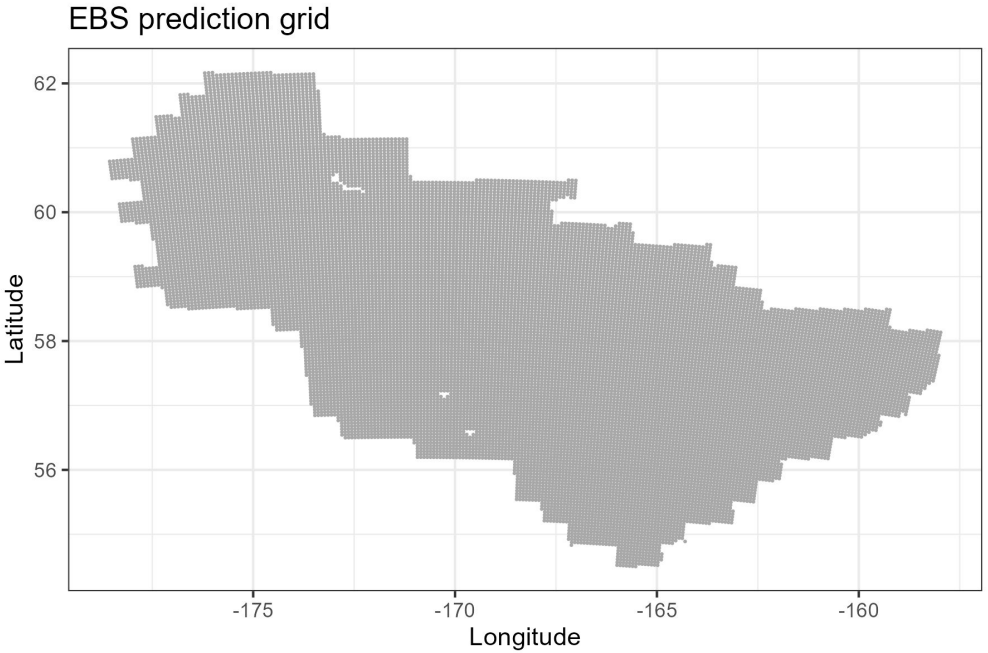
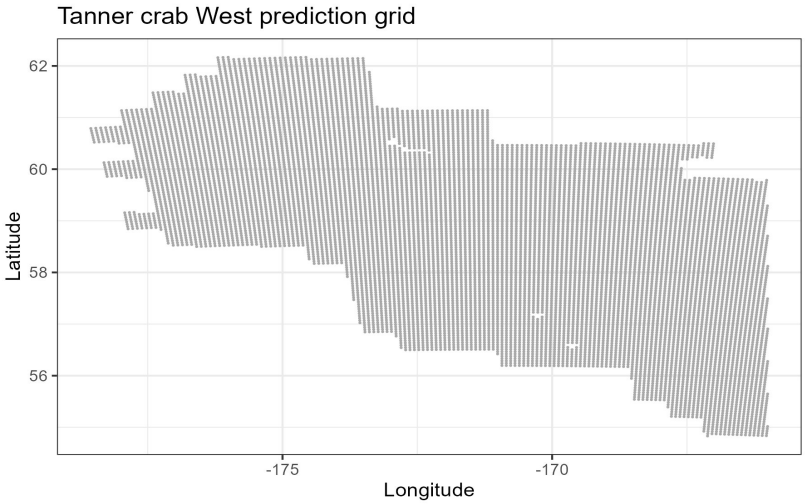
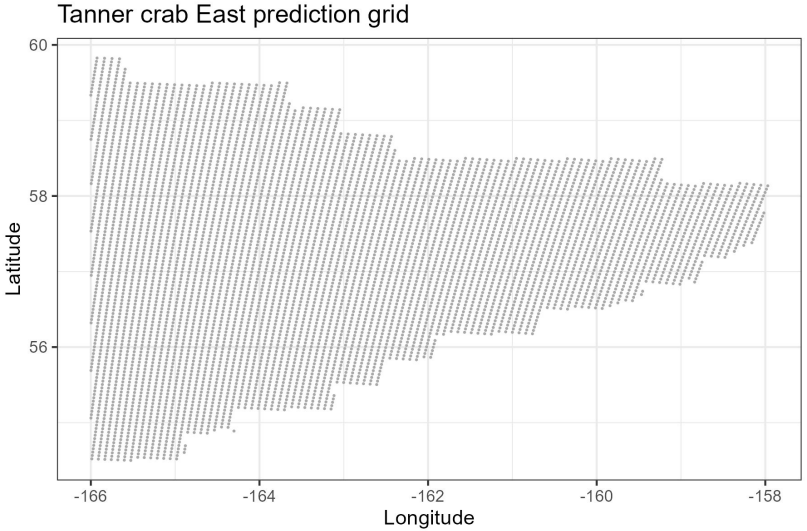
Prediction grids

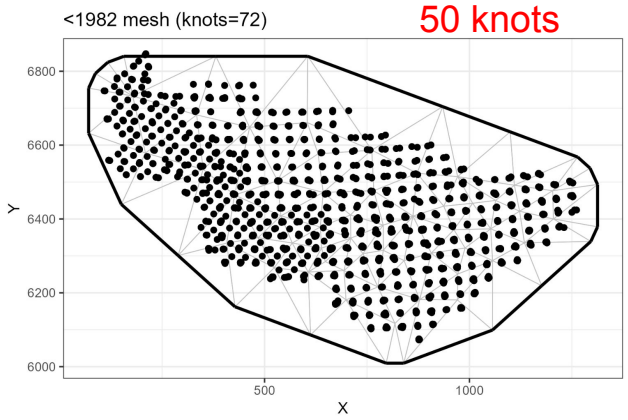
- 5 km^2 resolution, no land

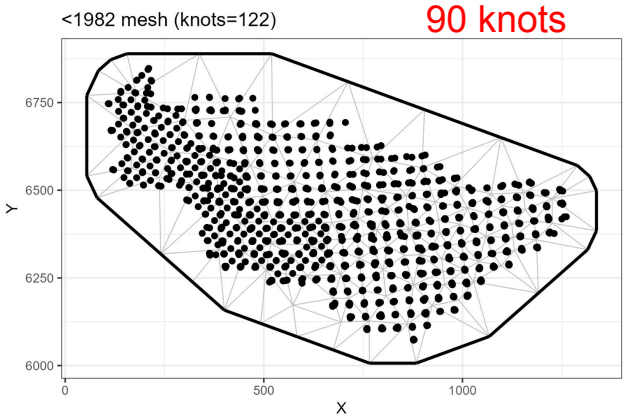


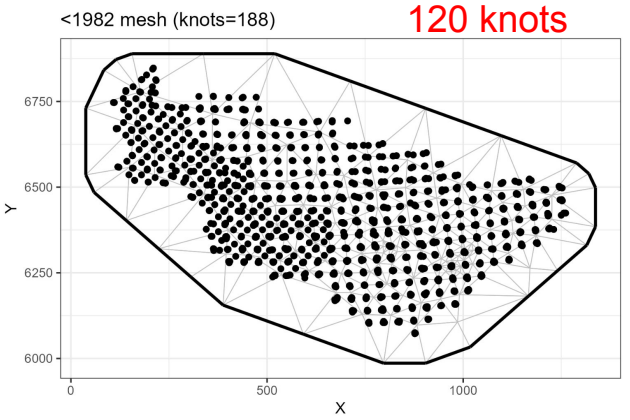


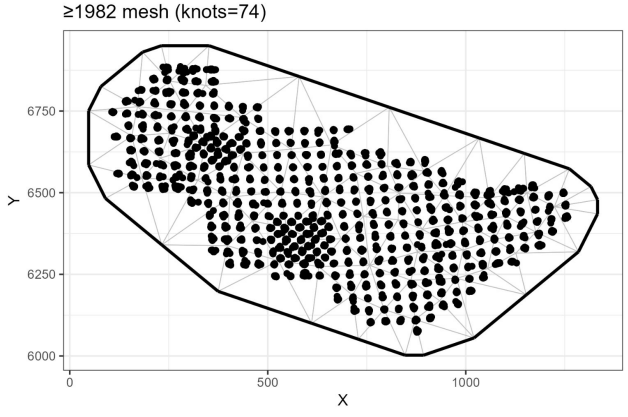


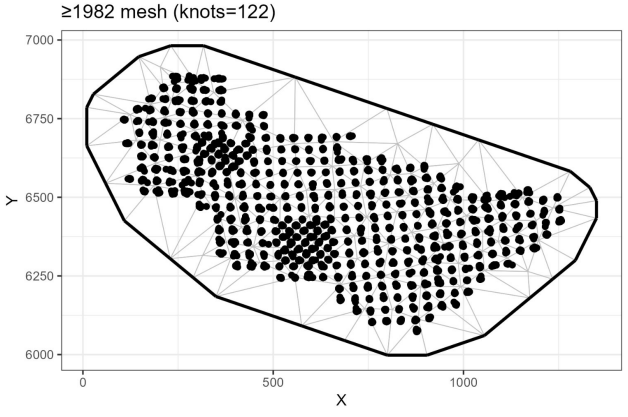
Model mesh

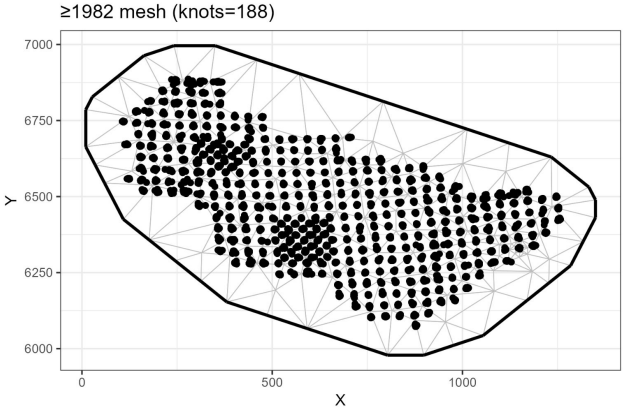

<1982 mesh (knots=72)
50 knots
Y
X


<1982 mesh (knots=122)
90 knots
Y
X


<1982 mesh (knots=188)
120 knots
Y
X


≥1982 mesh (knots=74)
Y
X


≥1982 mesh (knots=122)
Y
X


≥1982 mesh (knots=188)
Y
X

Overall model diagnostics

- Best: delta-gamma, 50-knot mesh
- Other model-specifications could be selected by fitting period and sex-maturity category
- Delta-lognormal did not pass model diagnostics, AR1 and random walk did not converge

knots	family	n	loglik	BEST
<int>	<chr>	<int>	<dbl>	<chr>
50	Delta_gamma	6	-194983.	"YES"
50	Tweedie	6	-195595.	""
90	Delta_gamma	6	-195454.	""
90	Tweedie	6	-195515.	""
120	Delta_gamma	6	-196720.	""
120	Tweedie	6	-196297.	""

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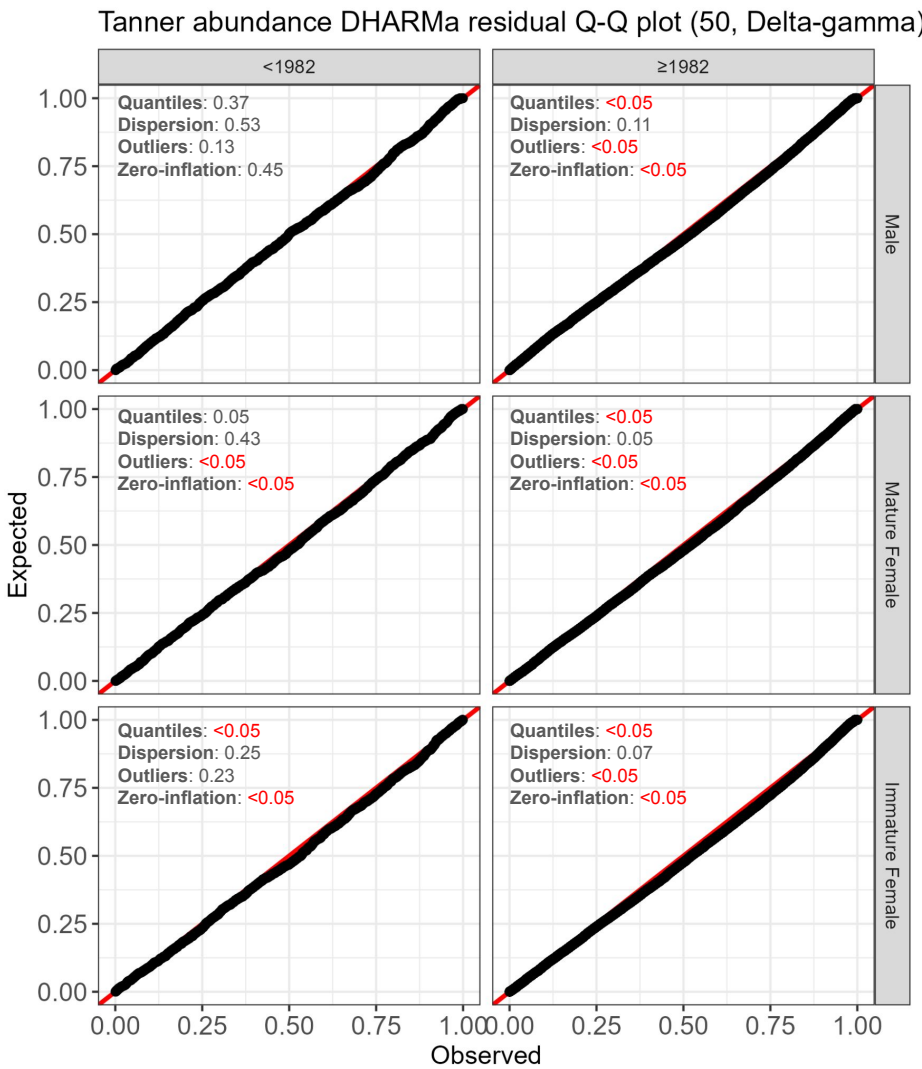
Abundance model diagnostics

- No significant residual deviation from 1-1 line
- Statistical evidence of quantile deviation, outliers, and zero-inflation
- True regardless of model family or knot number

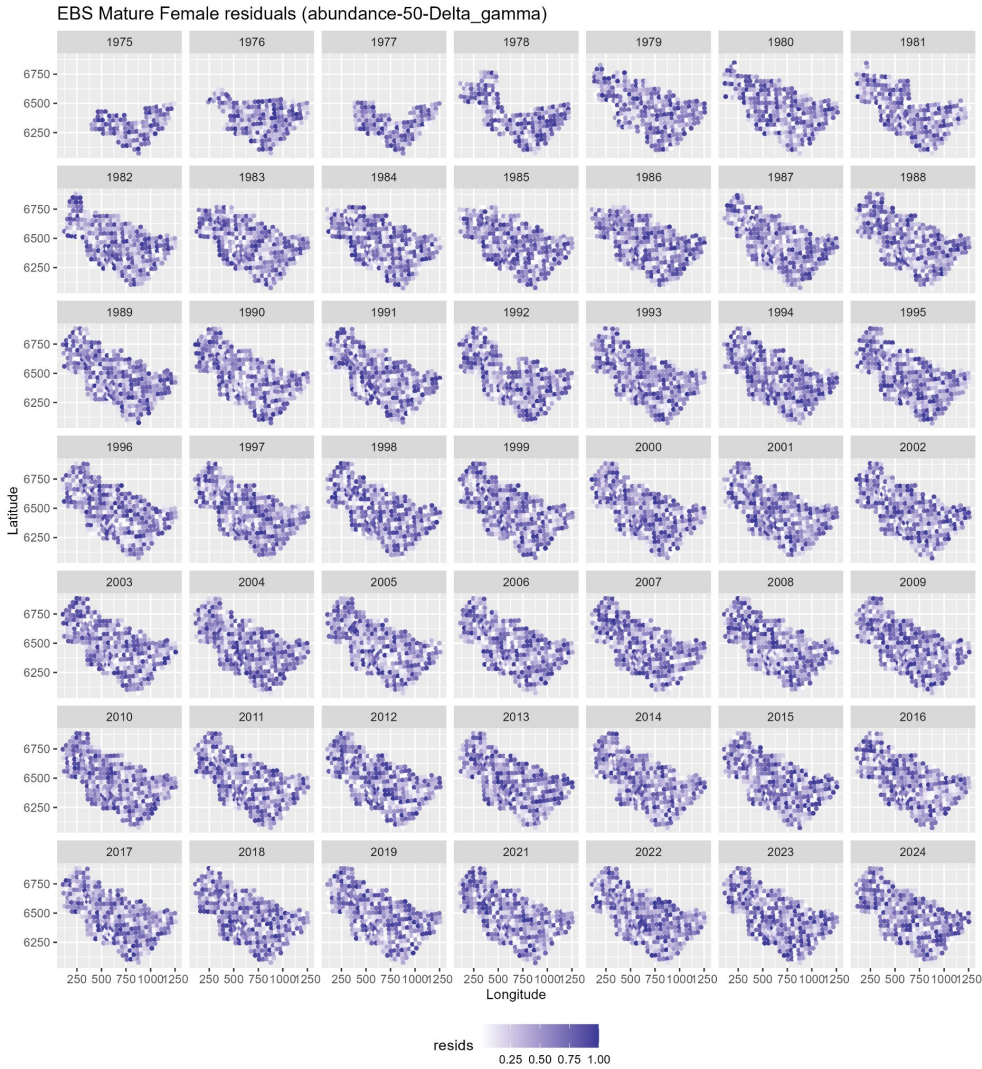
Delta-gamma, 50 knots

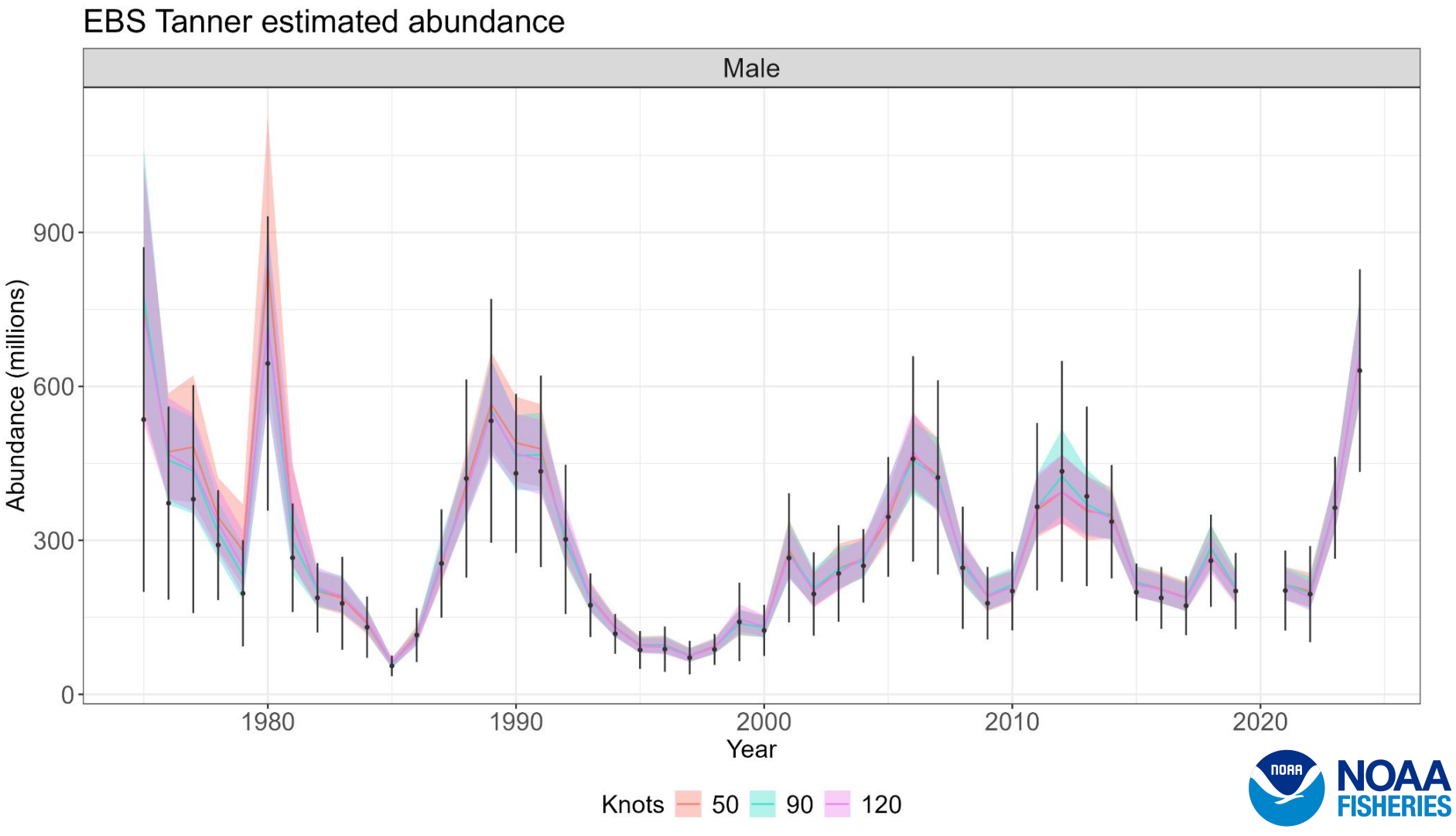


Abundance model diagnostics

- No evidence of spatiotemporal autocorrelation of DHARMa residuals across categories

Delta-gamma, 50 knots




EBS Tanner estimated abundance
Male
Abundance (millions)
900
600
300
0
1980
1990
2000
2010
2020
Year
Knots
50
90
120
NOAA
NOAA
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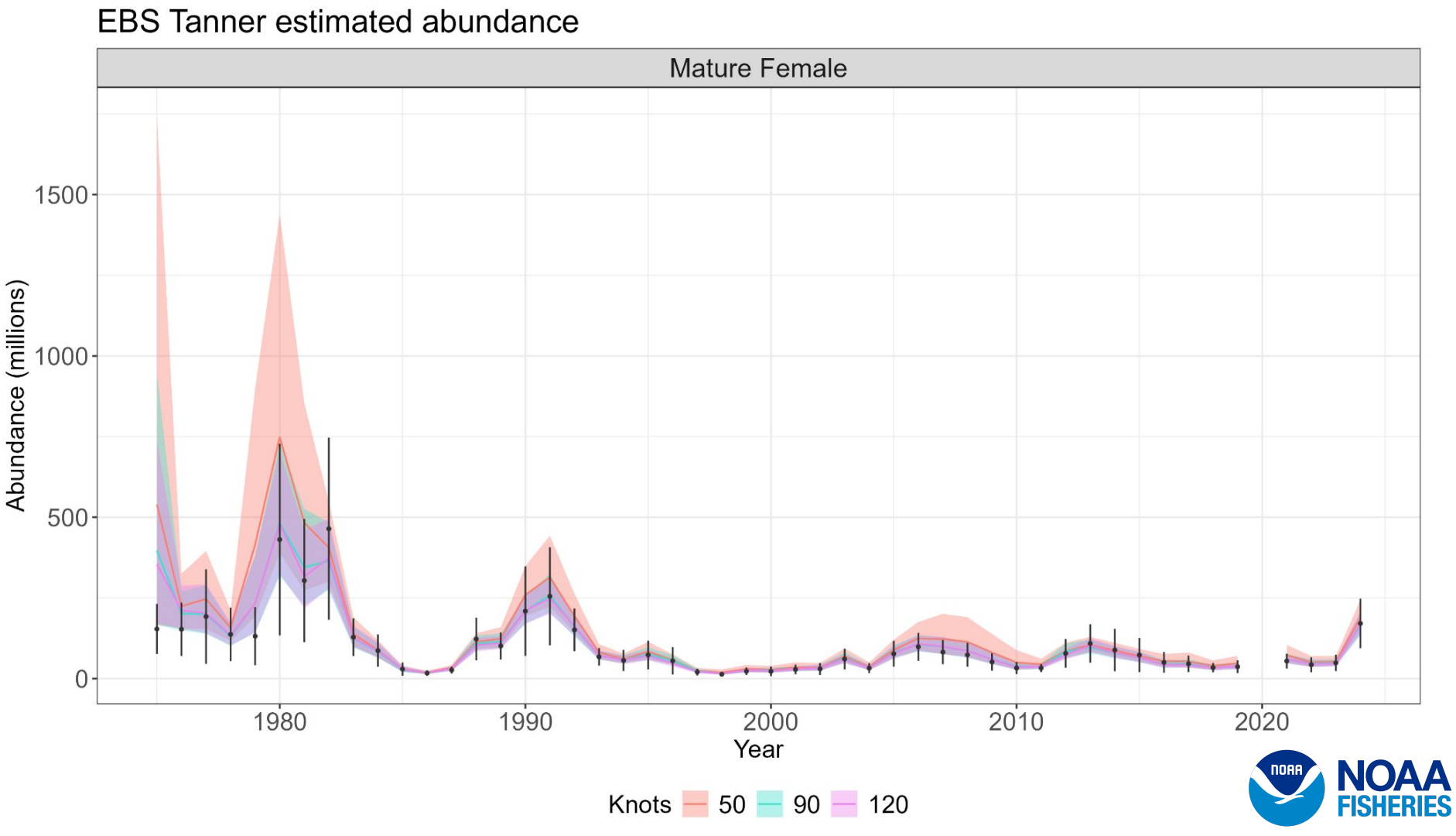
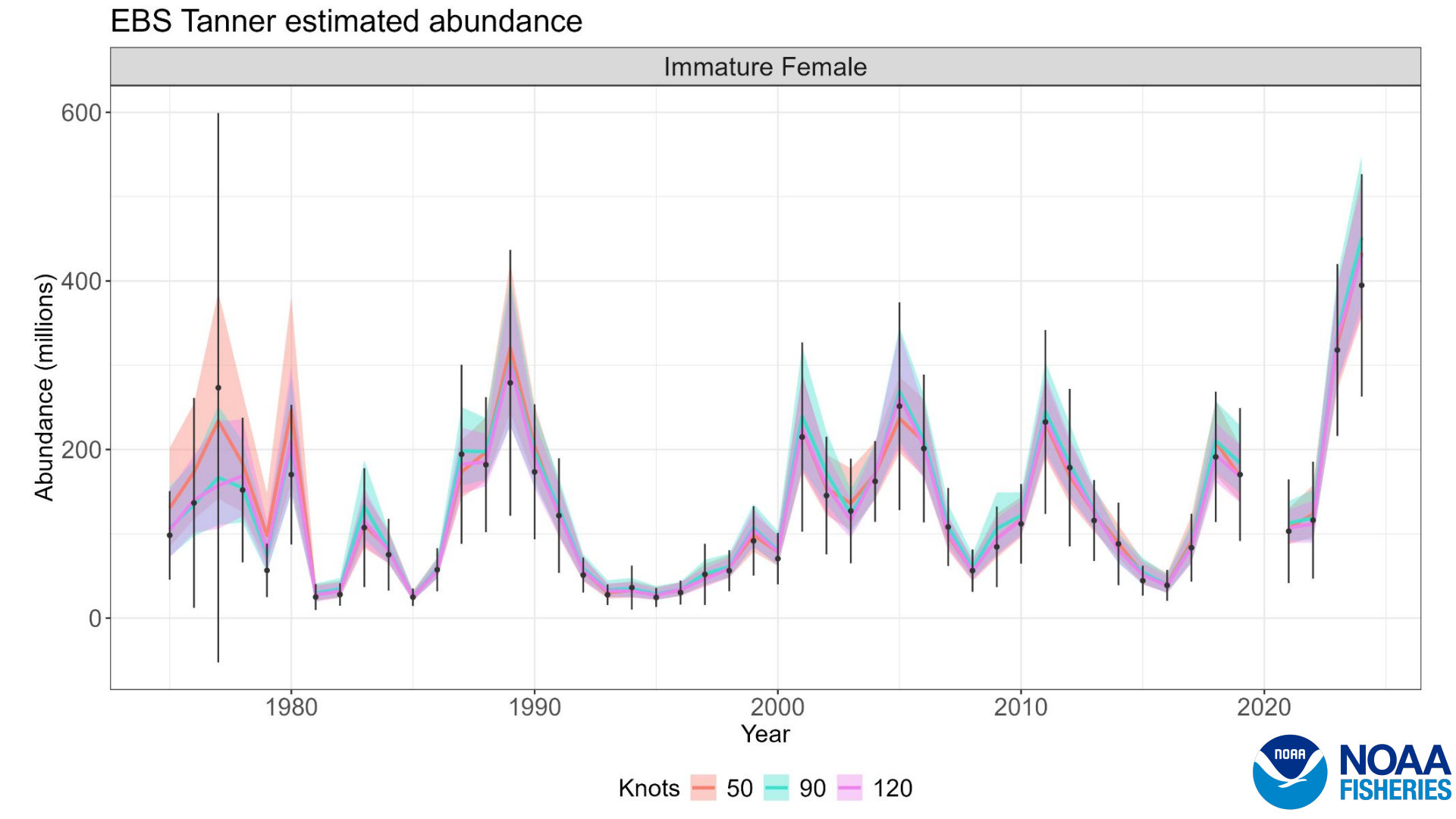
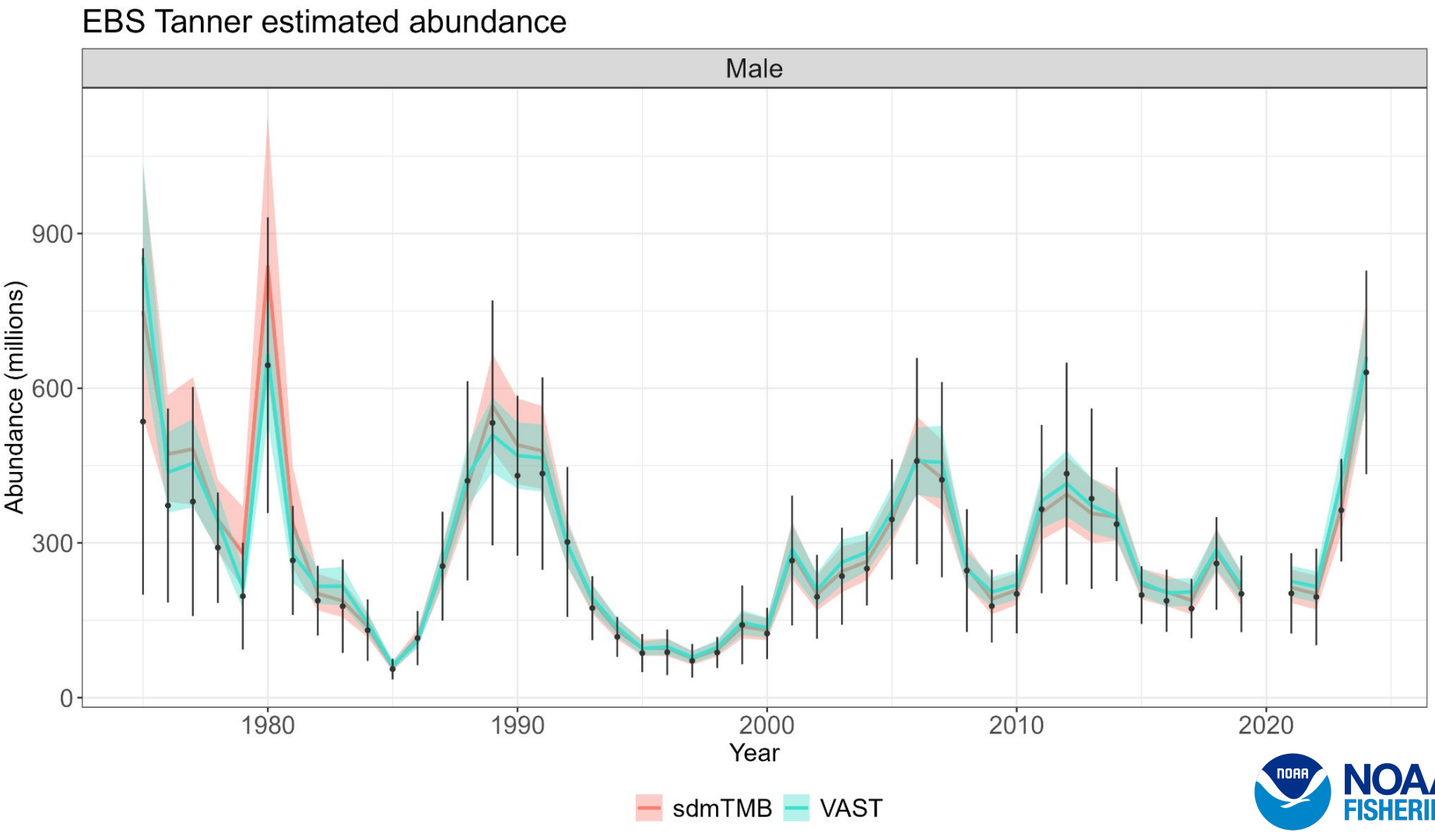

EBS Tanner estimated abundance
Mature Female
Abundance (millions)
1500
1000
500
0
1980
1990
2000
2010
2020
Year
Knots
50
90
120
NOAA
FISHERIES


EBS Tanner estimated abundance
Immature Female
600
400
200
0
Abundance (millions)
1980
1990
2000
2010
2020
Year
Knots
50
90
120
NOAA
NOAA
FISHERIES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900
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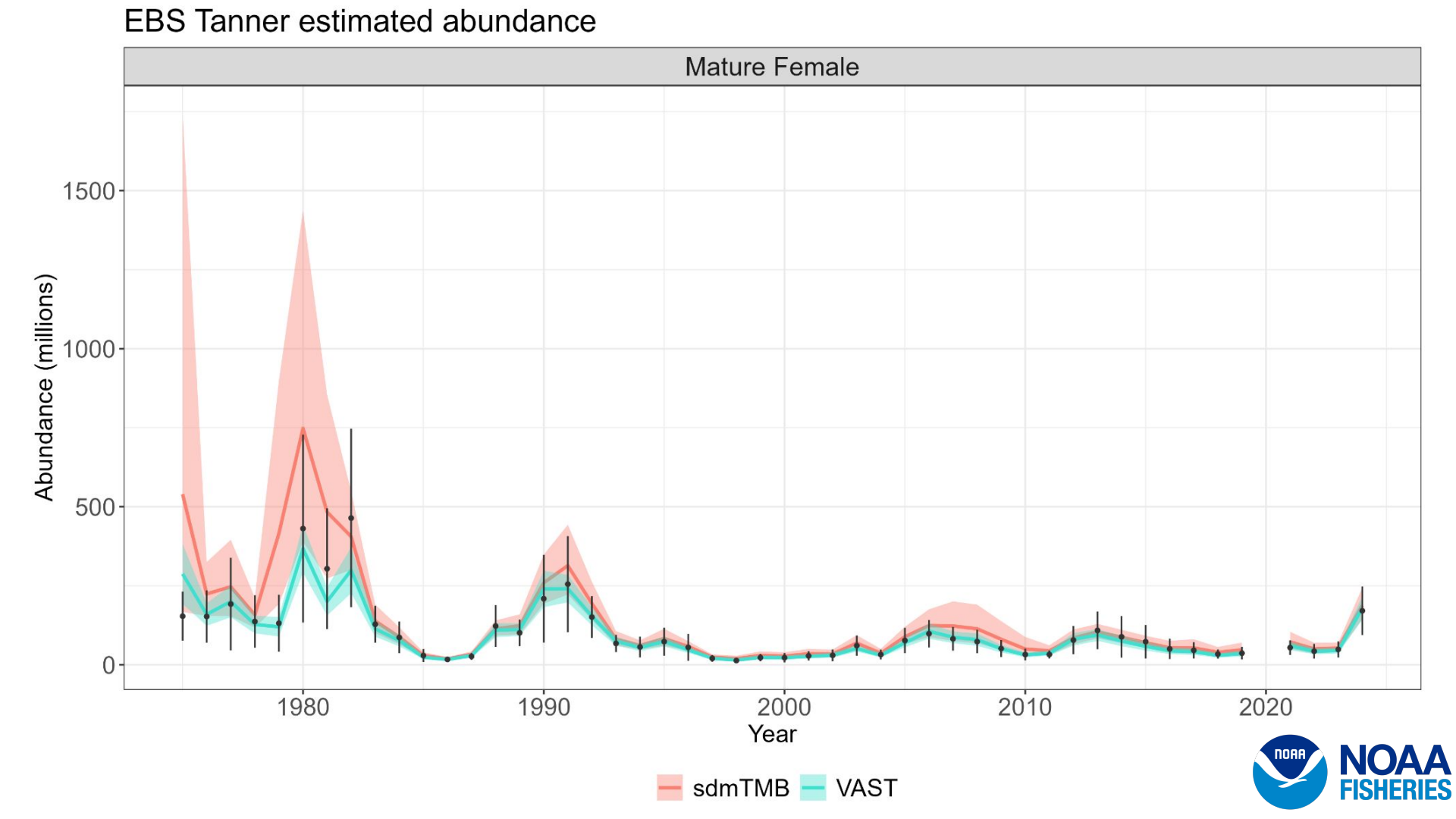
sdmTMB
VAST
NOAA
FISHERIES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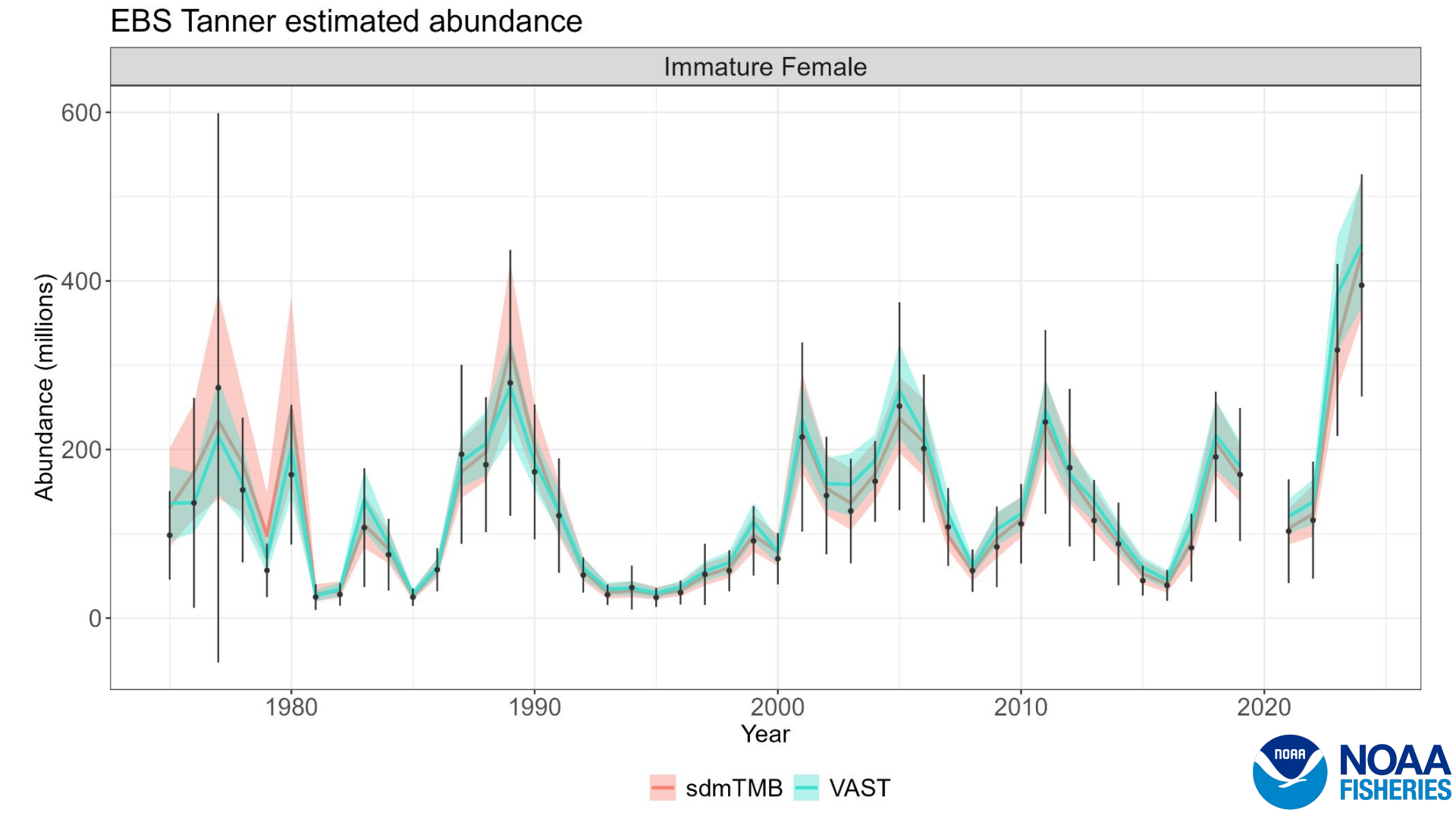
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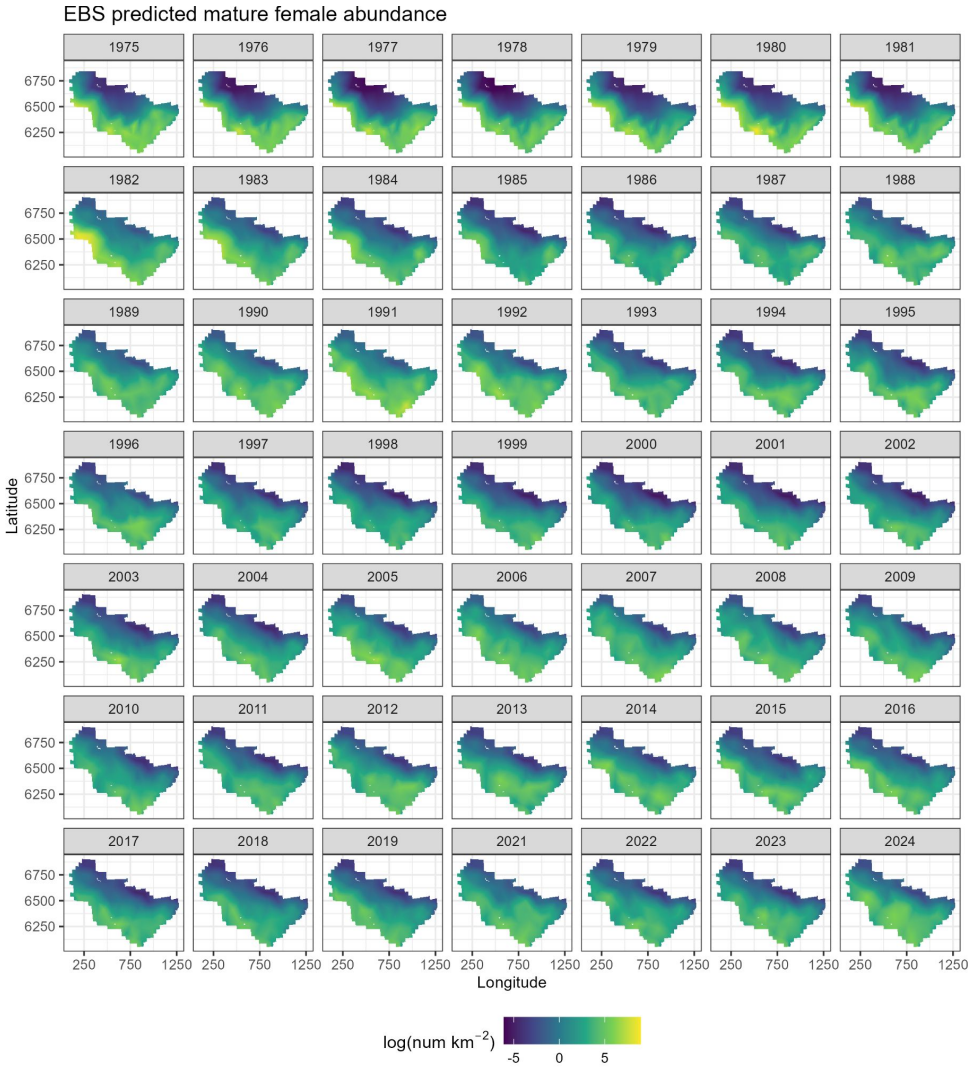
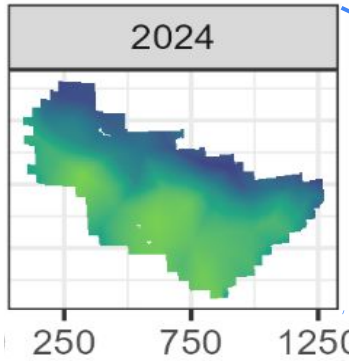
VAST
NOAA
FISHERIES

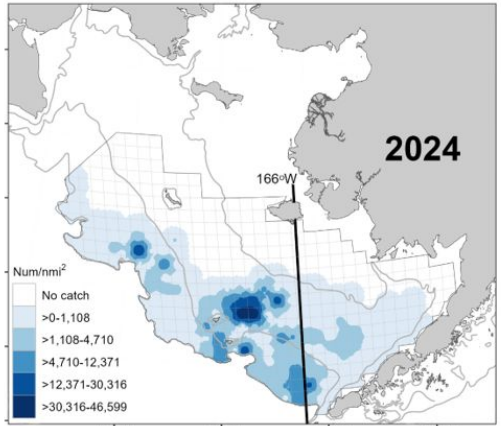
Predicted abundance

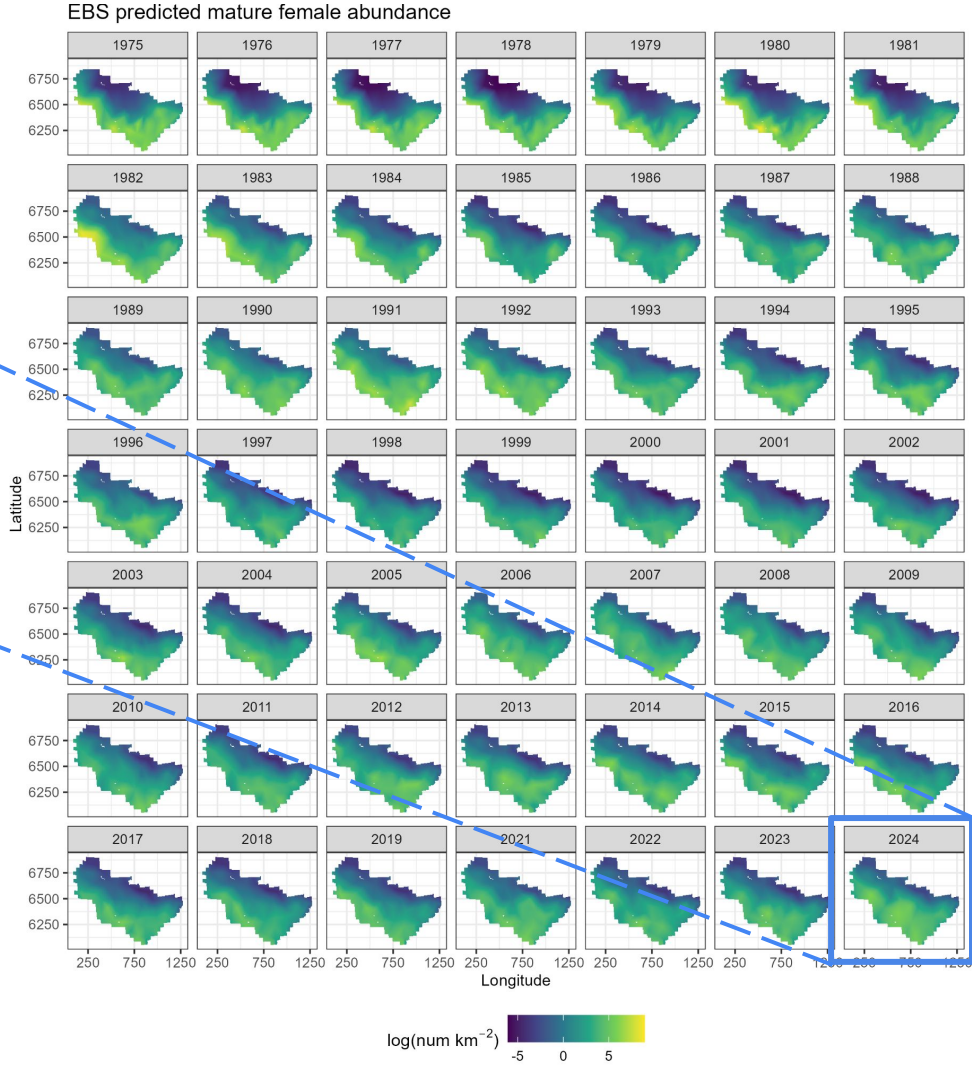
Delta-gamma, 50 knots



Predicted abundance







Tanner crab conclusions and next steps

- Delta-gamma using a 50-knot mesh has the best overall predictive skill
- Questions:
  1. Should model frameworks be specific to period and/or sex-maturity category or the same?
  2. How to balance model diagnostics versus visual fits to observations?

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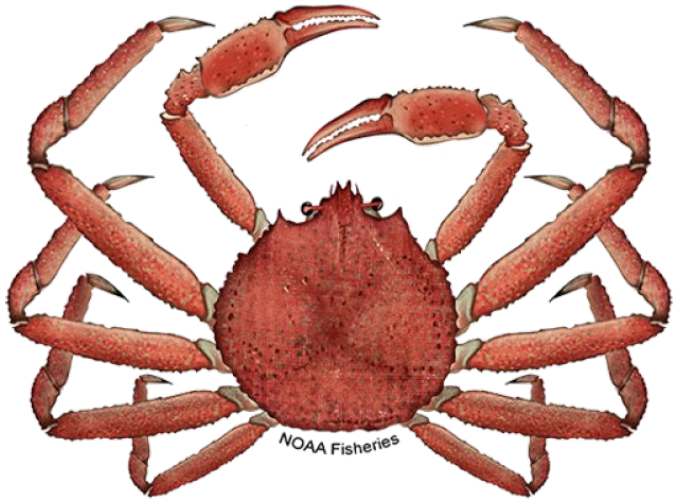
Snow crab

Specific methods for snow crab

- Only fit biomass models
- Fit models for males > 95mm and mature females
- Fit models with EBS-only and EBS-NBS data, predict to EBS, compare
- Model family: delta-gamma and Tweedie
- Random field:
  - IID (EBS-data only)
  - AR1 (EBS-NBS data)



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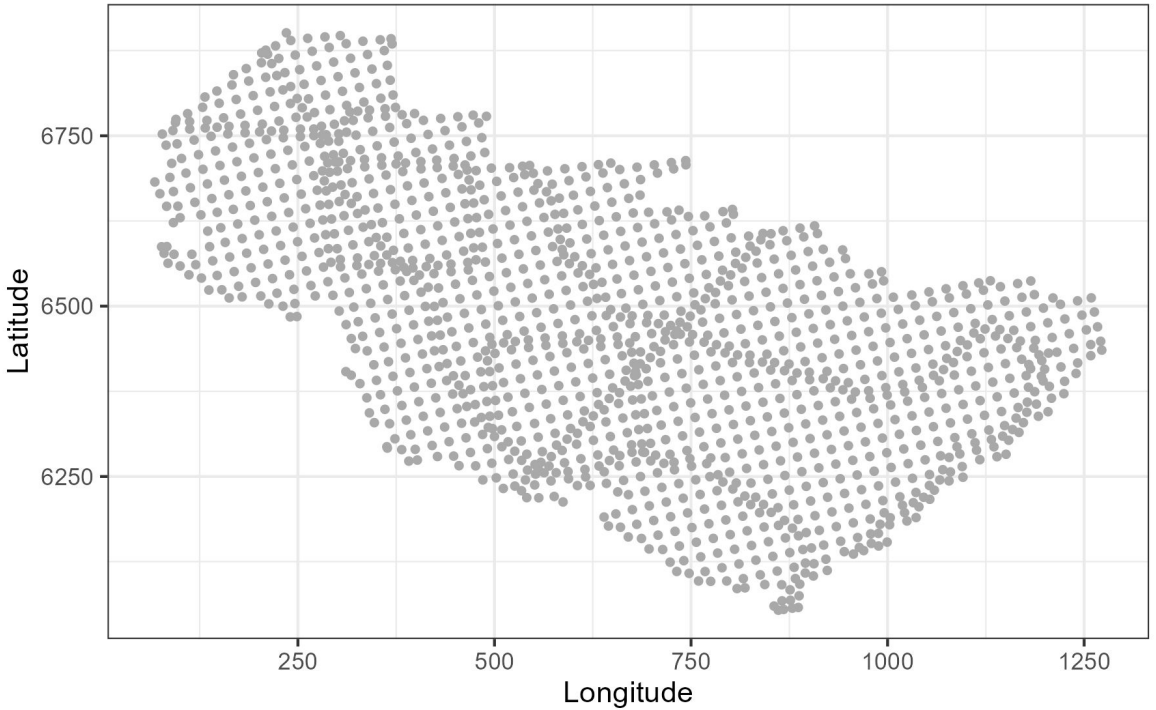
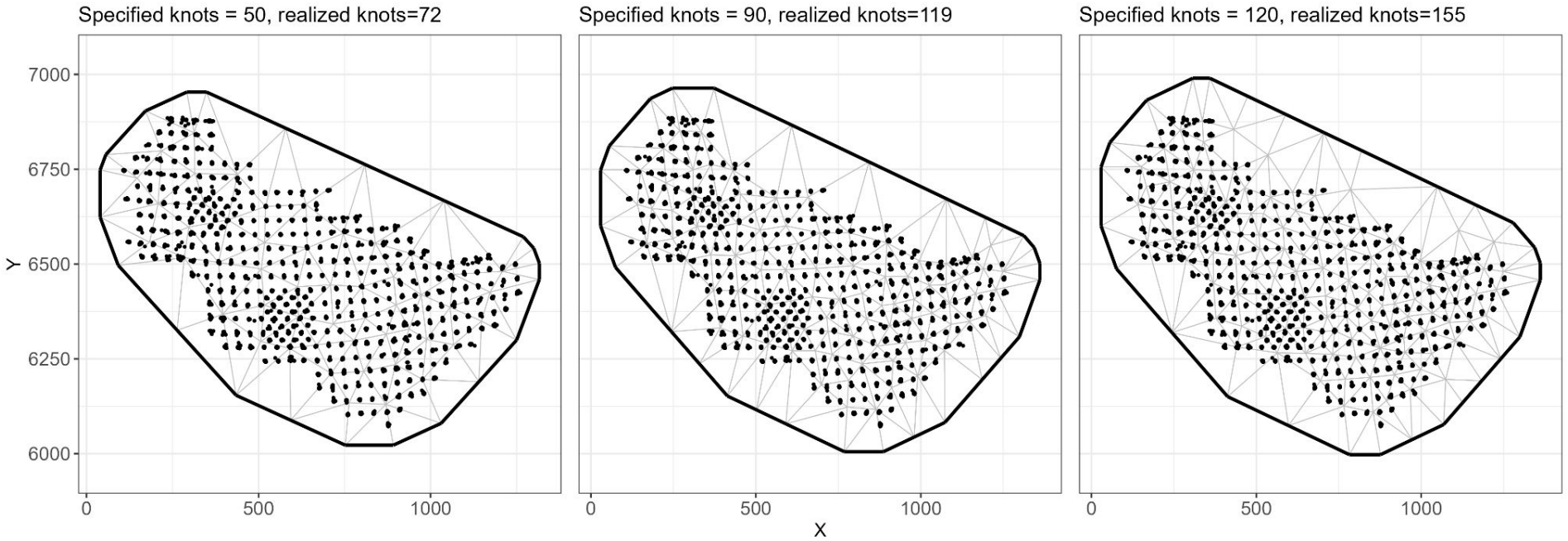
Prediction grid

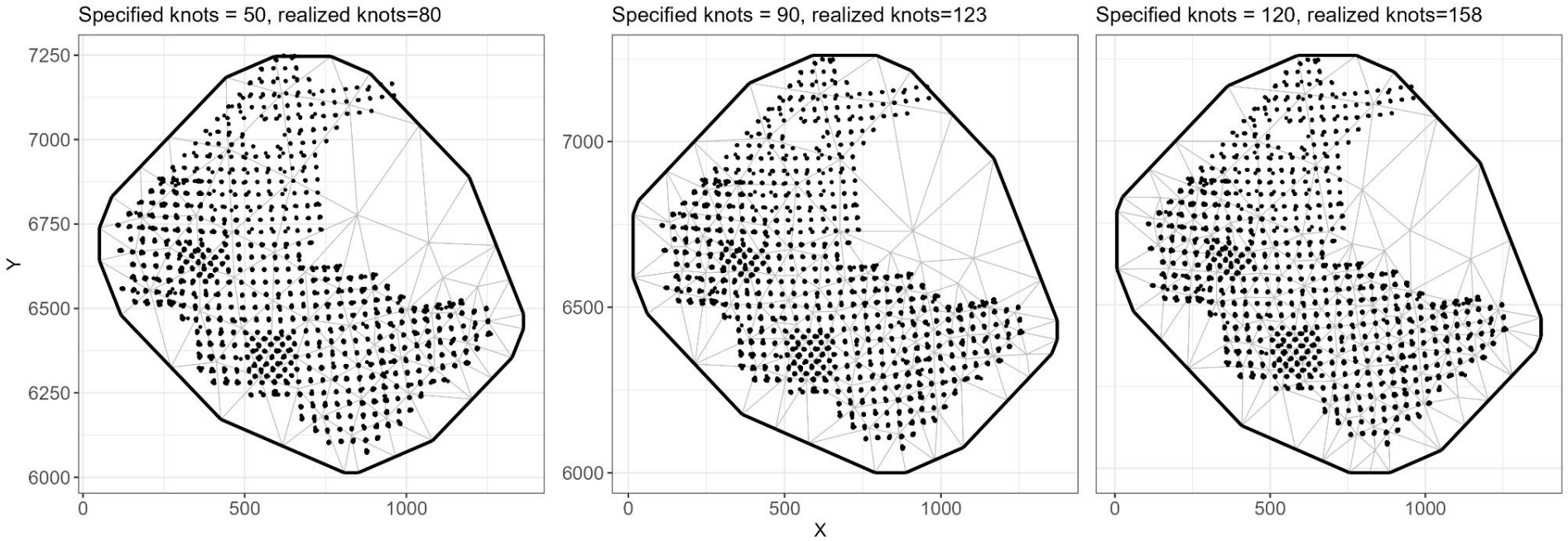
- 41 km^2 resolution, no land



EBS model mesh



EBS-NBS model mesh



Overall model diagnostics

- Best: delta-gamma
  - 90-knot mesh for males > 95mm
  - 50-knot mesh for mature females
- IID Tweedie models had difficulty converging
- Cross validation could not be completed for some model combinations → used other diagnostics

category	region	knots	family	method	loglik	BEST
<chr>	<chr>	<dbl>	<chr>	<chr>	<dbl>	<chr>
Male95	EBS-NBS	90	Delta_gamma	ar1	-61673.	Y
Male95	EBS	90	Delta_gamma	iid	-61745.	Y
Mature female	EBS-NBS	50	Delta_gamma	ar1	-47619.	Y
Mature female	EBS	50	Delta_gamma	iid	-46460.	Y

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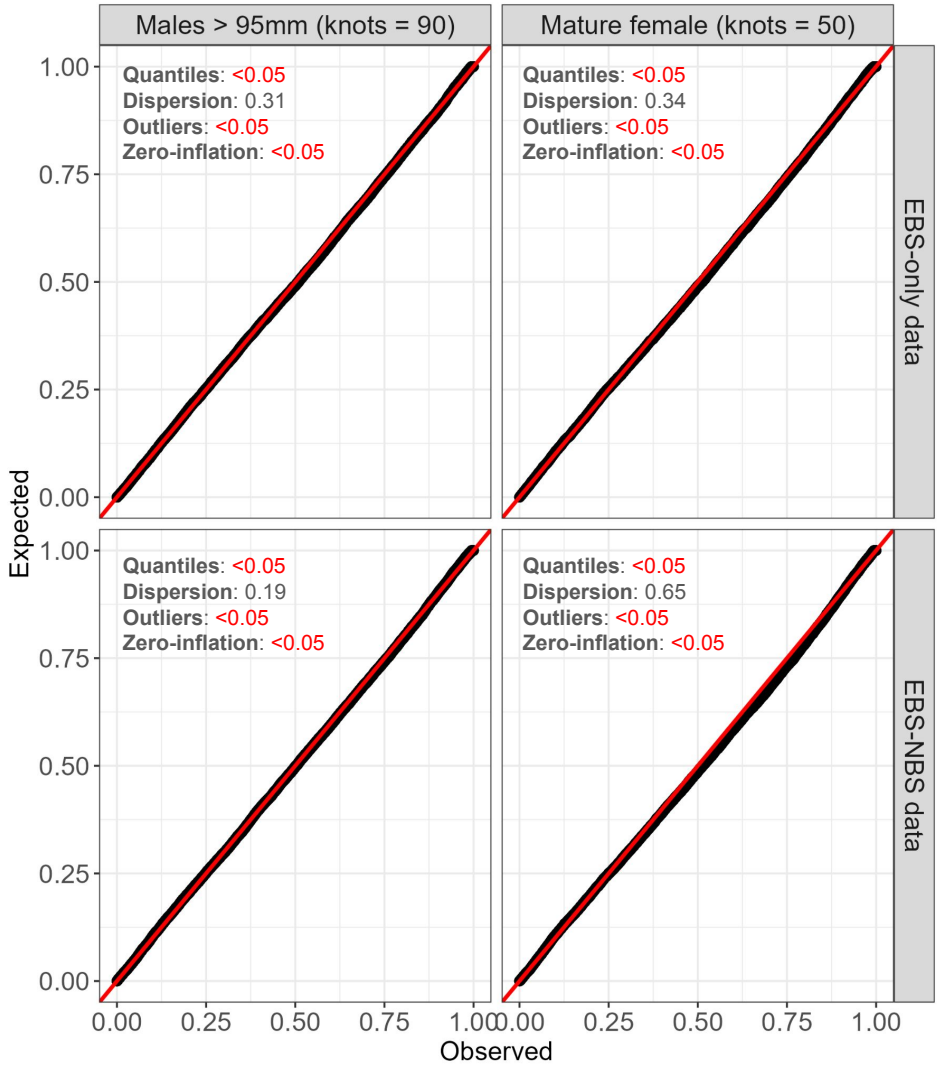
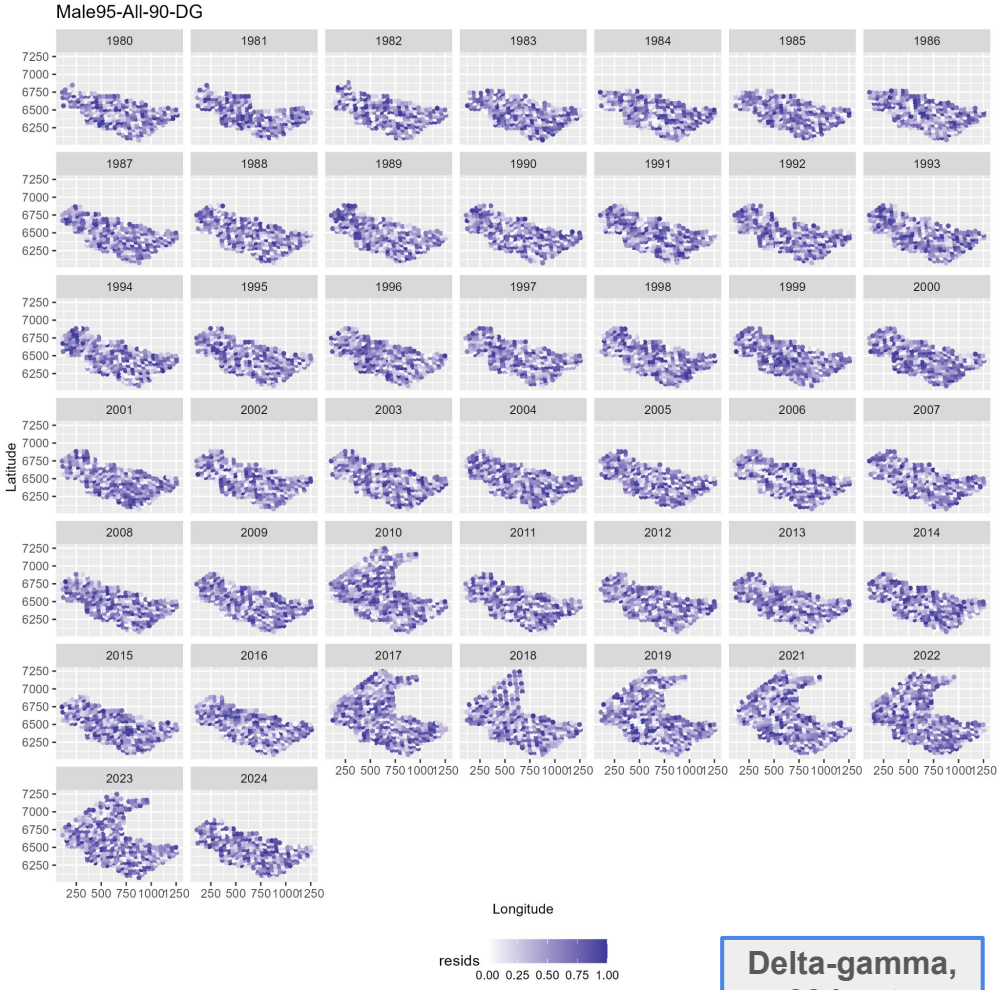
Biomass model diagnostics

- No significant residual deviation from 1-1 line for delta-gamma models
- Statistical evidence of quantile deviation, outliers, and zero-inflation
- True regardless of model family, knot number, or data region



Male biomass model diagnostics: EBS-NBS data

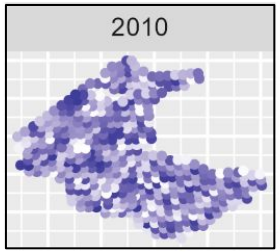
- No evidence of spatiotemporal autocorrelation of DHARMa residuals

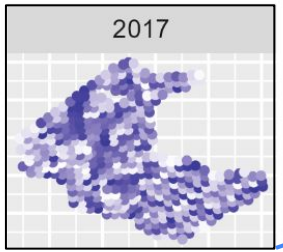


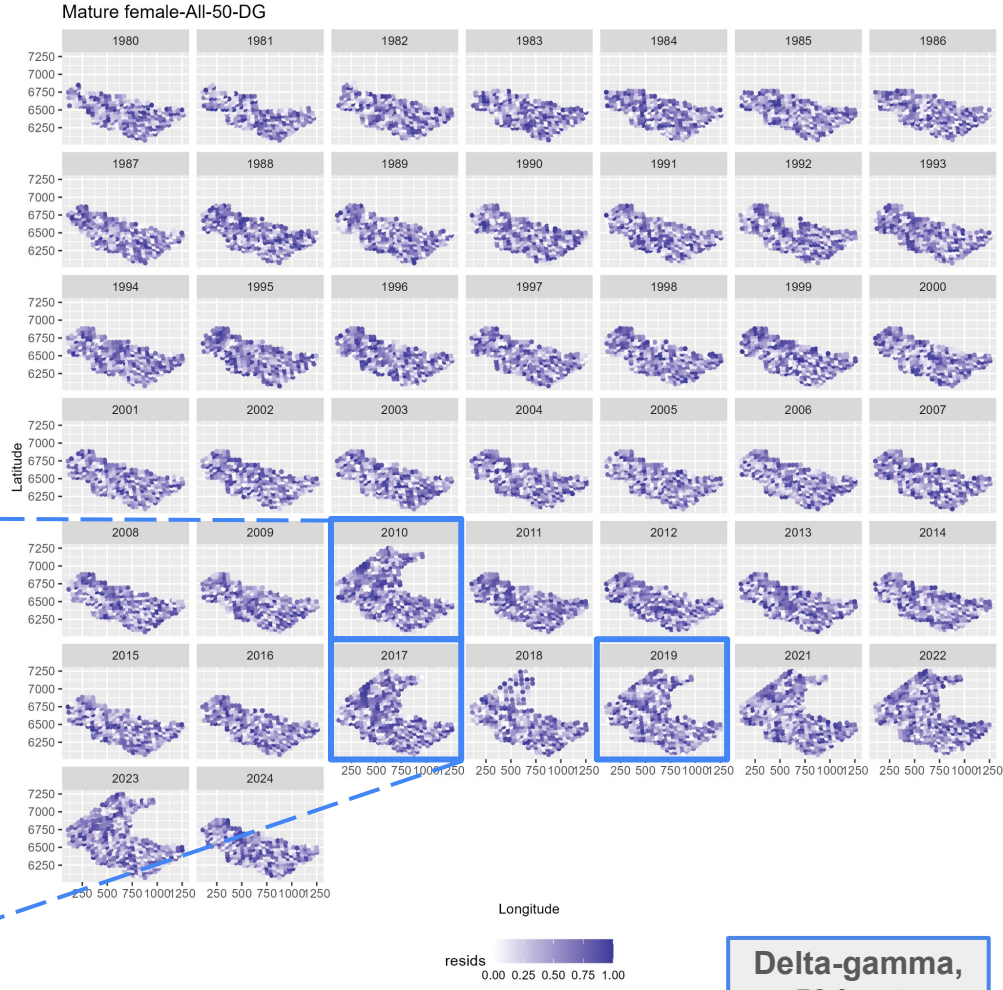
Delta-gamma, 90 knots

Female biomass model diagnostics: EBS-NBS data

- Some evidence of spatiotemporal autocorrelation of DHARMa residuals



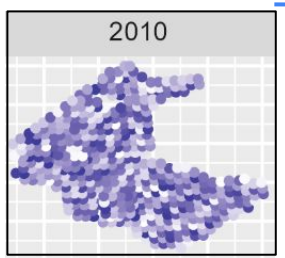


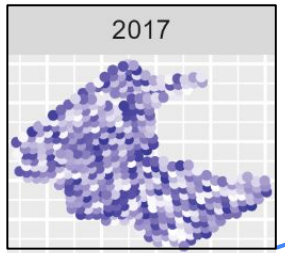


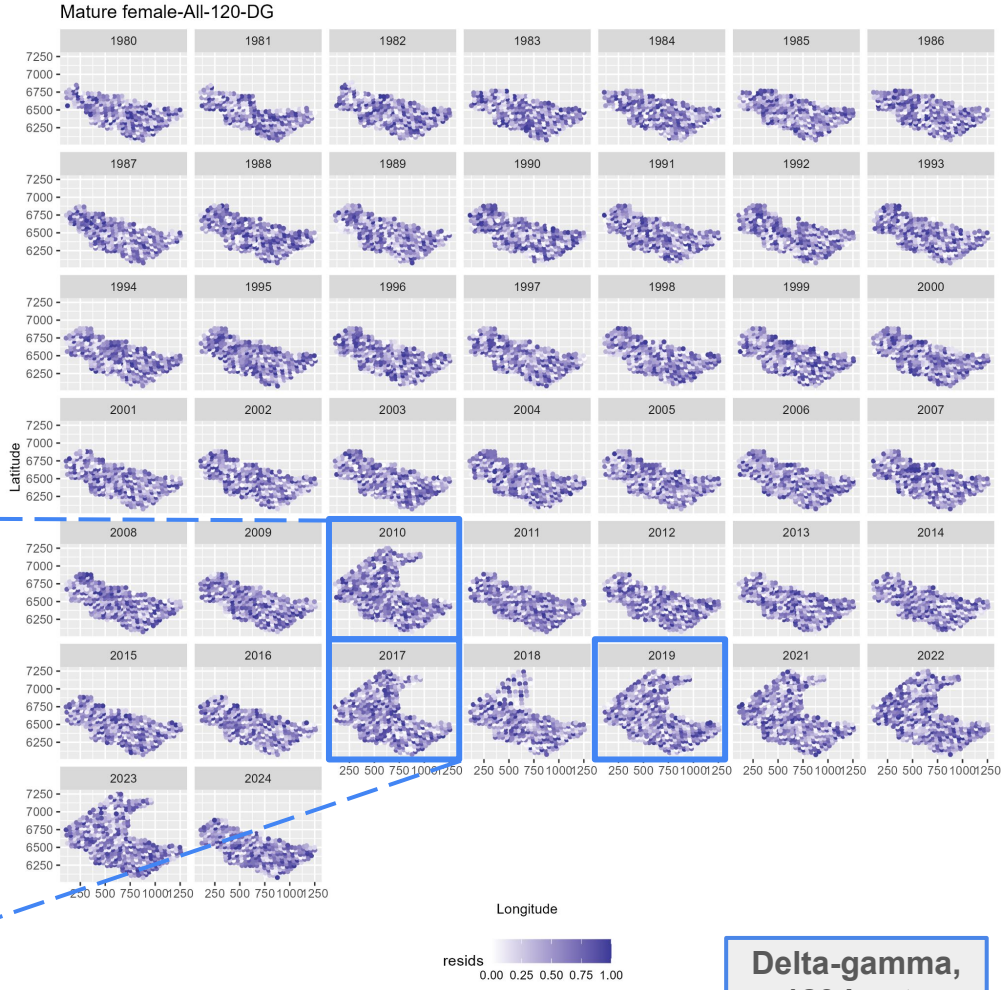
Delta-gamma, 50 knots

Female biomass model diagnostics: EBS-NBS data

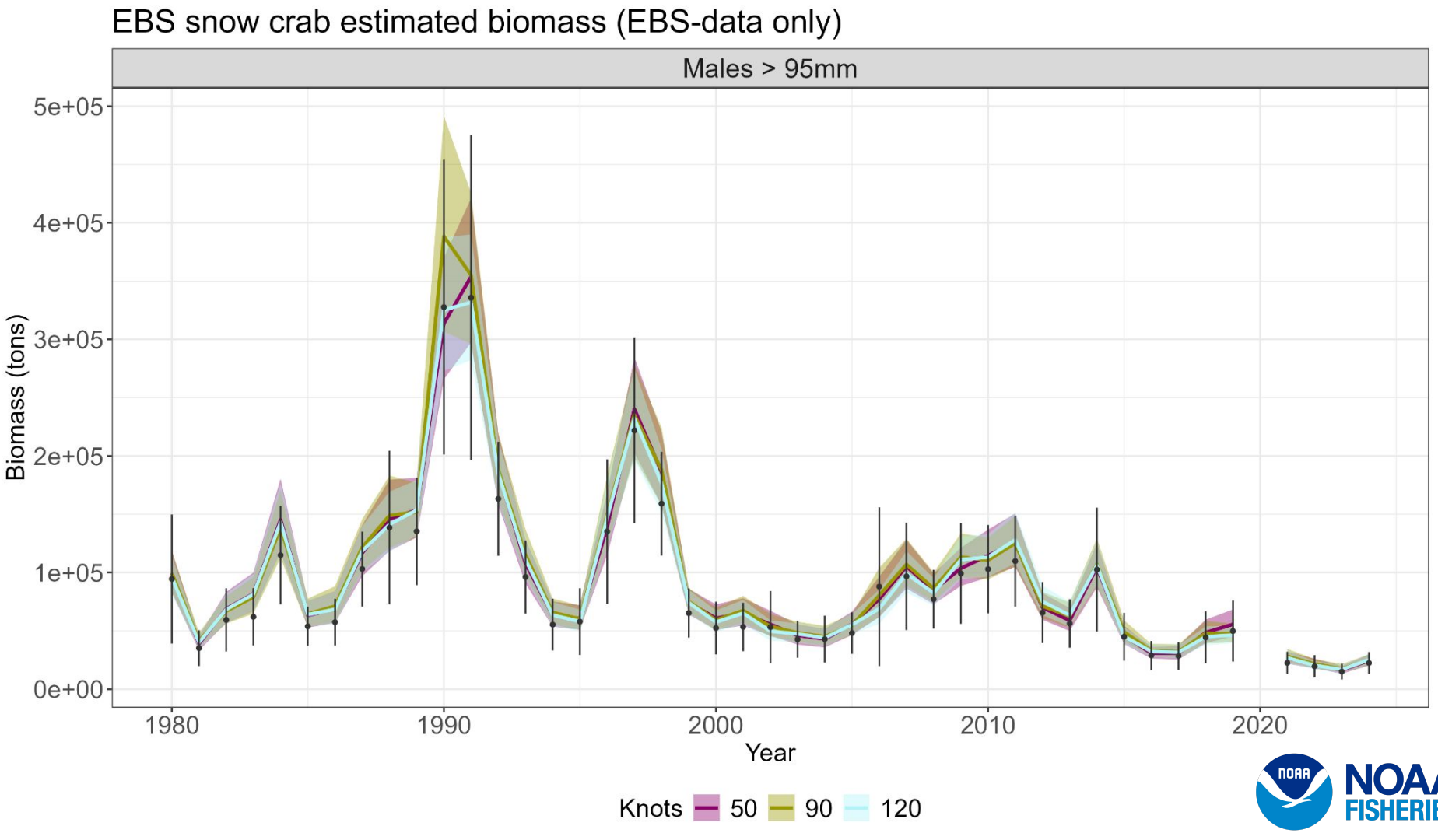
- Autocorrelation patterns improve with higher resolution mesh

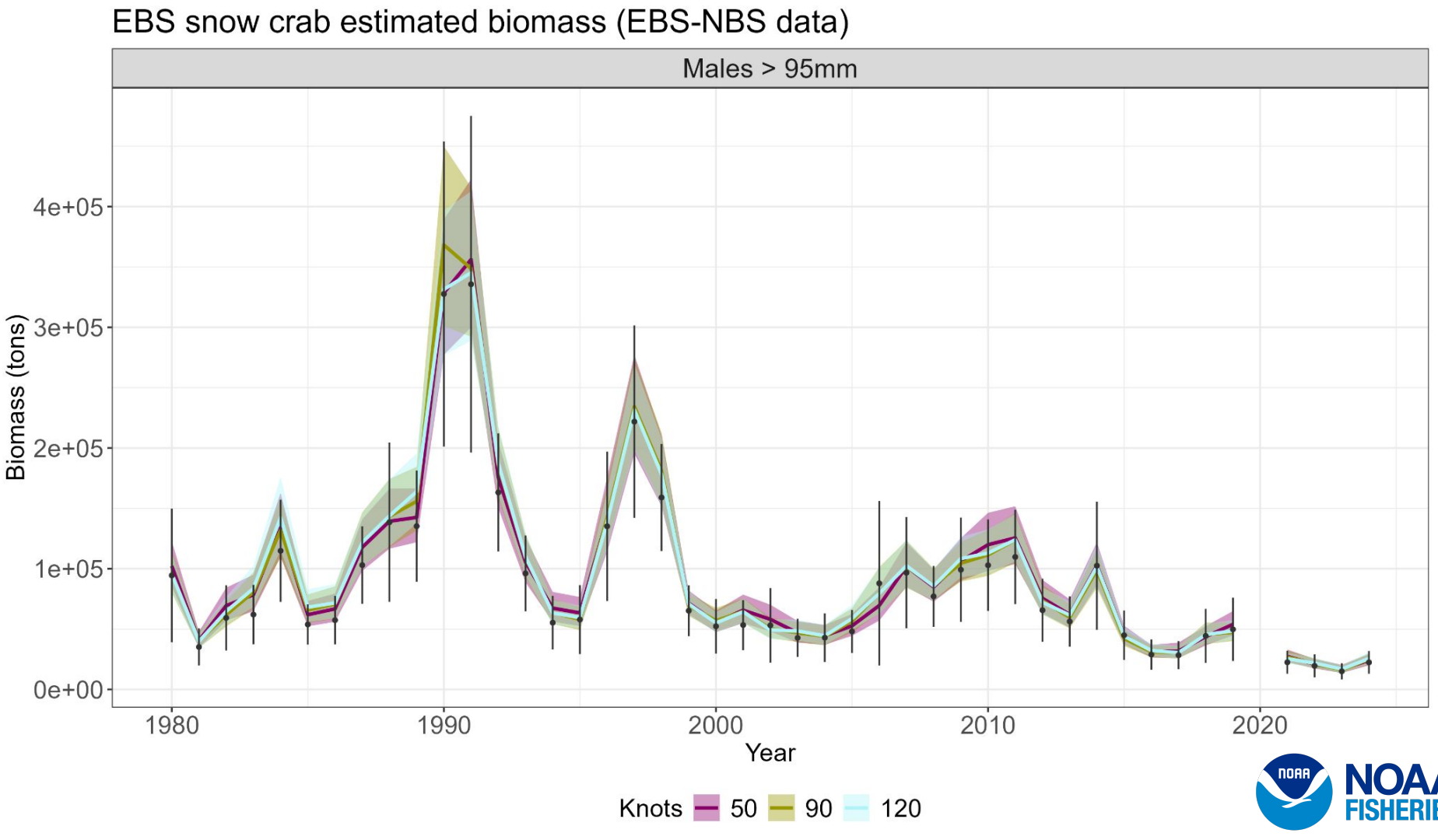






Delta-gamma, 120 knots


EBS snow crab estimated biomass (EBS-data only)
Males > 95mm
Biomass (tons)
5e+05
4e+05
3e+05
2e+05
1e+05
0e+00
1980
1990
2000
2010
2020
Year
Knots
50
90
120
NOAA
FISHERIES


EBS snow crab estimated biomass (EBS-NBS data)
Males > 95mm
Biomass (tons)
4e+05
3e+05
2e+05
1e+05
0e+00
1980
1990
2000
2010
2020
Year
Knots
50
90
120
NOAA
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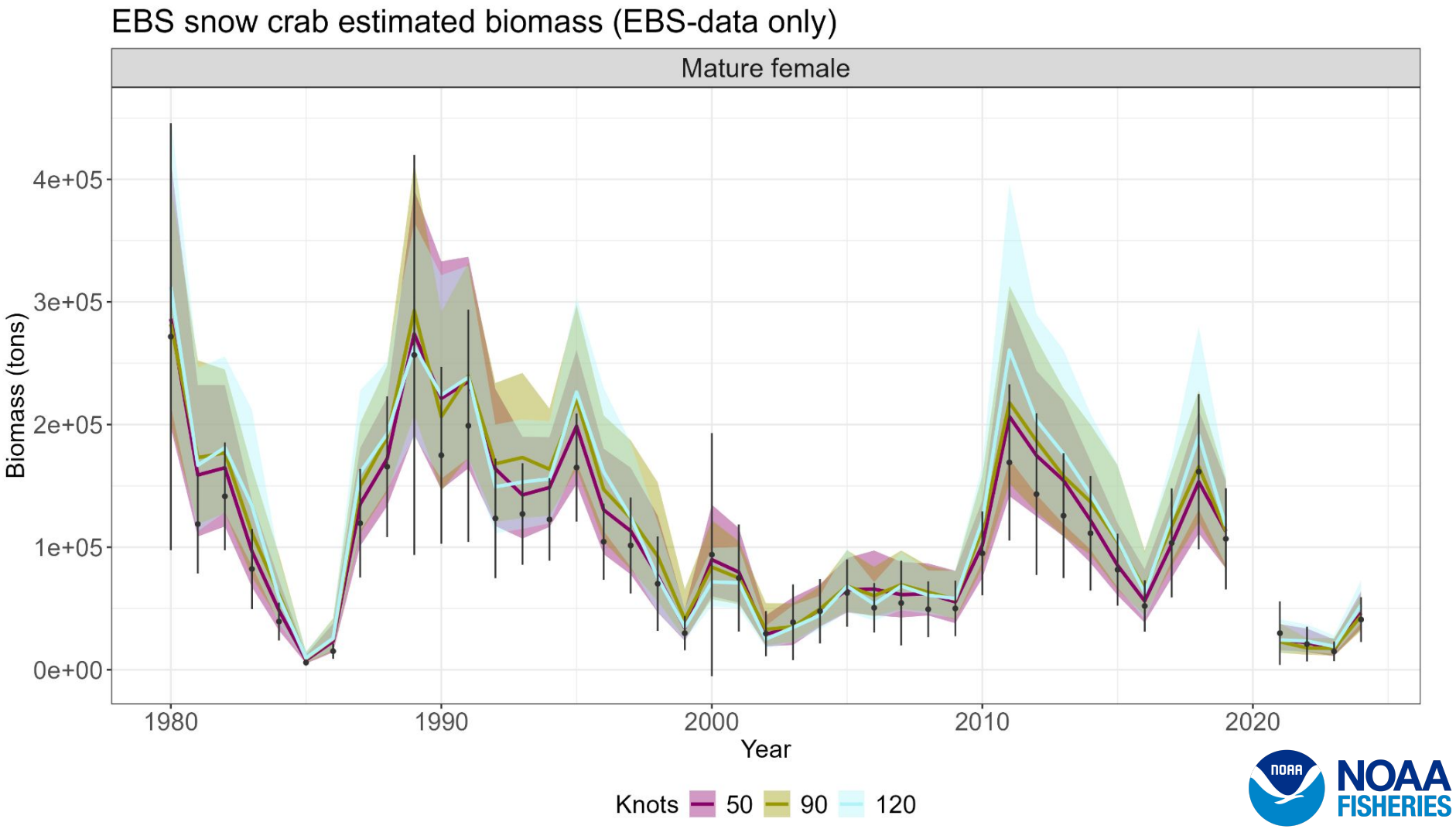
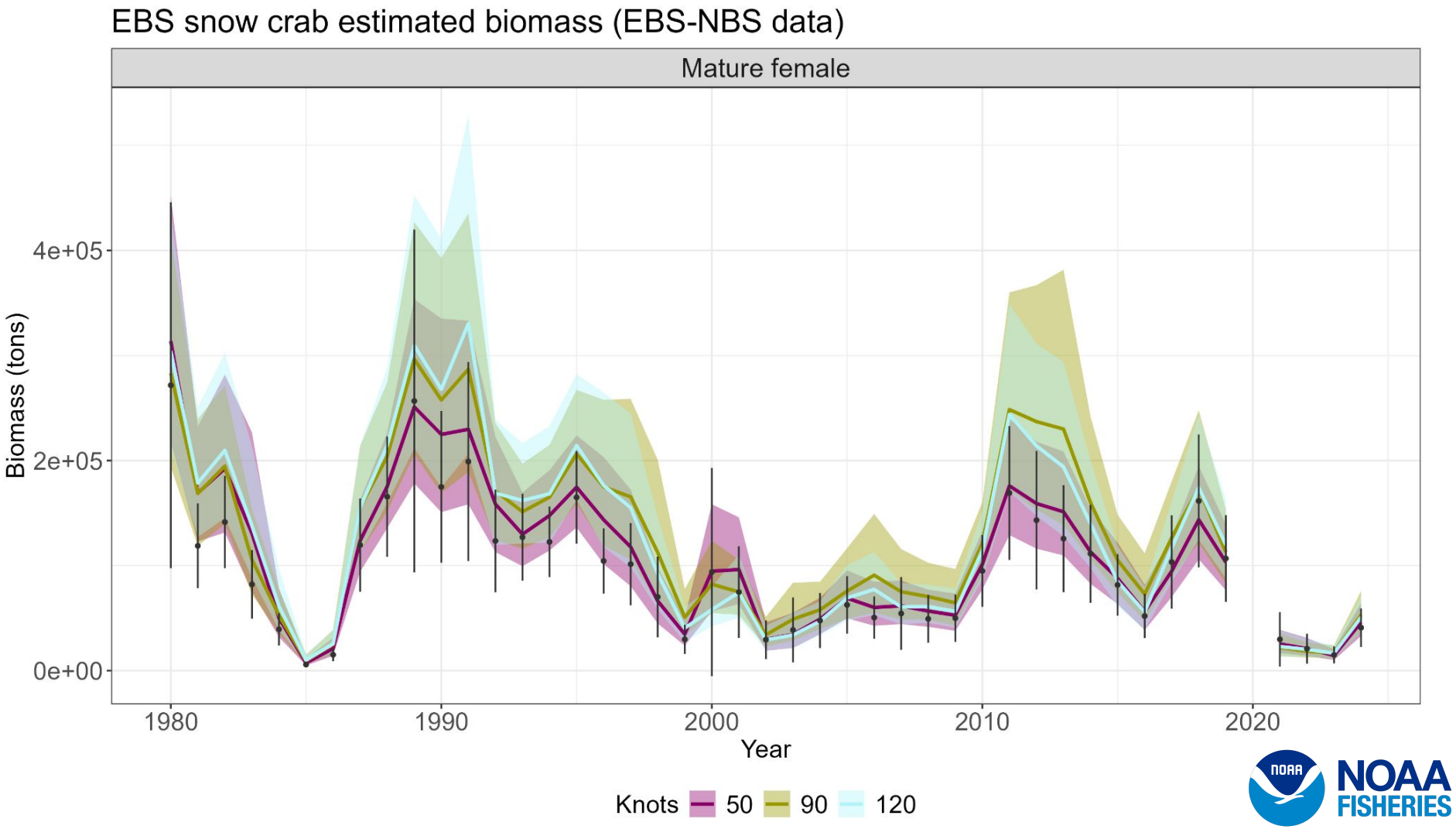
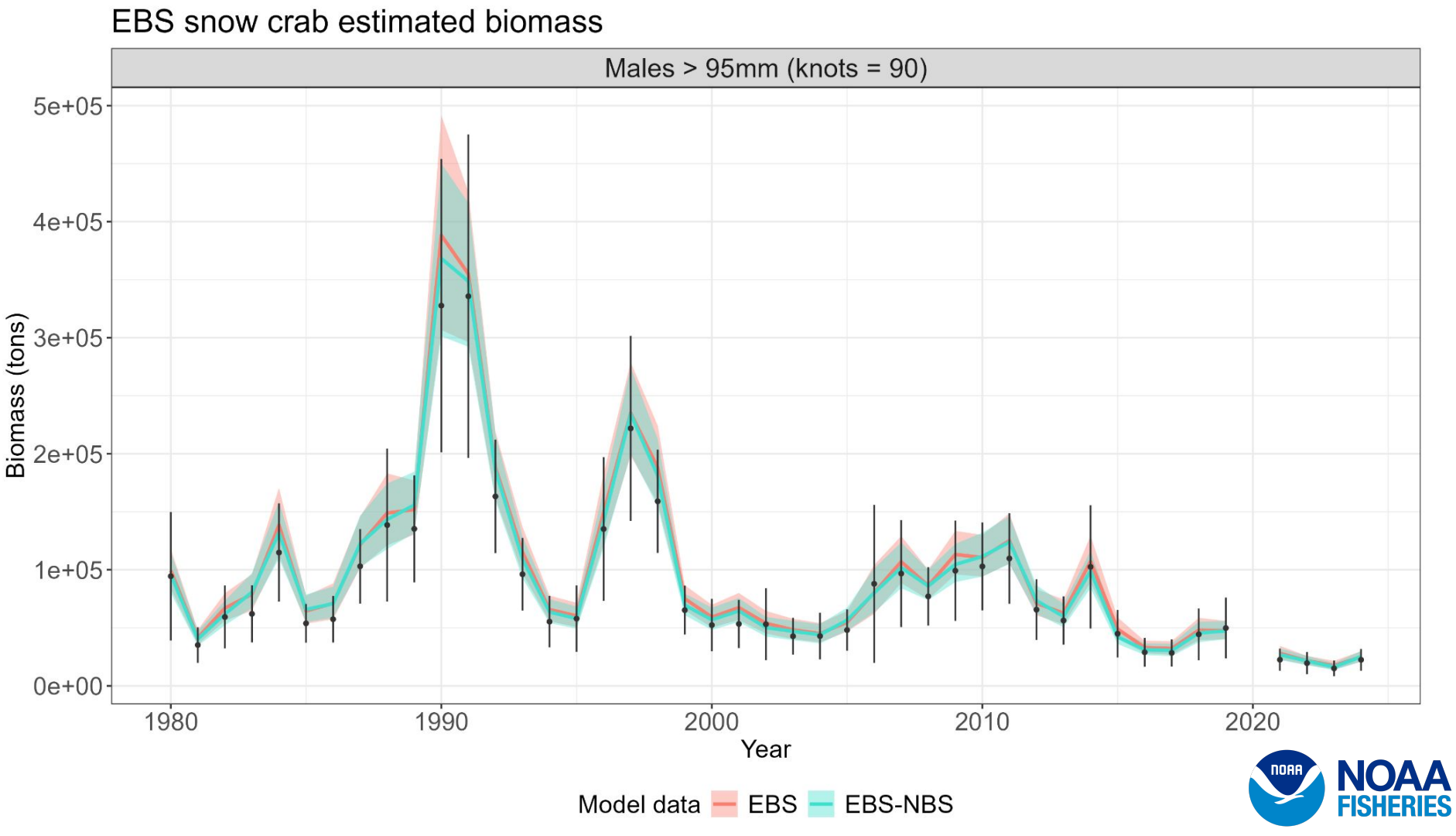
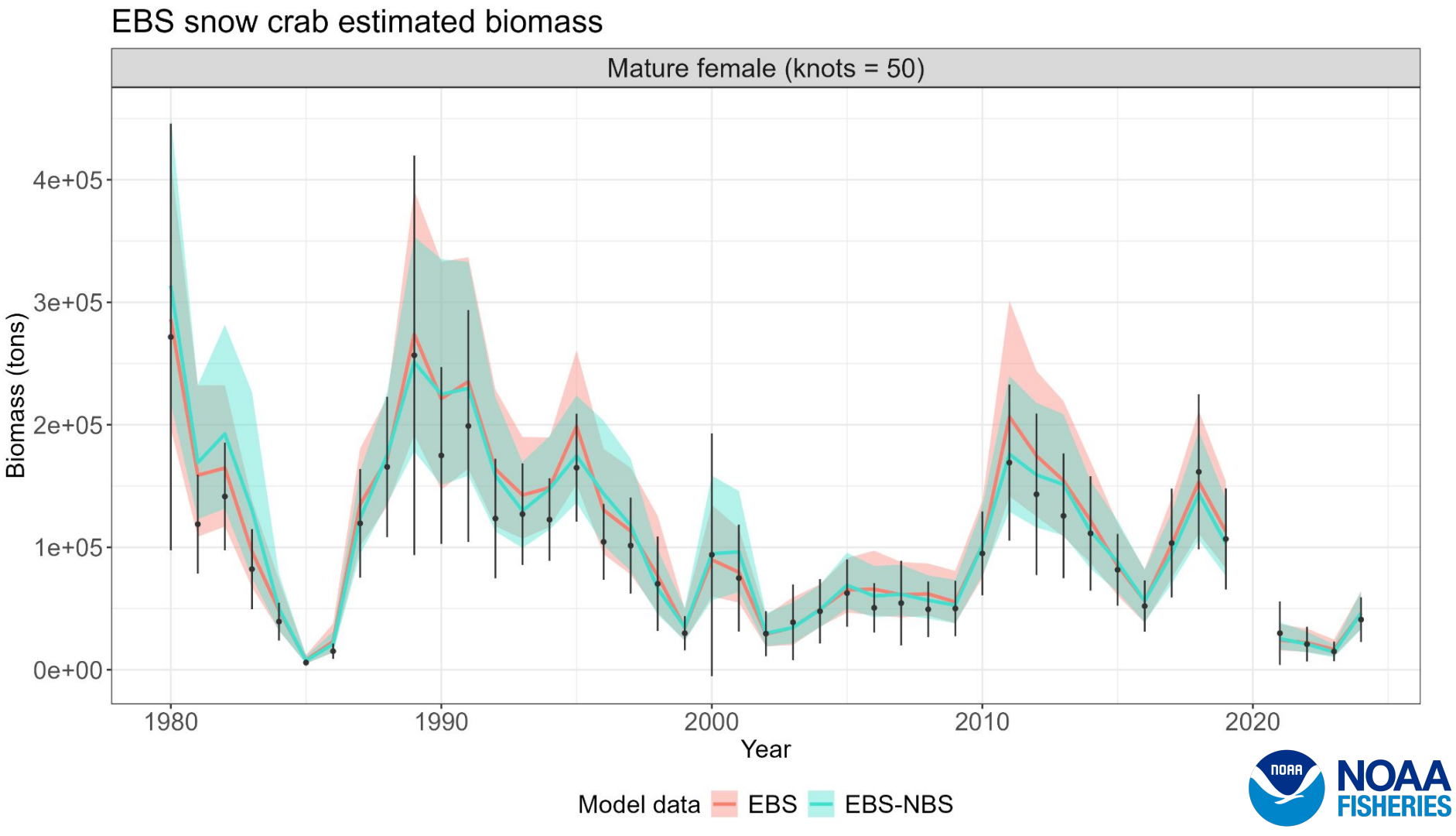
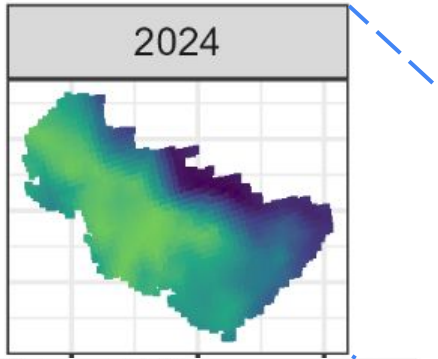

EBS snow crab estimated biomass (EBS-data only)
Mature female
Biomass (tons)
4e+05
3e+05
2e+05
1e+05
0e+00
1980
1990
2000
2010
2020
Year
Knots
50
90
120
NOAA
NOAA FISHERIES

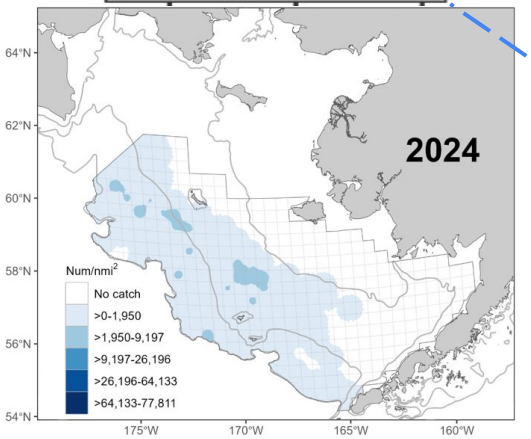

EBS snow crab estimated biomass (EBS-NBS data)
Mature female
Biomass (tons)
4e+05
2e+05
0e+00
1980
1990
2000
2010
2020
Year
Knots
50
90
120
NOAA
FISHERIES

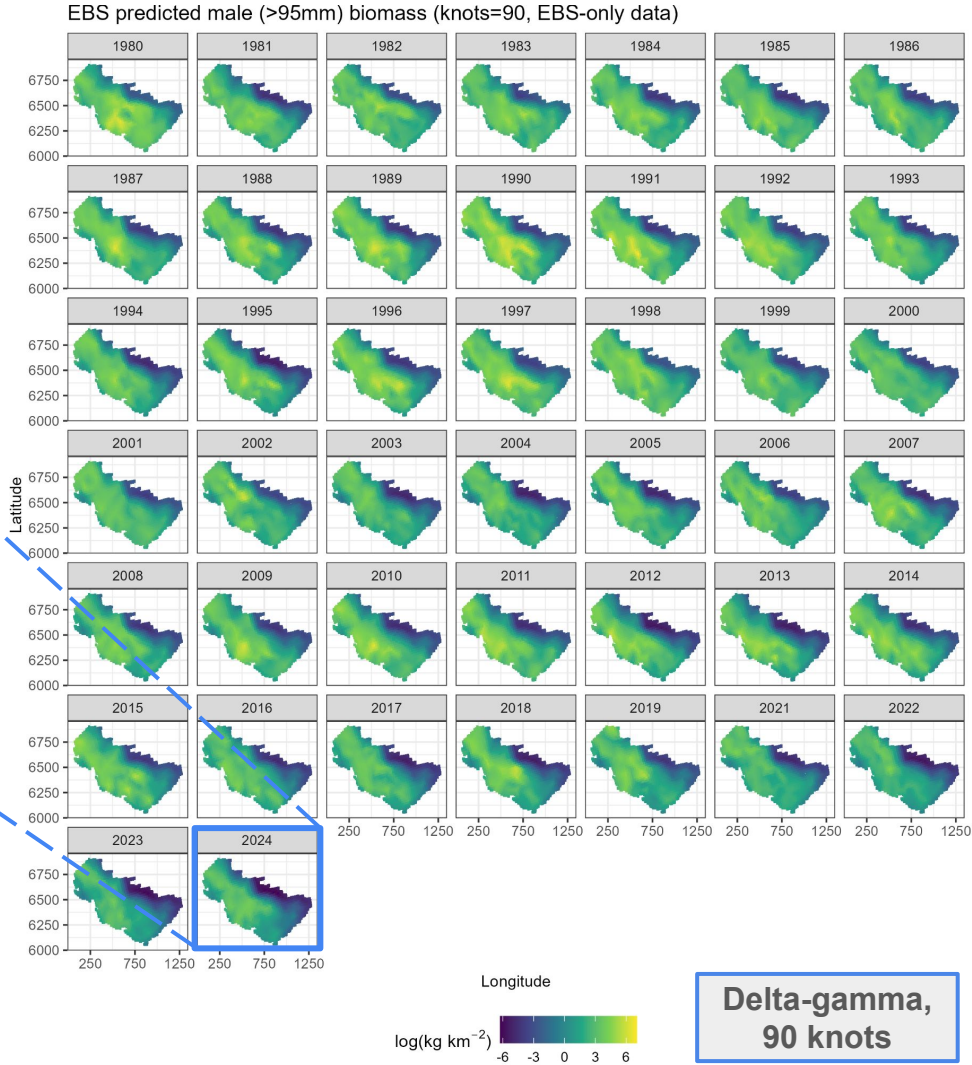

EBS snow crab estimated biomass
Males > 95mm (knots = 90)
Biomass (tons)
5e+05
4e+05
3e+05
2e+05
1e+05
0e+00
1980
1990
2000
2010
2020
Year
Model data
EBS
EBS-NBS
NOAA
FISHERIES


EBS snow crab estimated biomass
Mature female (knots = 50)
Biomass (tons)
4e+05
3e+05
2e+05
1e+05
0e+00
1980
1990
2000
2010
2020
Year
Model data
EBS
EBS-NBS
NOAA
FISHERIES

Predicted male biomass: EBS data

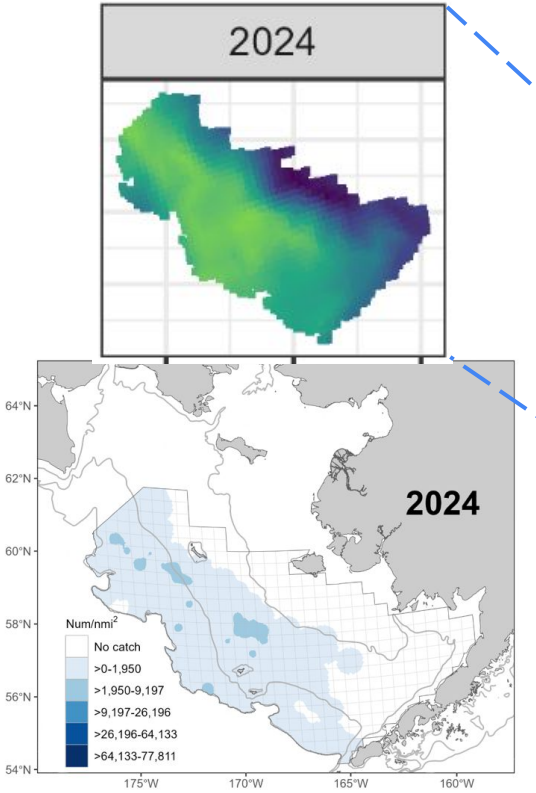


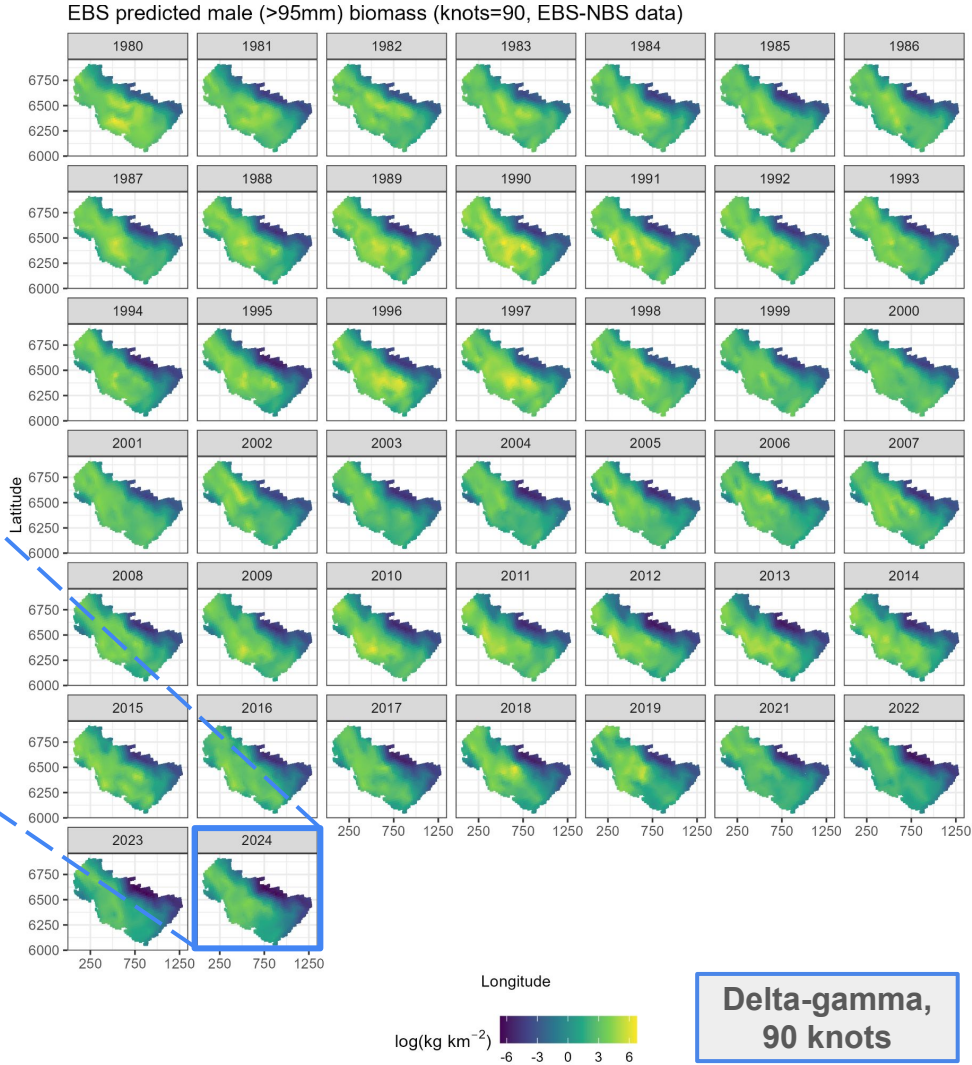




Delta-gamma, 90 knots

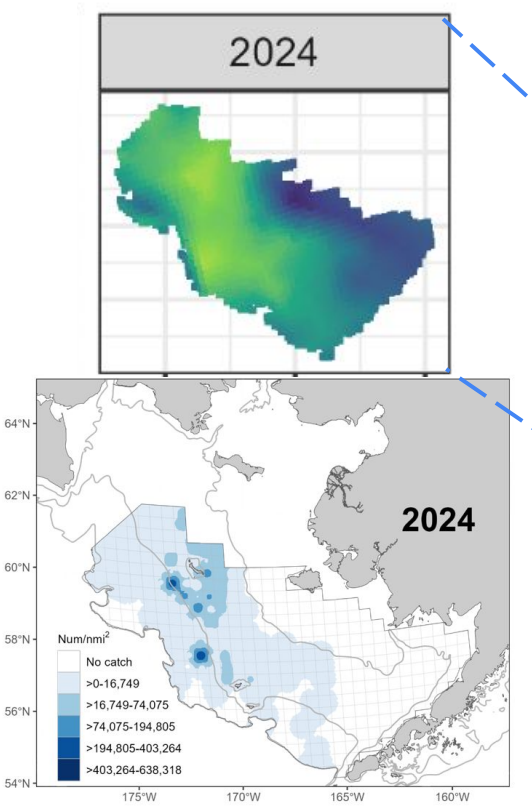
Predicted male biomass: EBS-NBS data

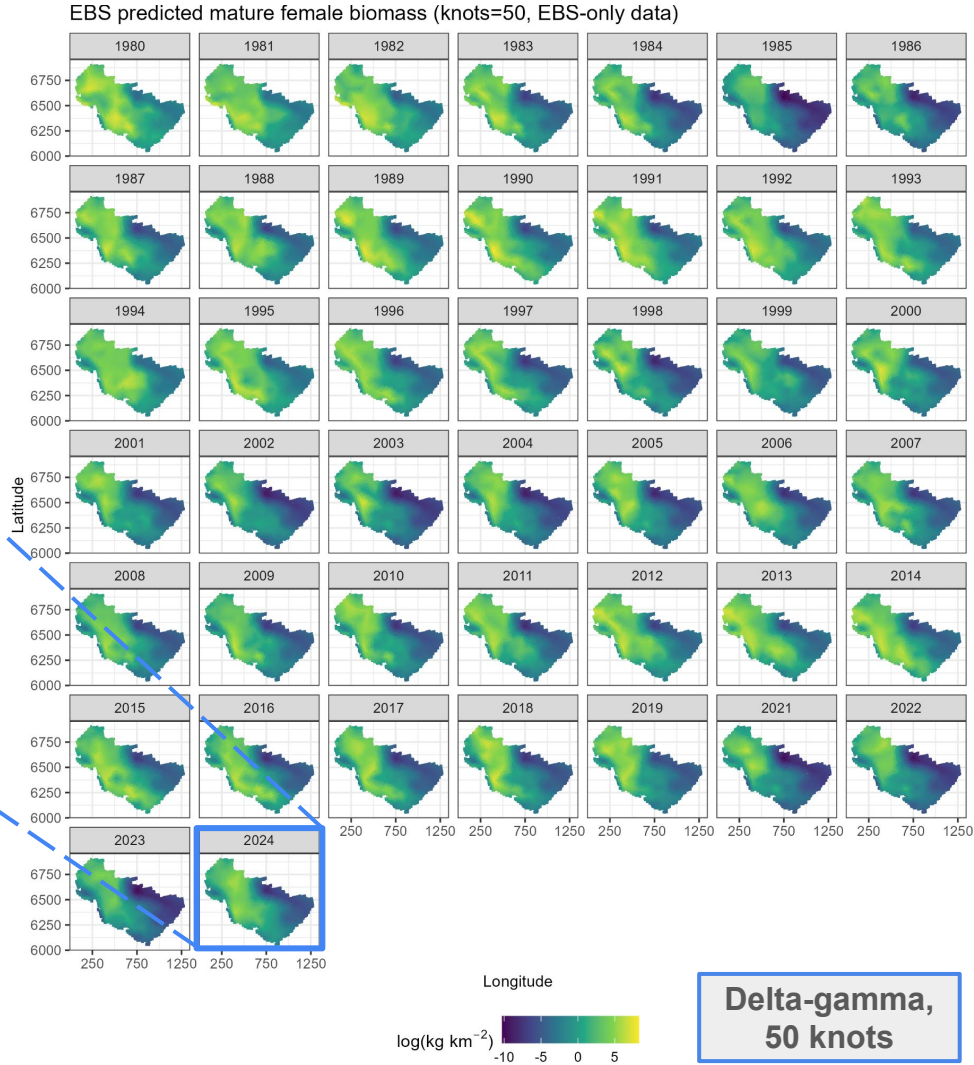




Delta-gamma, 90 knots

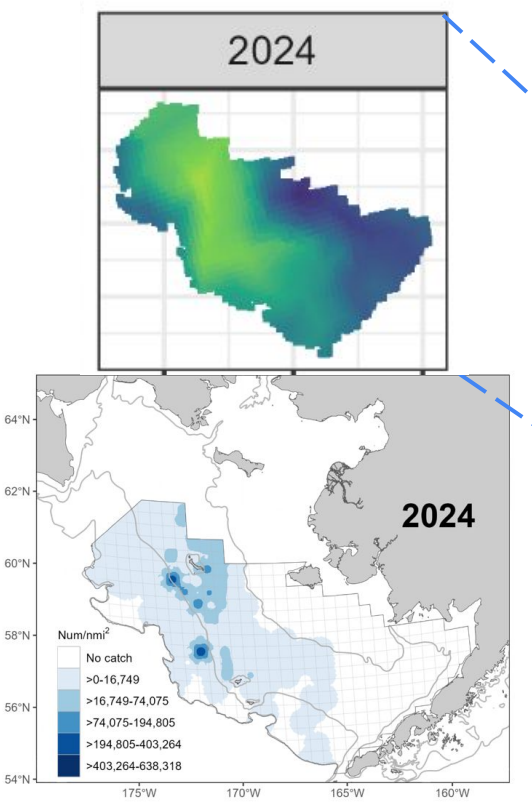
Predicted female biomass: EBS data

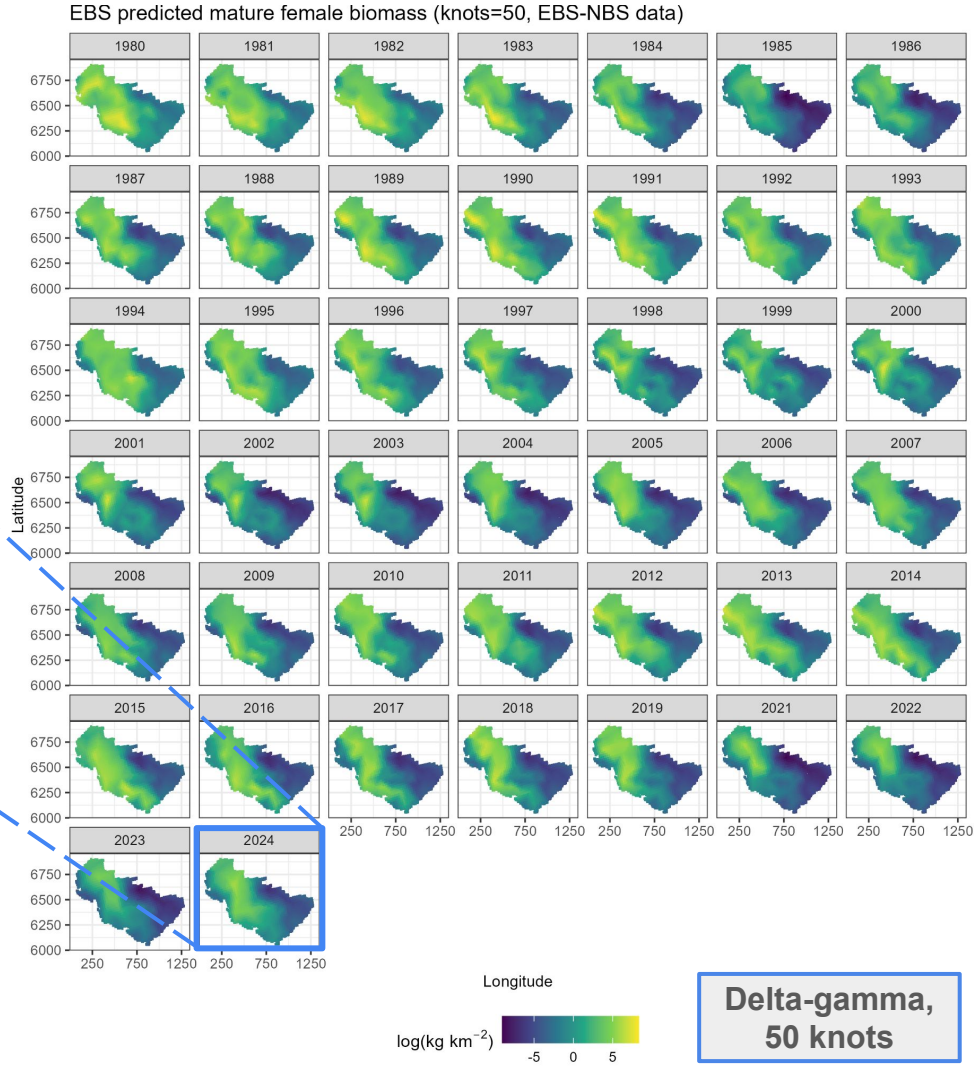




Delta-gamma, 50 knots

Predicted female biomass: EBS-NBS data

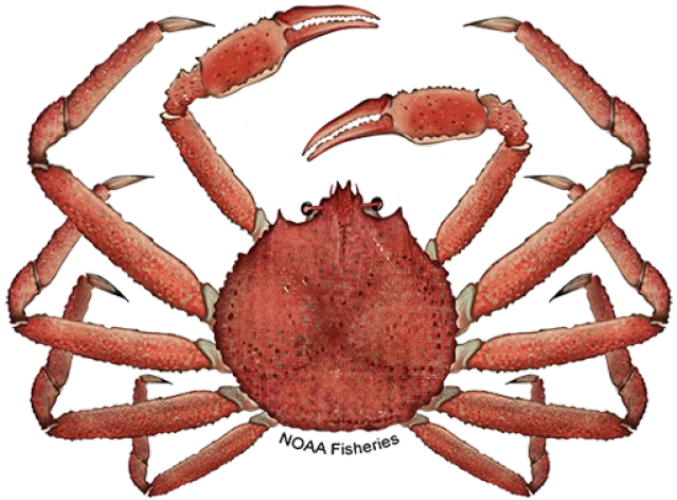




Delta-gamma, 50 knots

Snow crab conclusions and next steps

- Best model framework:
  - Delta-gamma, 90-knot mesh for males > 95mm
  - Delta-gamma, 50-knot mesh for mature females
  - EBS data only? EBS-NBS combined?
- Next steps:
  - Evaluate spatiotemporal autocorrelation with explicit statistics (e.g., global Moran's I clustering analysis)
  - Explore methods for reducing NBS autocorrelation (e.g., mesh size, covariates)



NOAA FISHERIES

MODEL-BASED SIZE FREQUENCIES

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INTRODUCTION

- EBS Tanner crab
- VAST
- Ongoing effort
- Complimentary to model based population estimates
- Previously, model based estimates used w/design based size frequencies
- System resources
- Model fit issues

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PROGRESS

- It runs! (kind of)
- Models run in sequence
- By 5 mm size bin
- Output compiled
- Multiple series run exploring different settings

COMMON SETTINGS

- ObsModel (2,4)
  - Delta-gamma model
  - Poisson-link
  - Encounter probability set to 1/0
- 75 or 125 kts (latest series)
  - Group sample locations for estimation of spatial variables
  - Spatial/spatiotemporal variation of a knot assumed constant within time steps
  - Tradeoff: Estimation accuracy vs computation efficiency
- Beta
  - Temporal variation in encounter/catch
  - **IID**
- Rho
  - Specifies temporal structuring of intercepts/spatiotemporal variation
  - **0 (fixed effect)**

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INDIVIDUALIZED SETTINGS

- Settings changed (within series)
  - Omega, Epsilon, anisotropy
    - Omega: spatial variation
    - Epsilon: spatio-temporal variation
      - 2 parameters each
        - 1 for encounter probability
        - 1 for positive catch rates
    - Anisotropy: directionality in autocorrelation

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- Models at size range extremes very simple (limited sample sizes)
  - Most spatial parameters disabled
  - Anisotropy disabled
  - Not sufficient in some cases
- Central models fully parameterized
- Run times; 20 min to 4+ hrs
  - ~80 model runs required to do males, immature females and mature females
  - Currently running 4th series of models
    - #1: Minimum basic settings common to all models
    - #2 and 3: More settings/parameters enabled where possible
    - #4: settings for #3, but more knots
  - >300 models run

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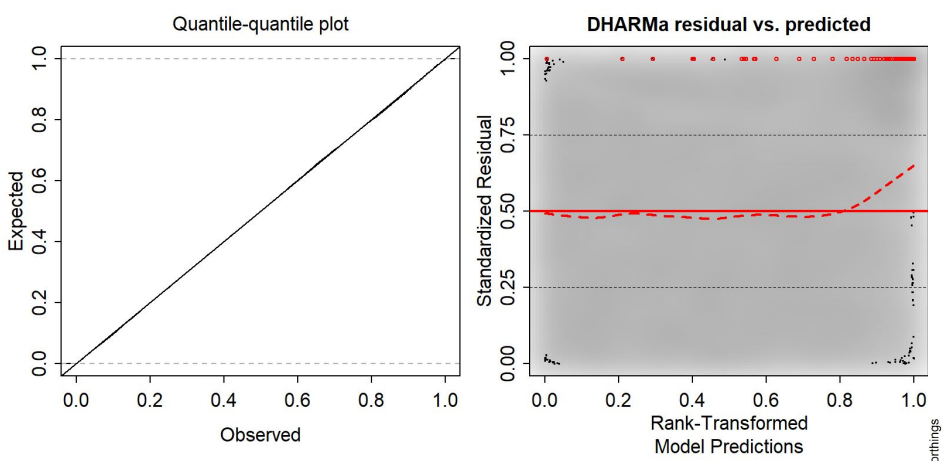
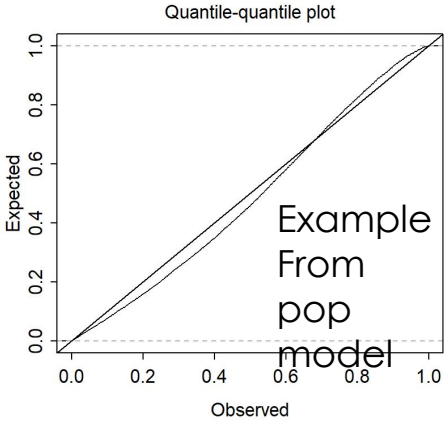
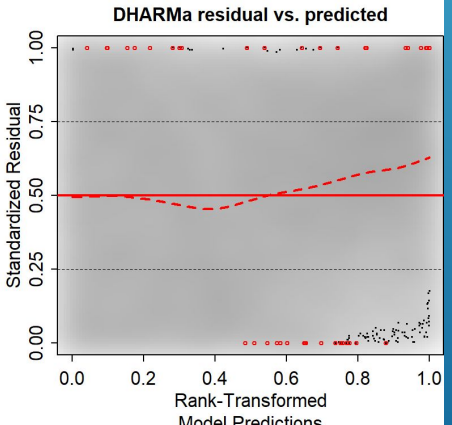
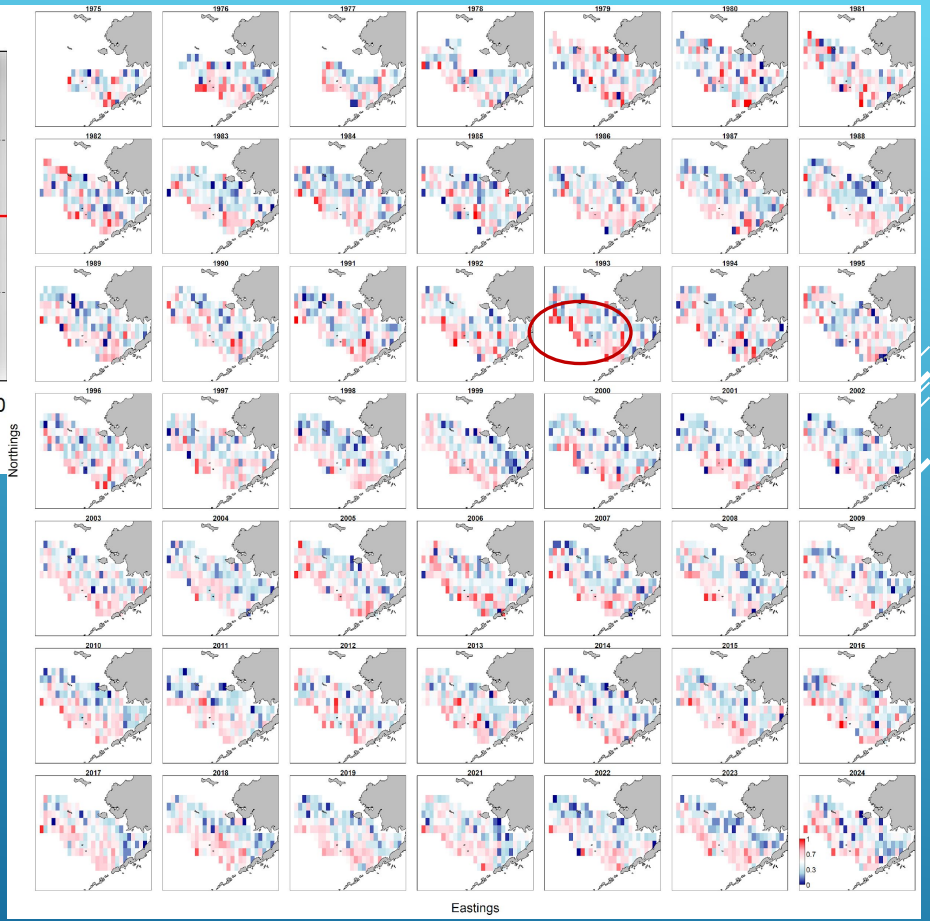
EXAMPLE DIAGNOSTICS

MALES 30-35MM

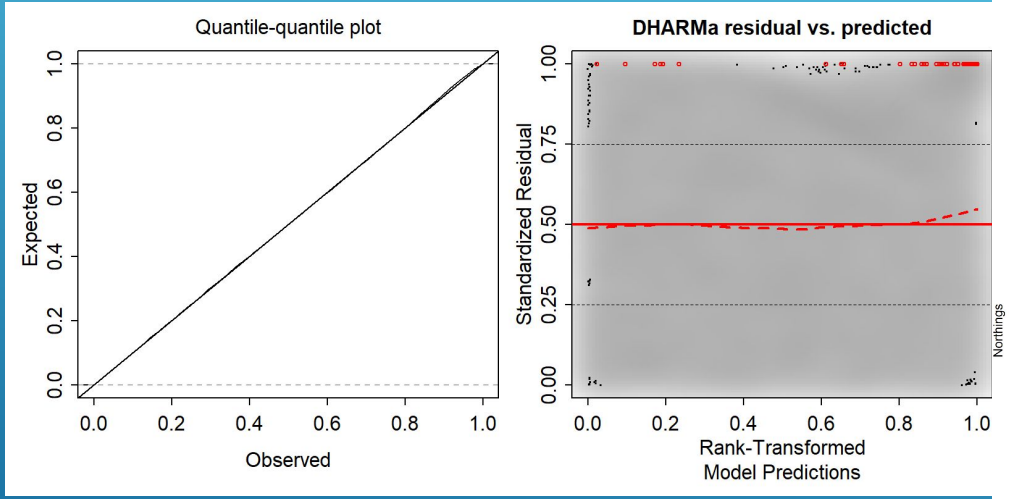


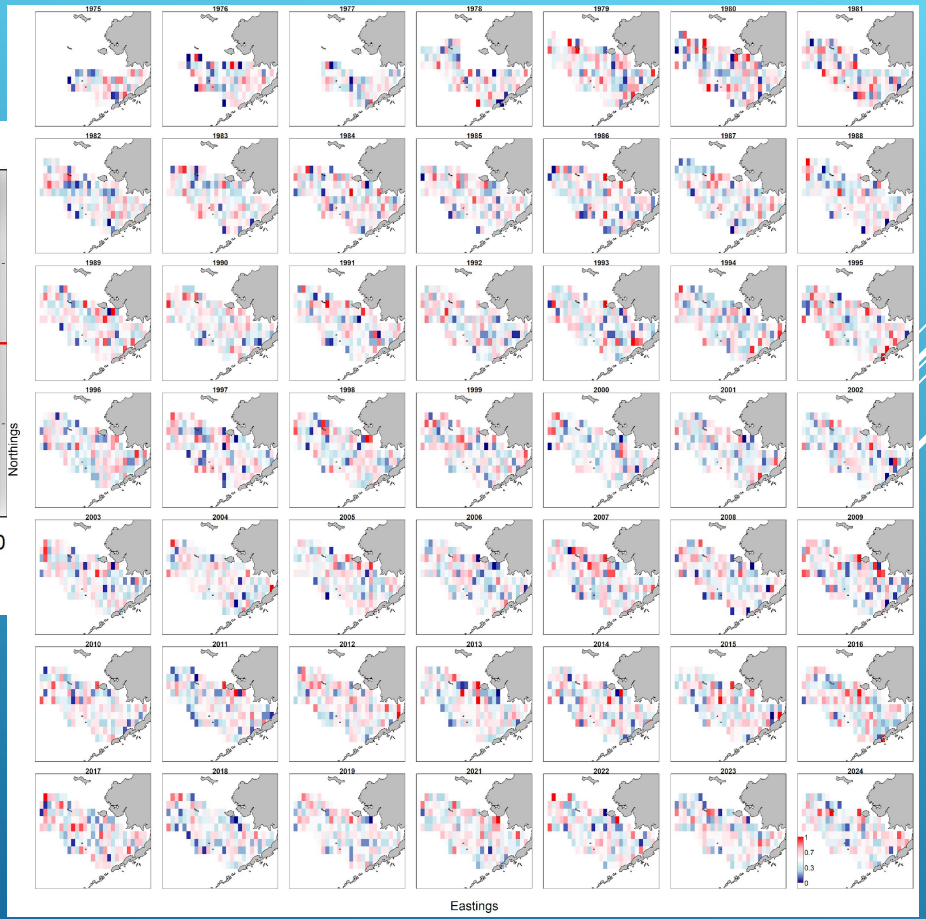




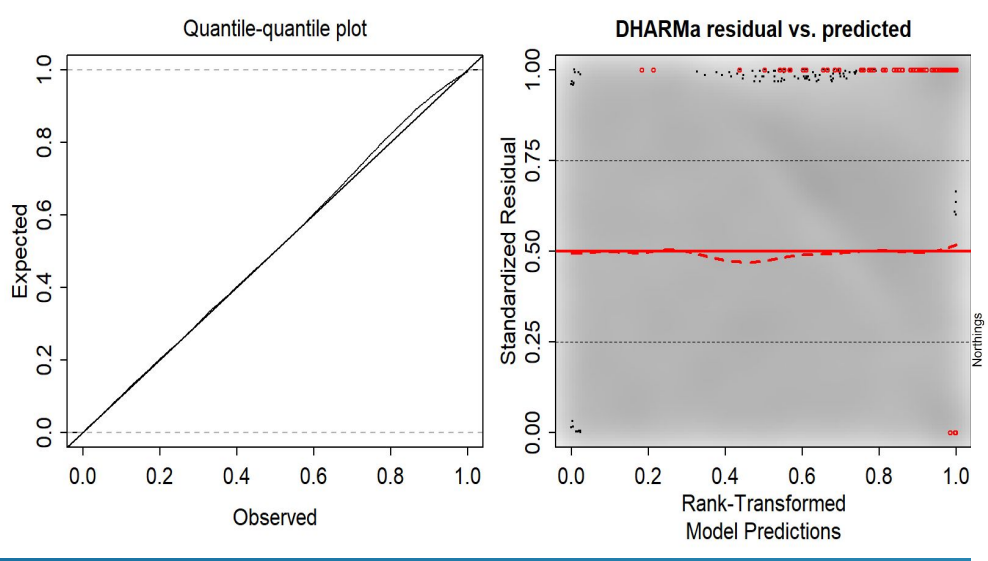


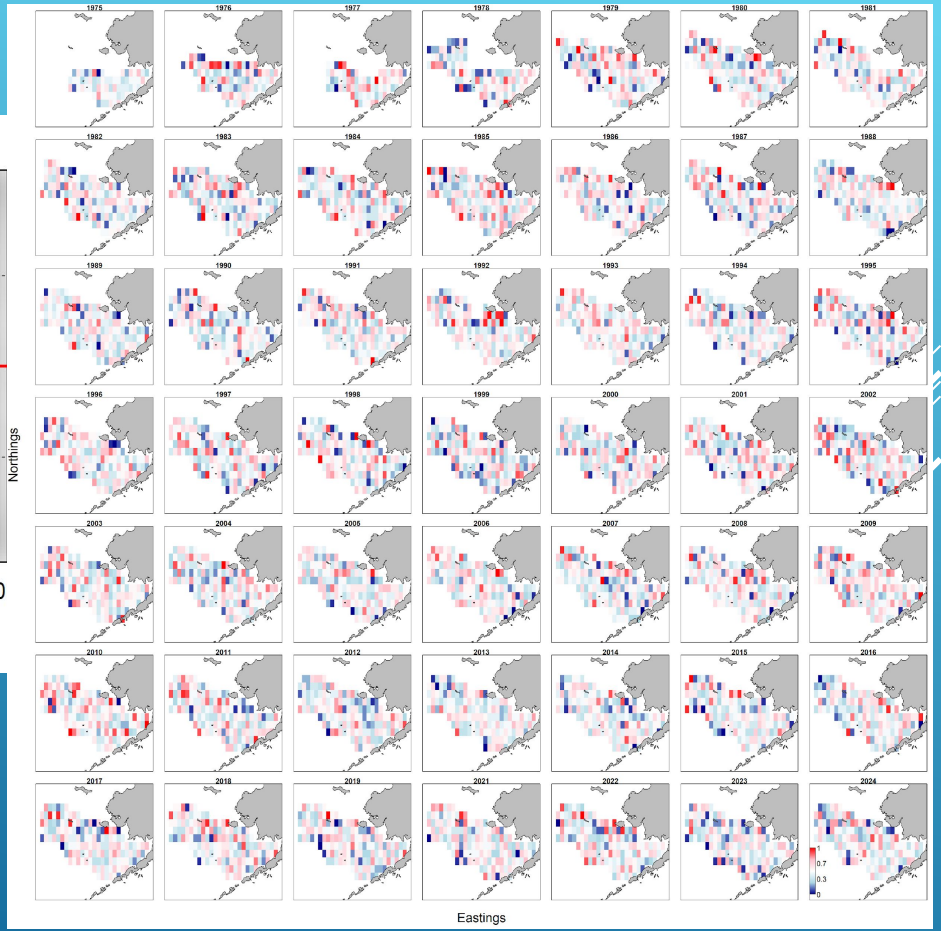
MALES 50-55MM



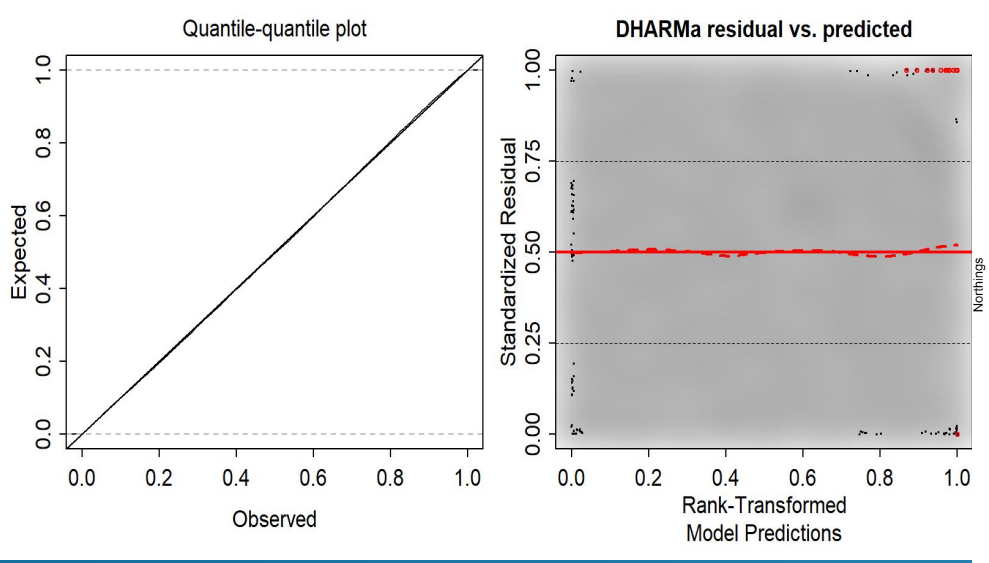


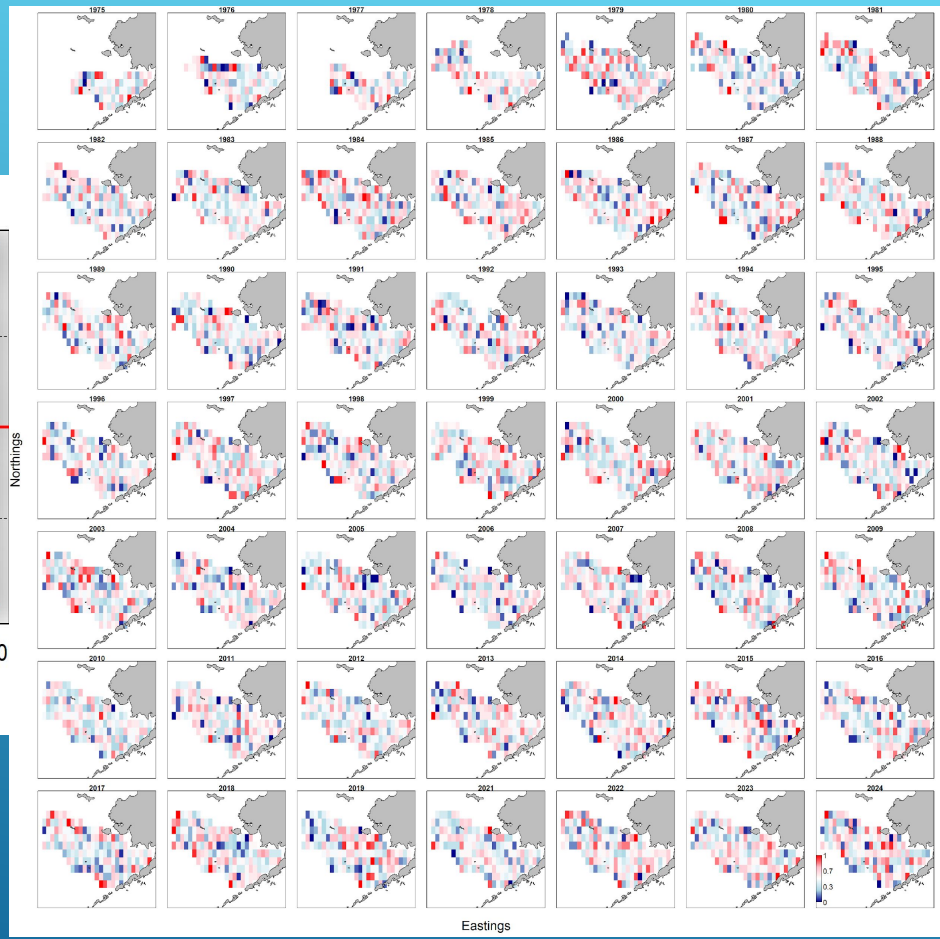
MALES 100-105 MM



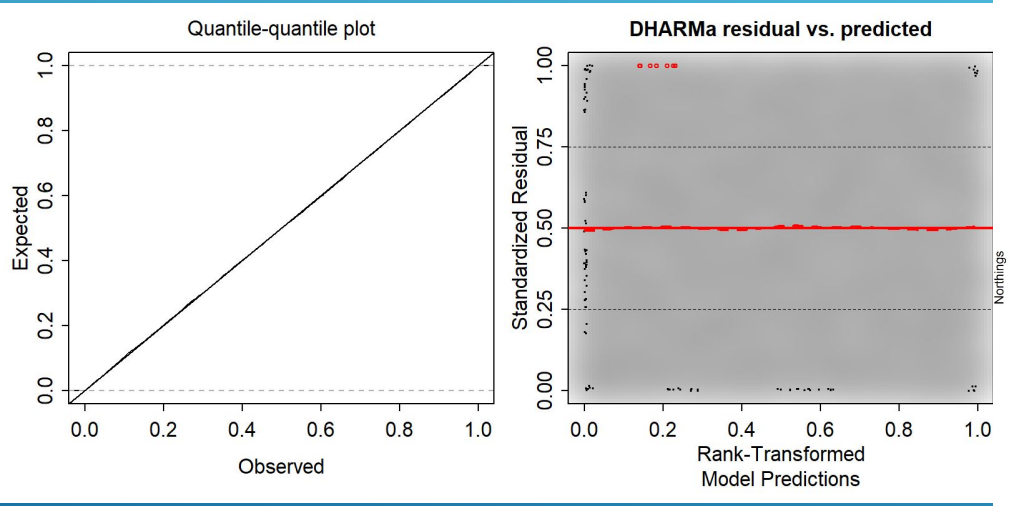


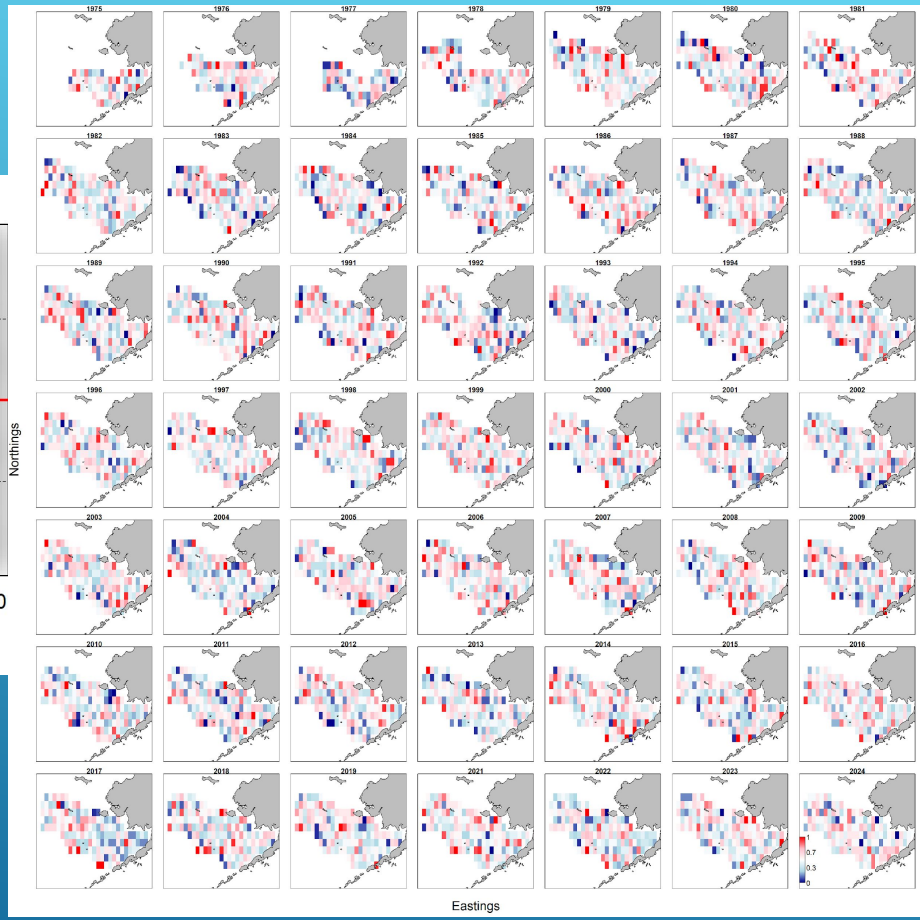
MALES 150-155MM





MALES 180+


Quantile-quantile plot
Expected
Observed
0.0
0.2
0.4
0.6
0.8
1.0
DHARMa residual vs. predicted
Standardized Residual
Rank-Transformed
Model Predictions
0.00
0.25
0.50
0.75
1.00


1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
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1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
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2002
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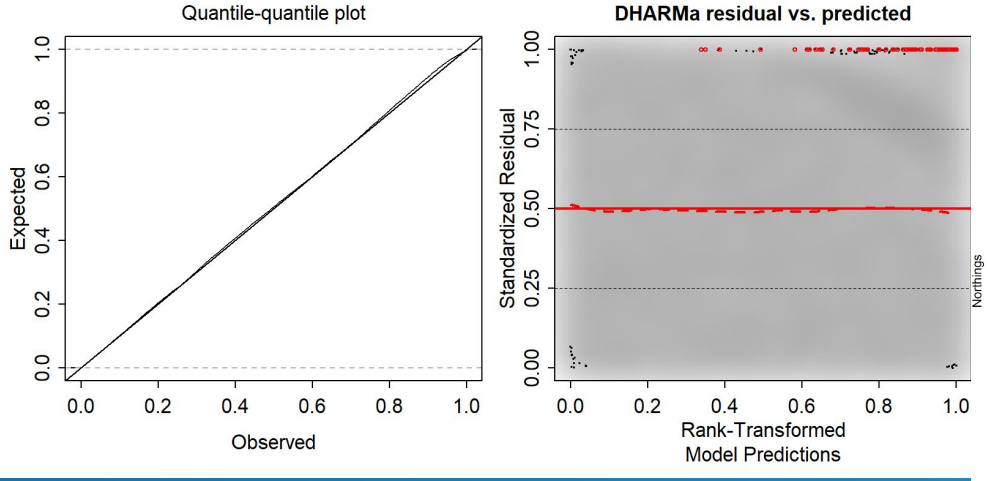
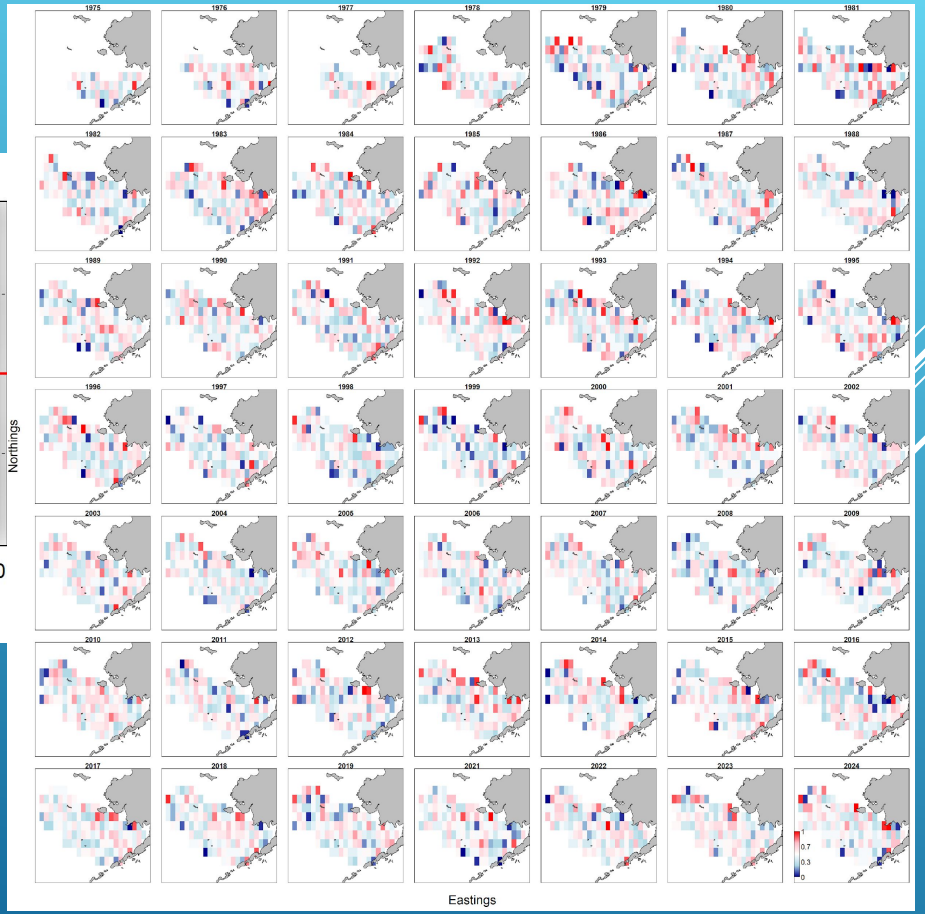
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2021
2022
2023
2024
Northings
Eastings

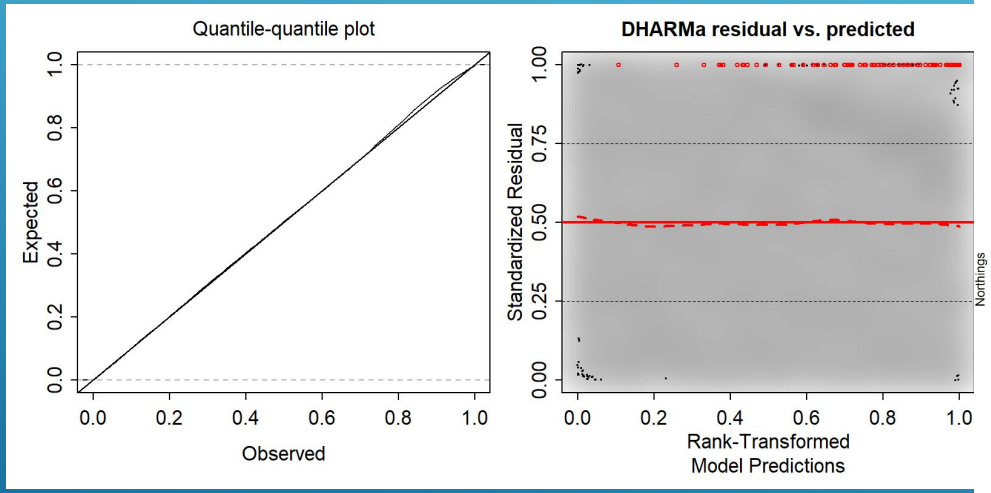
IMMATURE FEMALES

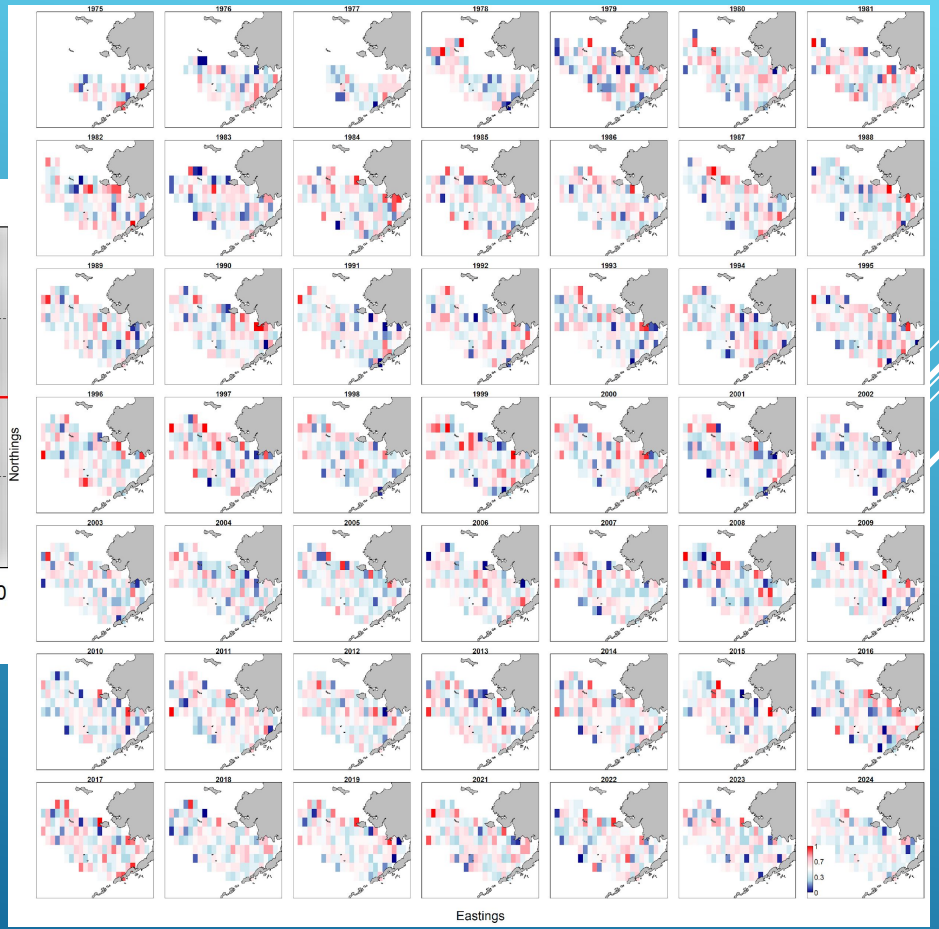
IMMATURE FEMALES 25-30 MM



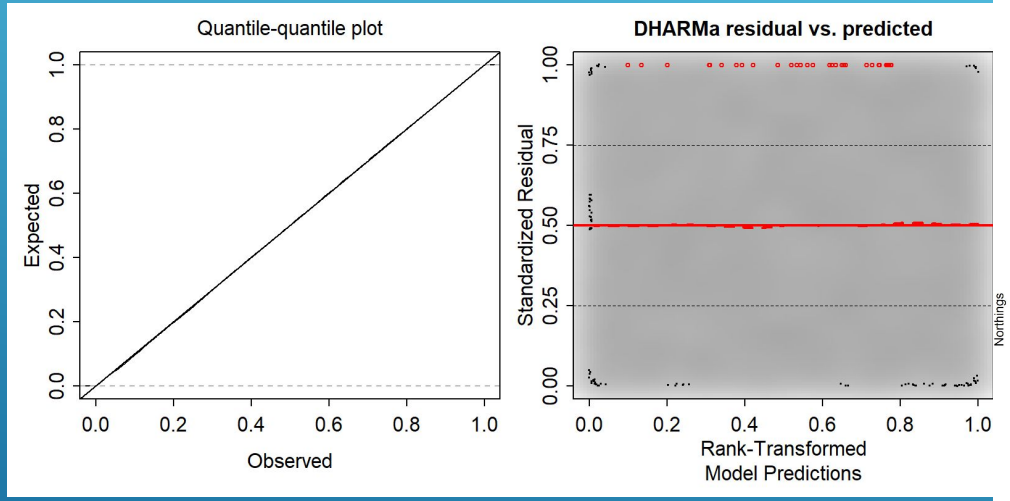


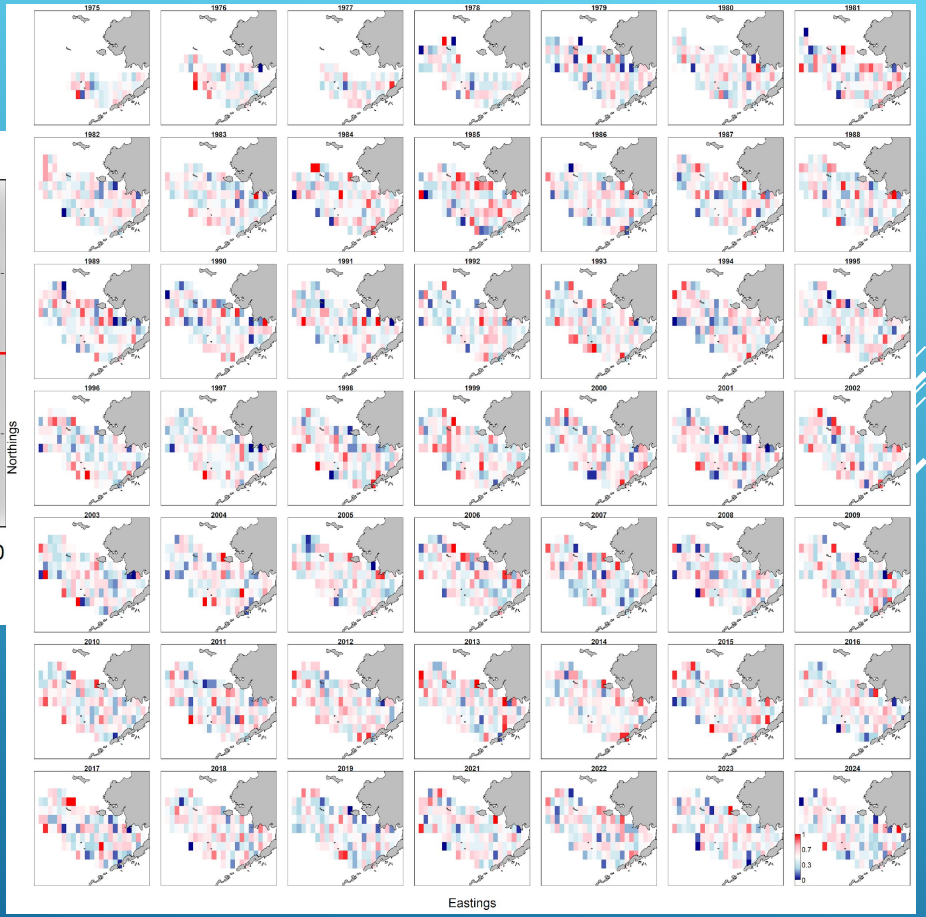
IMMATURE FEMALES 50-55MM





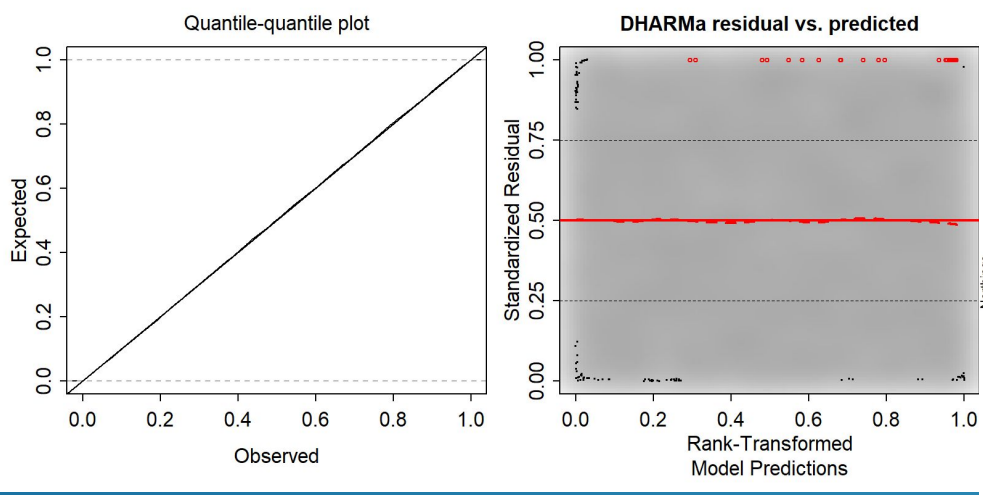
IMMATURE FEMALES 90-95 MM

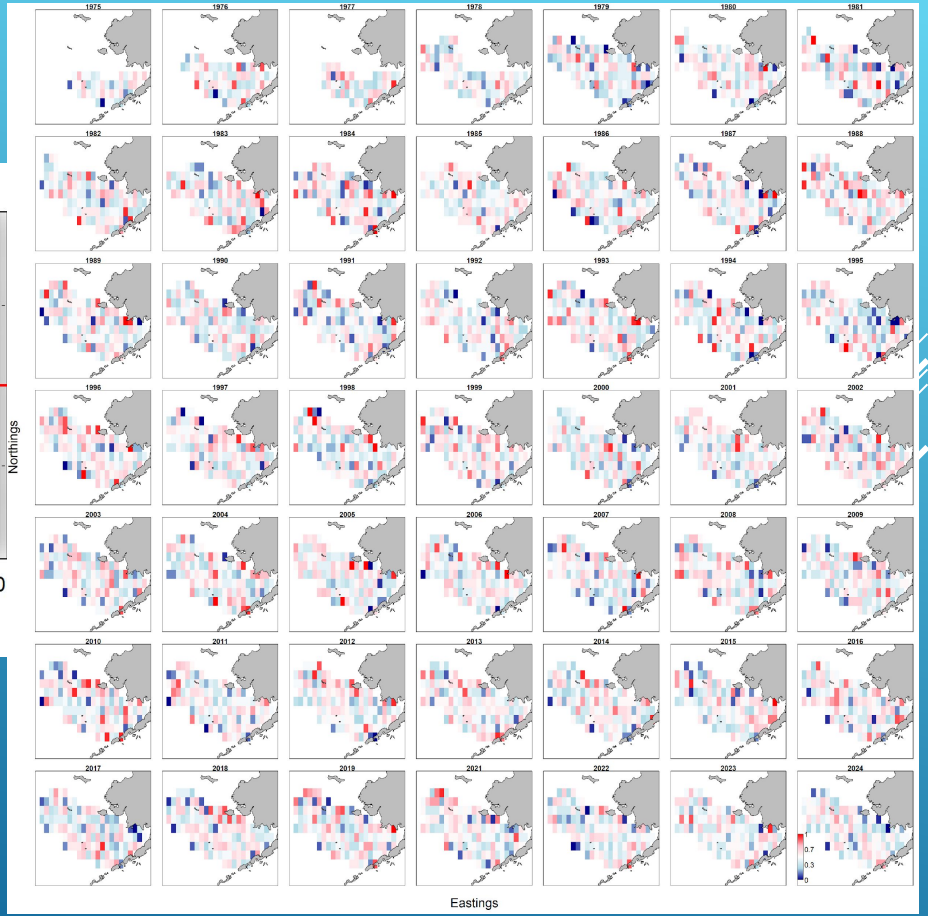




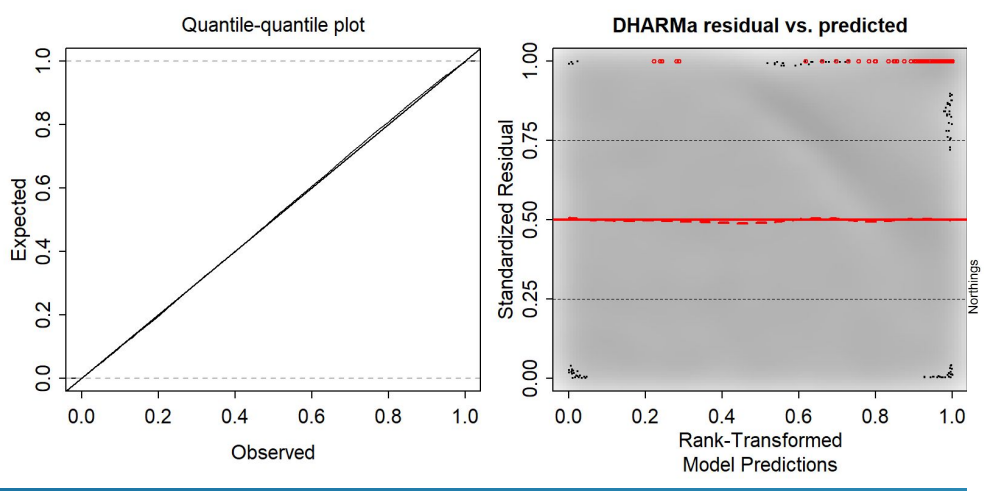
MATURE FEMALES

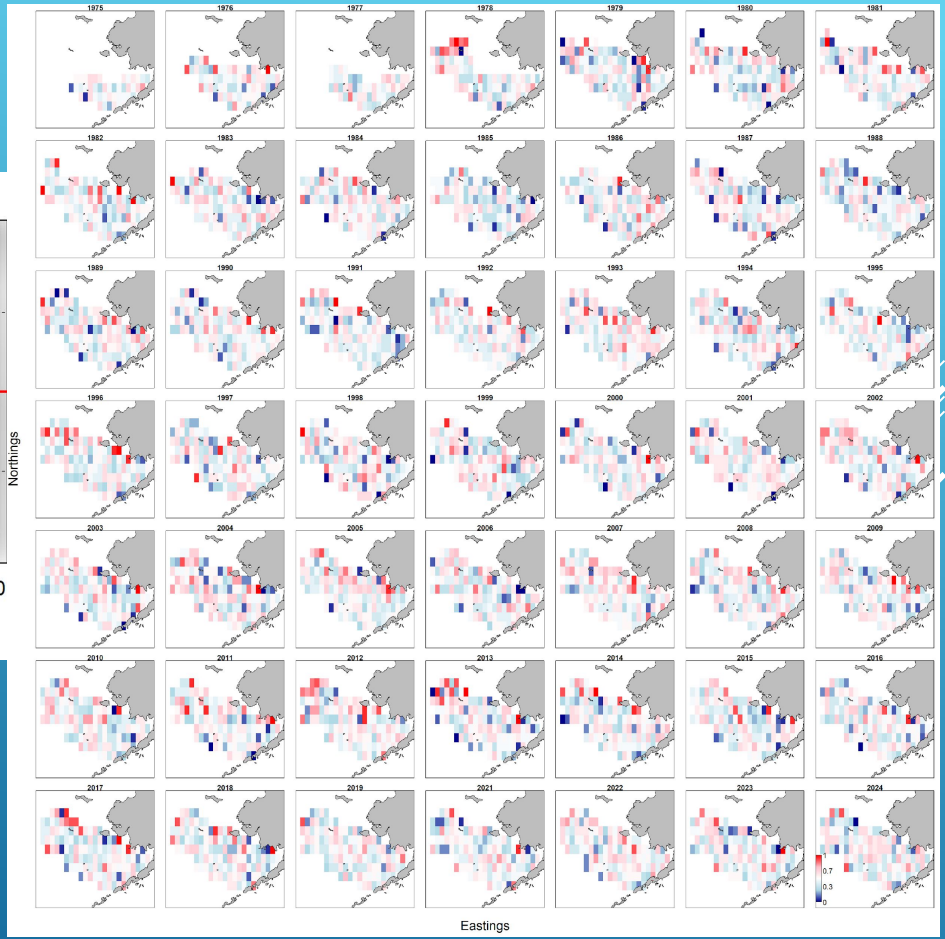
MATURE FEMALES 60-65 MM



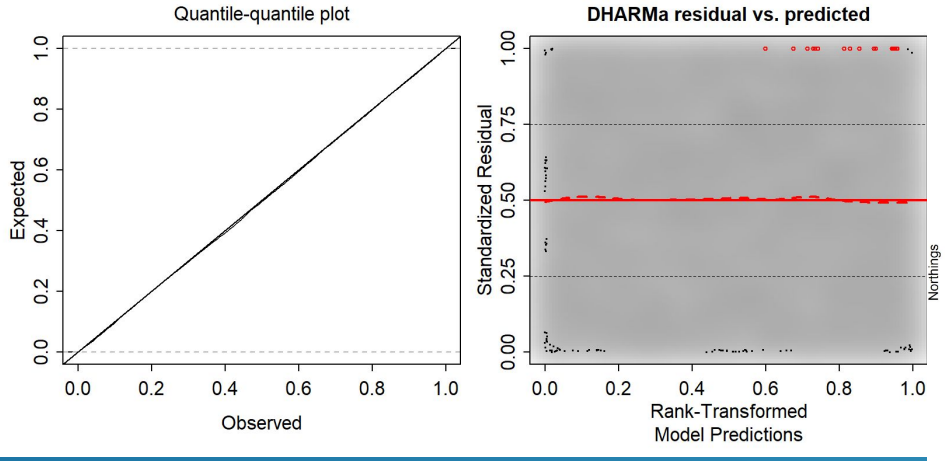


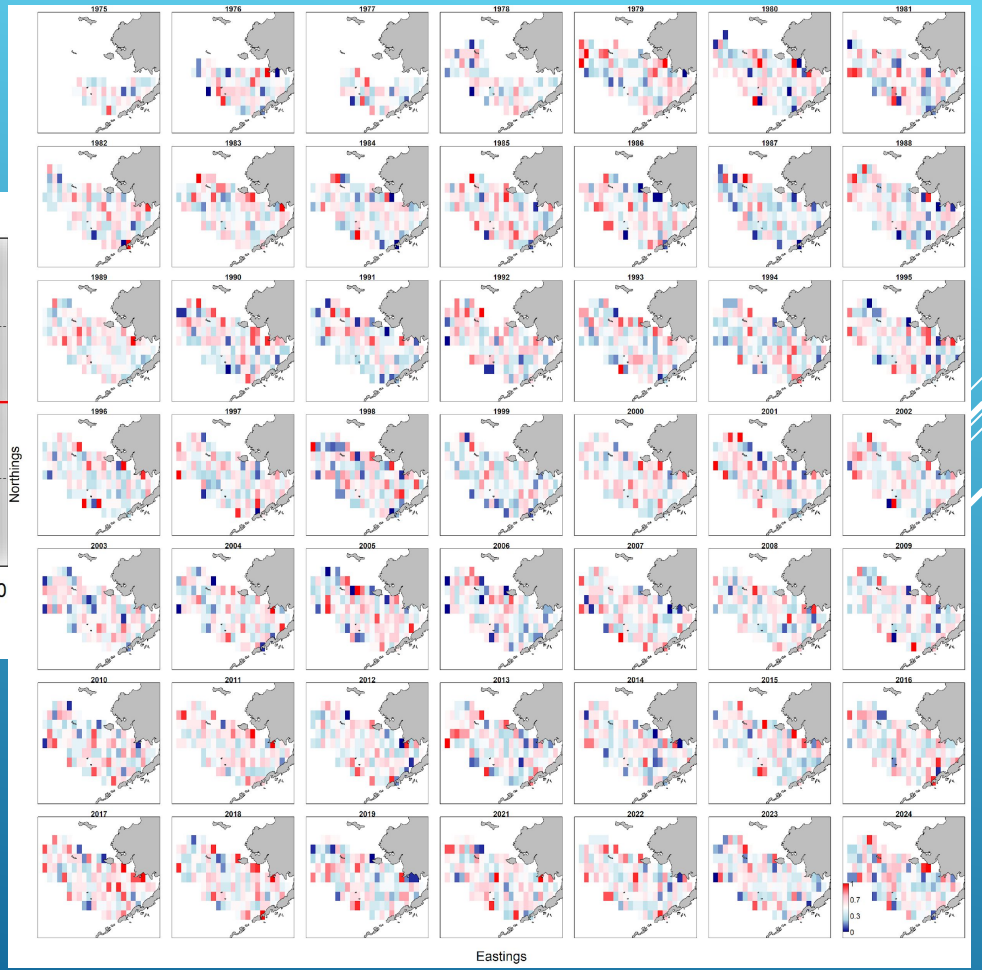
MATURE FEMALES 85-90 MM





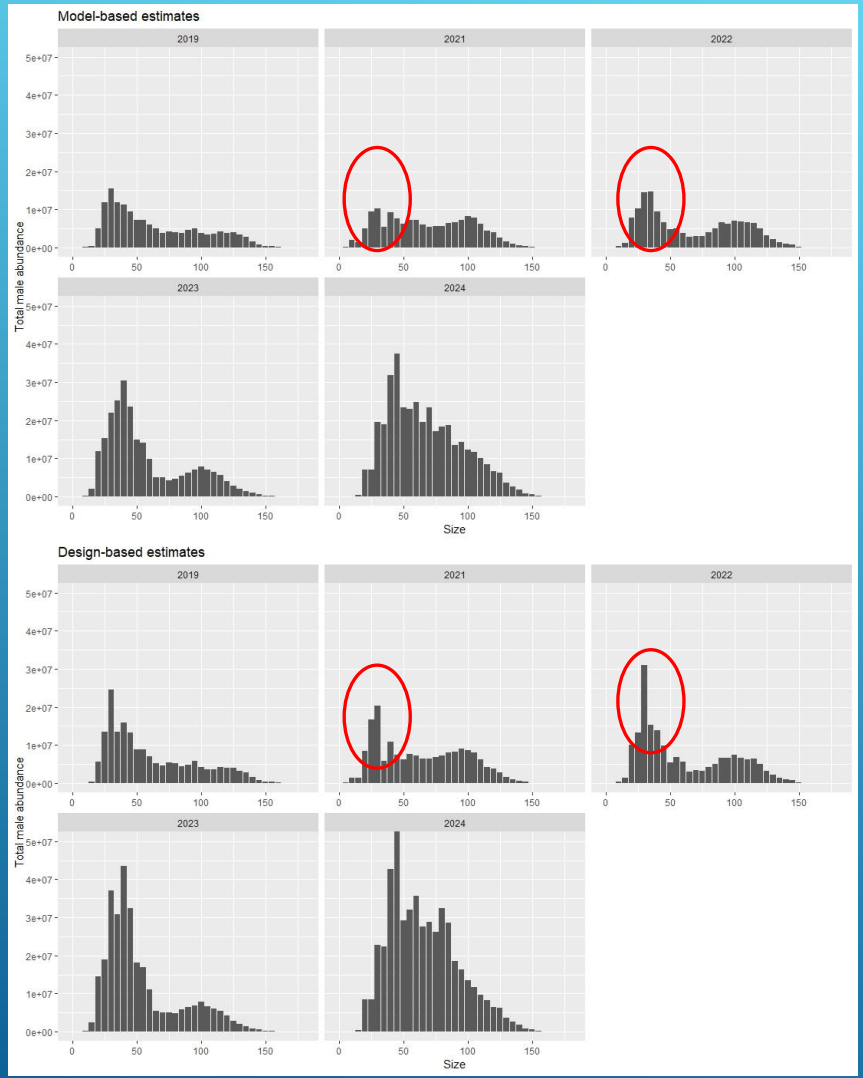
MATURE FEMALES 110-115 MM

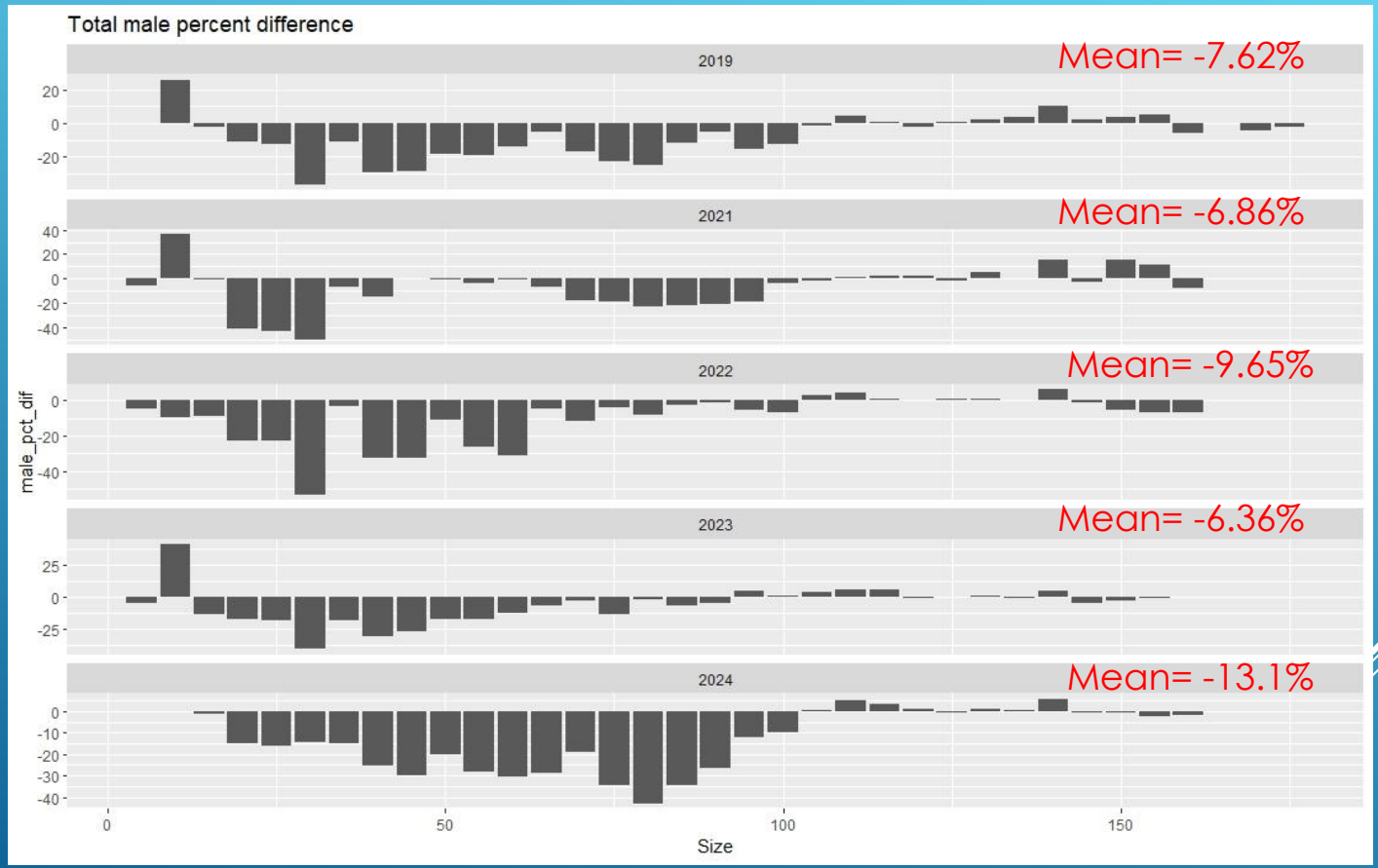




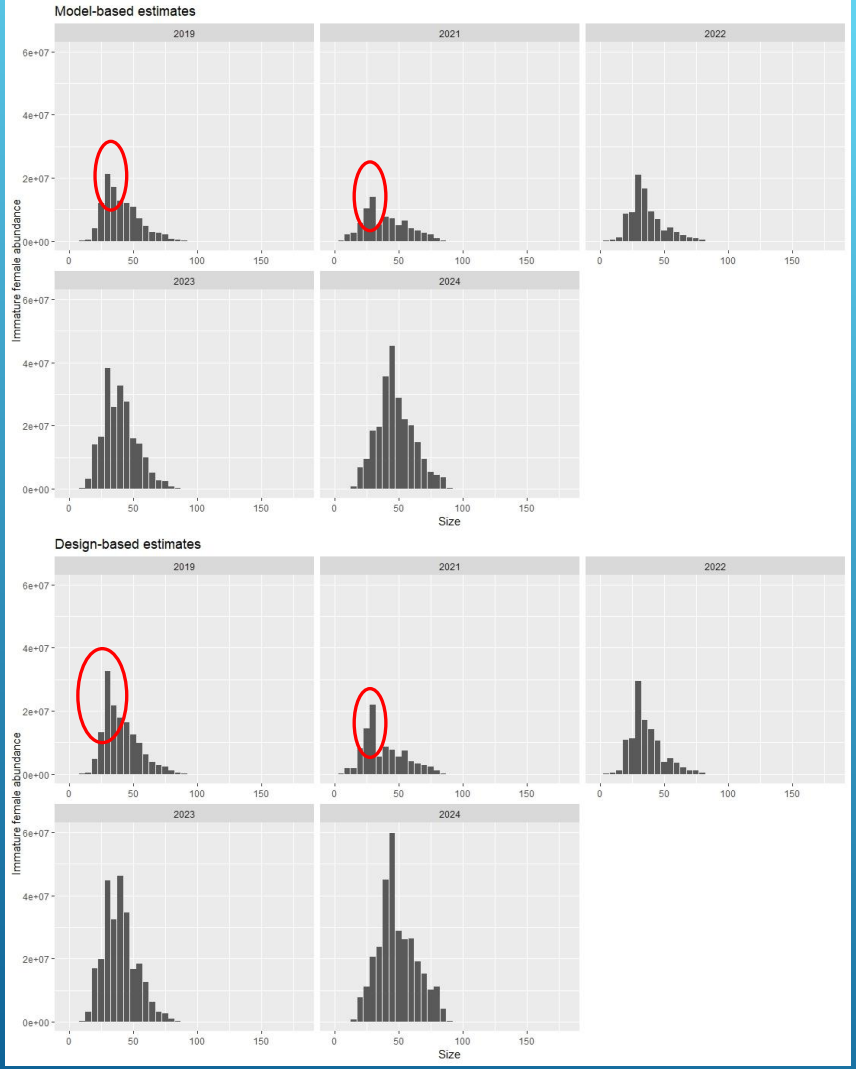
COMPILED SIZE-FREQUENCIES

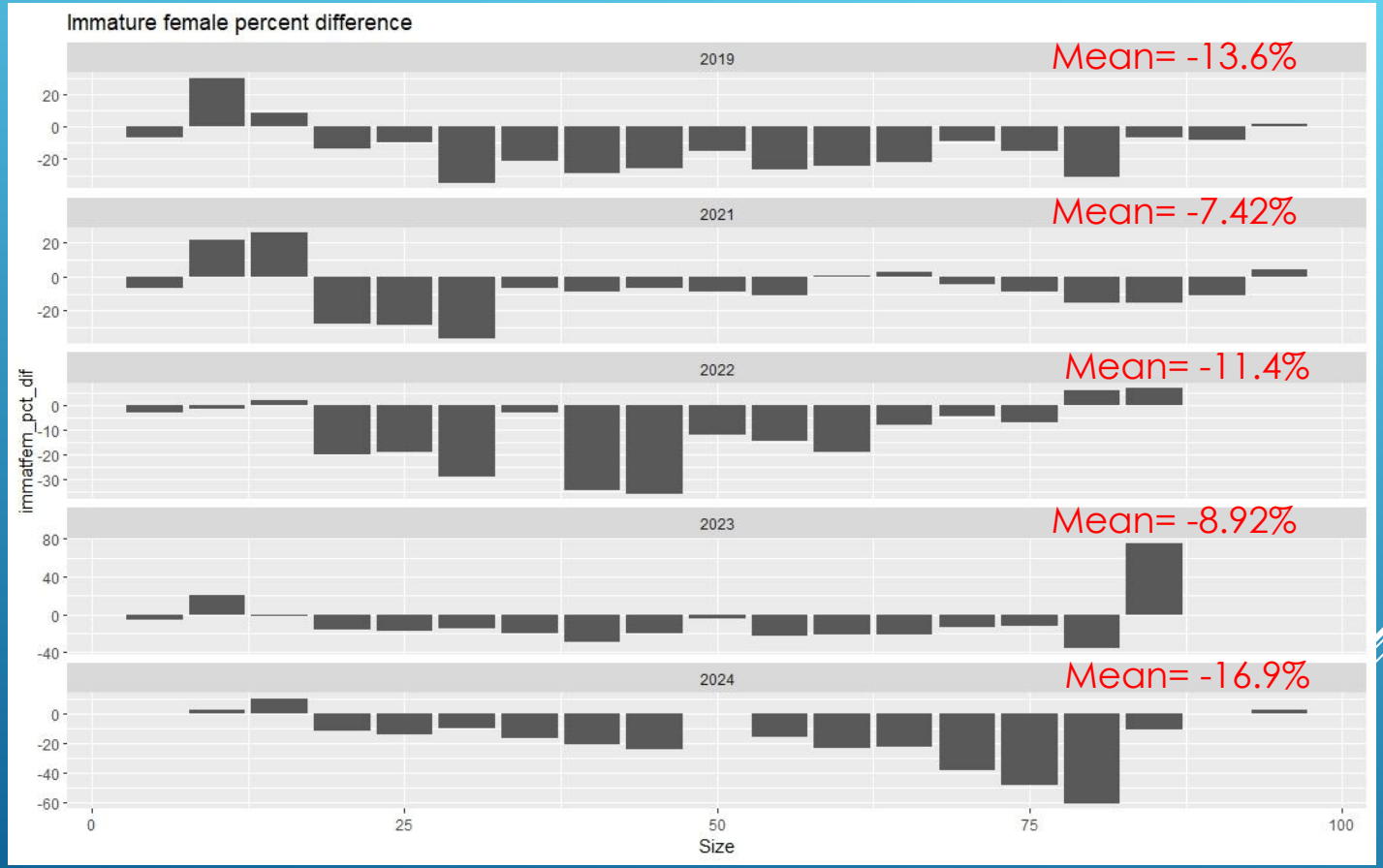
TOTAL MALES


Model-based estimates
2019
2021
2022
2023
2024
Total male abundance
Size
Design-based estimates
2019
2021
2022
2023
2024
Total male abundance
Size

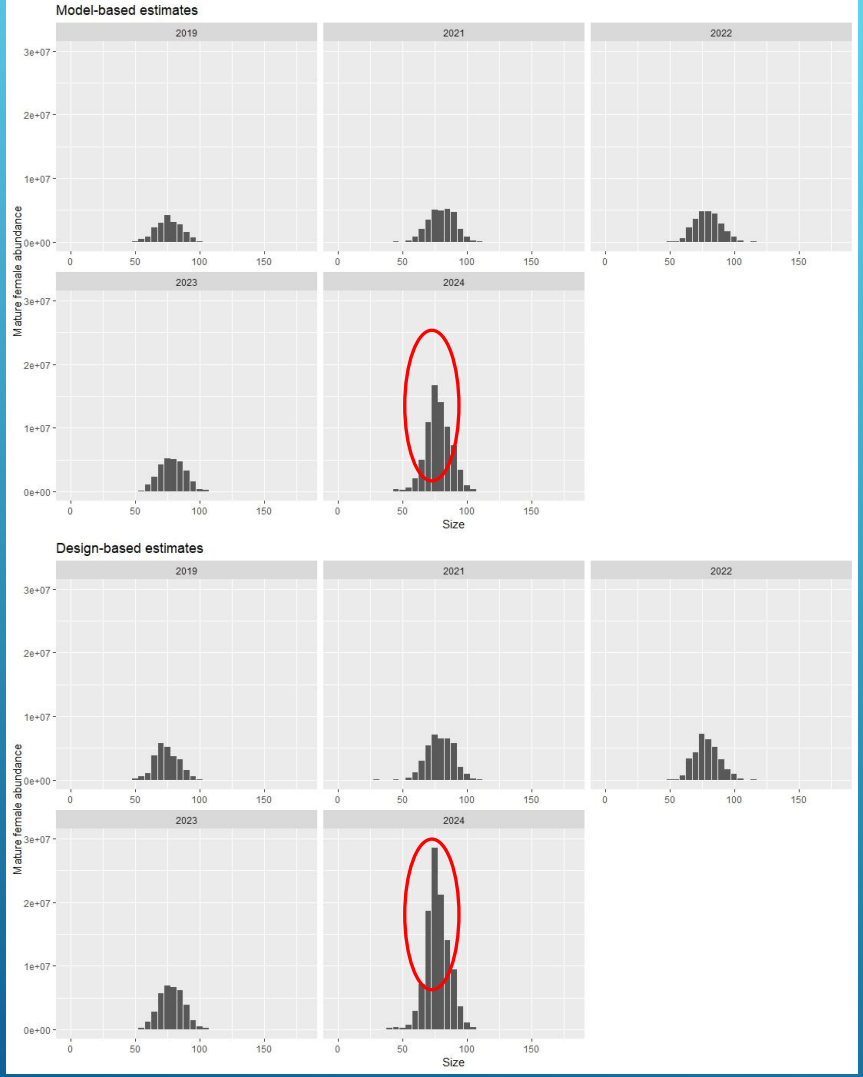

Total male percent difference
2019
Mean= -7.62%
2021
Mean= -6.86%
2022
Mean= -9.65%
2023
Mean= -6.36%
2024
Mean= -13.1%
male_pct_dif
Size
0
50
100
150

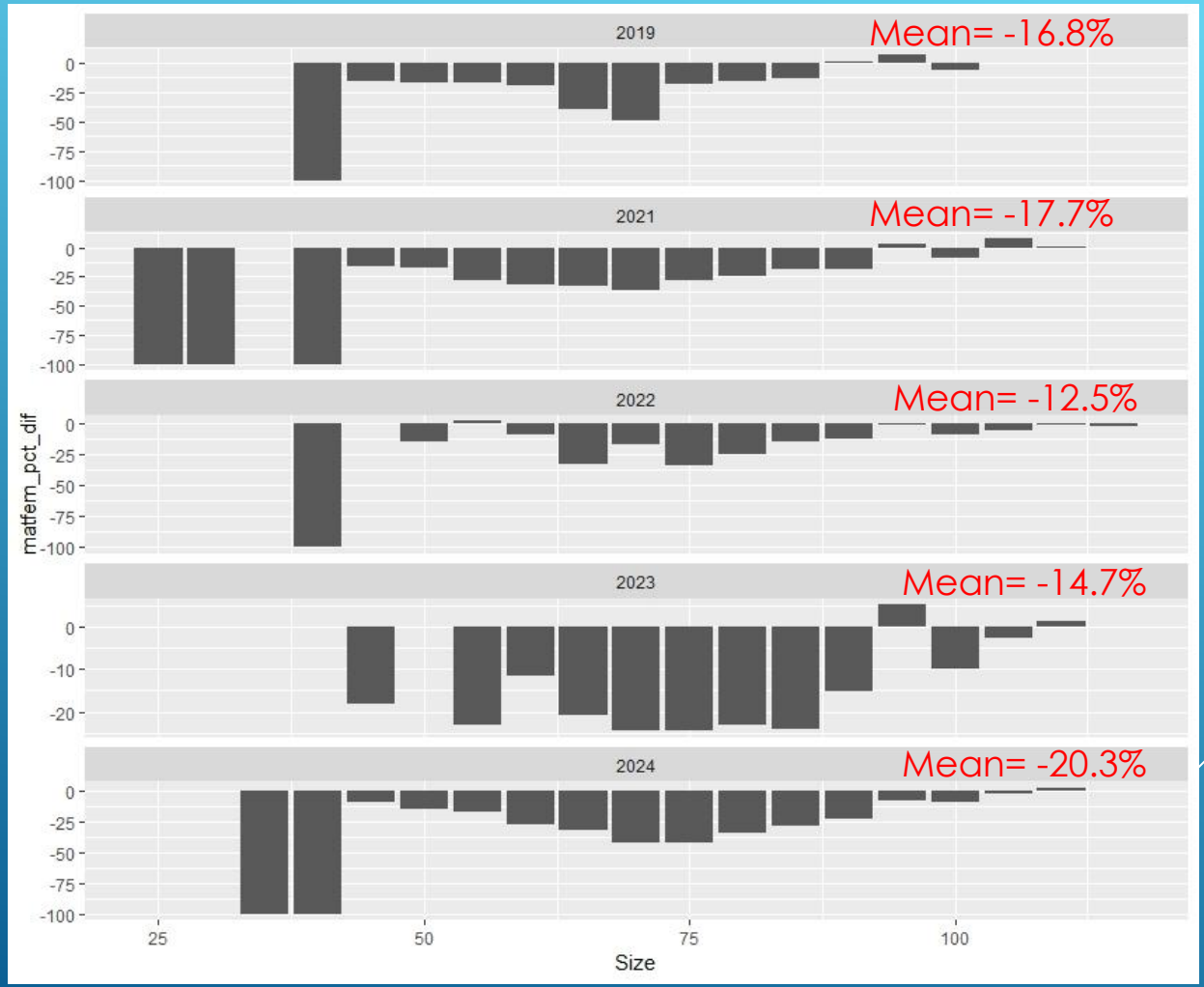
IMMATURE FEMALES


Model-based estimates
2019
2021
2022
2023
2024
Immature female abundance
6e+07
4e+07
2e+07
0e+00
0
50
100
150
Size
Design-based estimates
2019
2021
2022
2023
2024
Immature female abundance
6e+07
4e+07
2e+07
0e+00
0
50
100
150
Size


Immature female percent difference
2019
Mean= -13.6%
2021
Mean= -7.42%
2022
Mean= -11.4%
2023
Mean= -8.92%
2024
Mean= -16.9%
immatfem_pct_dif
Size
0
25
50
75
100

MATURE FEMALES


Model-based estimates
2019
2021
2022
2023
2024
Mature female abundance
3e+07
2e+07
1e+07
0e+00
0
50
100
150
Size
Design-based estimates
2019
2021
2022
2023
2024
Mature female abundance
3e+07
2e+07
1e+07
0e+00
0
50
100
150
Size


2019
Mean= -16.8%
2021
Mean= -17.7%
2022
Mean= -12.5%
2023
Mean= -14.7%
2024
Mean= -20.3%
matfem_pct_dif
0
-25
-50
-75
-100
-10
-20
25
50
75
100
Size

SUMMARY

- Model diagnostics look *good*
- Estimates generally lower than design based
  - Model specification issue?
  - Consequence of down weighting significance of large haul-stations?
- Design-based and model-based size-frequencies *broadly* similar, but estimate discrepancies are…….concerning

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FUTURE DIRECTIONS

- Continue effort to investigate/resolve discrepancies (May-July)
- Beta/ObsModel/Rho
  - 125 kts probably ceiling given run times
- Move to tinyVAST, or given iterative approach, sdmTMB (Fall)

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