

Spatiotemporal model-based indices for BSAI crab stocks

Update for Crab Plan Team modeling workshop

Caitlin Stern, Emily Ryznar, and Jon Richar
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Goals

1. Develop spatiotemporal model-based indices for:
 - Bering Sea Tanner crab
 - St. Matthew Island blue king crab
 - Norton Sound red king crab
2. Develop a transparent process for evaluating and selecting models



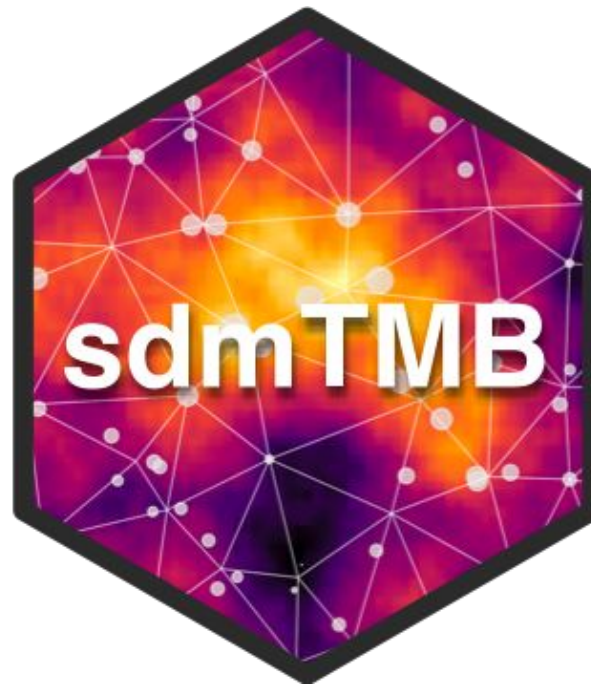
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Approach

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



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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 using the best sdmTMB model specification
- Lewis Barnett (NOAA) has demonstrated the equivalence of VAST and sdmTMB models 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



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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"))
```



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



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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



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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. Barnett³, Eric J. Ward⁴, Sean C. Anderson⁵ and Timothy E. Essington²

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



Tanner crab



Specific methods for Tanner crab

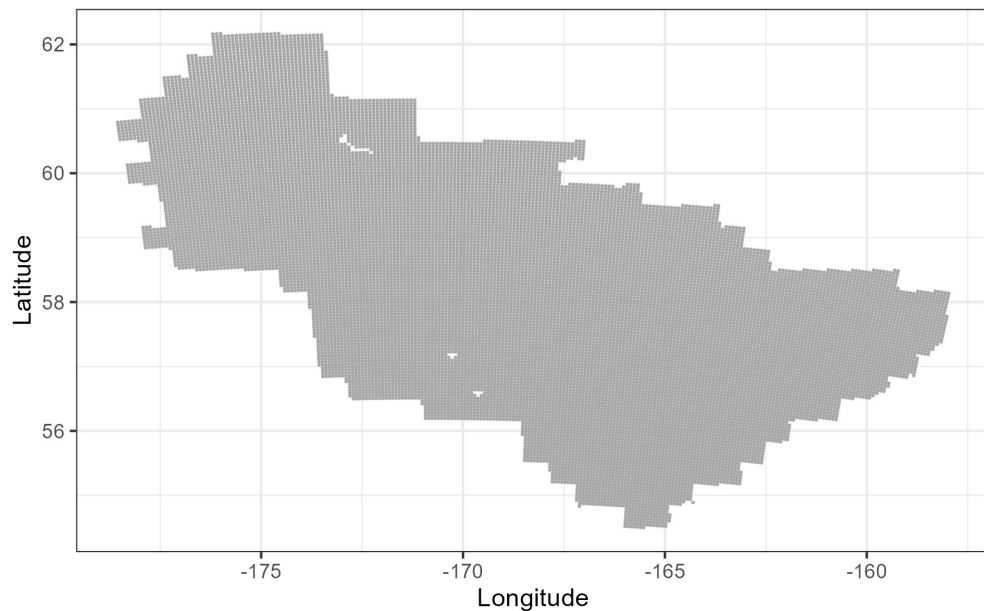
- Fit models for abundance and biomass
- Fit models for all males, mature females, immature females
- Fit separate models for survey data <1982 and ≥ 1982 due to gear change
- Fit EBS-wide models, predict Tanners east and west of 166°
- Model family: delta-gamma, Tweedie, delta-lognormal
- Random field: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



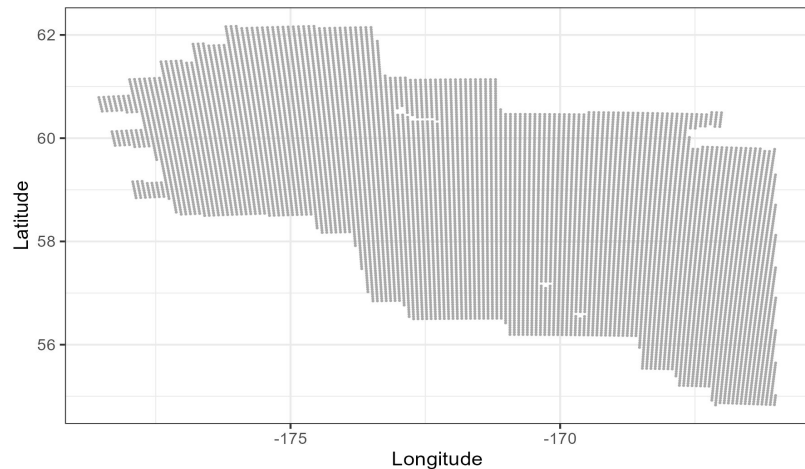
Prediction grids

- 5 km² resolution, no land

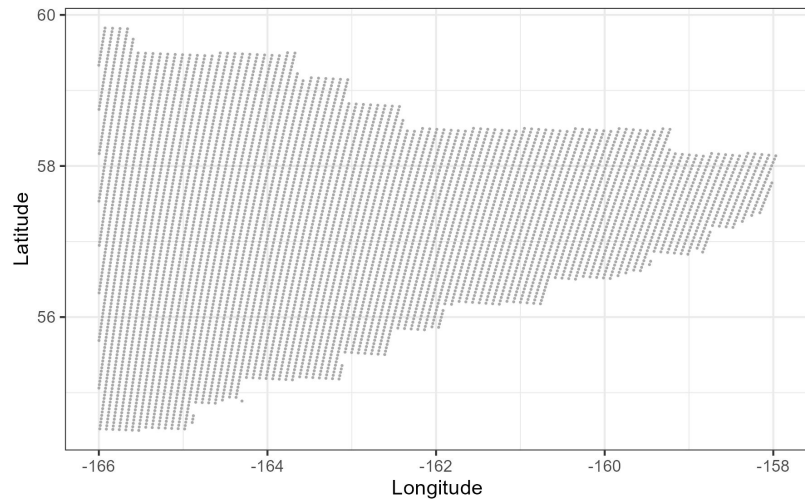
EBS prediction grid



Tanner crab West prediction grid



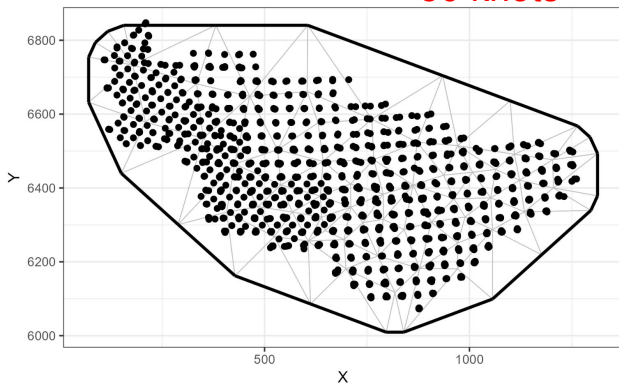
Tanner crab East prediction grid



Model mesh

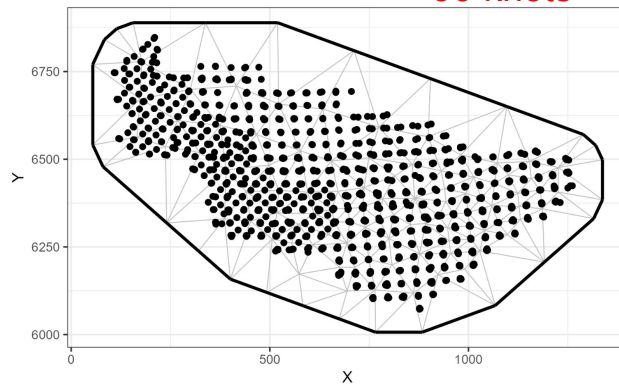
<1982 mesh (knots=72)

50 knots



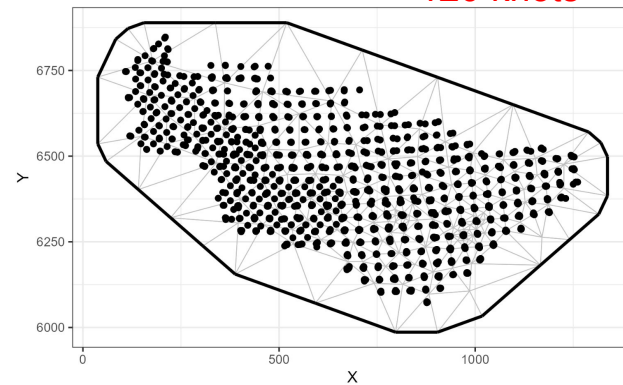
<1982 mesh (knots=122)

90 knots

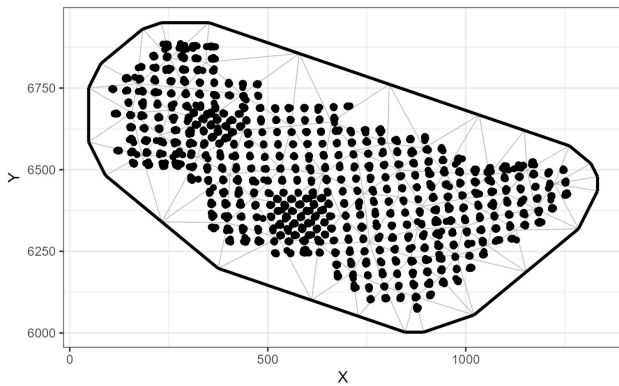


<1982 mesh (knots=188)

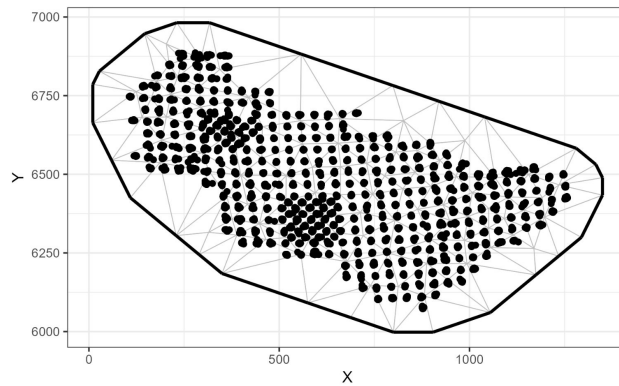
120 knots



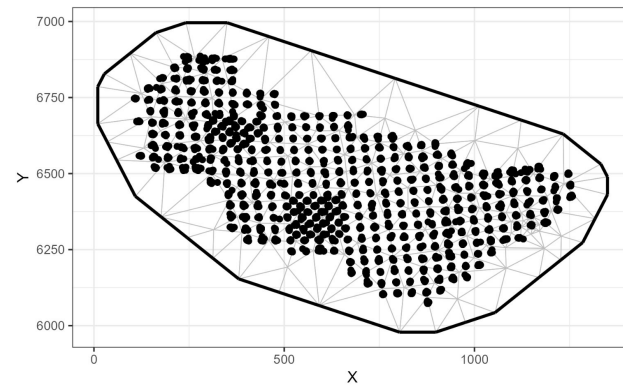
≥ 1982 mesh (knots=74)



≥ 1982 mesh (knots=122)



≥ 1982 mesh (knots=188)



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

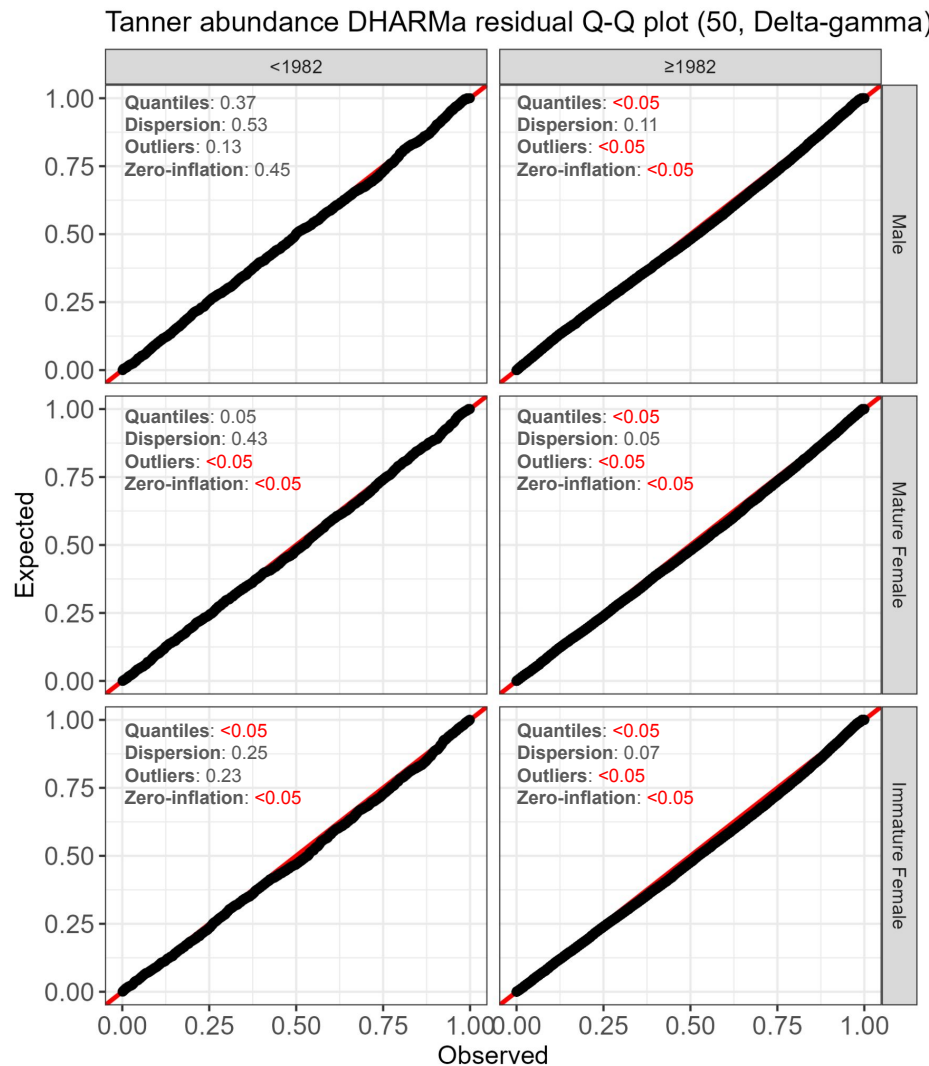
knots	family	n	loglik	BEST
<int>	<chr>	<int>	<dbl>	<chr>
50	Delta_gamma	6	- <u>194983.</u>	"YES"
50	Tweedie	6	- <u>195595.</u>	""
90	Delta_gamma	6	- <u>195454.</u>	""
90	Tweedie	6	- <u>195515.</u>	""
120	Delta_gamma	6	- <u>196720.</u>	""
120	Tweedie	6	- <u>196297.</u>	""



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

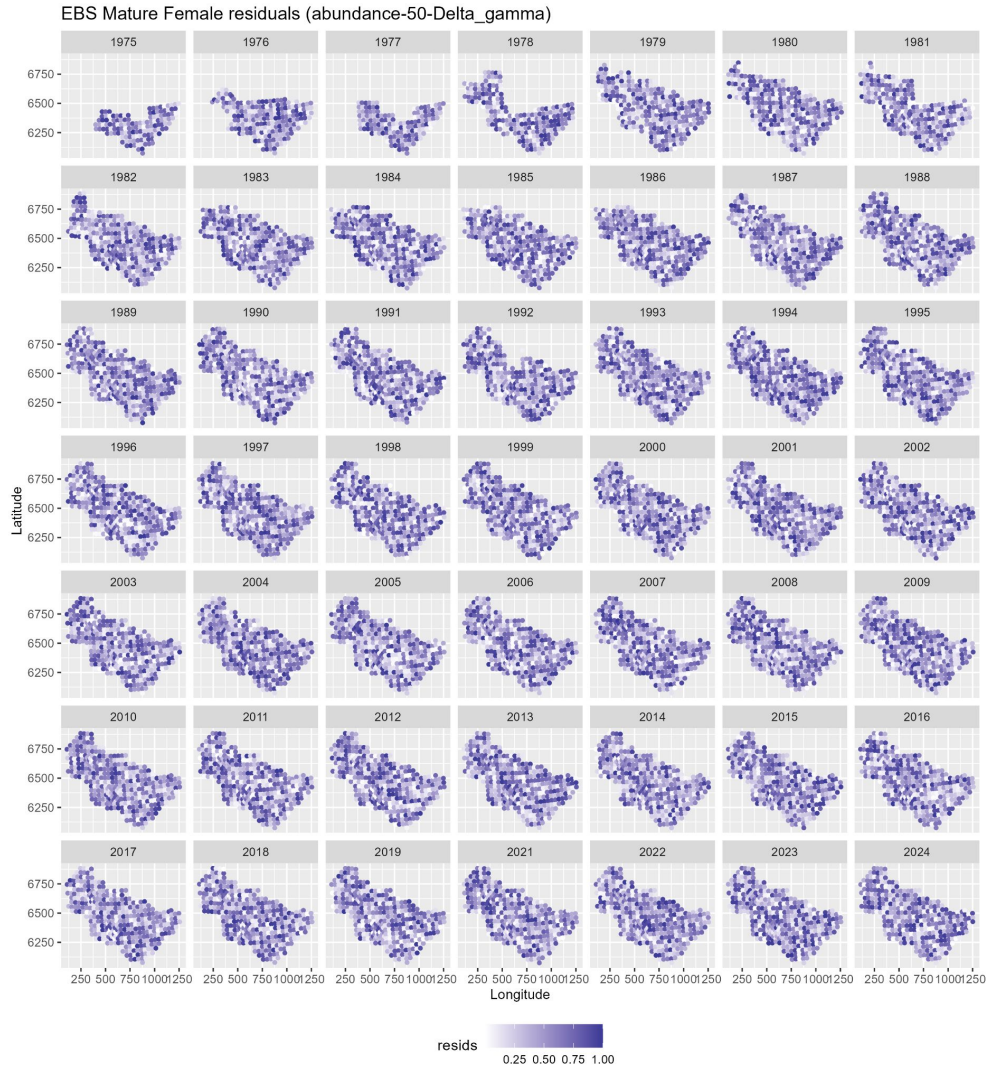
Delta-gamma, 50 knots



Abundance model diagnostics

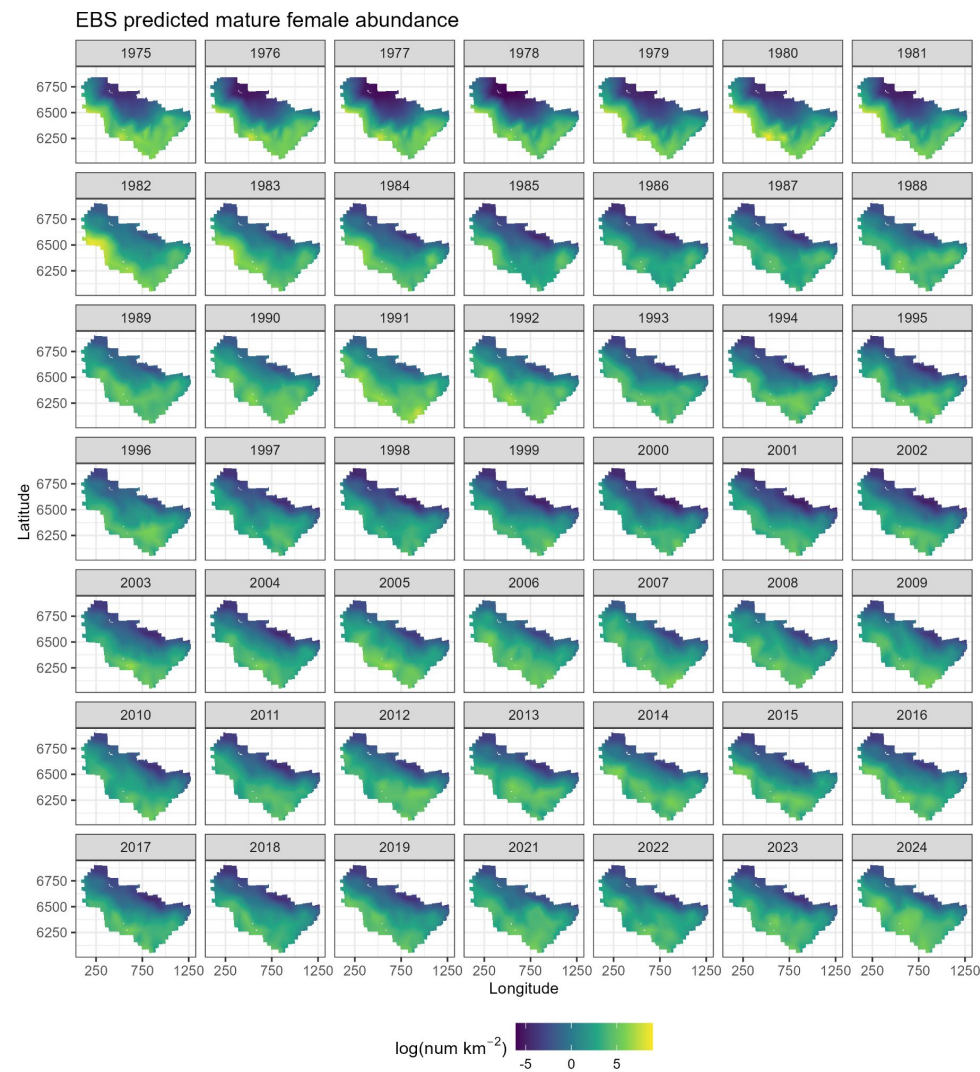
- No evidence of spatiotemporal autocorrelation of DHARMA residuals across categories

Delta-gamma, 50 knots

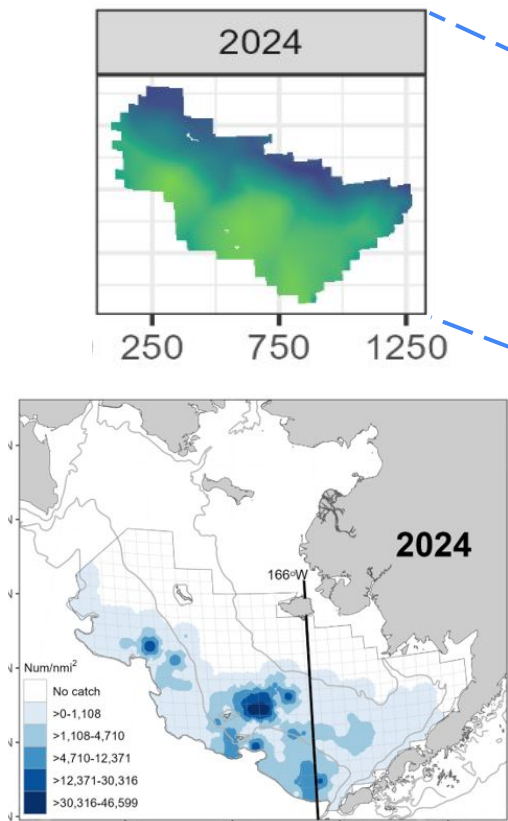


Predicted abundance

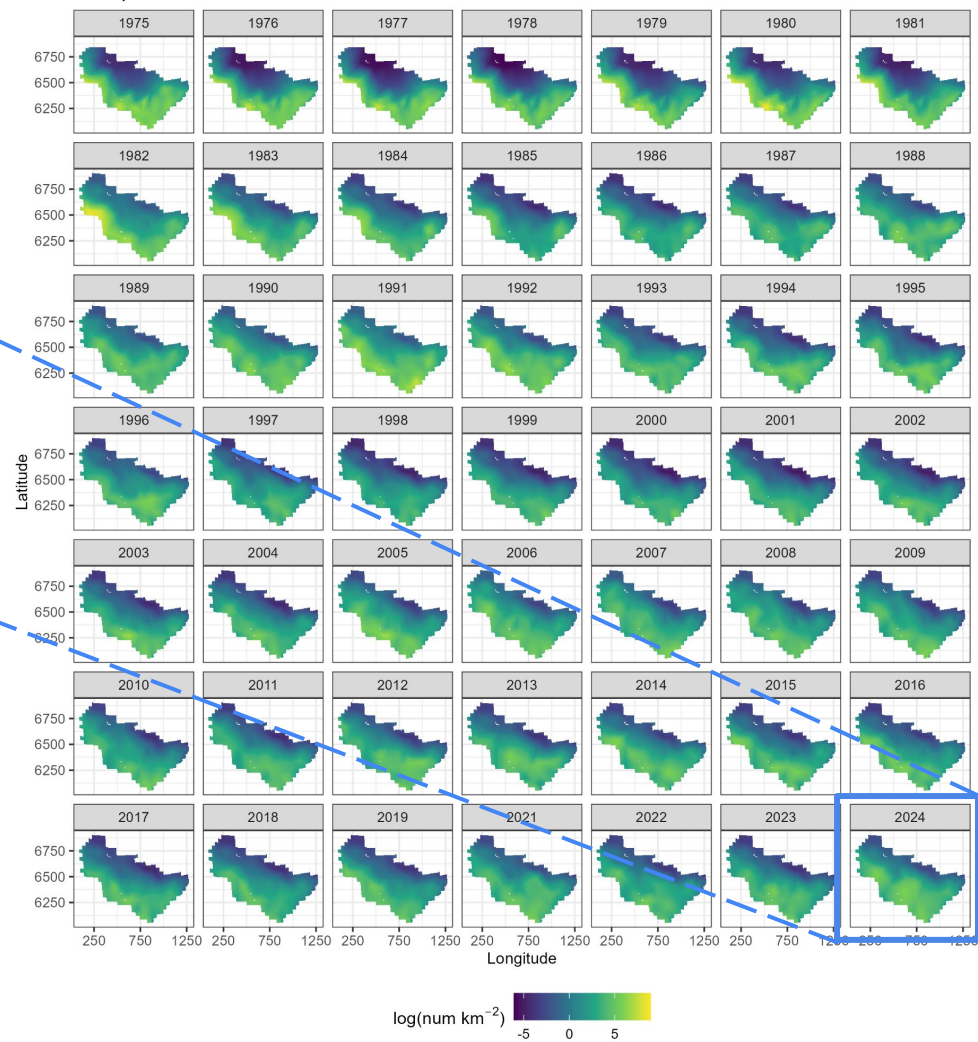
Delta-gamma, 50 knots



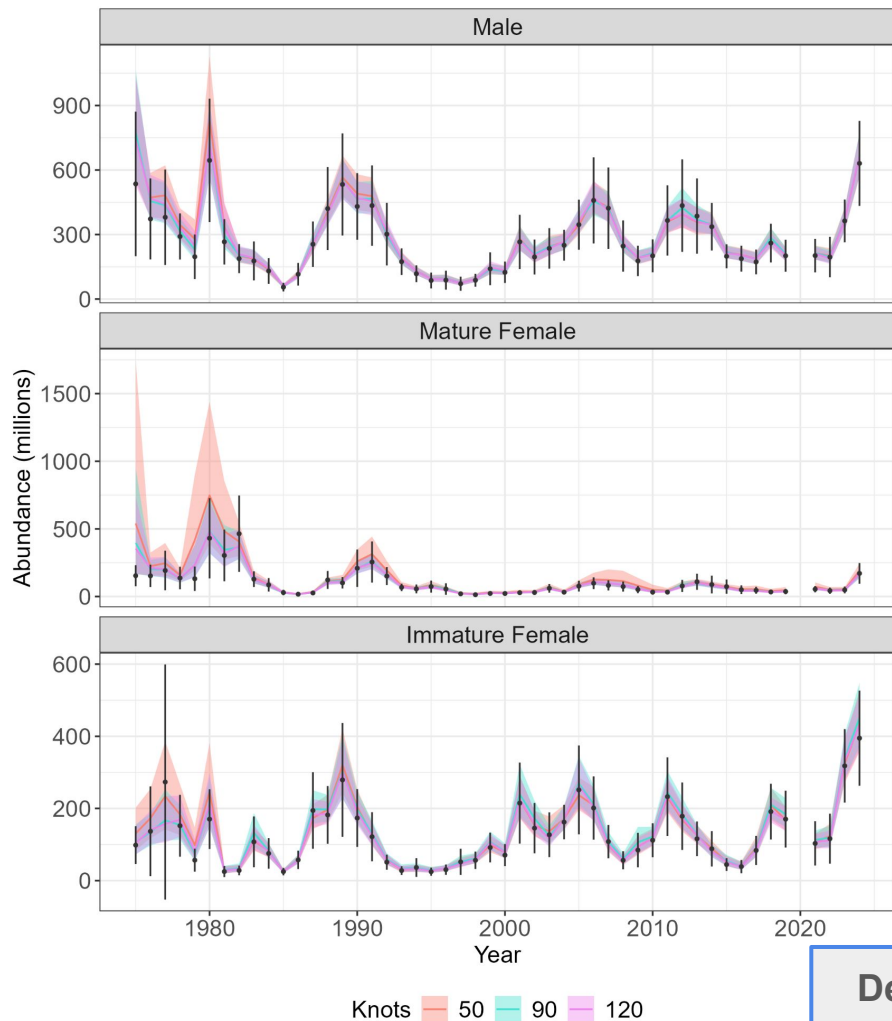
Predicted abundance



EBS predicted mature female abundance



EBS Tanner estimated abundance



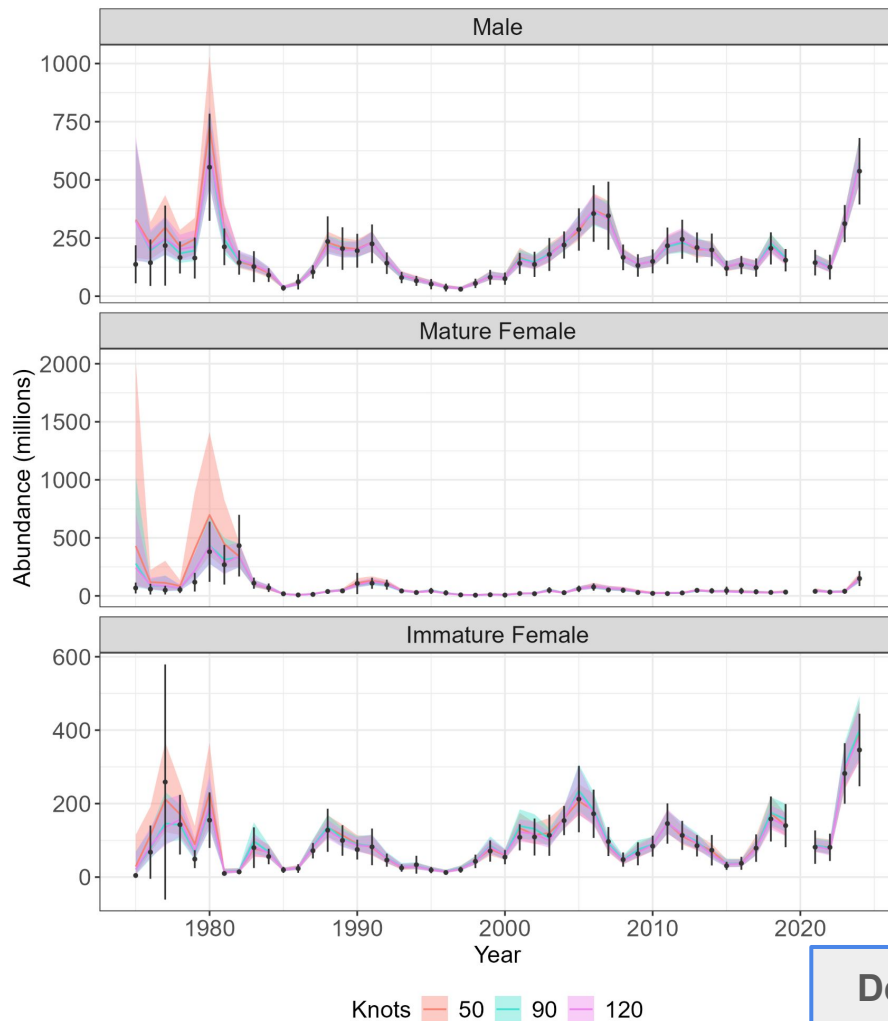
- Close alignment with survey observations (black)
- Greatest differences among knots for <1982 predictions and mature females
- Greater uncertainty for 50-knot models

Delta-gamma



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Tanner West estimated abundance



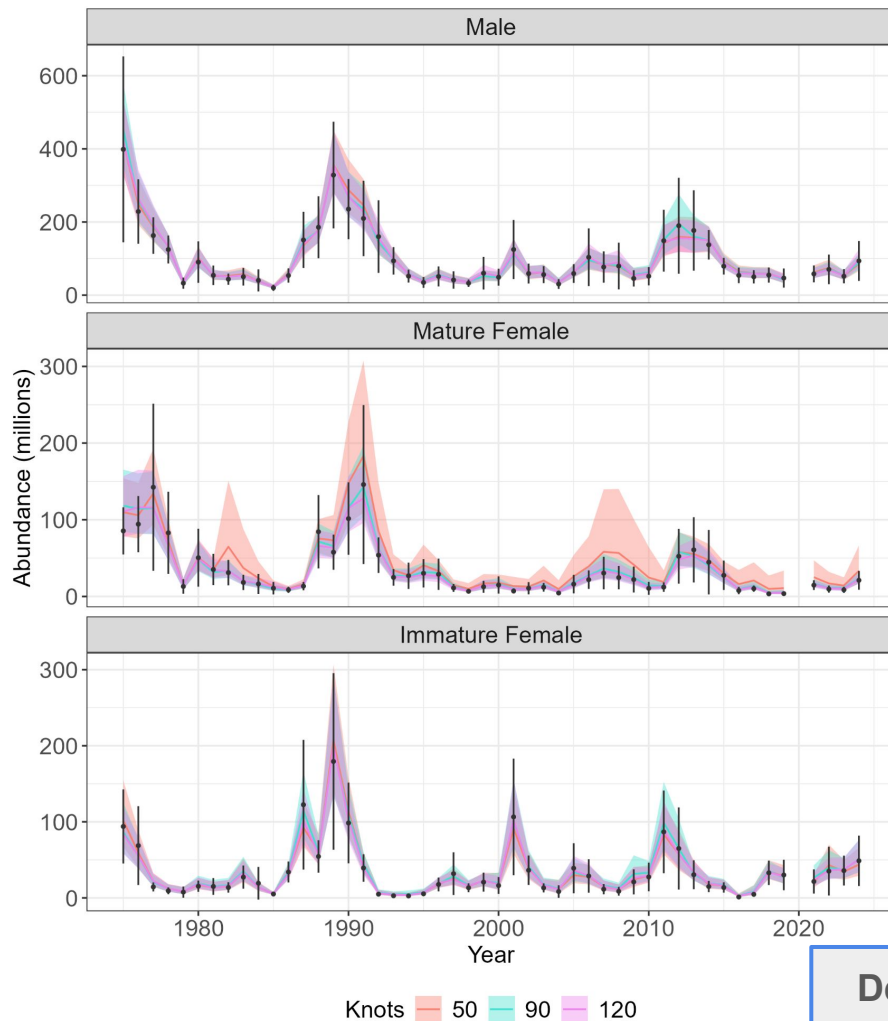
- Close alignment with survey observations (black)
- Greatest differences among knots for <1982 predictions and mature females
- Greater uncertainty for 50-knot models

Delta-gamma



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Tanner East estimated abundance



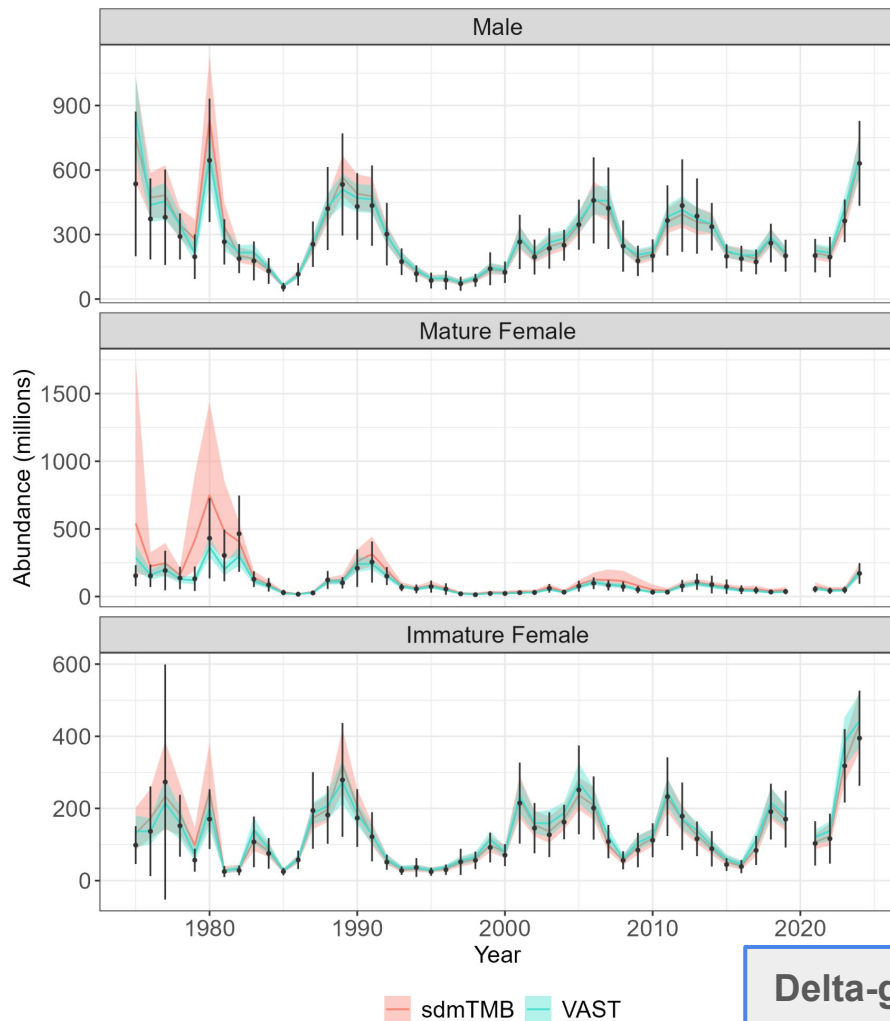
- Close alignment with survey observations (black)
- Greatest differences among knots for <1982 predictions and mature females
- Greater uncertainty for 50-knot models

Delta-gamma



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EBS Tanner estimated abundance



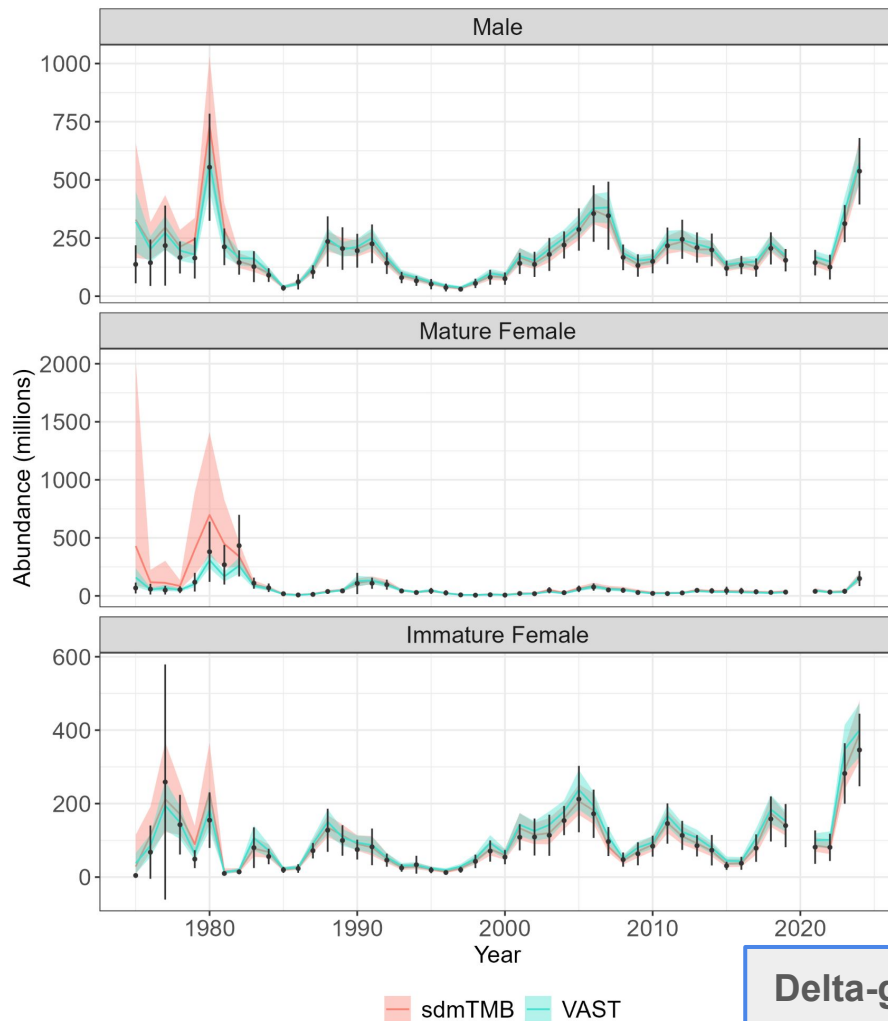
- VAST estimates generally lower
- Greatest differences for <1982 predictions and mature females
- Generally greater uncertainty for sdmTMB predictions

Delta-gamma, 50 knots



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Tanner West estimated abundance



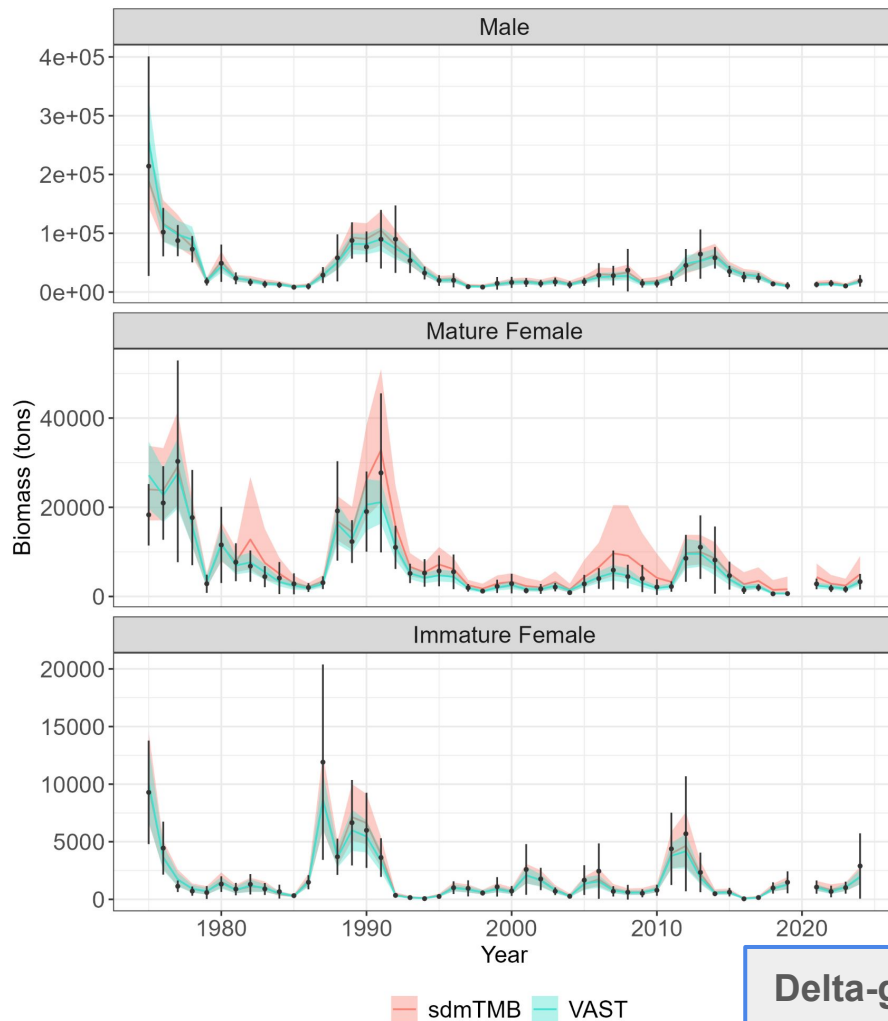
- VAST estimates generally lower
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- Generally greater uncertainty for sdmTMB predictions

Delta-gamma, 50 knots



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Tanner East estimated biomass



- VAST estimates generally lower
- Greatest differences for <1982 predictions and mature females
- Generally greater uncertainty for sdmTMB predictions

Delta-gamma, 50 knots



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Tanner crab take-home

- Delta-gamma using 50 knots 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?

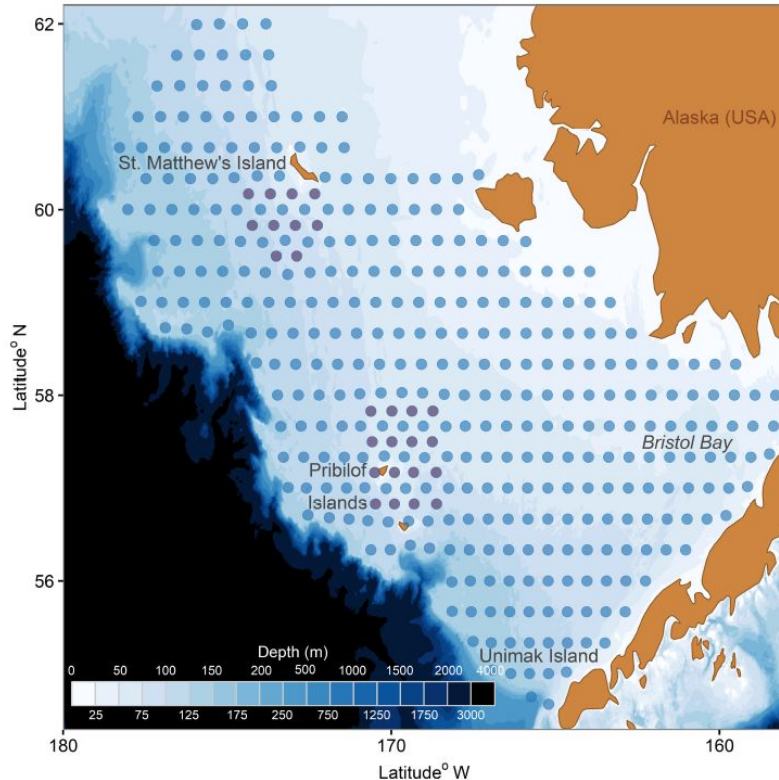


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St. Matthew Island blue king crab



Motivation for developing a model-based biomass index



Source:
DePhilippo et al. (2023)
Front. Mar. Sci.
10:1219283

For SMBKC, EBS trawl survey data set spatial footprint changes over time:

- Corner stations 1983-2023
- No corner stations 2024+

SSC, October 2024:

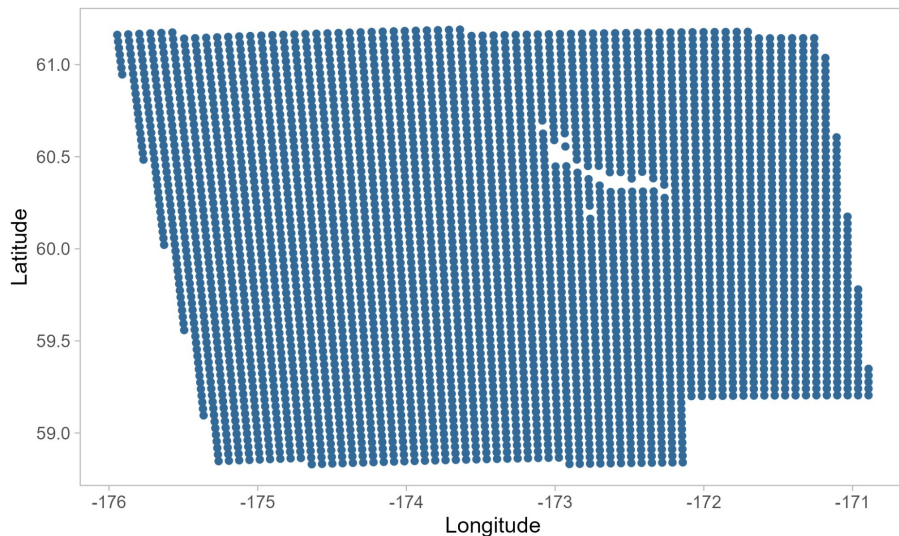
*The biomass estimates are now computed based on a single stratum, instead of high and low-density strata with corner stations. This change has introduced a consistent downward bias, possibly due to the exclusion of the corner stations, or a previous upward bias when they were included. This discrepancy deserves further investigation, highlighting the **potential benefits of model-based estimates that incorporate historical corner station data to address any biases**. For this assessment, using the corner stations prior to 2024 is acceptable, but this issue should be addressed in the next full assessment.*



Model fitting

Model options tested:

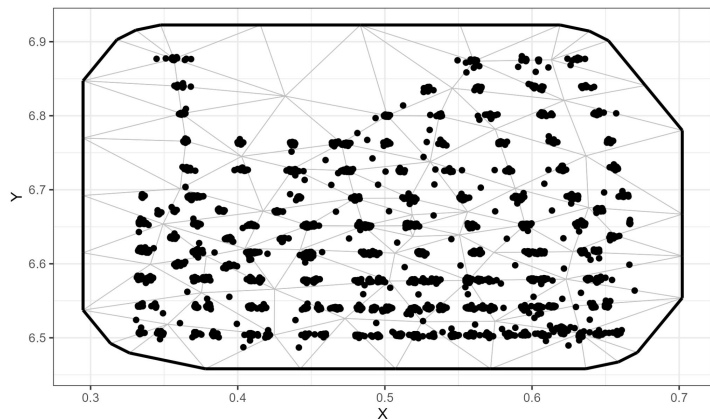
- Spatiotemporal random fields estimation methods: independent and identically distributed (IID), first-order autoregressive (AR1), random walk
- Model family: Tweedie, delta-gamma, delta-lognormal



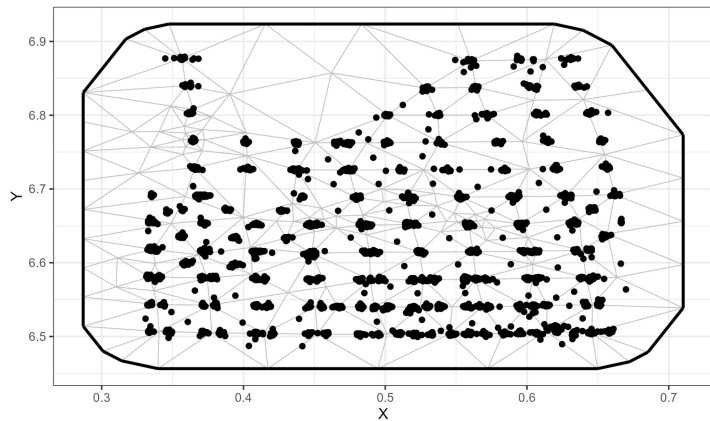
prediction grid: 4 km² resolution, no land



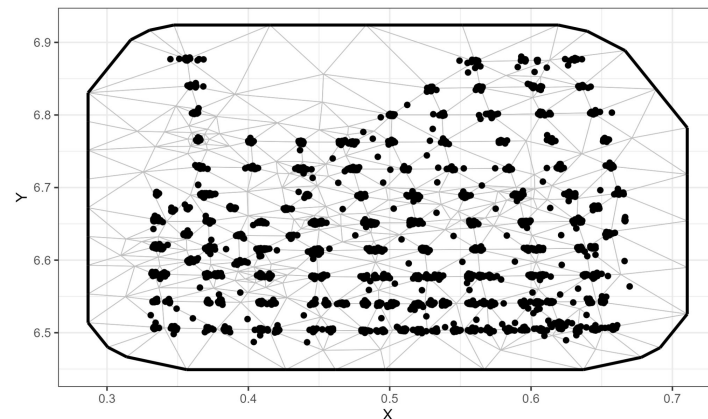
Model mesh



50-knot mesh



90-knot mesh



120-knot mesh



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Model diagnostics

Family	Estimation method	Knots	Log-likelihood	Quantiles	Dispersion	Outliers	Zero inflation
Tweedie	IID	120	-9880.9	0	0	0.6	0.0
Tweedie	IID	90	-9924.0	0	0	0.1	0.6
Tweedie	IID	50	-9732.6				
delta gamma	IID	120					
delta gamma	IID	90					
delta gamma	IID	50					
delta lognormal	IID	120					
delta lognormal	IID	90					
delta lognormal	IID	50					
Tweedie	RW	120	-9646.6	0	0	0.5	0.0
Tweedie	RW	90	-9630.6	0	0	0.5	0.6
Tweedie	RW	50	-9636.0	0	0	0.6	0.7
delta gamma	RW	50					
delta lognormal	RW	50					
Tweedie	AR1	120	-9952.4	0	0	0.8	0.1
Tweedie	AR1	90	-9860.5	0	0	0.4	0.6
Tweedie	AR1	50	-9700.1	0	0	0.4	0.9
delta gamma	AR1	50					
delta lognormal	AR1	50					



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Model diagnostics

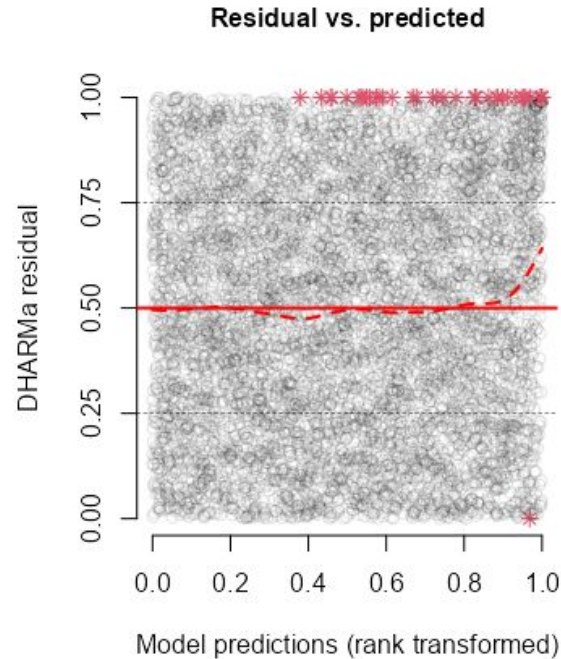
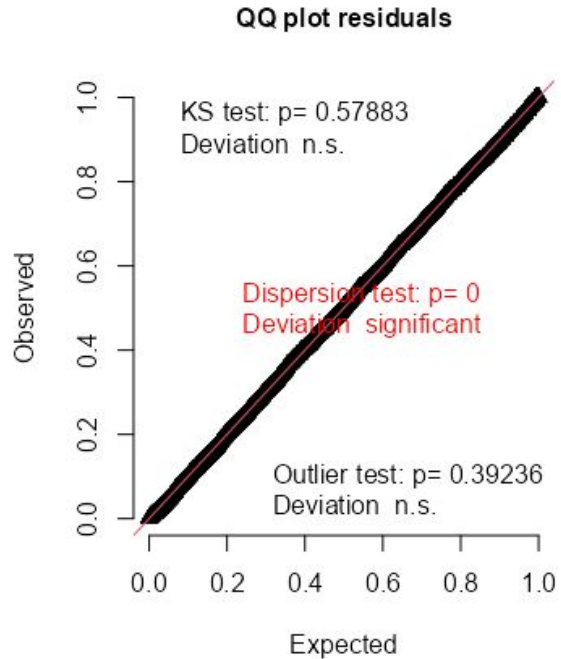
Family	Estimation method	Knots	Log-likelihood	Quantiles	Dispersion	Outliers	Zero inflation
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Tweedie	IID	50	-9732.6				
delta gamma	IID	120					
delta gamma	IID	90					
delta gamma	IID	50					
delta lognormal	IID	120					
delta lognormal	IID	90					
delta lognormal	IID	50					
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Tweedie	RW	50	-9636.0	0	0	0.6	0.7
delta gamma	RW	50					
delta lognormal	RW	50					
Tweedie	AR1	120	-9952.4	0	0	0.8	0.1
Tweedie	AR1	90	-9860.5	0	0	0.4	0.6
Tweedie	AR1	50	-9700.1	0	0	0.4	0.9
delta gamma	AR1	50					
delta lognormal	AR1	50					



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Model diagnostics

DHARMA residual



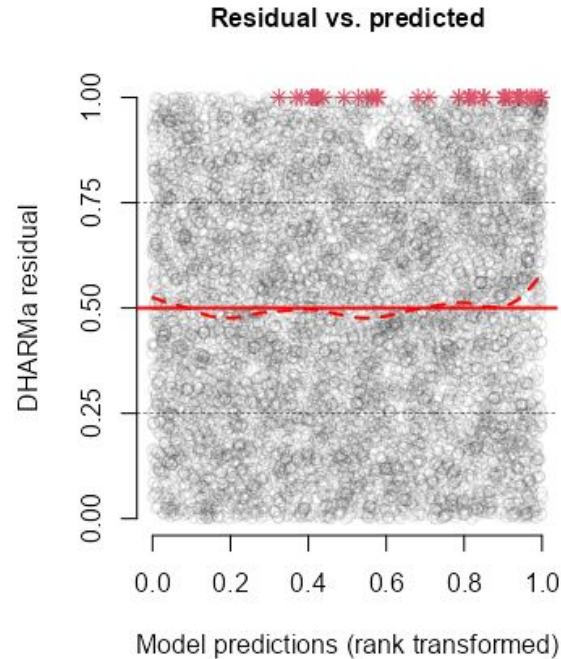
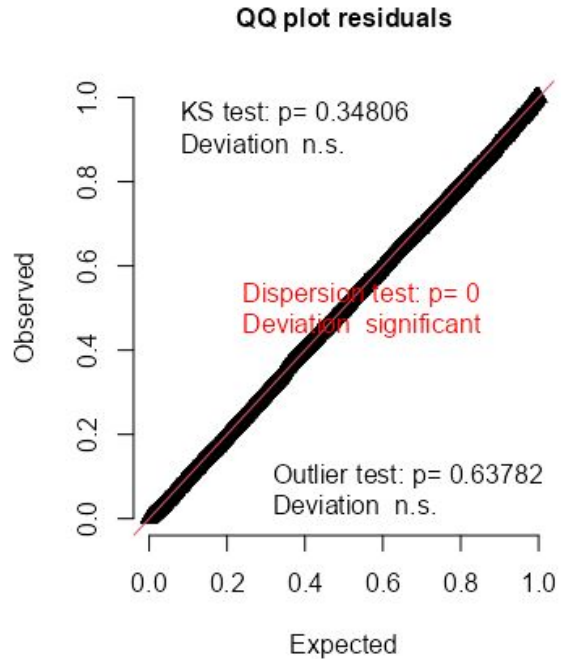
Random walk
Tweedie
90 knots



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Model diagnostics

DHARMA residual



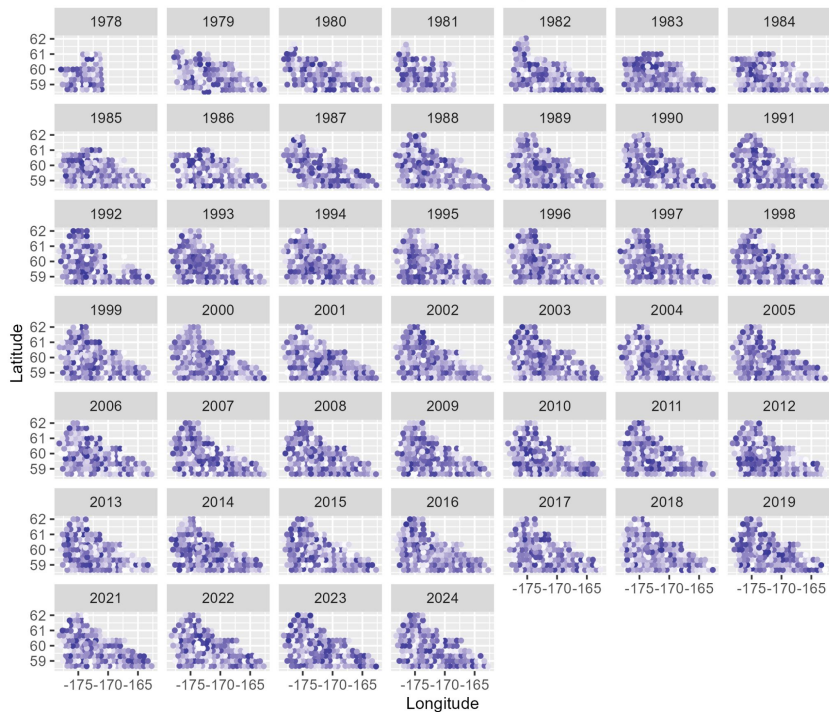
Random walk
Tweedie
50 knots



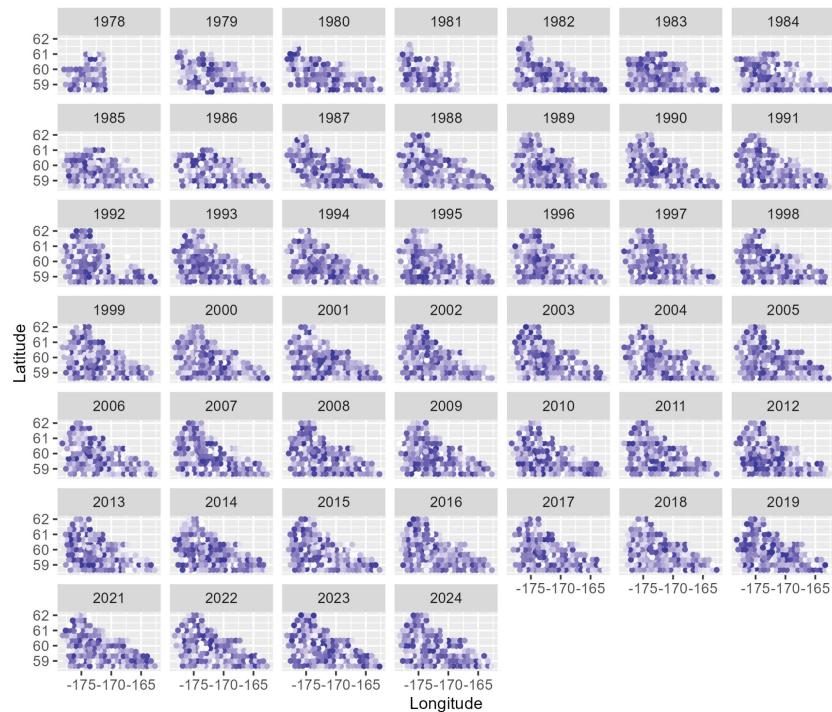
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Model diagnostics

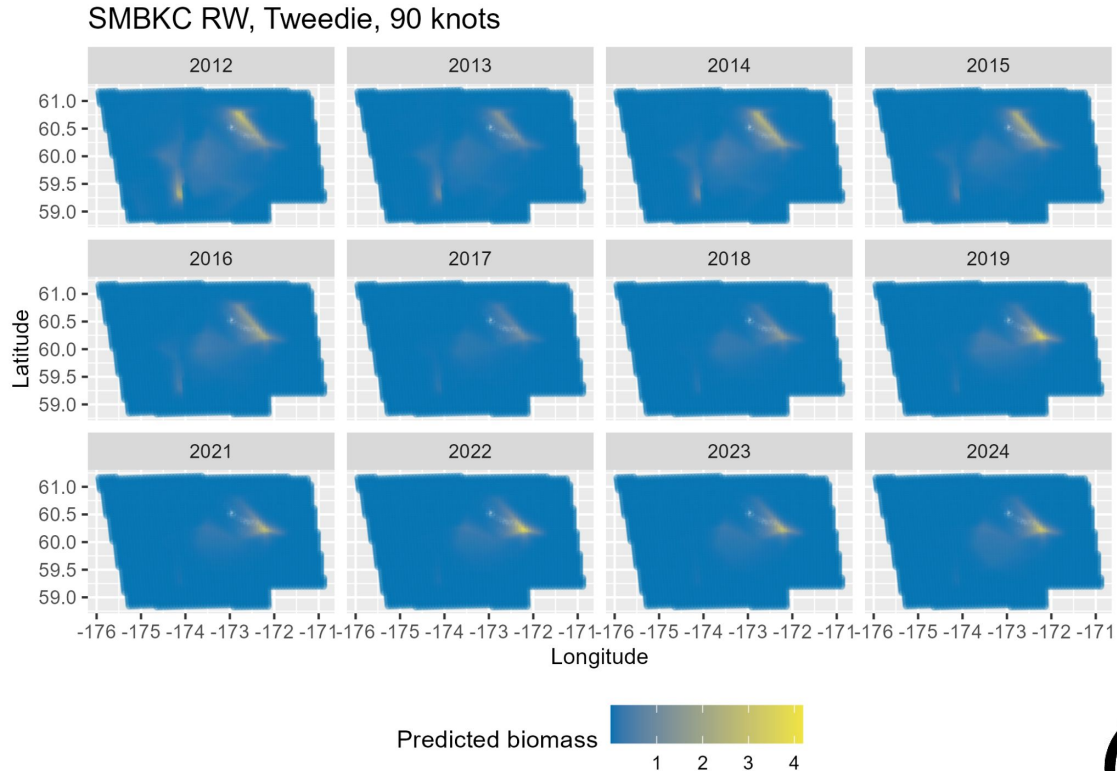
SMBKC random walk Tweedie model residuals (90 knots)



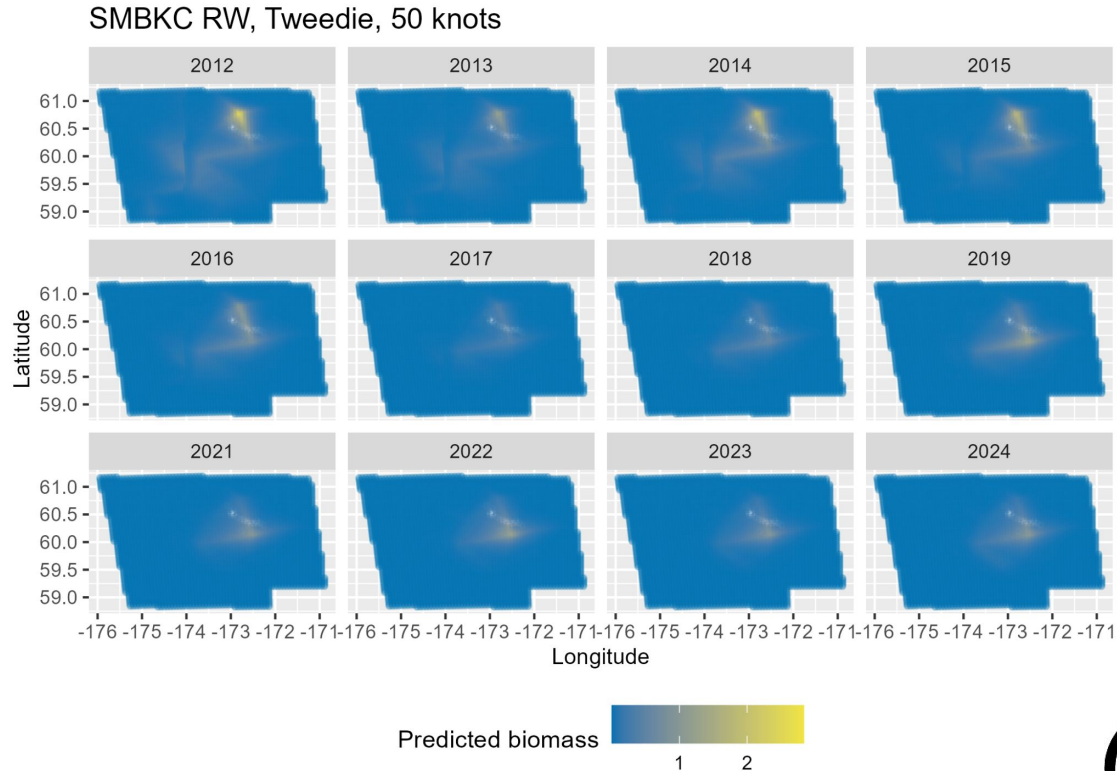
SMBKC random walk Tweedie model residuals (50 knots)



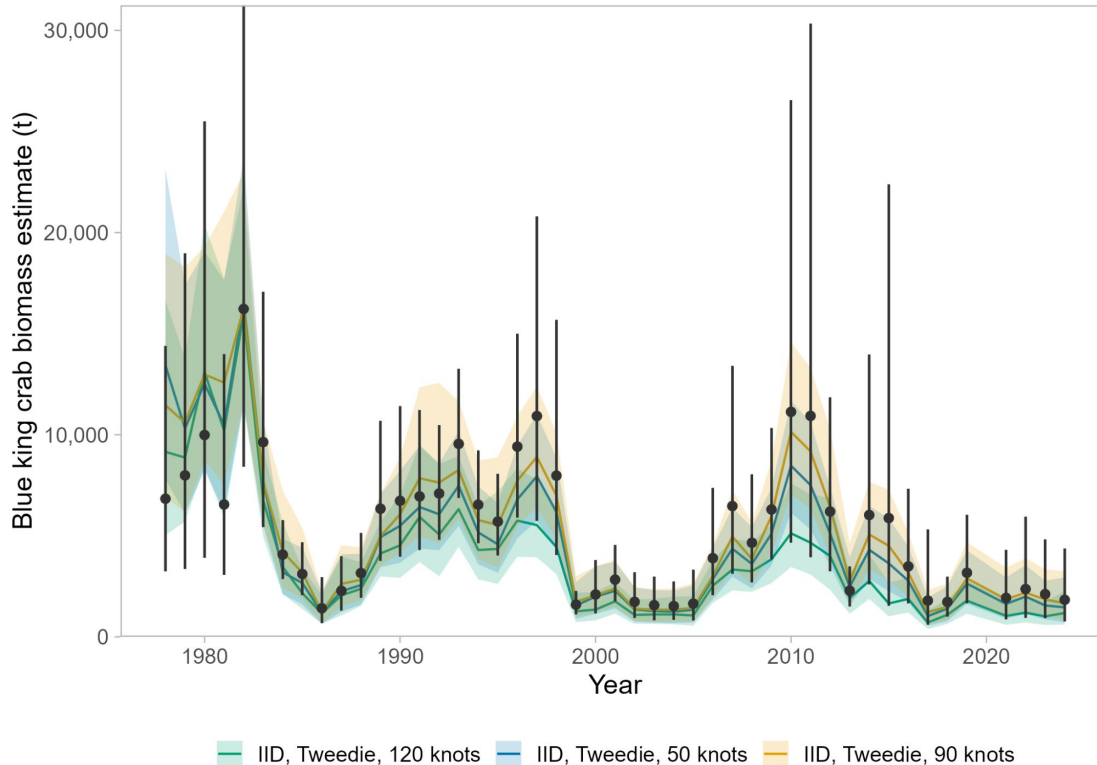
Spatial predictions



Spatial predictions



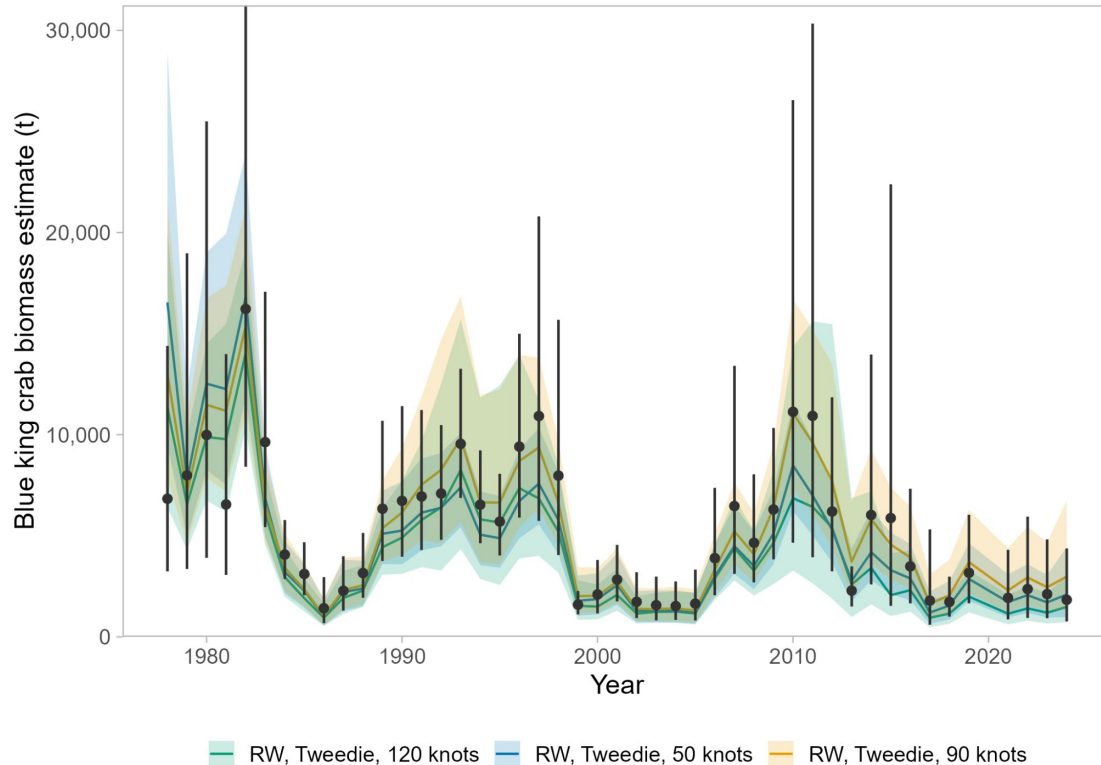
Model-predicted index: IID



- Model fitted with 90-knot mesh predicts highest biomass
- Model fitted with 120-knot mesh predicts lowest biomass
- Model with best predictive skill: 50-knot mesh



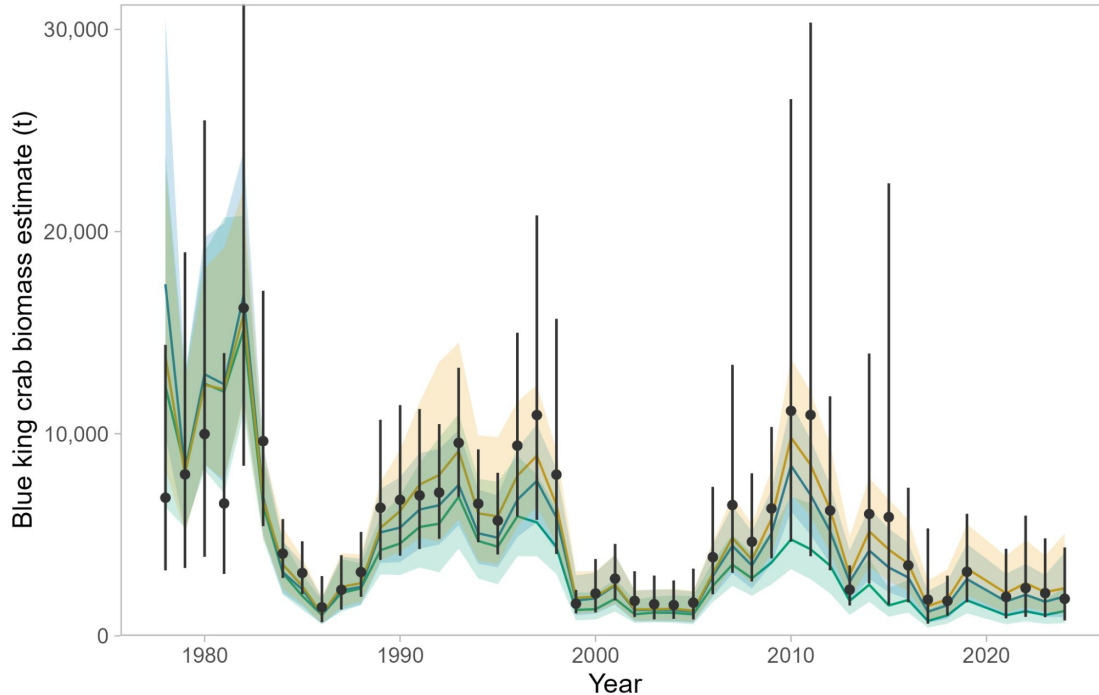
Model-predicted index: random walk



- Model fitted with 90-knot mesh predicts highest biomass
- Model fitted with 120-knot mesh predicts lowest biomass
- Model with best predictive skill: 90-knot mesh



Model-predicted index: AR1

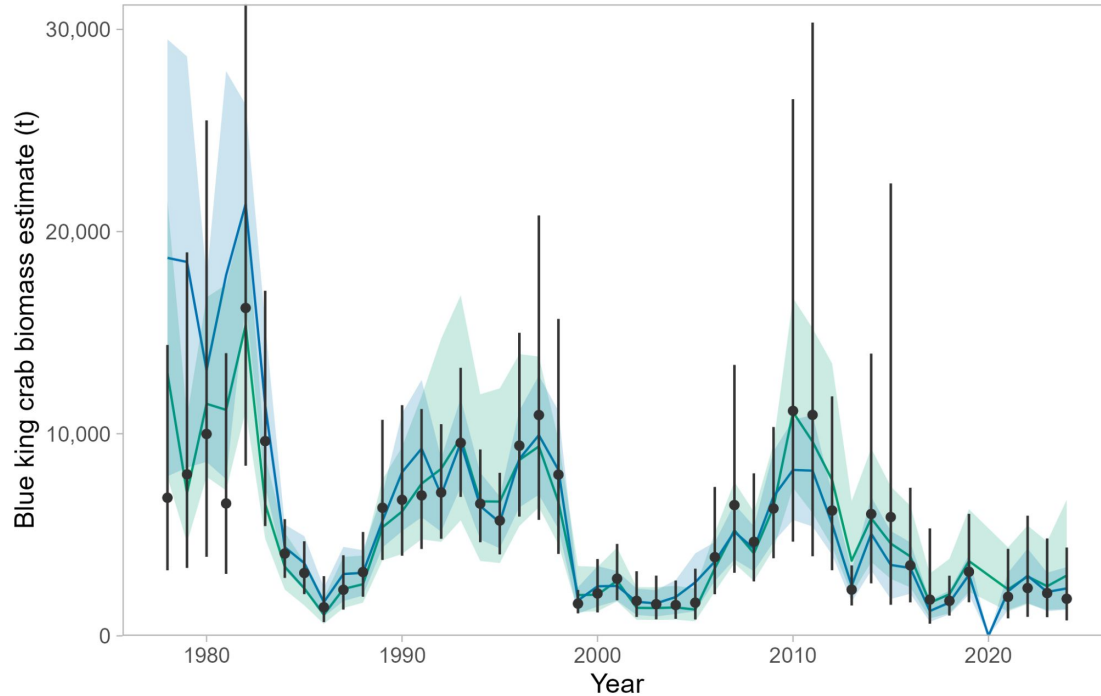


— AR1, Tweedie, 120 knots — AR1, Tweedie, 50 knots — AR1, Tweedie, 90 knots

- Model fitted with 90-knot mesh predicts highest biomass
- Model fitted with 120-knot mesh predicts lowest biomass
- Model with best predictive skill: 50-knot mesh



Comparison with VAST index: 90-knot mesh

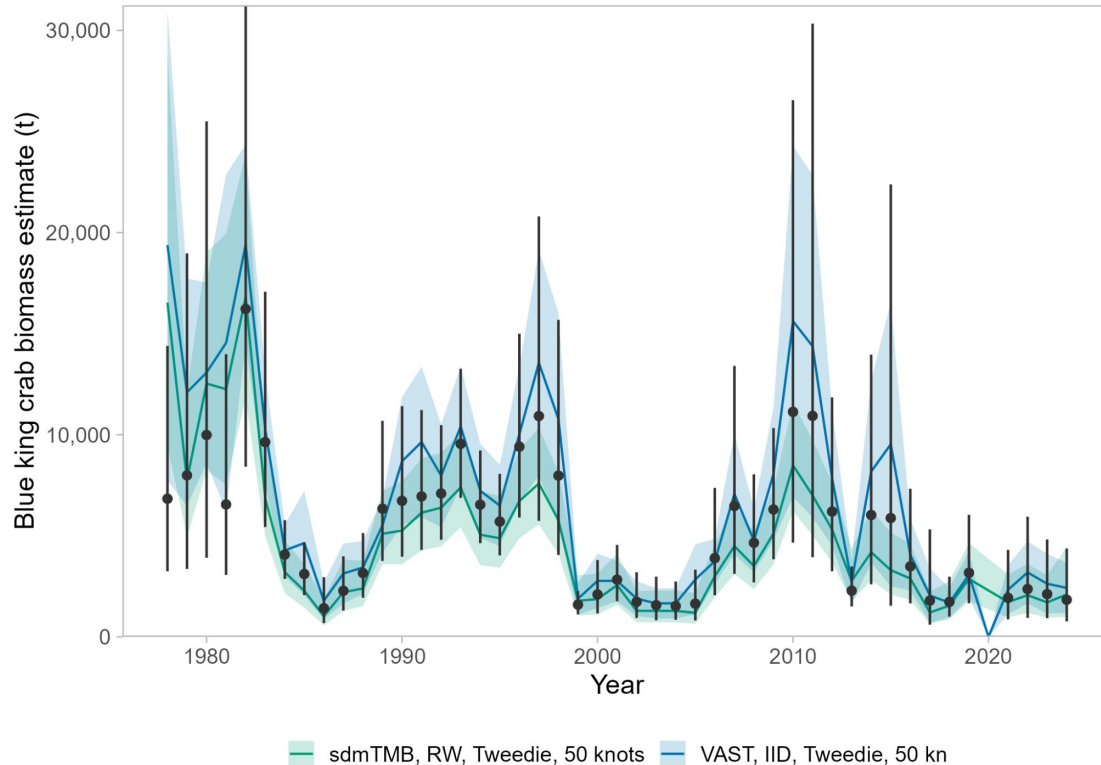


sdmTMB, RW, Tweedie, 90 knots VAST, IID, Tweedie, 90 kn

- Matched comparison with VAST not possible due to lack of VAST models using random walk spatiotemporal random fields estimation



Comparison with VAST index: 50-knot mesh



- Matched comparison with VAST not possible due to lack of VAST models using random walk spatiotemporal random fields estimation



SMBKC recommendations and next steps


- Generate biomass index using the model with best predictive skill (random walk/Tweedie/90-knot mesh)
- Compare GMACS model output with model-based versus design-based trawl survey index
- Investigate appropriate “area swept” for the ADF&G pot survey



Cory Lescher



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A close-up photograph of a Norton Sound red king crab. The crab's carapace is a deep, mottled reddish-brown color, covered in numerous small, raised bumps and spines. Its legs are thick and segmented, showing a similar color pattern with lighter, yellowish-orange areas. The crab is positioned on a light-colored, textured surface, possibly sand or gravel. The lighting is bright, highlighting the texture of the crab's shell and legs.

Norton Sound red king crab

Motivation for developing a model-based abundance index



Norton Sound Economic Development Corporation

NSRKC stock assessment model uses abundance information from three trawl surveys:

- NMFS trawl survey (1976-1991)
- ADF&G trawl survey (1996-2024)
- NMFS NBS trawl survey (2010-2023)

Using model-based abundance estimates for a consistent area (prediction grid) could improve comparability of estimates across the time series

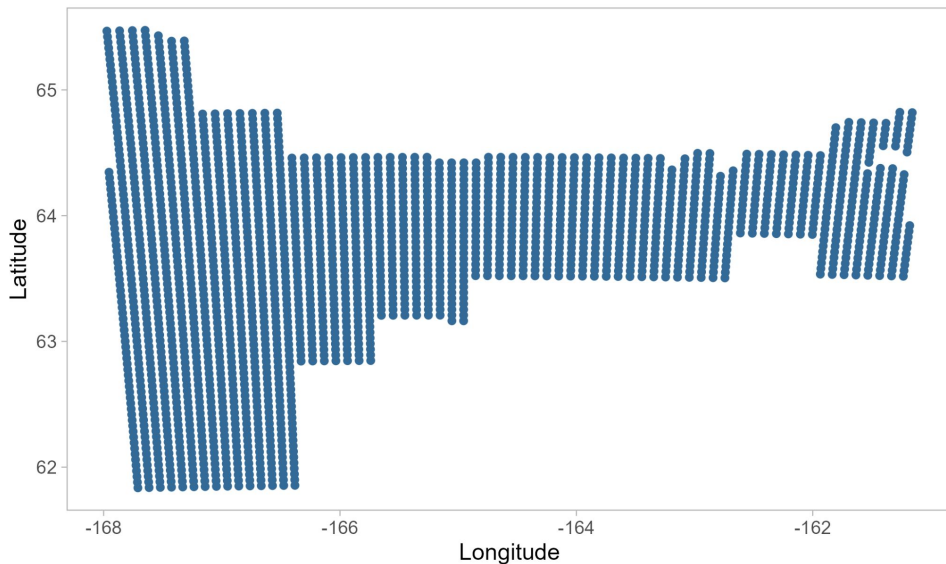
NMFS NBS trawl survey data modeled here



Model fitting

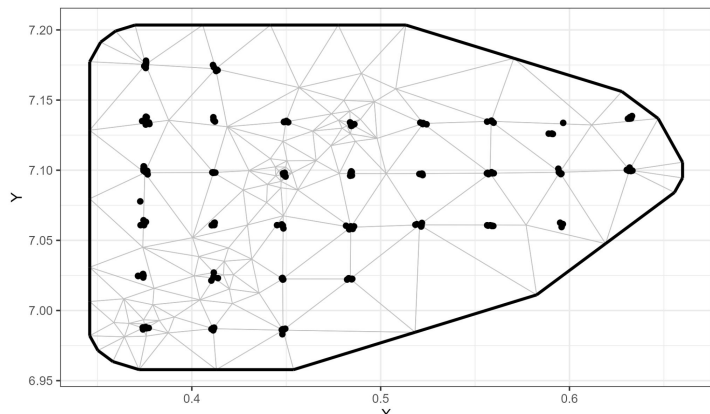
Model options tested:

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- Model family: Tweedie, delta-gamma, delta-lognormal

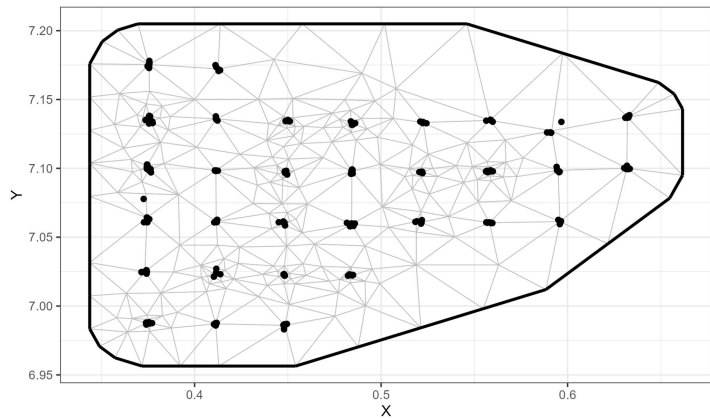


prediction grid: 5 km² resolution, no land

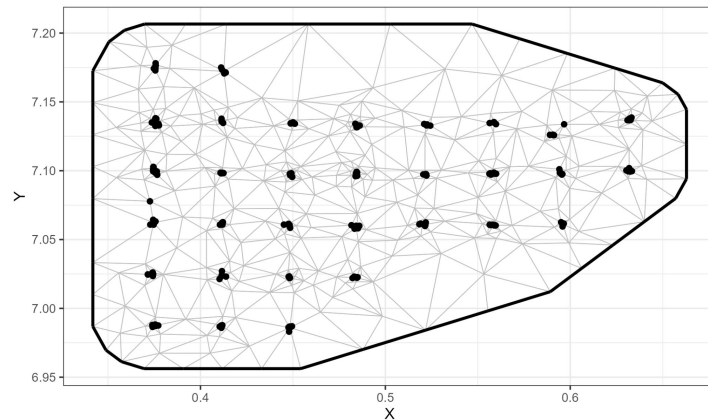
Model mesh



30-knot mesh



50-knot mesh



100-knot mesh



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Model diagnostics

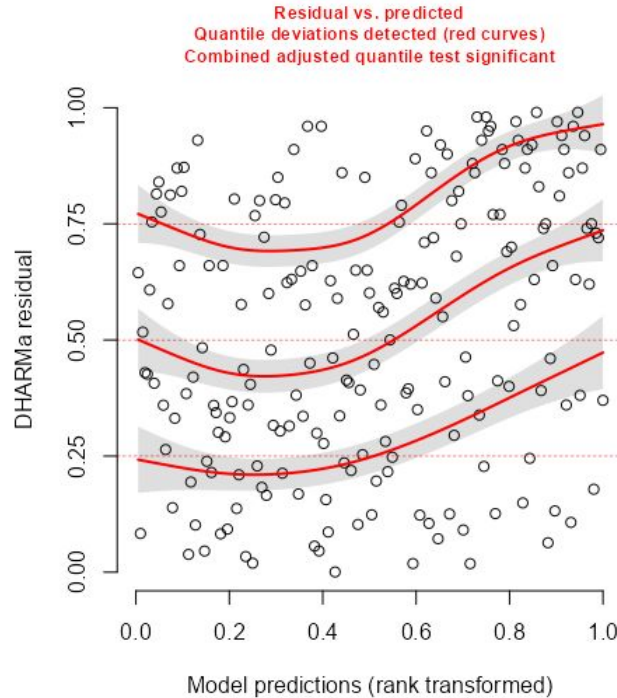
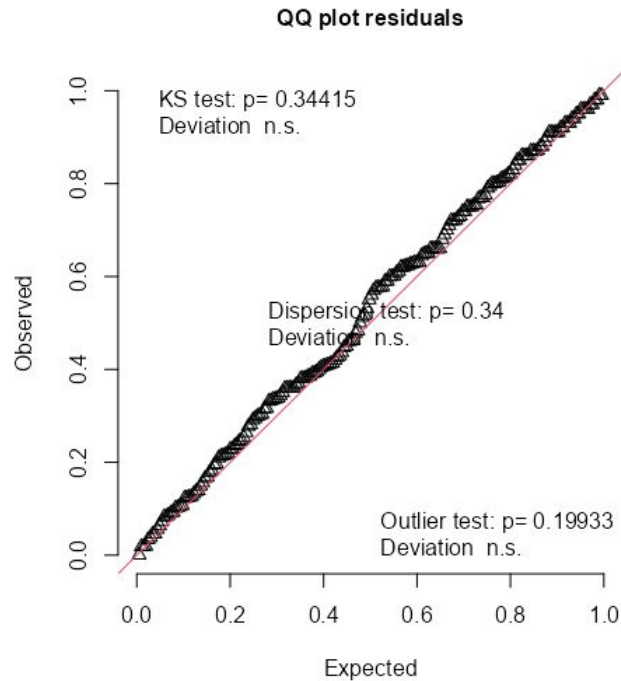
Family	Estimation method	Knots	Log-likelihood	Quantiles	Dispersion	Outliers	Zero inflation
Tweedie	IID	100					
Tweedie	IID	50					
Tweedie	IID	30					
delta gamma	IID	100					
delta gamma	IID	50					
delta gamma	IID	30					
delta lognormal	IID	100					
delta lognormal	IID	50					
delta lognormal	IID	30					
Tweedie	RW	100					
Tweedie	RW	50					
Tweedie	RW	30	-658.1	0.0	0.2	0.6	0.1
delta gamma	RW	100					
delta gamma	RW	50					
delta gamma	RW	30					
delta lognormal	RW	100					
delta lognormal	RW	50					
delta lognormal	RW	30					
Tweedie	AR1	100					
Tweedie	AR1	50					
Tweedie	AR1	30					
delta gamma	AR1	100					
delta gamma	AR1	50					
delta gamma	AR1	30					
delta lognormal	AR1	100					
delta lognormal	AR1	50					
delta lognormal	AR1	30					



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Model diagnostics

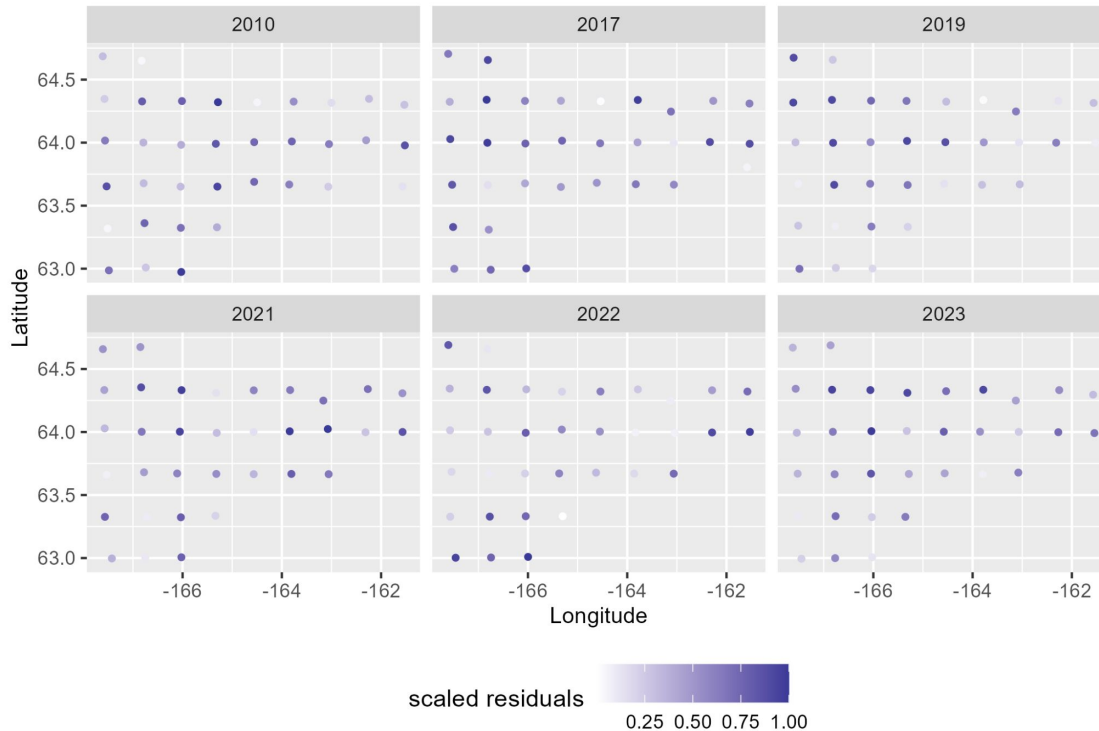
DHARMA residual



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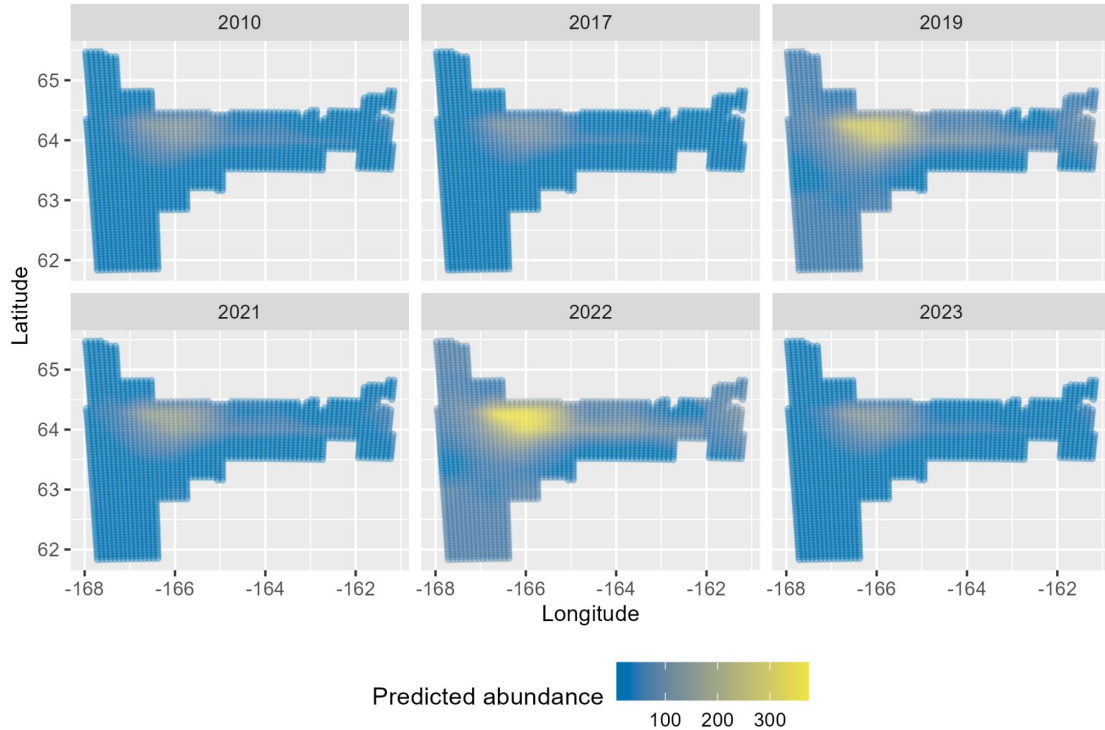
Model diagnostics

NSRKC RW Tweedie model residuals (30 knots)

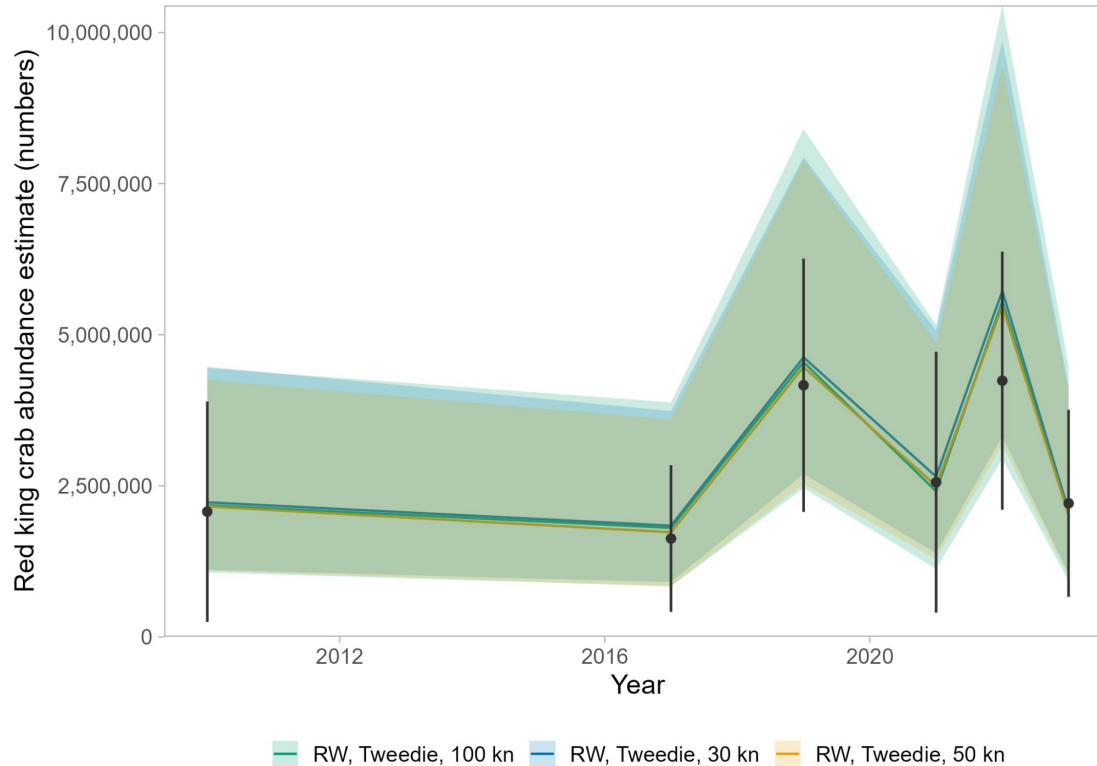


Spatial predictions

NSRKC RW, Tweedie, 30 knots



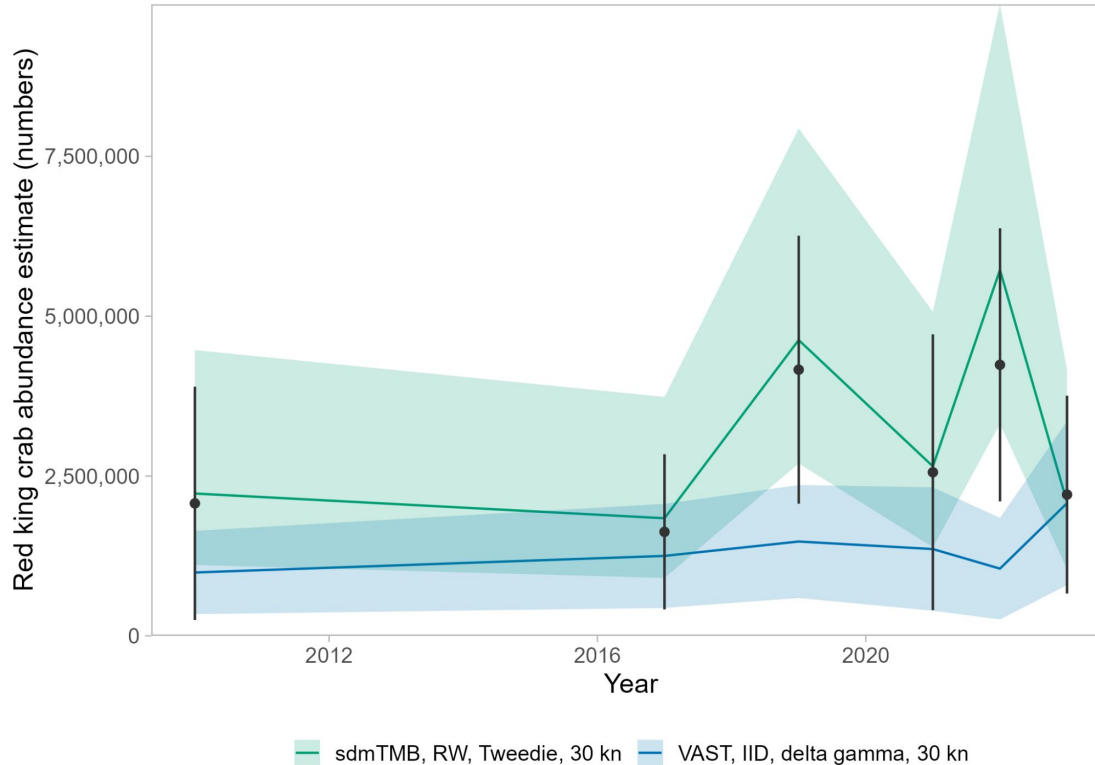
Model-predicted index



- Only model fitted with 30-knot mesh passed sanity checks; others shown for comparison



Comparison with VAST index



- Matched comparison with VAST not possible due to lack of VAST models using random walk spatiotemporal random fields estimation



NSRKC recommendations and next steps

- Generate abundance index using the model with best predictive skill (random walk/Tweedie/30-knot mesh)
- Investigate spatiotemporal models for the two other survey data sets
- Compare GMACS model output with model-based versus design-based survey abundance indices



An underwater photograph of a dark, rocky seabed. A crab is visible on the right side, and there are patches of reddish-brown coral or anemones. The text "Thanks!" is overlaid in the upper center.

Thanks!

emily.ryznar@noaa.gov
caitlin.stern@alaska.gov
jon.richar@noaa.gov

Abundance model diagnostics

Category	Period	Family	Knots	Log-likelihood	Quantiles	Dispersion	Outliers	Zero-inflation
Immature Female	<1982	Delta-gamma	90	-6371.5	0.0	0.0	0.5	0.5
Immature Female	<1982	Tweedie	90	-6475.4	0.0	0.0	0.0	0.1
Immature Female	<1982	Tweedie	120	-6666.0	0.1	0.0	0.4	0.2
Immature Female	<1982	Delta-gamma	50	-6716.3	0.0	0.2	0.2	0.0
Immature Female	<1982	Tweedie	50	-6850.9	0.1	0.0	0.1	0.1
Immature Female	<1982	Delta-gamma	120	-6907.8	0.0	0.0	0.1	0.1
Immature Female	>=1982	Delta-gamma	50	-53281.6	0.0	0.1	0.0	0.0
Immature Female	>=1982	Tweedie	50	-53380.1	0.0	0.0	0.0	0.0
Immature Female	>=1982	Tweedie	90	-53543.3	0.0	0.0	0.0	0.0
Immature Female	>=1982	Delta-gamma	90	-53553.8	0.0	0.2	0.0	0.0
Immature Female	>=1982	Tweedie	120	-53722.7	0.0	0.0	0.0	0.0
Immature Female	>=1982	Delta-gamma	120	-53852.8	0.0	0.7	0.0	0.0
Male	<1982	Delta-gamma	50	-9256.2	0.4	0.5	0.1	0.4
Male	<1982	Tweedie	90	-9339.9	0.0	0.0	0.0	0.1
Male	<1982	Delta-gamma	90	-9349.7	0.0	0.1	0.5	0.3
Male	<1982	Tweedie	120	-9397.7	0.0	0.0	0.0	0.0
Male	<1982	Delta-gamma	120	-9398.7	0.1	0.5	0.4	0.1
Male	<1982	Tweedie	50	-9540.7	0.0	0.0	0.0	0.0
Male	>=1982	Delta-gamma	50	-76006.3	0.0	0.1	0.0	0.0
Male	>=1982	Tweedie	50	-76072.9	0.0	0.0	0.0	0.0
Male	>=1982	Tweedie	90	-76229.4	0.0	0.0	0.0	0.0
Male	>=1982	Delta-gamma	90	-76277.7	0.0	0.1	0.0	0.0
Male	>=1982	Tweedie	120	-76318.2	0.0	0.0	0.0	0.0
Male	>=1982	Delta-gamma	120	-76509.5	0.0	0.1	0.0	0.0
Mature Female	<1982	Tweedie	90	-6089.8	0.1	0.4	0.1	0.0
Mature Female	<1982	Delta-gamma	90	-6097.3	0.0	0.8	0.5	0.6
Mature Female	<1982	Delta-gamma	50	-6097.4	0.0	0.4	0.0	0.0
Mature Female	<1982	Delta-gamma	120	-6108.3	0.2	0.3	0.1	0.0
Mature Female	<1982	Tweedie	120	-6132.7	0.0	0.0	0.8	0.0
Mature Female	<1982	Tweedie	50	-6189.4	0.1	0.0	0.0	0.0
Mature Female	>=1982	Tweedie	50	-43560.9	0.0	0.0	0.0	0.0
Mature Female	>=1982	Delta-gamma	50	-43625.4	0.0	0.0	0.0	0.0
Mature Female	>=1982	Delta-gamma	90	-43803.8	0.0	0.0	0.0	0.0
Mature Female	>=1982	Delta-gamma	120	-43943.3	0.0	0.0	0.0	0.0
Mature Female	>=1982	Tweedie	90	-43837.0	0.0	0.0	0.0	0.0
Mature Female	>=1982	Tweedie	120	-44059.6	0.0	0.0	0.0	0.0



Biomass model diagnostics

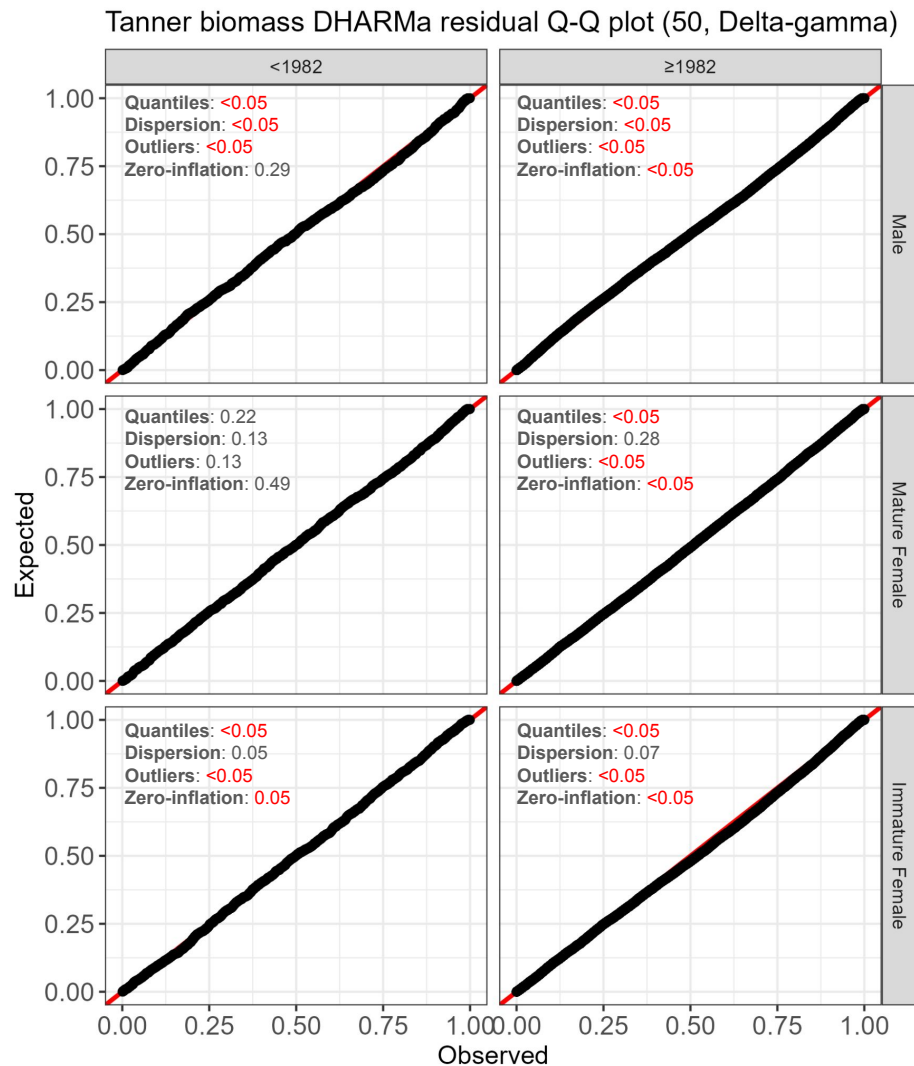
Category	Period	Family	Knots	Log-likelihood	Quantiles	Dispersion	Outliers	Zero-inflation
Immature Female	<1982	Tweedie	90	-6356.8	0.2	0.0	1.0	0.0
Immature Female	<1982	Delta-gamma	90	-6514.3	0.1	0.3	0.4	0.1
Immature Female	<1982	Delta-gamma	120	-6630.5	0.0	0.1	0.9	0.3
Immature Female	<1982	Tweedie	120	-6823.7	0.1	0.1	0.7	0.8
Immature Female	<1982	Delta-gamma	50	-6874.7	0.0	0.0	0.0	0.0
Immature Female	<1982	Tweedie	50	-7246.5	0.0	0.0	0.2	0.3
Immature Female	>=1982	Tweedie	50	-53292.8	0.0	0.0	0.0	0.0
Immature Female	>=1982	Delta-gamma	50	-53303.1	0.0	0.1	0.0	0.0
Immature Female	>=1982	Tweedie	90	-53587.3	0.0	0.0	0.0	0.0
Immature Female	>=1982	Delta-gamma	120	-53639.8	0.0	1.0	0.0	0.0
Immature Female	>=1982	Tweedie	120	-53652.8	0.0	0.0	0.0	0.0
Immature Female	>=1982	Delta-gamma	90	-53652.9	0.0	0.9	0.0	0.0
Male	<1982	Delta-gamma	50	-9275.5	0.0	0.0	0.0	0.3
Male	<1982	Tweedie	90	-9295.3	0.0	0.0	0.1	0.3
Male	<1982	Tweedie	50	-9309.6	0.0	0.0	0.0	0.1
Male	<1982	Delta-gamma	120	-9343.0	0.0	0.0	0.1	0.7
Male	<1982	Delta-gamma	90	-9349.5	0.0	0.0	0.4	0.0
Male	<1982	Tweedie	120	-9422.2	0.0	0.0	0.5	0.6
Male	>=1982	Delta-gamma	50	-75992.4	0.0	0.0	0.0	0.0
Male	>=1982	Tweedie	50	-76031.1	0.0	0.0	0.0	0.0
Male	>=1982	Delta-gamma	90	-76307.0	0.0	0.0	0.0	0.0
Male	>=1982	Tweedie	120	-76345.7	0.0	0.0	0.0	0.0
Male	>=1982	Delta-gamma	120	-76382.0	0.0	0.0	0.0	0.0
Male	>=1982	Tweedie	90	-76489.4	0.0	0.0	0.0	0.0
Mature Female	<1982	Tweedie	50	-6101.9	0.2	0.0	0.0	0.0
Mature Female	<1982	Delta-gamma	50	-6108.2	0.2	0.1	0.1	0.5
Mature Female	<1982	Delta-gamma	120	-6108.8	0.0	0.4	0.4	0.4
Mature Female	<1982	Delta-gamma	90	-6134.0	0.0	0.3	0.4	0.6
Mature Female	<1982	Tweedie	90	-6135.2	0.2	0.9	0.5	0.0
Mature Female	<1982	Tweedie	120	-6159.8	0.2	0.1	0.0	0.0
Mature Female	>=1982	Tweedie	50	-43735.8	0.0	0.0	0.0	0.0
Mature Female	>=1982	Delta-gamma	90	-43746.8	0.0	0.1	0.0	0.0
Mature Female	>=1982	Tweedie	90	-43818.5	0.0	0.0	0.0	0.0
Mature Female	>=1982	Delta-gamma	50	-43898.4	0.0	0.3	0.0	0.0
Mature Female	>=1982	Delta-gamma	120	-44076.4	0.0	0.0	0.0	0.0
Mature Female	>=1982	Tweedie	120	-44166.4	0.0	0.0	0.0	0.0



Biomass model diagnostics

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

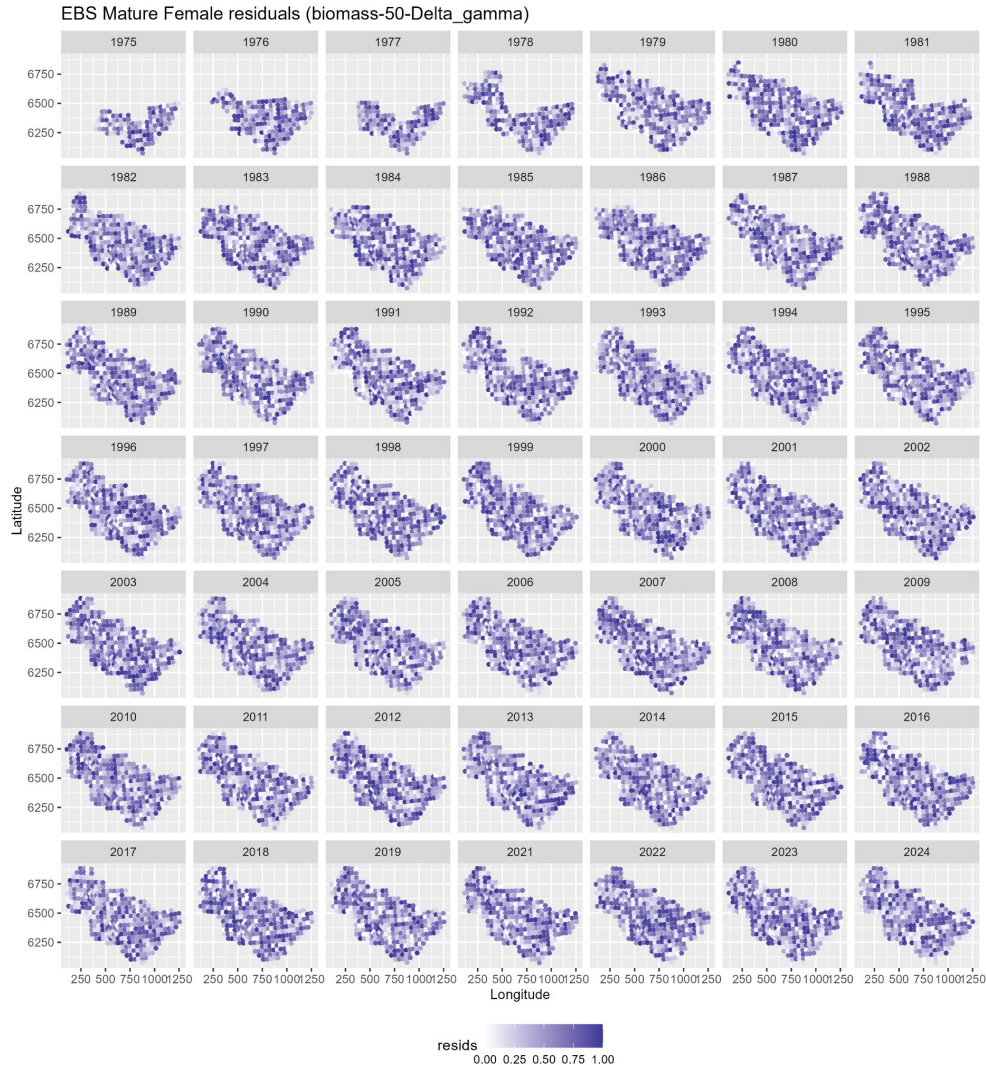
Delta-gamma, 50 knots



Biomass model diagnostics

- No evidence of spatiotemporal autocorrelation of DHARMA residuals across categories

Delta-gamma, 50 knots



Predicted biomass

Delta-gamma, 50 knots

