Acoustic-Trawl Survey Uncertainty

NPFMC Groundfish Plan Team Meeting, 22 September 2023

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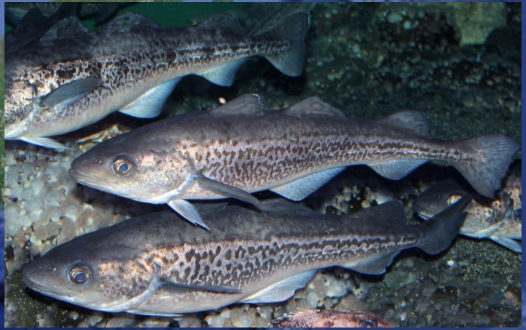
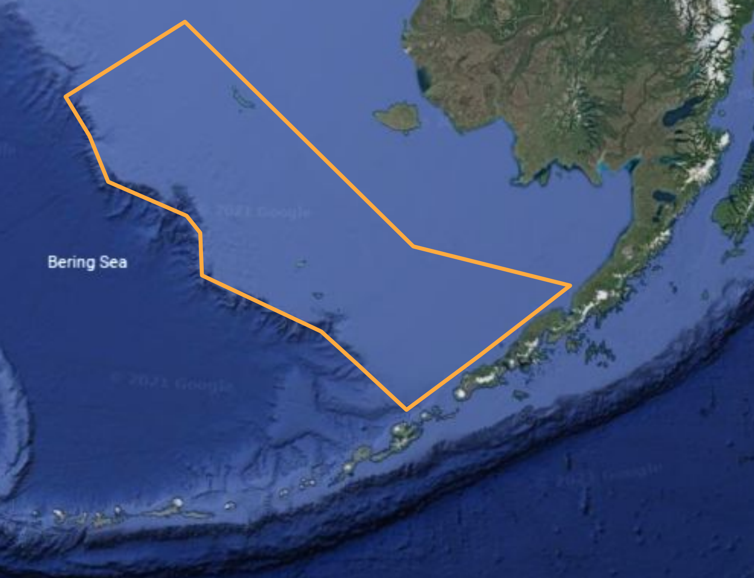
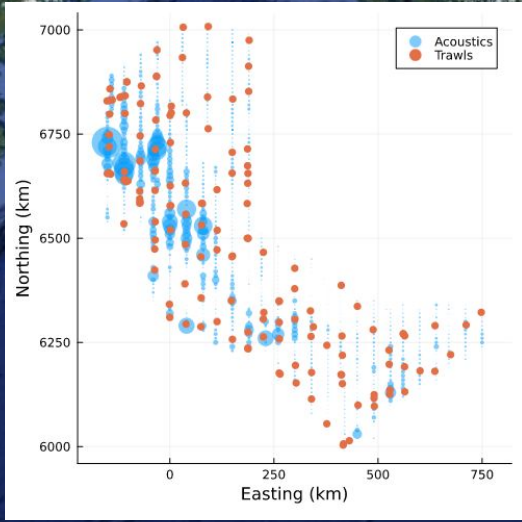
Acoustic-trawl surveys of Alaska pollock in EBS





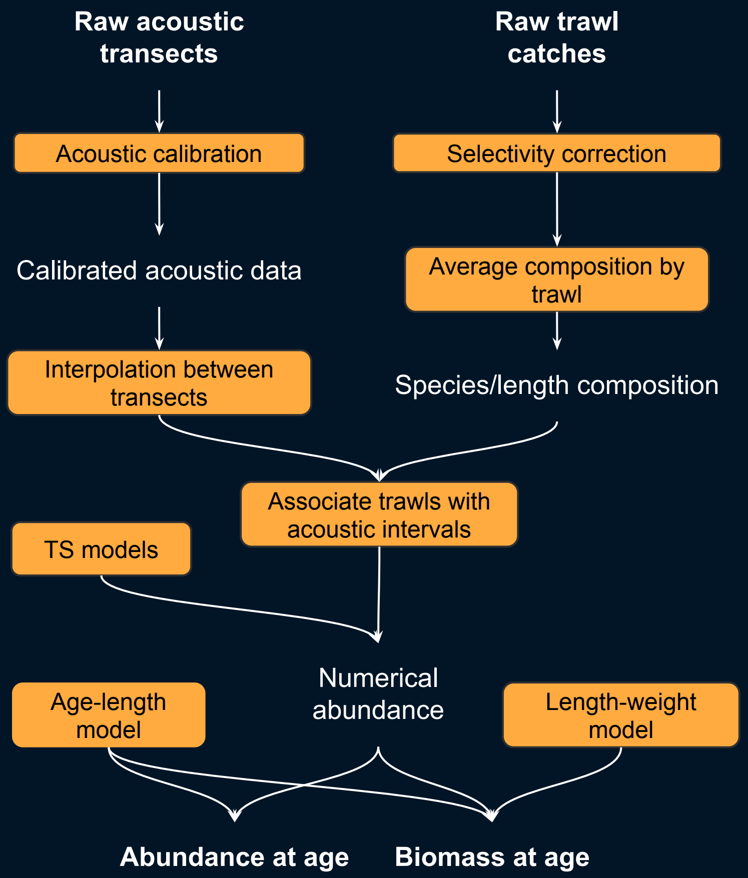


- Currently, estimate relative error using 1D geostatistics
- Typical coefficient of variation: 4-8%
- Seems too precise, so inflated to 20% for stock assessment
- What is it really?

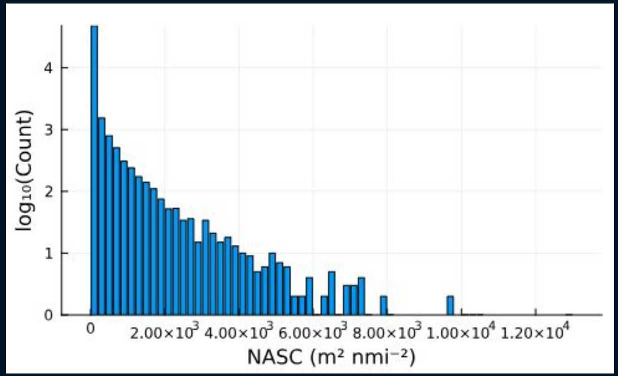
Estimating uncertainty is a challenge for acoustic-trawl surveys

- A few more-comprehensive estimates elsewhere:
    - Newfoundland cod (Rose et al. 1999)
    - Antarctic krill (Demer 2004)
    - New Zealand hoki (O’Driscoll 2004)
    - Norwegian herring (Løland et al. 2007)
- …And for pollock at AFSC:
    - 2007: Walline, “Geostatistical simulations of EBS walleye pollock…”
    - 2016: Woillez et al., “Evaluating total uncertainty…”
    - 2020-present: myself

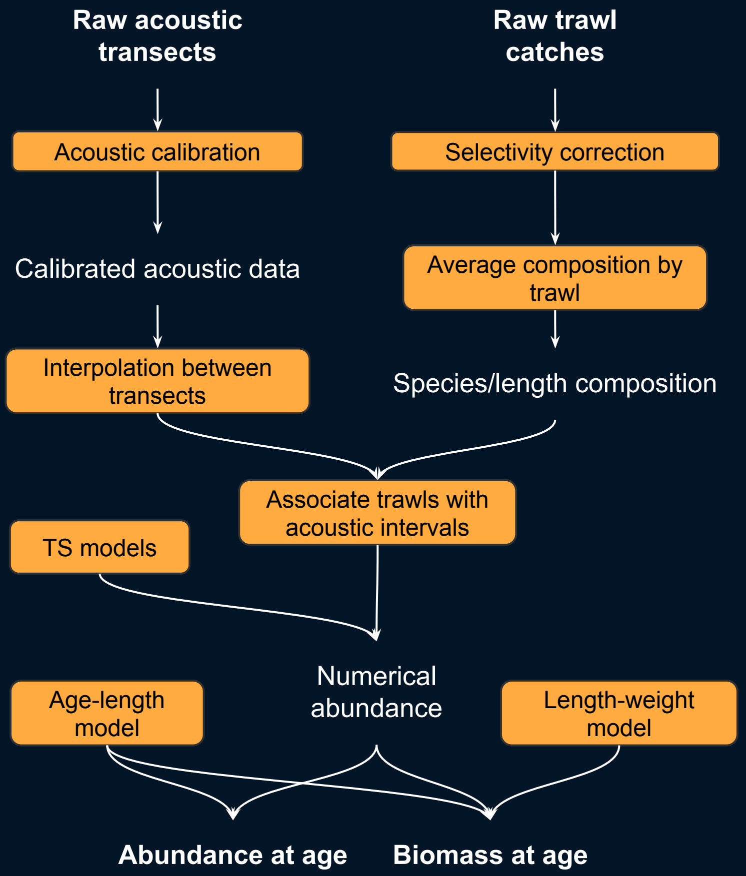
Why this is a hard problem



- Multiple steps between acoustics/ trawls and numbers/biomass
- Combining two datasets with:
  - Unique uncertainties/biases
  - Very different spatial scales
- Acoustic data are *extremely* non-Gaussian



Parametric and non-parametric bootstrapping



- Follows attempts at integrated Bayesian modeling
- Resampling/simulation for each step of calculations
- Mirrors standard MACE survey analysis
- Computationally fast and stable
  - Can investigate contributions of individual sources of uncertainty

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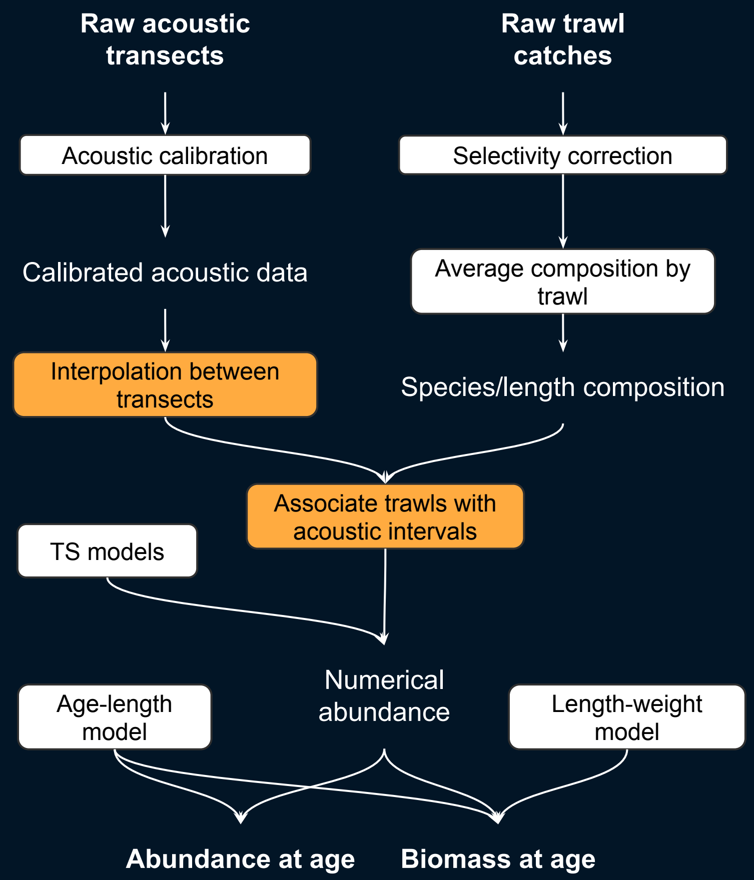

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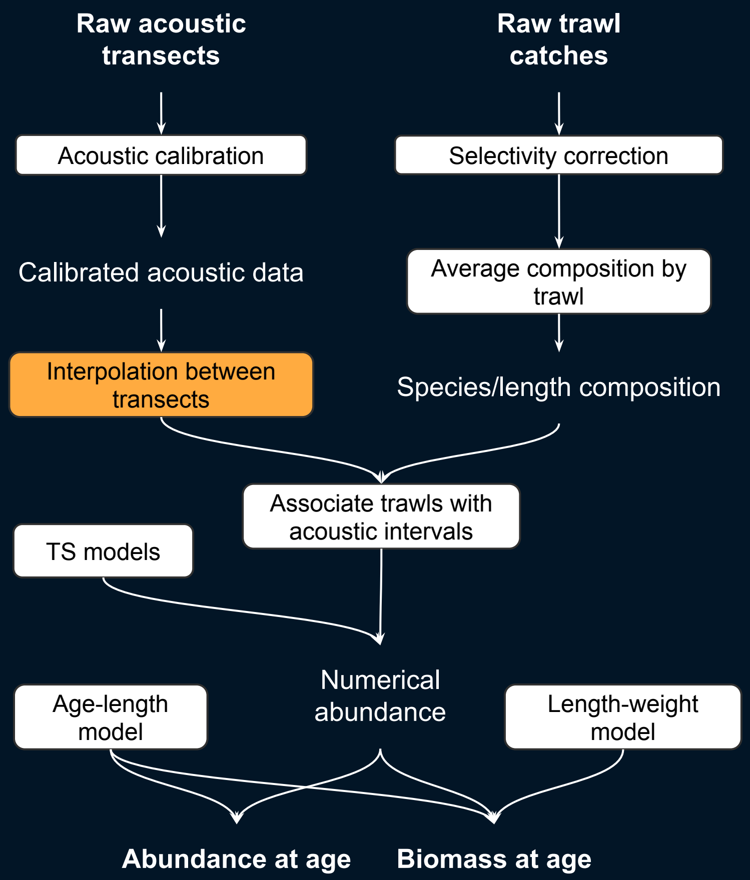

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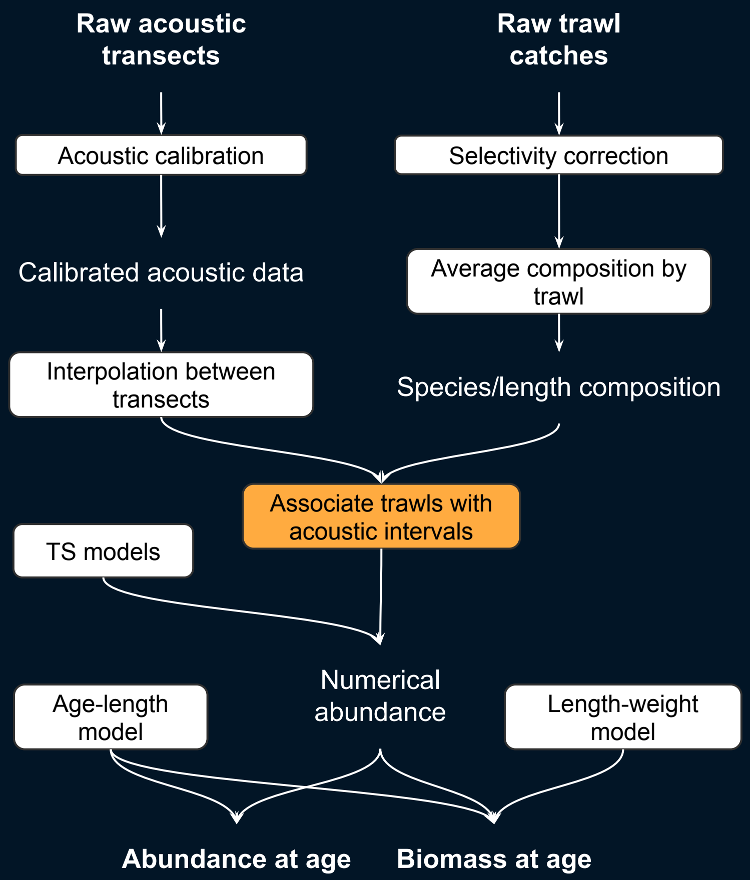

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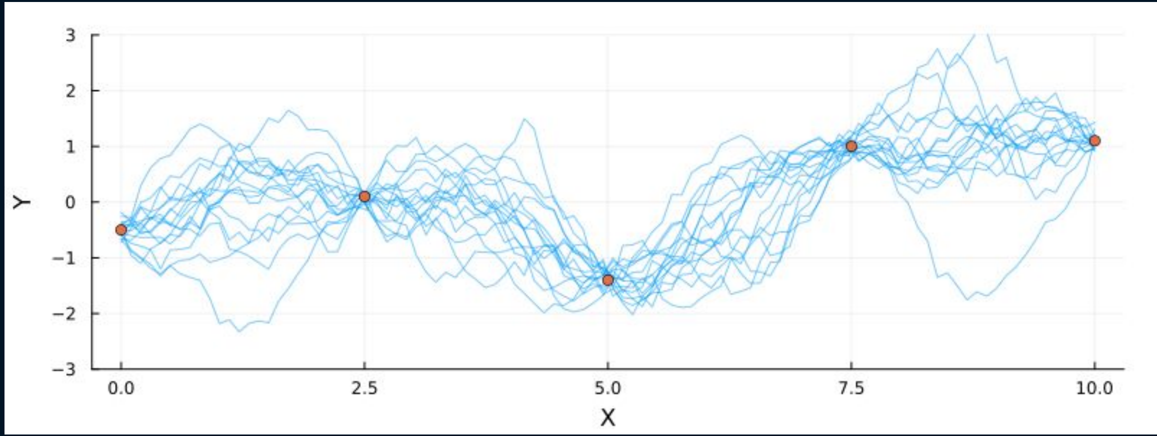
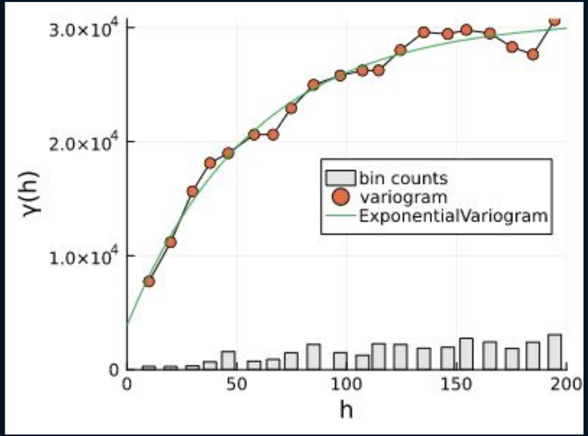
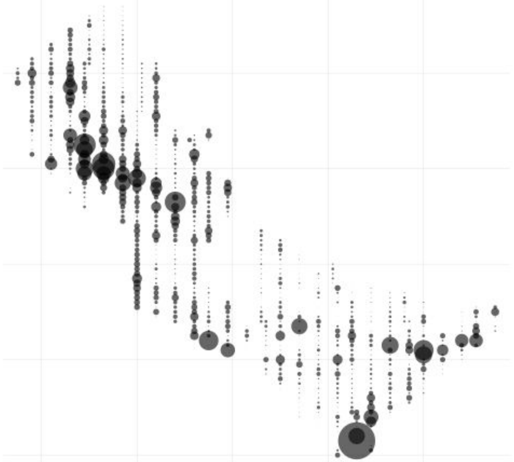
- Key: interpolate acoustics and trawls to common spatial grid
  - Conditional geostatistical simulation
  - Randomized spatial assignment

Conditional (non-) Gaussian geostatistical simulation





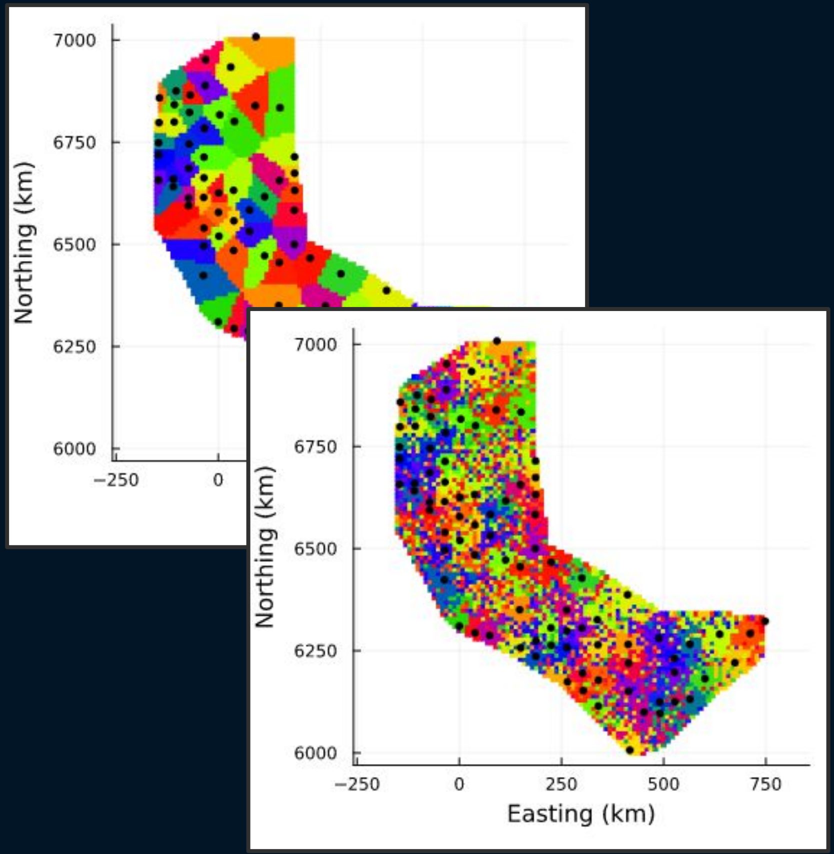
- Standard routine for Gaussian data
  - Variogram defines covariance matrix *Q* of desired simulated data *x*
  - Uses “Cholesky trick,” a.k.a. “Lower-upper Gaussian simulation,” LUGS
  - If $Q = LL'$, then $x = L z$, where $z \sim$ i.i.d. Normal(0, 1)
- Non-Gaussian data: can transform it, but complicated and/or biased
- But...turns out, *z* doesn’t have to be normal! Just need var(*z*) = 1
  - Lower-upper non-Gaussian simulation: LUNGS
  - Choose *z* from {Gamma, Inv. Gamma, Inv. Gaussian, Lognormal} based on KLD of *x* from observed backscatter



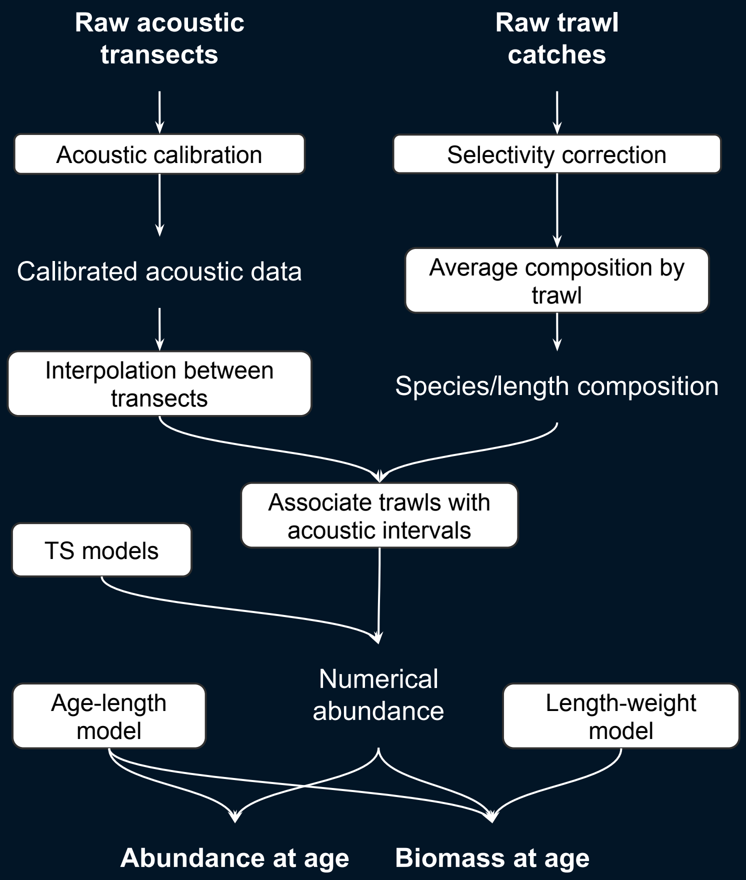
Conditional simulations on 10 x 10 km grid

Randomized acoustic-trawl assignment

- Trawl composition gives us species, sizes, target strengths
- Each acoustic interval scaled by nearest trawl
- Are these scaling factors representative of area?
- Randomly assign each grid cell to a trawl, probability ~ distance^{-1}



Bootstrapping procedure at each iteration:



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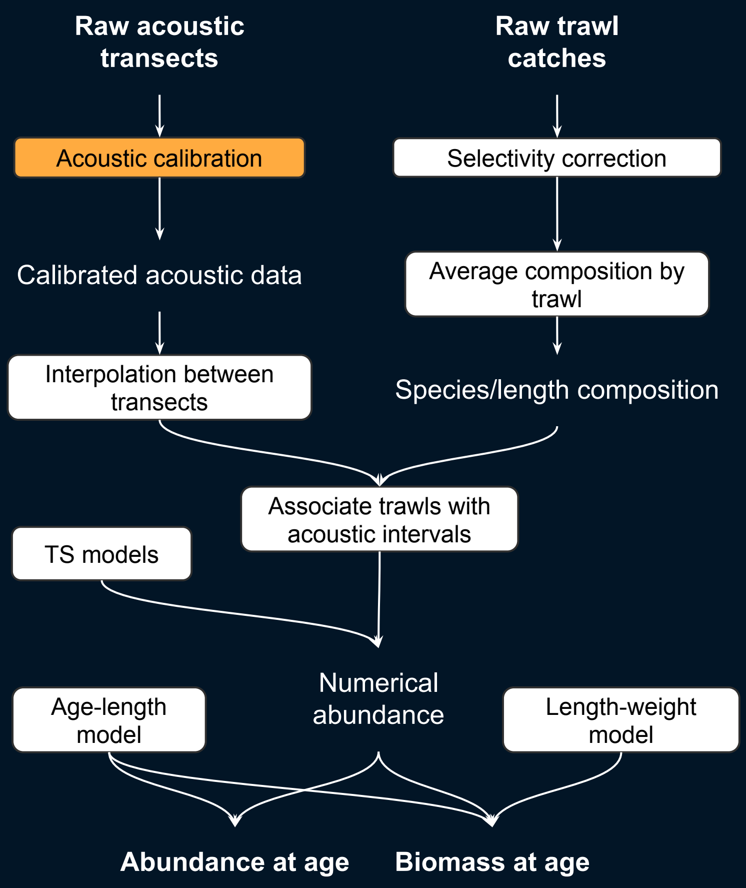

Apply random “calibration error” from normal distribution with standard deviation of 0.1 dB (about 2.4% in linear terms).

Based on variability in past calibrations and acoustic theory.

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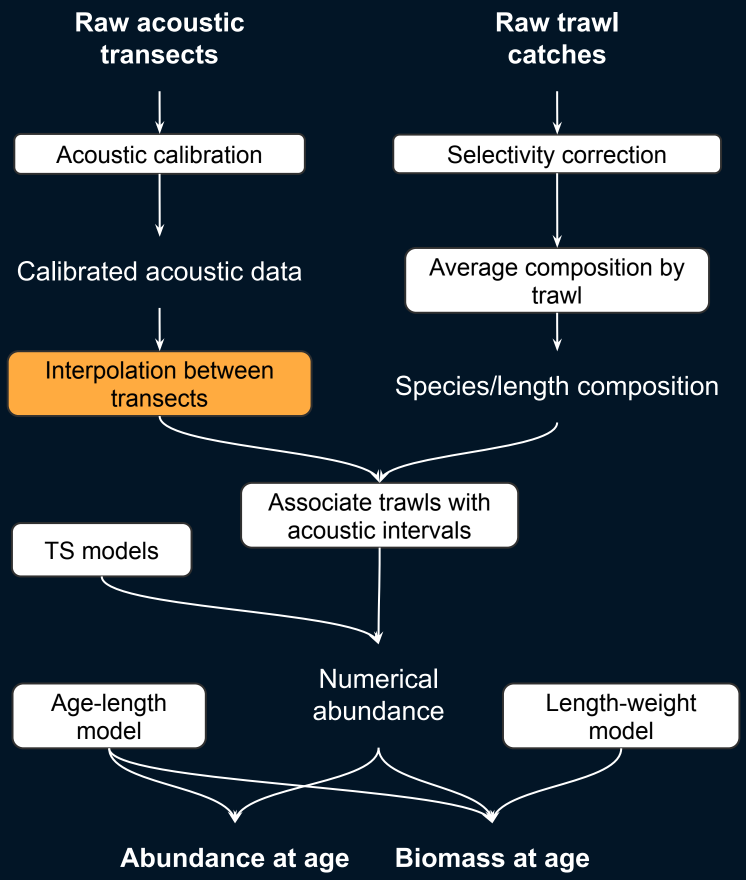
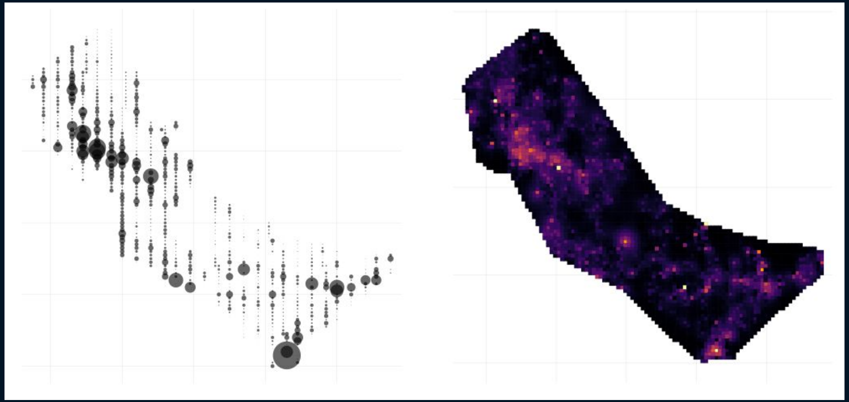


Spatial sampling error: simulate backscatter field, conditional on variogram model and data observed along transects.



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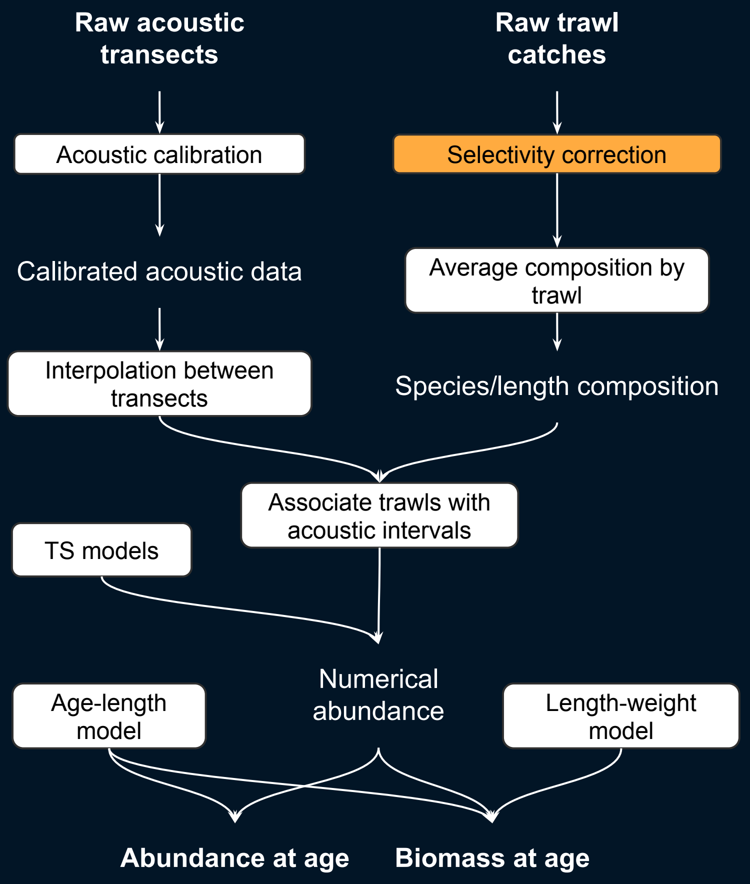
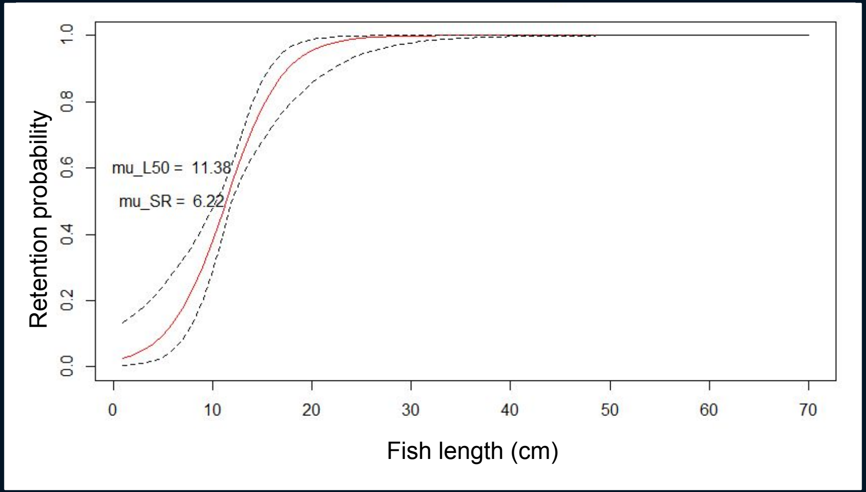


Choose random trawl selectivity curve.

Based on models fit to pocket-net data by Kresimir Williams et al.



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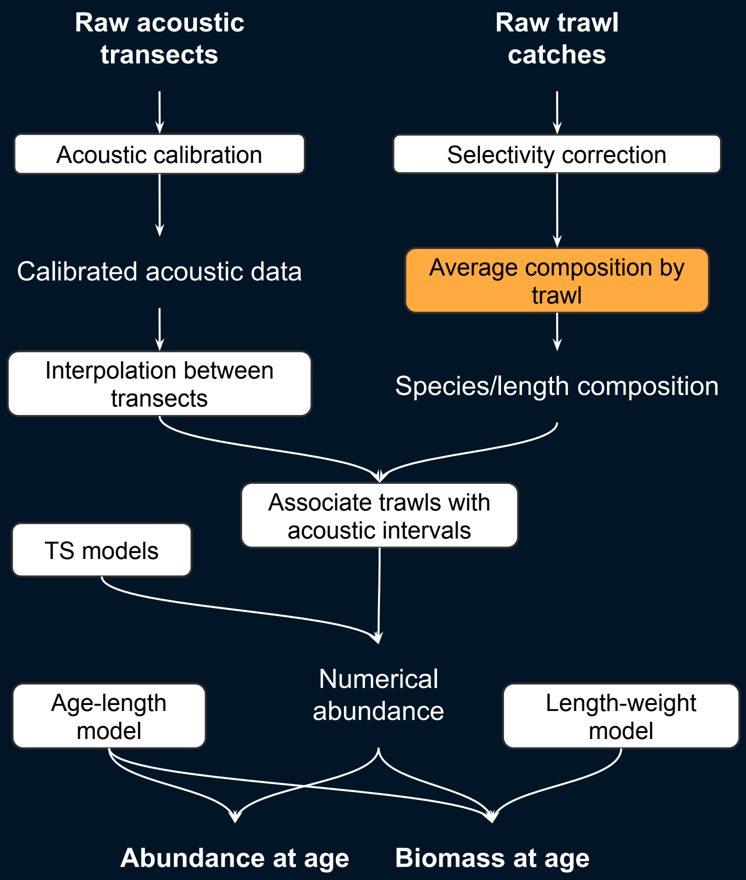
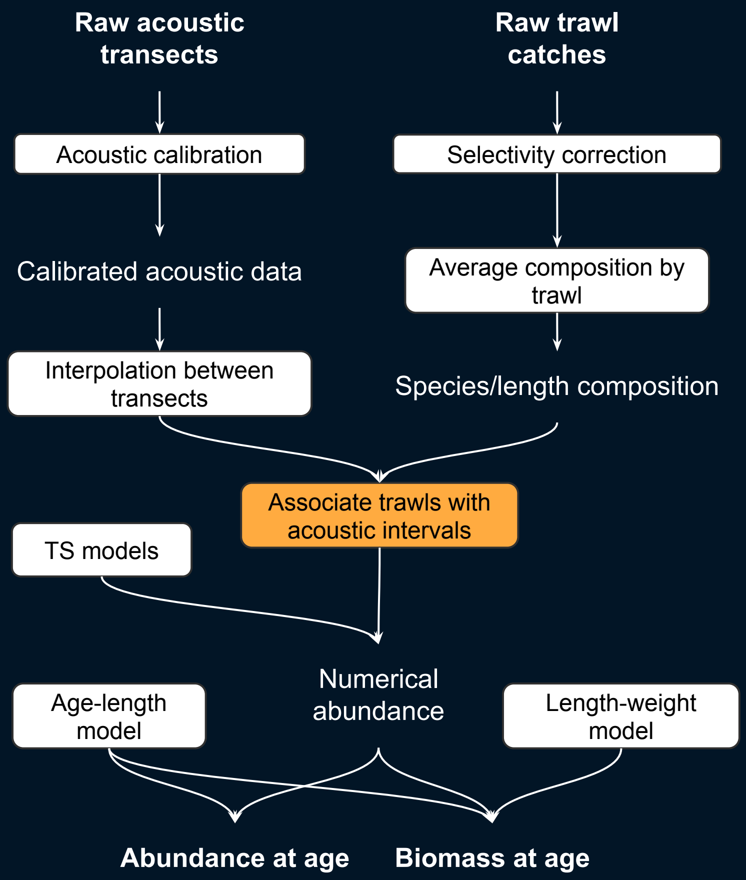


Resample catch (individual fish) in each trawl with replacement.

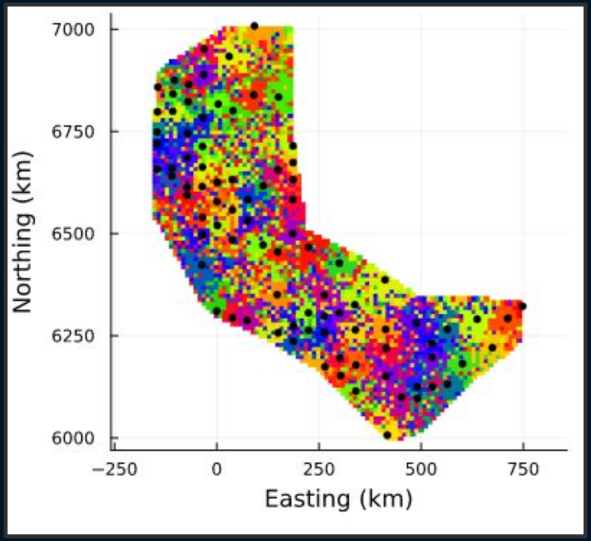
Calculate species/length composition, corrected for selectivity using function from prior step.

Bootstrapping procedure at each iteration:



Drop one trawl at random.

Assign each grid cell to a trawl, with probability inversely related to distance.



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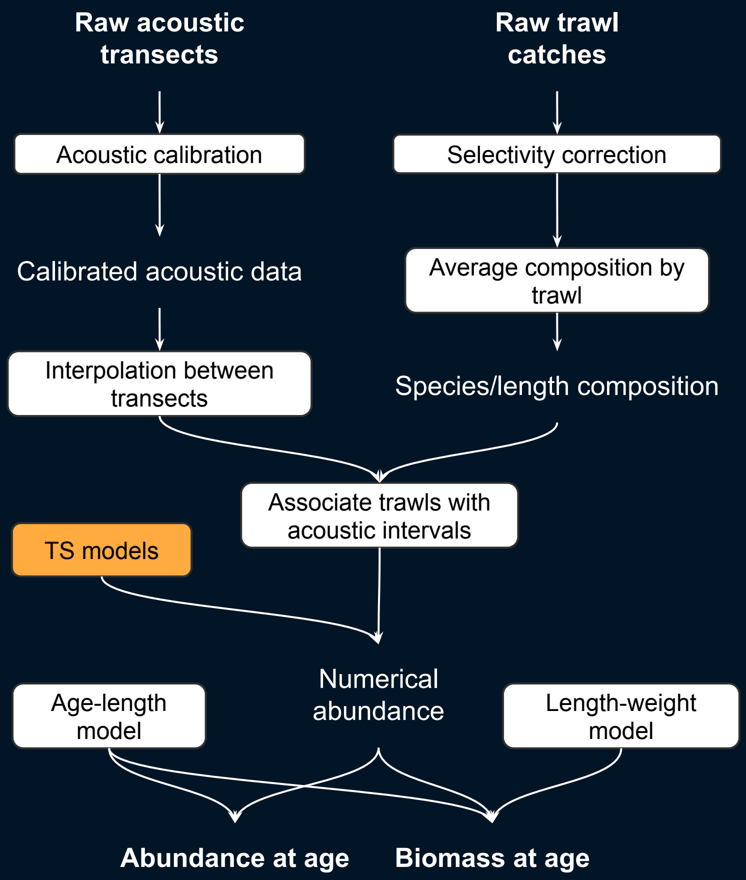
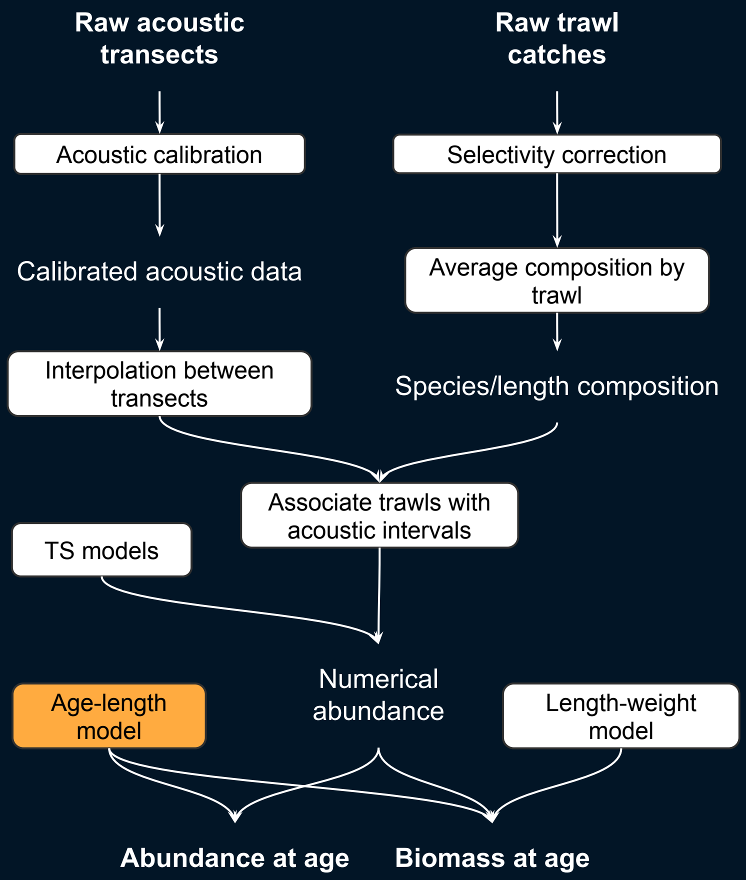


Generate random length-TS function for pollock. TS uncertainty is 0.14 dB, about 3% in linear terms (Lauffenburger et al 2023).

For all other species, assume ± 3 dB uncertainty (100 % in linear terms–being conservative).

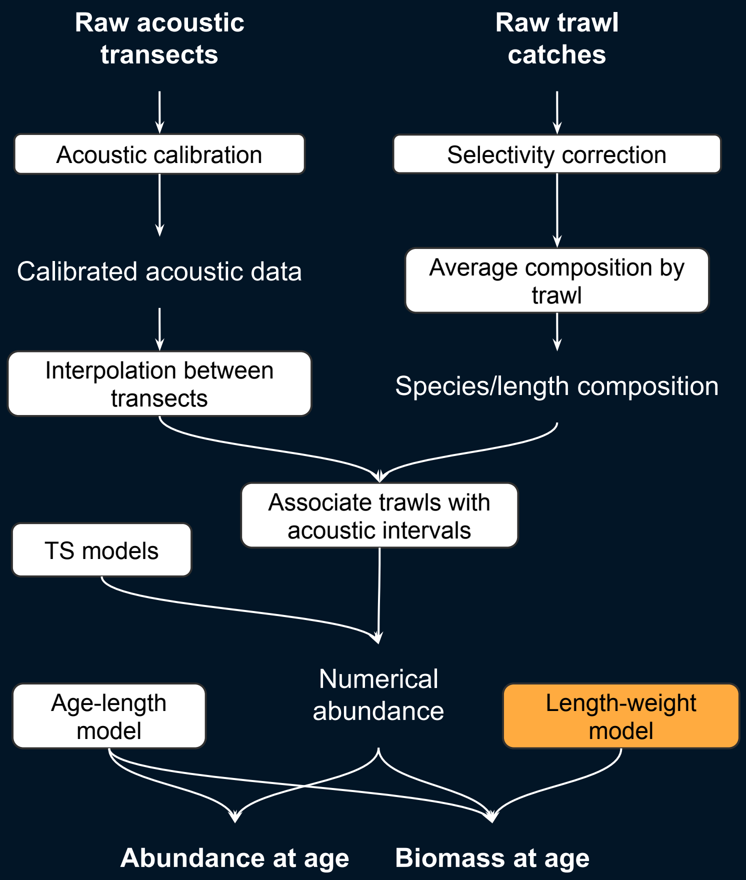
Bootstrapping procedure at each iteration:



Resample age data (otolith reads) from survey to get age composition.

Use to parameterize standard Gaussian mixture model for age-length key.

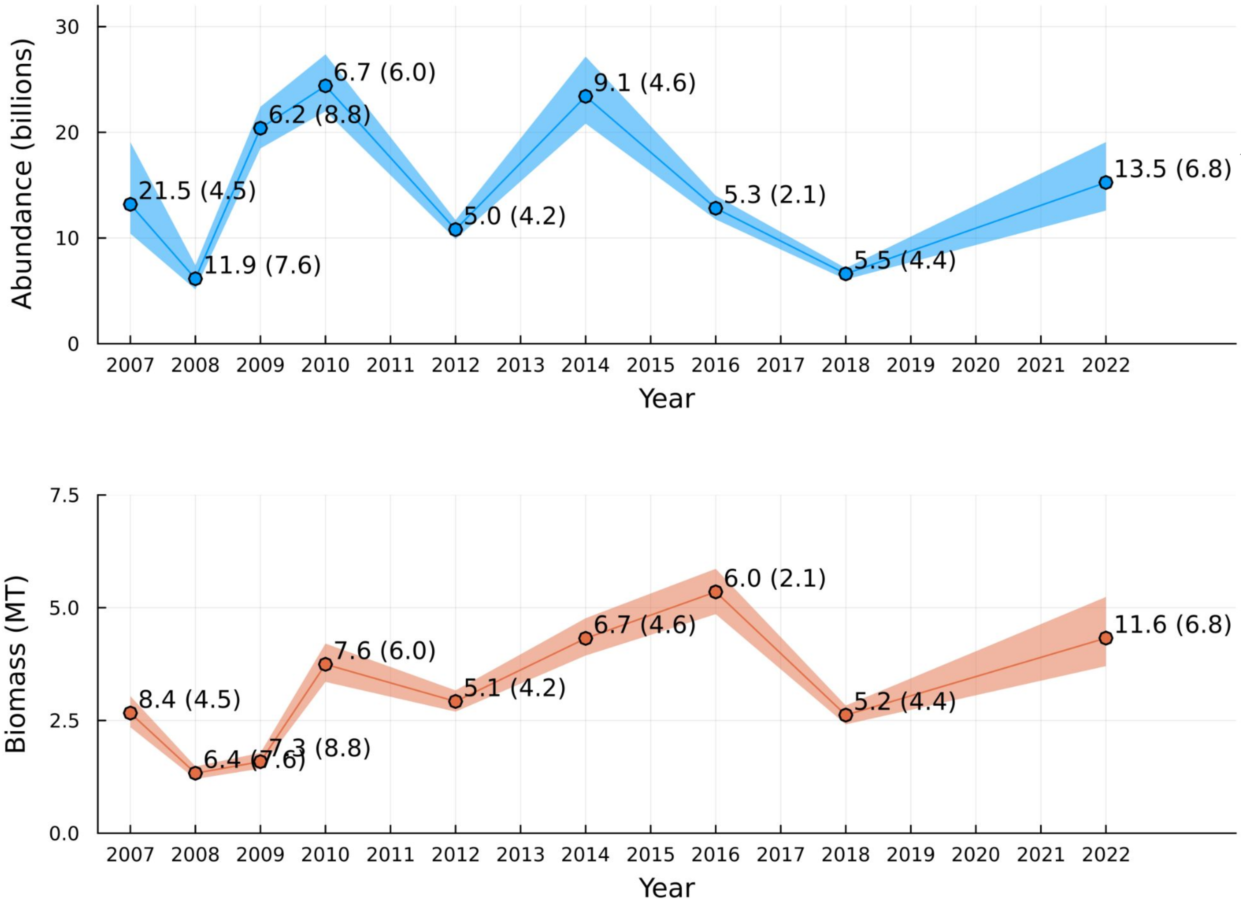
Bootstrapping procedure at each iteration:



Resample fish measured during survey with replacement.

Generate length-weight function based on resampled measurements (De Robertis and Williams 2008).

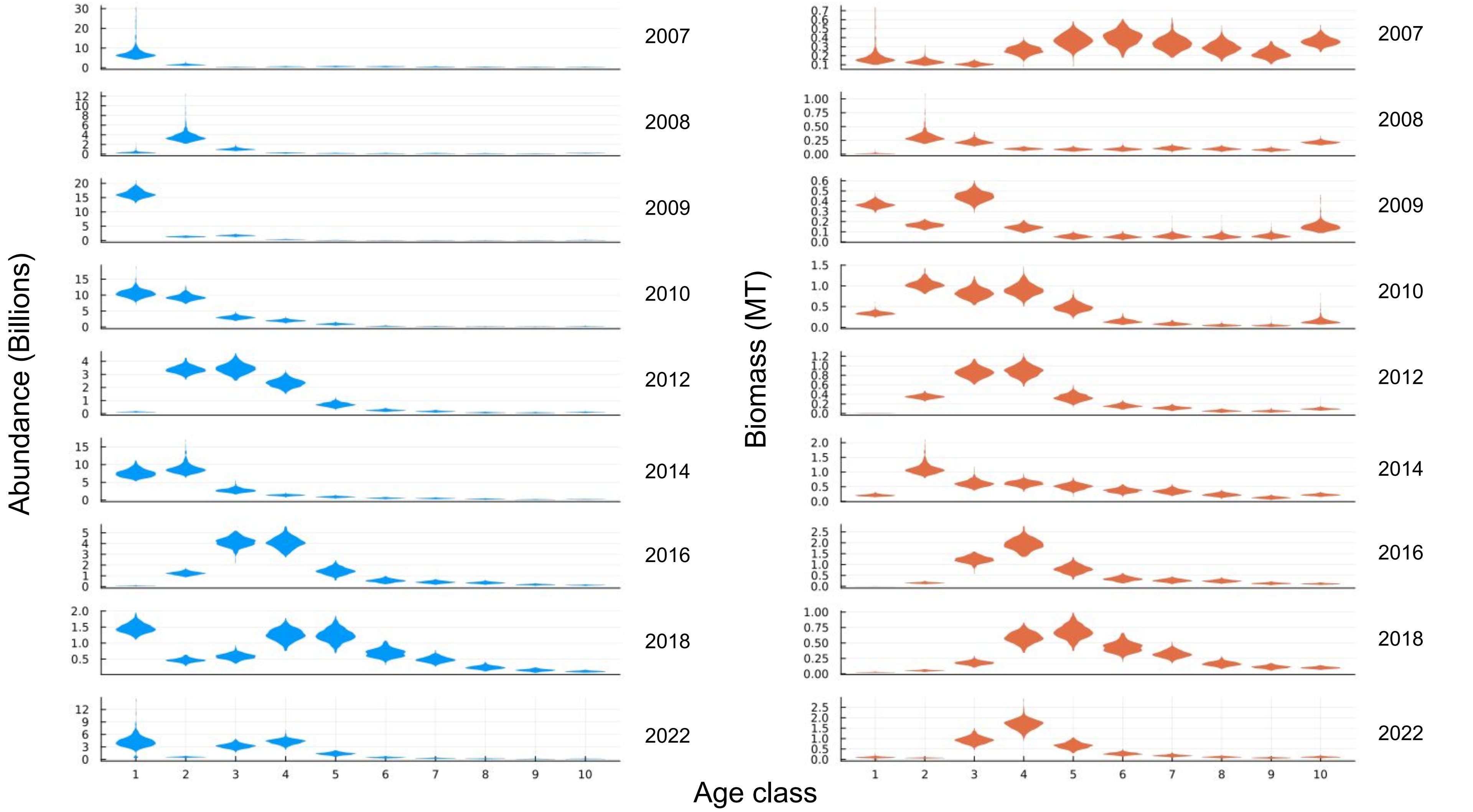
Total pollock abundance and biomass 2007-2022



CV (%) from:
Bootstrap (1D geostats)

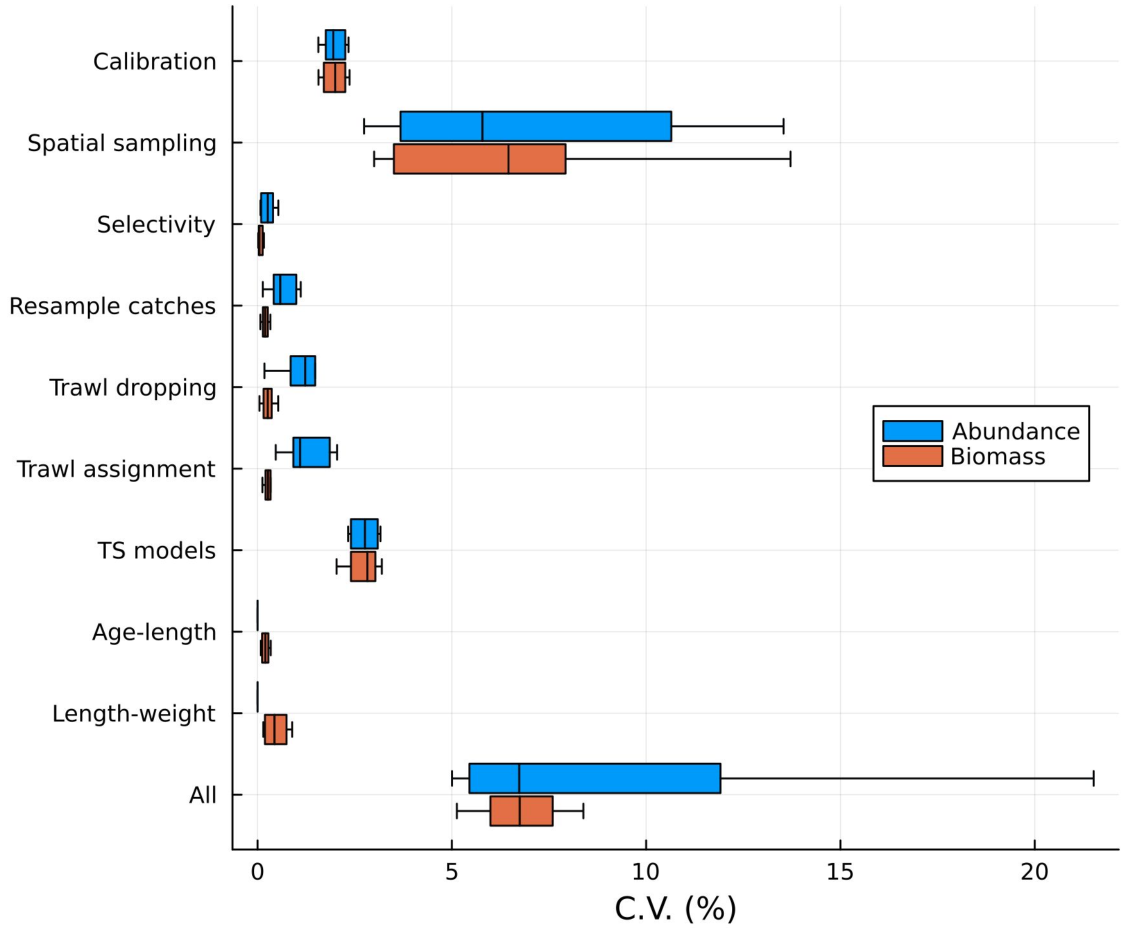
Median new CV / old CV:

- 1.57 for numbers
- 1.27 for biomass



Abundance (Billions)
Biomass (MT)
Age class
2007
2008
2009
2010
2012
2014
2016
2018
2022
1 2 3 4 5 6 7 8 9 10

Contributions of individual uncertainty sources



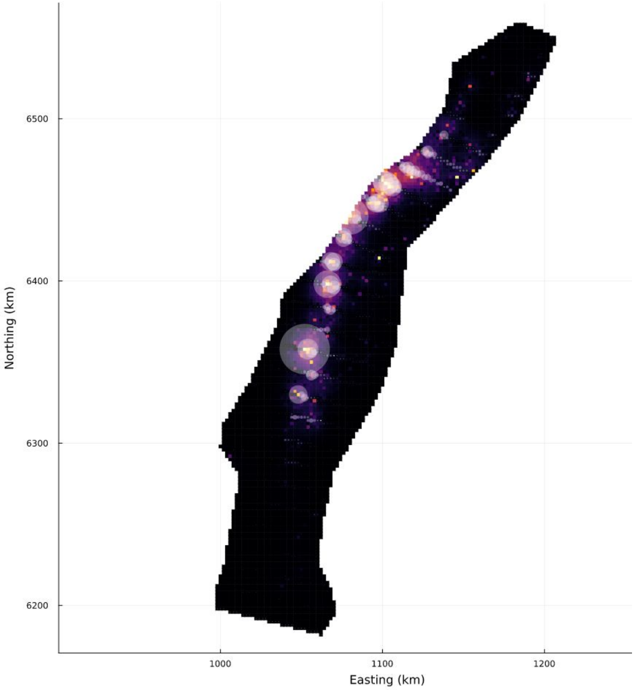
- Re-analyzed all surveys, turning on one component at a time
- Largest individual sources, on average:
  - Spatial sampling error
  - TS models
  - Echosounder calibration
  - Trawling-related sources (mostly for abundance)

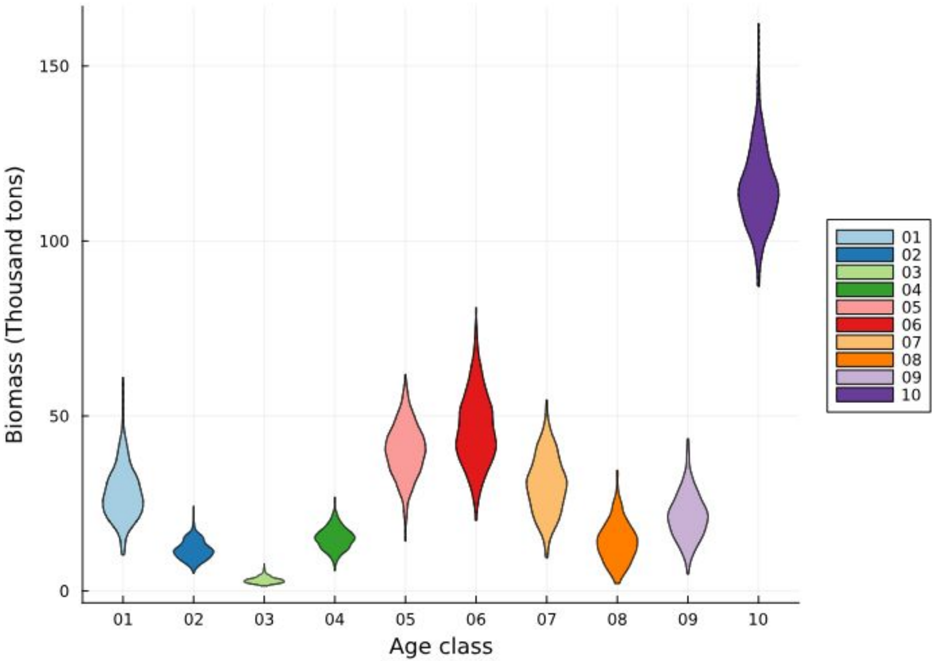
- Some differences year-to-year
- EBS is homogenous–trawling likely more important in GOA

Caveats

- A few sources of uncertainty remain unaccounted for:
  - Acoustic classification errors
  - Near-bottom acoustic dead zone
  - Survey domain/geographic availability
  - Fish movement
  - Some remaining questions about calibration and TS
- Currently, ignoring bottom 3 meters of water column (~25% of biomass)
- Uncertainty of absolute biomass vs. relative index
- Results may vary in other ecosystems, but…

Works in GOA too: Shelikof Strait, Winter 2023



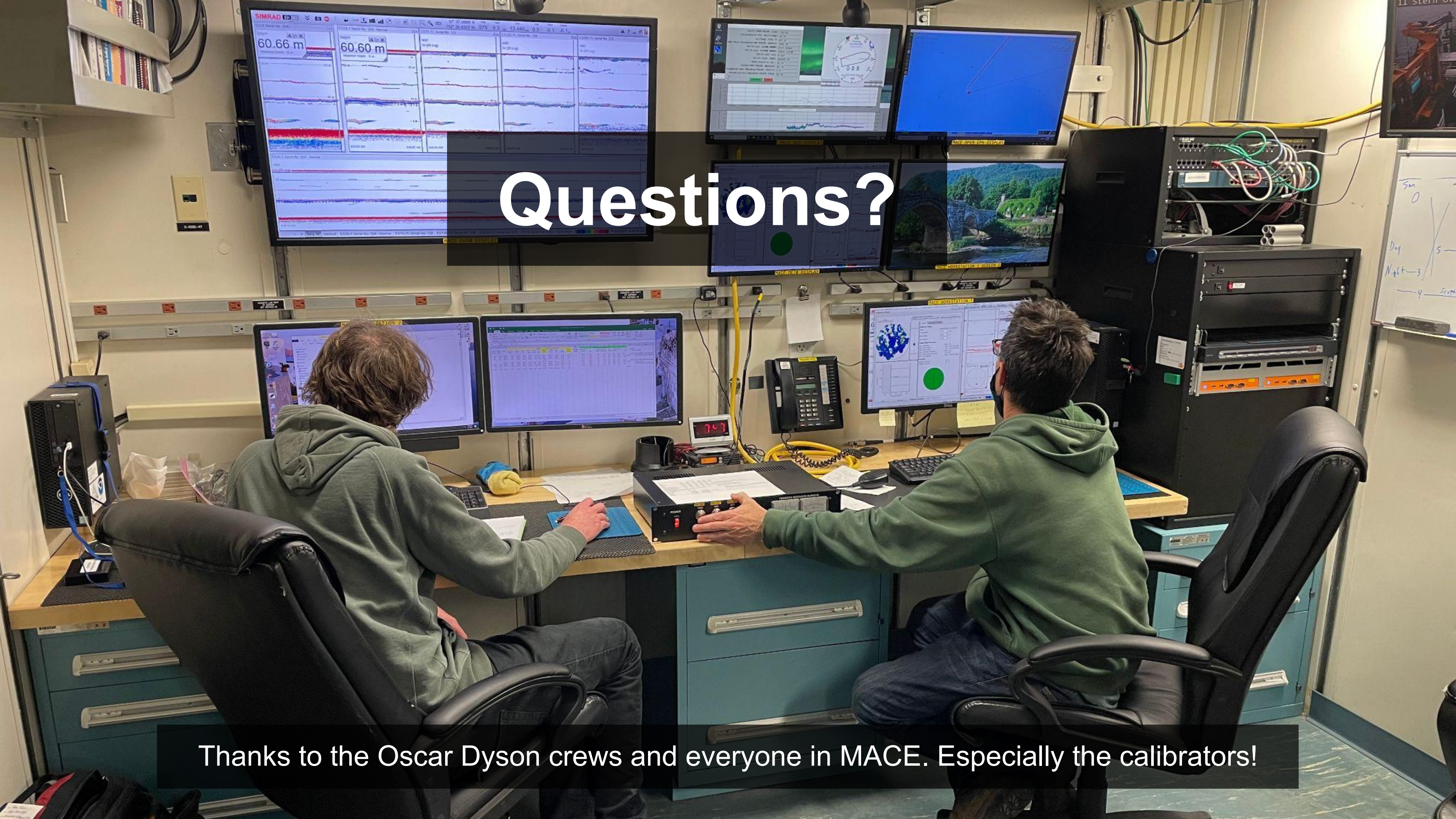


Age	1	2	3	4	5	6	7	8	9	10+
CV (%)	27.1	24.2	30.2	21.2	18.8	12.9	27.3	41.3	31.1	9.6

Conclusions

- Total biomass uncertainty for MACE EBS pollock surveys is typically 5-11%
  - For individual age classes, 10-30%
- Spatial sampling error, TS, and calibration are main sources
  - For less abundant age classes/species, uncertainty may be higher/have different drivers
  - More transects = less uncertainty
- On average 1.9 and 1.5 x 1D geostatistical estimates for numbers and biomass
- 2-4 times smaller than assumed in stock assessment
- Framework can be used to think about effort allocation/reduction

Questions?



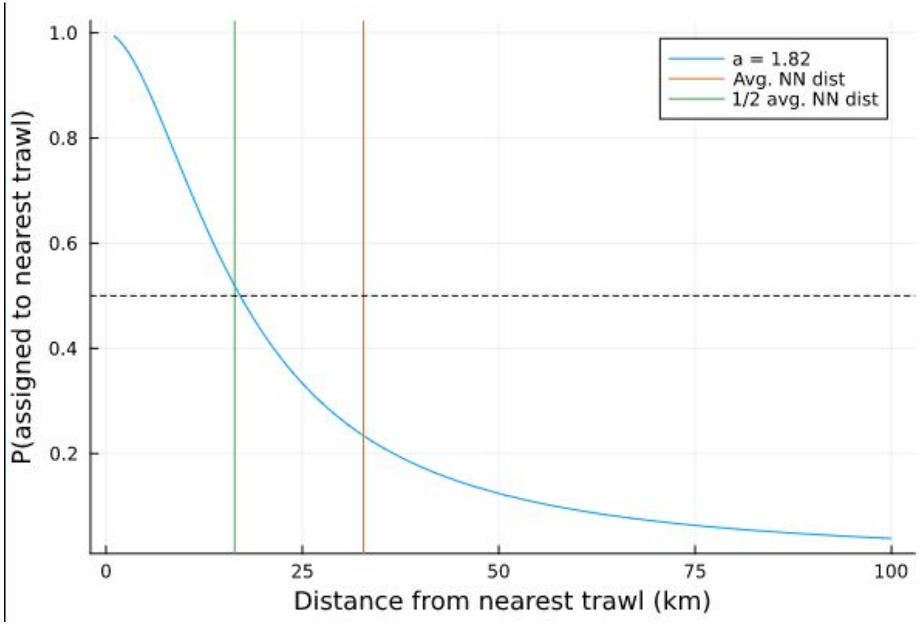
Thanks to the Oscar Dyson crews and everyone in MACE. Especially the calibrators!

LUNGS details and the “Cholesky trick”

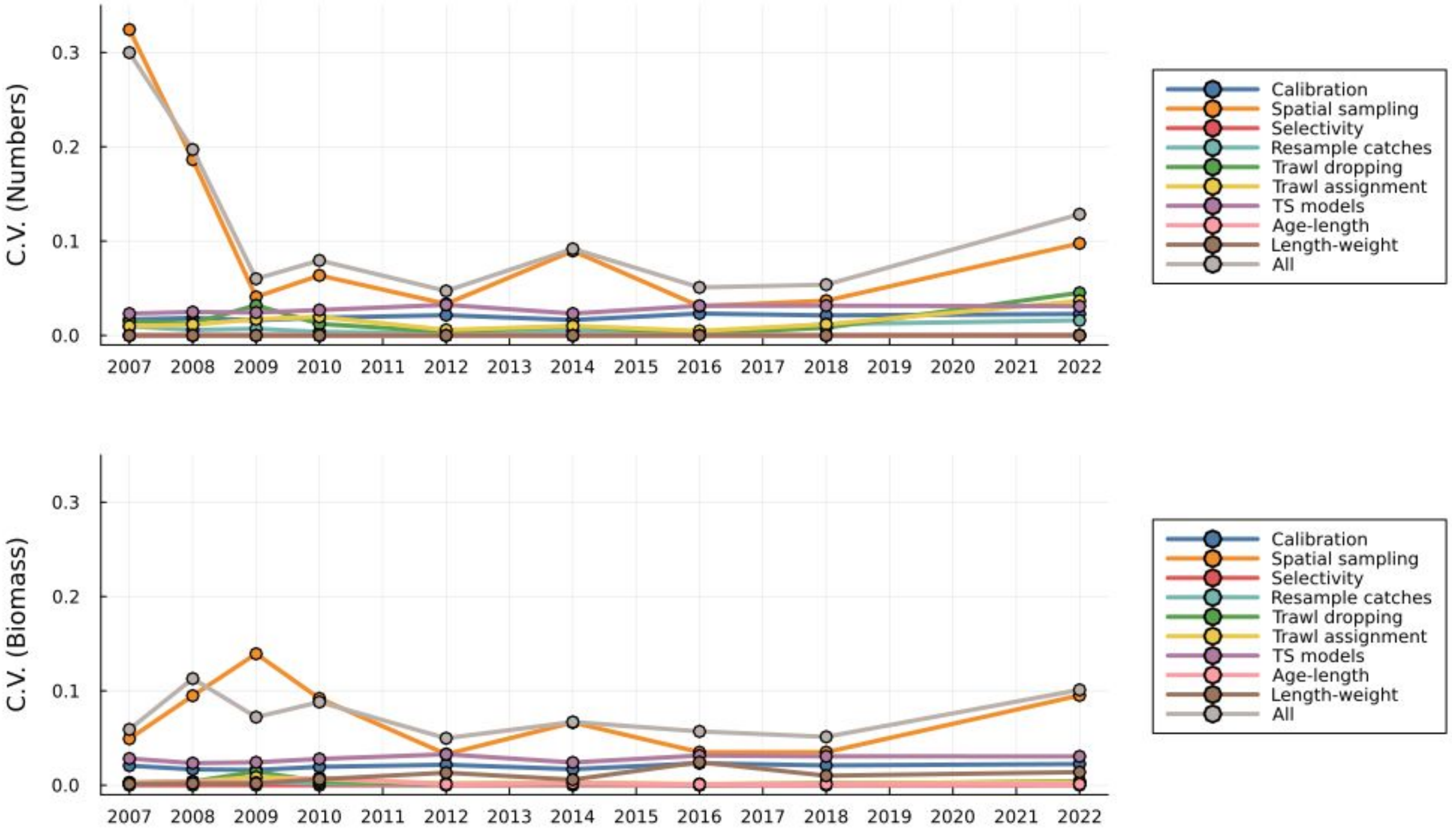
- Normal “lower-upper Gaussian simulation” (LUGS):
  - Use data + variogram model to define mean (μ_x) and covariance (Q) for simulation locations
  - Cholesky (LU) decomposition of covariance matrix $Q = L\ L^{-1}$
  - If the vector $\boldsymbol{z}$ is i.i.d standard normal, product $\boldsymbol{x} = L\ \boldsymbol{z}$ will have covariance Q
  - Q = cov(x) = E[$x\ x'$]
  - cov(z) = $E[z\ z'] = I$
  - $Q = L\ L' = L\ I\ L' = L\ E[z\ z']\ L' = E[(L\ z)\ (L\ z)']$
  - From definition of covariance, cov($L\ z$) = Q
- But, $\boldsymbol{z}$ does not have to be normal–as long as var($\boldsymbol{z}$) = 1.0, cov($L\boldsymbol{z}$) = Q
  - Get means to match: $\mu_z = L^{-1}\ \mu_x$
  - Know required mean and variance (1.0) for each element of $\boldsymbol{z}$, can then translate into parameters for whatever non-negative distribution you want

Trawl shuffle details

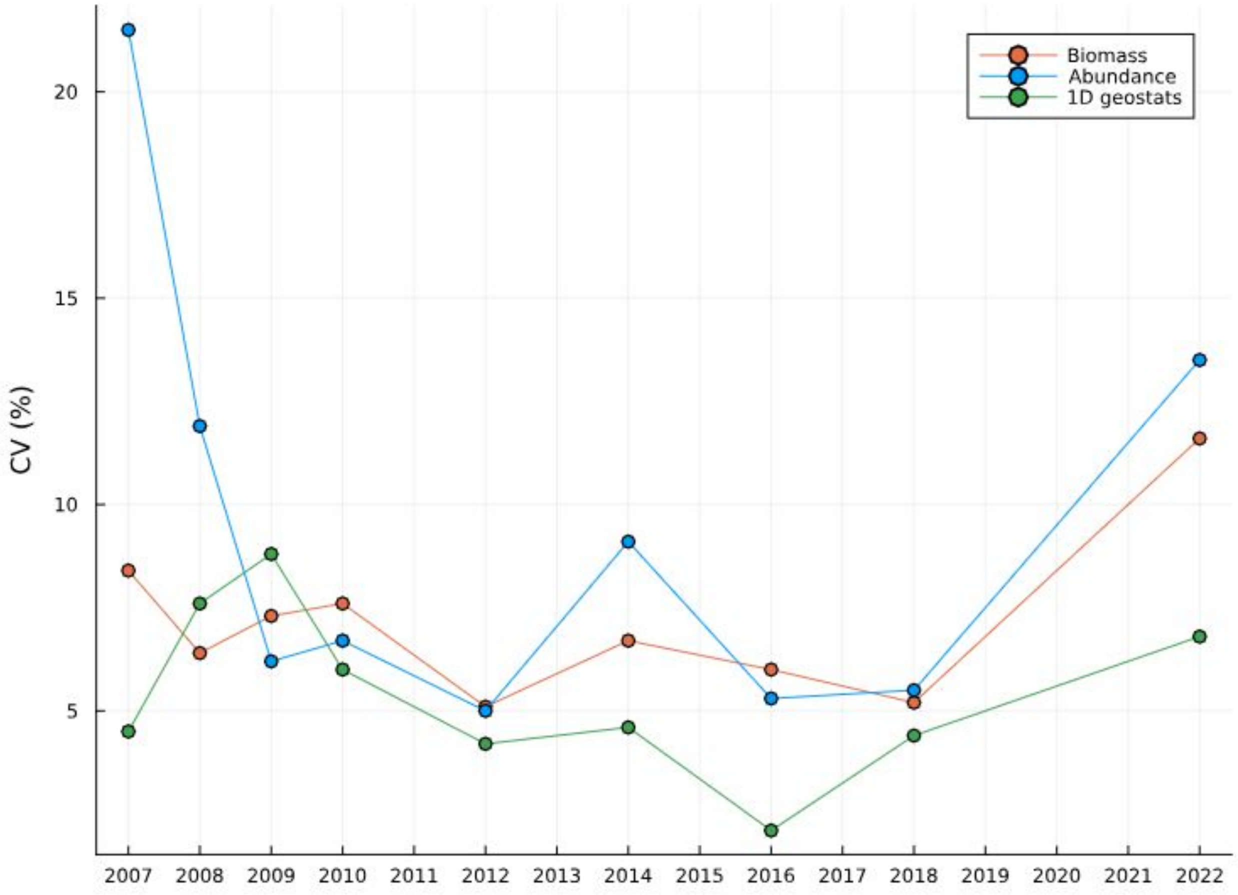
- Randomly assign each acoustic cell to a trawl
- Inverse distance weighted: $1 / d^a$
- Exponent *a* set so average pixel has 50/50 chance of getting nearest trawl when ½ distance to nearest neighbor



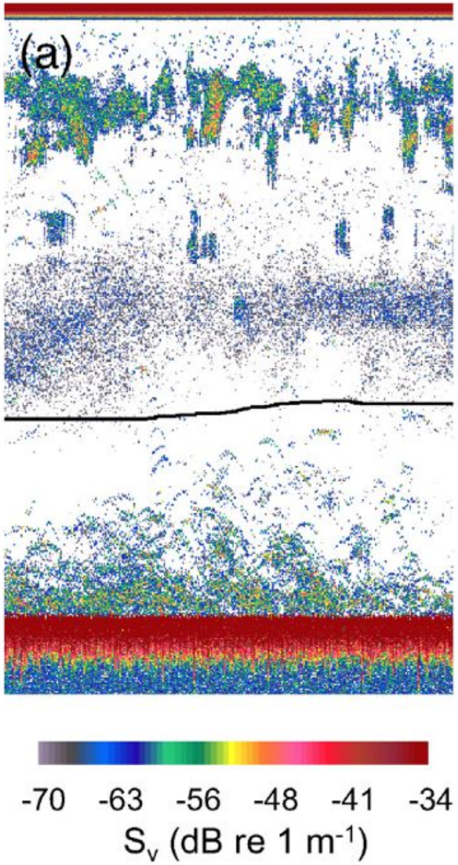
Individual error contributions through time



Coefficients of variation over time



Separating backscatter into "scaling strata"



Scaling Stratum 2
(small, dense schools)

Scaling Stratum 1
(continuous
near-bottom
backscatter)