Pacific cod in Space and Time

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Joint NPFMC Groundfish Plan Team
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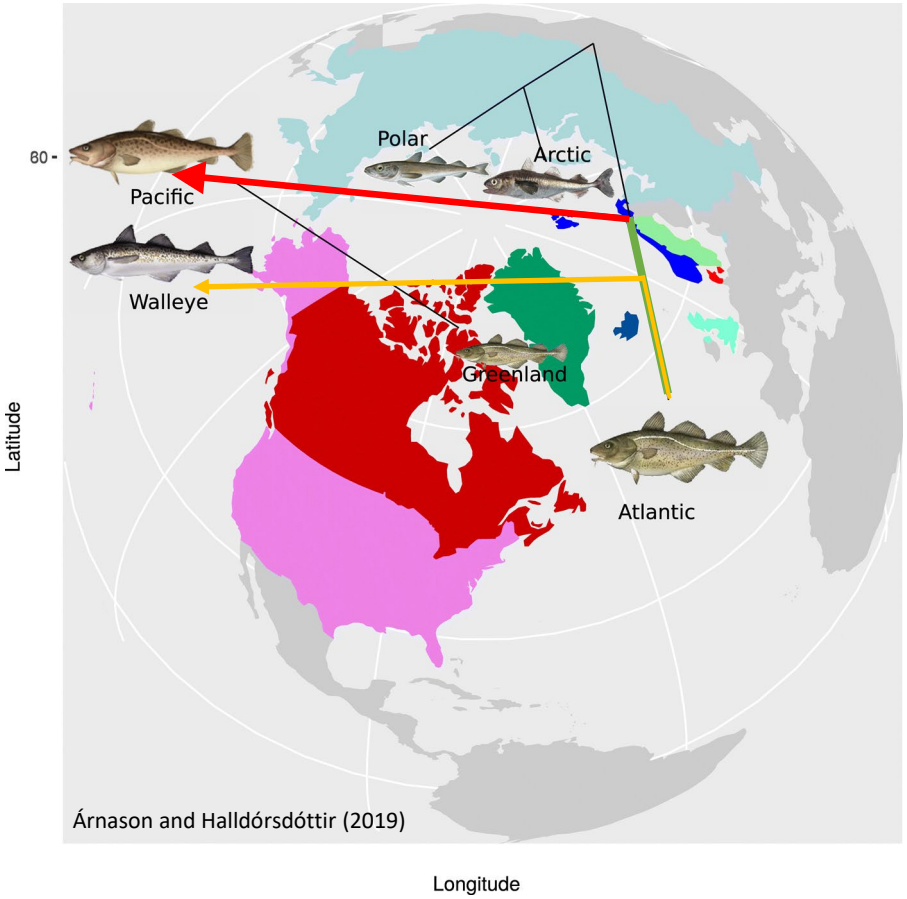
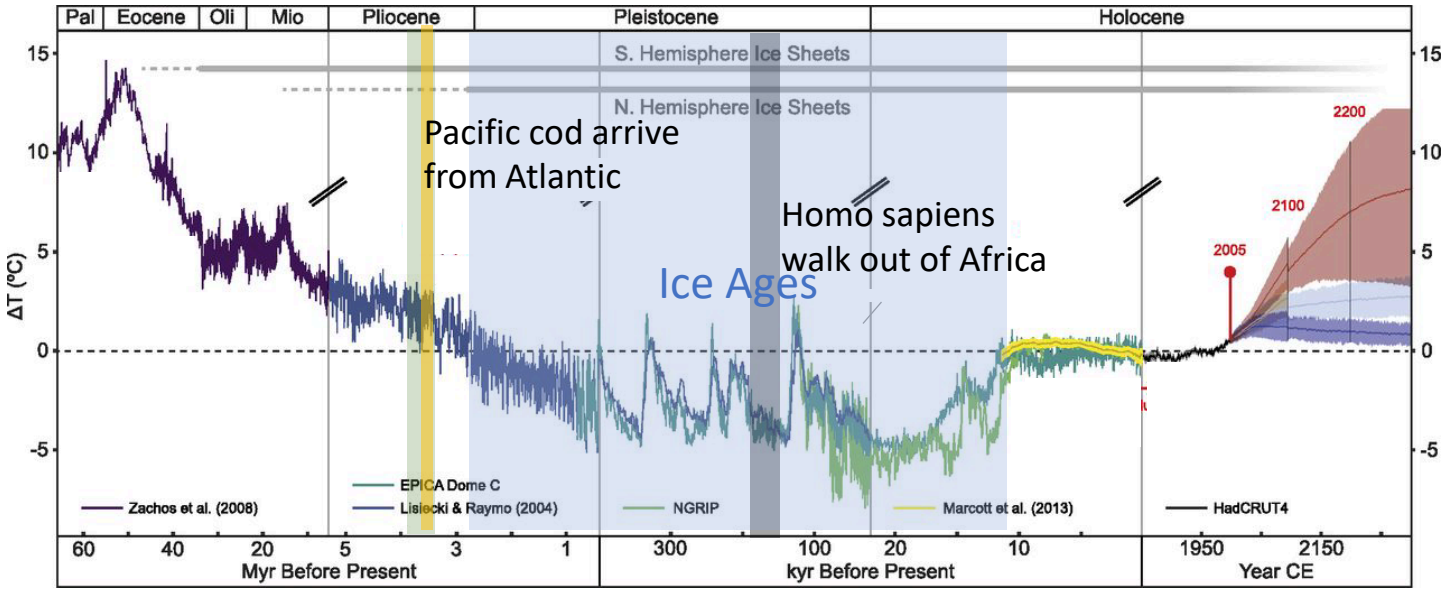
Pre-history of gadids in the Pacific Ocean

- Pacific cod and walleye pollock are both derived from an Atlantic cod common ancestor
- Pliocene divergence
  - Pacific cod ~4 million years
  - Pollock ~3.8 million years



Árnason and Halldórsdóttir (2019)



Burke et al. (2018.)

Pre-history from genetic studies

Coulson, M.W., Marshall, H.D., Pepin, P. and Carr, S.M., 2006. Mitochondrial genomics of gadine fishes: implications for taxonomy and biogeographic origins from whole-genome data sets. Genome, 49(9), pp.1115-1130

Árnason, E. and Halldórsdóttir, K., 2019. Codweb: Whole-genome sequencing uncovers extensive reticulations fueling adaptation among Atlantic, Arctic, and Pacific gadids. Science advances, 5(3), p.eaat8788.

Pacific Cod in Space and Time

Management and assessment structure may not fully capture spatial and seasonal *dynamics*

1 BSAI and GOA managed as separate stock

FMPs

BSAI FMP | GOA FMP

Pacific cod in the BSAI and GOA are managed as separate stocks due to the division of FMPs.

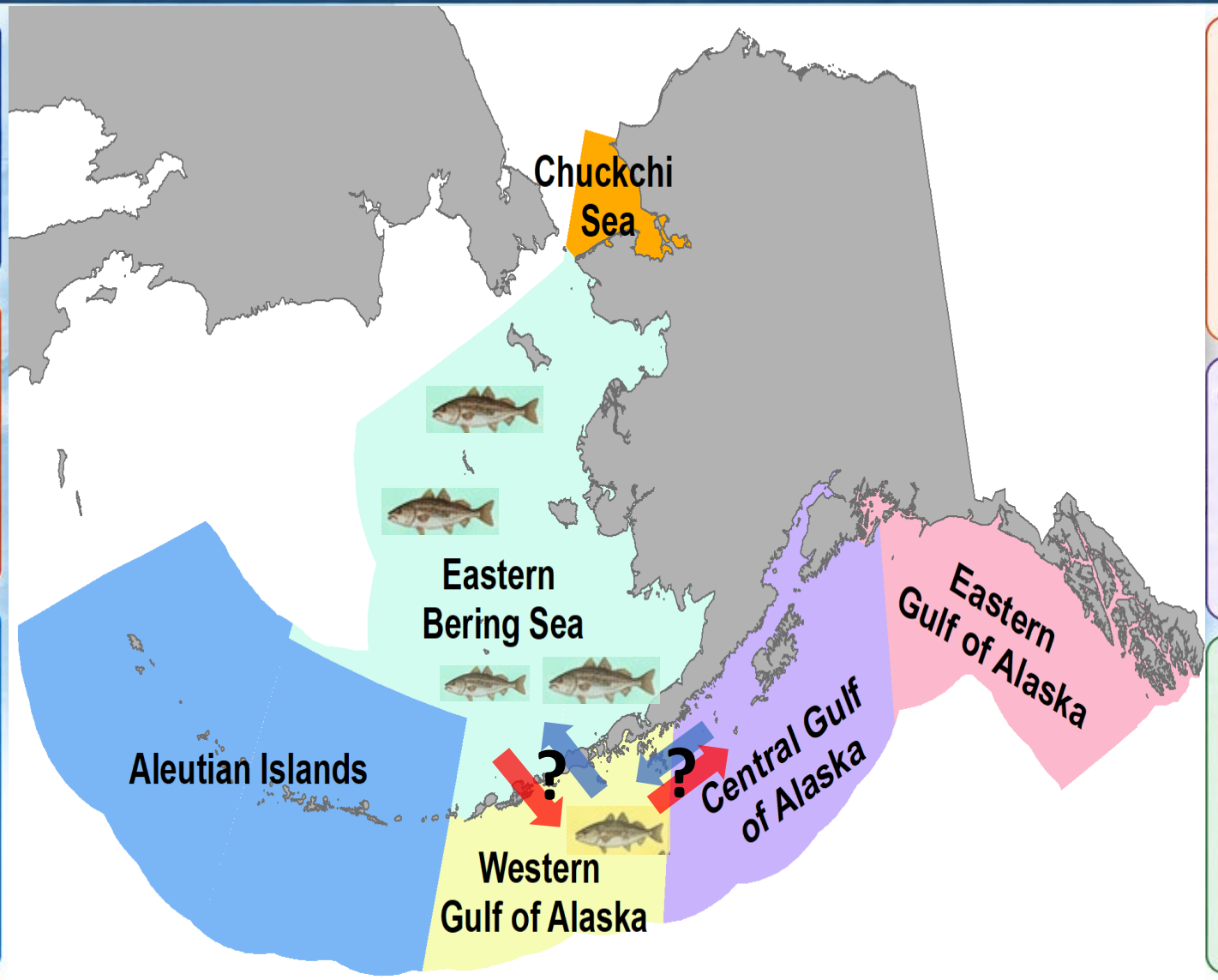
2 Fishers observe an influx of Pacific cod into the Western GOA in winter

Commercial fishers report an influx of Pacific cod from the Bering Sea/Aleutians into the Western GOA during winter.

3 Summer only surveys may not adequately reflect Western GOA population in the winter

Bottom trawl surveys are conducted in summer (June–September), which may miss the winter influx of cod in the Western GOA.

Summer surveys (June September)



4 Western GOA is primarily a winter fishery

The Western GOA Pacific cod fishery primarily occurs in winter (October–April).

Winter fishery (October–April)

5 Current assessment models are FMP specific

Assessment models are developed for each FMP (BSAI and GOA) and may not adequately capture the spatial and seasonal dynamics of the stock.

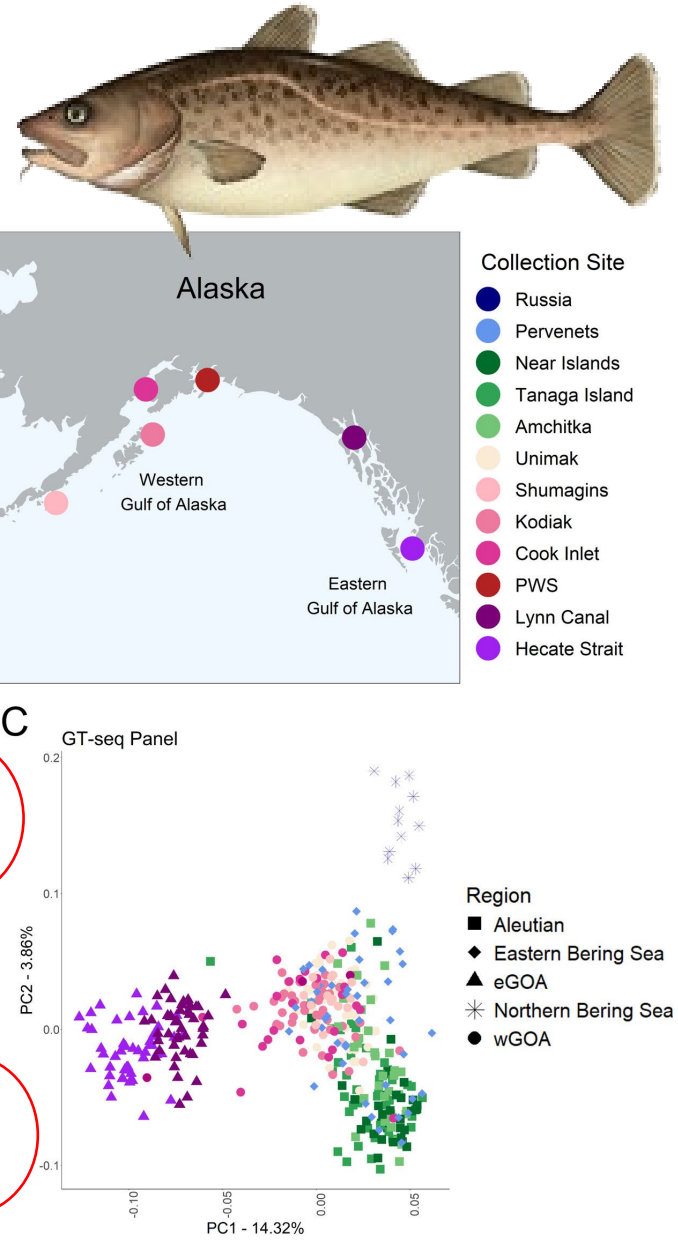
6 Current GOA apportionment by summer surveys may not adequately represent fished population

The allocation of GOA Pacific cod based on summer survey results may not reflect the actual population available to the winter fishery in the Western GOA.

A mismatch between management/assessment structure and the actual seasonal distribution of Pacific cod may lead to an incomplete understanding of the stock.

What does Genetics tell us?

- Genetic break between Aleutian Islands and Eastern Bering Sea
- Genetic break from Eastern Bering Sea to NBS/Russia
- Genetic break from Eastern GOA to Western GOA
- No break in genetic structure between the Central GOA, Western GOA, and EBS



Schaal et al. 2026. Genetic Data Reveal Nonlocal Juvenile Recruitment and Variable Seasonal Movement of a Highly Mobile Marine Fish Across Alaska. Evolutionary Applications 19:1 https://doi.org/10.1111/eva.70174Digital Object Identifier (DOI)

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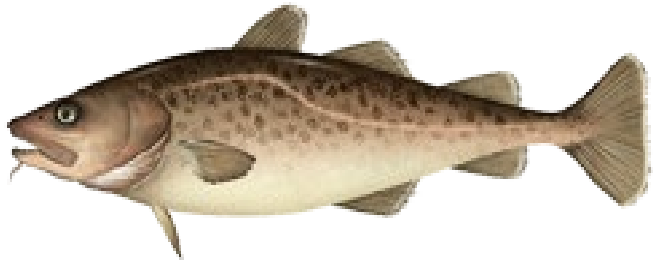

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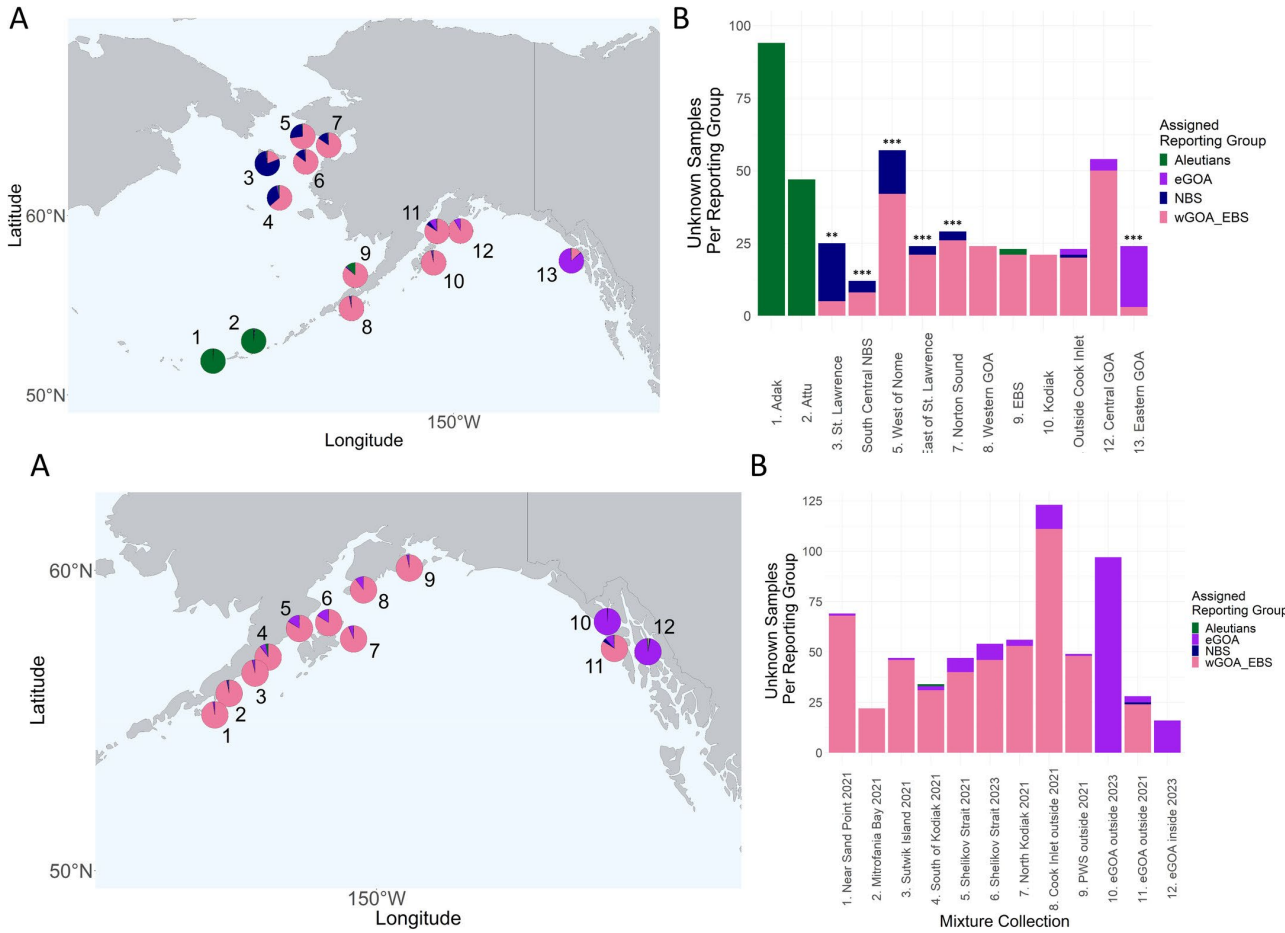

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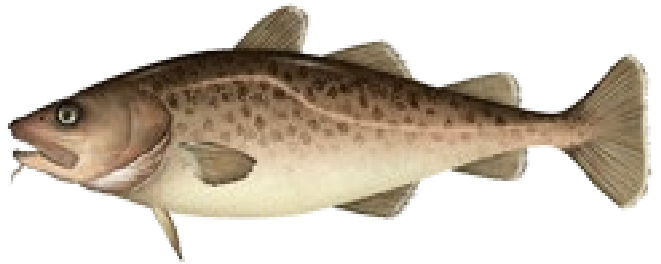
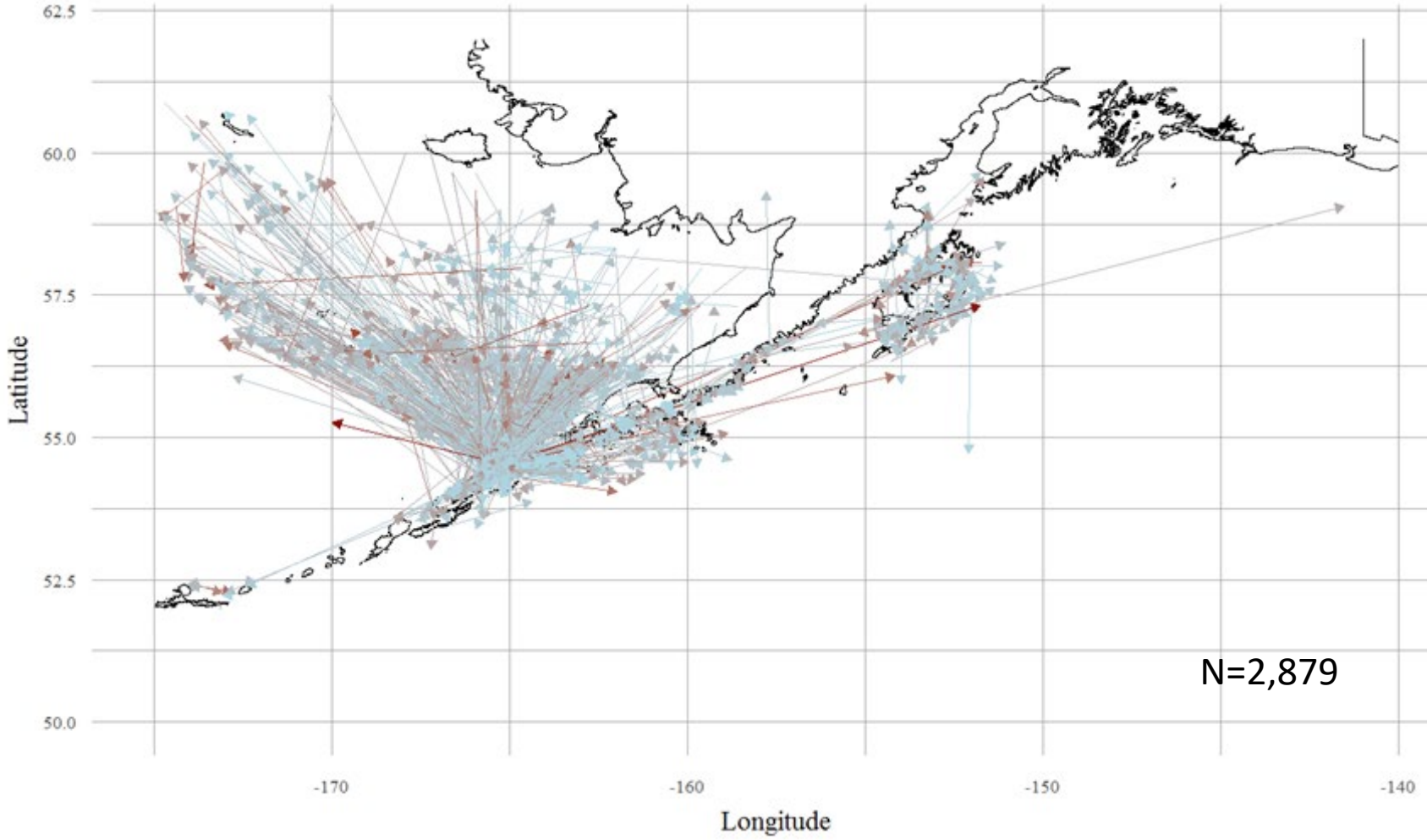
Conventional Tagging 1982-2020



- Substantial movement between the Western GOA and Eastern Bering Sea
- Limited movement between Central GOA and Western GOA



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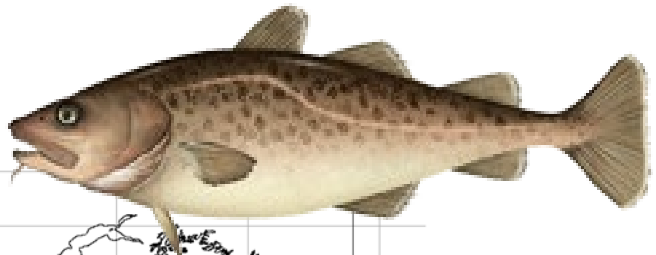

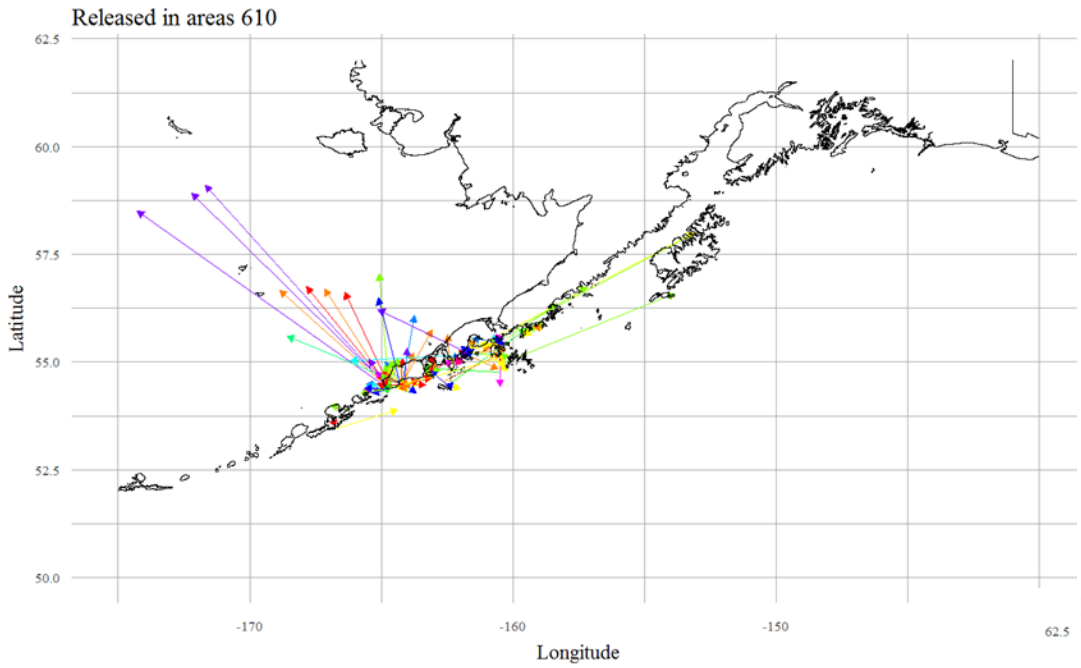

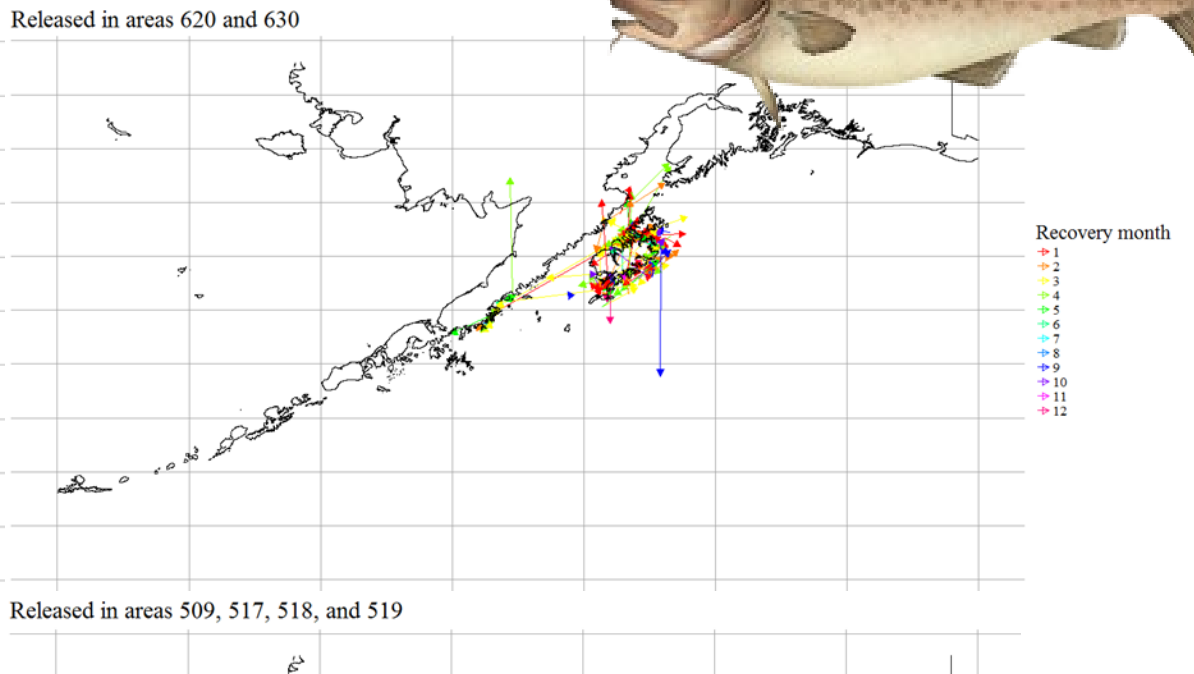

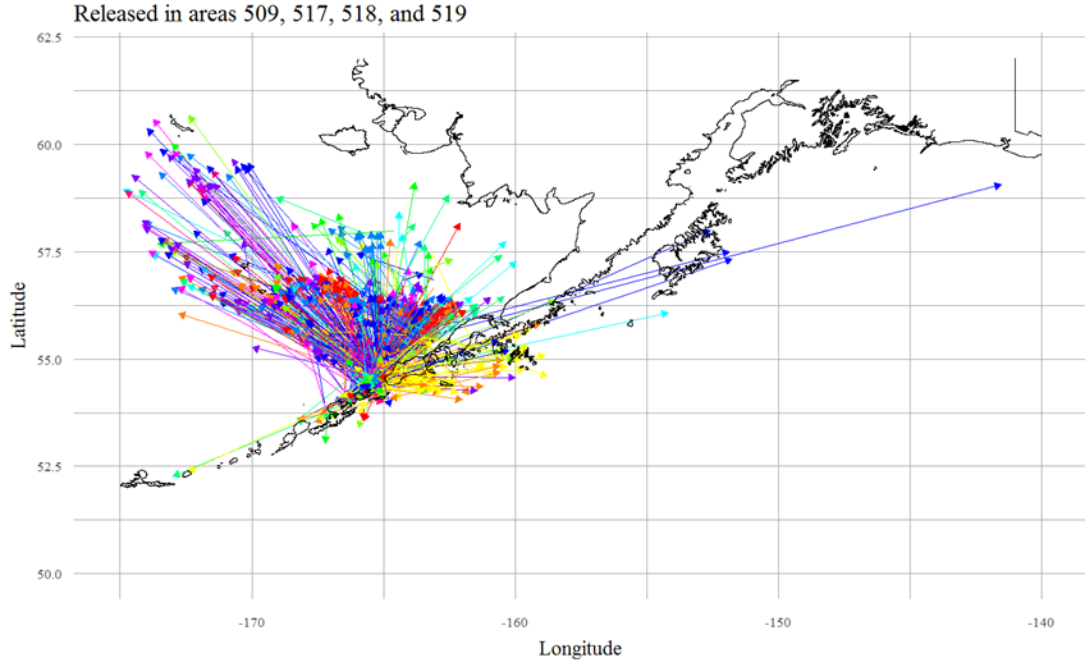

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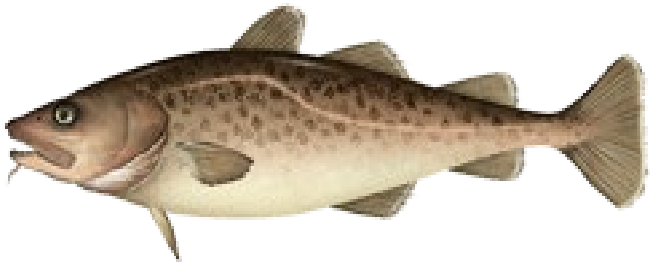
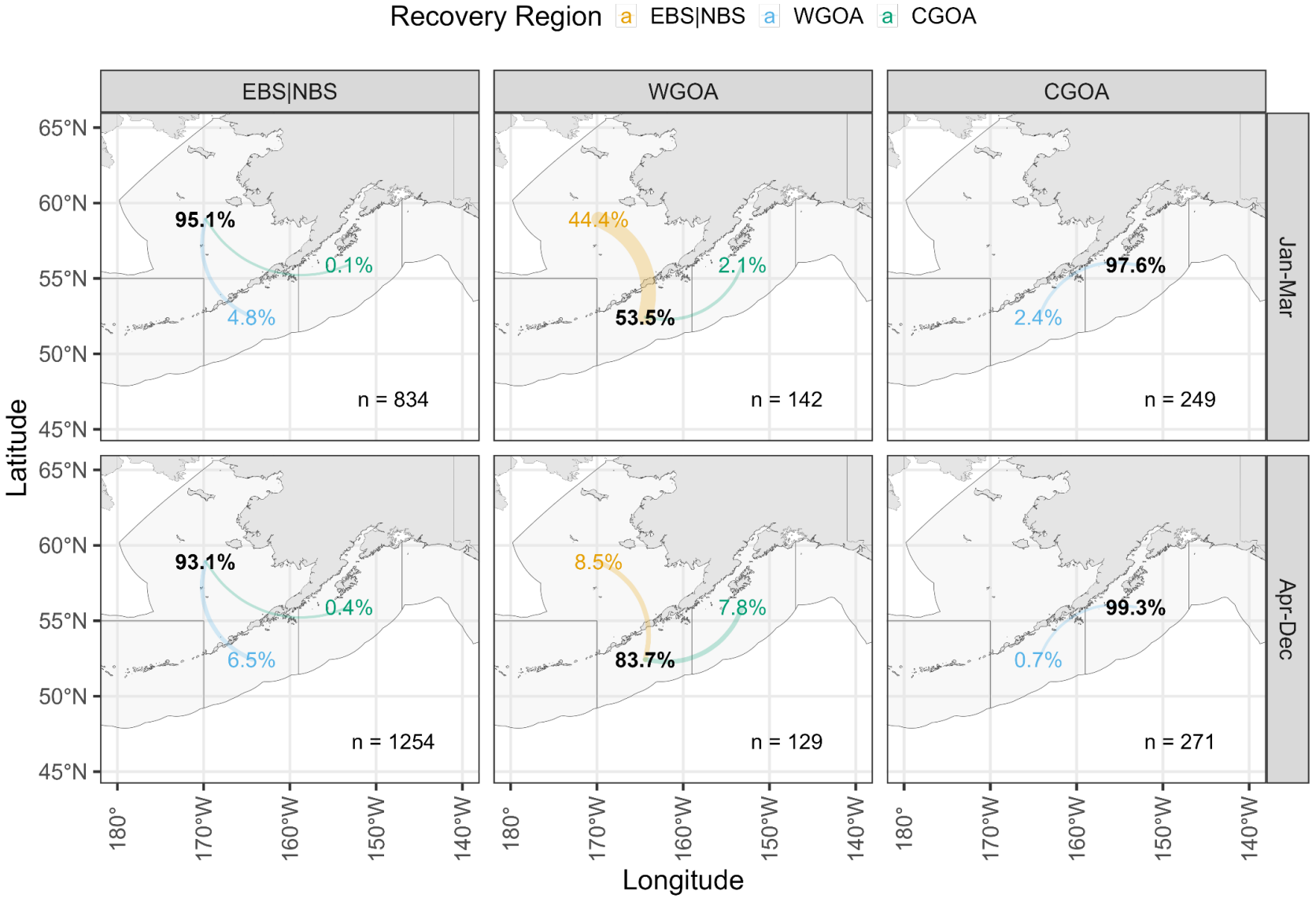


- Movement is seasonal with majority of movement among areas in January-March



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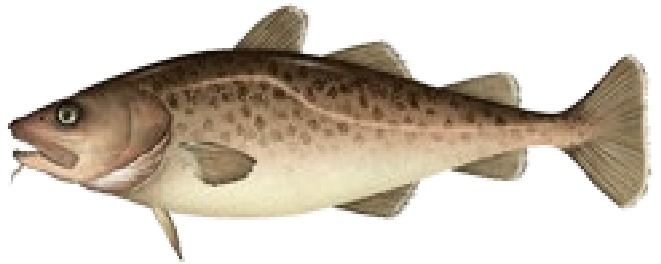
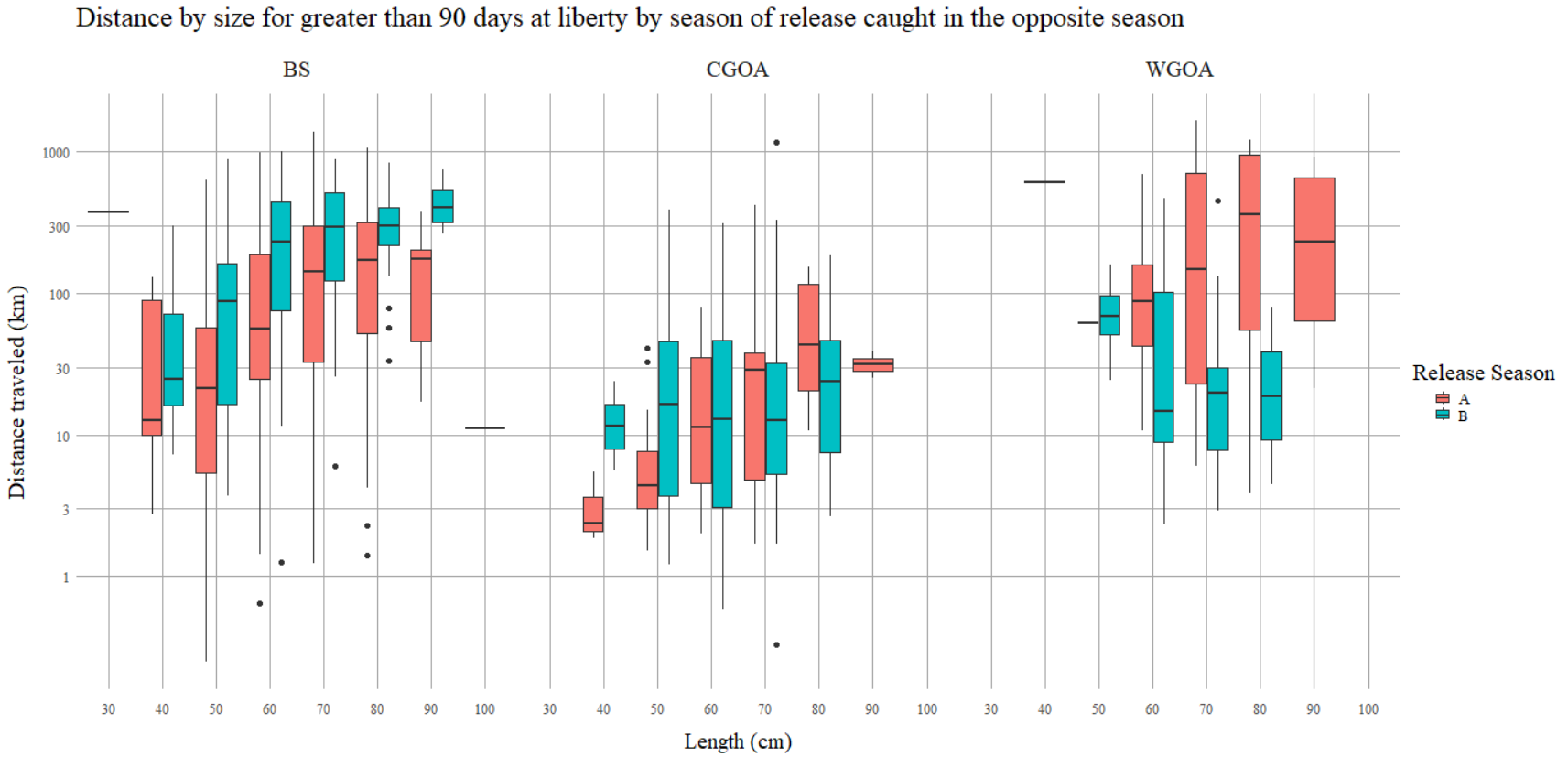


- Distance traveled/movement rate is size dependent
- Bering Sea and western GOA fish travel further distances
- Central GOA fish do not travel long distances
- Western GOA fish tagged in the summer appear to not travel long distances

Fish recovered in the opposite season from release

Distance traveled (km)



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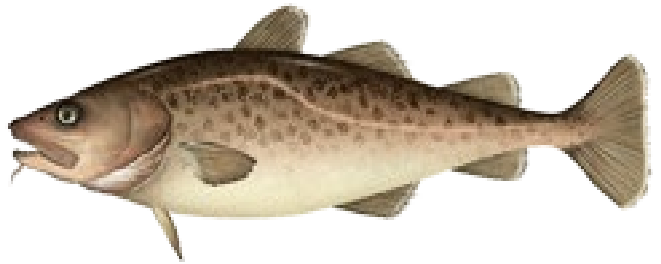

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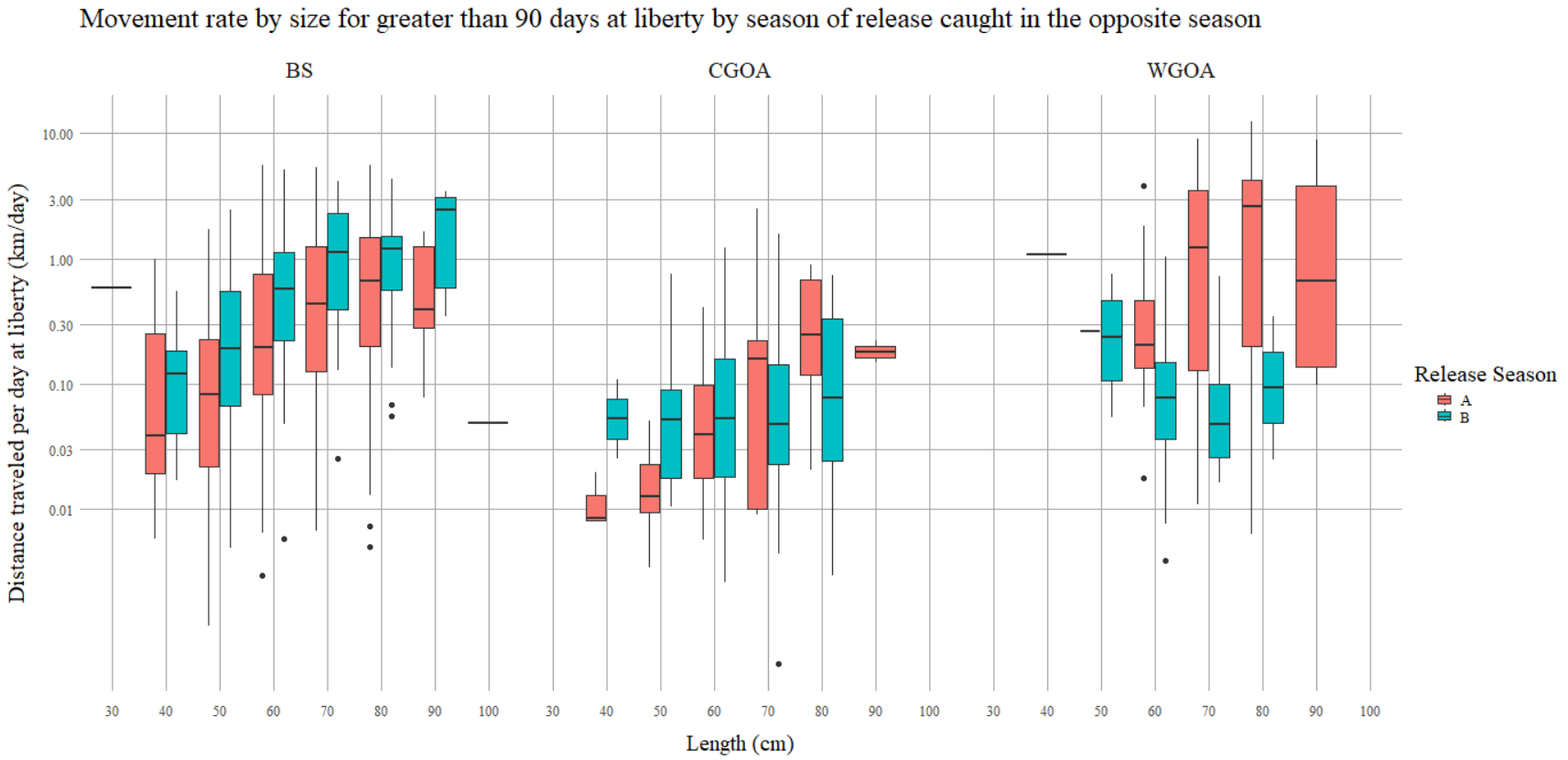
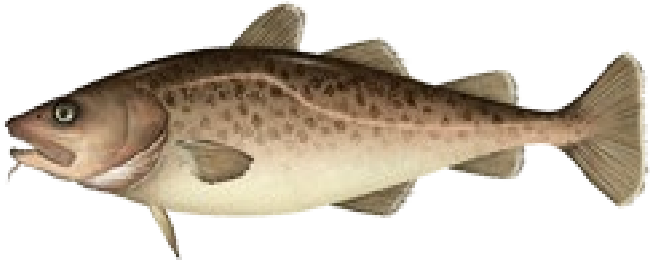
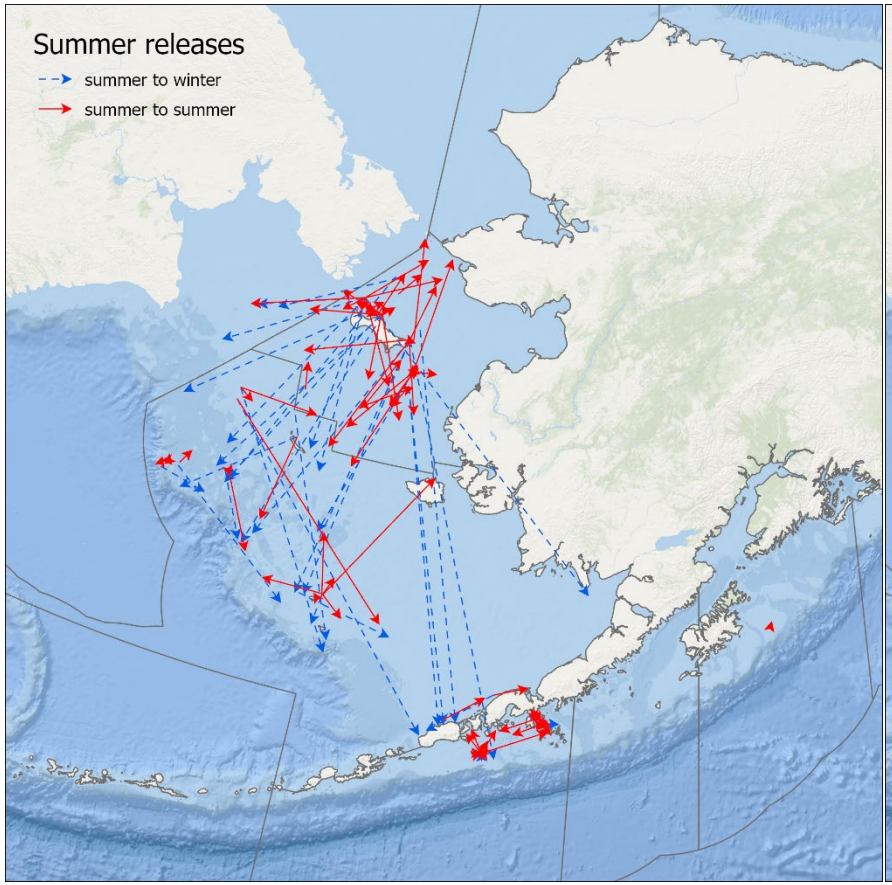
Movement rate (km/day)

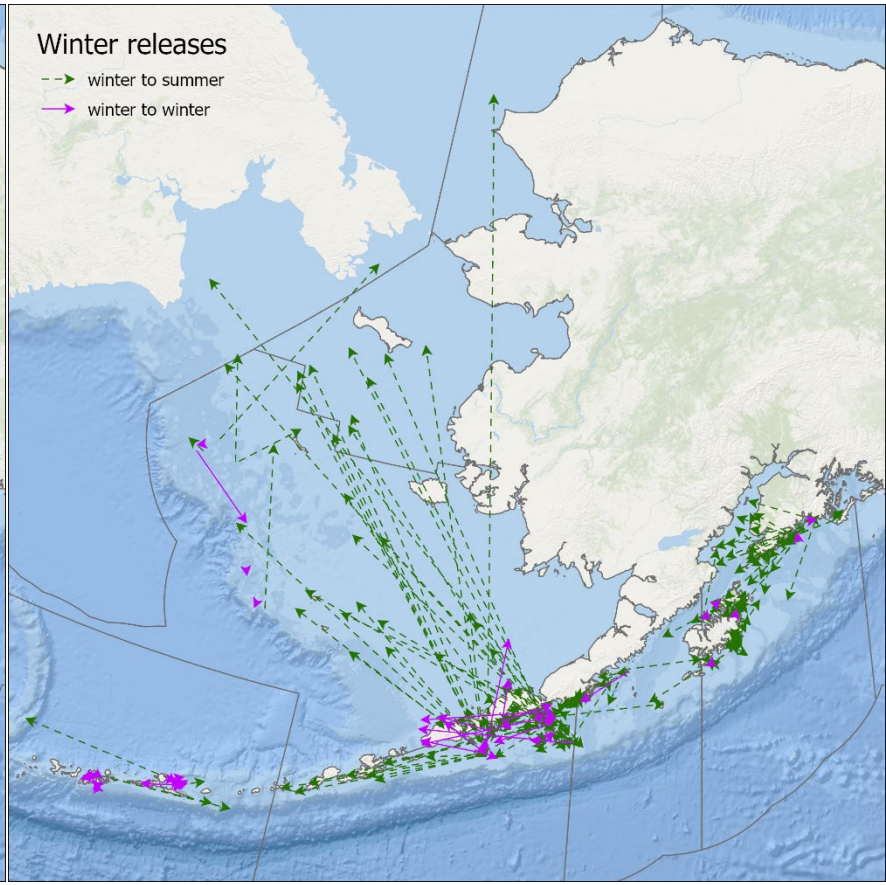


Pop-up Satellite Tagging 2019-2026



- Movement between Western GOA and Eastern Bering Sea is Seasonal
- Little movement between the Central and Western GOA





Feasibility of developing spatial models in Stock Synthesis for Pacific cod – explorations

Model structure (all models)

Two areas
WGOA and EBS/NBS

Two fishing fleets
WGOA and EBS/NBS

Two growth morphs

Base model

Model 26.1.2
Single catchability per survey
No movement

Catchability models (2)

Model 26.1.2.0
Catchability with random walk

Model 26.1.2.1
Catchability with mean bottom temperature covariate

Movement models (3)

Model 26.1.3.0
Constant movement

Model 26.1.3.1
Annual movement parameter with random walk

Model 26.1.3.2
Annual movement parameter with mean bottom temperature covariate

Data in the models

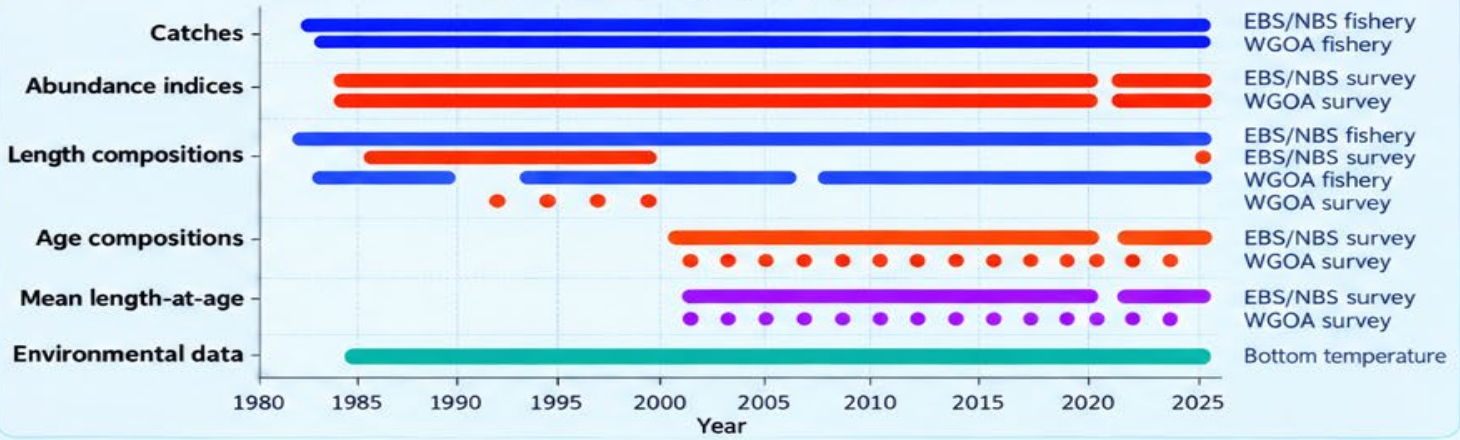
Survey indices
sdmTMB derived indices (WGOA & EBS/NBS)

Length and age composition
Design-based

Mean length-at-age
Survey design-based

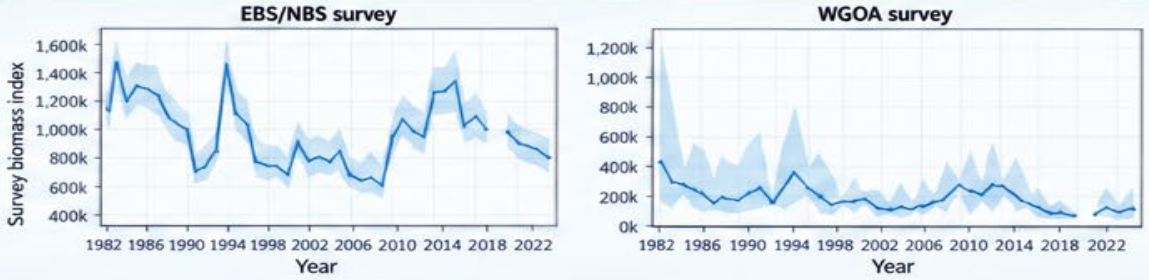
Tagging data
Not included

Data coverage in the models

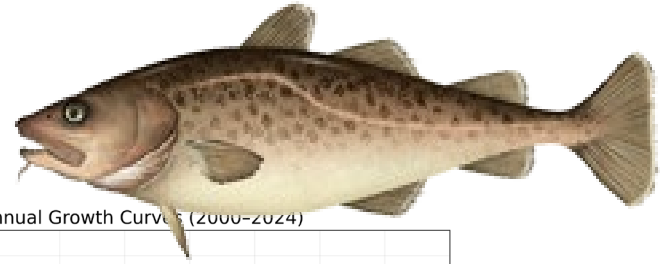


Survey indices (sdmTMB)

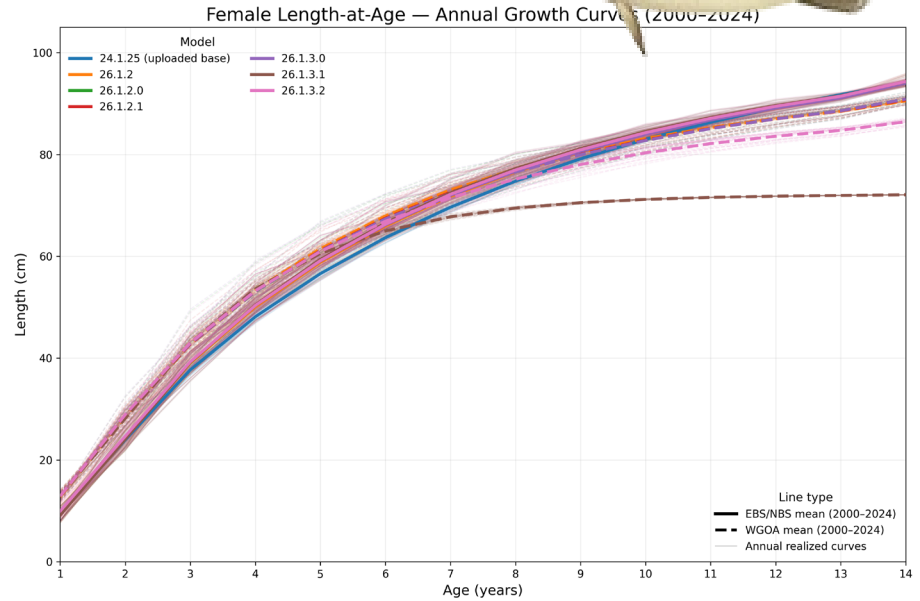
- Same methods presented last September, without the WBS data
- WGOA and EBS/NBS
- sdmTMB derived indices
- Single model with split biomass index
- Barrier mesh
- 1982–2024

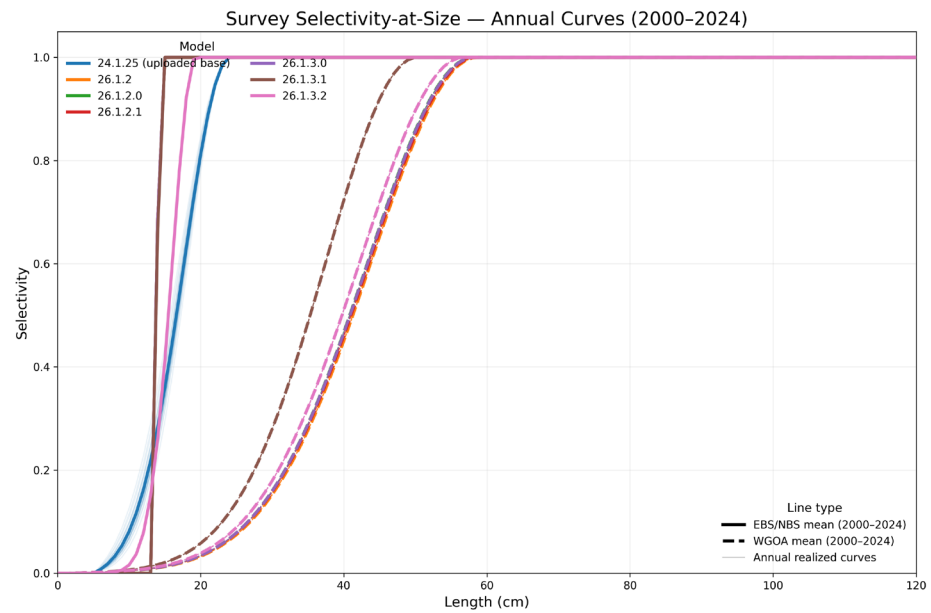


Stock Synthesis explorations



- Models predict faster growth but smaller asymptote for WGOA fish
- Growth is similar among models except:
  - Model 26.1.3.1 RW has smaller asymptote in WGOA.
- Survey selectivity has larger peak selectivity for WGOA
- Selectivity patterns similar among models except:
  - Model 26.1.3.1 differs from other models with smaller peak selectivity for WGOA





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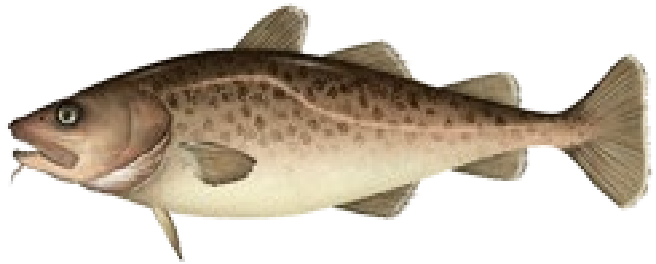
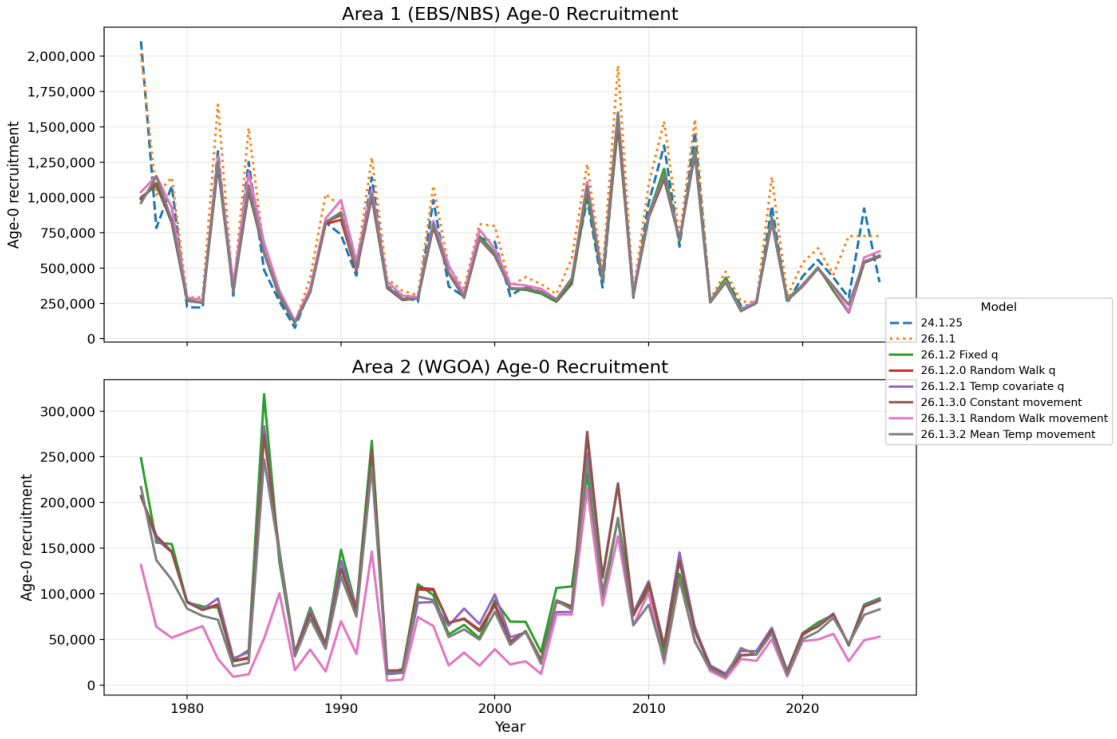
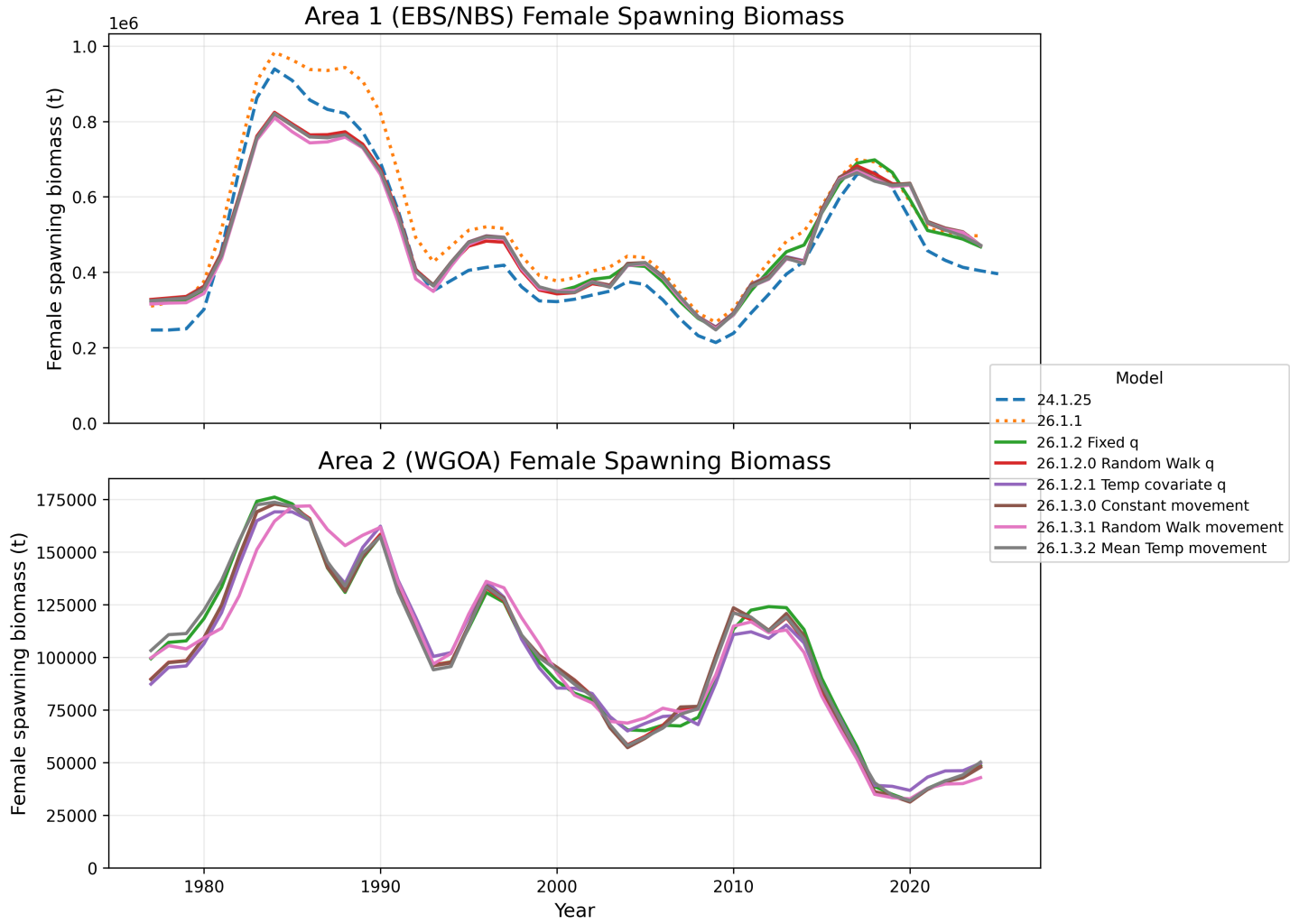


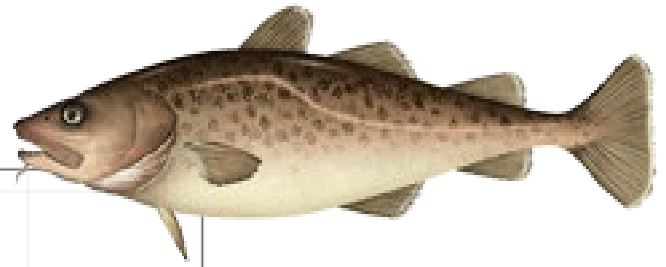
- Little difference in results among models

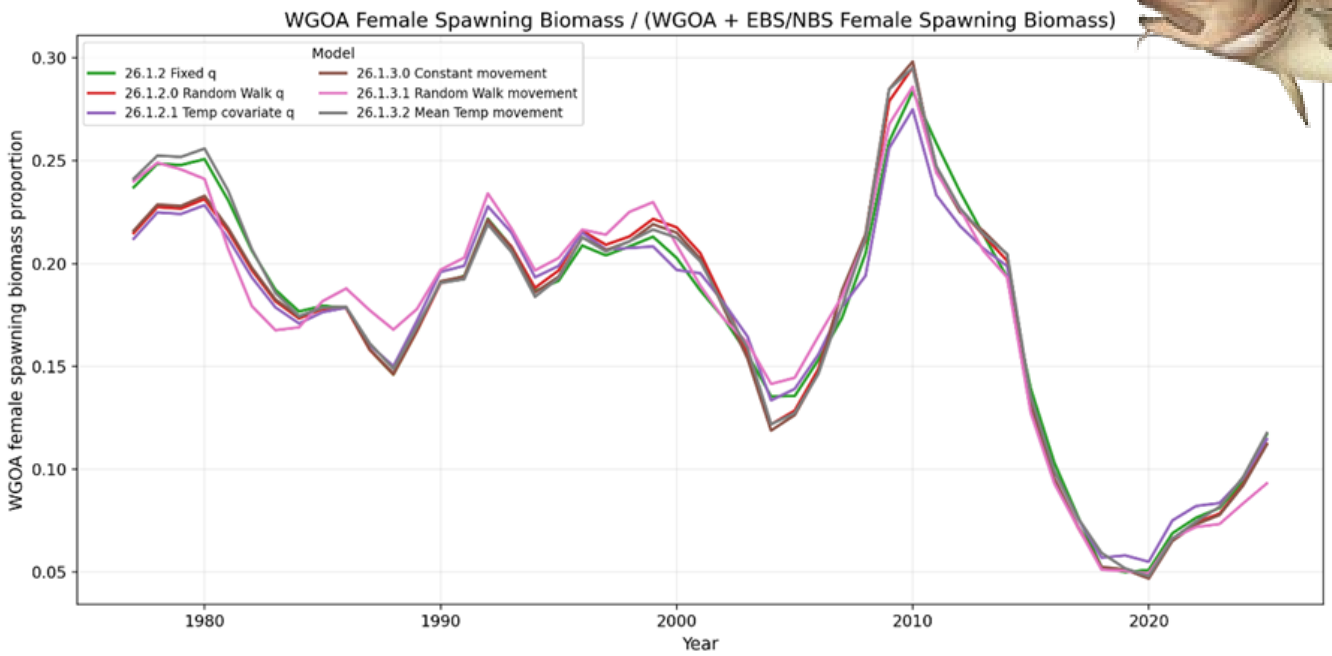


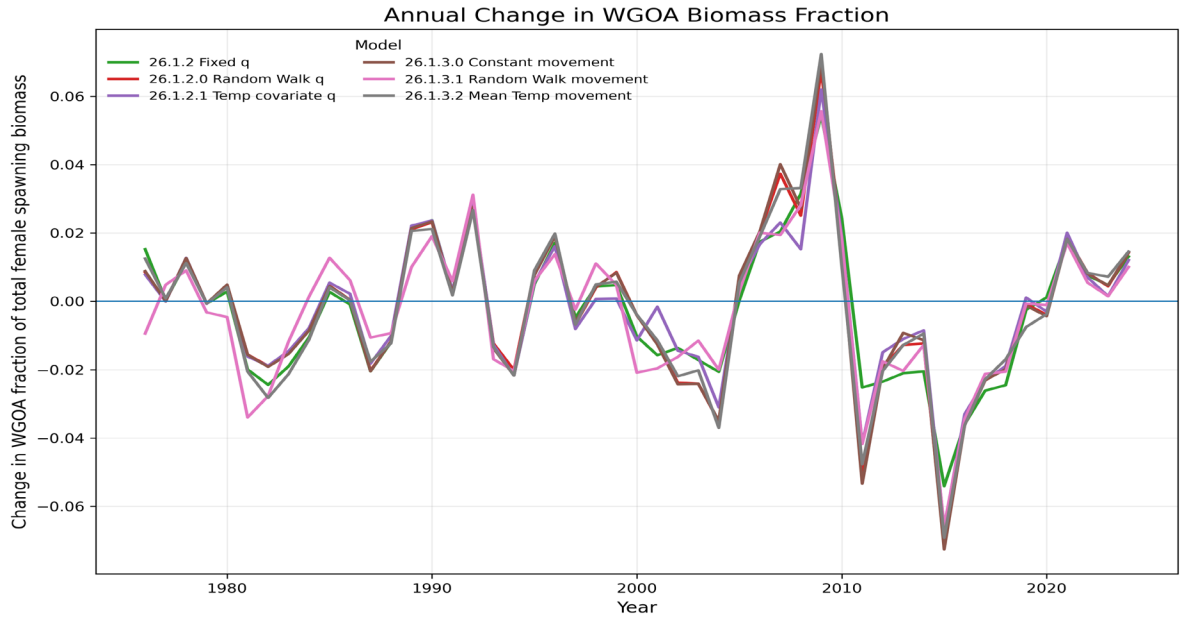


Proportionality

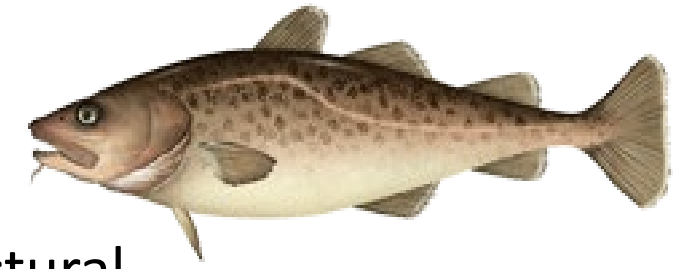
- Little difference among model results
- 5-30% of spawning biomass in the Western GOA



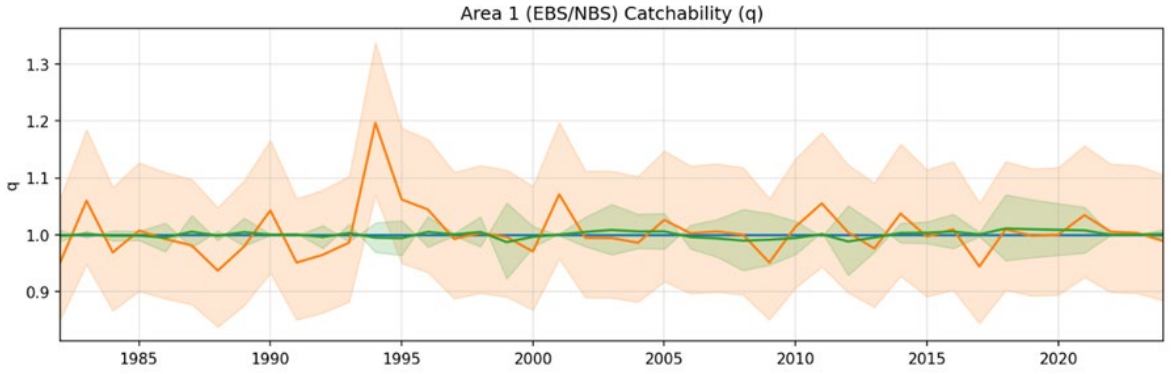


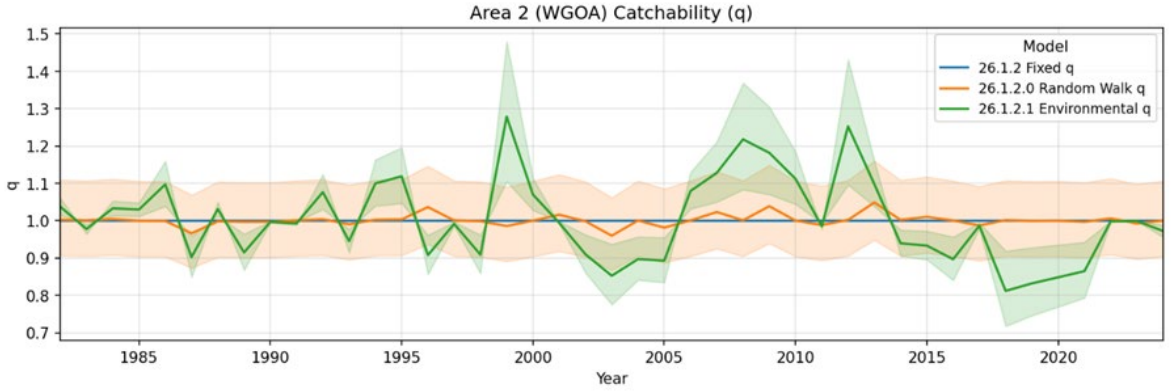


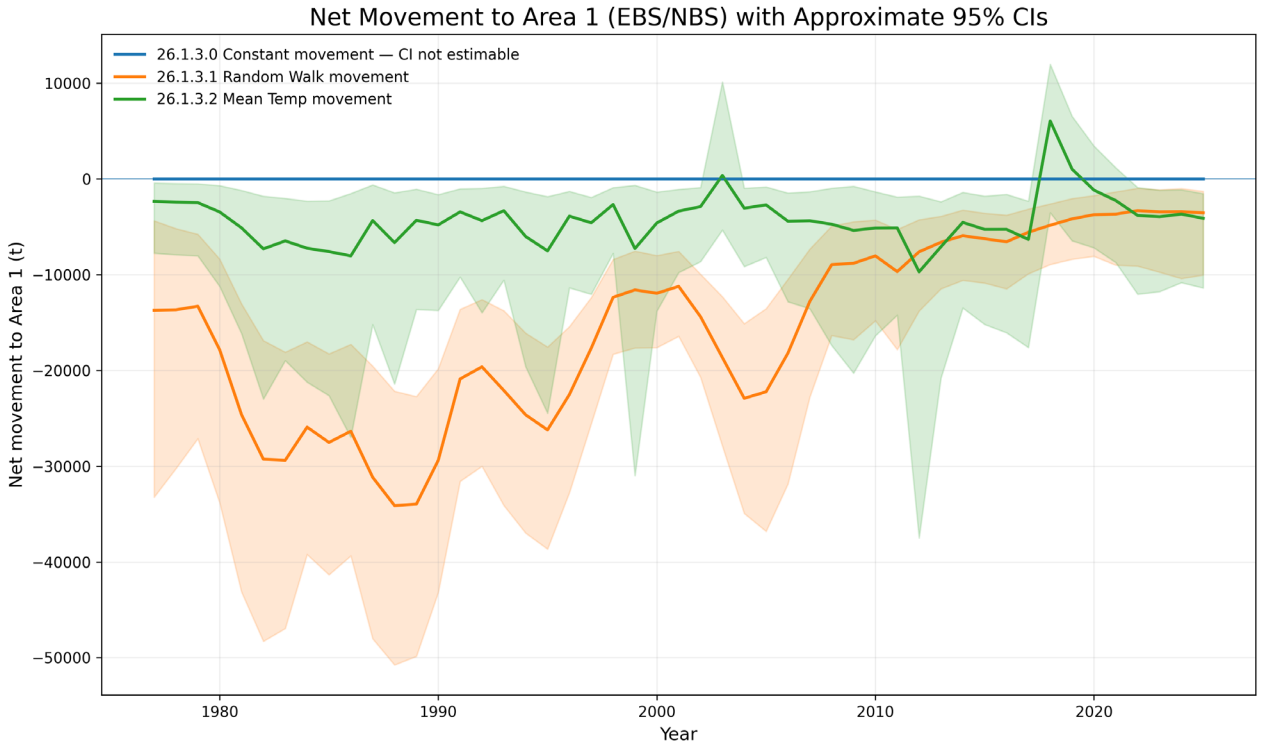
Catchability or movement?



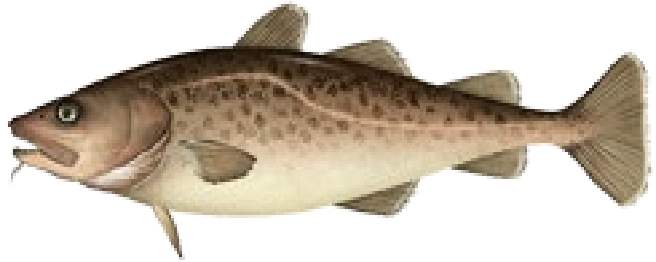
- Agreement in spatial state among models but substantial structural uncertainty in spatial mechanism





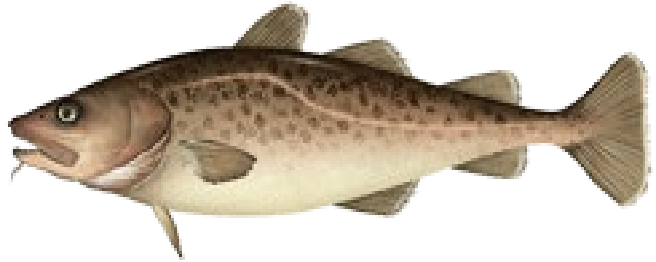


Limitation of Stock Synthesis?



- These models are finding multiple ways to explain essentially the same data. Changes or discrepancies in indices and composition can be absorbed by q, movement, recruitment allocation, and growth or selectivity.
- In Stock Synthesis there is no easy ways to rigorously test among various hypothesis on how spatial processes impact stock dynamics.
- Stock Synthesis demonstrates that a two-area Pacific cod model is feasible, but the current explorations reveal substantial confounding among catchability, movement, recruitment allocation, growth, and selectivity. A spatial-first RTMB framework such as SPoRC may provide a more flexible and sustainable platform for resolving these hypotheses, incorporating direct movement data, and developing the model further.

Twelve reasons to move to SPoRC and away from Stock Synthesis

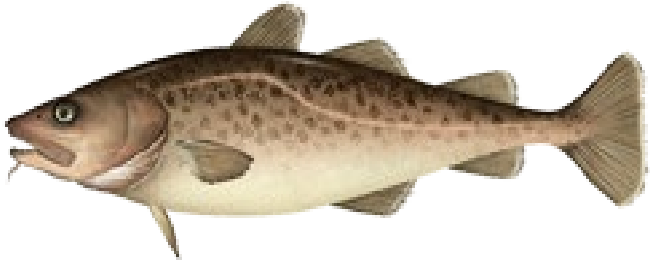


- **ADMB is a legacy dependency with limited future development.**
  - The ADMB Foundation announced retirement from active development, with the goal of leaving a stable release that can continue compiling existing models such as Stock Synthesis.

- **SPoRC was designed as a spatial model from the outset.**
  - Multi-region, age-, sex-, and time-varying population processes are core design features rather than additions to a predominantly general-purpose integrated assessment framework. It supports flexible regional structures, recruitment allocation, fleet structures, and connectivity assumptions.

- **Stock Synthesis can do spatial models, but the implementation becomes complicated quickly.**
  - SS requires area-specific fleets/data, recruitment-distribution decisions, movement definitions, and often growth morphs to represent regional biological differences.

Twelve reasons to move to SPoRC and away from Stock Synthesis

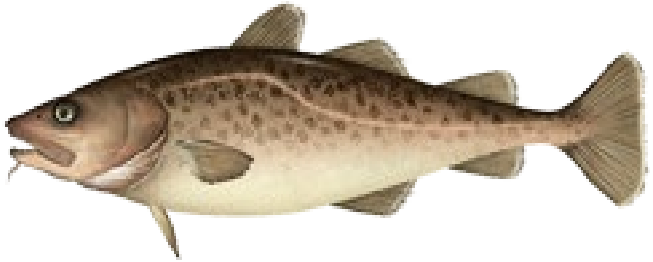


- **Random effects are much more natural in RTMB/TMB.**
  - Allows more direct testing of spatial and movement processes: annual movement, annual catchability, recruitment allocation, and environmental effects. TMB was developed with efficient Laplace approximation for random effects, whereas SS/ADMB requires implementing these processes through large sets of annual deviation parameters and penalties.

- **A state-space formulation is a better conceptual match for time-varying spatial processes.**
  - Rather than treating annual movement or catchability variation primarily as fixed annual parameters with penalties, SPoRC explicitly supports stochastic time-varying processes as random effects.

- **It should be easier to separate competing hypotheses about spatial dynamics.**
  - We can explicitly formulate models such as “distribution changes through recruitment,” “distribution changes through movement,” “survey availability changes through q,” or combinations of these, while keeping the rest of the model structure more directly comparable unlike Stock Synthesis.

Twelve reasons to move to SPoRC and away from Stock Synthesis

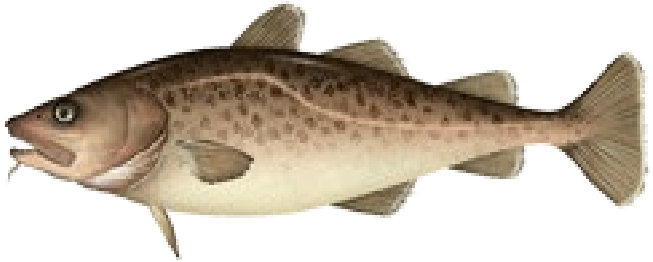


- **The code is more transparent and easier to modify.**
  - SPoRC is implemented in R/RTMB, putting much more of the model in a language assessment scientists already use. That lowers the barrier to inspecting equations, adding a new movement function, changing an environmental relationship, or testing a new likelihood. Accessibility, collaboration, and knowledge transfer are explicitly stated as design goals.

- **Better suited to team development.**
  - A modular R package can be version-controlled, unit-tested, reviewed, and extended without requiring most assessment scientists to understand the internals of ADMB or the very large Stock Synthesis codebase.

- **Tagging data fit naturally into the spatial framework.**
  - SPoRC was designed to integrate catch, indices, compositions and tagging.

Twelve reasons to move to SPoRC and away from Stock Synthesis



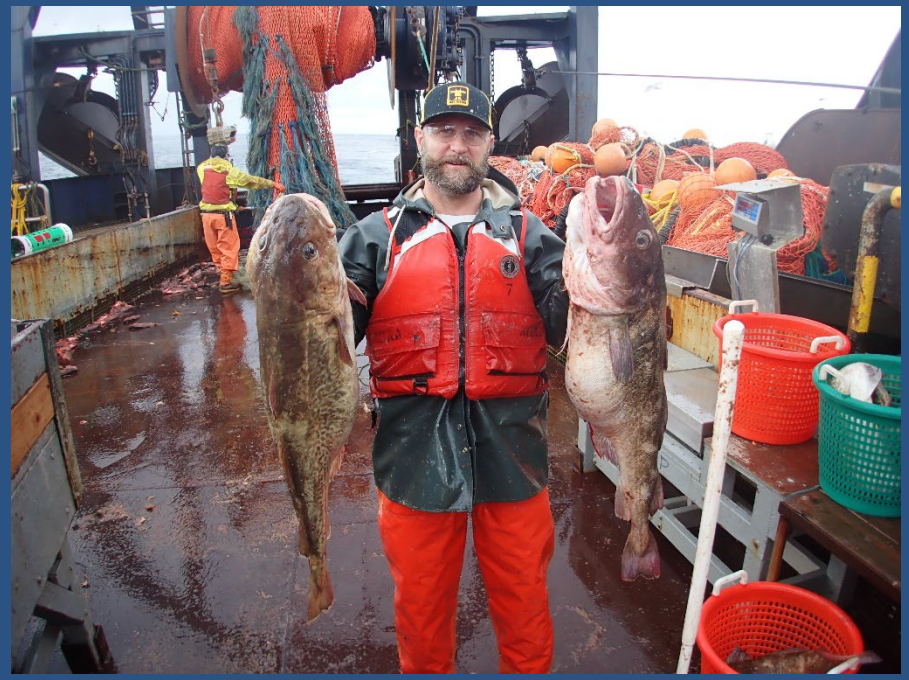
- **Simulation and MSE are built into the philosophy of the platform.**
  - SPoRC includes simulation and closed-loop evaluation, making it much easier to ask whether your proposed spatial model can actually recover movement, recruitment allocation, and q under known truth before using it operationally.

- **Uncertainty estimation is more flexible.**
  - RTMB/TMB supports delta-method uncertainty and efficient random-effects integration, while SPoRC can also interface with NUTS/MCMC for Bayesian estimation when the likelihood surface is highly nonlinear.

- **It is better aligned with where assessment software development is going.**
  - TMB/RTMB-based approaches are now used in frameworks such as SAM, WHAM, FIMS, and SPoRC, particularly because of random-effects and state-space capabilities.

Western GOA Pcod assessment research

September 2026 Plan Team



Outline

1. What is SPoRC?
2. Model/Data set up
3. Model/Data scenarios
4. Data exploration
5. Next steps/timeline
6. ***Things to consider***

What is SPoRC?

- Stochastic (S) Population (P) over (o) Regional (R) Components (C)
- Stock assessment platform written in R and RTMB
- Statistical catch-at-age model w/ *spatial*, sex, and fleet-structure
  - Supports random effects (Laplace Approximation) and Bayesian inference (rstan)
- R package that includes model fitting, comprehensive stock assessment model diagnostics, and simulation tools

The SPoRC stock assessment package: A generalized next-generation platform to assess spatial, age, and sex-structured populations

Matt Cheng, Dan Goethel, Curry Cunningham, Pete Hulson, Jim Ianelli, Kristen Omori

NOAA National Stock Assessment Seminar

7/2/2026

UAF COLLEGE OF FISHERIES AND OCEAN SCIENCES
University of Alaska Fairbanks

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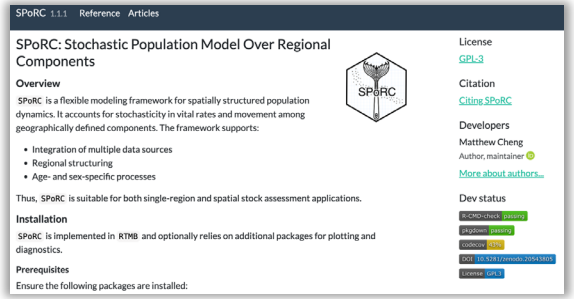
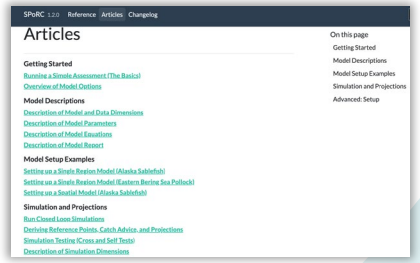
https://chengmatt.github.io/SPoRC/





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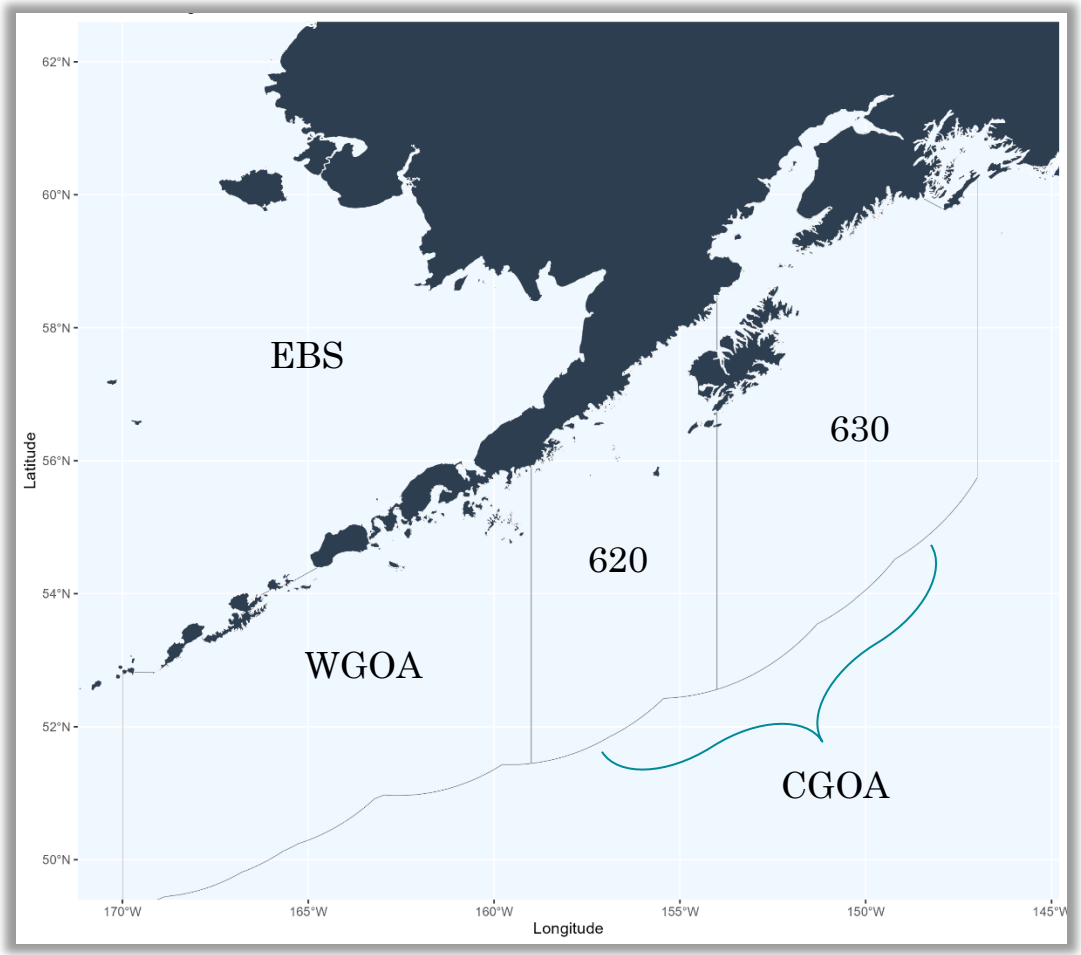
Model/Data set up

1. How do we think about populations and sub-populations?
2. Where do we draw the lines?



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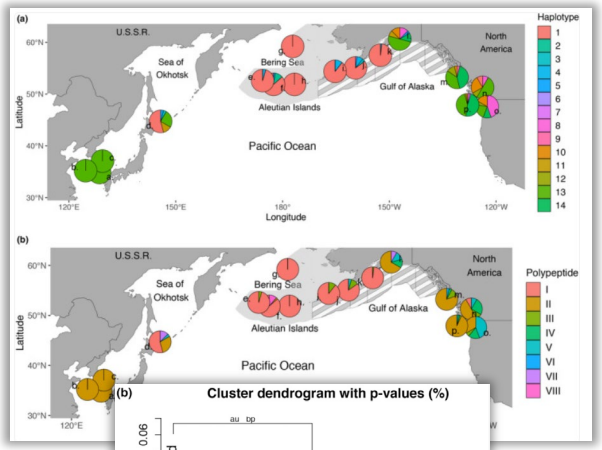
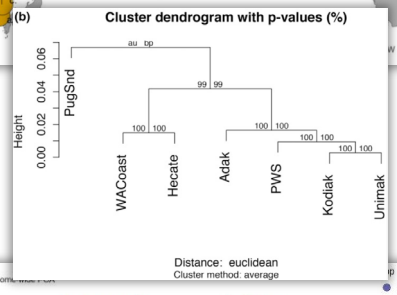
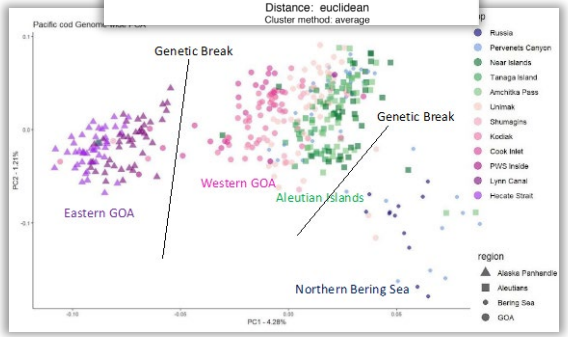
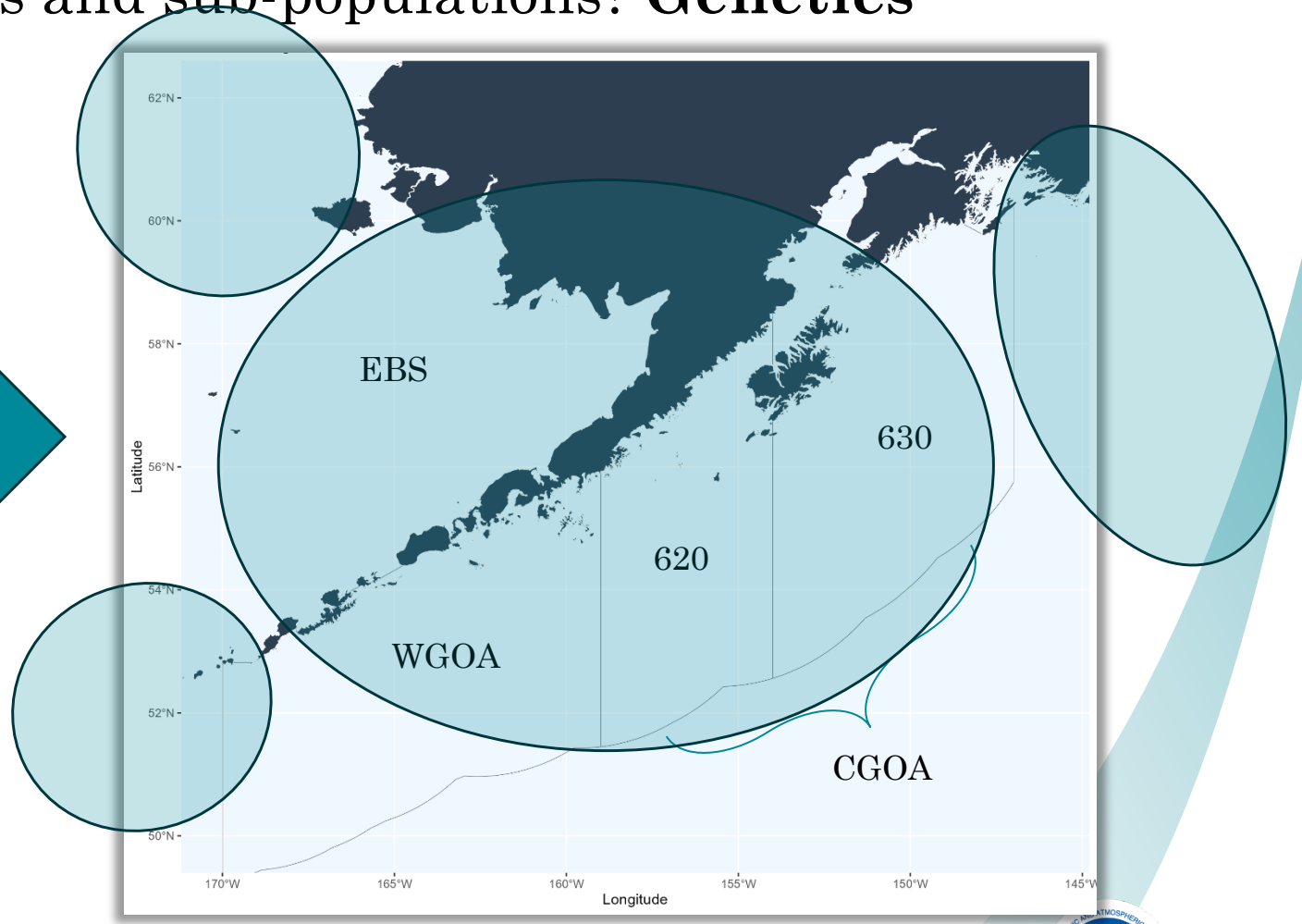
Model/Data set up

- How do we think about populations and sub-populations? **Genetics**





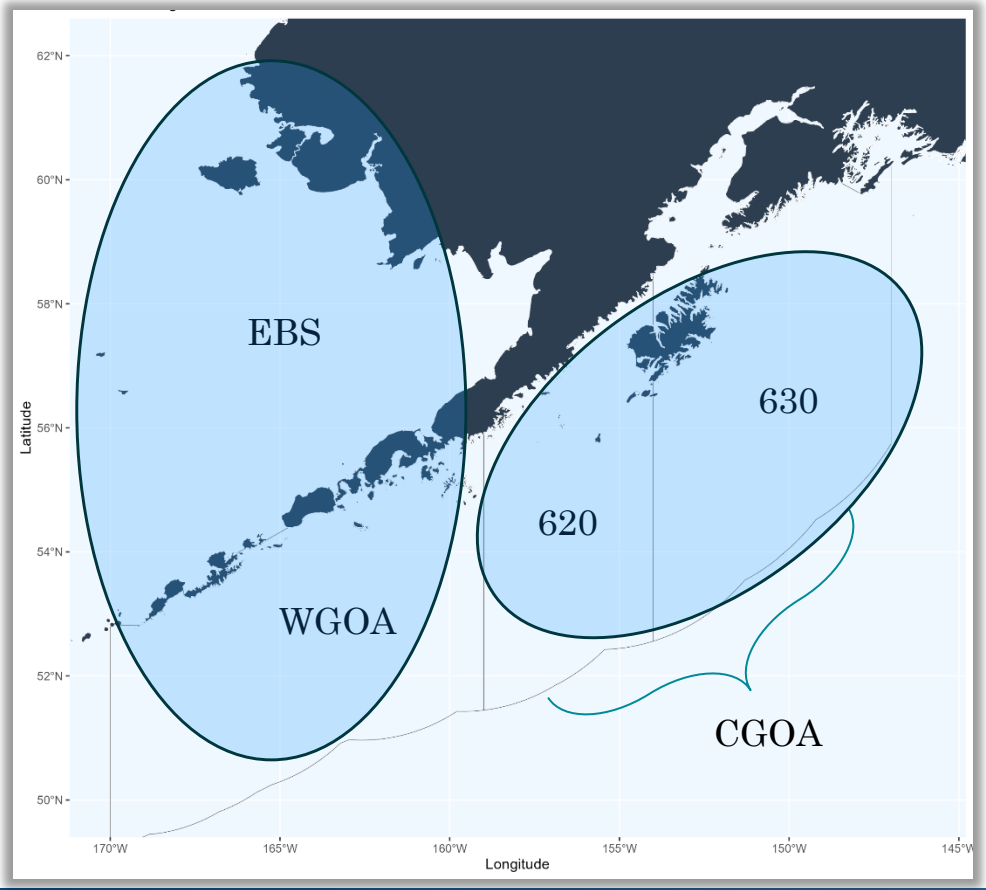




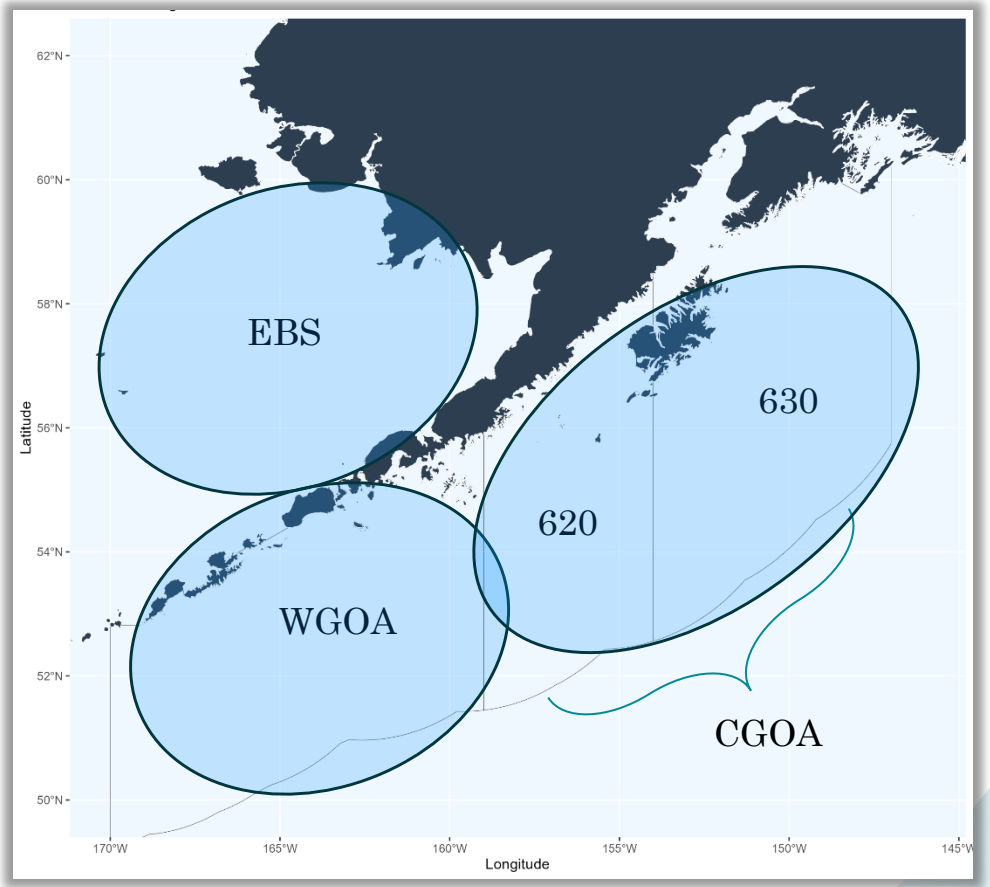
Model/Data set up

- How do we think about populations and sub-populations? **Movement**

Case 1: 2 Sub-populations based upon overall movement exchange

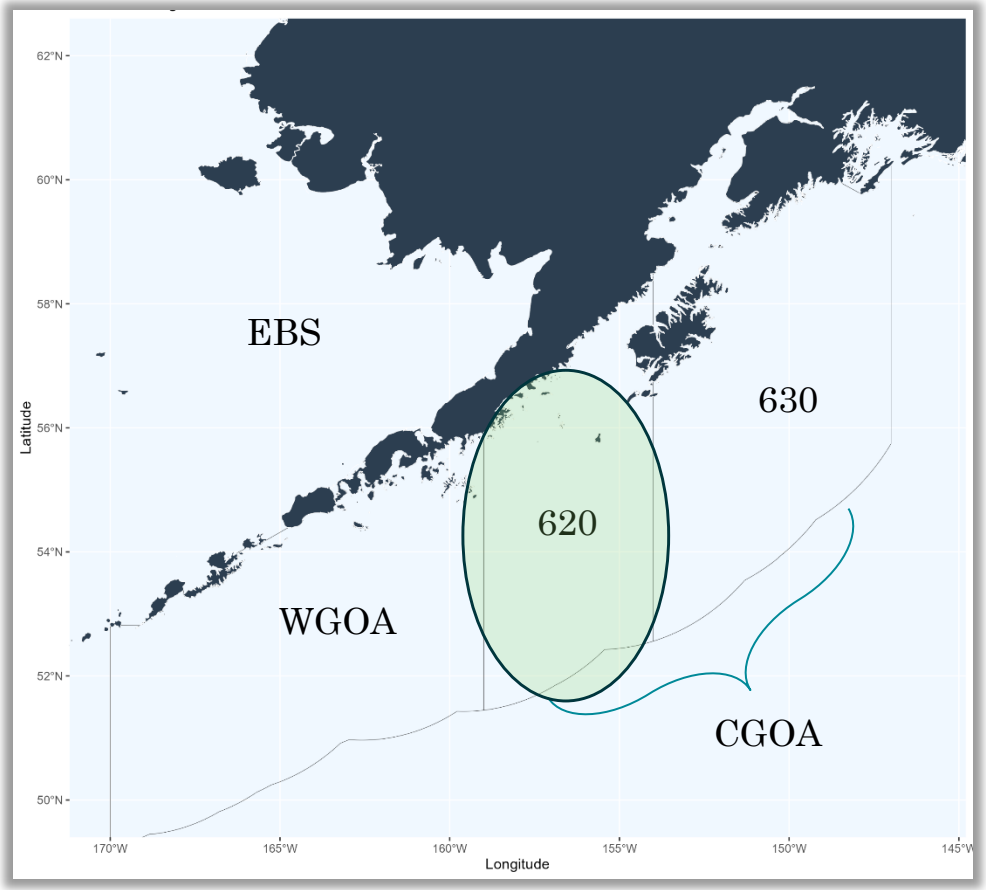


Case 2: 3 Sub-populations based upon seasonal movement exchange



Model/Data set up

- Where do we draw the lines?



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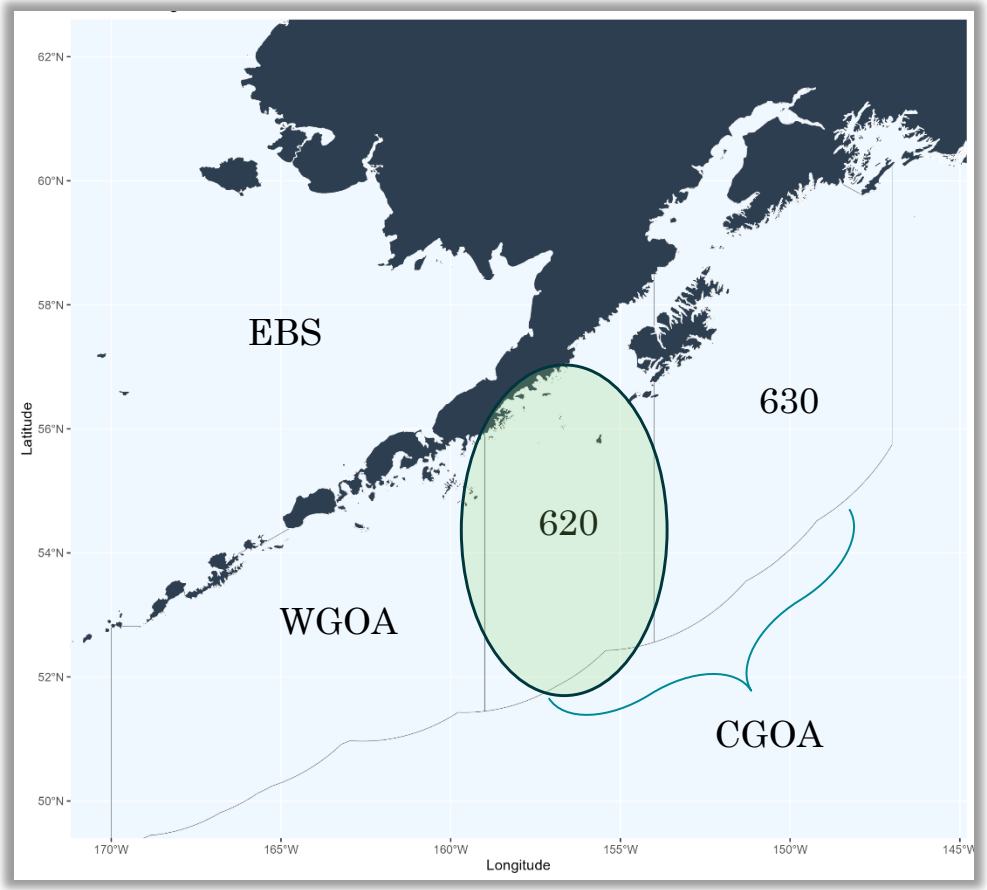
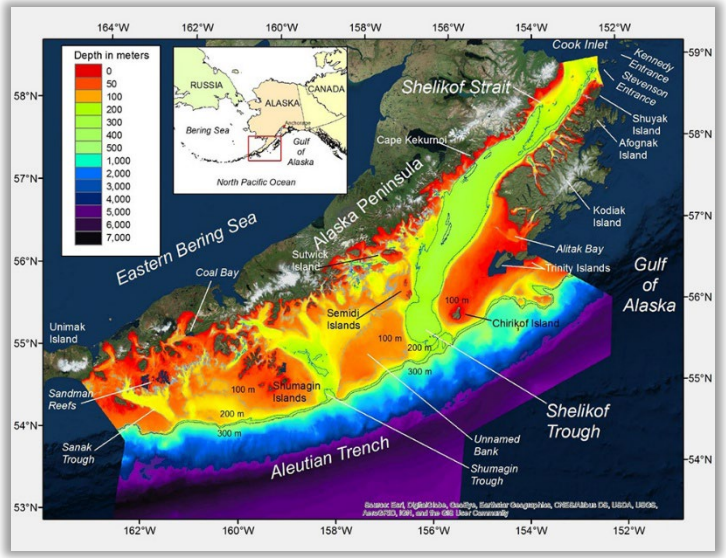
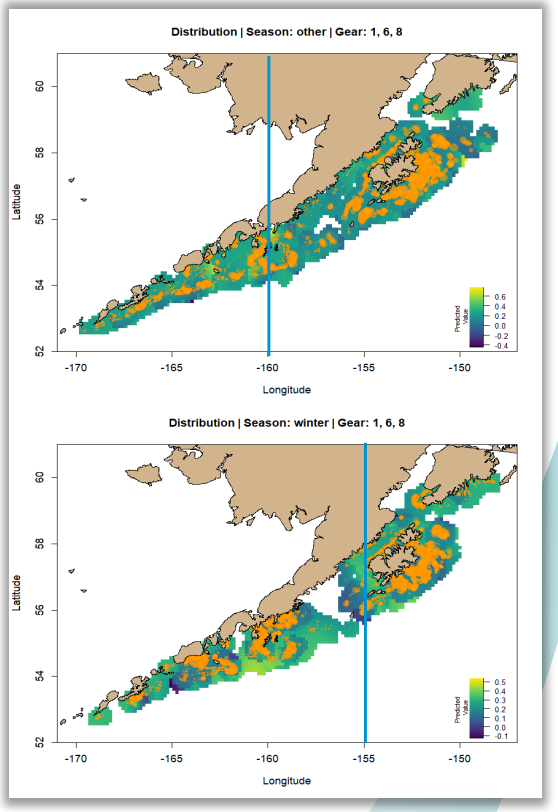
Model/Data set up

- Where do we draw the lines? **Fishery data (Rebecca Howard)**

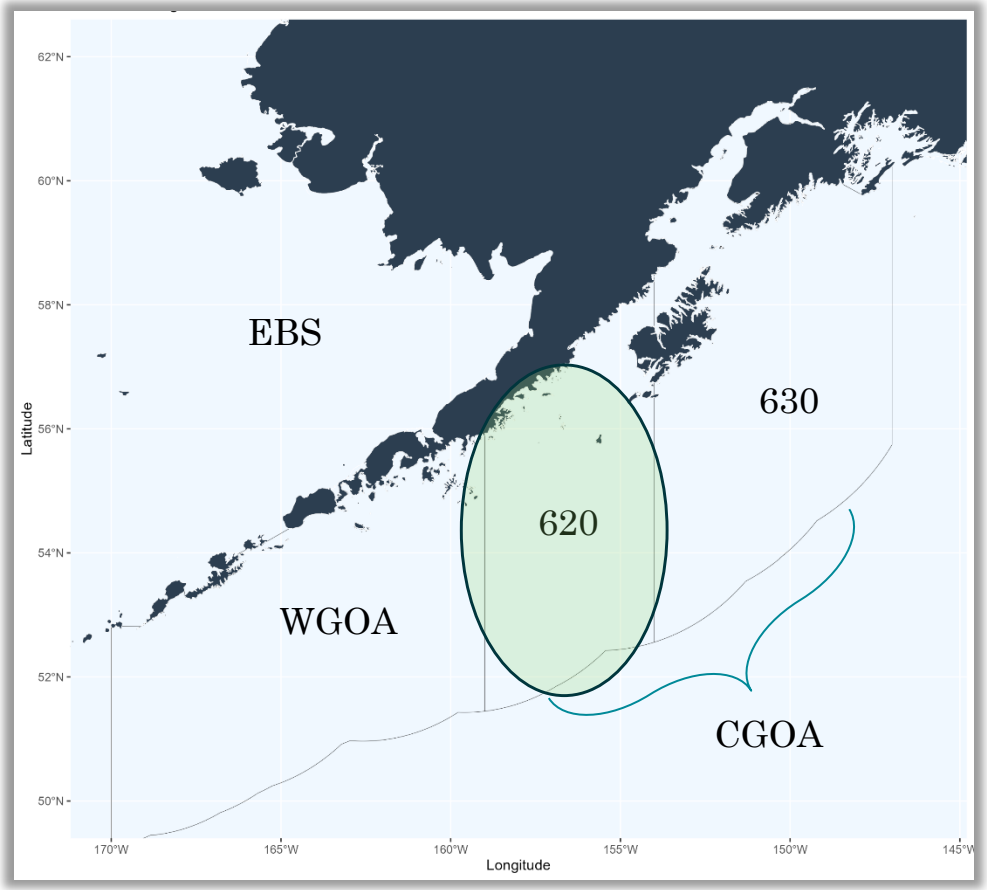


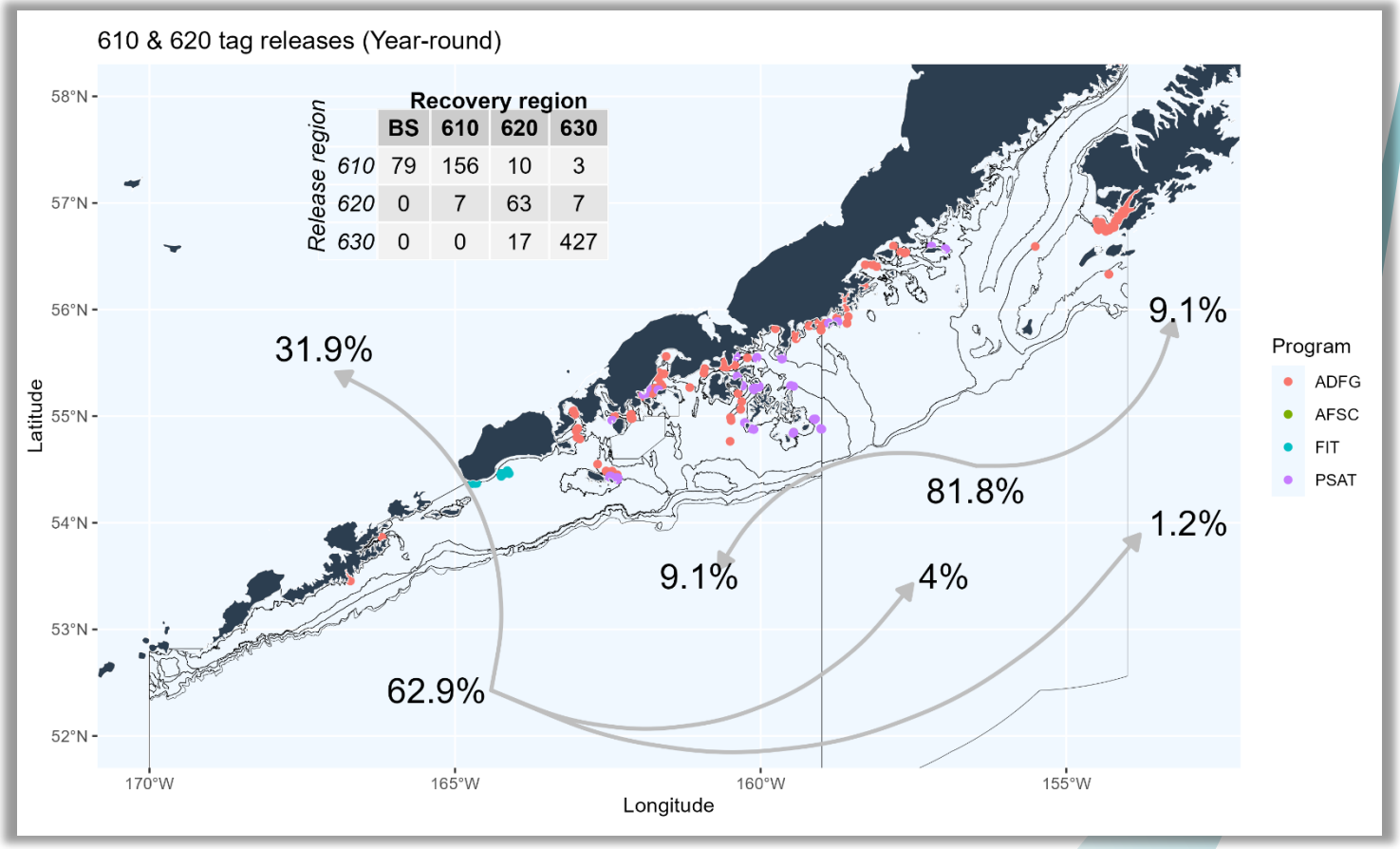




Model/Data set up

- Where do we draw the lines? **Tagging data**





Model/Data set up

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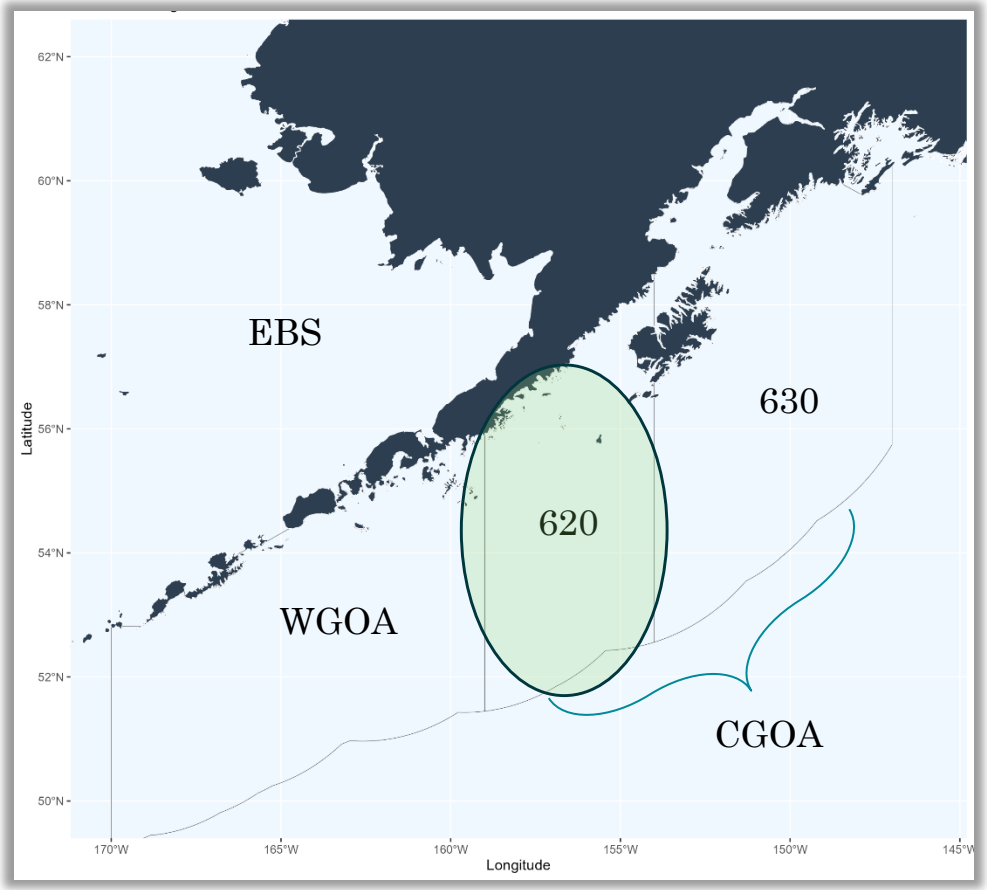

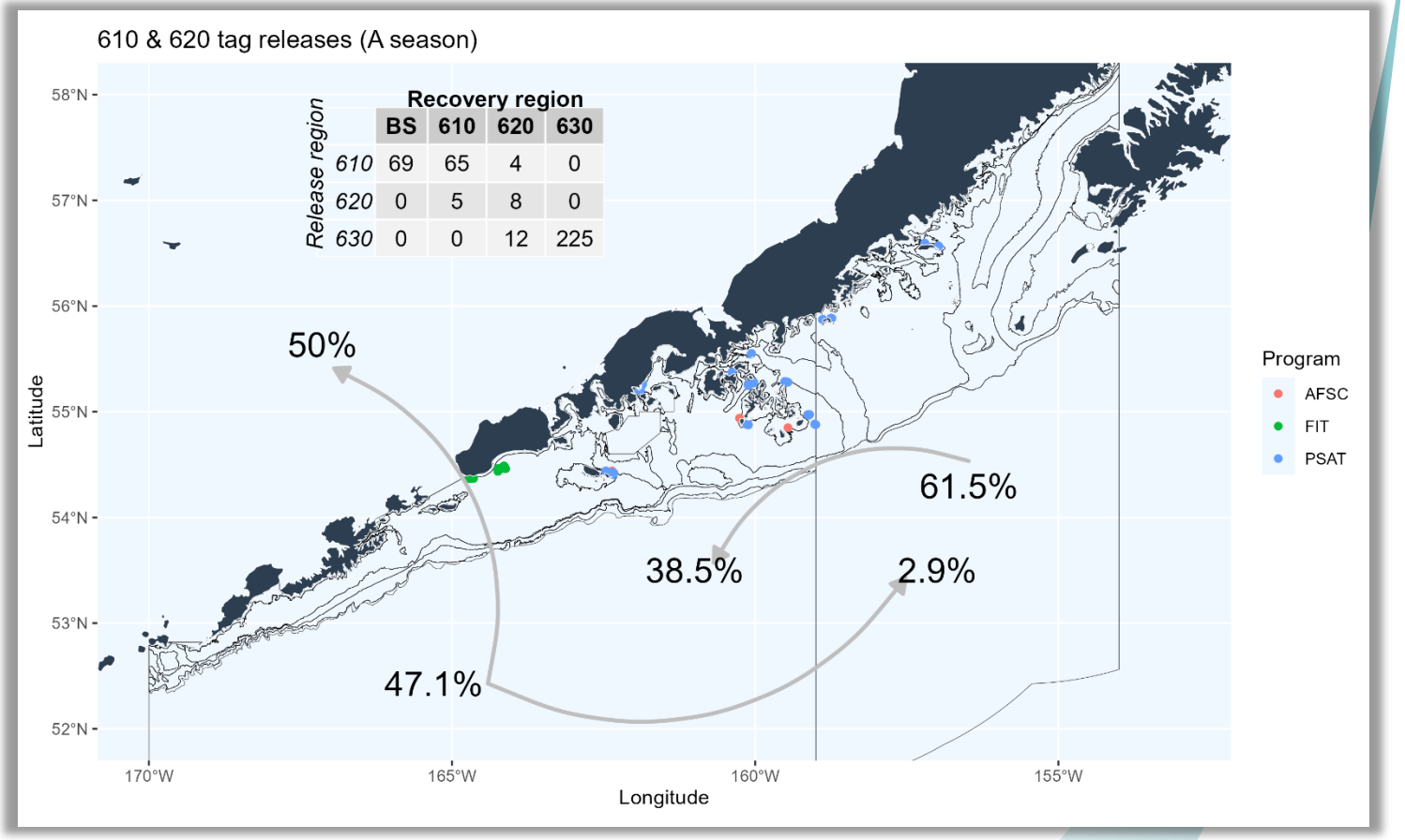

Model/Data set up

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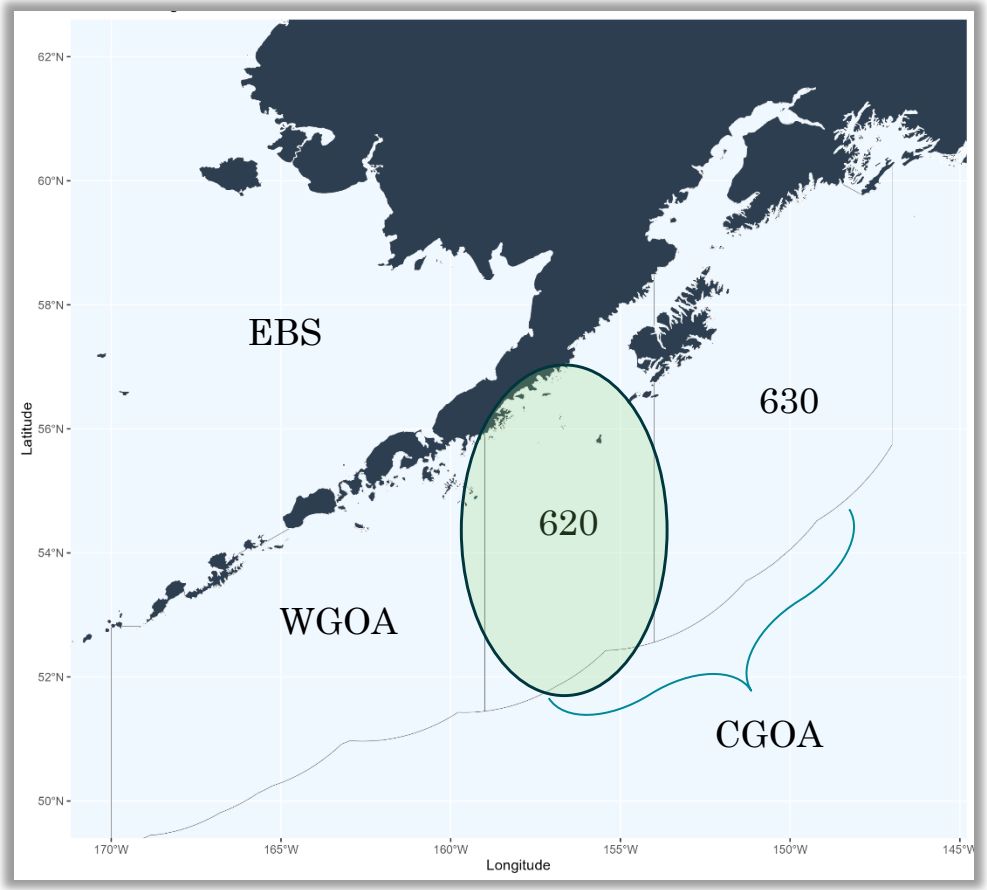
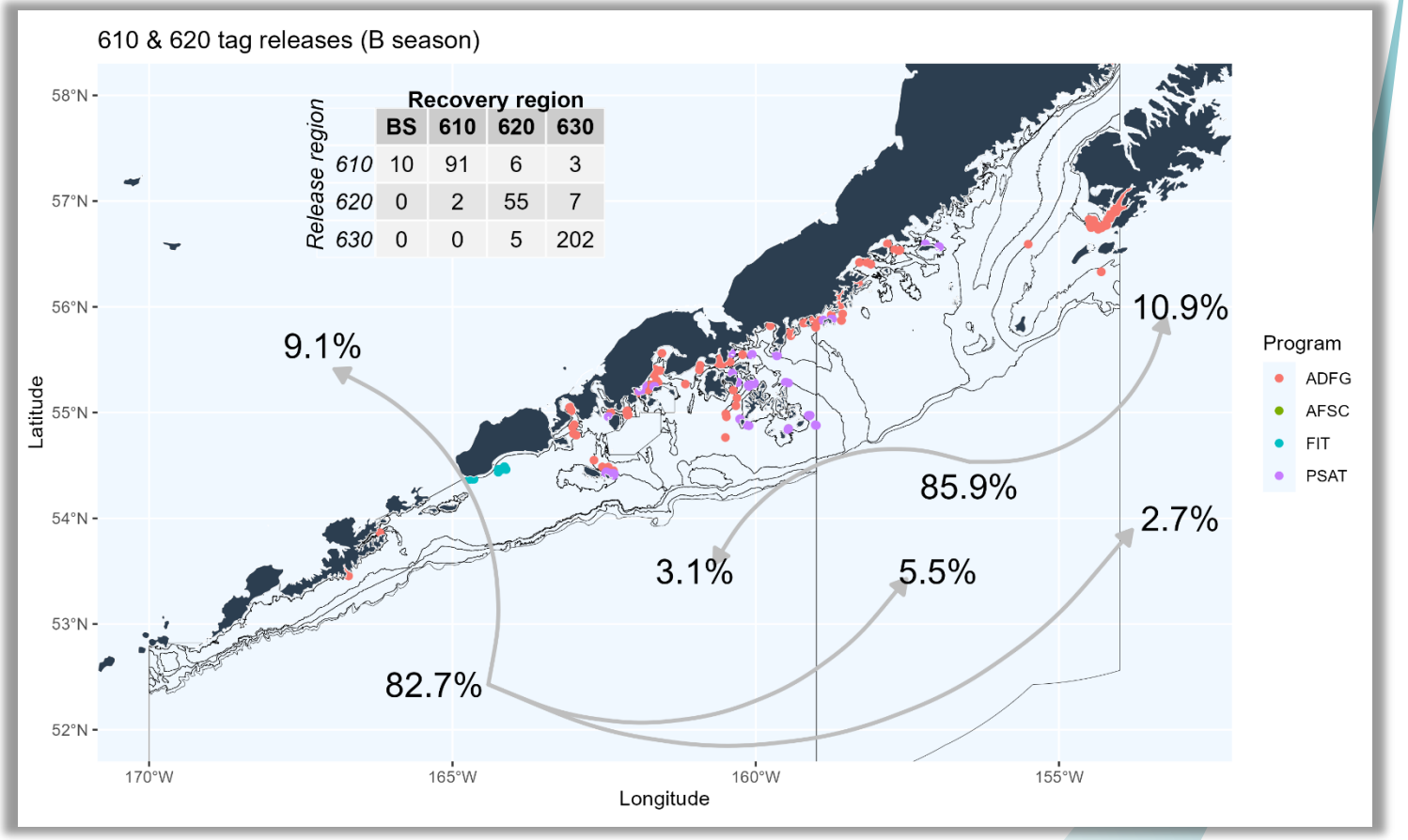
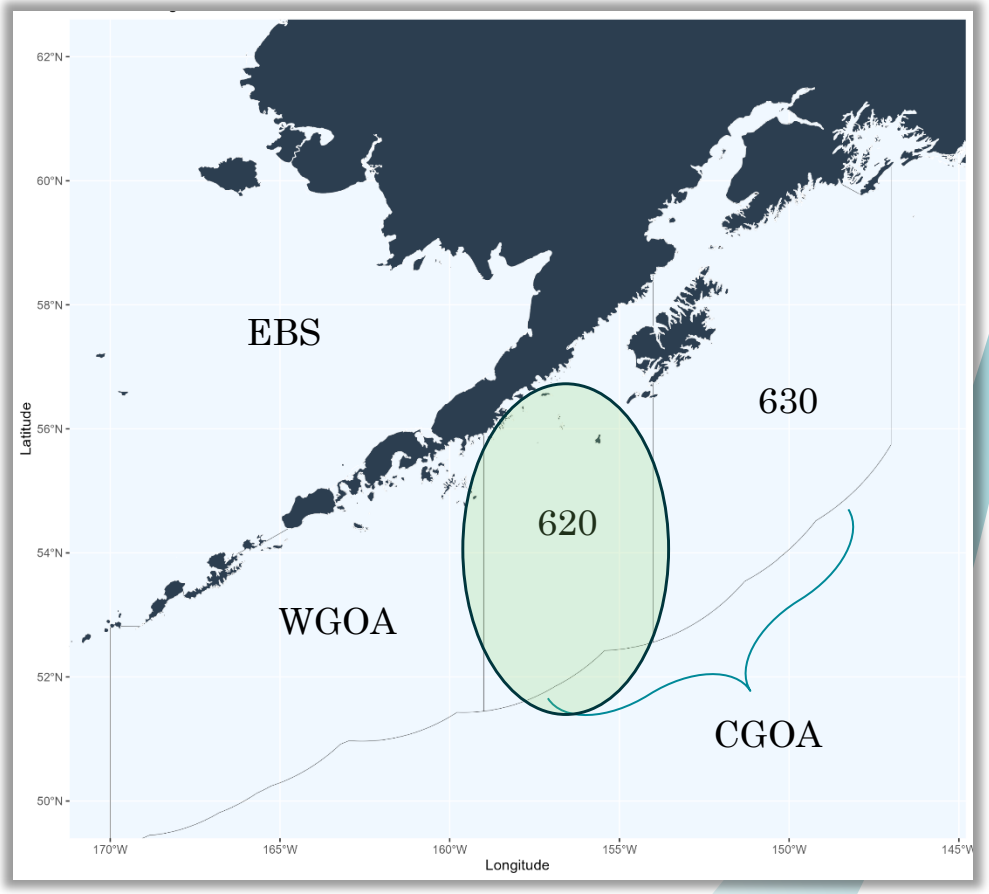




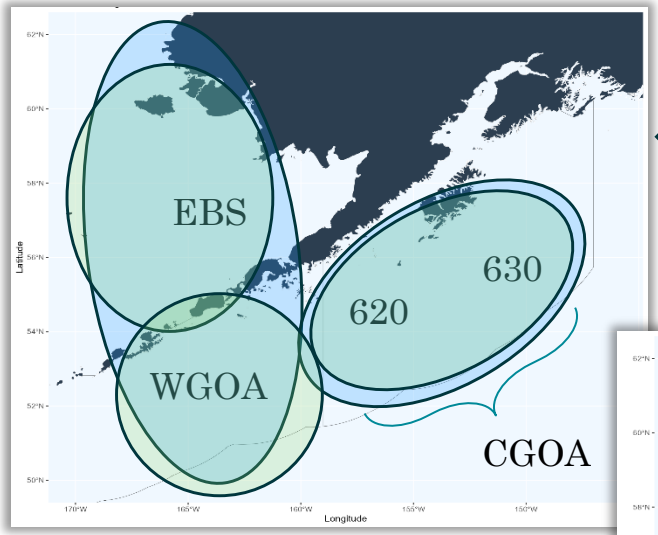
Model/Data set up

- Where do we draw the lines?
- Hard to know what to do with 620, and where to draw line defining the edge of the Central GOA sub-populations
- 2 cases for defining regions:
  - Case 1: Define 620 & 630 as Central GOA, 610 as Western GOA (status quo)
  - Case 2: Define 630 as Central GOA, 610 & 620 as Western GOA

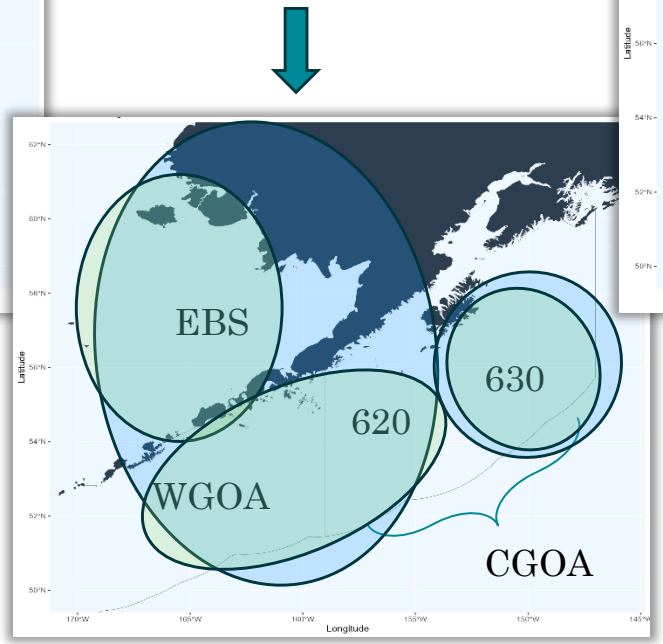


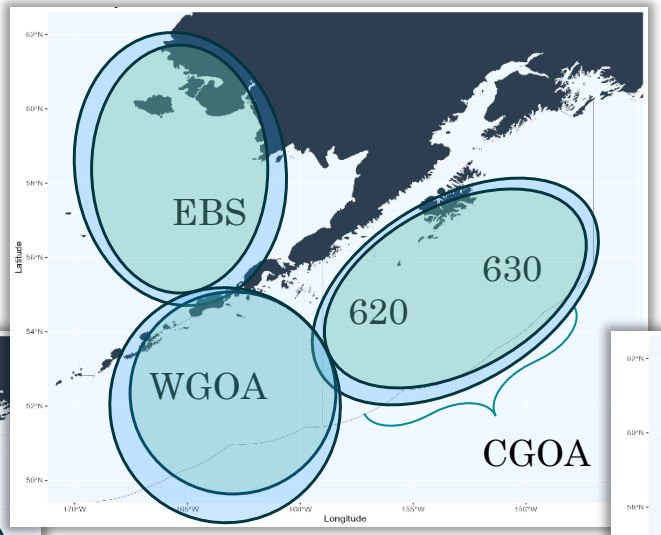
Model/Data scenarios

- Combination of 4 cases: 2 sub-population x 2 regional

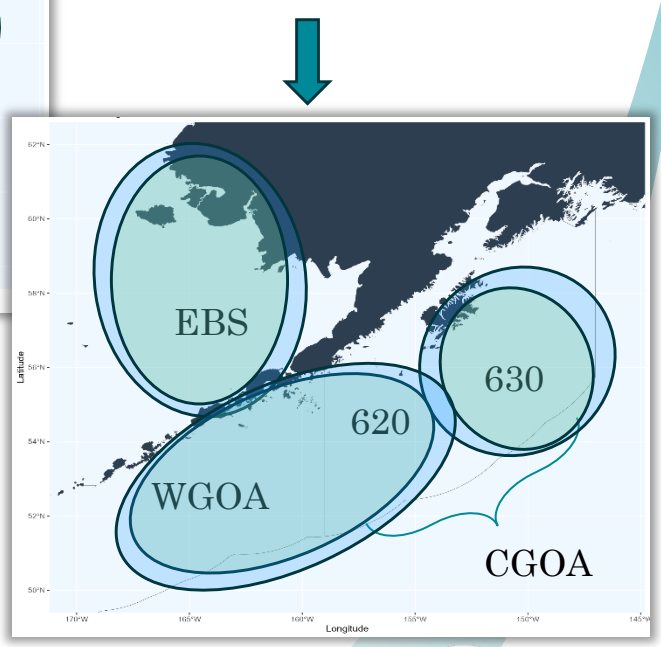


2 sub-pop'n,
3 region



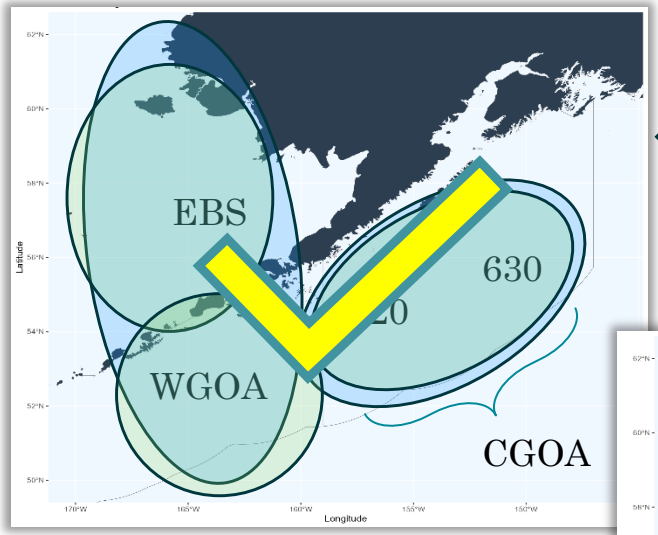


3 sub-pop'n,
3 region

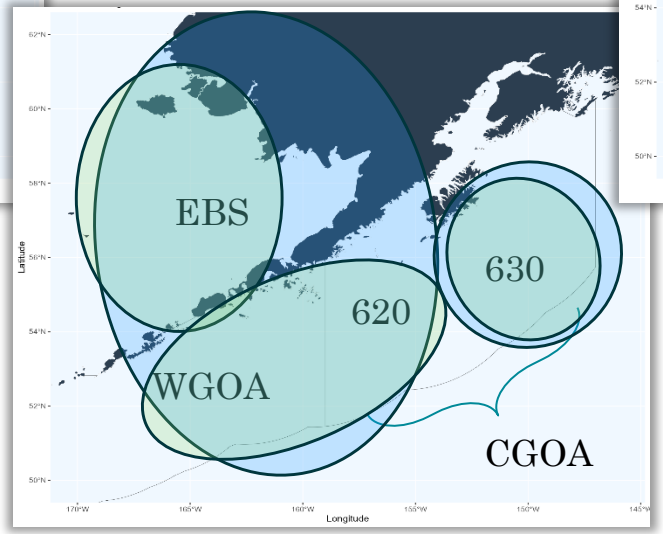


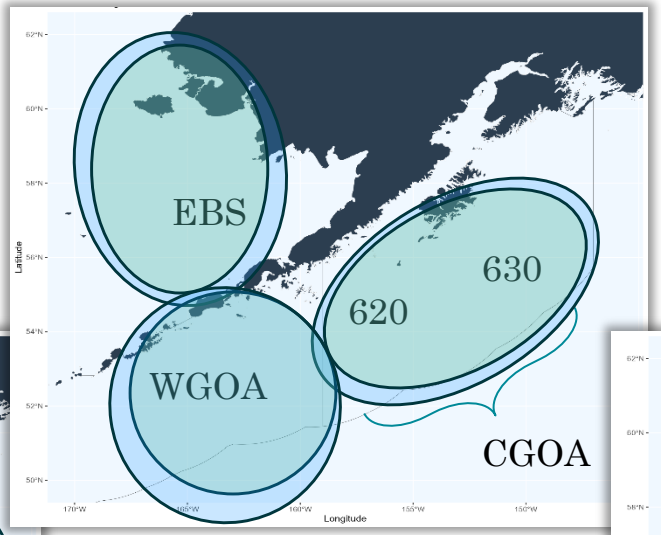
Model/Data scenarios

- Combination of 4 cases: 2 sub-population x 2 regional

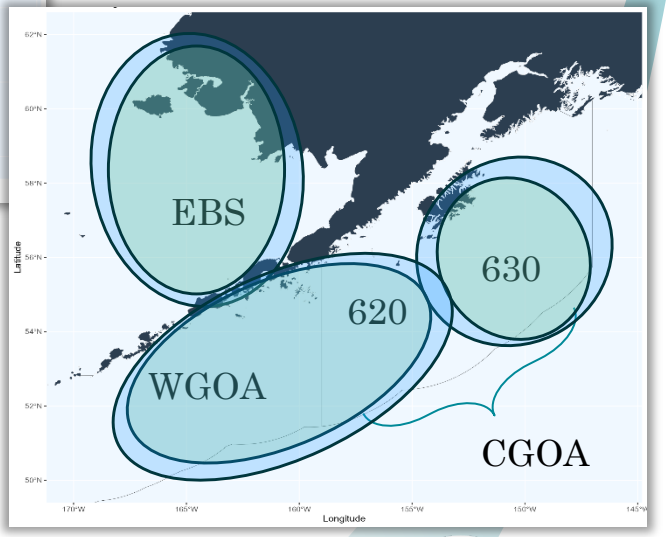


2 sub-pop'n,
3 region





3 sub-pop'n,
3 region



Data explorations

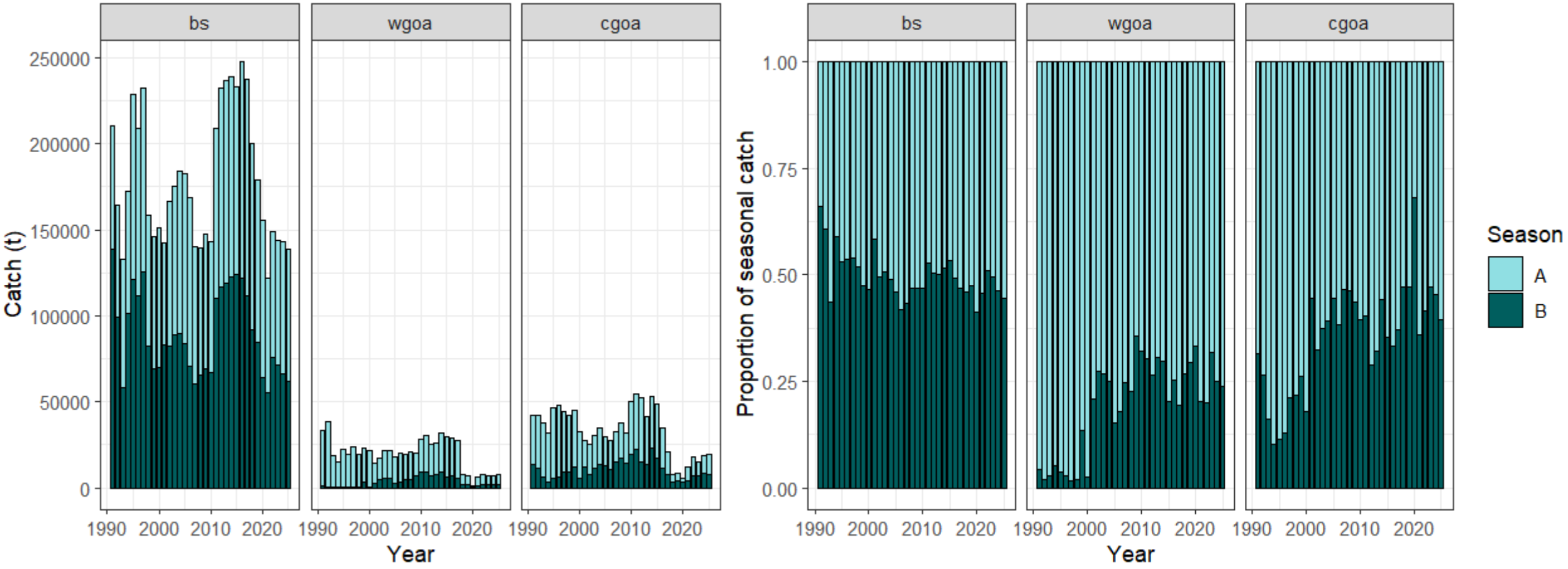
- Fitted data sources:
  - Catch: by season (A – Jan-Mar, B – Apr-Dec) and region (EBS, WGOA, CGOA)
    - Note: can only split back to 1991, set as model start year
  - Index: Summer bottom trawl survey by region
    - Note: Plan to add longline survey for GOA, mix of model-based (EBS) and design-based (GOA)
  - Composition: Age and length (when age not available) for fishery (seasonal) and survey (summer/B season)
    - Note: plus age-10+, 5 cm length bins

Data explorations

- Other data sources:
  - Growth: empirical weight/size-at-age, seasonal and regional
    - Notes:
      1. Time-invariant, looking into time-dependent for EBS
      2. Little data available in A season to inform growth, particularly in GOA. Used SS3 beginning of year estimate from operational assessments to offset summer (mid-year) data from survey
  - Maturity: taken directly from operational assessments (regional, WGOA = CGOA)
  - Ageing error: taken from assessments
    - Note: Ageing bias also implemented as in operational assessment, will discuss/explore regionally aggregated ageing error with collaborators

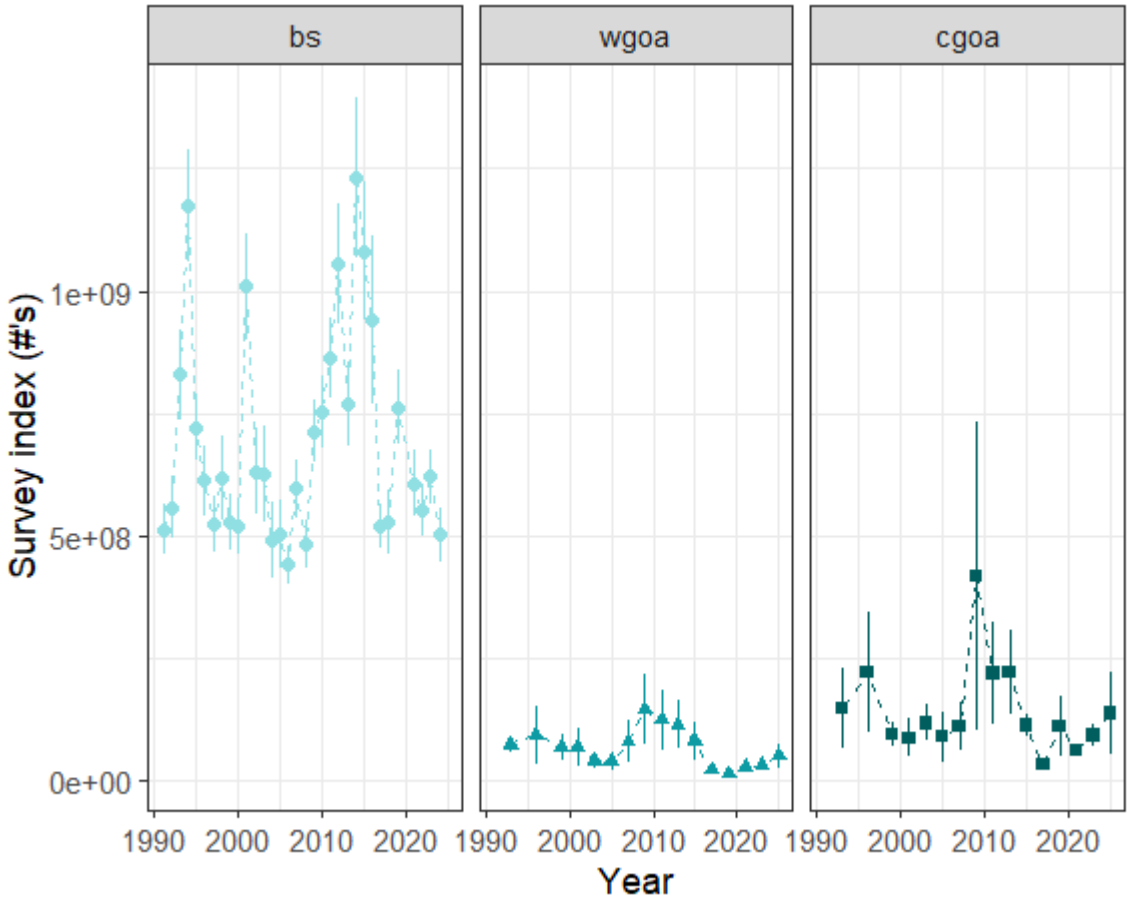
Data explorations

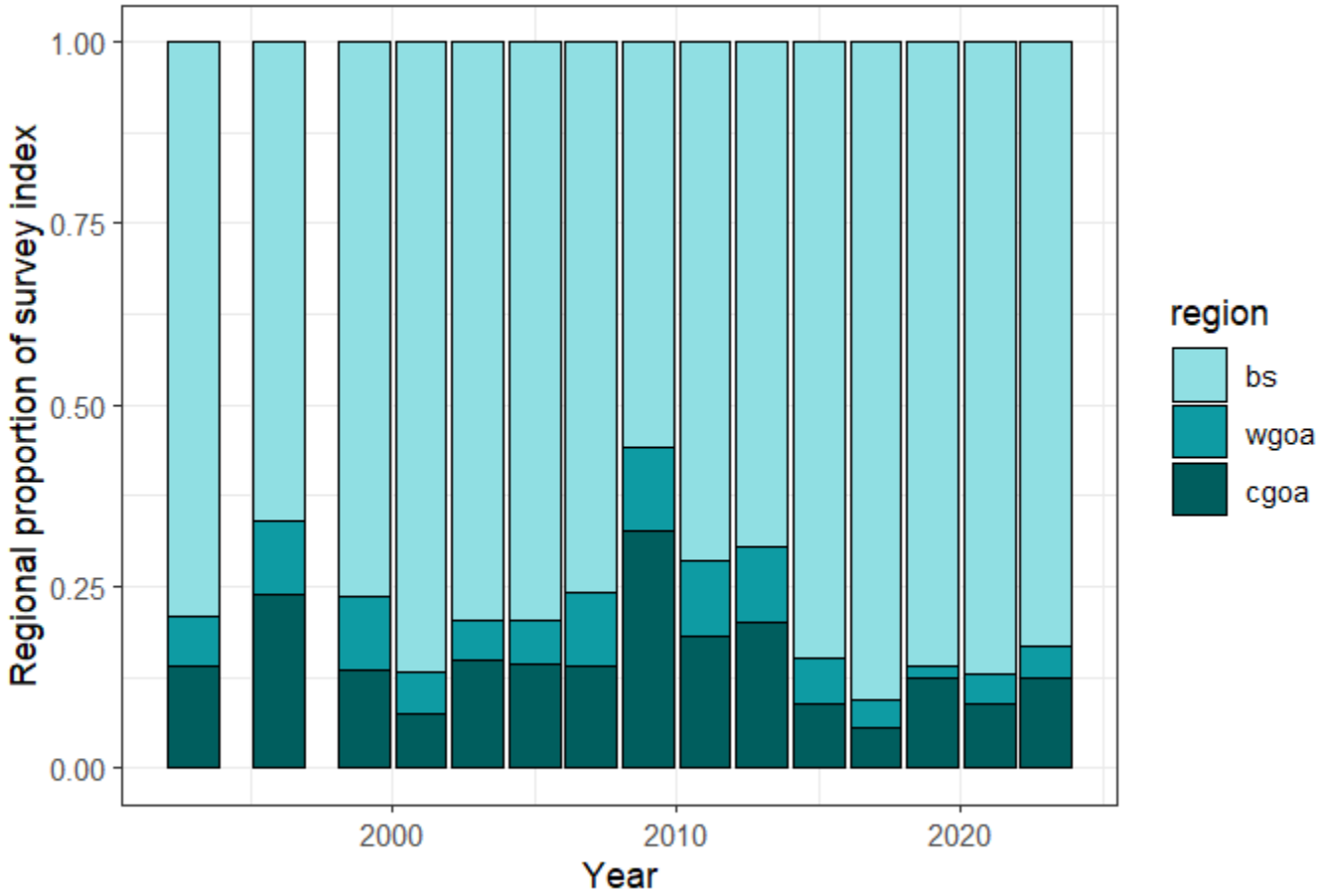
- Catch (by season):



Data explorations

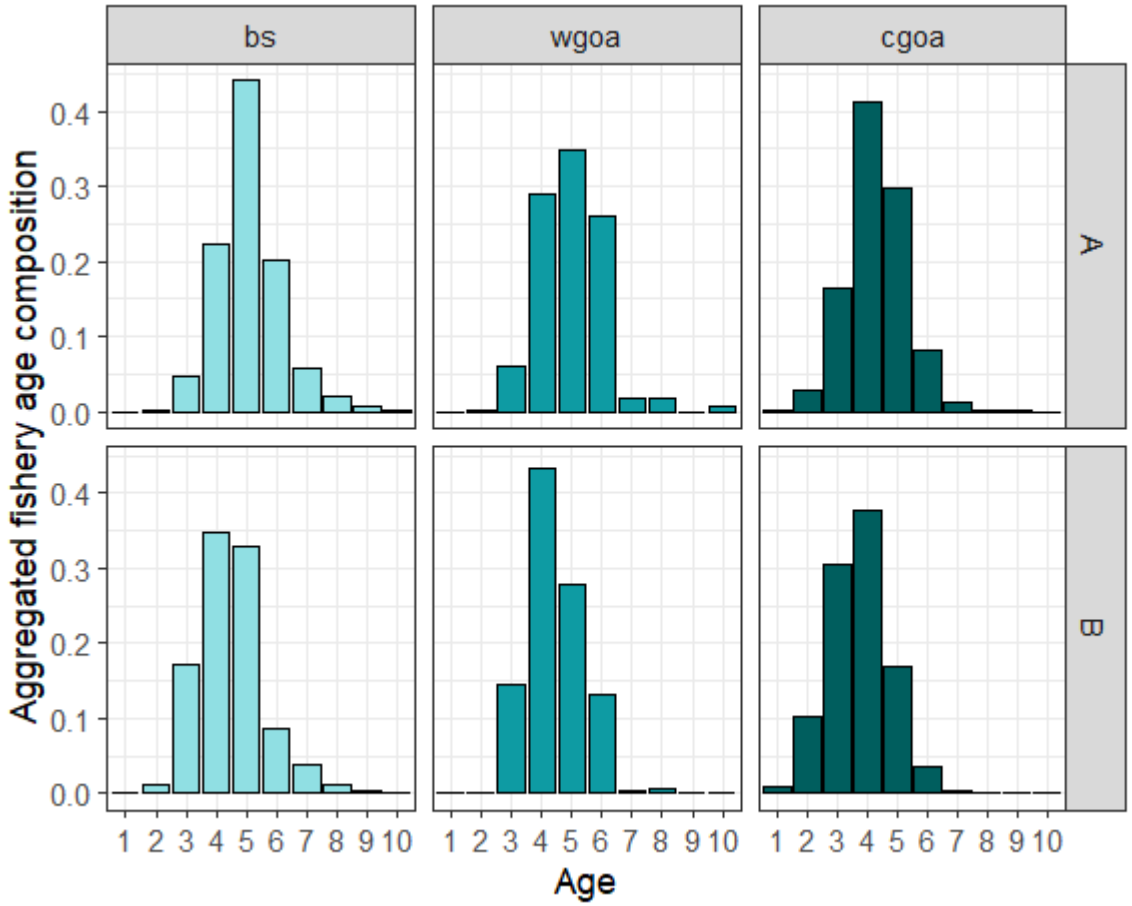
- Bottom trawl survey index:

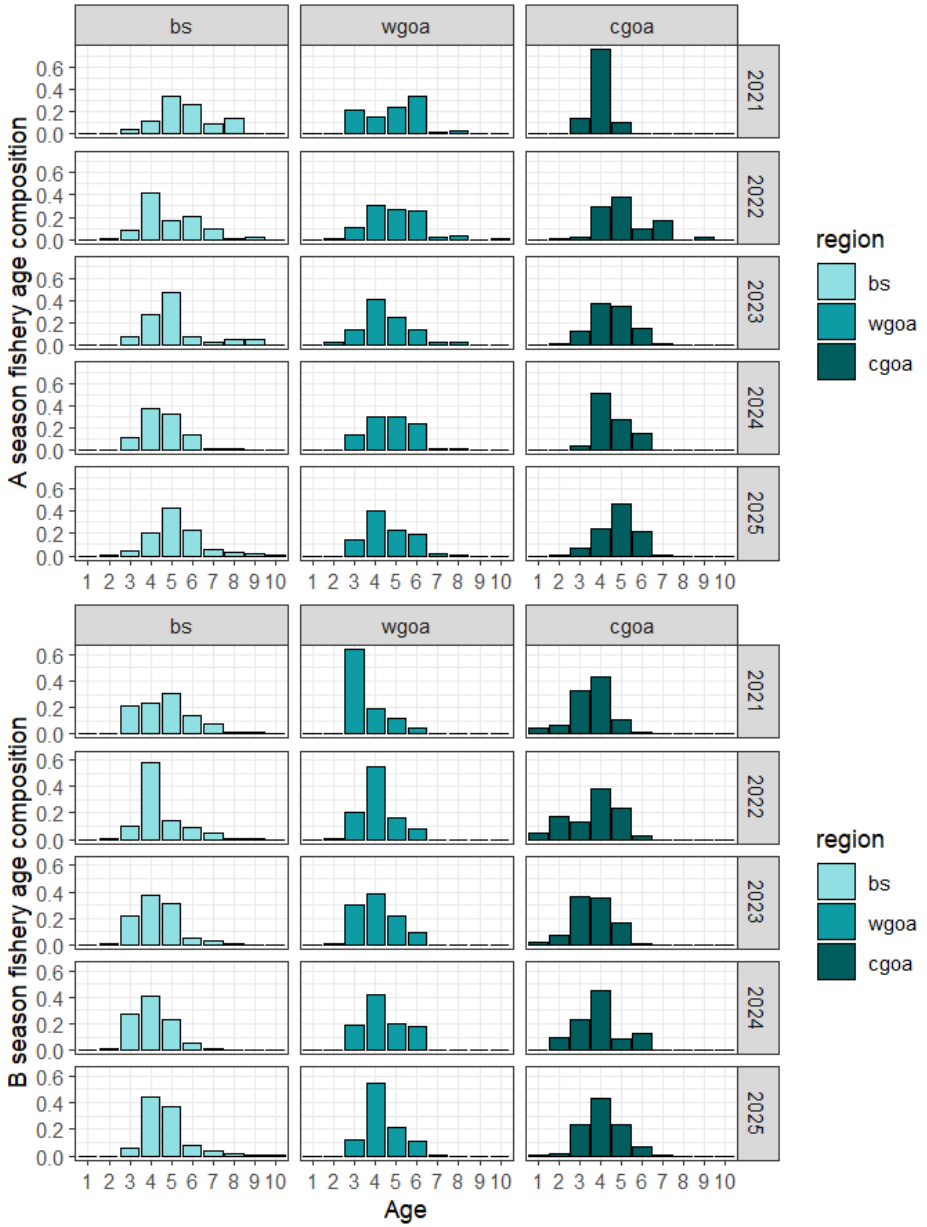




Data explorations

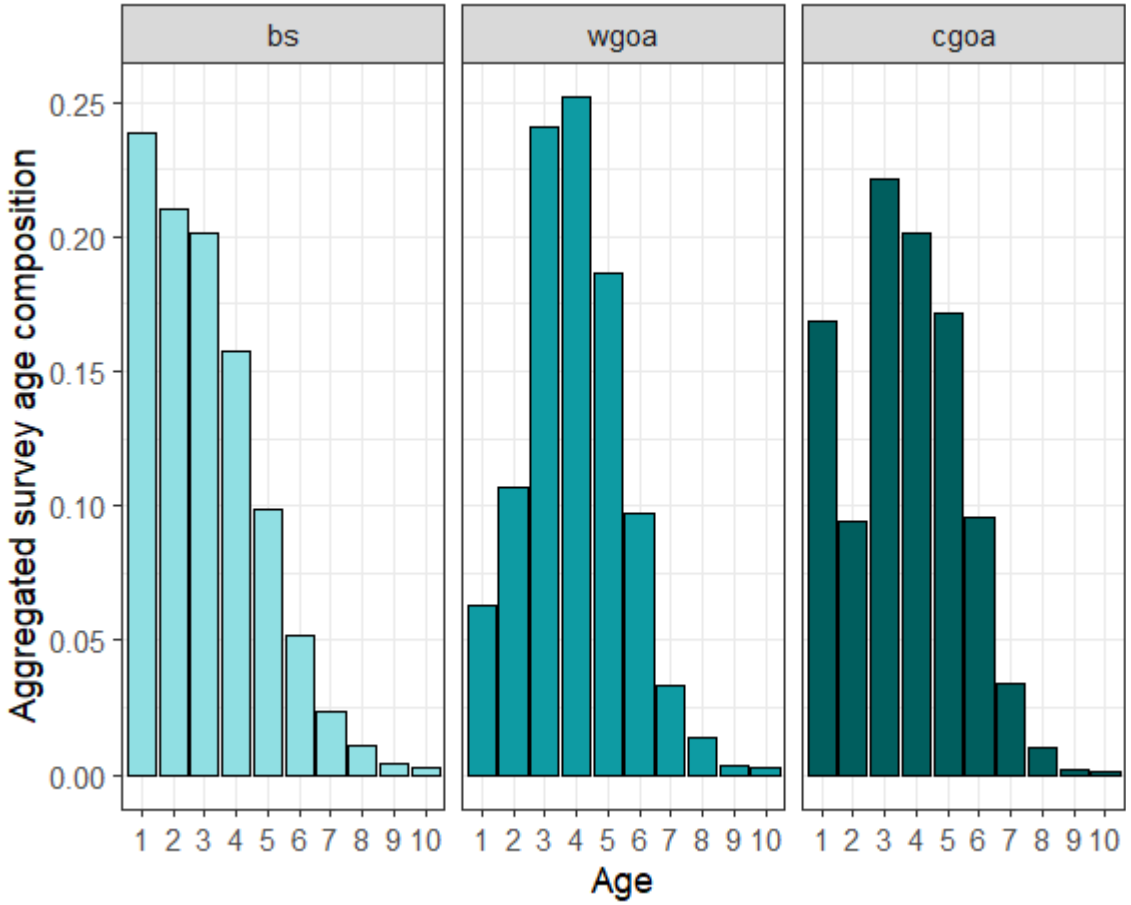
- Fishery age comps

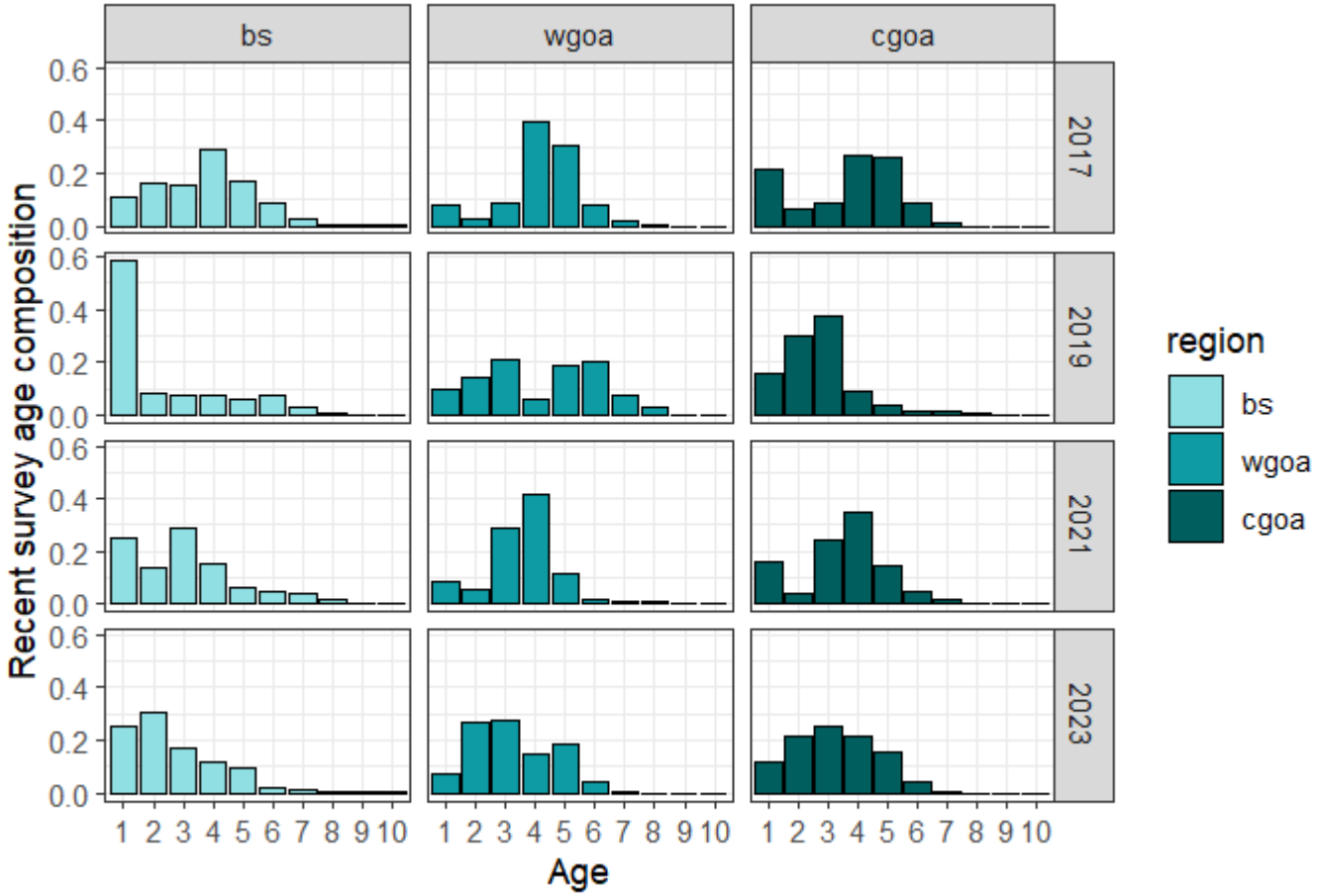




Data explorations

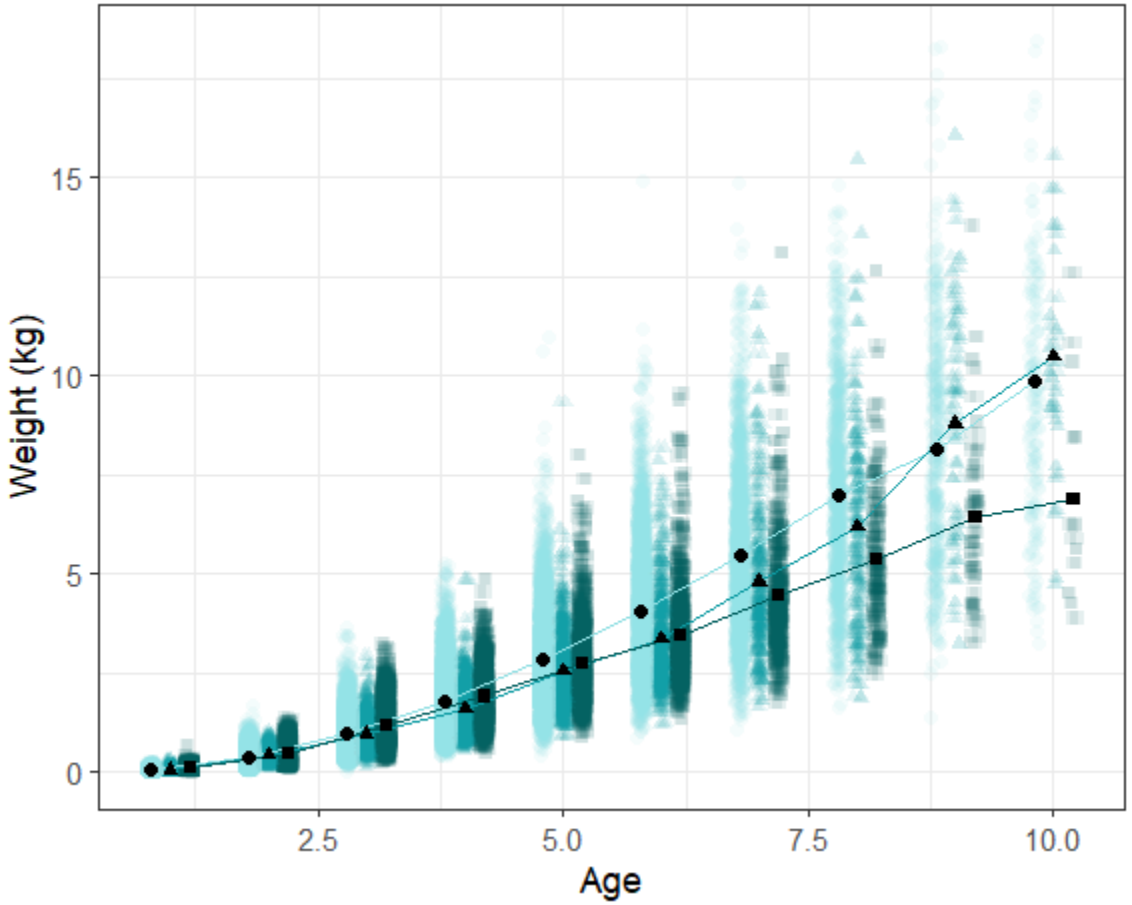
- Survey age comps

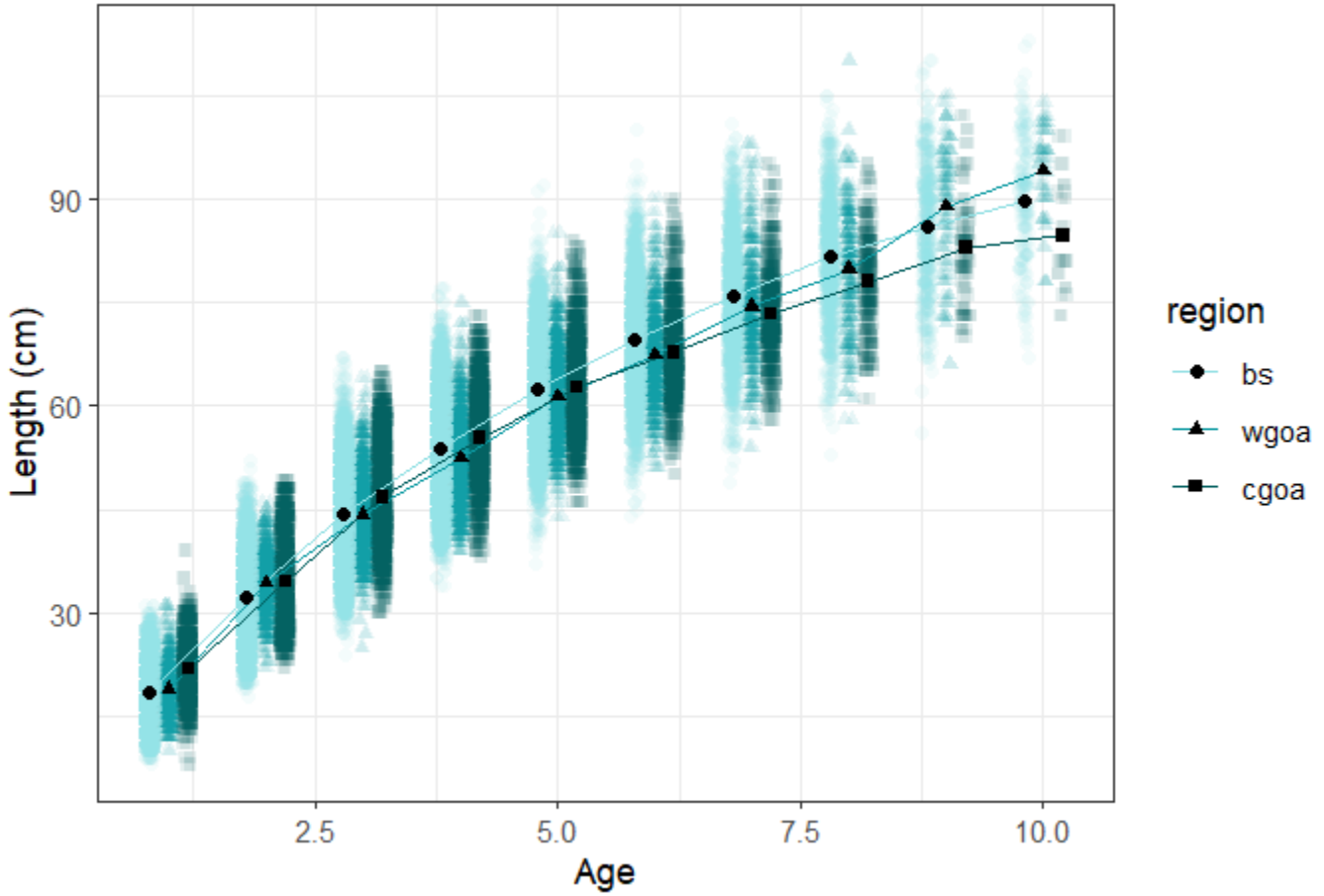




Data explorations

- Growth (survey)





Next steps/Timeline

- Next steps:
  - Continue to refine model/data assumptions
  - Build and evaluate cases of sub-populations/regions
  - Understand and explore results in comparison with operational assessments
  - Ultimate goal: construct MSE to explore consequences of alternative and status quo ABC/TAC apportionment between EBS/WGOA
- Timeline
  - Present spatial model results 2027 Sept Plan Team
  - Conduct CIE review of spatial model and apportionment alternatives in Spring 2028
  - Present CIE results and potential apportionment alternatives in Fall 2028

Things to consider

- Data limitations:
  - We have **NO** index of abundance in the A season. Past explorations into fishery CPUE (particularly in WGOA) have proved fruitless. A season abundance is *inferred* from fits to tagging and fishery composition/catch data.
  - We have limited tagging data, both across space and time. **NEED** consistent and reliable source of tagging data, particularly if we want to understand environmental influence on movement
- Management conundrums
  - If operational model used to set ABC and spatial model used to inform apportionment: GOA TAC > ABC? Increase in TAC must be seasonal
  - Alternatively: if WGOA recommended to be incorporated within EBS assessment, cross-FMP complications to consider

Things to consider

- Range of options, from complex to simple:
  1. *Spatially and seasonally-explicit model that estimates movement*
  2. *Single area BS|WGOA integrated model (w or w/o seasonality)*
  3. **Ad hoc adjustment to current methodology informed by tagging**
- Simple example to get a feel for what magnitude we're talking about:

% of BS biomass	Movement rate from WGOA		
	30%	40%	50%
2019	2.2%	3.4%	5.1%
2021	2.9%	4.5%	6.7%
2023	3.7%	5.7%	8.6%
Avg	2.9%	4.5%	6.8%

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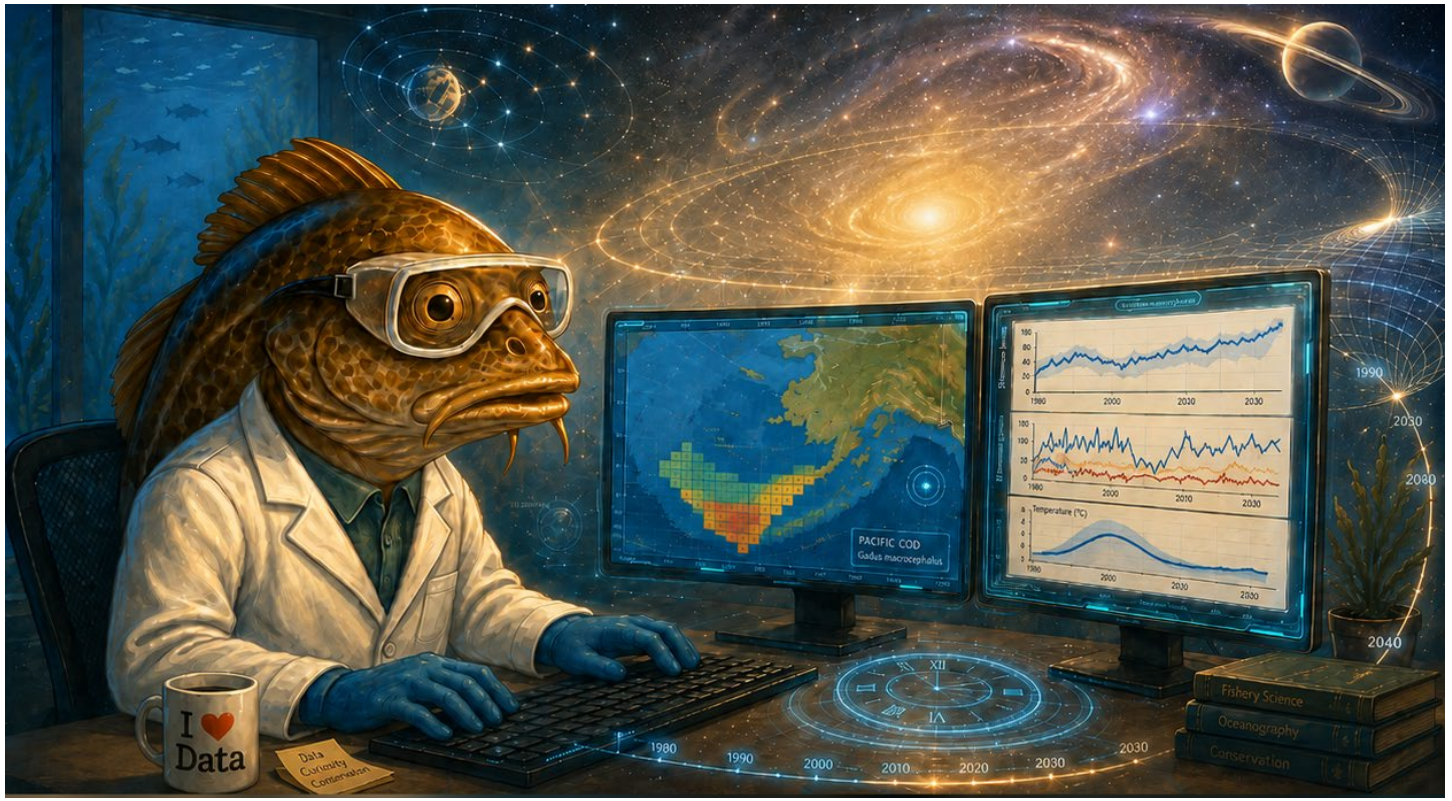
Questions?



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