Development of an Atlantis ecosystem model for the Gulf of Alaska

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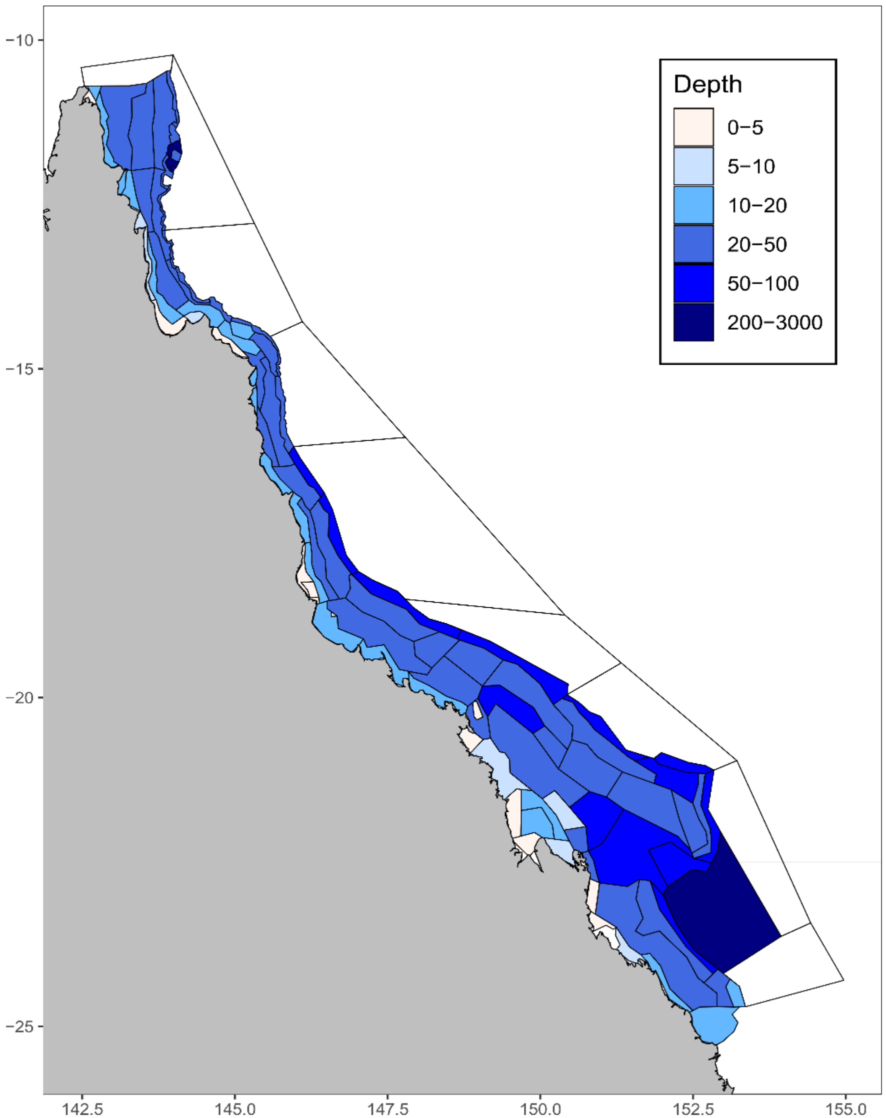
Introduction

- Alberto Rovellini: Postdoc at AFSC and University of Washington
- Worked on an Atlantis model for the Great Barrier Reef (Victoria University of Wellington – New Zealand – and CSIRO – Australia)
    - Focus on integrating benthic organisms in an ecosystem model for a coral reef
    - Extended the Atlantis code to capture some benthic ecological processes
- Primary collaborators for this project: Martin Dorn, Andre Punt (UW), Isaac Kaplan (NWFSC)



Brief overview of Atlantis

Atlantis ecosystem model

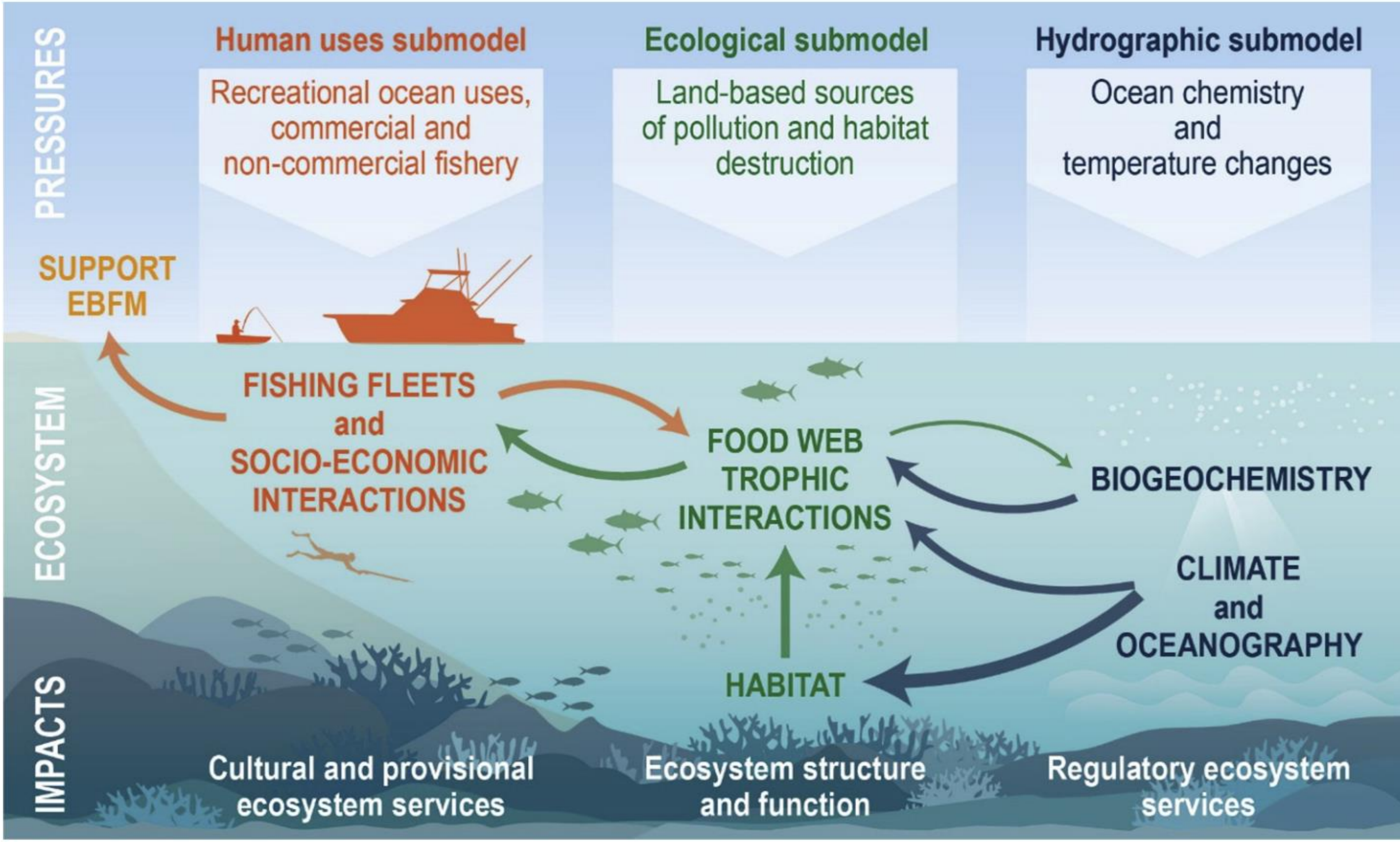
Original purpose: to create a “virtual ecosystem” for scenario evaluation and hypothesis testing

- “End-to-end” ecosystem model
- Developed by Dr Beth Fulton (CSIRO)
- Early 2000’s
- Holistic representation of marine ecosystems

CSIRO

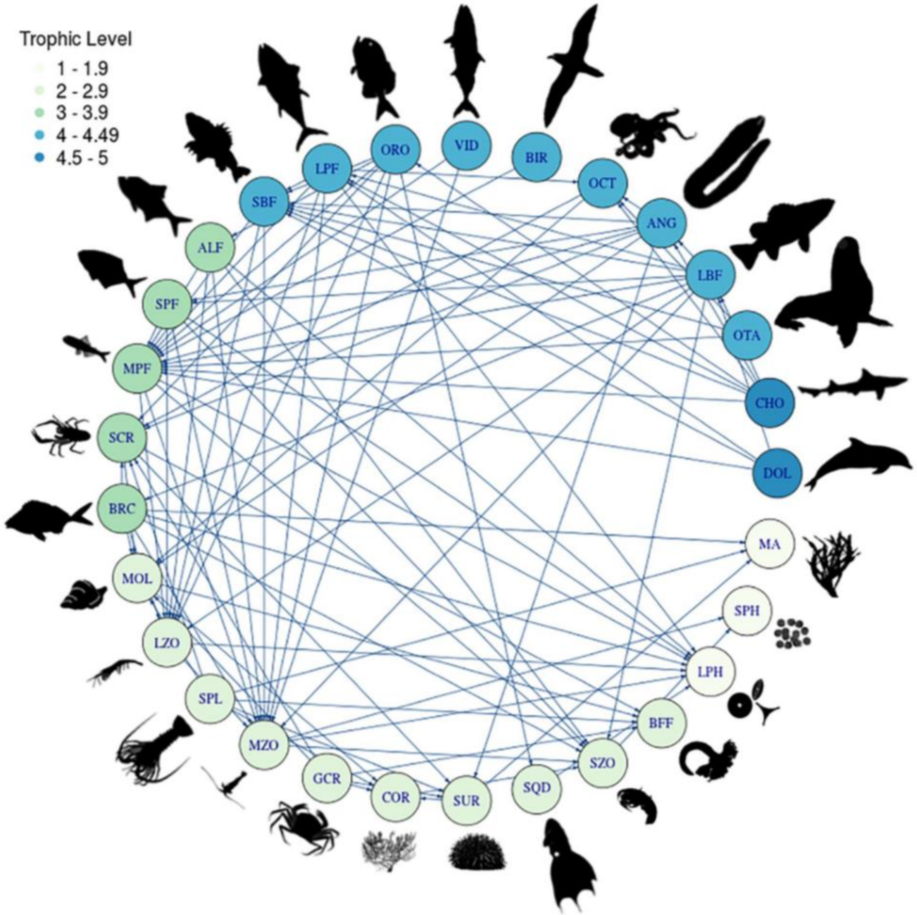
Model structure overview

H.R. Pethybridge, et al.



Technical overview

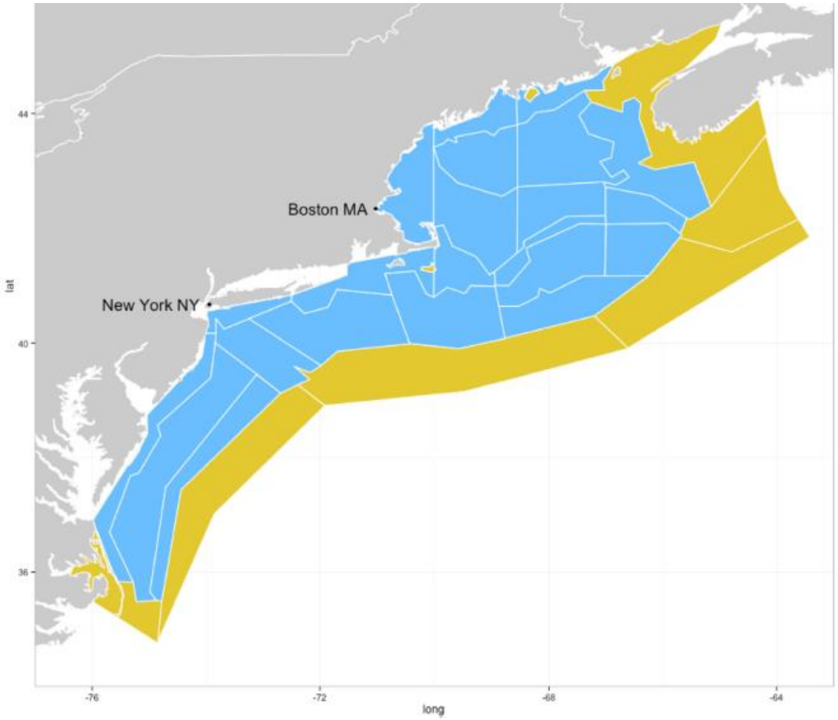
- C++ simulation code base
- Forward difference equations describing production and consumption in the system
- Tracks nutrients through the ecosystem (nitrogen is the “common currency”)

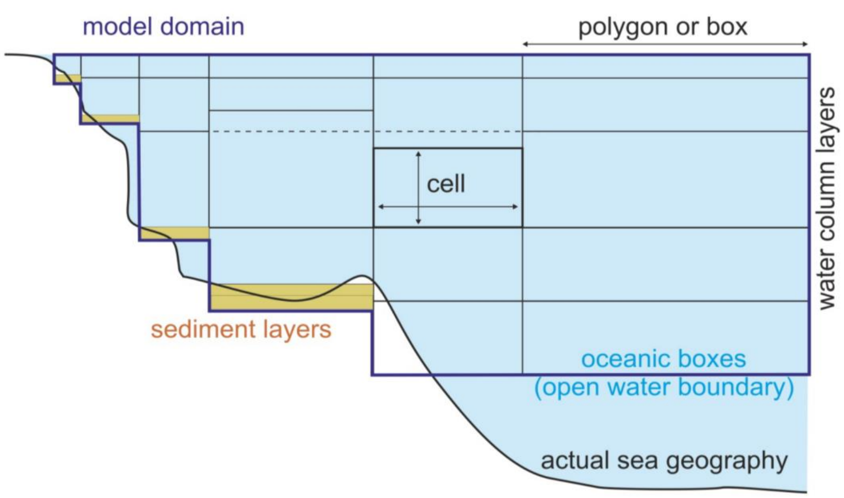


Porobic et al. 2019

Technical overview

- C++ simulation code base
- Forward difference equations describing production and consumption in the system
- Tracks nutrients through the ecosystem (nitrogen is the “common currency”)
- 3-dimensional structure: set of polygons and vertical layers
- Linked to oceanographic models (e.g., ROMS)





Technical overview

- Optionally linked to biogeochemical models (e.g. NPZ)
- Modules for fishery and economy (2-way coupling)
- Invertebrates: biomass pools
- Vertebrates: age structured
- Multiple options for movement, predation, recruitment, response to environmental variables, etc.

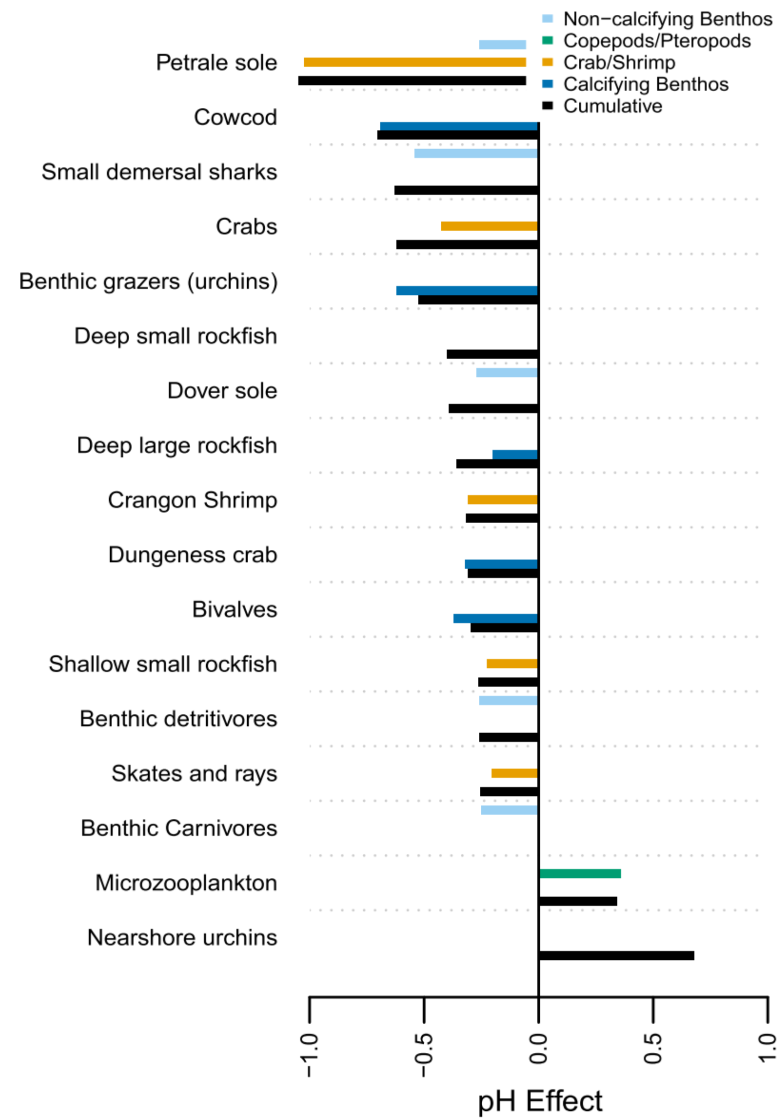
Model building and parametrisation

Data hungry

- Model geometry: topography, biogeography, management boundaries, etc.
- Physics: Oceanographic models used to force Atlantis (e.g., ROMS, HYCOM, etc.)
- Biology:
  - Survey data (e.g., bottom trawl surveys, acoustic surveys, mid-water trawl, seabird counts, experiments etc.)
  - Model output: stock assessments, species distribution models, etc.
- Harvest: catch data, observer data, fleet dynamics models

Applications

- Climate change simulation and projection



Marshall et al. 2017

Applications

- Climate change simulation and projection
- Management strategy evaluation

Porobic et al. 2019

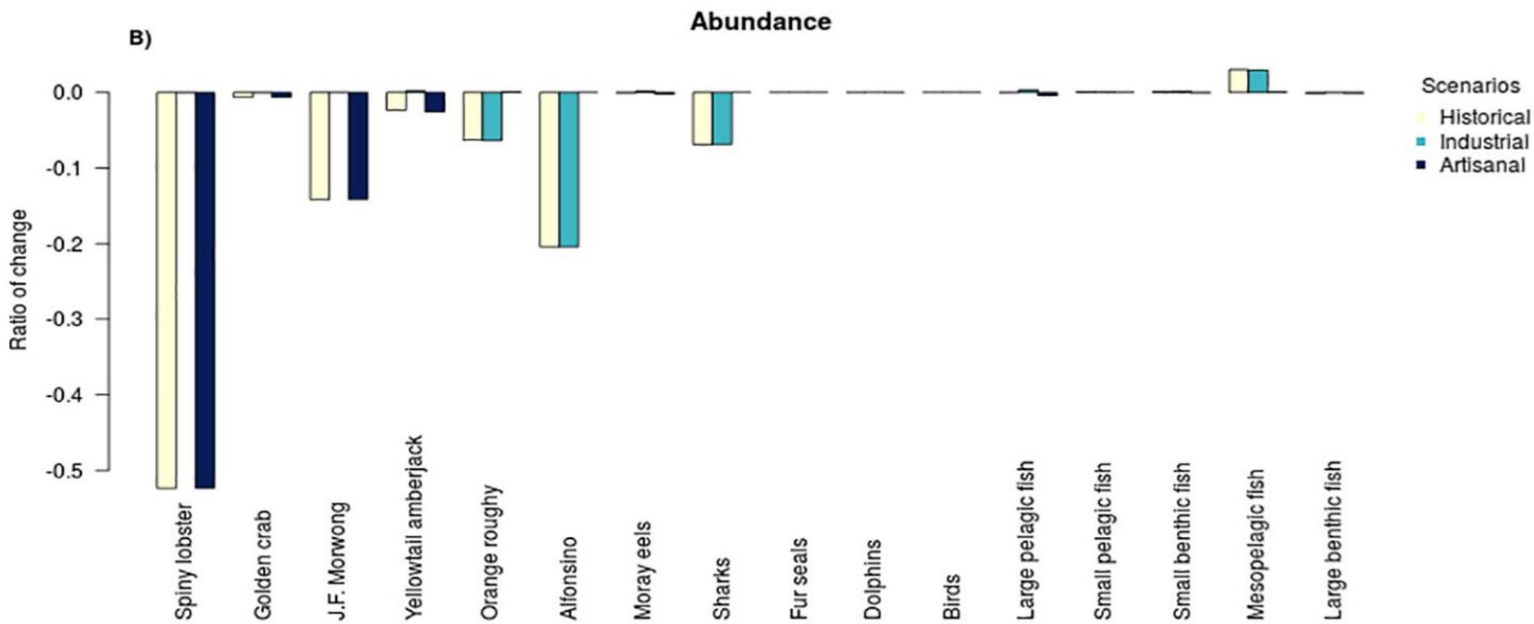
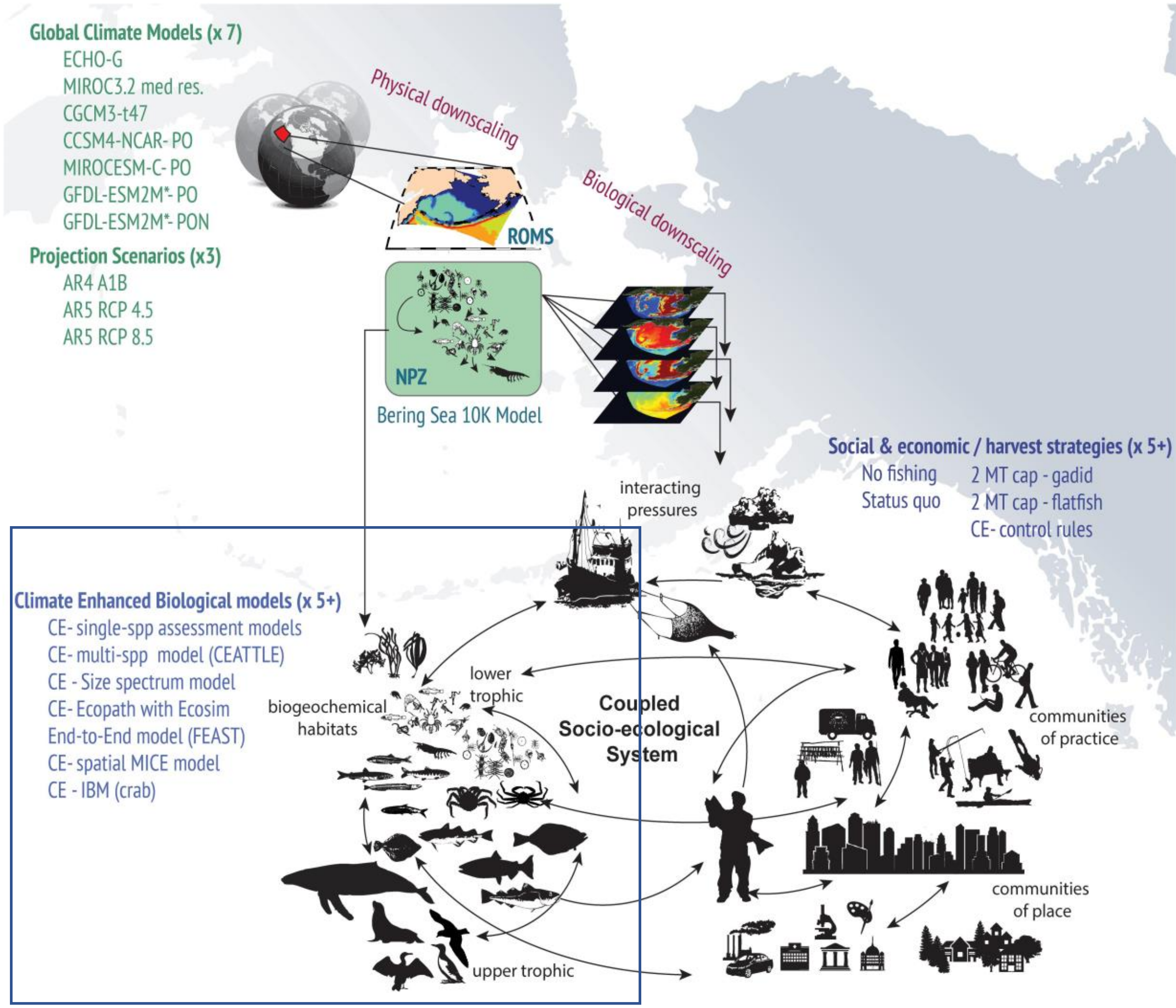


Fig 5. Relative change in biomass (A) and abundance (B) for the scenarios with only artisanal, industrial and the historical fisheries (industrial + artisanal). An unfished ecosystem is the base case for comparisons. Note that the y-axes is the ratio of change against the starting conditions—so a -0.5 result indicates a 50% decrease and a 0.5 result indicates a 50% increase -.

Applications

- Climate change simulation and projection
- Management strategy evaluation
- Hypothesis testing
- Multi-model inference



Hollowed et al. 2020

Applications

- Climate change simulation and projection
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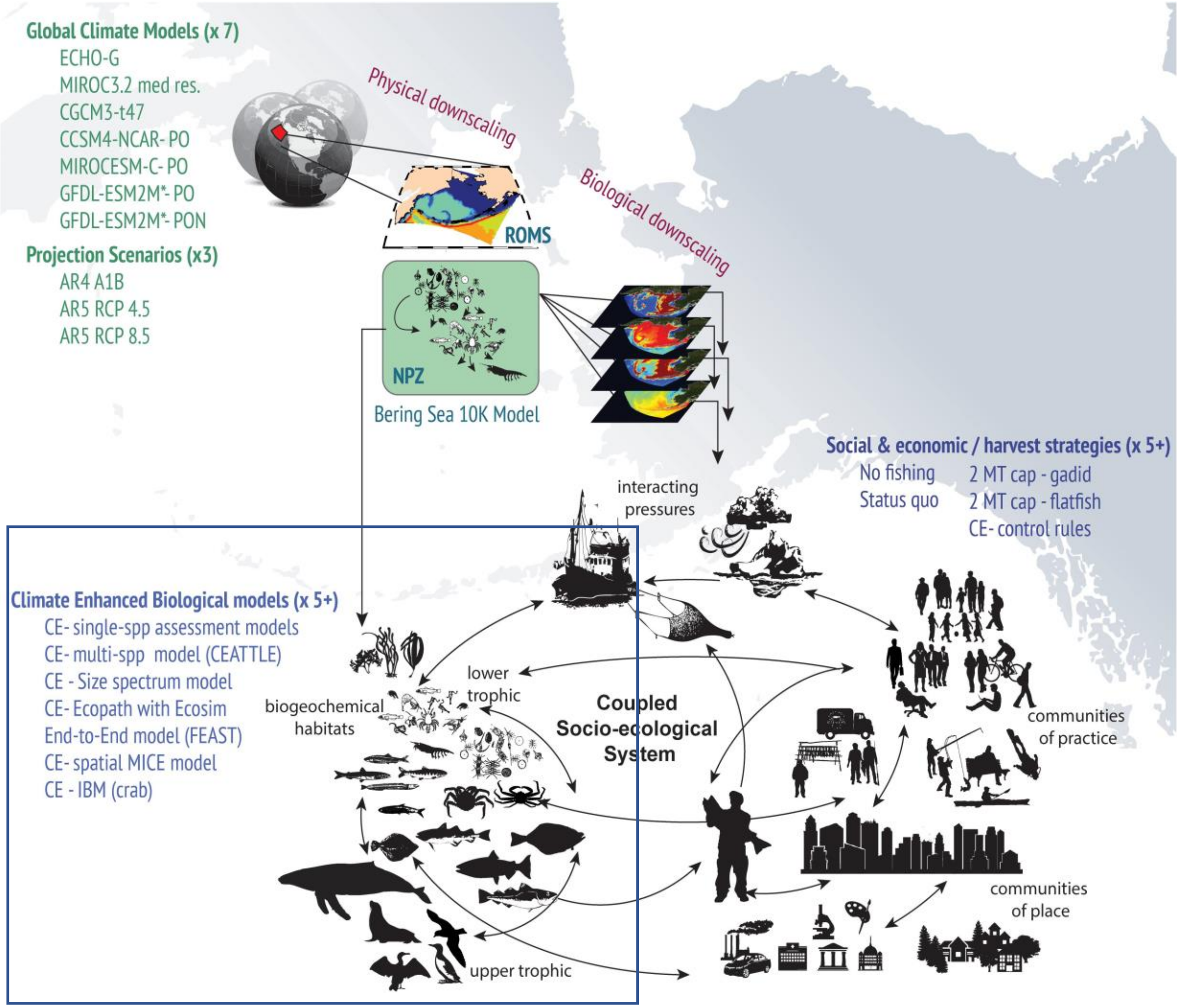
Strategic advice to Ecosystem-Based Fishery Management



Hollowed et al. 2020

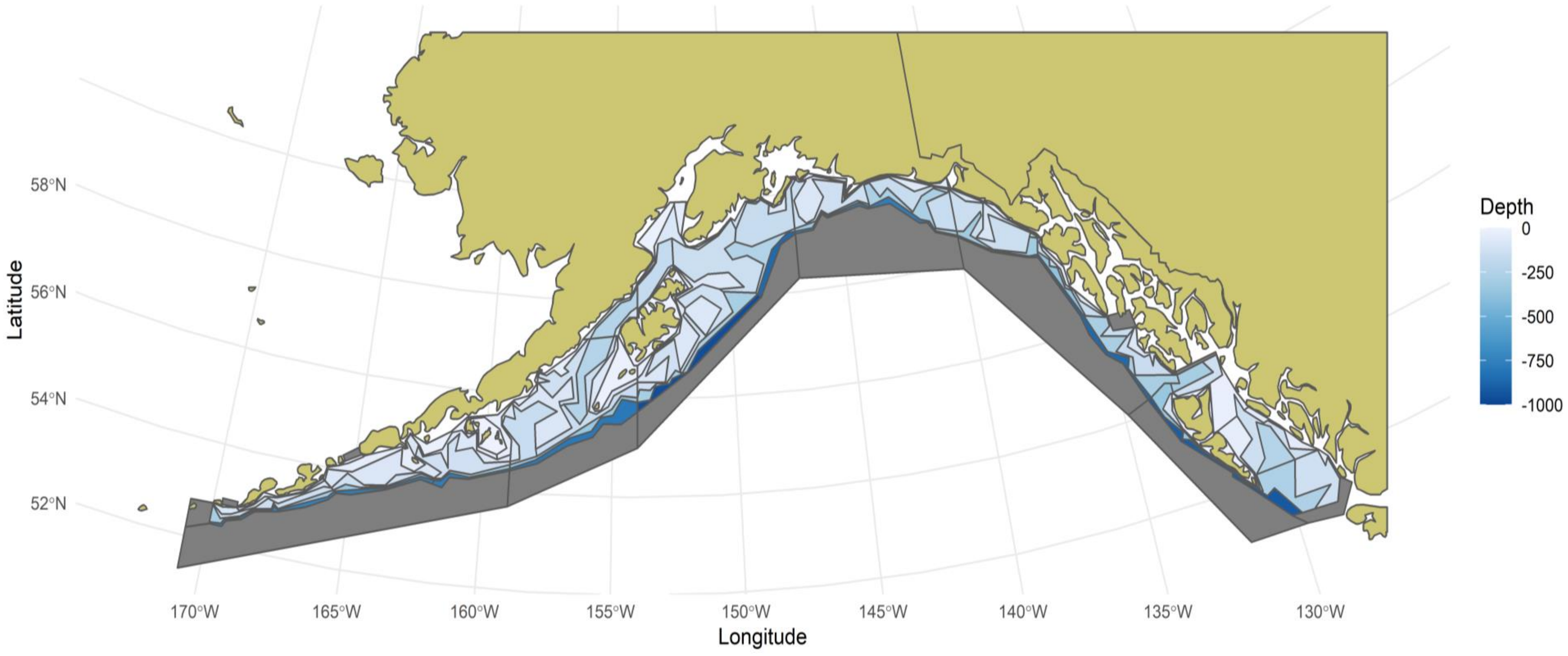
Existing Atlantis applications

30+ applications to date, and growing (Audzijonyte et al. 2019)

Atlantis GOA model development

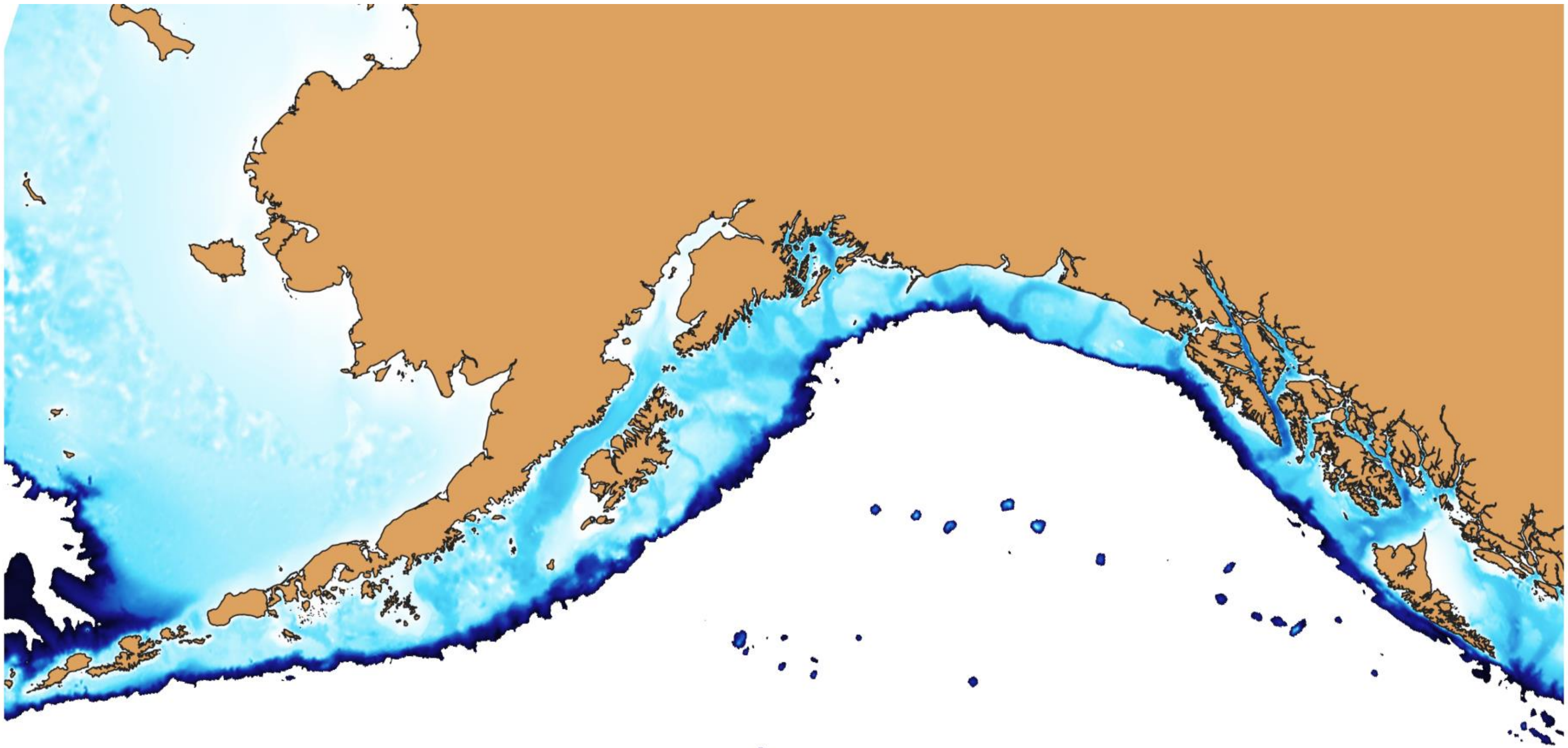
Model geometry

- Spatial extent of the model domain
- Collection of irregular polygons ('boxes')
- Homogeneous conditions within one depth layer of one box
- Design based on physical, ecological, and socioeconomic considerations
- Computational constraints to # of boxes



Model geometry: Bathymetry

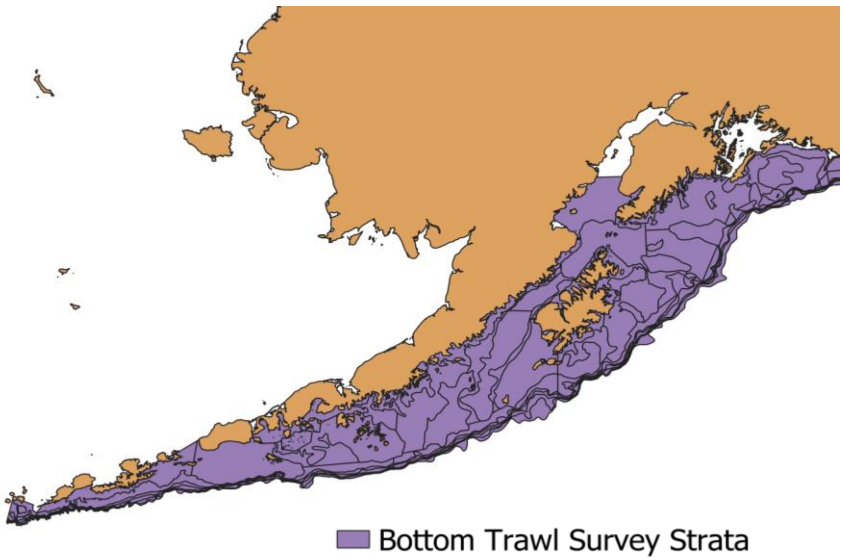
- Capture:
  - Seafloor morphology
  - Mesoscale topography (e.g., gullies, seamounts, islands)
- Only modelling down to 1000 m depth
- Used ETOPO1 Global Relief Model

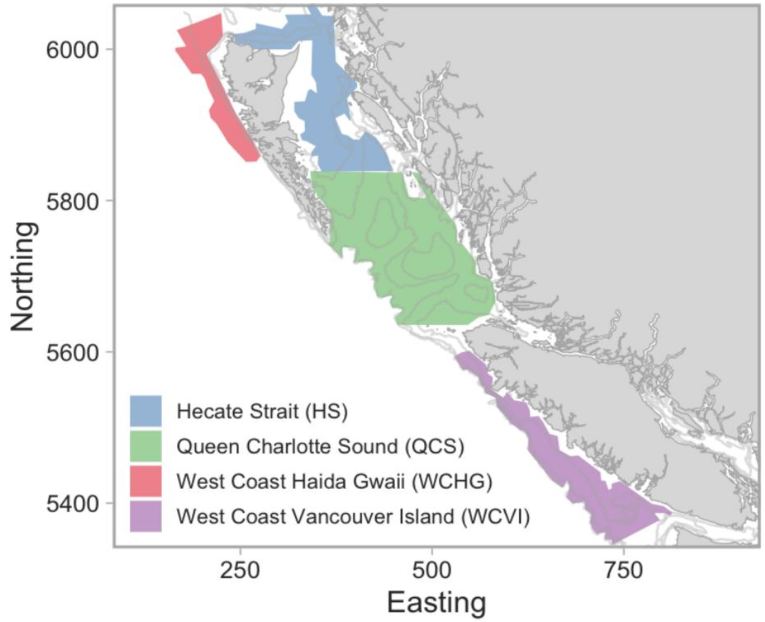


Model geometry: Data availability

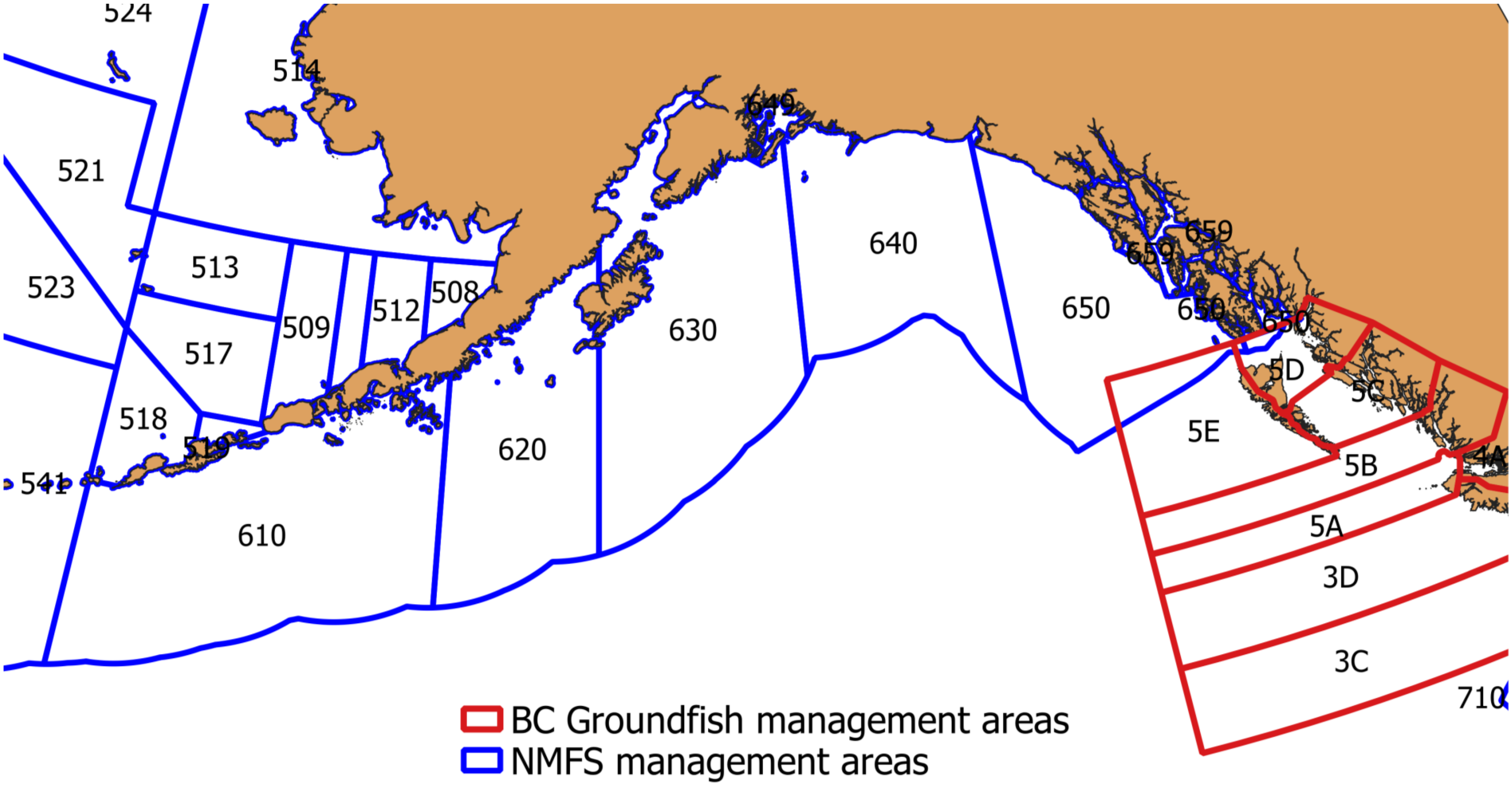
To facilitate model parametrization ,geometry design may account for:

- Spatial strata
- Sampling areas
- Spatial gaps in data sets





Model geometry: Fishery management

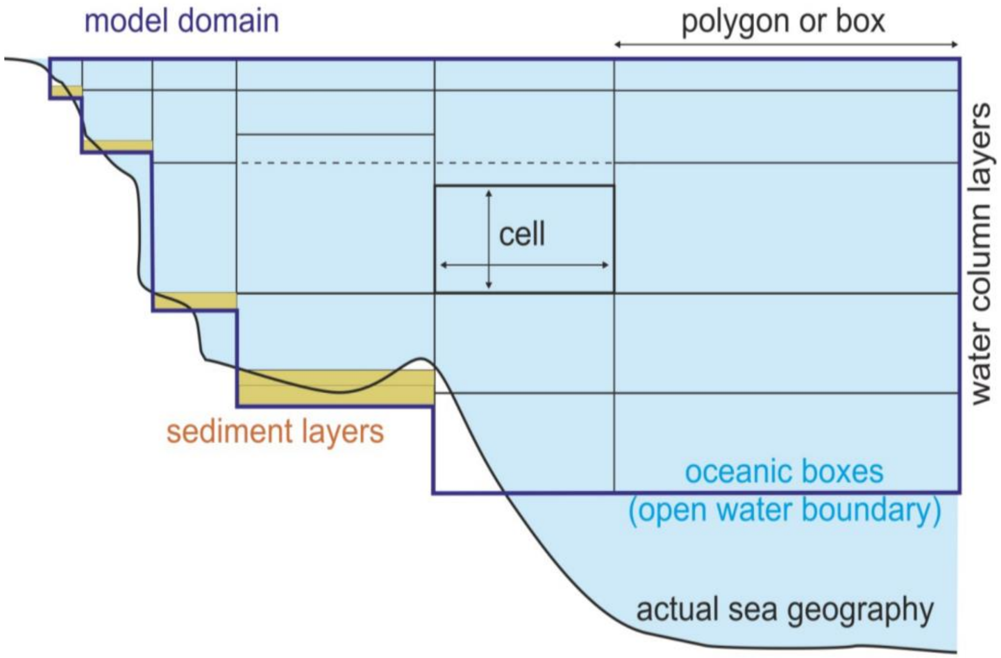


Atlantis GOA: 109 boxes

Model geometry: Vertical structure

Vertical structure:

- Discrete depth layers within each box
- Need not to be the same for all boxes, but it helps if it is



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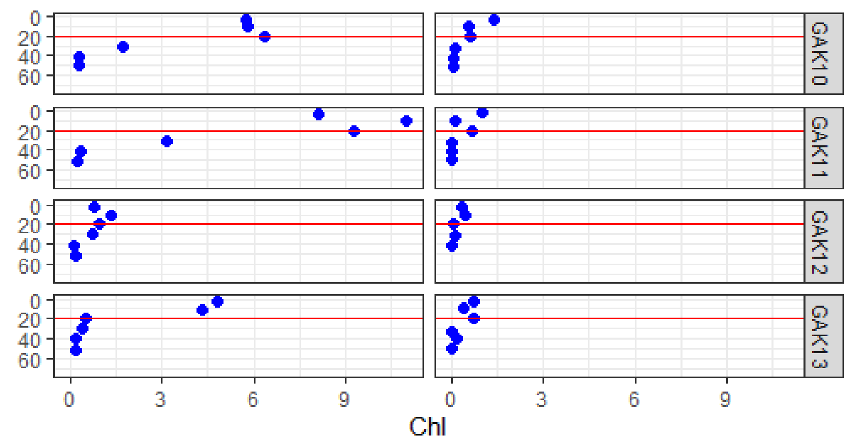
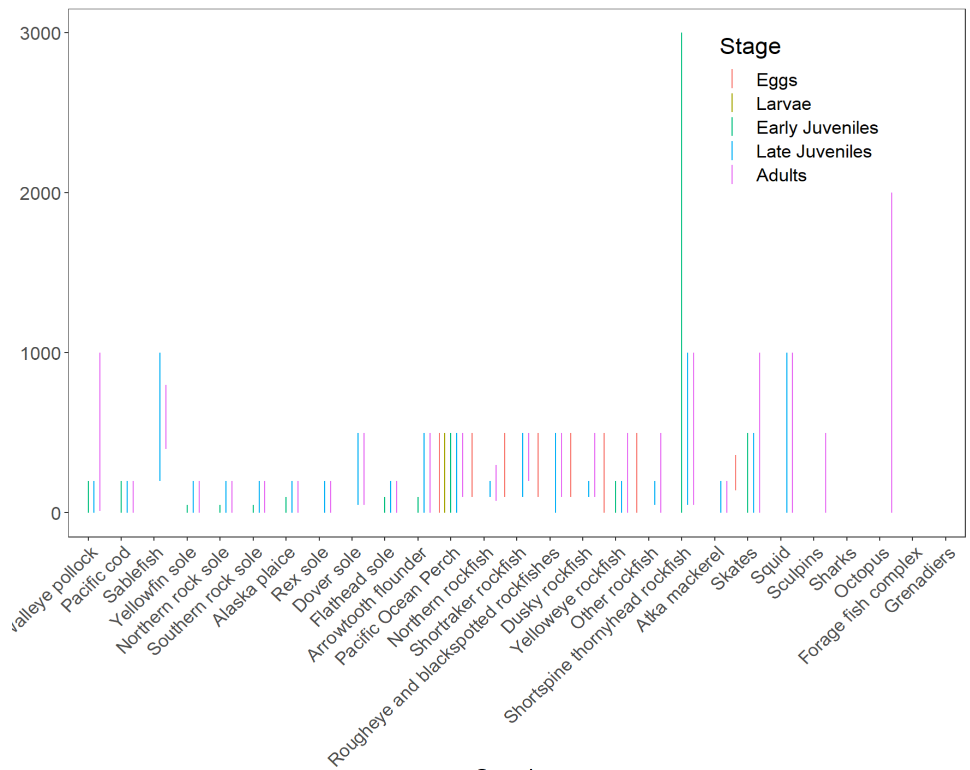


- It should capture:
  - Ecological processes
  - Vertical distribution of organisms
  - Fishery breaks
  - Etc.
- Atlantis GOA: 6 depth breaks (0 m, 30 m, 100 m, 200 m, 500 m, 1000 m)



Physics: Mapping ROMS to Atlantis

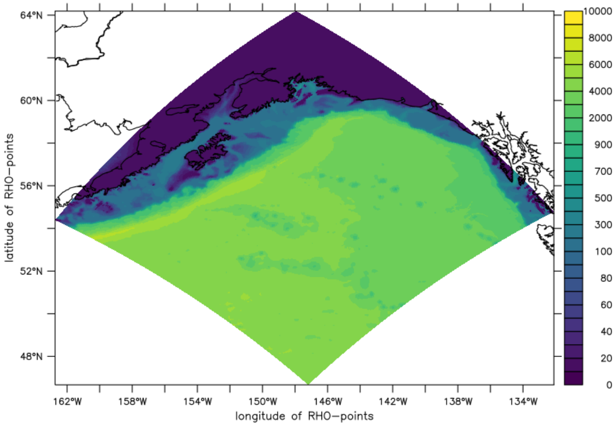
Atlantis has a physical submodel forced by the output of oceanographic models, like ROMS

ROMS variables needed by Atlantis:

- Temperature
- Salinity
- Water velocity

Atlantis GOA: ROMS (CGOA and NEP)

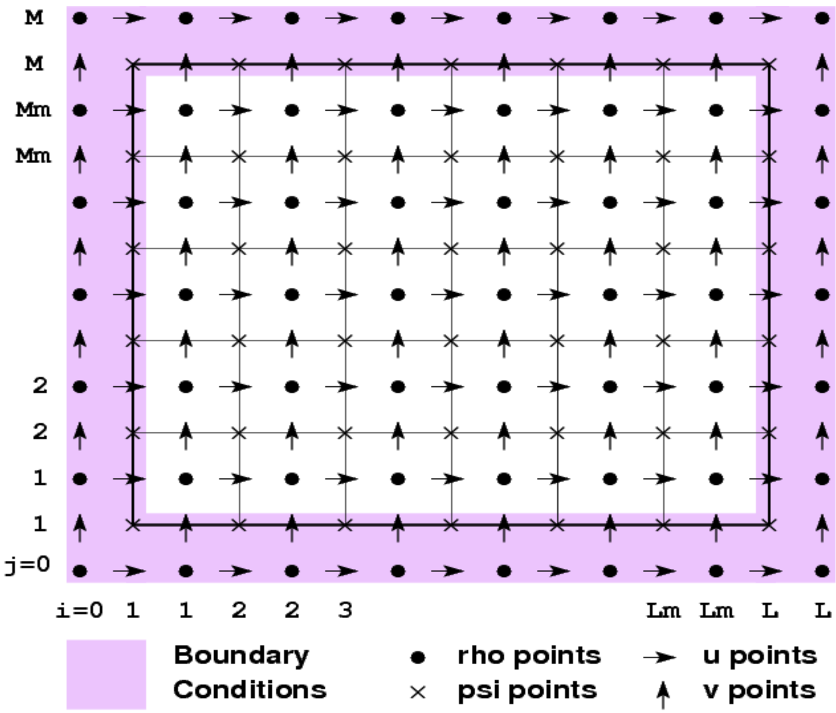
Physics: Mapping ROMS to Atlantis

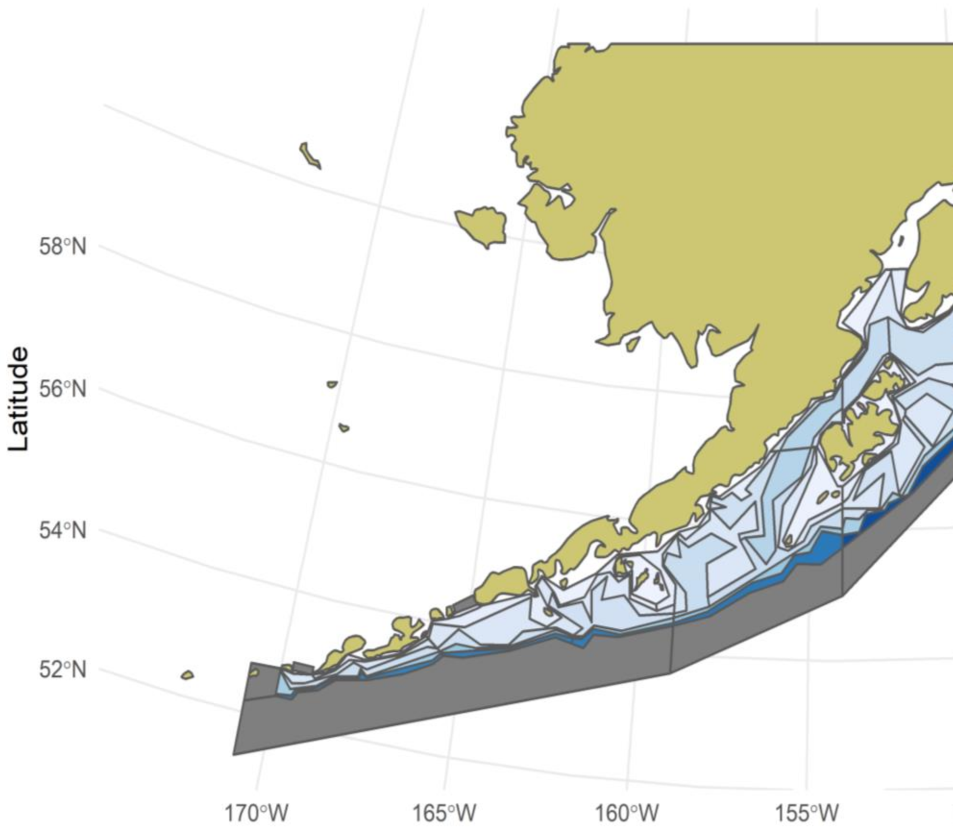


Final bathymetry at RHO-points (meter)

ROMS ρ, *u*, and *v* grids to Atlantis polygons

(horizontal transformation)

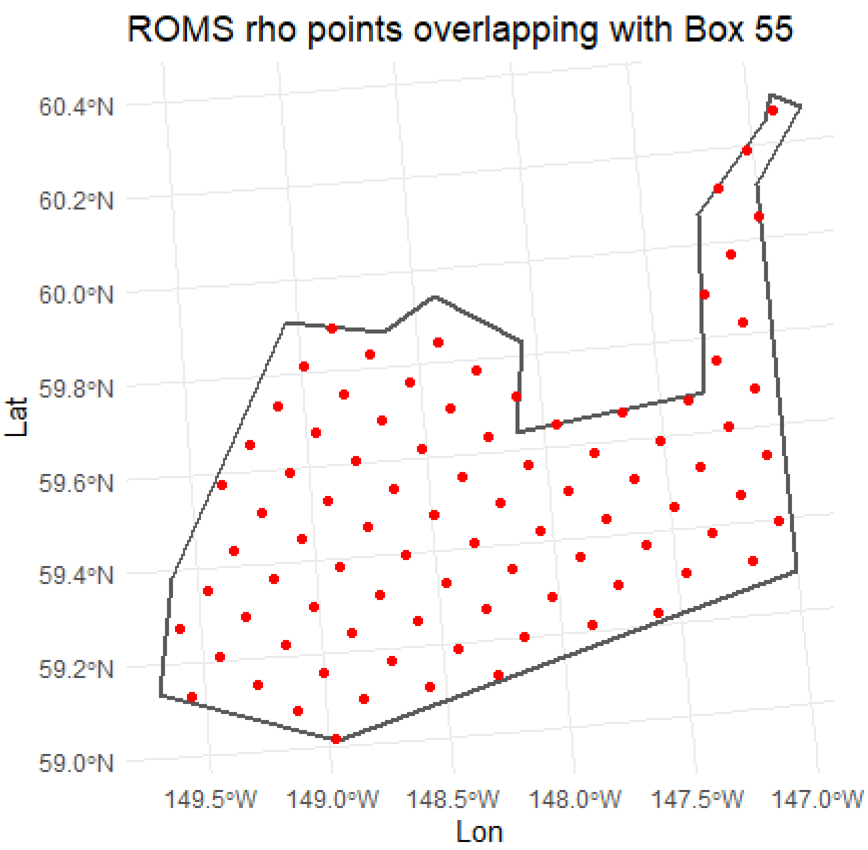


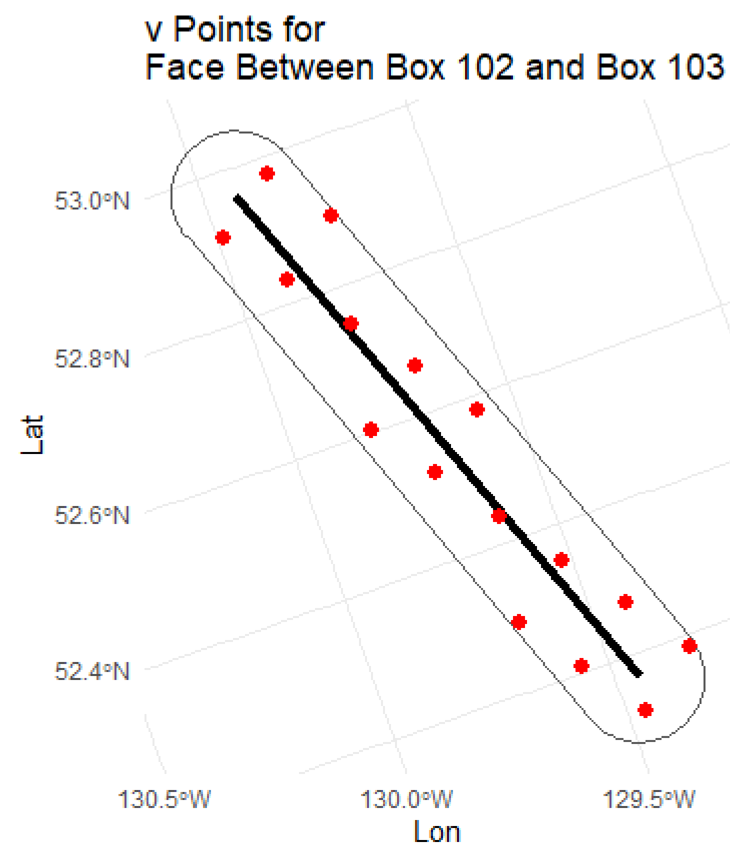


Physics: Mapping ROMS to Atlantis

Horizontal:

- Boxes: spatial join of ρ points with Atlantis boxes
- Faces: spatial join *u* and *v* points with a buffer around the face

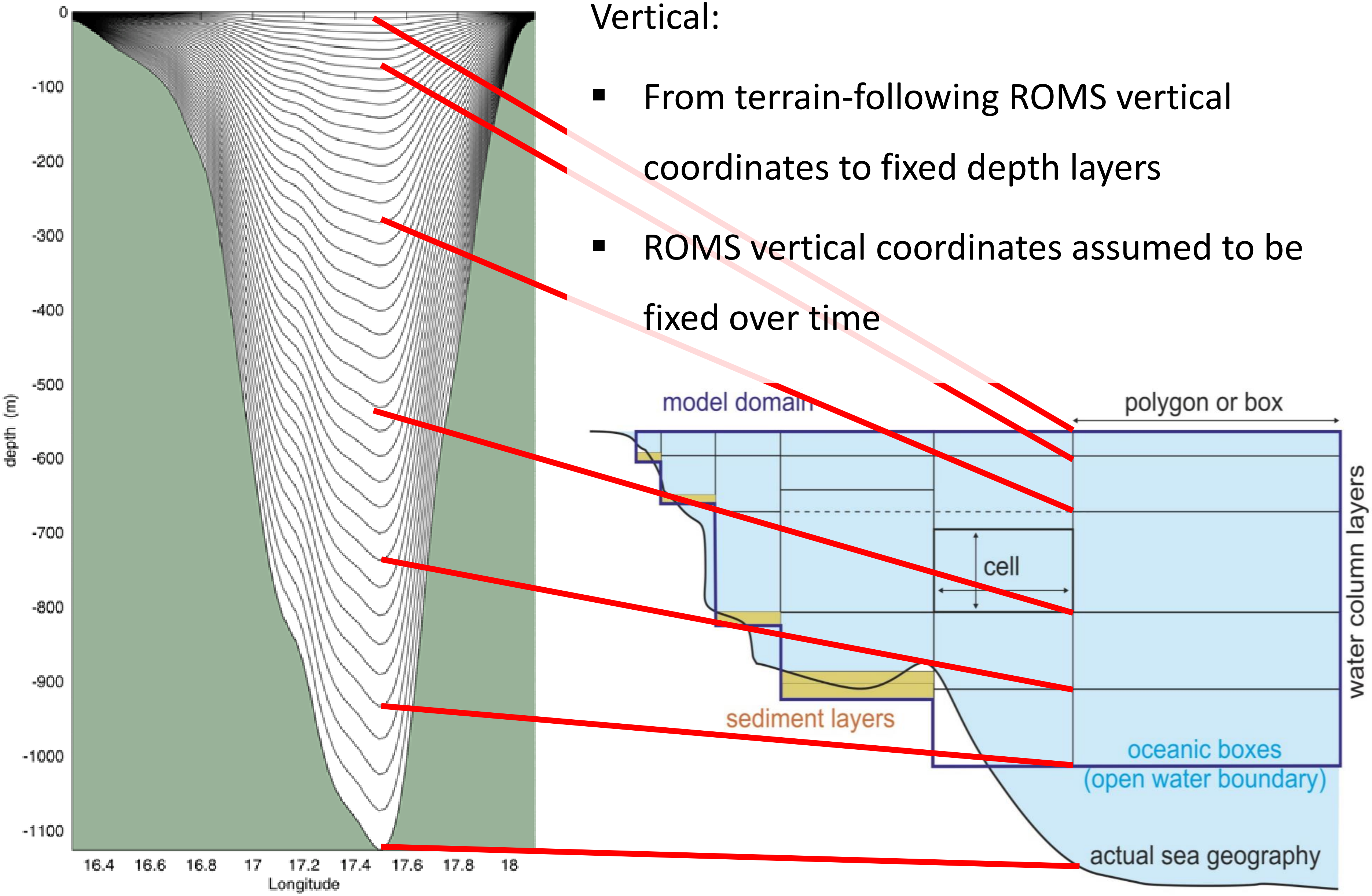




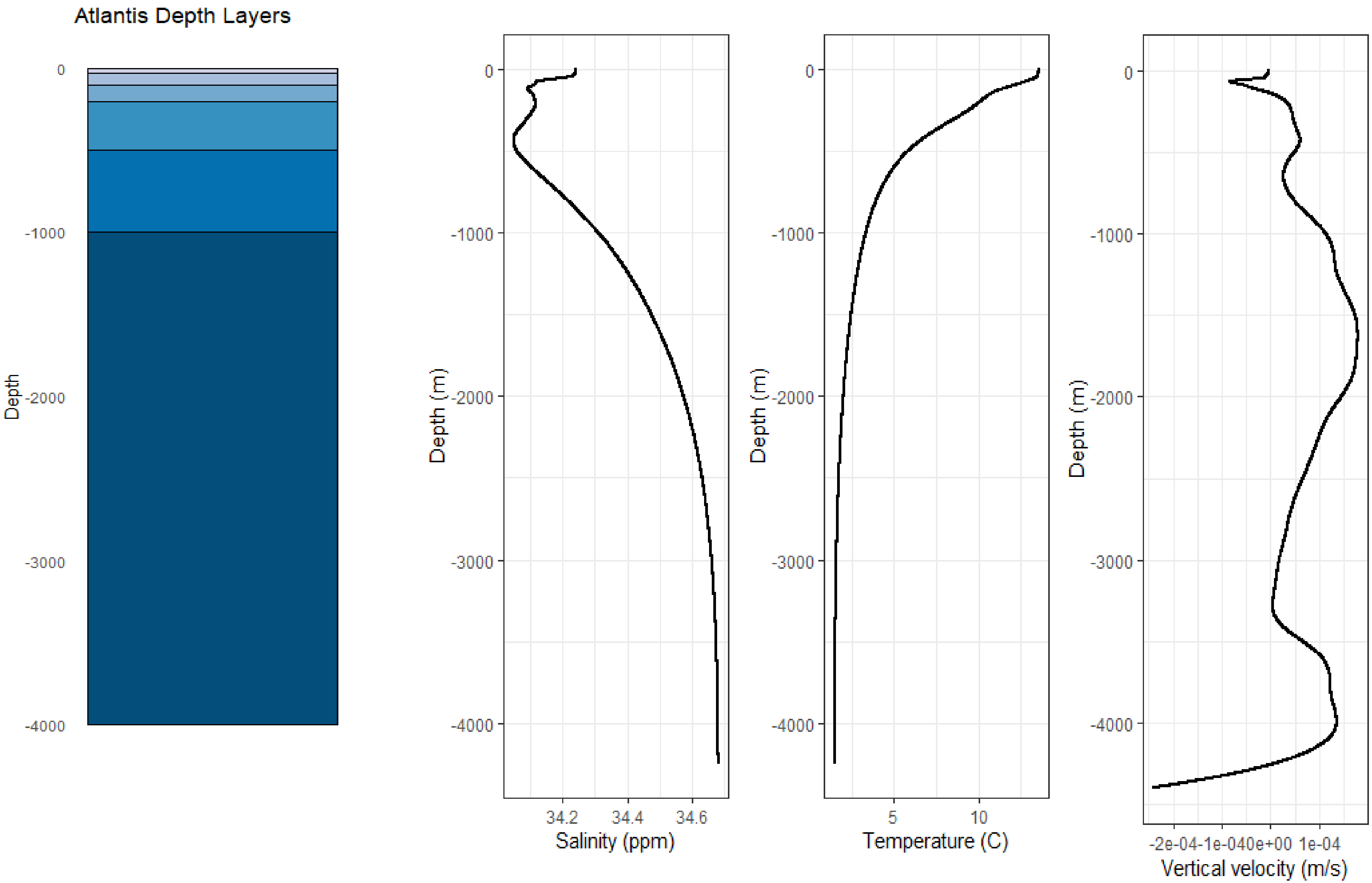
Physics: Mapping ROMS to Atlantis

Vertical:

- From terrain-following ROMS vertical coordinates to fixed depth layers
- ROMS vertical coordinates assumed to be fixed over time



Physics: Mapping ROMS to Atlantis



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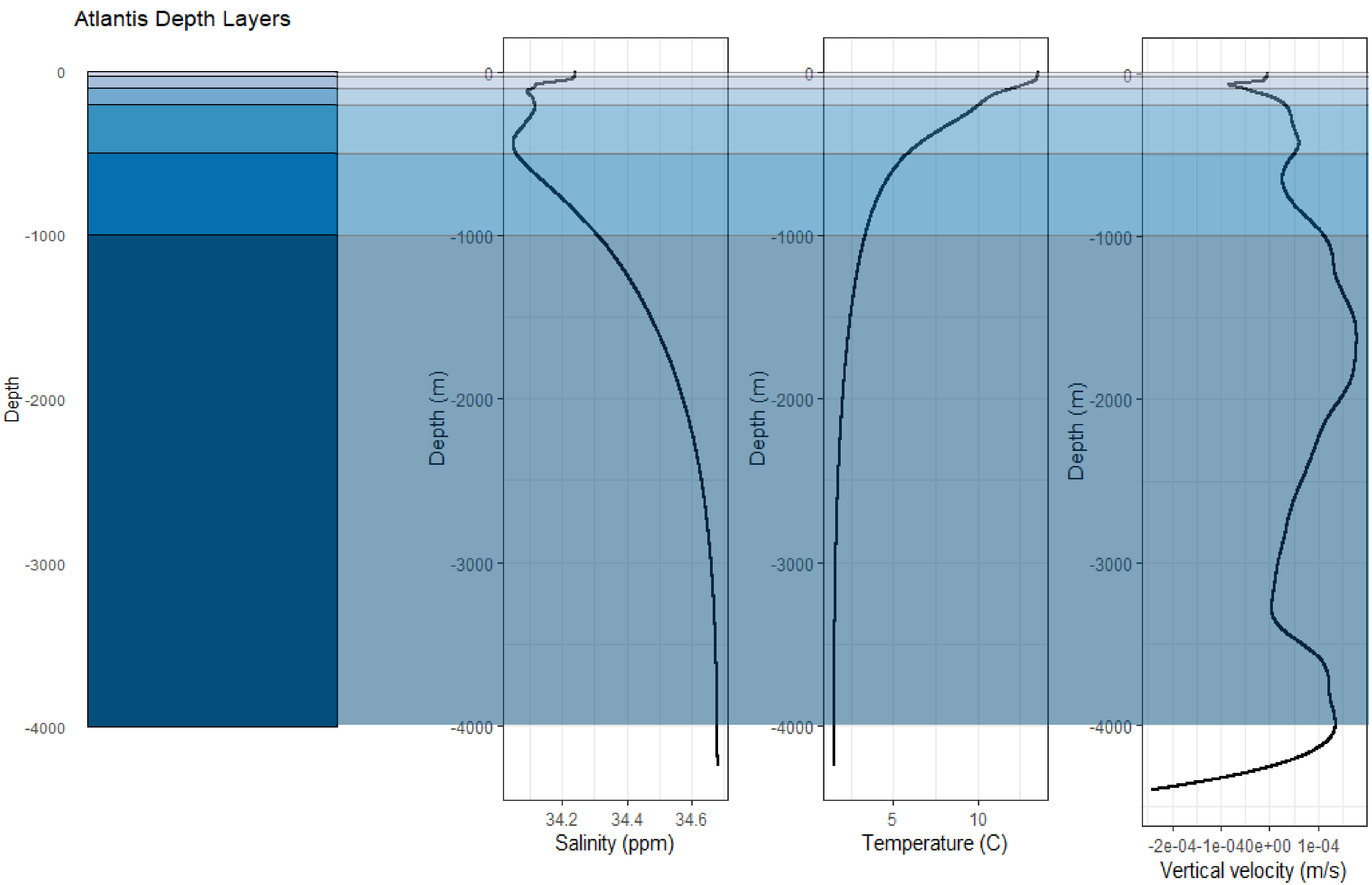
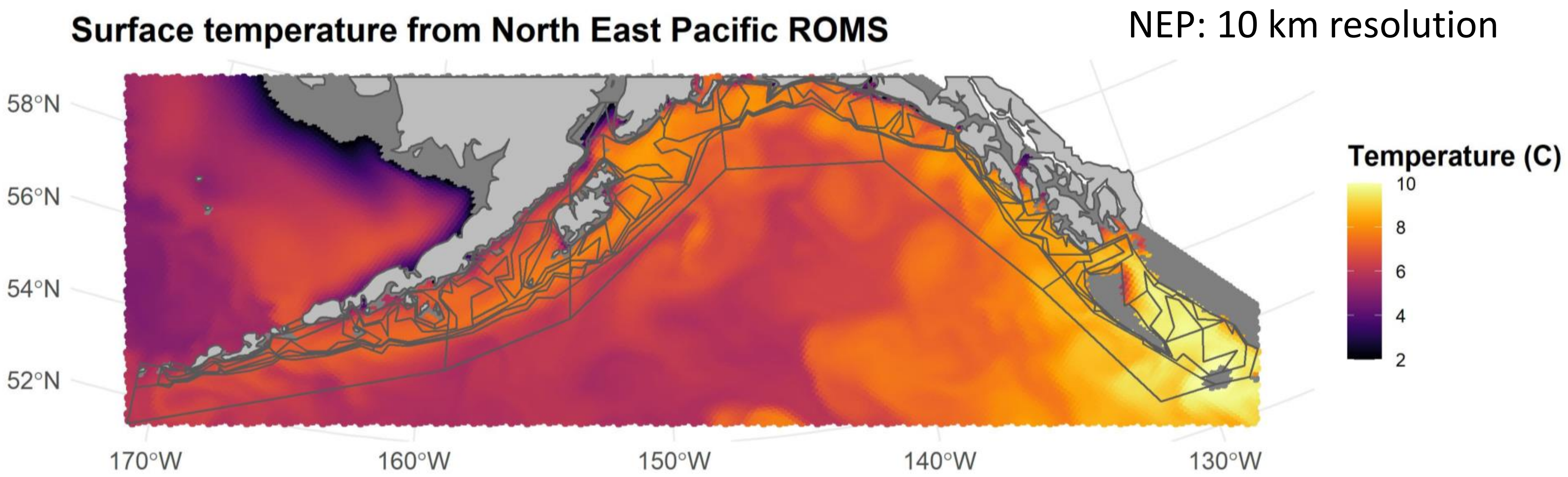
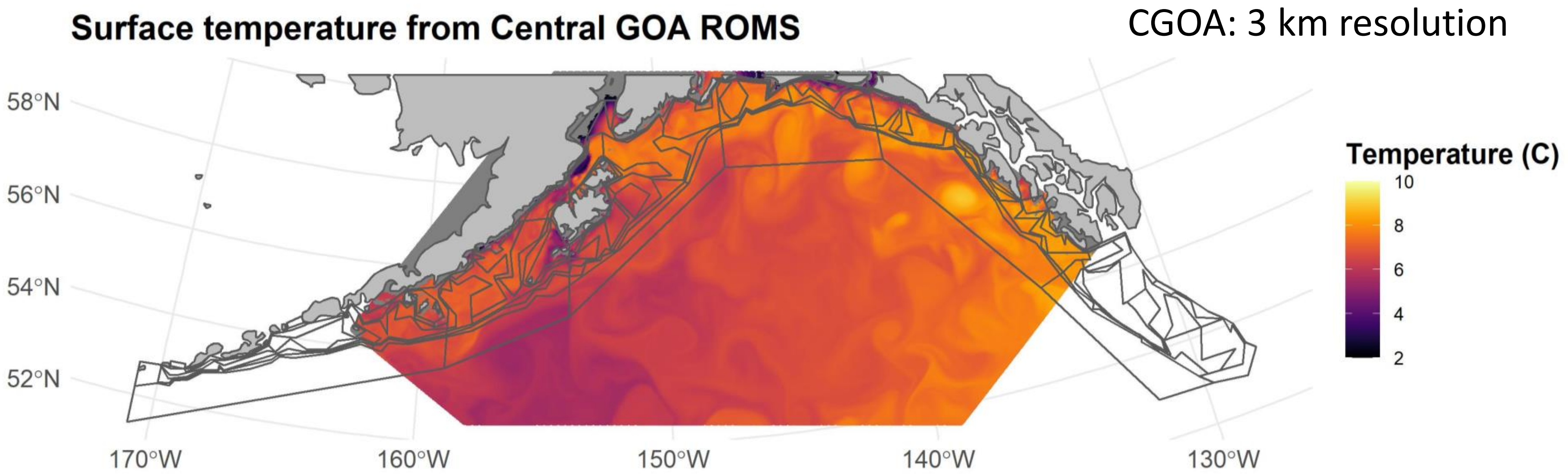


Physics: Mapping ROMS to Atlantis

NEP: 10 km resolution

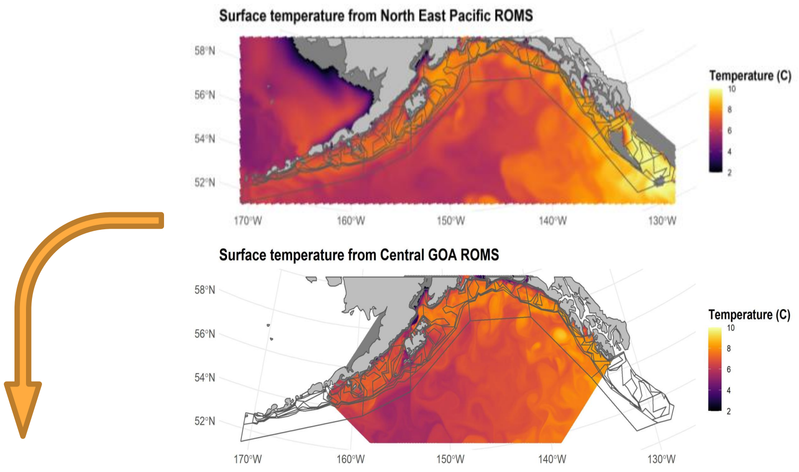


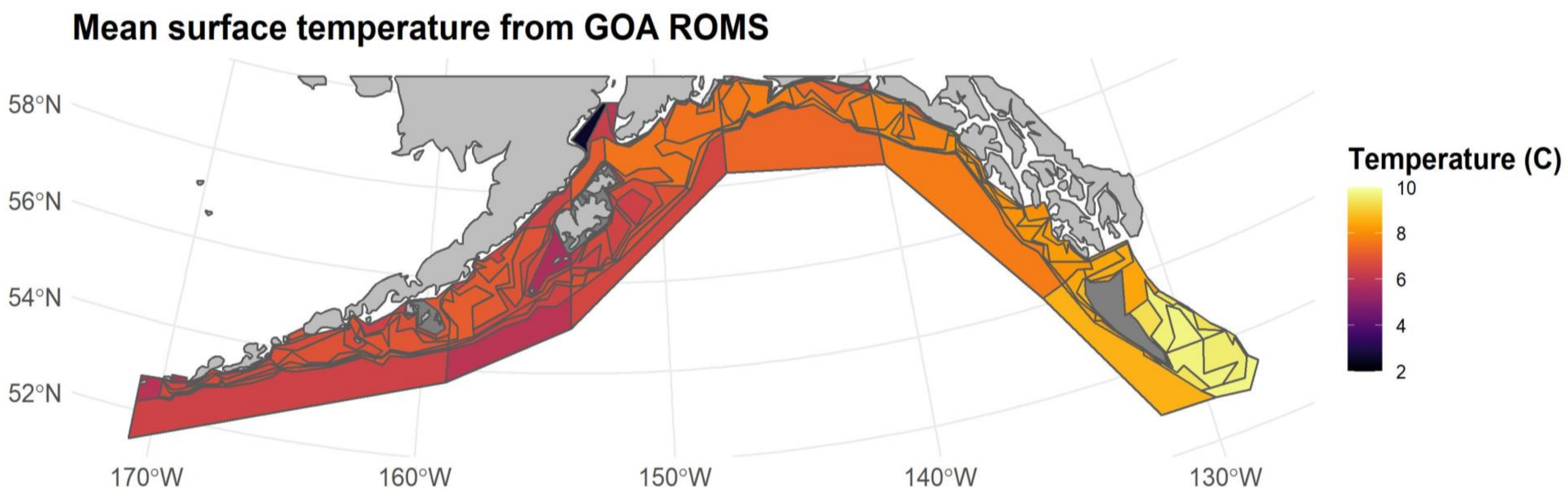
CGOA: 3 km resolution



Physics: Mapping ROMS to Atlantis

- Initially only NEP 10K (entire model domain)
- Working on ways of performing bias correction and incorporate both models

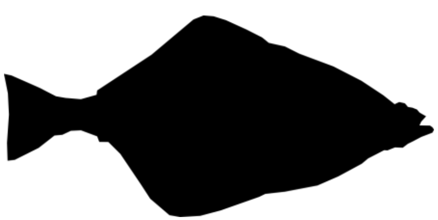




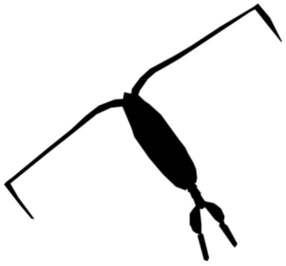
Model biology: Functional groups

- Need to aggregate species into functional groups
- Grouping based on:
  1. Ecology
  2. Trophic level
  3. Taxonomy
  4. Management considerations (e.g., FMP species complexes)
  5. Habitat considerations (e.g., shelf vs slope)
- Some groups more highly aggregated than others (ecological or commercial interest)

Pollock



Arrowtooth flounder



Mesozooplankton

Jellyfish

Model biology: Functional groups

- 78 functional groups:
  - **28 bony fish**
  - 3 sharks
  - 3 skates
  - 9 mammals
  - 4 birds
  - 26 invertebrates
  - 2 bacteria
  - 3 detritus

- Pollock
- Pacific cod
- Sablefish
- Halibut
- …
- Chinook salmon
- …
- Shallow water flatfish
- Rockfish demersal shelf
- …
- Forage fish

Model biology: Functional groups

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- Dogfish
- Demersal sharks (Pacific sleeper)
- Pelagic sharks (Salmon shark)
- Big skate
- Longnose skate
- Other skates

Model biology: Functional groups

- 78 functional groups:
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- Resident killer whales
- Transient killer whales
- Humpback whales
- Toothed whales
- …
- Steller sea lion
- Other pinnipeds

Model biology: Functional groups

- 78 functional groups:
  - 28 bony fish
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  - 2 bacteria
  - 3 detritus

- Diving feeders, fish eaters
- Surface feeders, fish eaters
- Diving feeders, inverts eaters
- Surface feeders, inverts eaters

Model biology: Functional groups

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  - 2 bacteria
  - 3 detritus

- King crab
- Tanner crab
- Octopus (GPO)
- Squids
- …
- Sponges
- Corals
- …
- Large phytoplankton
- …
- Macrozooplankton

Model biology: Functional groups

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  - **3 detritus**

Spatial distributions

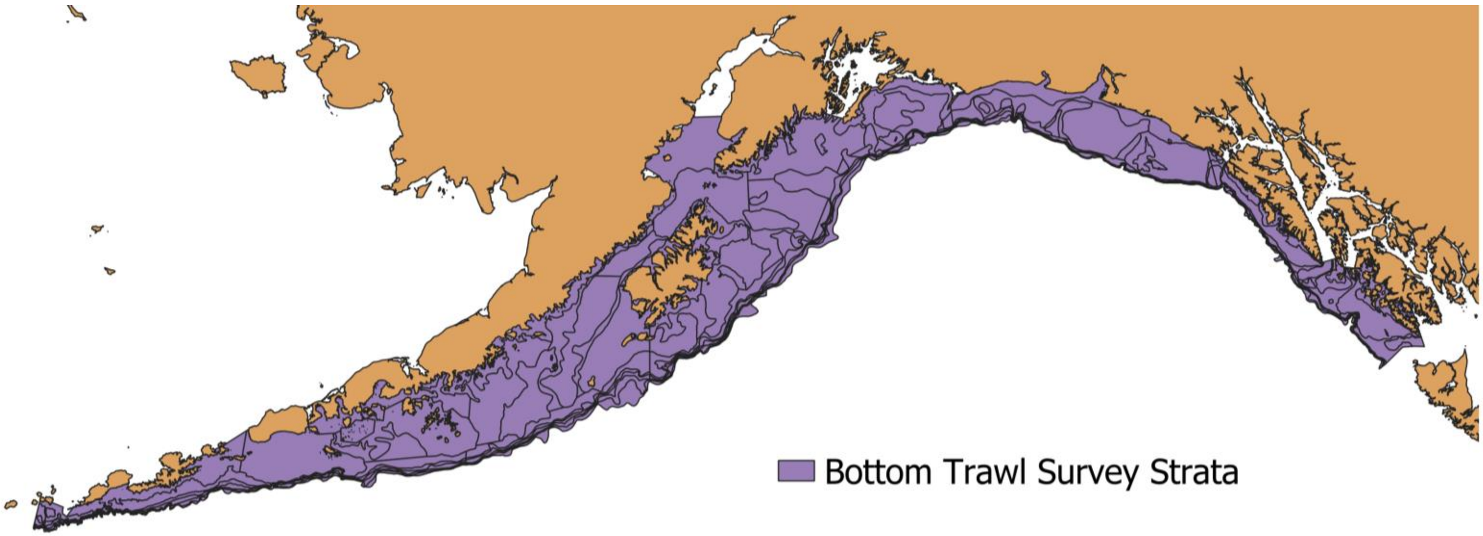
Aim:

- Distribute species biomass between Atlantis boxes at initial conditions (1990)
- Use as constraint to movement in the initial stages of model calibration

→ Capture spatial distribution of GOA species in Atlantis, 'representative' of the period 1990-present.

Many data sources, for example:

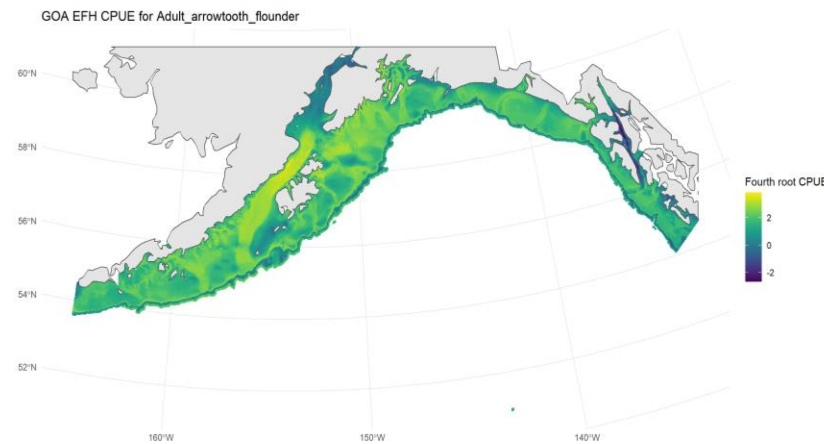
- Essential Fish Habitat (EFH 2017)
- Custom Species Distribution Models (SDMs)

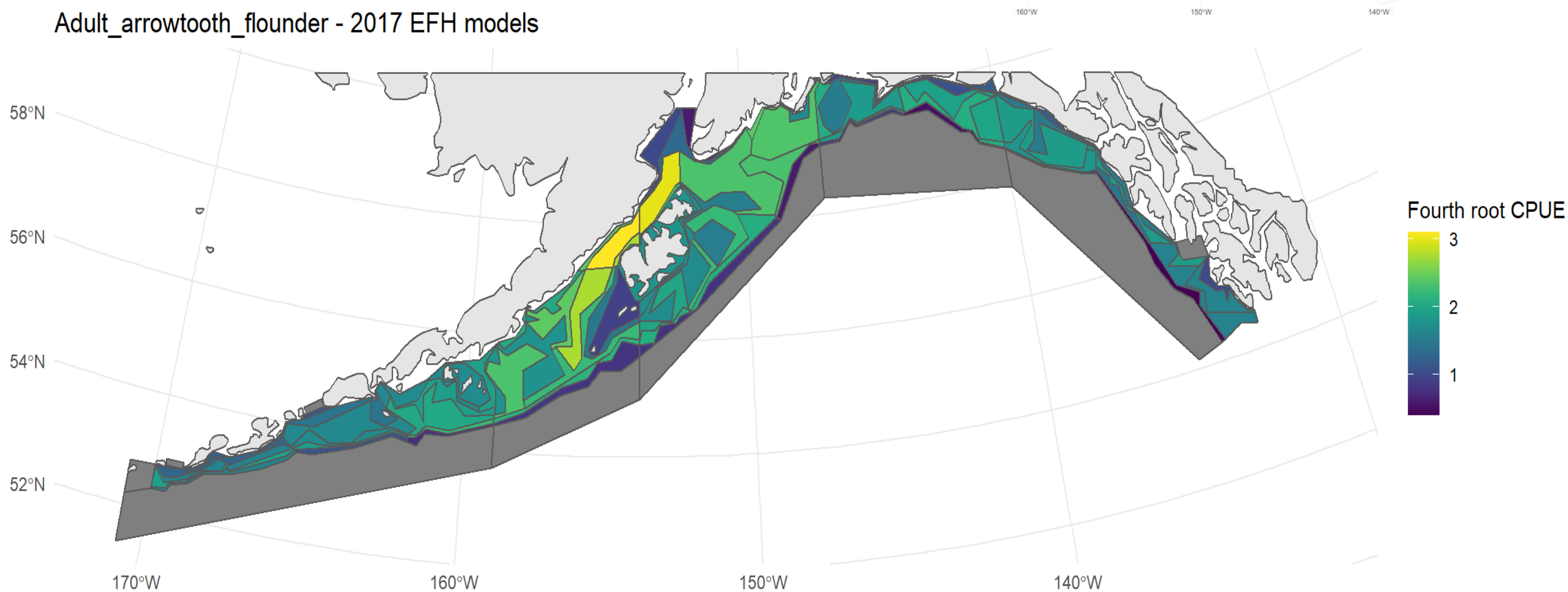


Spatial distributions: Essential Fish Habitat

Pros: Accounts for environmental covariates, validation process, ongoing effort

Cons: Available for limited species, not available for BC

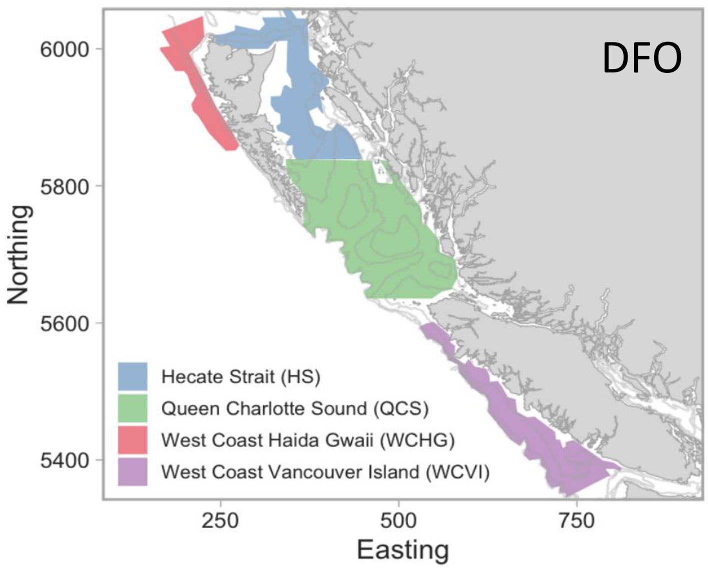


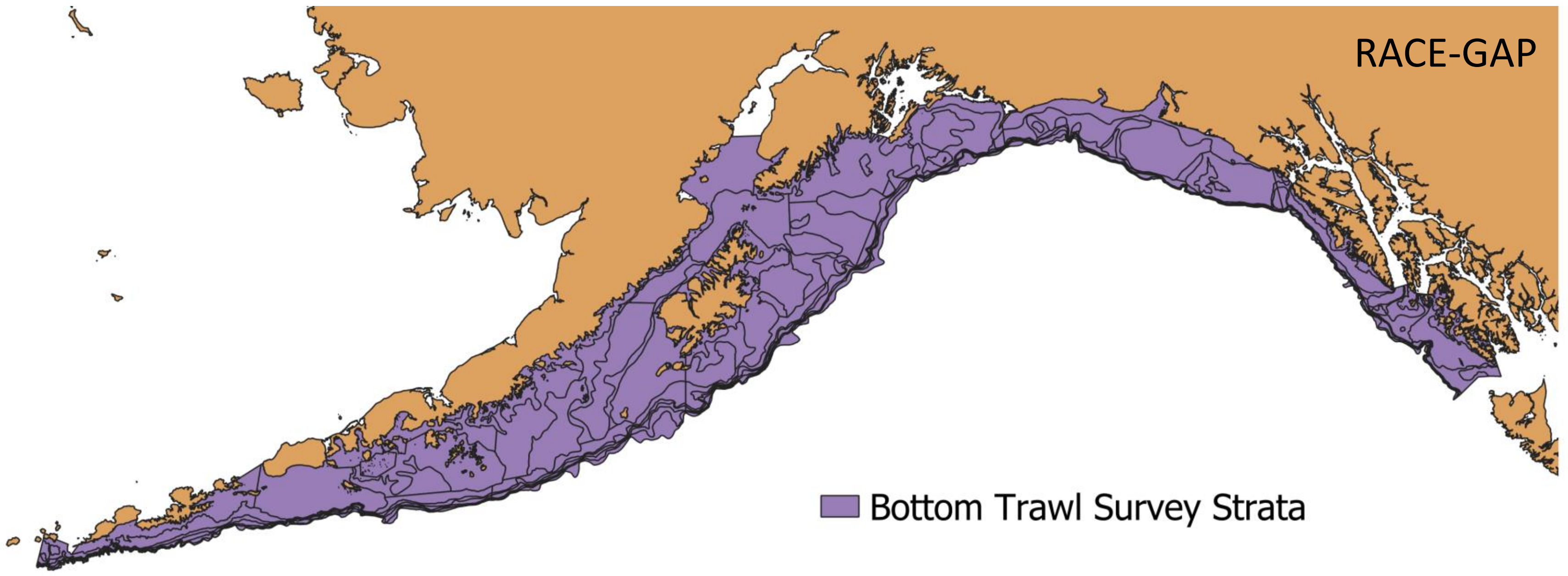


Spatial distributions: SDMs

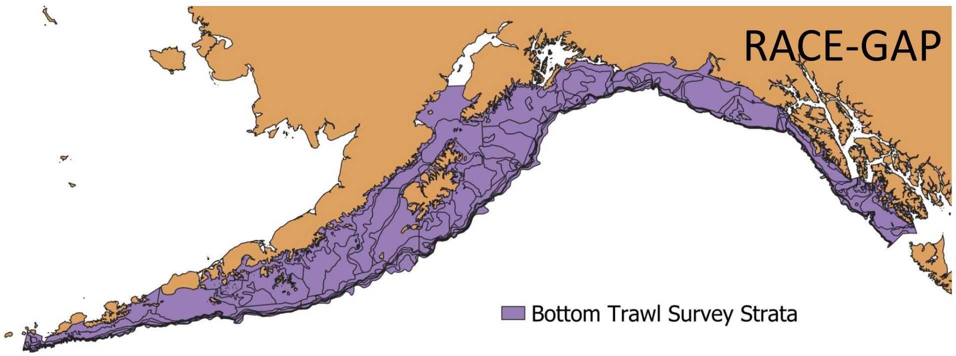
Species not modelled in EFH

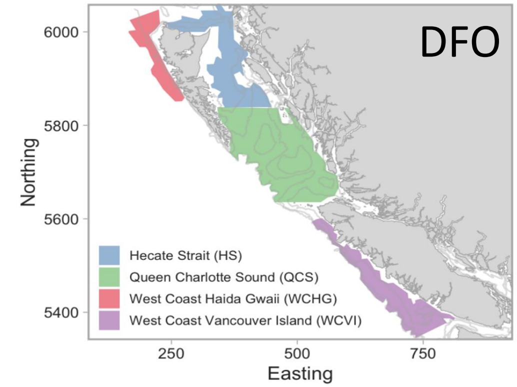
- Biomass index standardization with geostatistical modelling (sdmTMB)
- Based on bottom trawl survey data (AFSC and DFO)
- Only coordinates and depth
- Average spatial distributions from 1990's

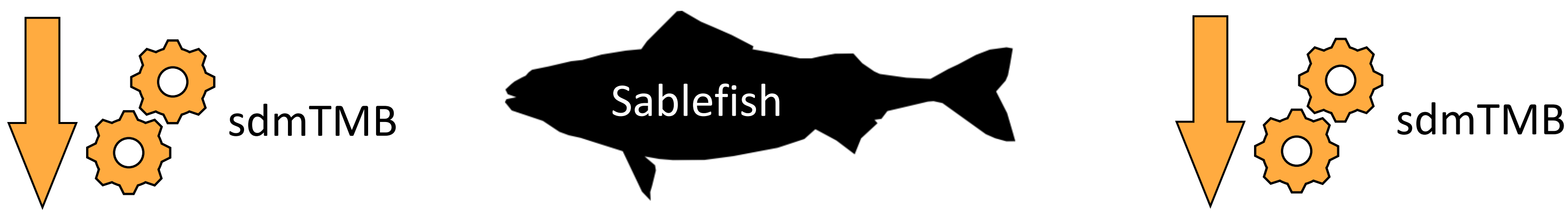


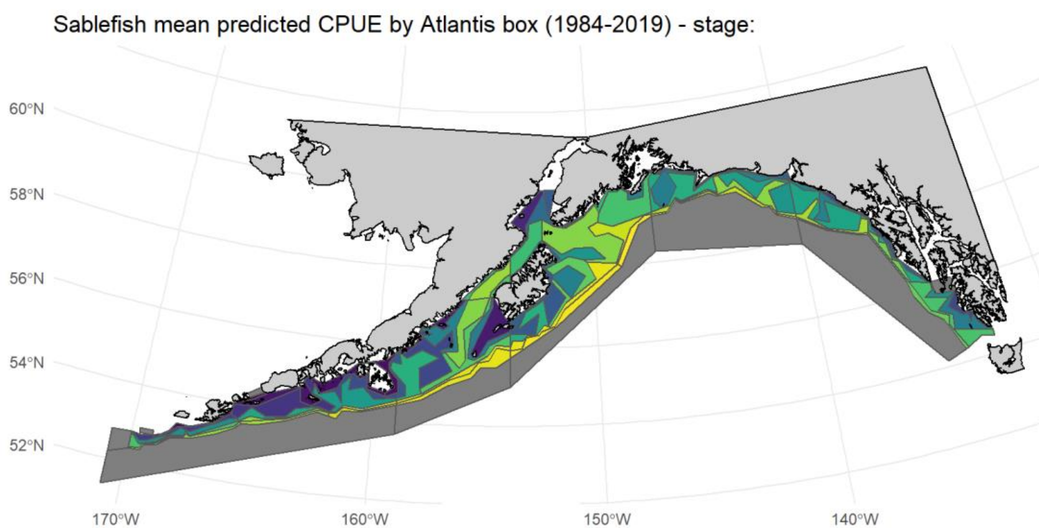


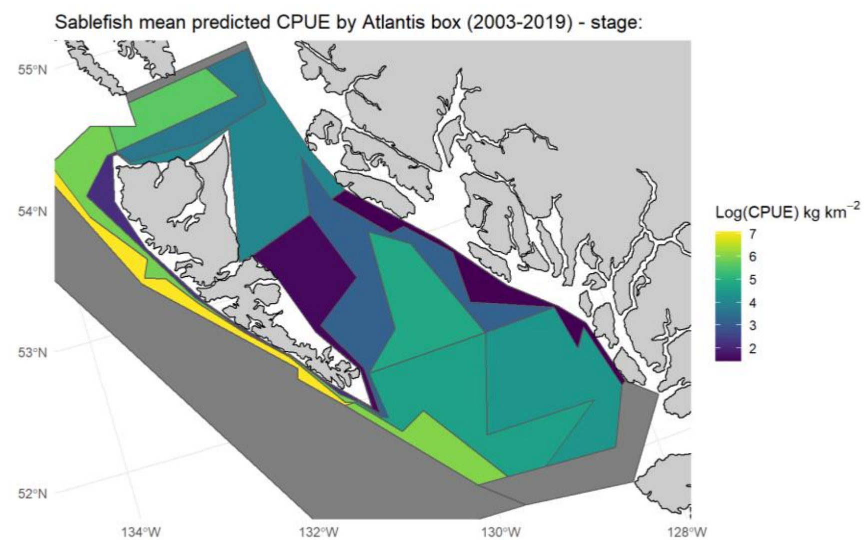
Spatial distributions: SDMs





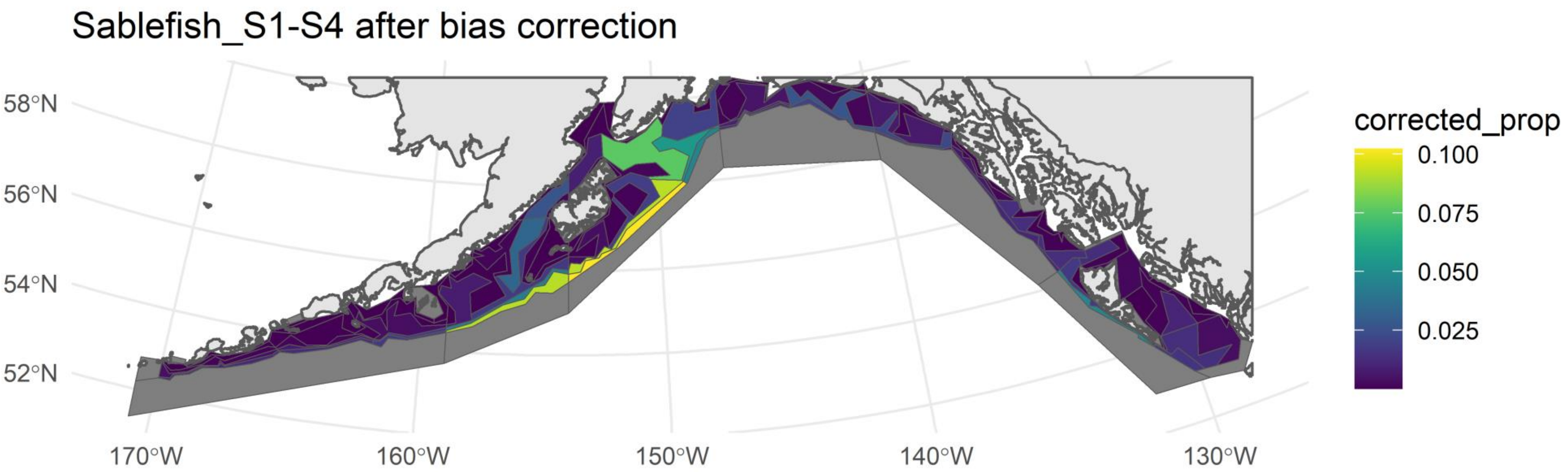






Spatial distributions: SDMs

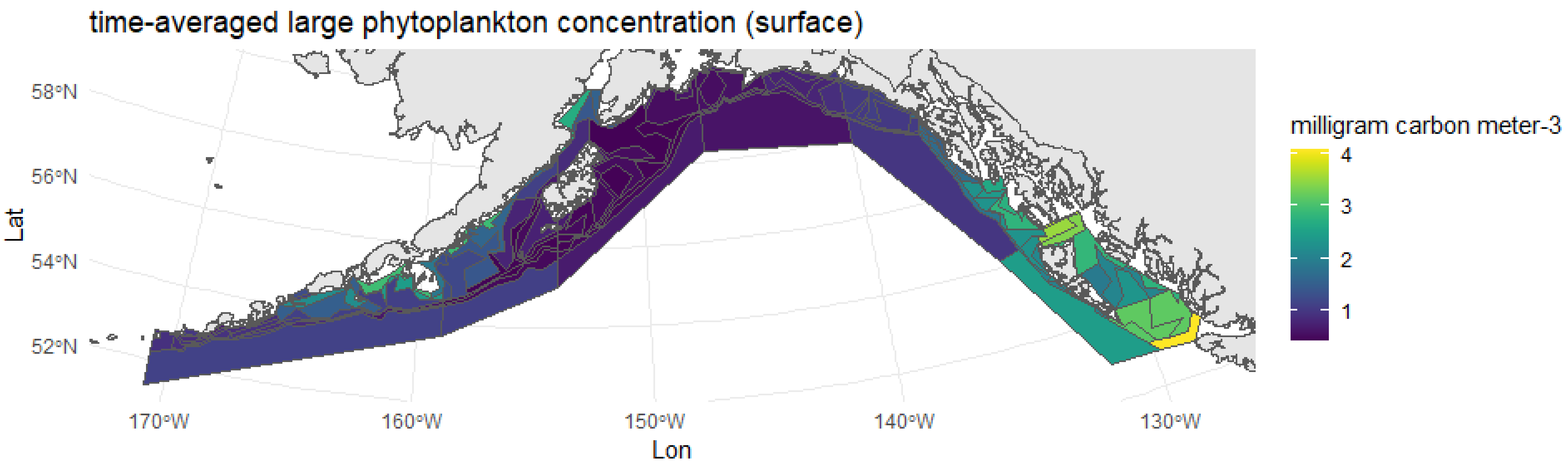
- Estimate proportion of total biomass per box
- Use these proportions to “seed” biomass estimates (e.g., from stock assessments) to the Atlantis domain
- But: it requires a (simple) bias correction between the two data sets



Spatial distributions: Other sources

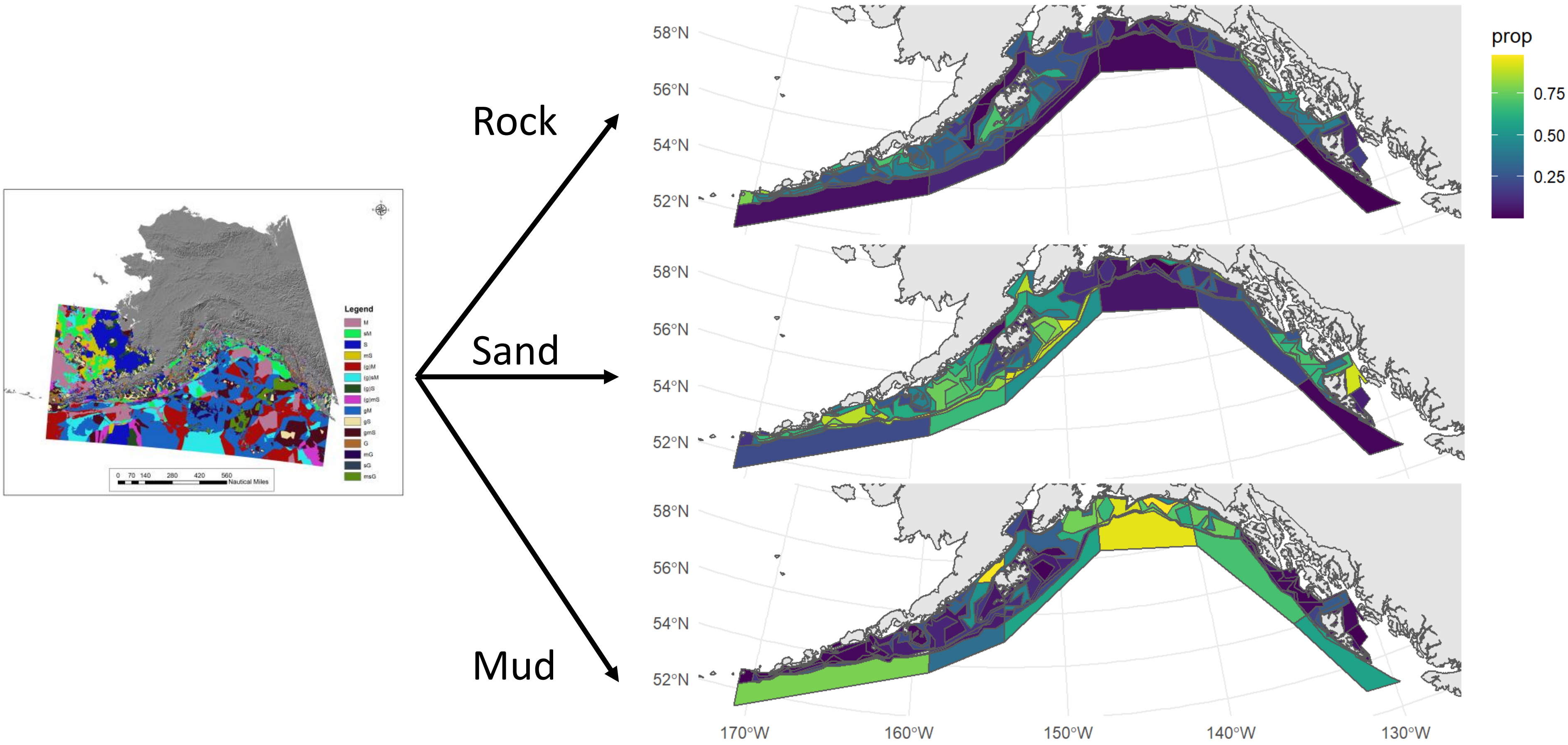
Bottom trawl data is not suitable to model distributions of all Atlantis groups

- Surface trawl (e.g., GOAIERP, Jamal Moss), midwater trawl (e.g., EcoFOCI) can fill some gaps
- Existing SDMs to inform specific groups
- NPZ to inform plankton



Physical habitat

- Species distributions and ecological processes in Atlantis can be tied to physical habitats
- Geological features from dbSEABED Global Database (Bob McConnaughey)

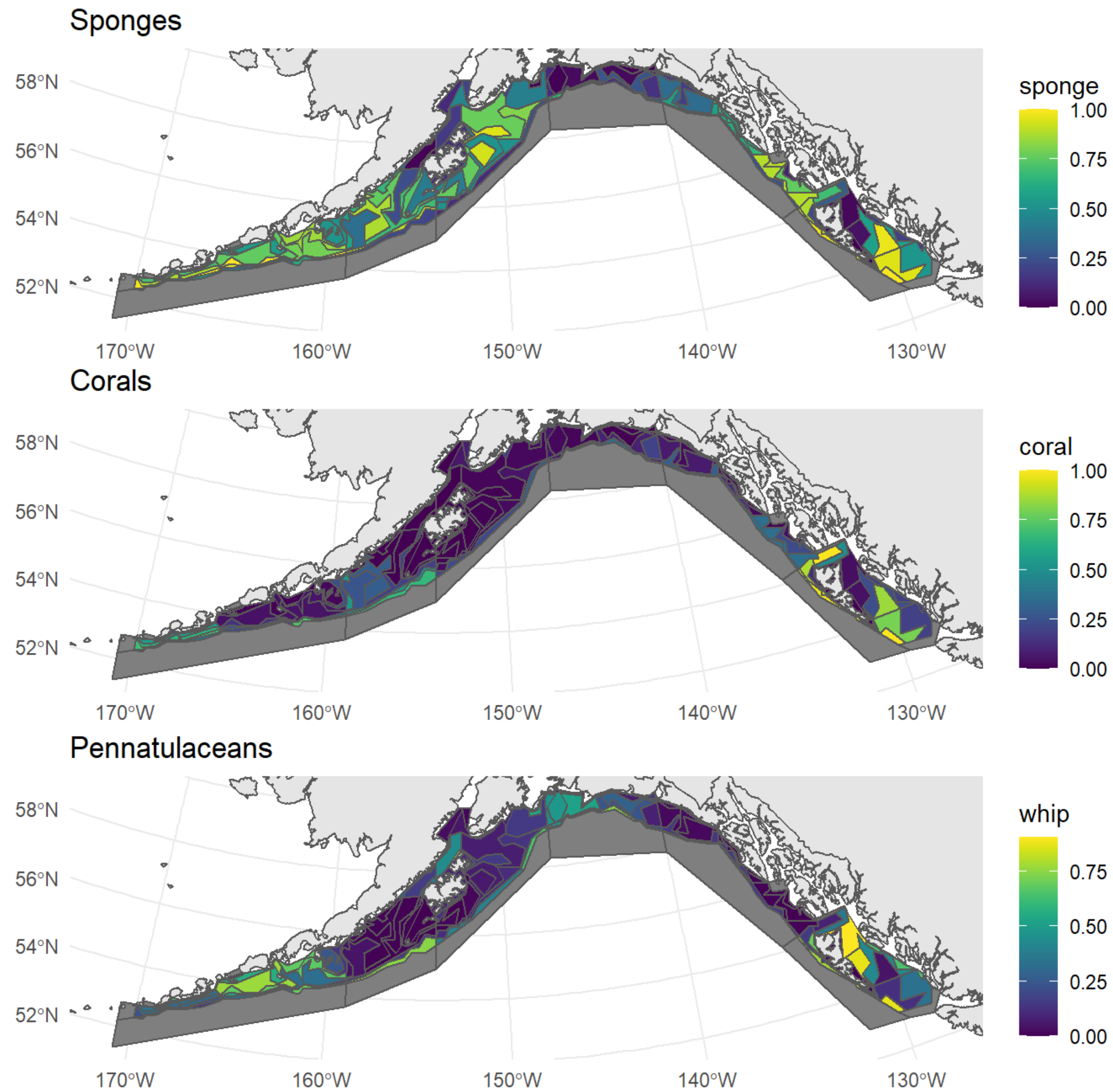


Biohabitats

Habitat-forming benthos: corals, sponges, other benthic invertebrates

Presence from published SDMs:

- Rooper et al. (2014, 2017): GOA and AI
- Chu et al. (2019): BC



Biology: Life history and biometrics

Atlantis allows for the modelling of growth, trophic interactions, spawning, recruitment, mortality, migrations, movement…

Life history parameters and biometrics from:

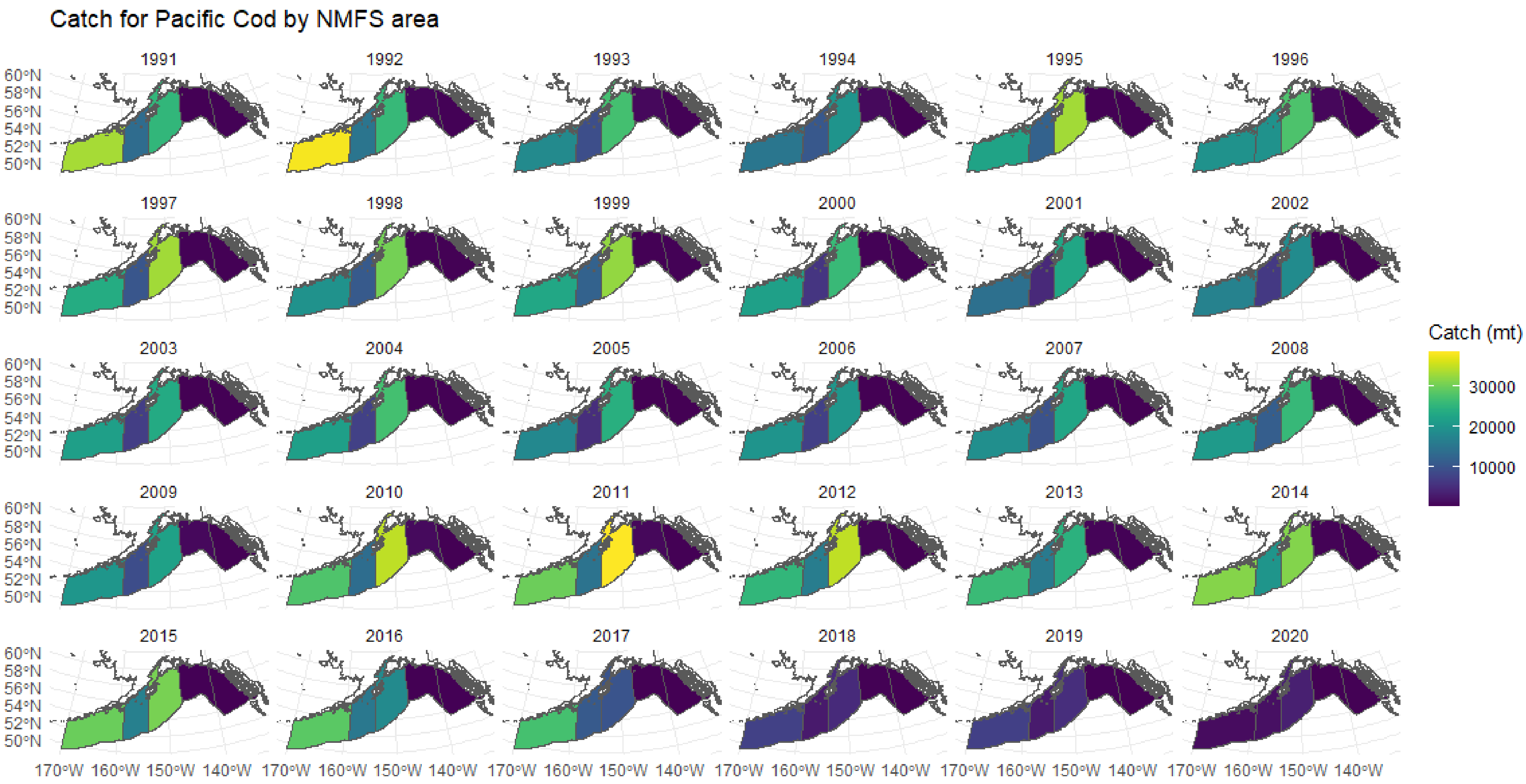
- Stock assessments
- Resource Ecology and Ecosystem Modeling Task
- Literature
- Synthesis of global databases (FishBase, R packages like Jim Thorson's FishLife)
- Other Atlantis models (Puget Sound, California Current)

Biology: Ontogenetic diet preferences

(REEM diet data)

Fisheries in Atlantis

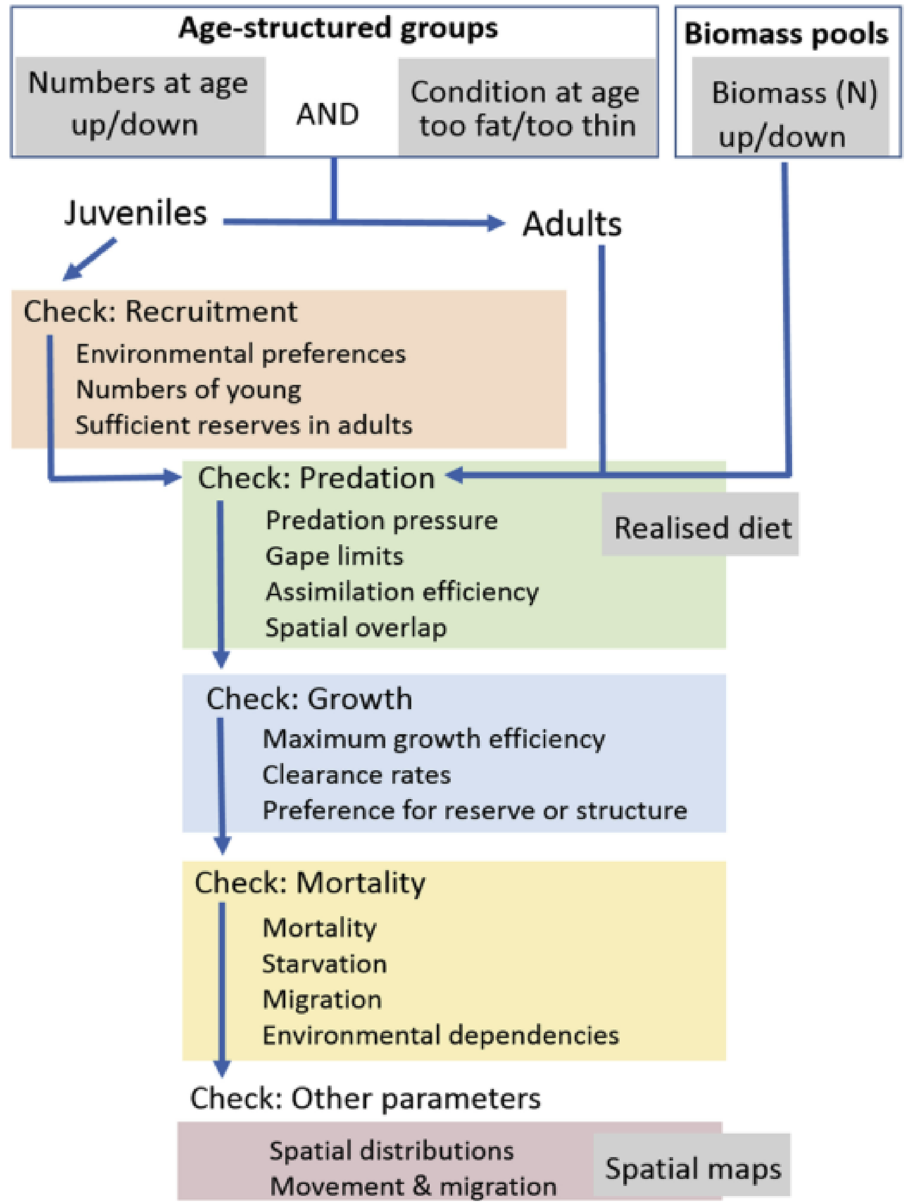
- Initially modelled as “imposed” catch for hindcast runs
- Can be modelled as *F* in forecast as first simple approximation
- Eventually the goal will be dynamic fishing – but some ways away



Next steps

Next steps: Calibration

- Change input parameters until model dynamics match observations
- Manual and time-consuming process
- One must look at dynamics at different spatial scales
- Parameters commonly adjusted include recruit production, growth and consumption rates, diet preferences



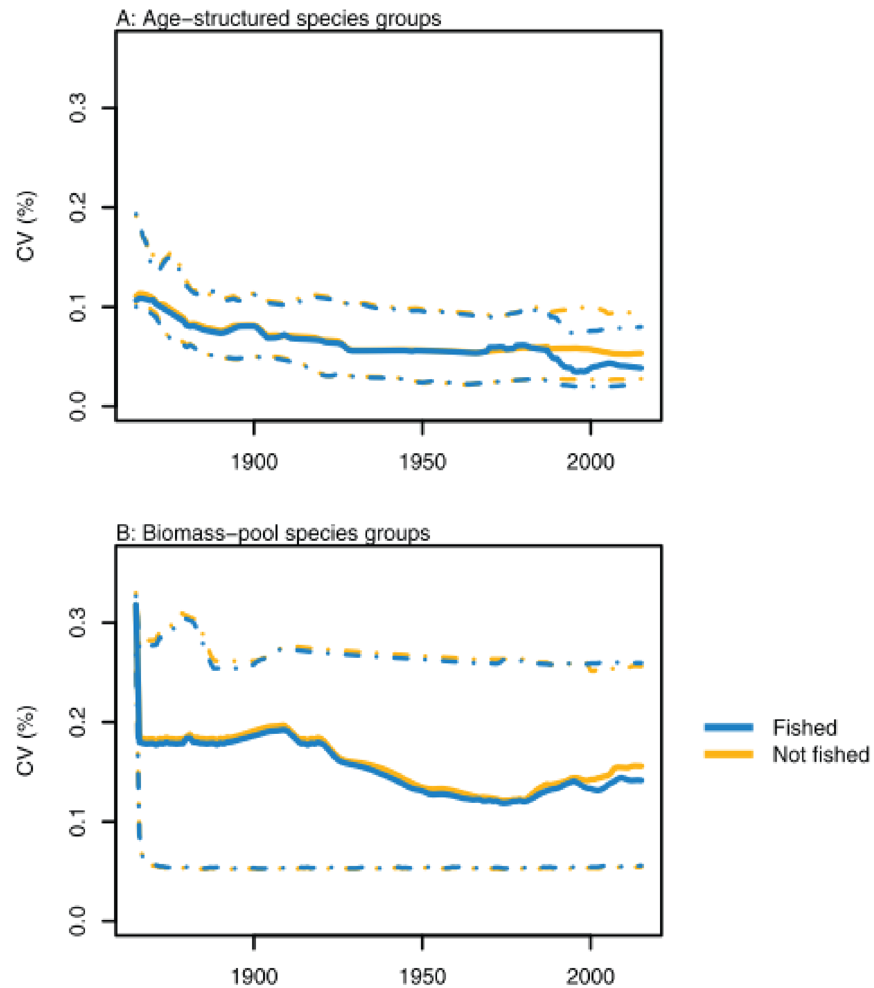
Pethybridge et al. (2019)

Next steps: Sensitivity analysis

Systematic sensitivity analysis is not viable in Atlantis (1000's of parameters)

Need to:

1. Identify uncertainty parametrization (e.g., for species with limited data)
2. Identify the parameters that the model is most sensitive to
3. Perturb a set of parameters for a set of species
4. Analyze the variability of output metrics of interest
5. Phytoplankton growth and mortality, top predator recruitment (Bracis et al. 2020)
6. Low trophic levels often most sensitive to perturbation (McGregor et al. 2019)

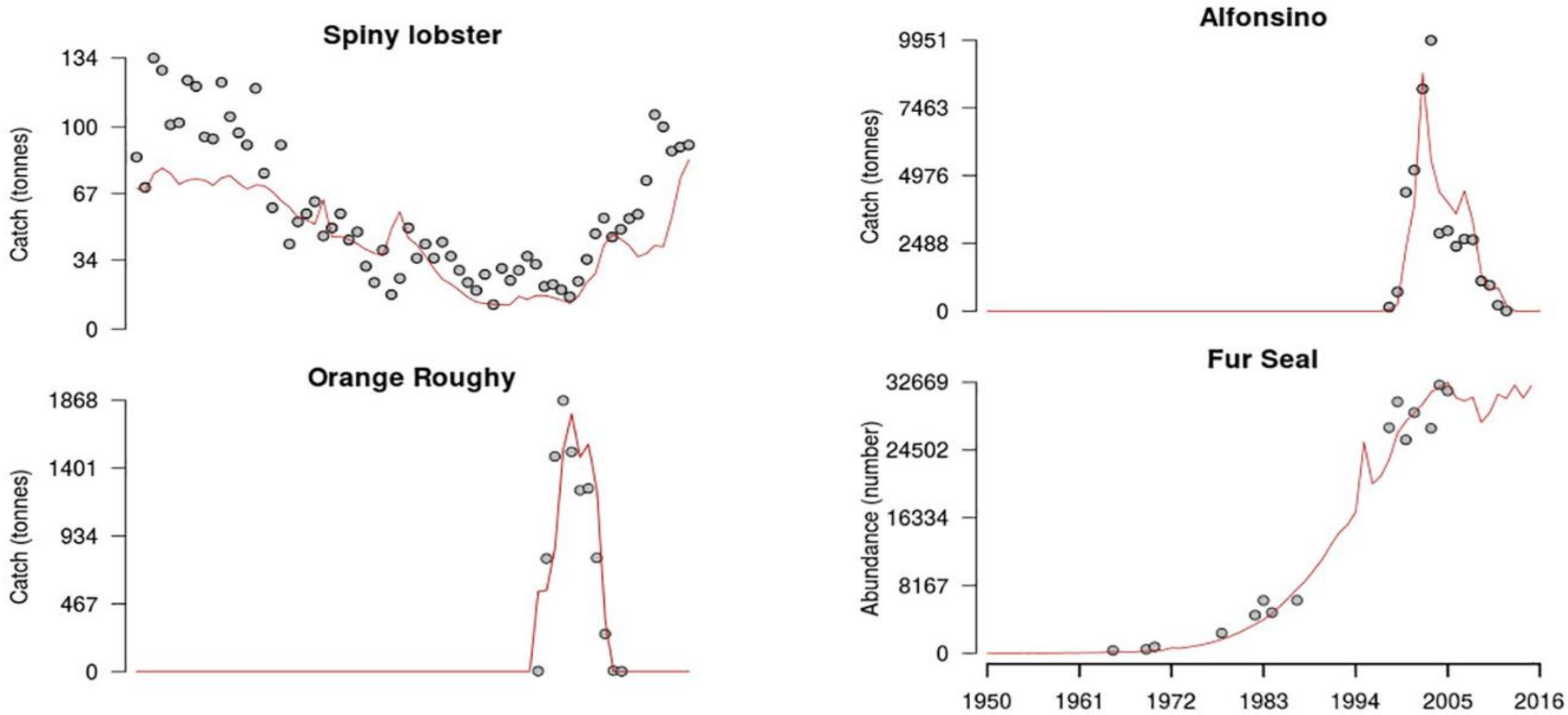


McGregor et al. 2019

Next steps: Validation

Hindcast skill: comparison with historical trends and data

- Can pick a target value (e.g., biomass must be within ±20% of the observation)



Porobic et al. 2019

Next steps: Validation

Table 2. List of ecosystem indicators calculated from the NEUS model data and the survey biomass and observed landings data.

Ecological indicators	
Total Biomass	Total biomass of fish, benthos, marine mammals, seabirds and cephalopods.
Total Catch	Total catch of commercial fish and benthos.
Catch/Biomass	Total catch as proportion of total biomass.
Fish Biomass	Total biomass of fish species.
Demersal/Pelagic Ratio	Biomass of all demersal fish as a proportion of biomass of all pelagic fish.
TEPs	Threatened, endangered, and protected species

Ecological indicators

+

Table 3. Skill metrics used in the analysis of ecosystem model skill.

Skill Metric	
AE	Average Error
AAE	Average Absolute Error
RMSE	Root Mean Squared Error
MEF	Modeling Efficiency
S	Spearman Rank Correlation
P	Pearson Correlation
K	Kendall Rank Correlation

Skill metrics

Olsen et al. 2016

Next steps: Hindcast simulations

- Initialize the model in early-mid 1990's
- Force the model with ROMS from 1996-2020
- Force removals from catch data

Focus:

- 2013-2016 heat wave
- Evaluate changes in ecosystem productivity
- Identify shifts in community composition, trophic structure, species distributions, etc.
- Evaluate the match of model results with stock assessment models and observations

Next steps: Forecast simulations

- Force the model with ROMS from 2041-2050 and 2081-2090
- Model fishing pressure as fixed *F* for different fisheries/fleets

Focus:

- Future climate change
- Evaluate changes in ecosystem productivity
- Identify shifts in community composition, trophic structure, species distributions, etc.
- Evaluate the Optimum Yield range for groundfish in the GOA under future climate change

Engagement of the Plan Team

Engagement of the Plan Team and other Council bodies will increase as we move to model calibration, validation, and projections.

<u>We are looking for feedback</u>:

- Apparent issues with model geometry?
- Concerns about species grouping?
- Can we reach out to assessment authors to help us validate model dynamics?

Modelling fisheries:

- Conversations with economists and social scientists to capture GOA fishing fleets
- Evaluating management strategies: what would you like to see us address with this model, when we use it for future projections?

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