Forage fish exhibit varied response to future ocean conditions: Implications for divergent predator-prey redistribution

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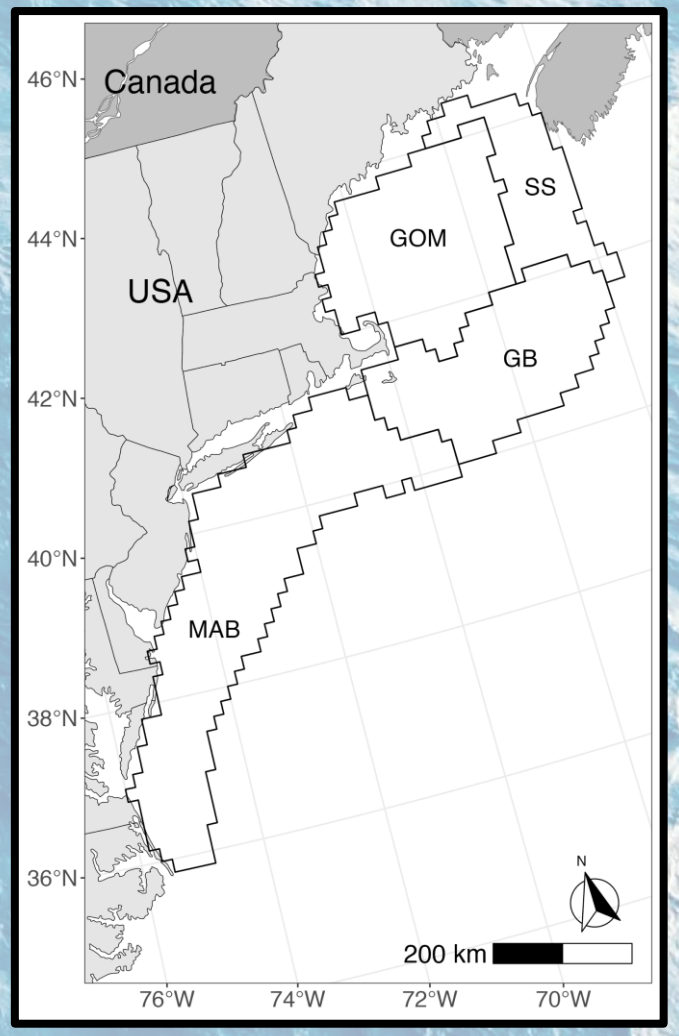
Background:

1. Forage fish dominate the biomass of many coastal upwelling systems (Suca et al. 2021)
2. Important energetic trophic link (Pikitch et al. 2014)
3. Yet spatiotemporal distributions and resulting ecosystem function are poorly understood (Staudinger et al. 2020)

NOAA Fisheries, Katie Rogers

Background: Northwest Atlantic Ocean

1. Productive, forage fish rich region



Suca et al. 2021

Background: Northwest Atlantic Ocean

1. Productive, forage fish rich region
2. Focus on four species:
   - Sand lance (*Ammodytes spp.*)
   - Butterfish (*Peprilus triacanthus*)
   - Atlantic herring (*Clupea harengus*)
   - Alewife (*Alosa pseudoharengus*)

Suca et al. 2021

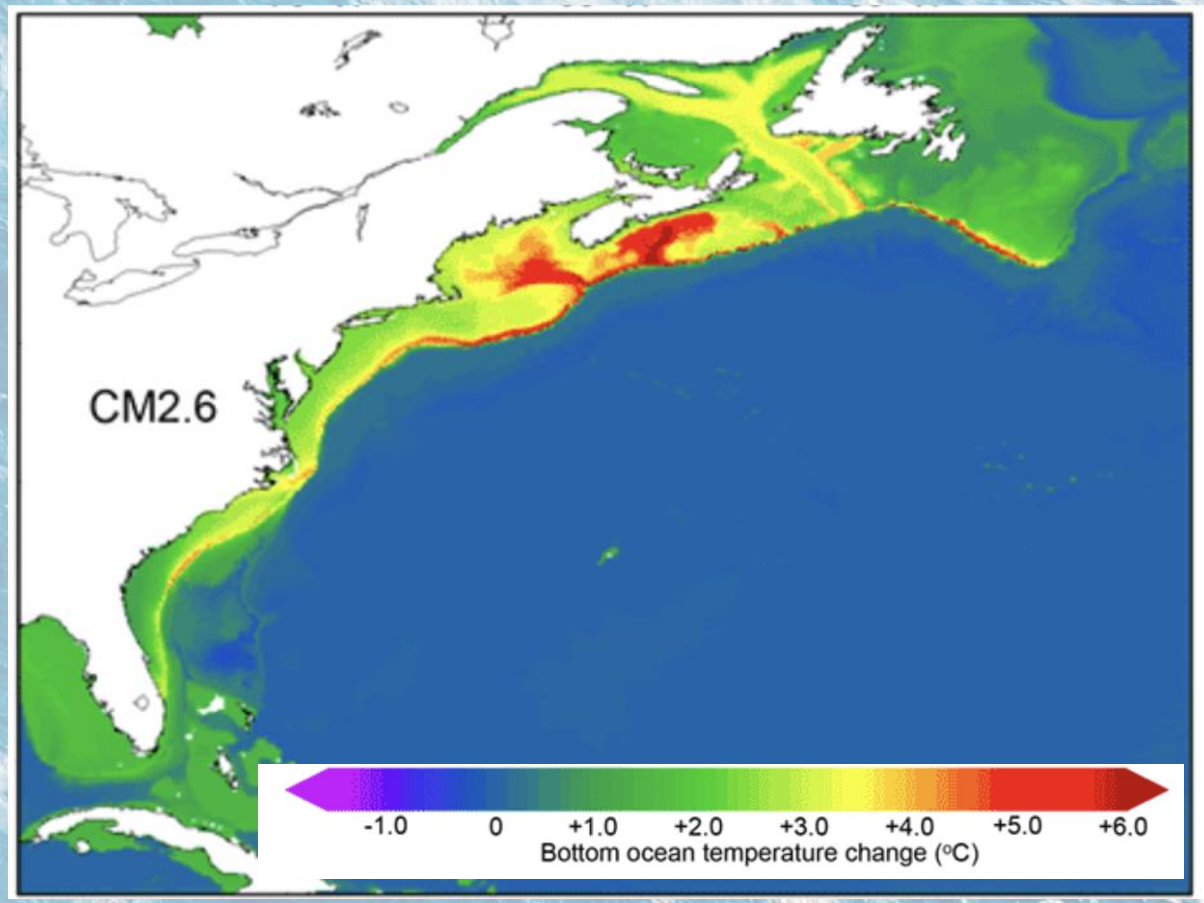
Background: Northwest Atlantic Ocean

1. Productive, forage fish rich region
2. Variable responses in assemblage under contemporary conditions
3. Varied relation between forage fish species and underlying oceanographic processes

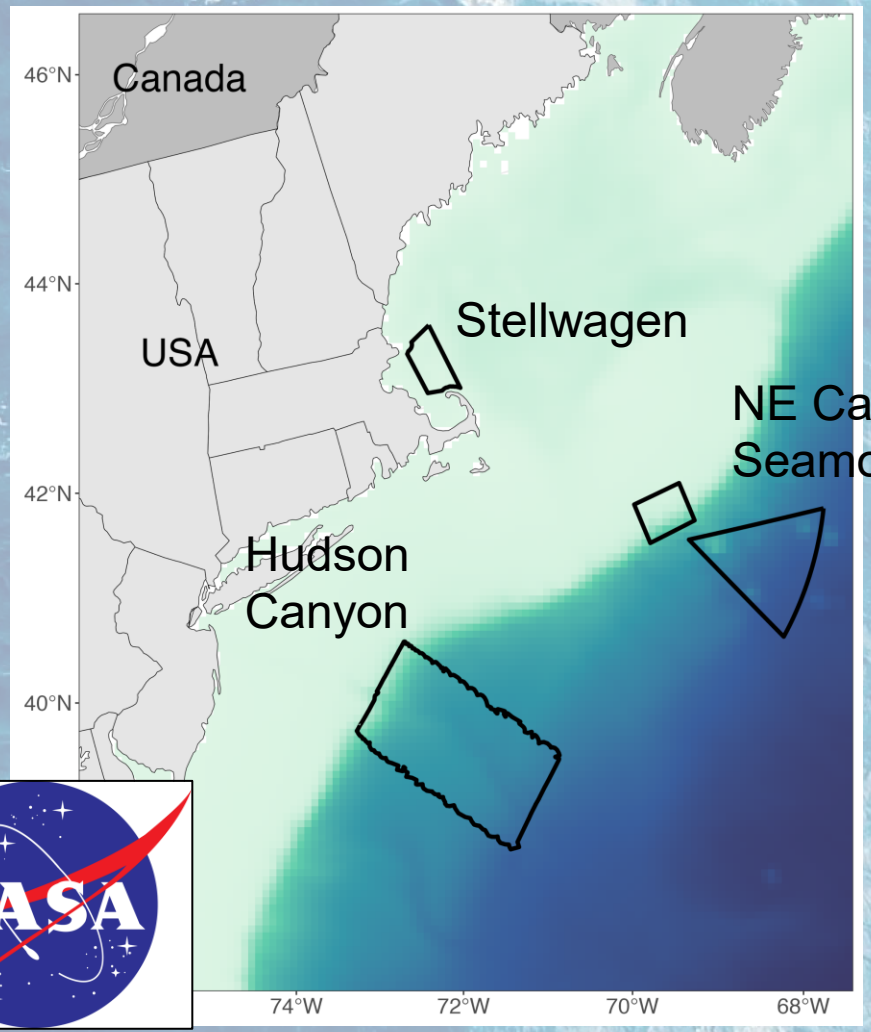
Suca et al. 2021

Background: Warming NWA

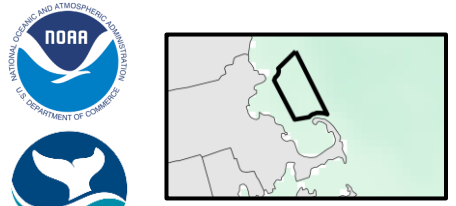
1. Among the fastest warming oceanic regions globally (Saba et al. 2016)
2. Projected decline in suitable habitat for array of highly migratory species by the end of the century (Braun et al. 2023)
3. Unknown how regional forage fish assemblage will respond



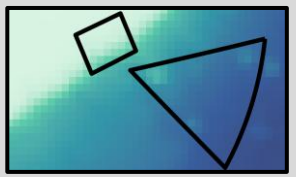
Project motivation



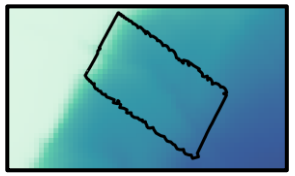
End users



Stellwagen Bank National Marine Sanctuary
- Tammy Silva, David Wiley, & Pete DeCola



Northeast Canyons & Seamounts Marine National Monument
- Cori Kane, Marianne Randall, Patrick Moffett



Hudson Canyon National Marine Sanctuary
(proposed)
- LeAnn Hogan

Objectives:

1. Quantify response of forage fish populations to future ocean conditions over the next ten years
2. Contextualize how the regional forage fish community may reshuffle under changing conditions

We hypothesize that shifts in suitable habitat are determined by:

1. Species-specific requirements
2. Region-specific constraints

Approach:

Northeast Fisheries Science Center Bottom Trawl (Politis *et al.*, 2014)

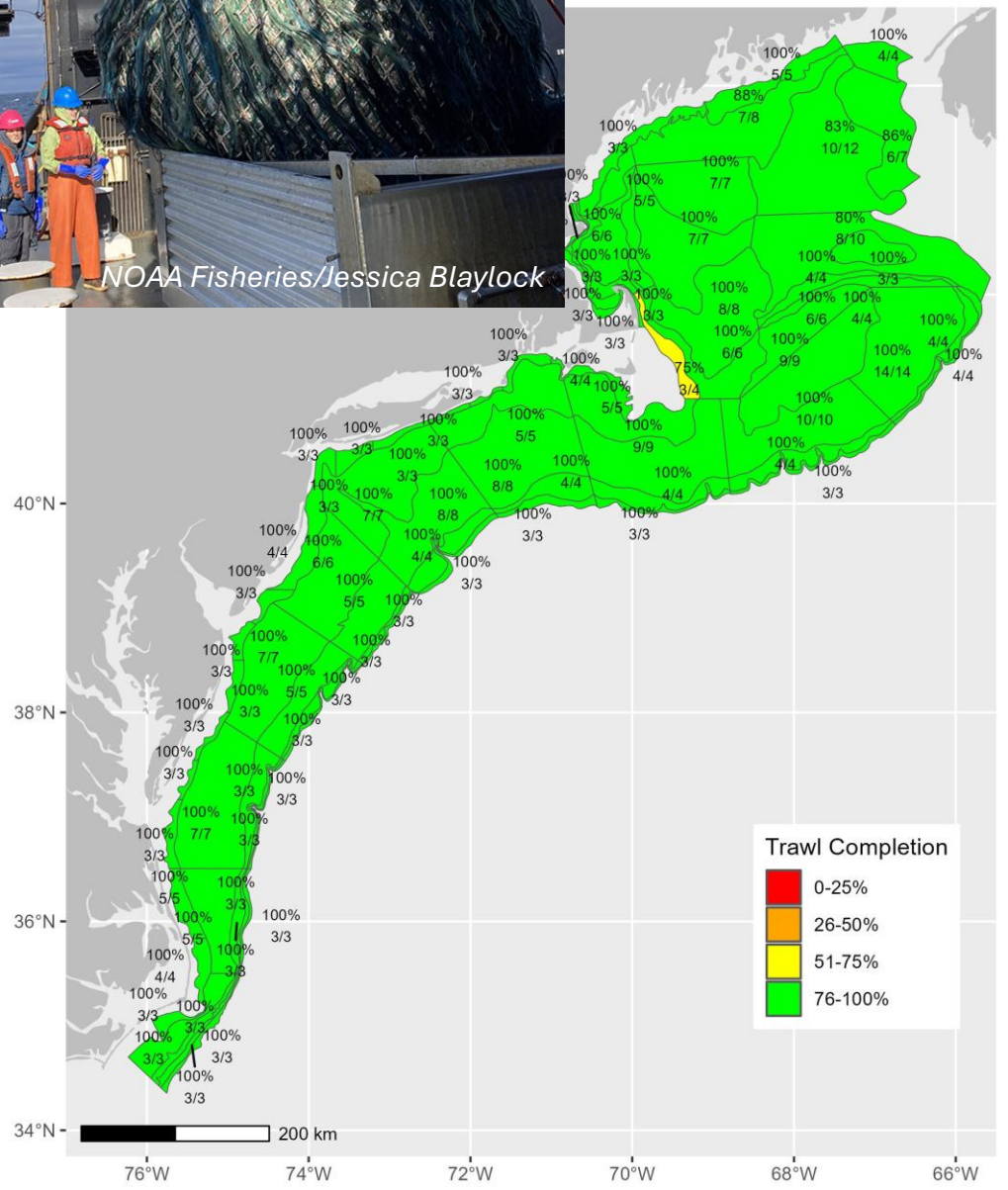
Two trawl seasons:

- Fall (September – December)
- Spring (February – June)

Split analysis among four ecoregions:

- Mid-Atlantic Bight
- Georges Bank
- Gulf of Maine
- Scotian Shelf

NOAA Fisheries/Jessica Blaylock



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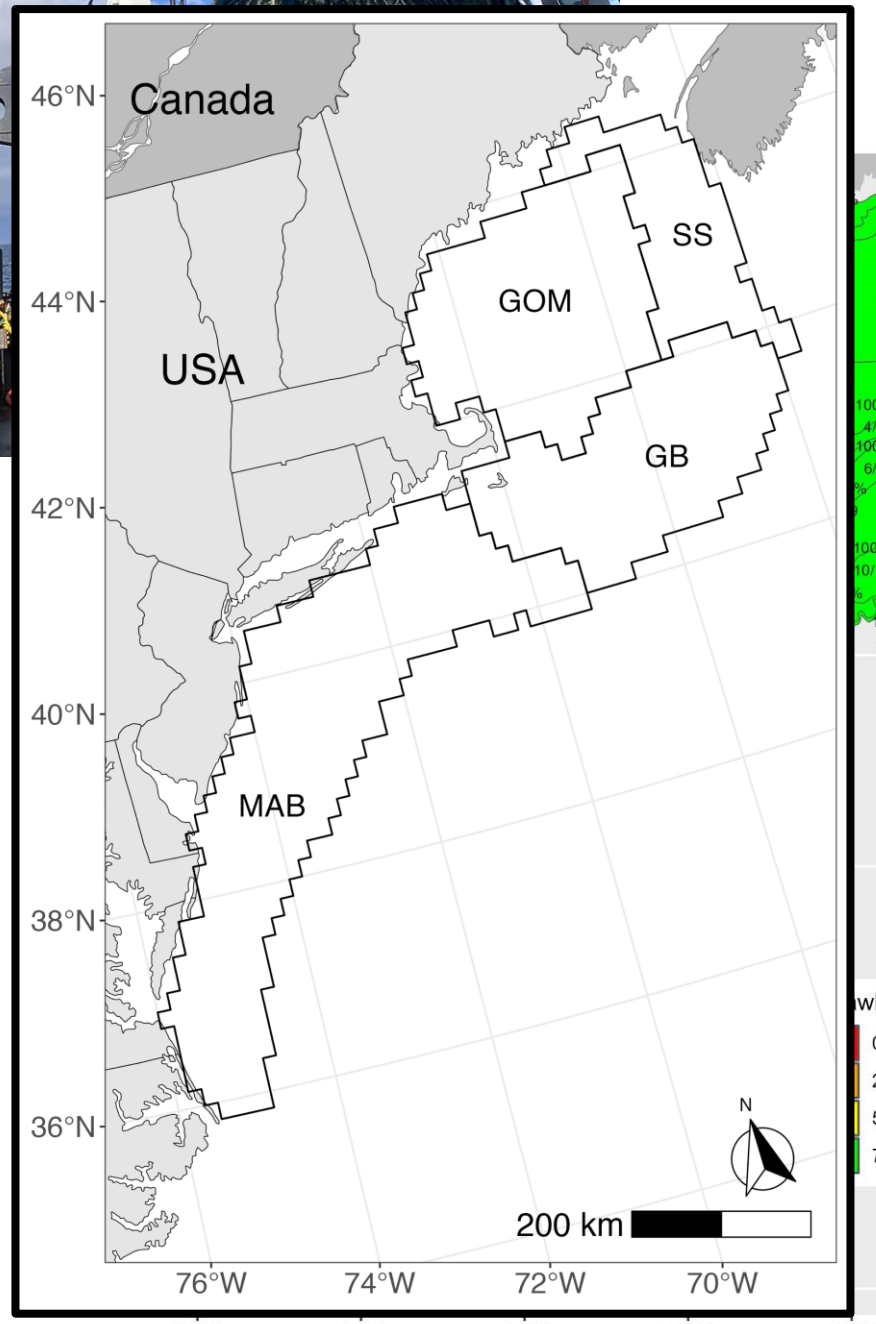

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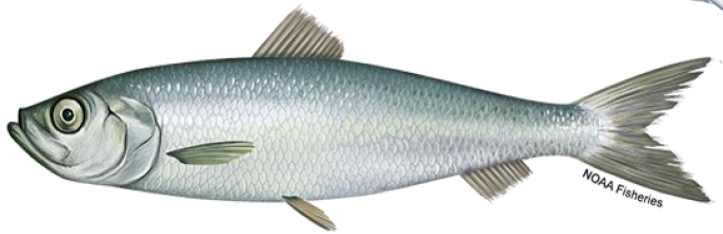


Total of 8 models, one per trawl season per species

Approach: Environmental data

Monthly updates at 1/12˚ resolution

Contemporary conditions (1993–2023)

- Copernicus Marine Service Global Ocean Physics Reanalysis (GLORYS)

  Lellouche et al. 2018

- The Nature Conservancy Northwest Atlantic Marine Ecoregional Assessment

  Anderson et al. 2010

Future Conditions (2025–2034)

NOAA Changing Ecosystem and Fishery Initiative Modular Ocean Model 6 (MOM6)

- Comes from NOAA's GFDL earth system model

  Ross et al. 2023

Resulting covariates:

- Bathymetry
- Sea surface temperature
- Bottom temperature
- Mixed layer depth
- Sea surface salinity
- Sediment*

Approach:

Spatiotemporal general linear mixed effect model

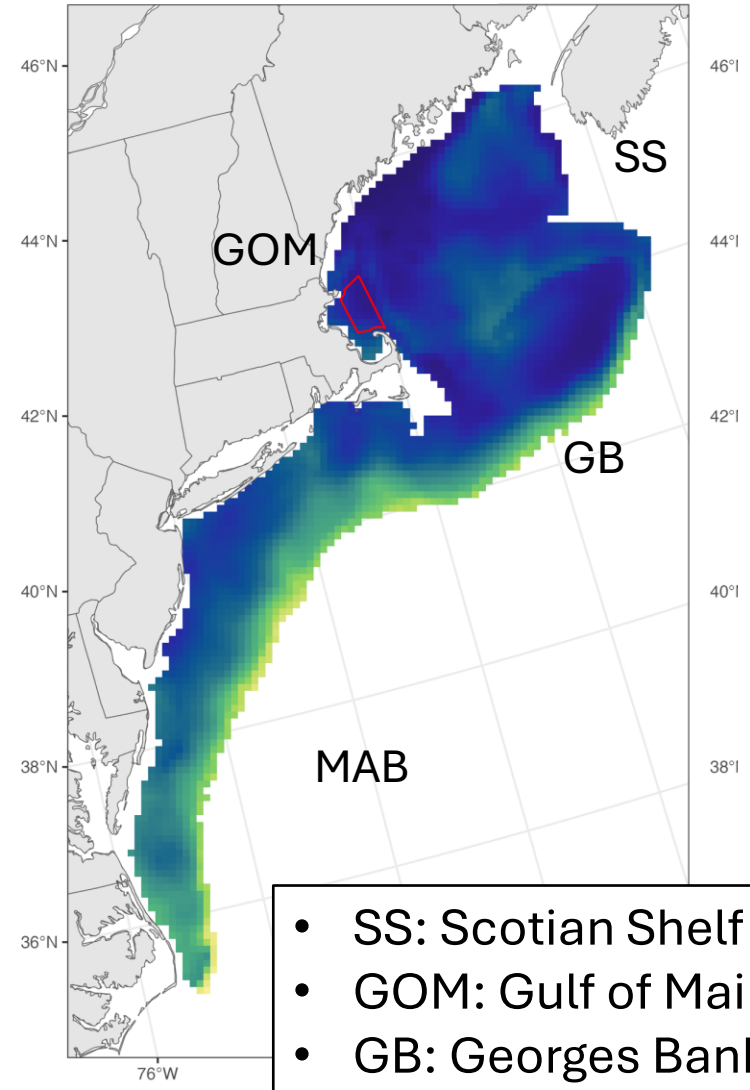
$$\hat{P}_i = logit^{-1}\left(\boldsymbol{x}_i^{sdmTMB}\beta_i^{sdmTMB} + \omega(\boldsymbol{s}) + \epsilon_t(\boldsymbol{s}) + \psi\right)$$

- $\boldsymbol{x}_i^{sdmTMB}$, i^{th} rows in the model matrix,
- β_i^{sdmTMB}, vectors of fixed effect coefficients,
- $\omega(\boldsymbol{s})$, spatial random effect,
- $\epsilon_t(\boldsymbol{s})$, spatiotemporal random year effect
- ψ, gear change random effect (Miller et al. 2010)

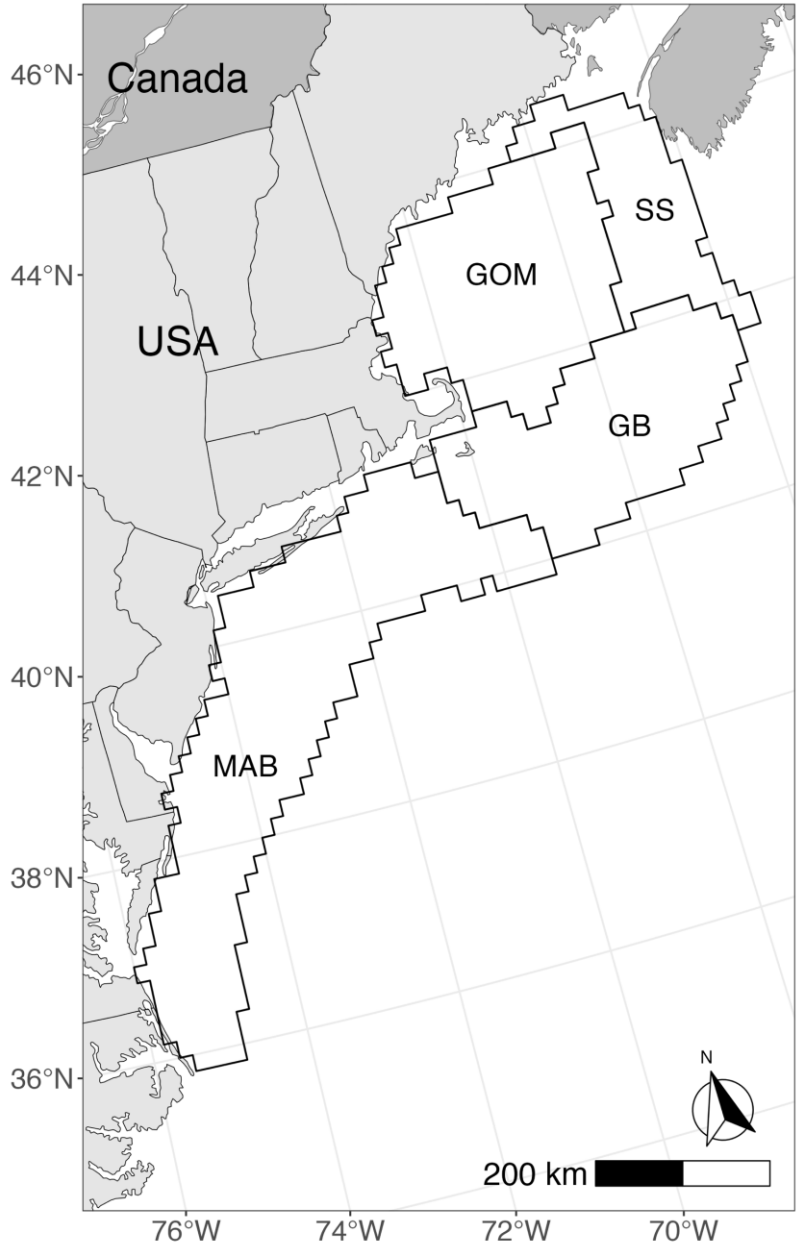
Anderson et al. 2025

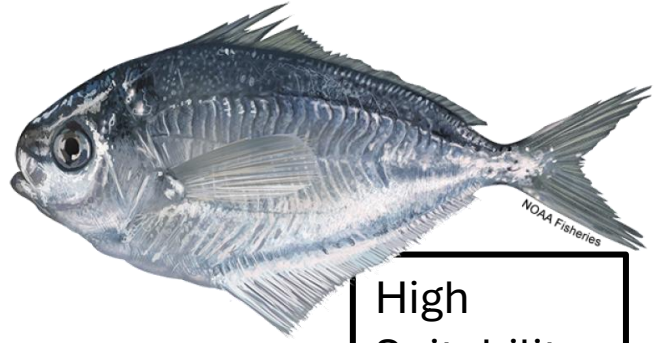
Results: Butterfish

Spring 1993–2002



- SS: Scotian Shelf
- GOM: Gulf of Maine
- GB: Georges Bank
- MAB: Mid-Atlantic Bight





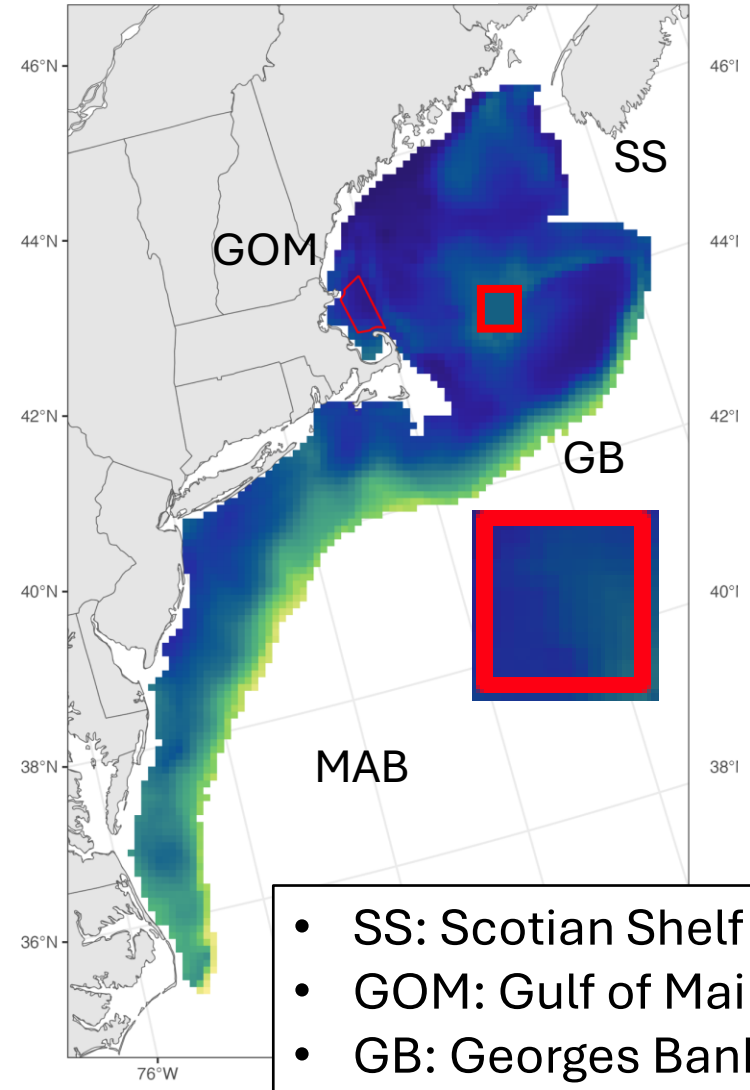
High Suitability

1.00
0.75
0.50
0.25
0.00

Low Suitability

Results: Butterfish

Spring 1993–2002



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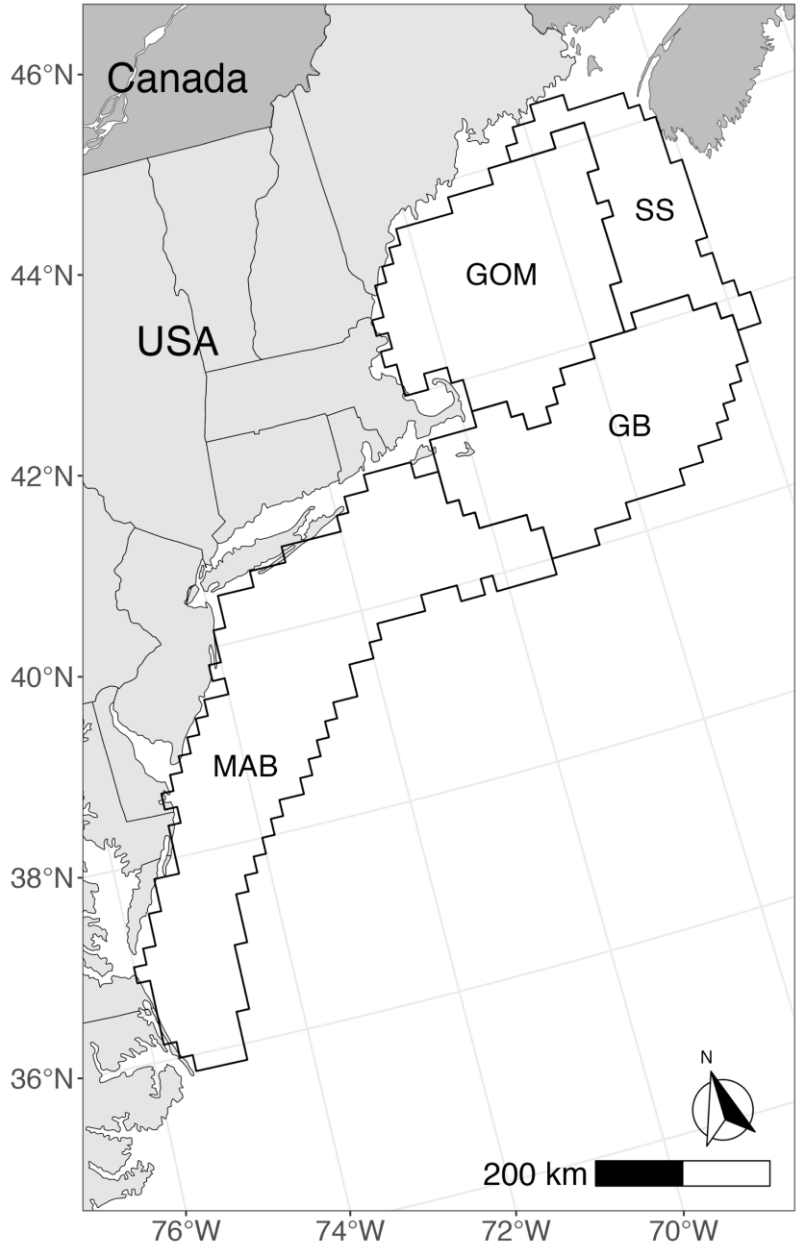

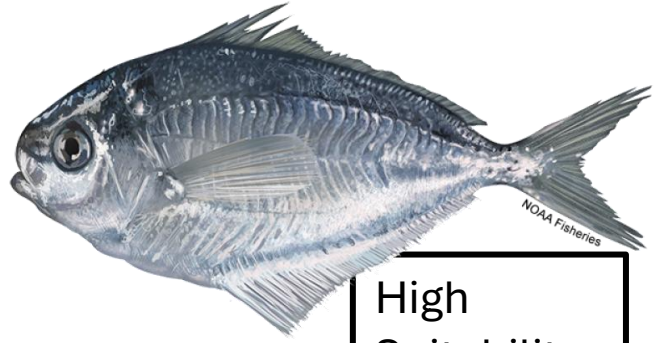

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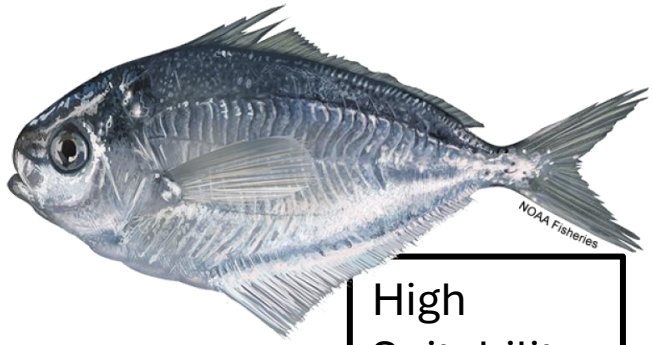
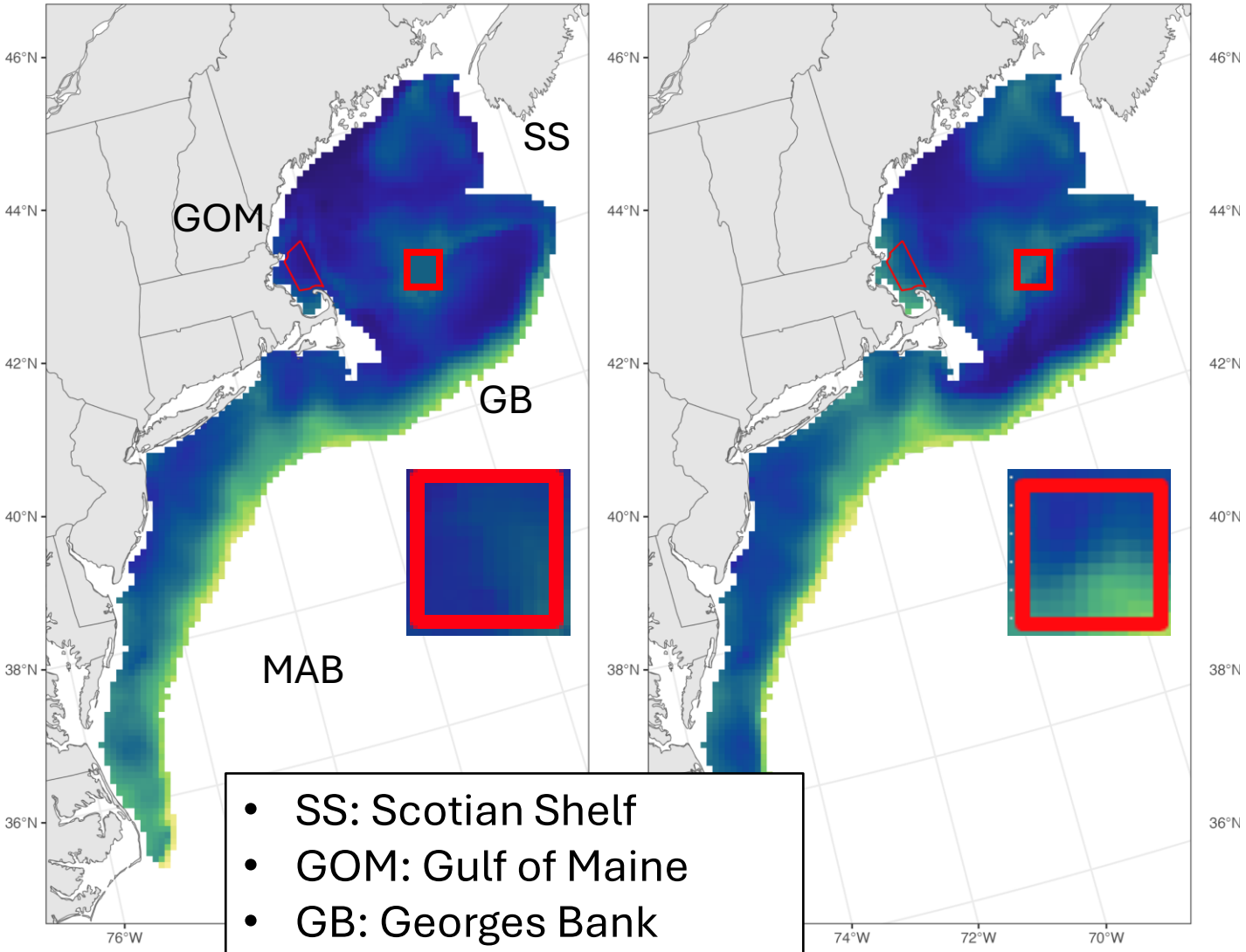


Spring 1993–2002

Spring 2025–2034



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0.75
0.50
0.25
0.00

Low Suitability

- SS: Scotian Shelf
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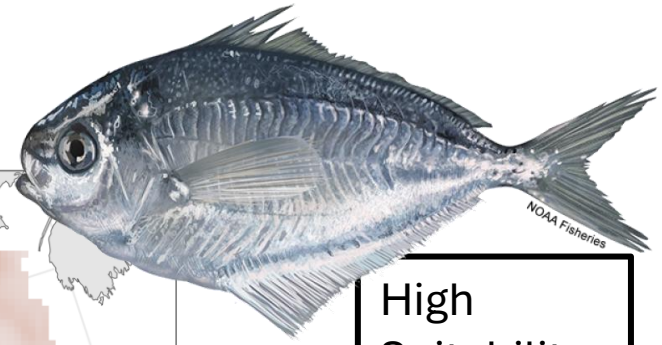
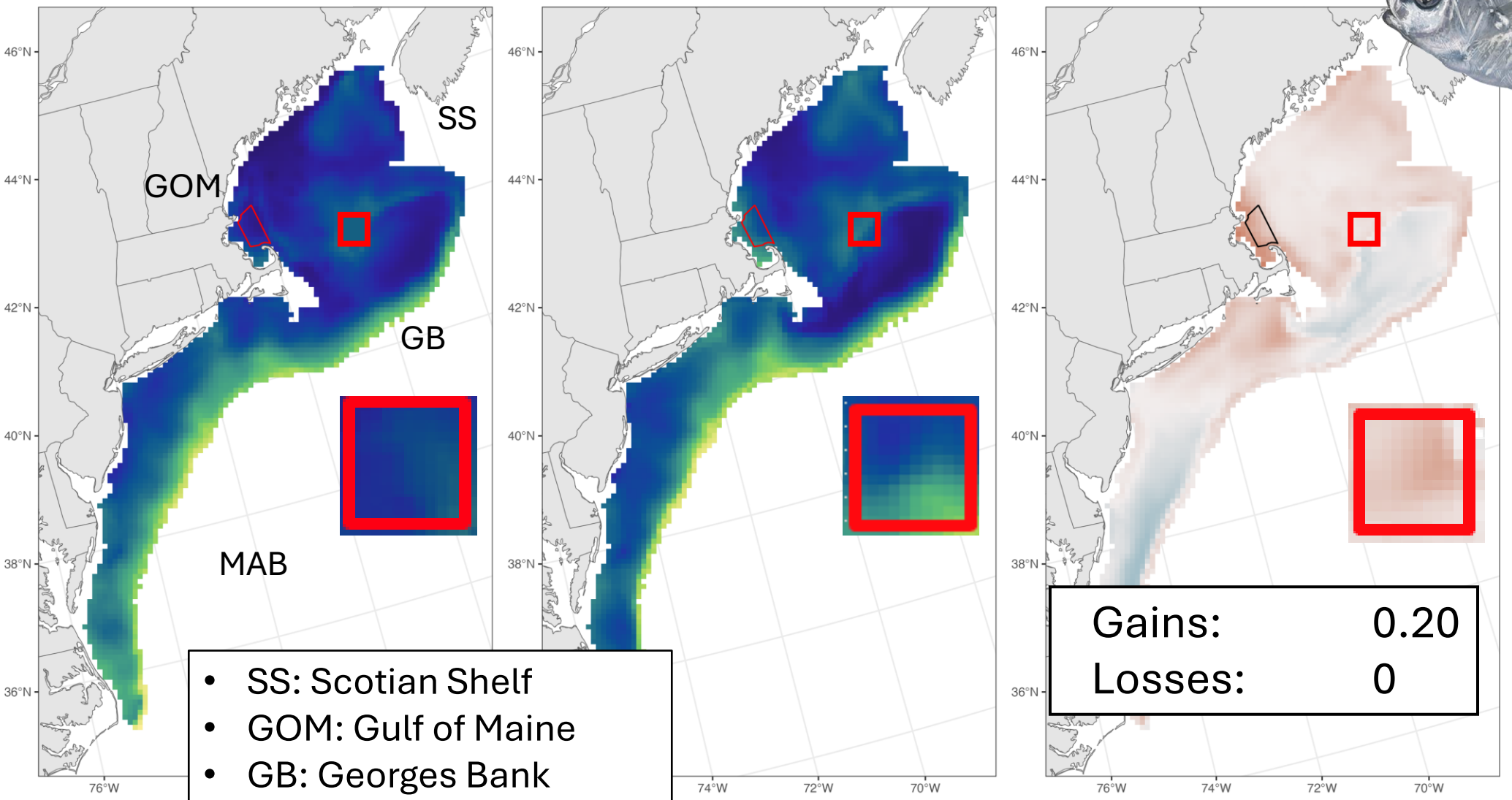
Results: Butterfish

Spring 1993–2002

Spring 2025–2034

Gain/Loss





- SS: Scotian Shelf
- GOM: Gulf of Maine
- GB: Georges Bank
- MAB: Mid-Atlantic Bight

Gains:	0.20
Losses:	0

High Suitability

1.00
0.75
0.50
0.25
0.00

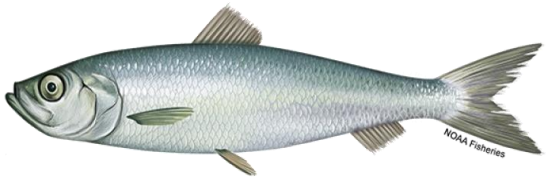
Low Suitability

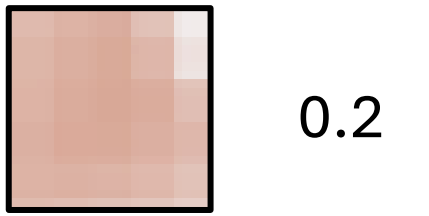
Gain

1.0
0.5
0.0
-0.5
-1.0

Loss

Community level workflow





0.2

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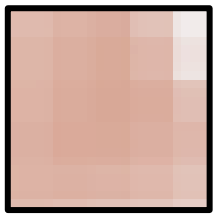
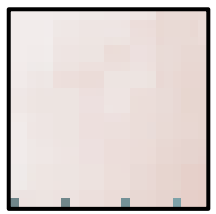


0.3

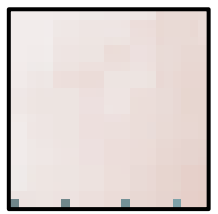
=

Total Gain in HS:

0.75

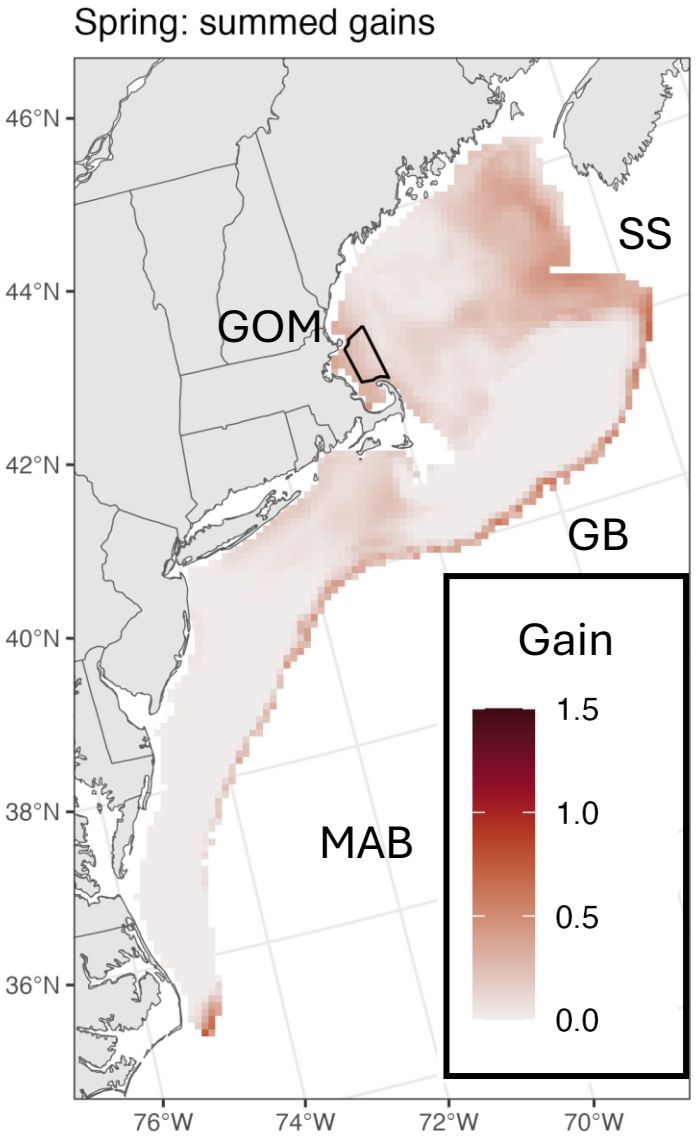


0.1



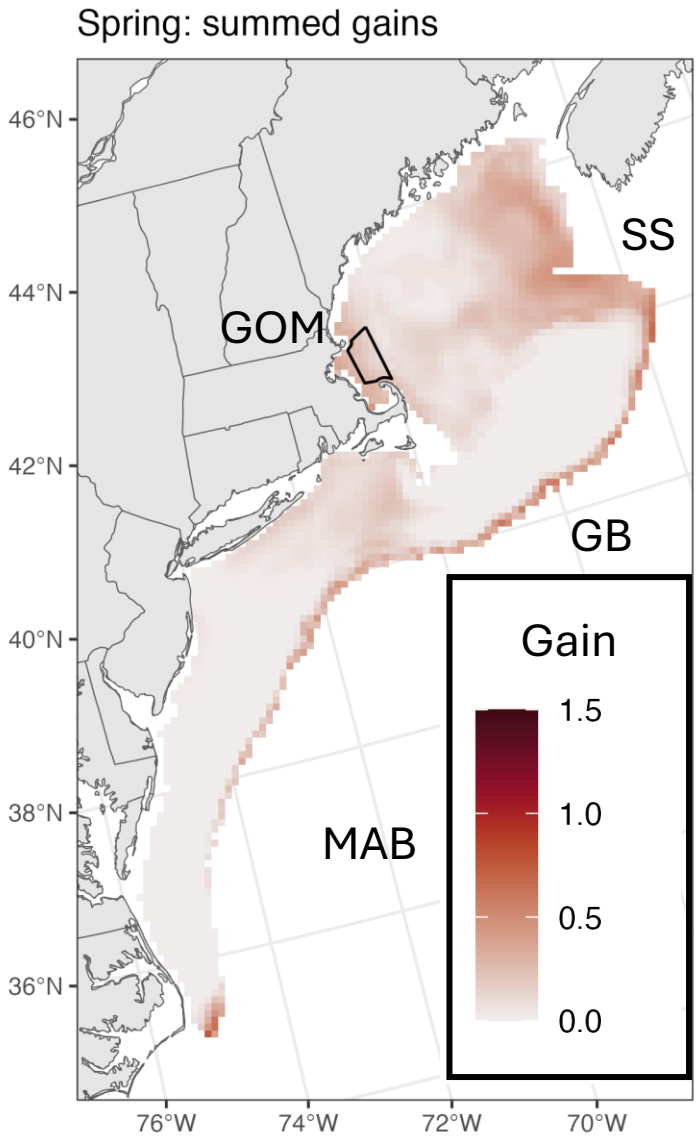
0.15

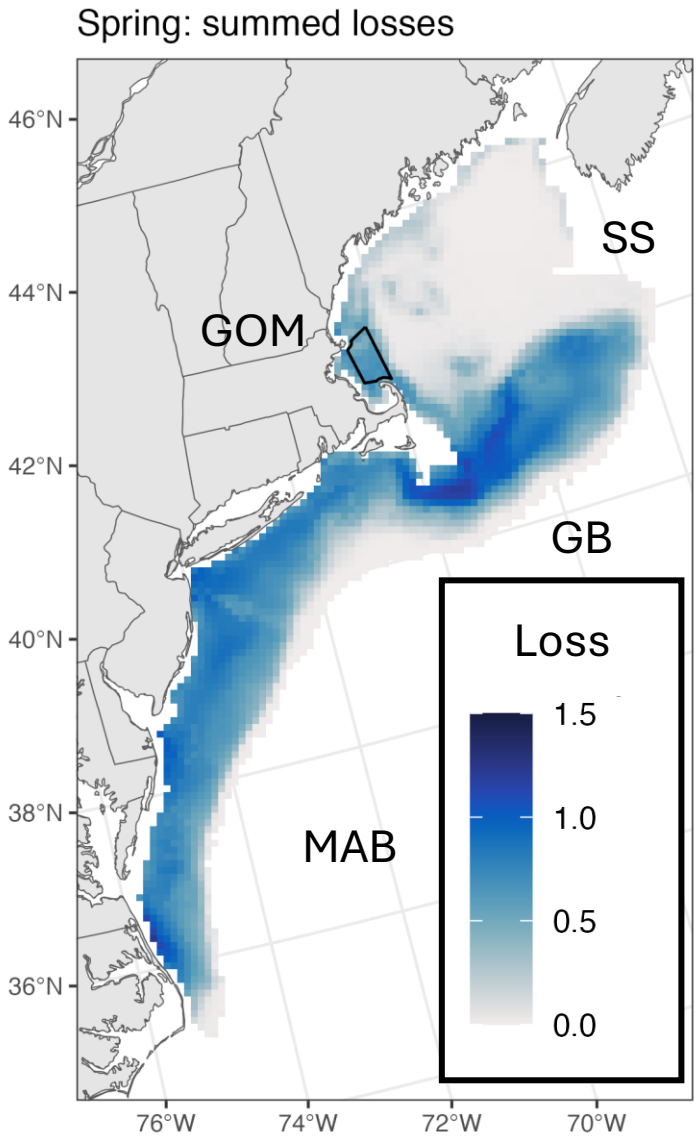
Results: Spring loss in community suitability



Marginal gains within the Scotian Shelf

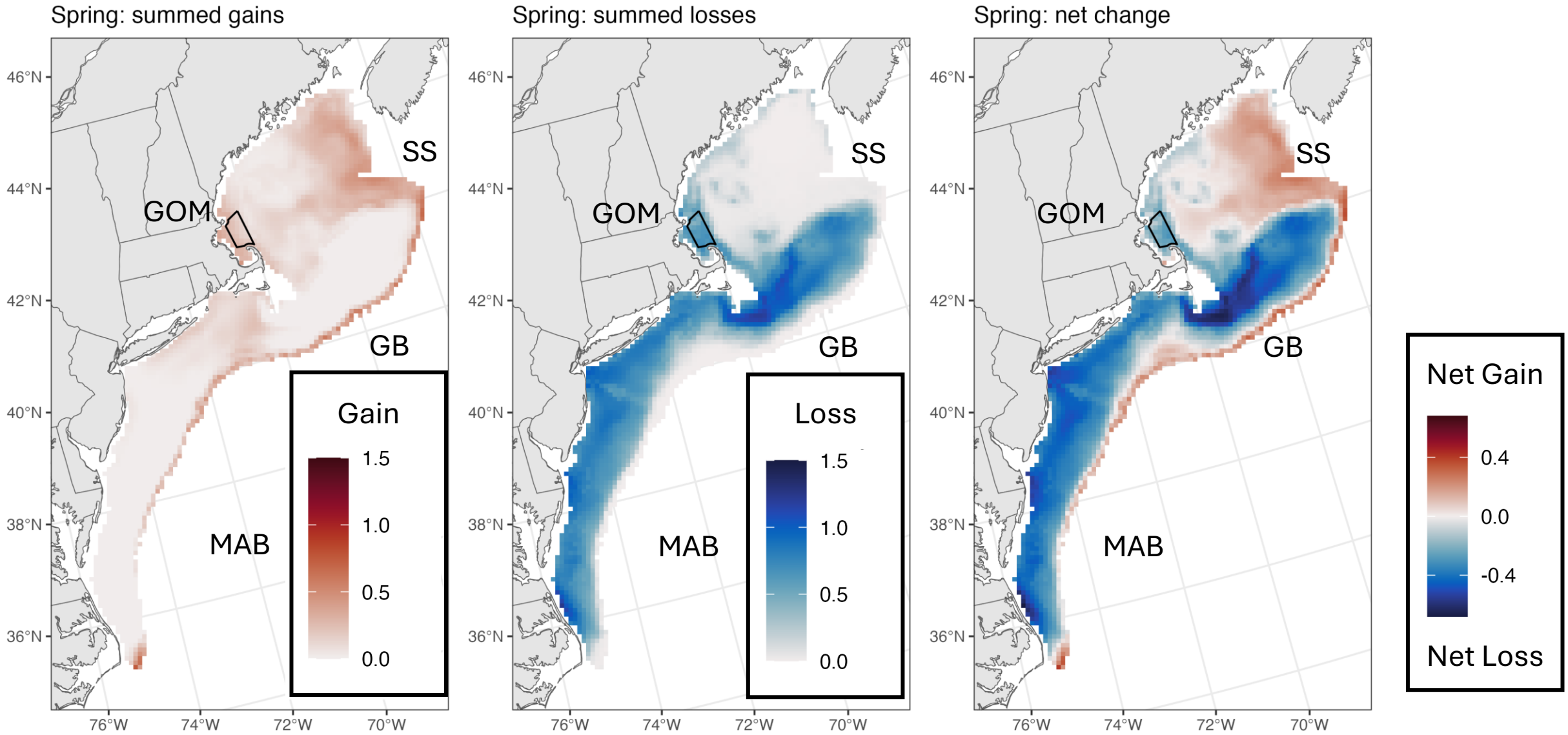
Results: Spring loss in community suitability



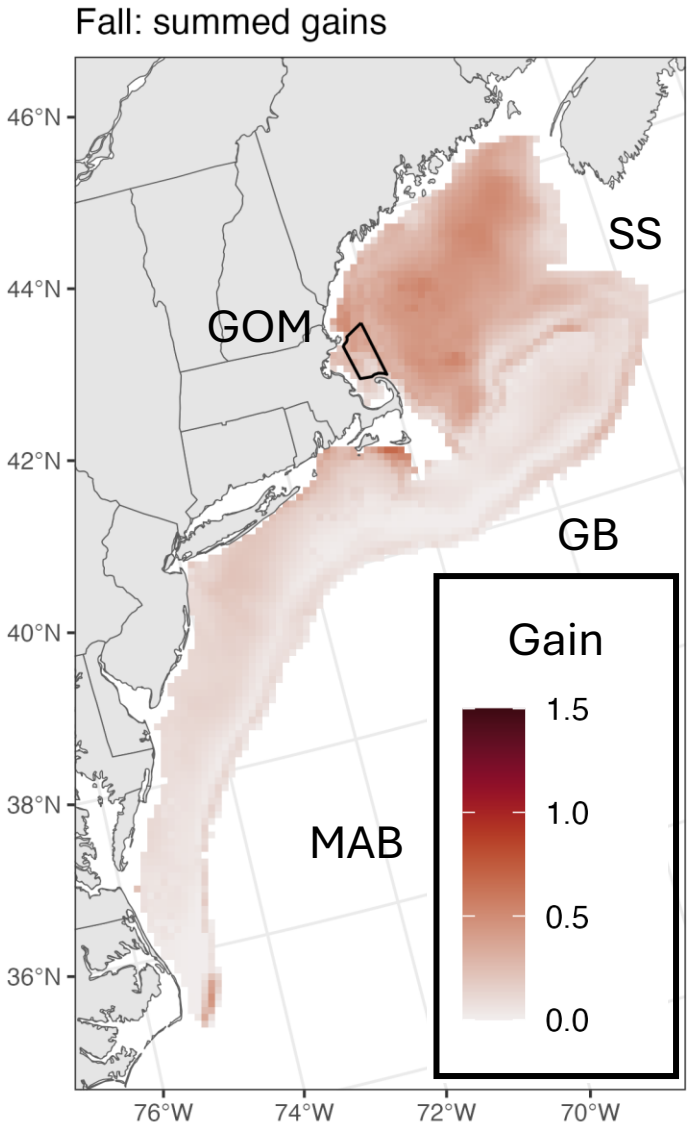


Larger losses in Georges Bank and Mid-Atlantic Bight

Results: Spring loss in community suitability

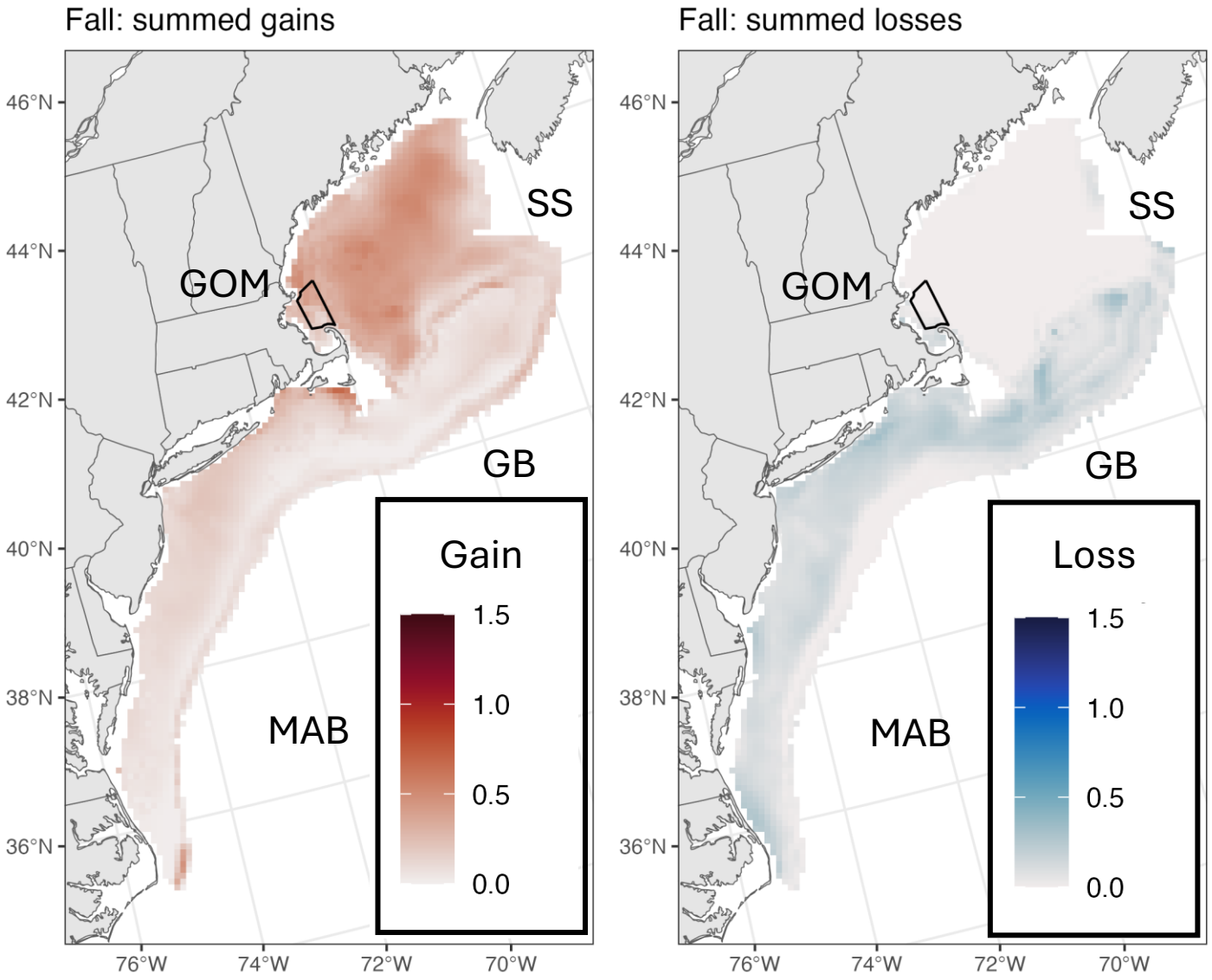


Results: Fall gains in community suitability



Greater gains within the Scotian Shelf and Gulf of Maine

Results: Fall gains in community suitability



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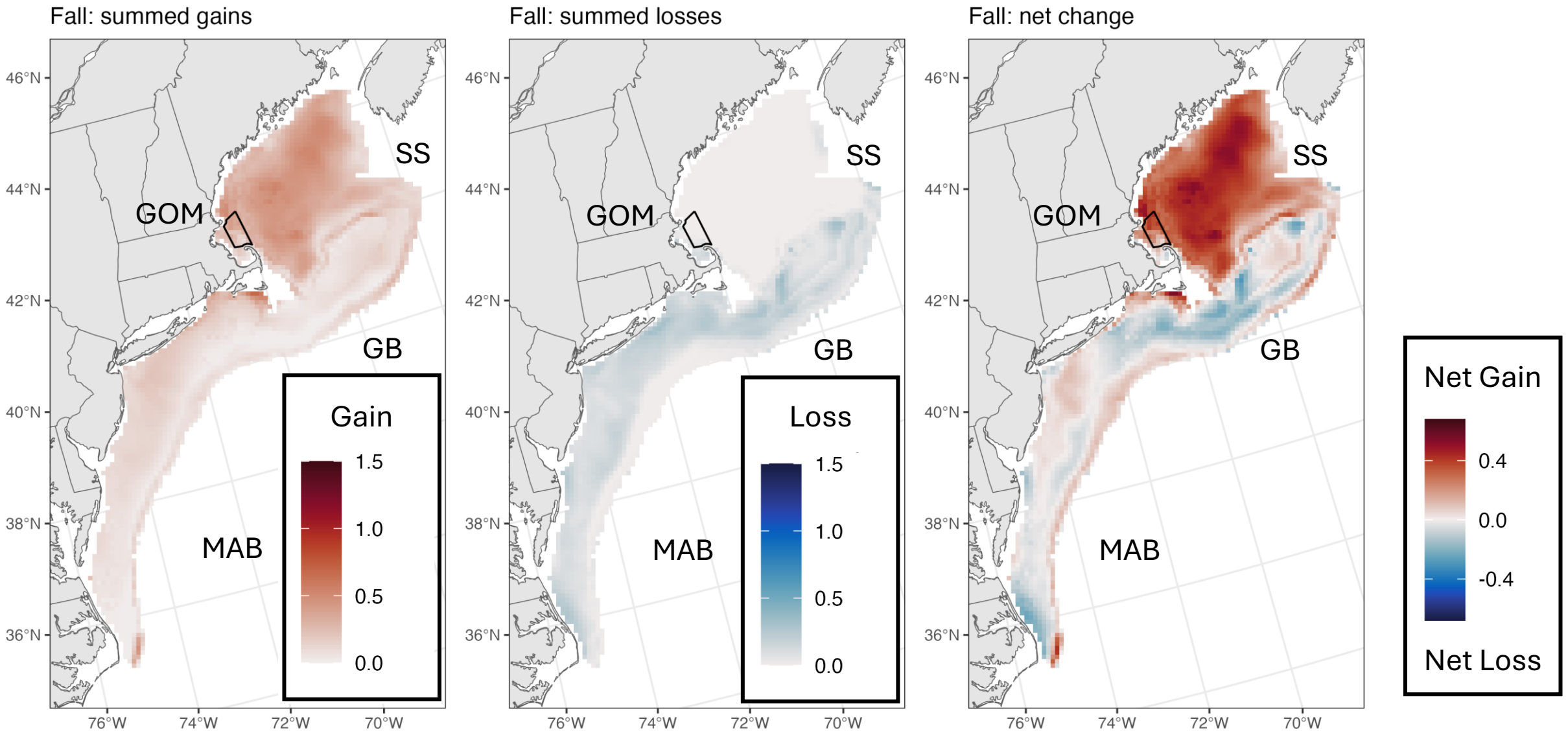
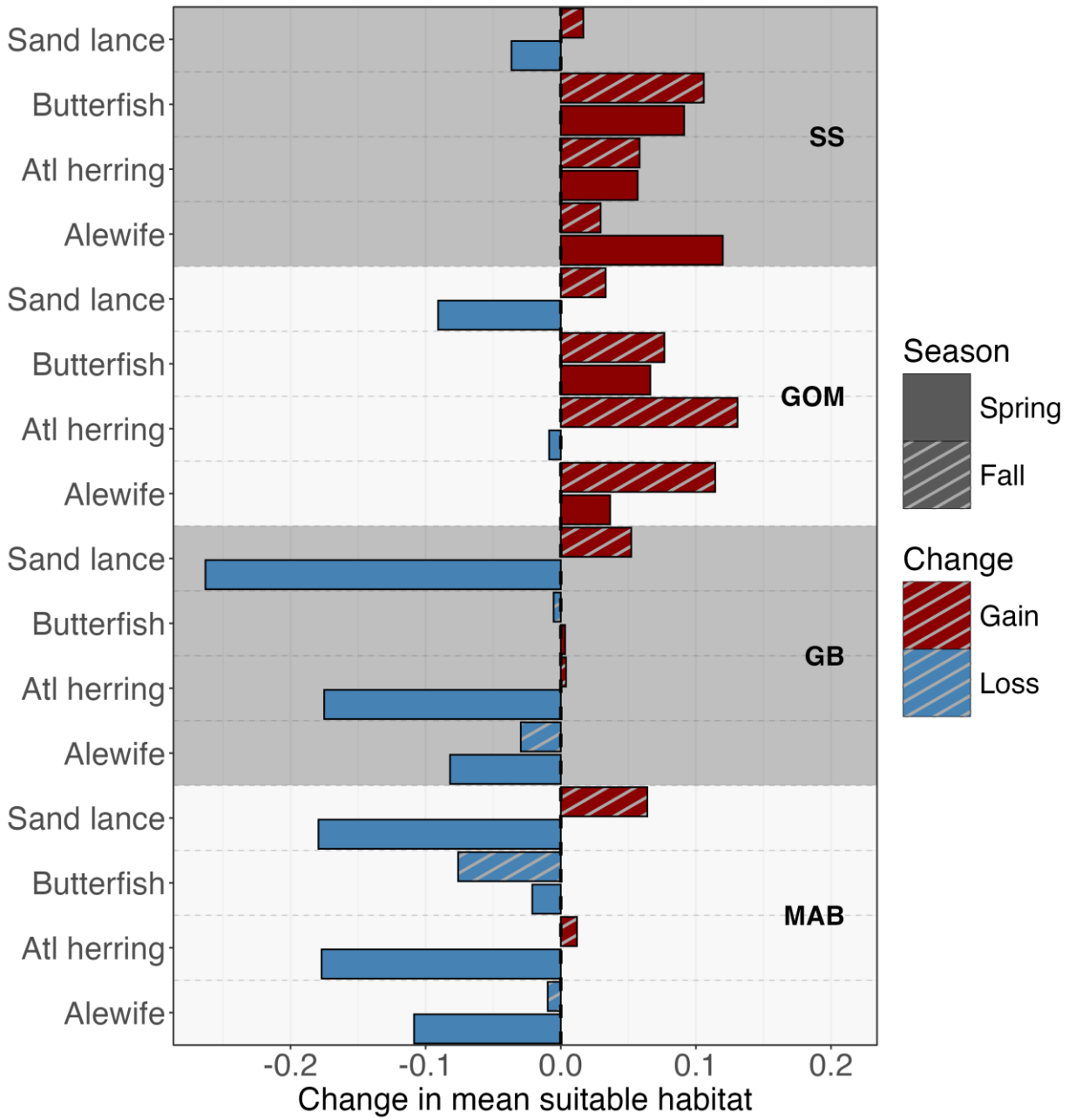
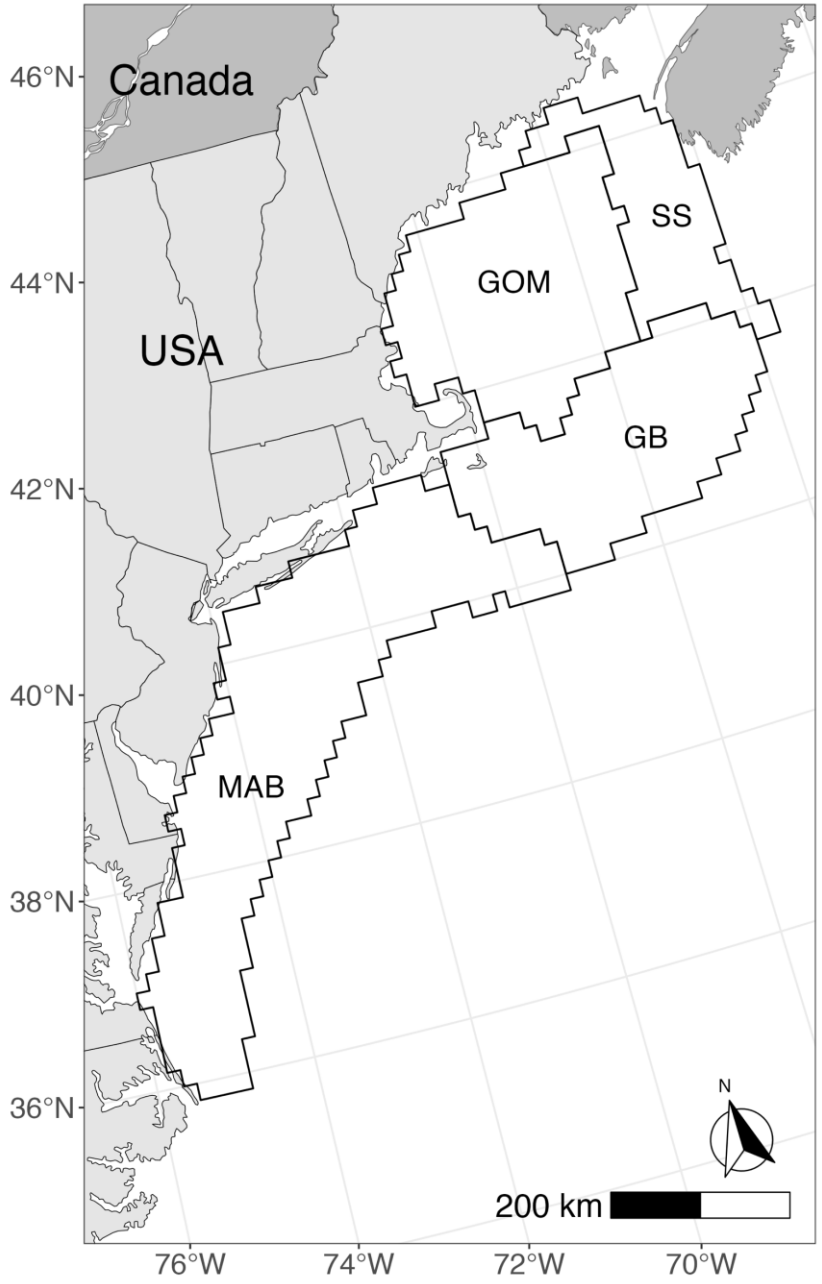
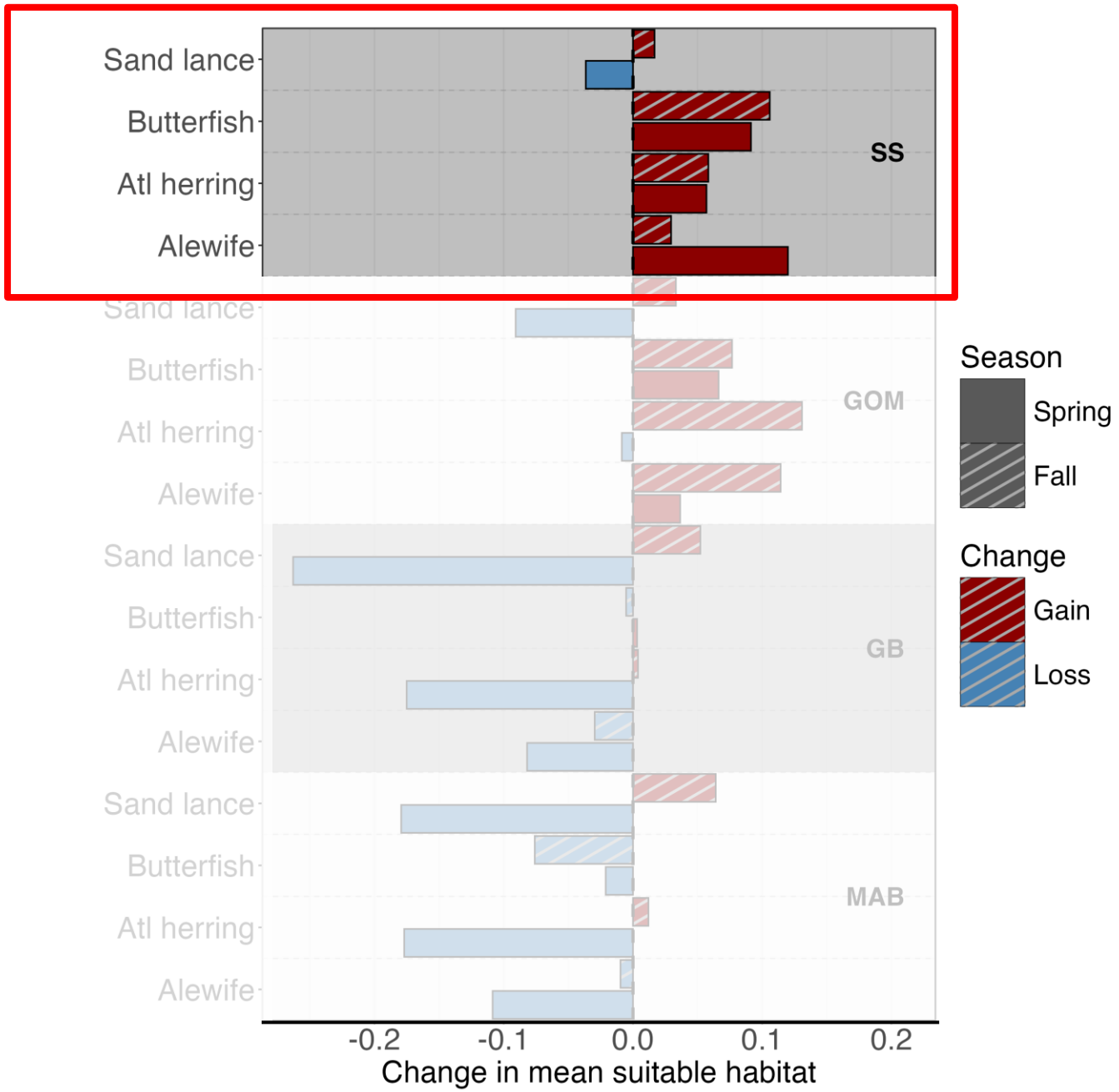


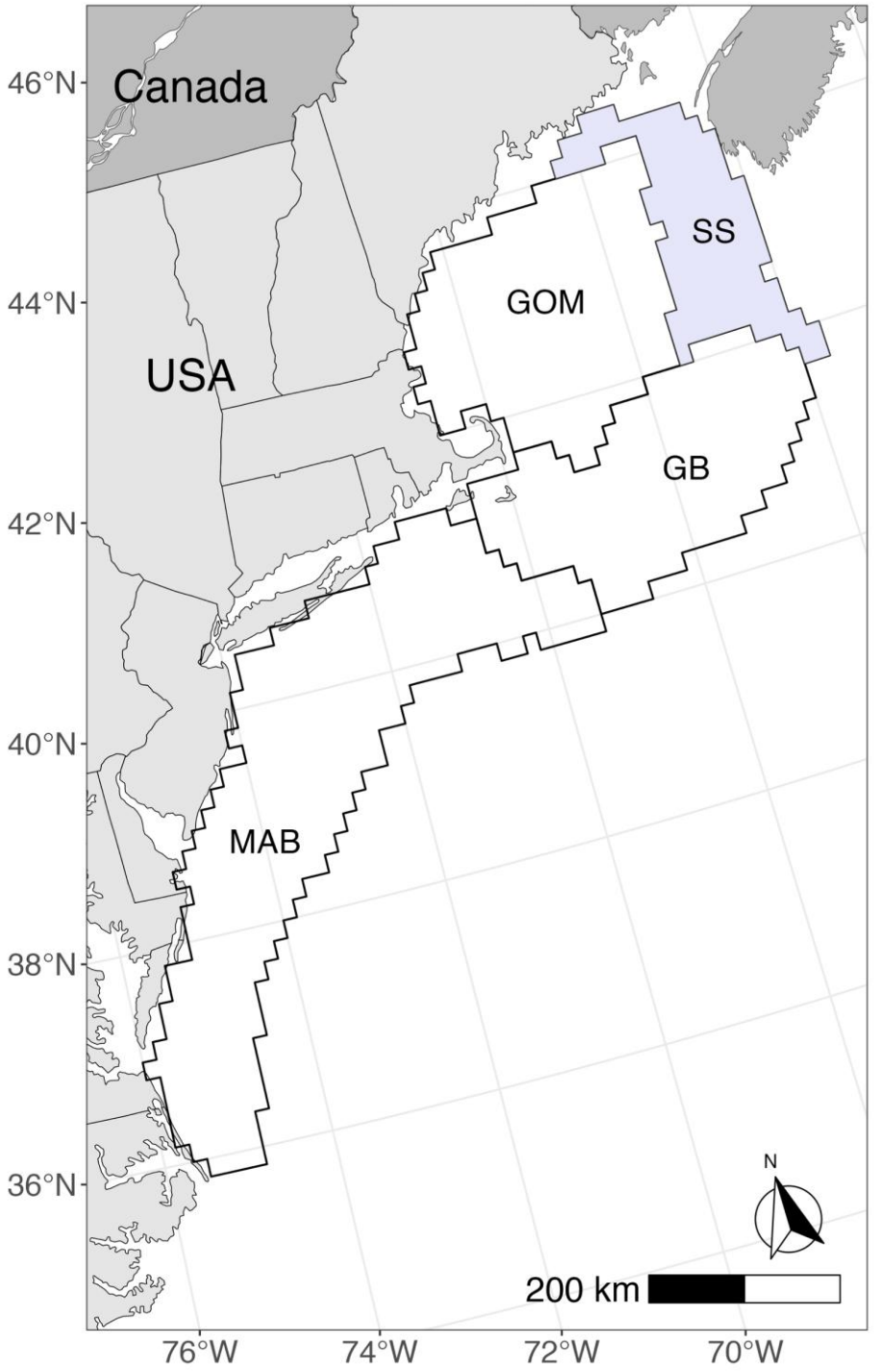
Results: Asynchronous community response





Results: Region-specific responses





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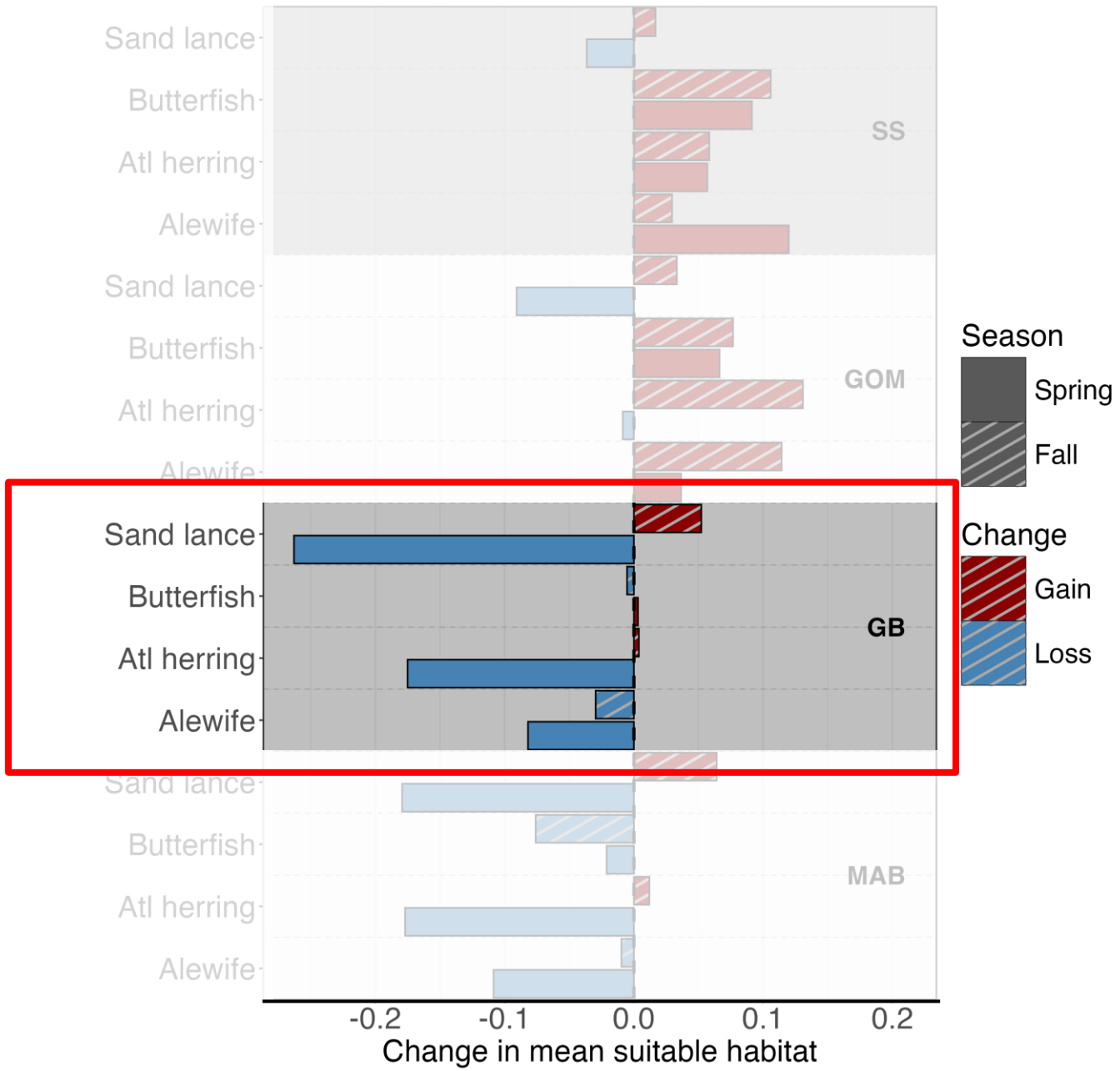
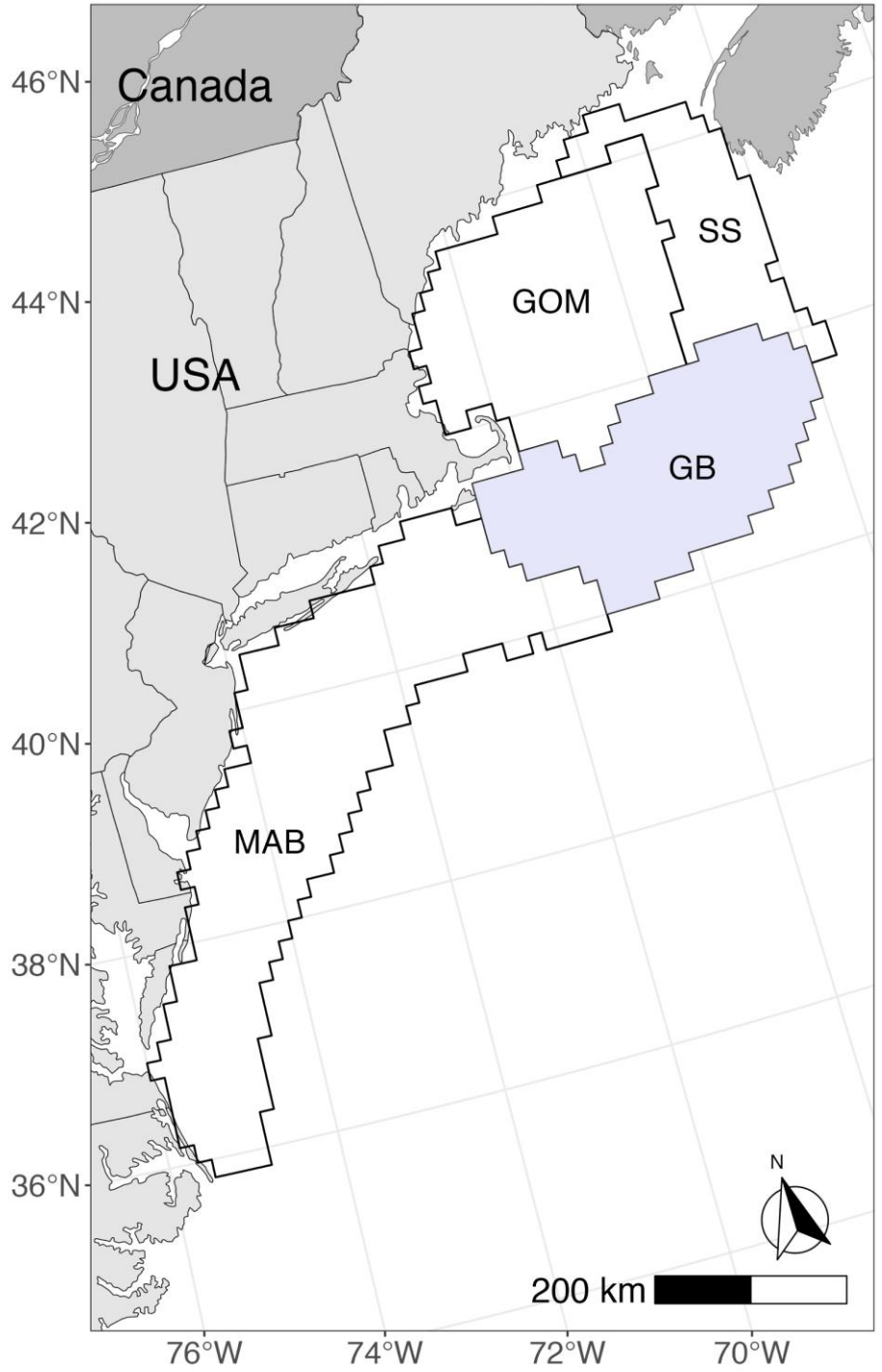
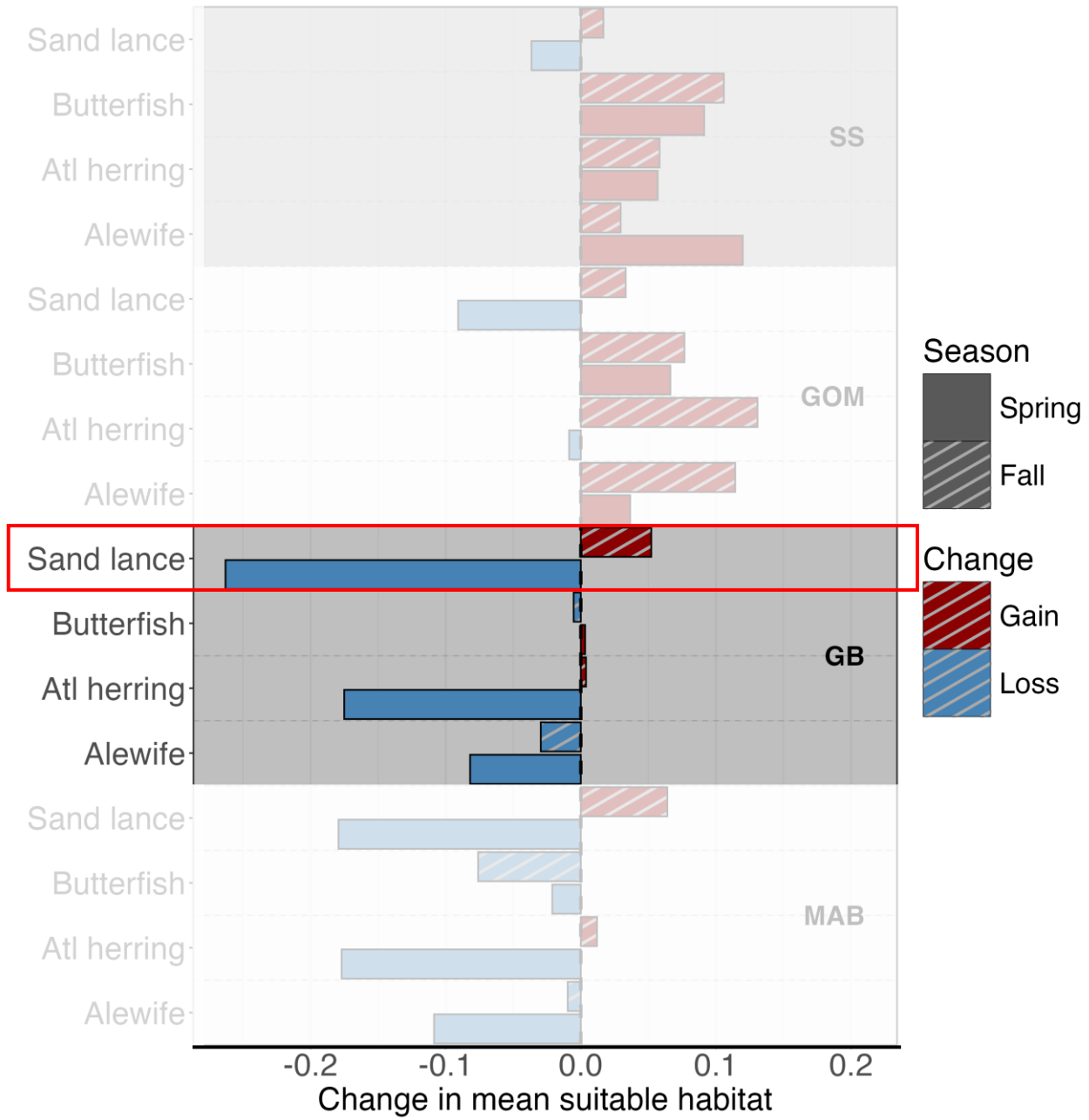
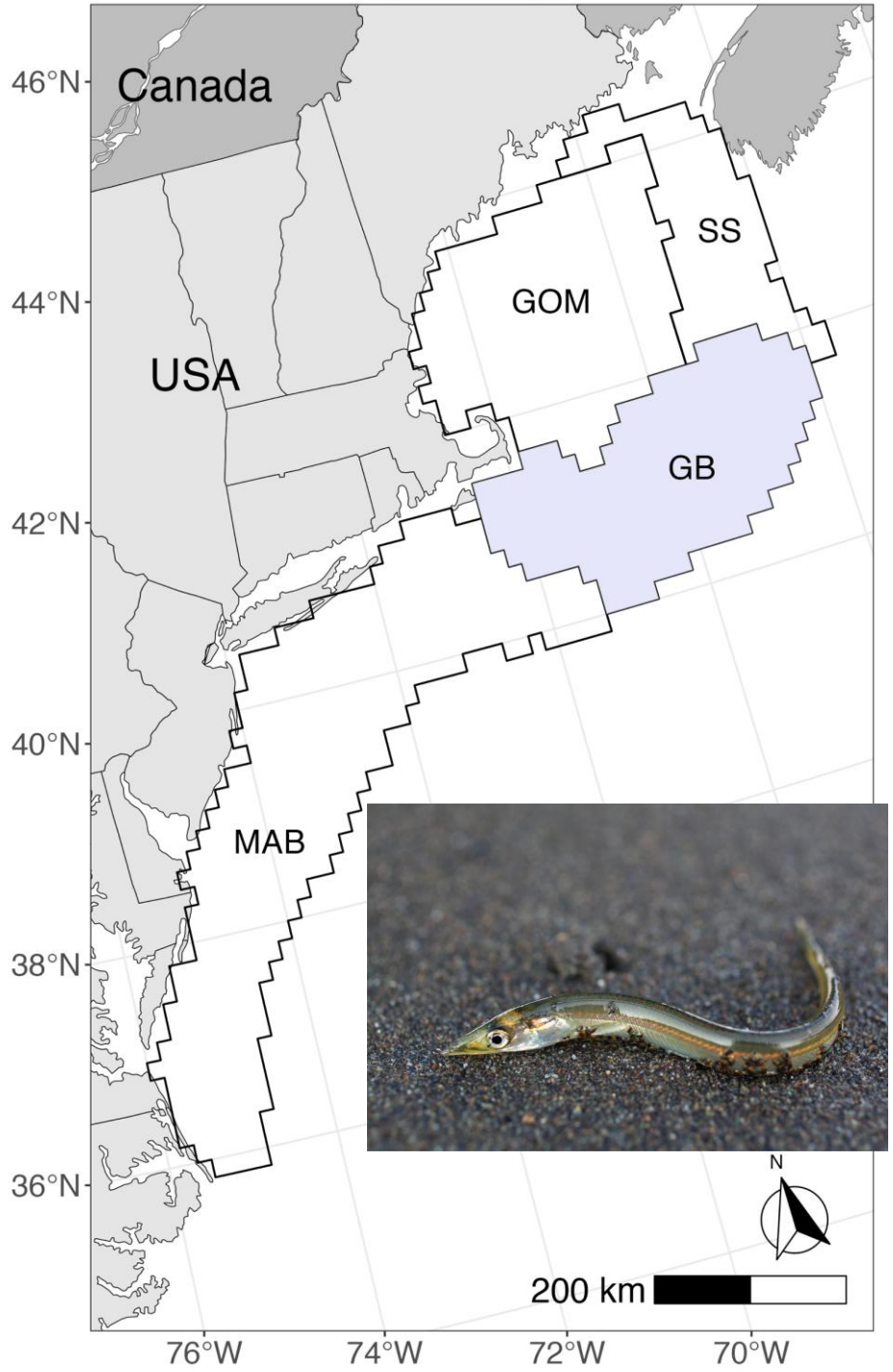




Results: Species-specific responses





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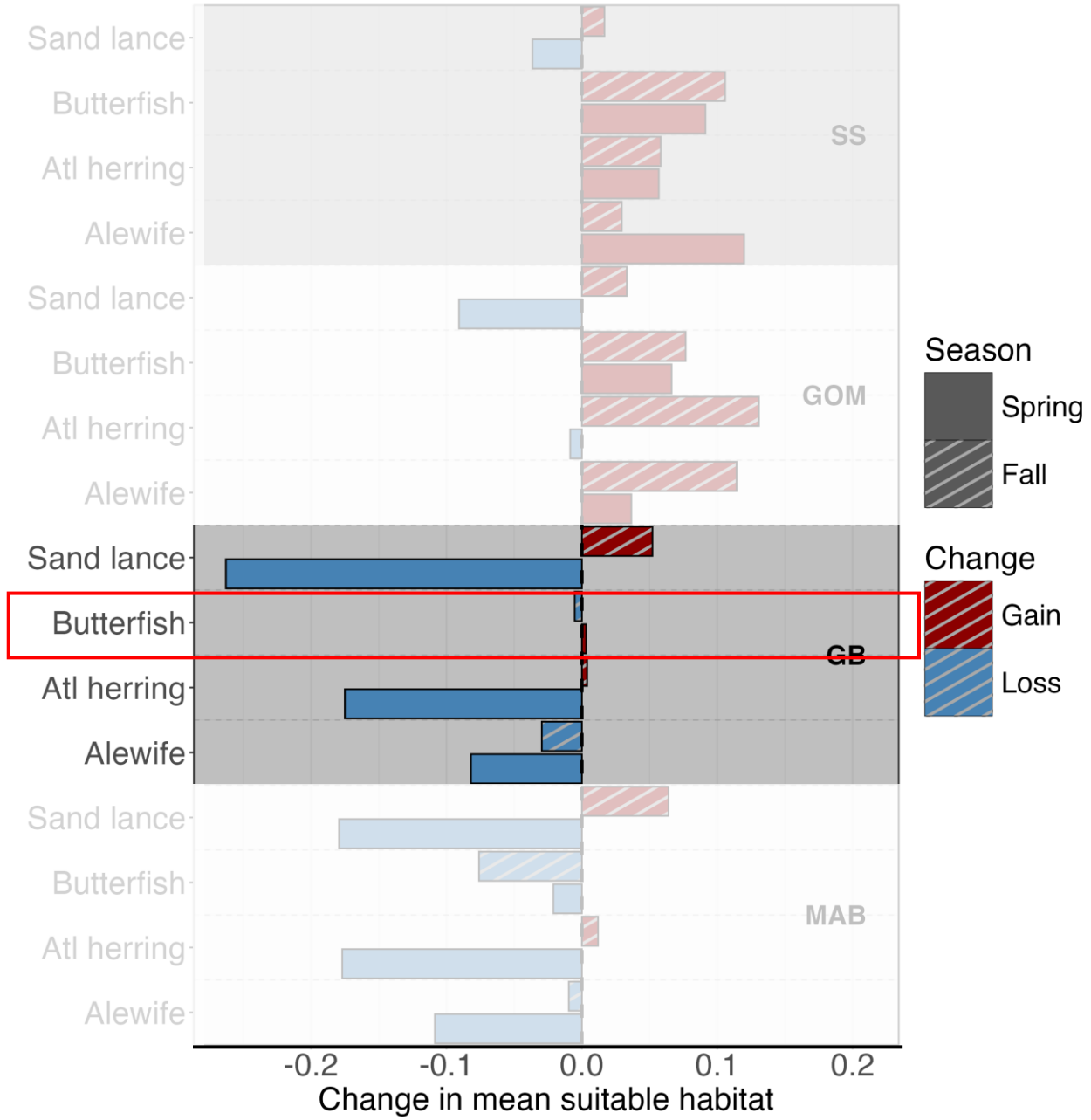

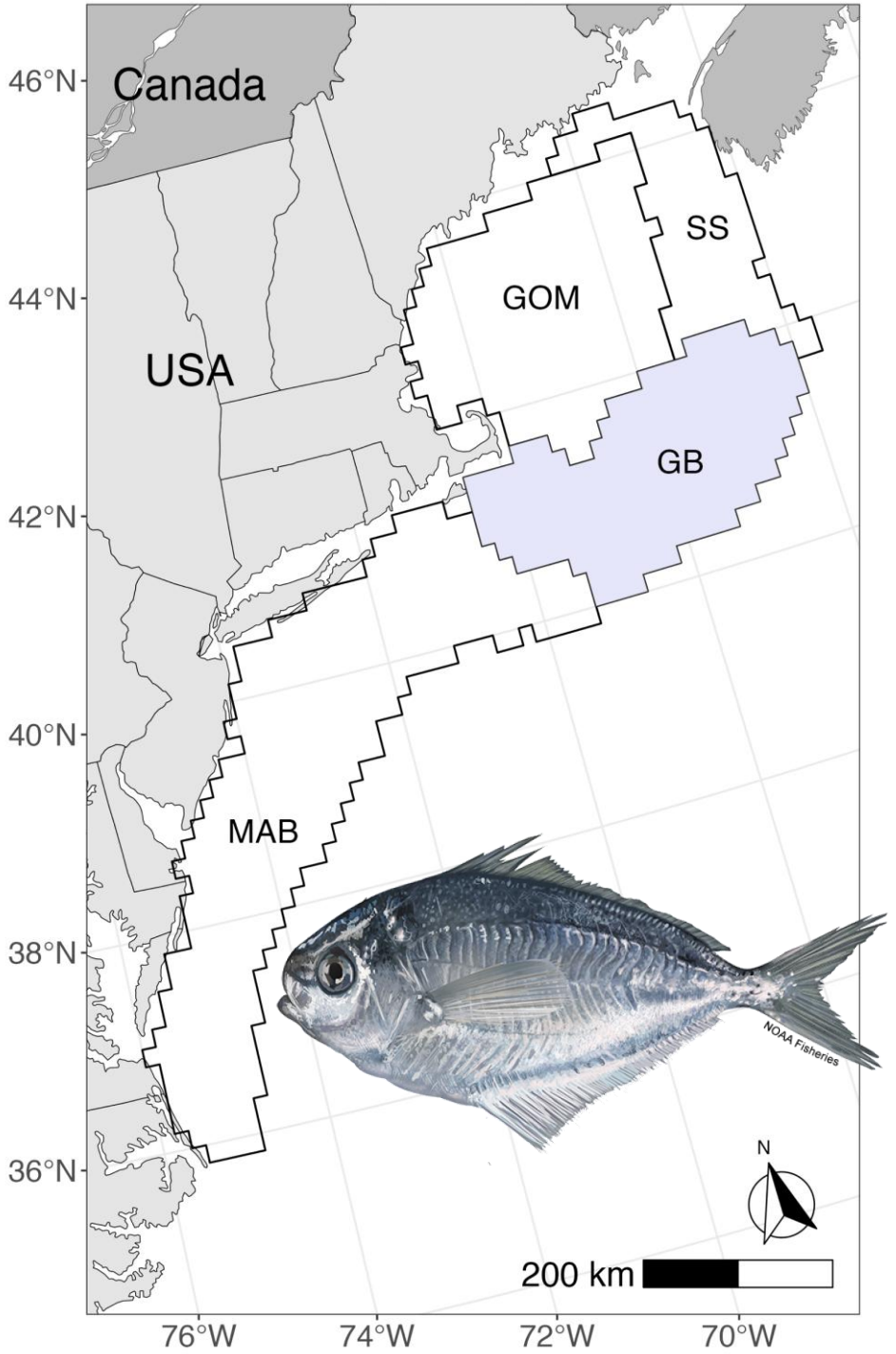

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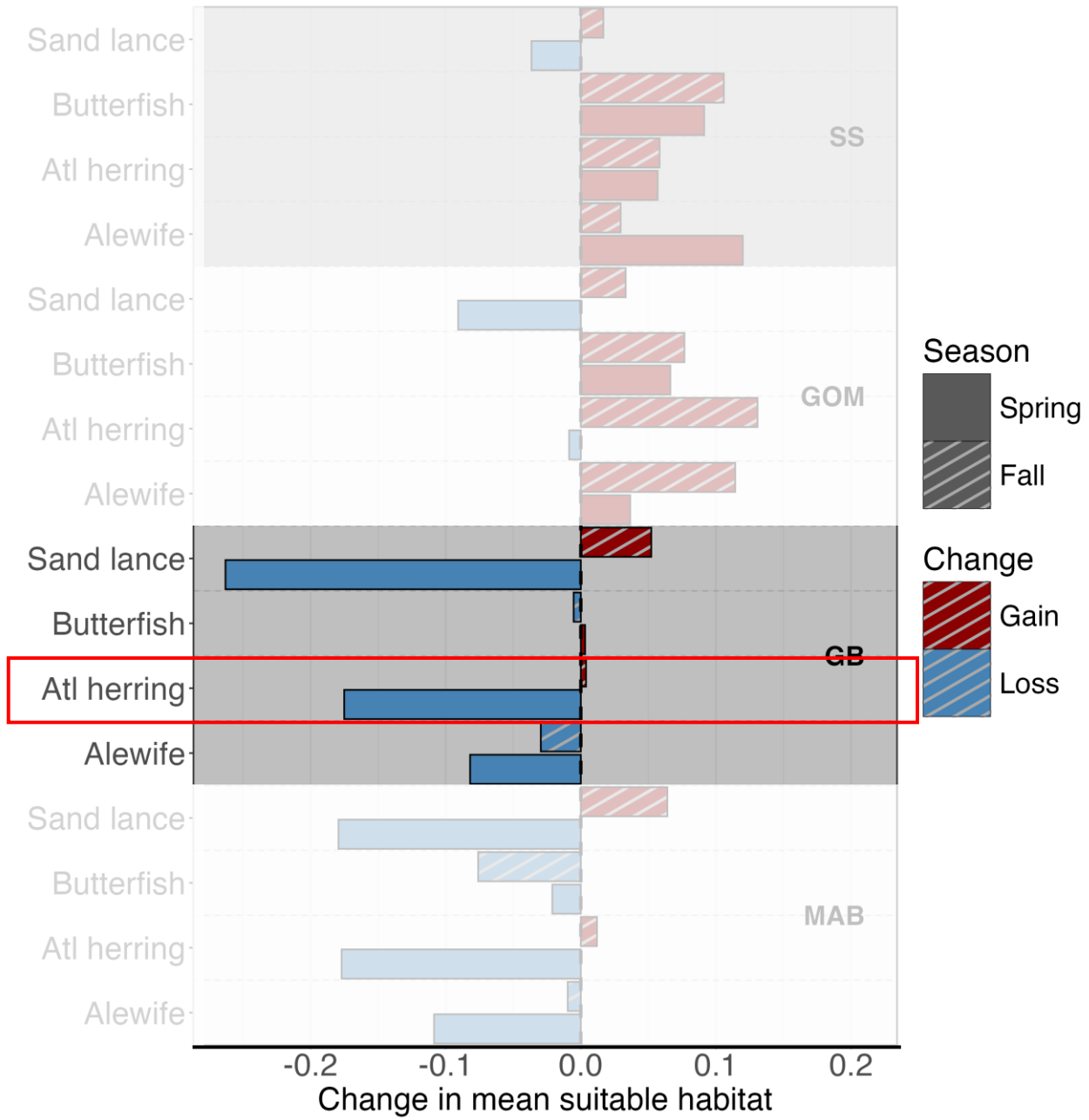
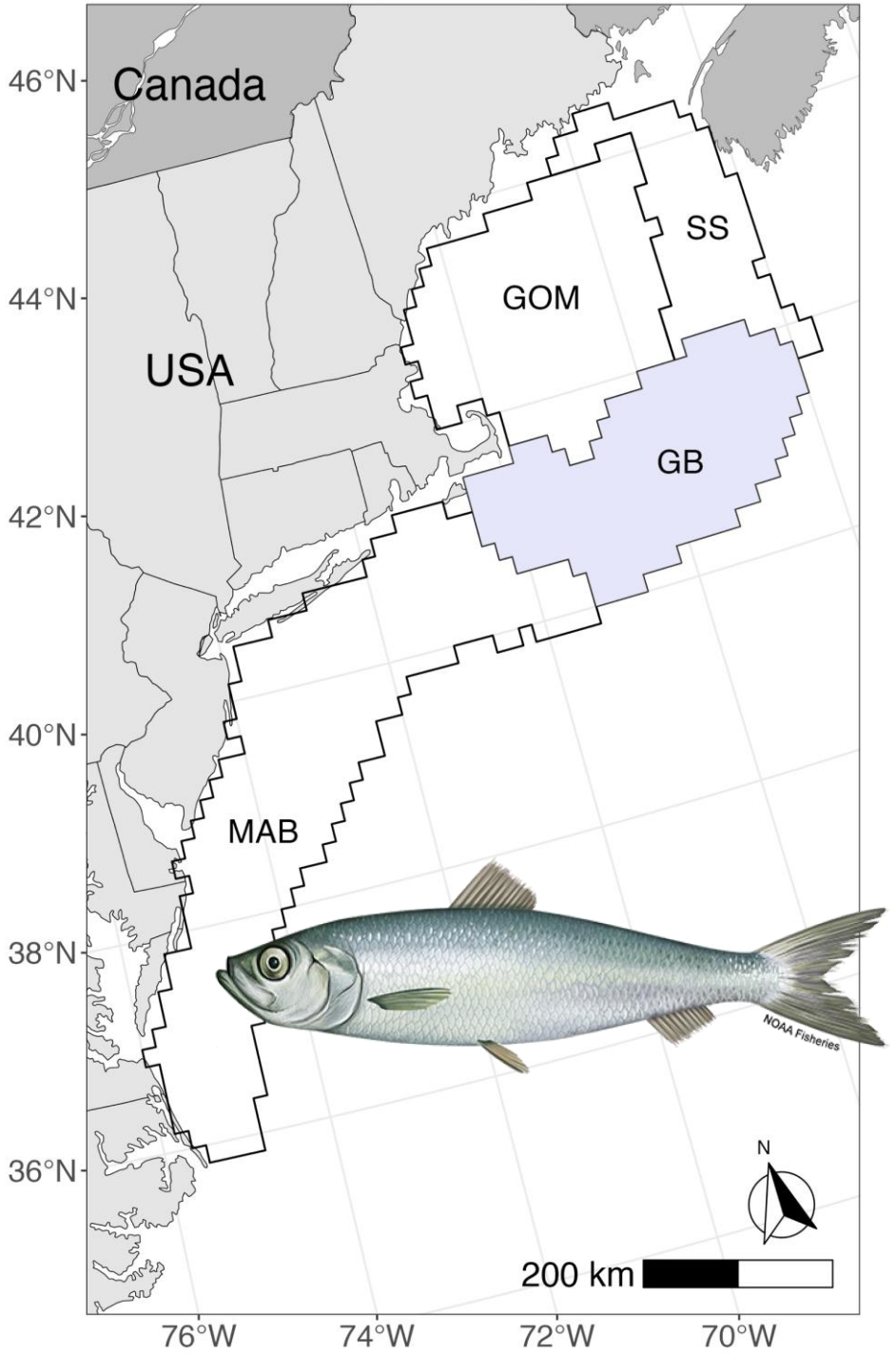


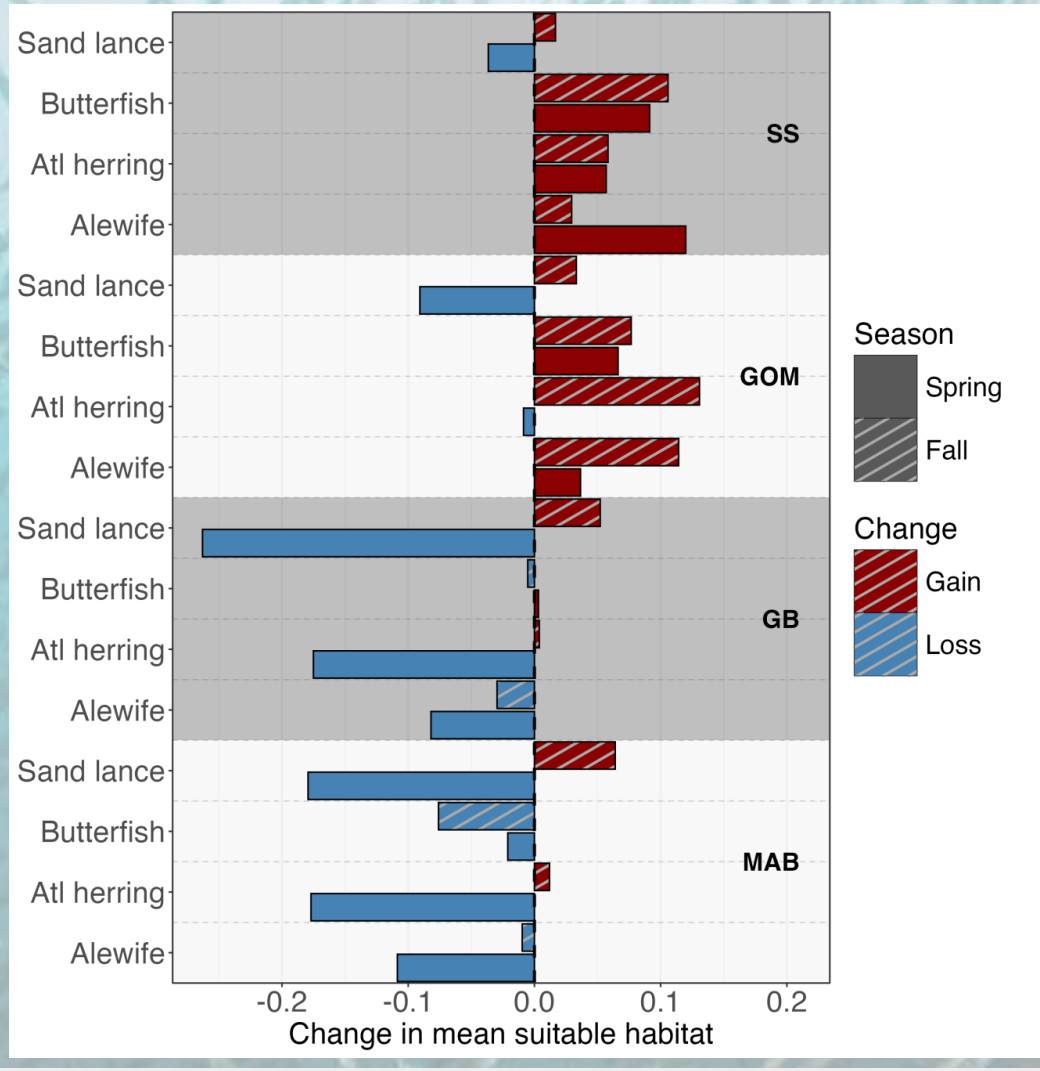


Key Takeaways

Asynchrony among forage fish responses

Season-specific:

- Spring losses exceed fall gains



SDSU San Diego State University

WOODS HOLE OCEANOGRAPHIC INSTITUTION

UCDAVIS

NROC Northeast Regional Ocean Council

U.S. FISH & WILDLIFE SERVICE

NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION U.S. DEPARTMENT OF COMMERCE

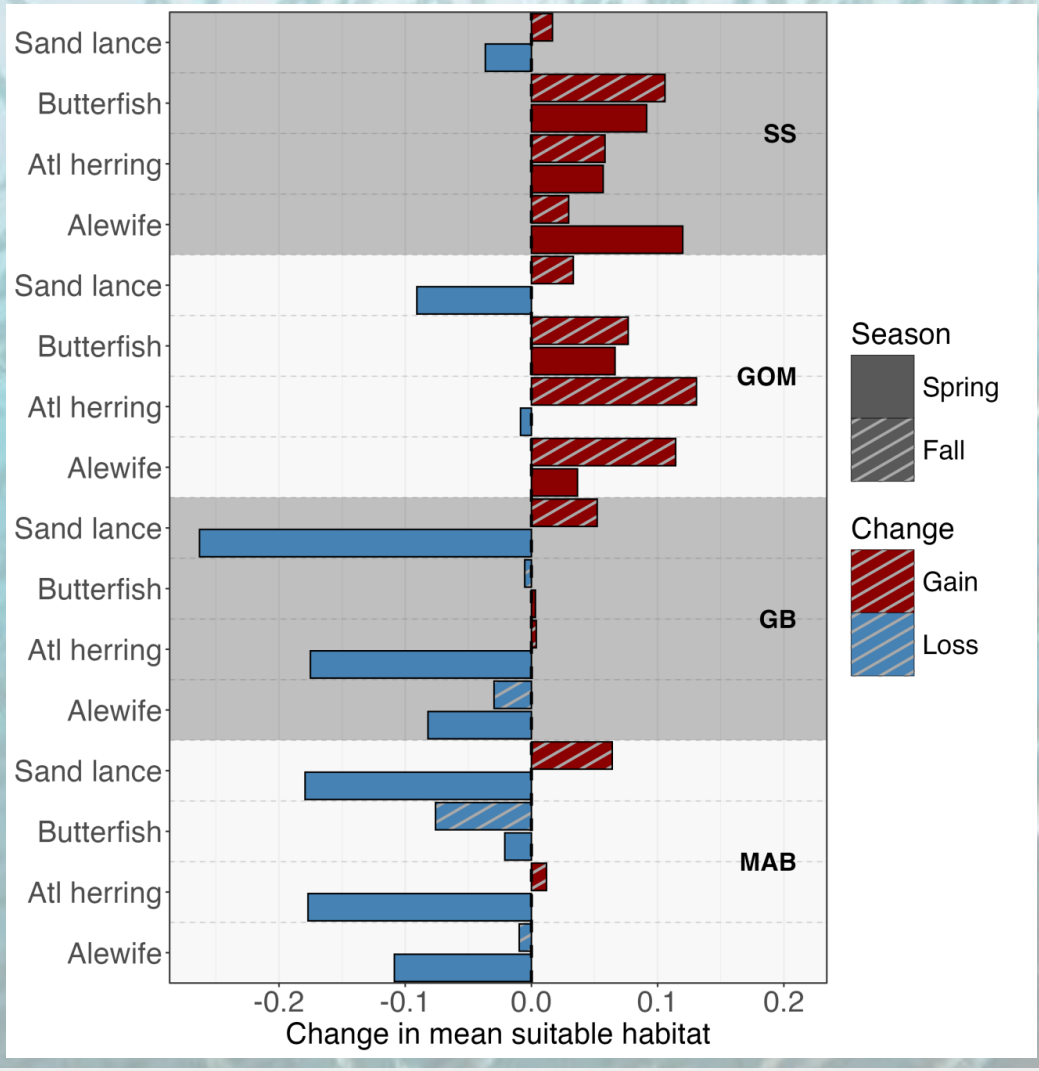
NASA

Key Takeaways

Asynchrony among forage fish responses

Region-specific:

- Overall declines: MAB, GB
- Overall increases: GOM, SS



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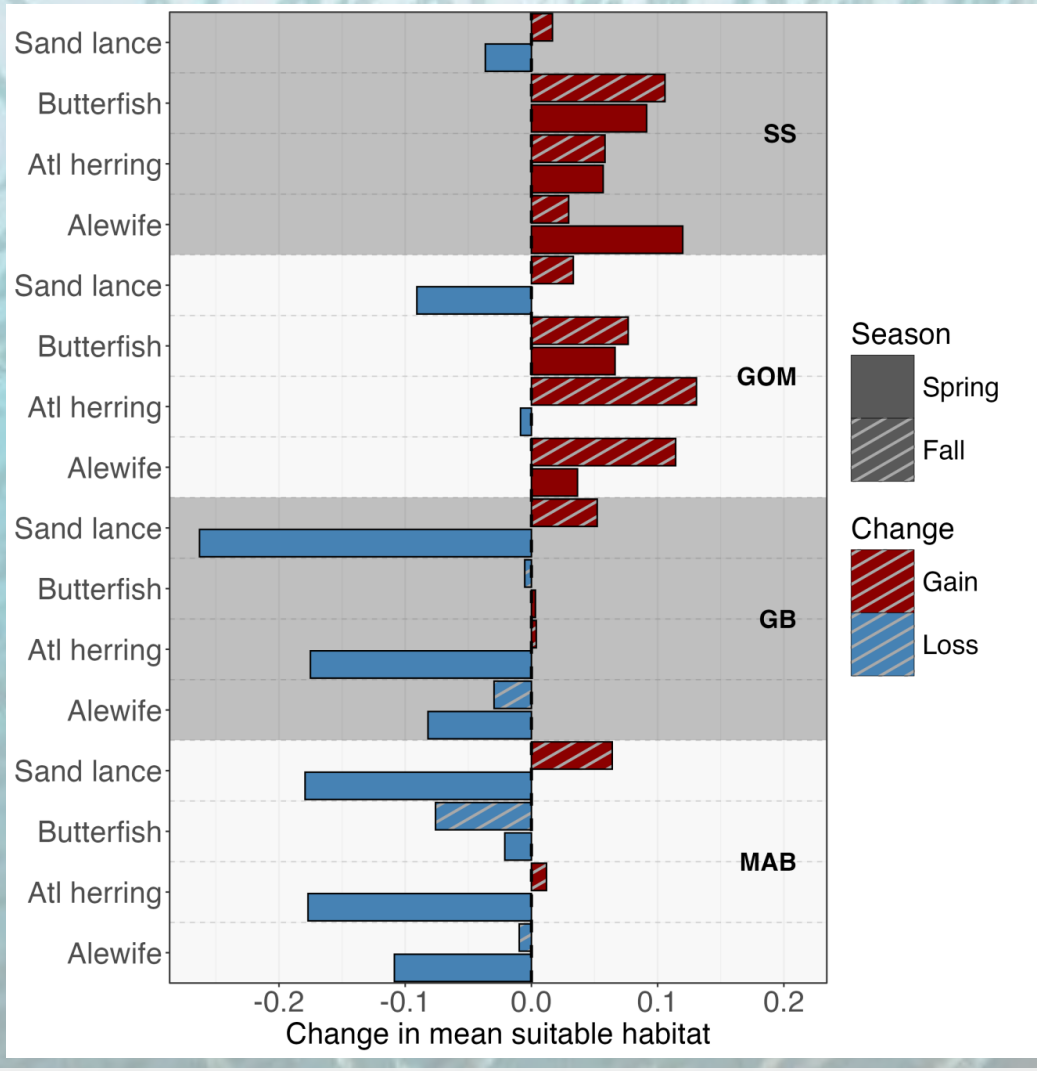
Asynchrony among forage fish responses

Species-specific:

- Simultaneous expansions, contractions, *status quo*



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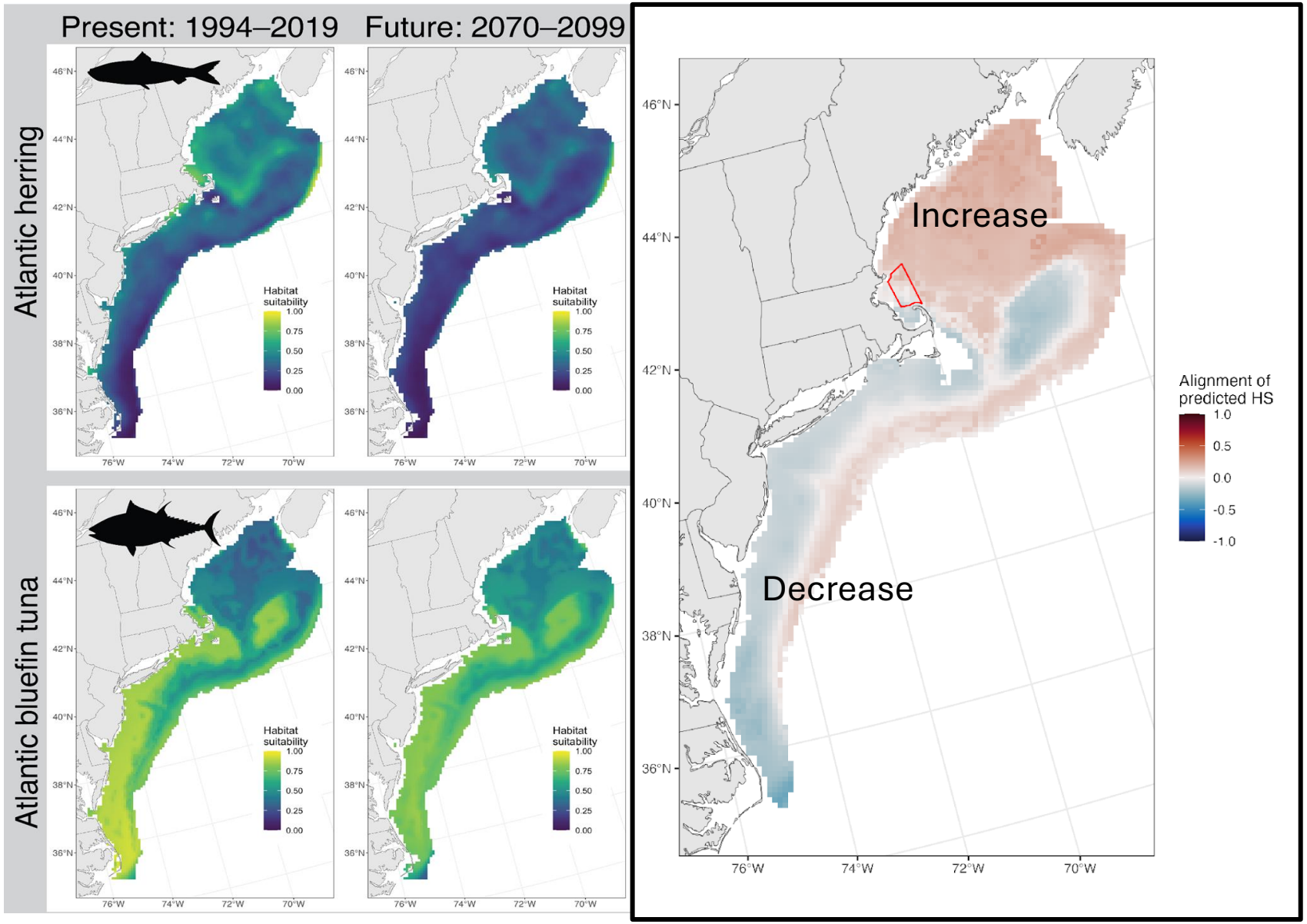
Next steps:

- Forage fish are foundational to marine foodwebs
- Forecast forage fish and predators to identify potential shifts or spatial or temporal misalignment

Ex: Atlantic bluefin tuna and Atlantic herring



Key Takeaways

Forecasted decadal spatial changes in the forage fish community in the U.S. Northeast Shelf

Forecasted changes dependent on:

- Species
- Region
- Season

Questions?

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FACET site

NROC data products

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SDSU San Diego State University

WOODS HOLE OCEANOGRAPHIC INSTITUTION

UCDAVIS

NROC Northeast Regional Ocean Council

U.S. FISH & WILDLIFE SERVICE

NOAA

NASA

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