The Northeast Regional Habitat Assessment:

A collaborative, multi-disciplinary project to develop decision support products for marine fish habitat management

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New England Fishery Management Council (Portland, ME)
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NRHA Goal: To describe and characterize estuarine, coastal, and offshore fish habitat distribution, abundance, and quality in the Northeast.

Four actions were identified as necessary to meet this goal:

1) Inshore fish habitat assessment
   a) Fish distribution and abundance
   b) Habitat distribution, status, and trends
2) Habitat vulnerability including response to changes in climate,
3) Spatial descriptions of species habitat use in the offshore area, and,
4) Habitat data visualization and decision support tools.

Geographic Scope: Northeast U.S.

South to North

North Carolina/South Carolina boundary to the western end of the Scotian Shelf and includes the Mid-Atlantic Bight, Southern New England, Georges Bank, and the Gulf of Maine.

Inshore to Offshore

Mean high water including estuaries to the shelf-slope break

Focus Species (65+, important to managers)

- **Mid-Atlantic Council:** Atlantic and chub mackerel, butterfish, longfin and shortfin squid, surfclam, ocean quahog, summer flounder, scup, black sea bass, bluefish, golden and blueline tilefish, spiny dogfish
- **New England Council:** Cod, cusk, haddock, pollock, Acadian redfish, plaice, halibut, winter flounder, witch flounder, yellowtail flounder, wolffish, windowpane, ocean pout, offshore, red, and white hake, monkfish, Atlantic herring, salmon, skates (seven species), red crab, sea scallop
- **Additional Atlantic States Marine Fisheries Commission (ASMFC):** Eel, lobster, croaker, menhaden, striped bass, Atlantic sturgeon, black drum, cobia, horseshoe crab, Jonah crab, northern shrimp, red drum, shad and river herring, Spanish mackerel, spot, spotted seatrout, tautog, weakfish, coastal sharks
- **Highly migratory with Habitat Areas of Particular Concern (HAPC) designations:** Sandbar shark, dusky shark

Assessment Products at a Glance

Data inventory
- Catch data from state and federal fisheries-independent surveys; including comparison table
- Environmental datasets (used as model covariates)
- One page metadata document for each survey or data set

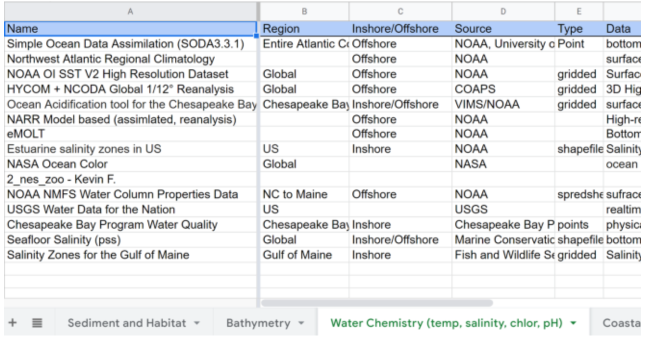
Habitat use
- Species profiles: Summarize life history and habitat use for each focus species
- Stage-based, single species and joint species distribution models (SDMs)
- Inshore Habitat Report

Climate vulnerability
- Species-habitat matrix and climate vulnerability narratives

Habitat data visualization and decision support tools
- NRHA Data Explorer: R-Shiny application used to show trends in species distribution and abundance at state and regional scales, and to share other products and documentation
- Working with partners at Mid-Atlantic Ocean Data Portal, Northeast Ocean Data Portal, and possibly NOAA DisMAP to share selected products

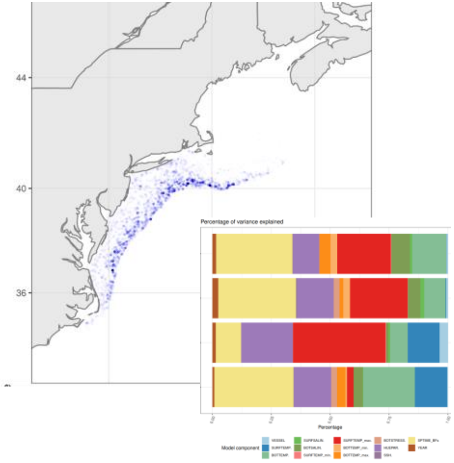
Scientific publications/reports
- Community-level Basis Function Modeling methods paper and R package; others in development

Data inventory

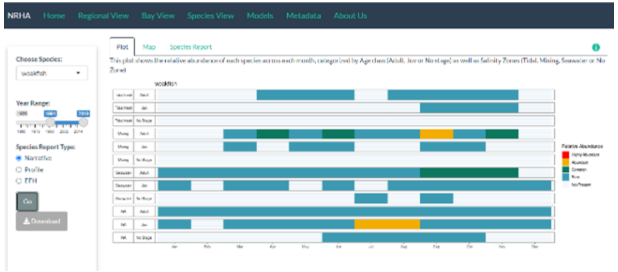


Name	Region	Inshore/Offshore	Source	Type	Data
Simple Ocean Data Assimilation (SODA3.3.1)	Entire Atlantic Co	Offshore	NOAA, University o	Point	bottom
Northwest Atlantic Regional Climatology		Offshore	NOAA		surface
NOAA OI SST V2 High Resolution Dataset	Global	Offshore	NOAA	gridded	Surfac
HYCOM + NCODA Global 1/12° Reanalysis	Global	Offshore	COAPS	gridded	3D Hig
Ocean Acidification tool for the Chesapeake Bay	Chesapeake Bay	Inshore/Offshore	VIMS/NOAA	gridded	surface
NARR Model based (assimlated, reanalysis)		Offshore	NOAA		High-re
eMOLT		Offshore	NOAA		Bottom
Estuarine salinity zones in US	US	Inshore	NOAA	shapefile	Salinity
NASA Ocean Color	Global		NASA		ocean
2_nes_zoo - Kevin F.					
NOAA NMFS Water Column Properties Data	NC to Maine	Offshore	NOAA	spredshe	suface
USGS Water Data for the Nation	US		USGS		realtim
Chesapeake Bay Program Water Quality	Chesapeake Bay	Inshore	Chesapeake Bay P	points	physica
Seafloor Salinity (pss)	Global	Inshore/Offshore	Marine Conservatic	shapefile	bottom
Salinity Zones for the Gulf of Maine	Gulf of Maine	Inshore	Fish and Wildlife Se	gridded	Salinity

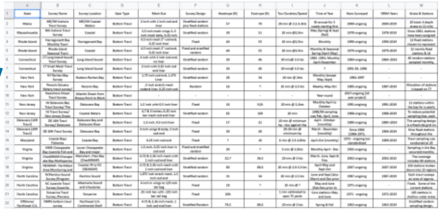
Model-based Approaches



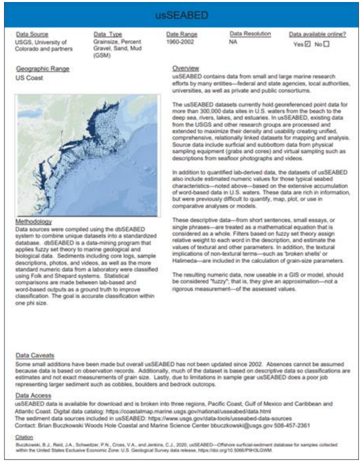
Inshore Fish Data



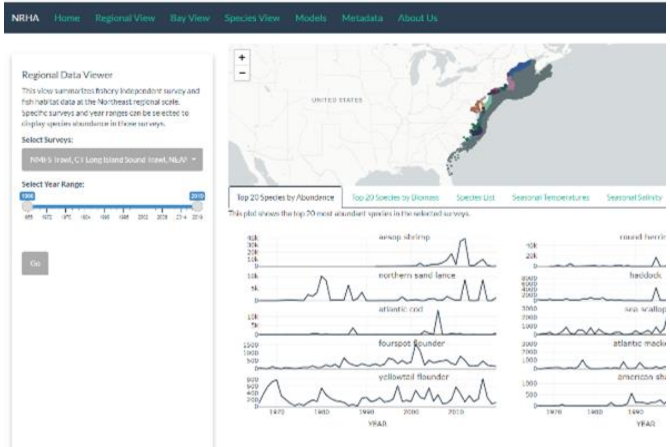
Trawl Survey Comparison



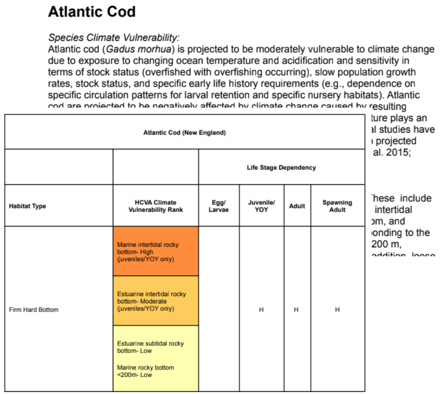
Metadata (1-pagers)



Data Explorer



NRHA/CVA/HCVA Crosswalk



Lots of Reports…

Climate Vulnerability Assessment Crosswalk

- Synthesis of information from NOAA’s FSCVA, HCVA, ACFHP species-habitat matrix, and EFH designations
- <u>Matrix</u> that indicates species’ dependency on (or association with) habitat types, by life stage
- <u>Narratives</u> that describe species and habitat climate vulnerabilities and habitat dependencies, in text and tables
- Will highlight critical/most concerning intersections of species and habitat climate vulnerability
- Products will be shared via NRHA Data Explorer

Atlantic Cod (New England)					
		Life Stage Dependency			
Habitat Type	HCVA Climate Vulnerability Rank	Egg/ Larvae	Juvenile/ YOY	Adult	Spawning Adult
Firm Hard Bottom	Marine intertidal rocky bottom- High (juveniles/YOY only) Estuarine intertidal rocky bottom- Moderate (juveniles/YOY only) Estuarine subtidal rocky bottom- Low Marine rocky bottom <200m- Low		H	H	H

Atlantic Cod

Species Climate Vulnerability:
Atlantic cod (*Gadus morhua*) is projected to be moderately vulnerable to climate change due to exposure to changing ocean temperature and acidification and sensitivity in terms of stock status (overfished with overfishing occurring), slow population growth rates, stock status, and specific early life history requirements (e.g., dependence on specific circulation patterns for larval retention and specific nursery habitats). Atlantic cod are projected to be negatively affected by climate change caused by resulting decreases in recruitment and suitable habitat (Hare et al. 2016). Temperature plays an important role in Atlantic cod recruitment, growth, and survival, and several studies have reported declines in populations in the southern extent of the range due to projected increased temperature (Drinkwater 2005; Fogarty et al. 2008; Pershing et al. 2015; Planque and Fredou 1999).

Habitat Dependence:
A number of estuarine and marine habitats are important to Atlantic cod. These include firm hard bottom habitat (corresponding to the HCVA categories of marine intertidal rocky bottom, marine rocky bottom <200 m, estuarine intertidal rocky bottom, and estuarine subtidal rocky bottom) and loose coarse bottom habitat (corresponding to the HCVA categories of marine intertidal rocky bottom, marine rocky bottom <200 m, estuarine intertidal rocky bottom, and estuarine subtidal rocky bottom). In addition, loose

Modeling Framework

Characterizing Habitat Use

What is Fish Habitat?

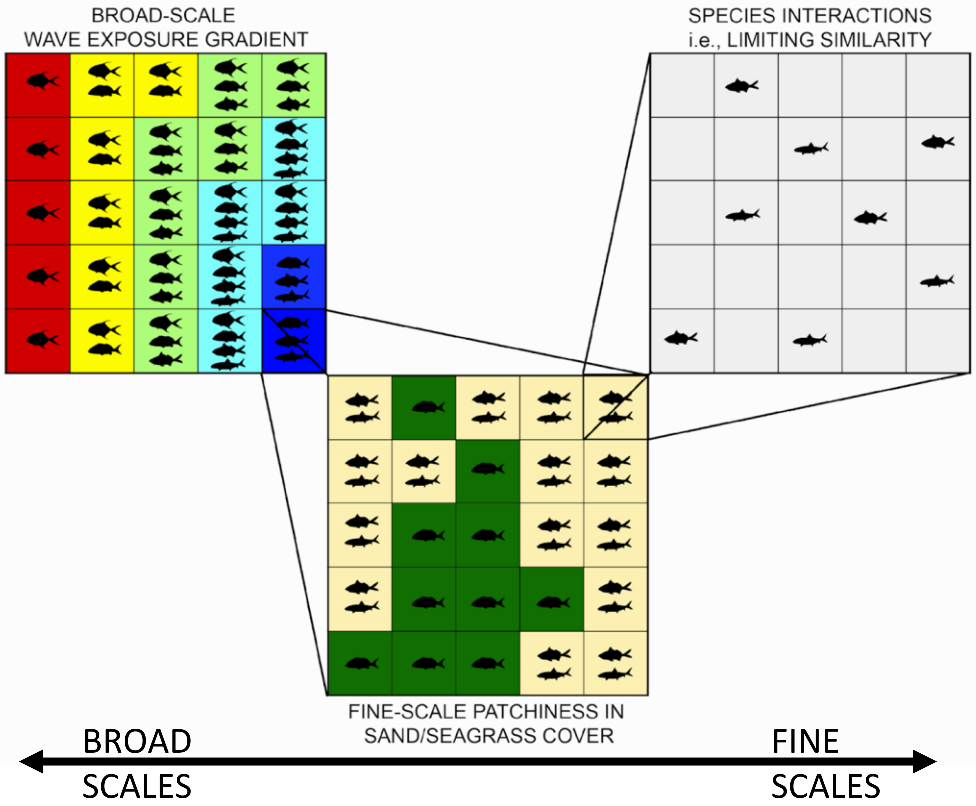
- **Necessary for growth, survival & reproduction of a species**
- A function of:
    - Innate **physiological tolerances** of the organism:
        - Temperature, salinity, flow regime
    - Basic **ecological requirements**:
        - Refuge from predators, food availability
    - **Life history stage** (often differing requirements)
    - ***Dynamic*** factors that fluctuate over time

Characterizing Habitat: A comprehensive strategy

- **Stage-based approach**
  - Partitioning spp. into distinct classes based on ontogeny (i.e., juveniles & adults)
  - Better resolution of stage-specific requirements or habitat shifts?
- **Joint-species distribution model**
  - Using a novel spatiotemporal approach (CBFM) w/ comparison to GAMs
  - Improved predictions & possible ecological insights?
- **Dynamic & ecologically relevant covariates**
  - Temporally varying predictors that reflect dynamic nature of the system
  - Predictors with direct consequences for ecological function of animals

Habitat Use & Community Ecology

- Habitat use patterns are shaped by multiple processes:
  1. **"Environmental filtering" -** Are abiotic conditions compatible with the limitations of the animal?
  2. **Biotic interactions –** Animals act on one another, influencing use of space
  3. **Dispersal limitations**
  - **Induce (+) or (-) correlations in spp pres/abs or abundance**

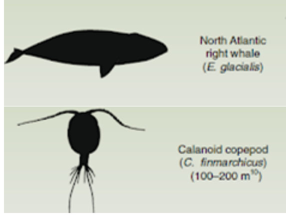


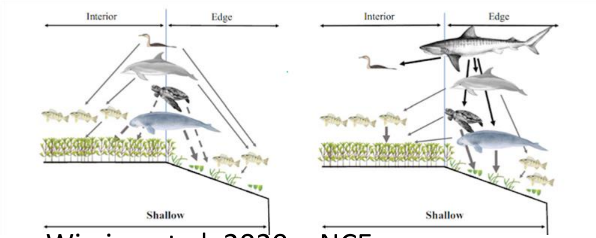
How Can Biotic Interactions Affect Habitat Use?

- **Competition: (-)** Species with similar niches may exclude each other
- **Migratory coupling: (+)** Movement of a consumer is driven by that of its prey
- **Non-consumptive effects: (-)** "Fear" of predators alters use of space by prey
- **Social interactions: (+)** Information exchange b/w species that share common predators or prey
- **Can "scale-up"!**

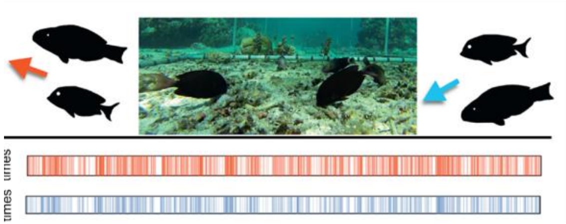
Connel 1961 – Competition

Furey et al. 2018 – Migratory coupling





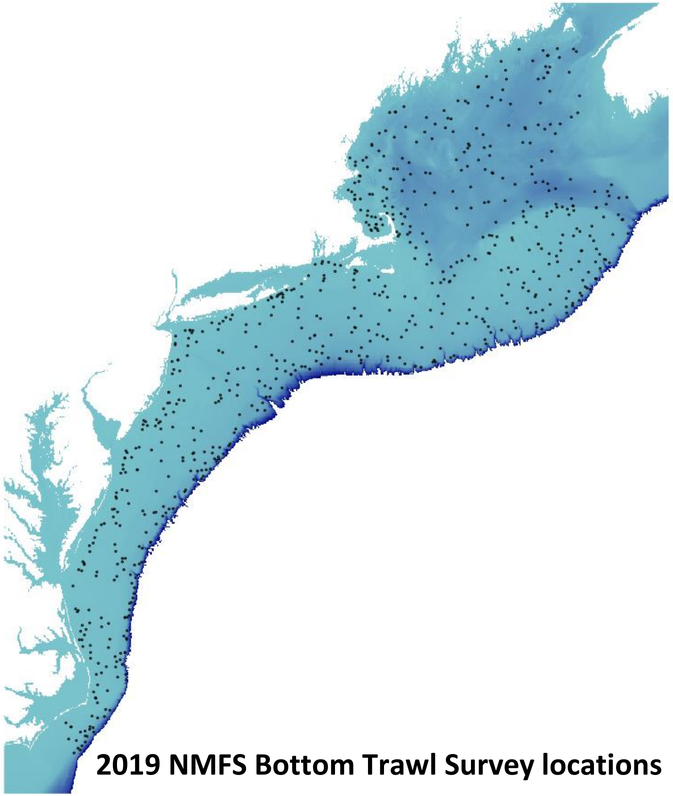
Wirsing et al. 2020 – NCEs



Gil & Hein 2017 – Social Interactions

How Do We Assess Habitat Use?

- **Based on observed densities, measured by surveys**
- Sampling is ***very sparse*** in space and time (e.g., NMFS Bottom Trawl)
  - NE Shelf ≈ 260,000 km^2 area
  - ≈700 tows/year (spring & fall)
  - < 0.1 km^2 surveyed by a tow
  - < 0.1% of seabed annually
- **How do we make use of sparse data?**

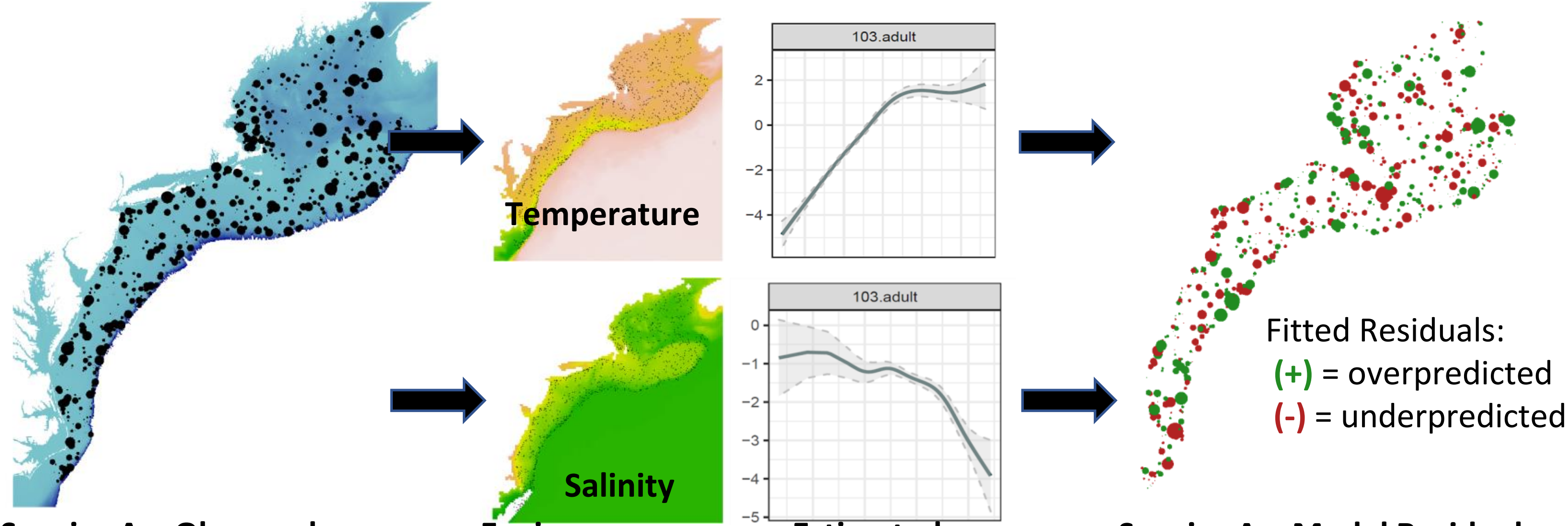


2019 NMFS Bottom Trawl Survey locations

SDMs: A Mechanistic View of Habitat

- **Species Distribution Models** (SDMs) estimate the habitat "niche" of organisms by relating observed densities to measured **environmental** predictor variables

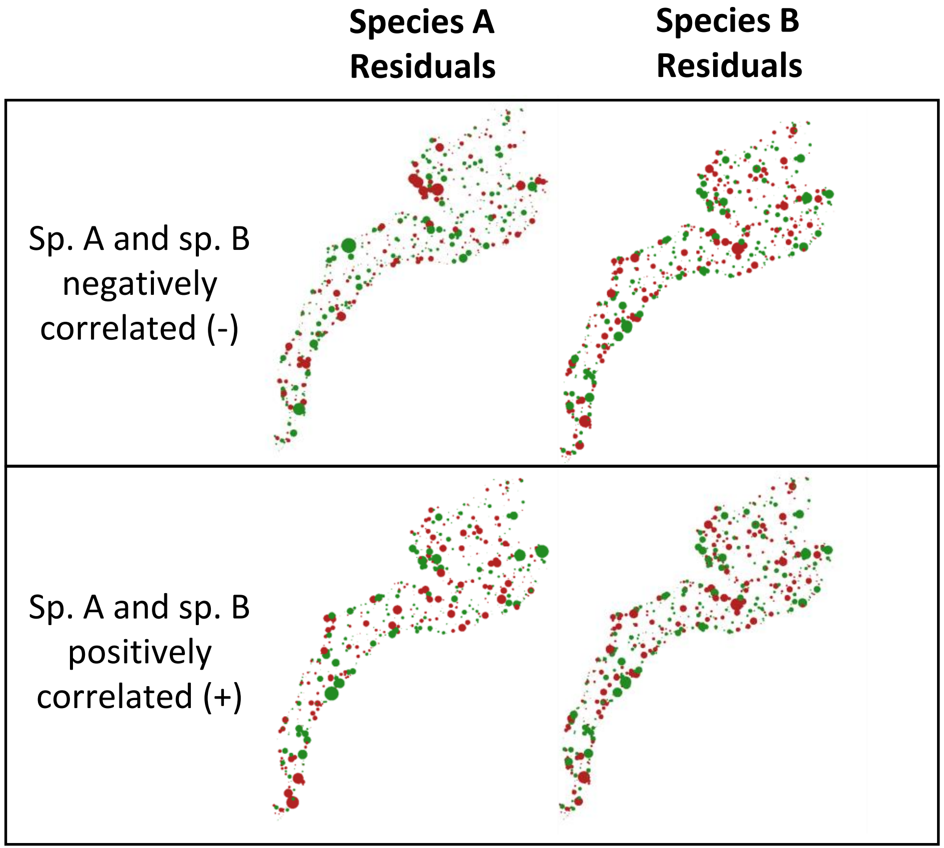
"Environmental filters"



Species A – Observed Density | **Enviro. Predictors** | **Estimated Niche** | **Species A – Model Residuals**

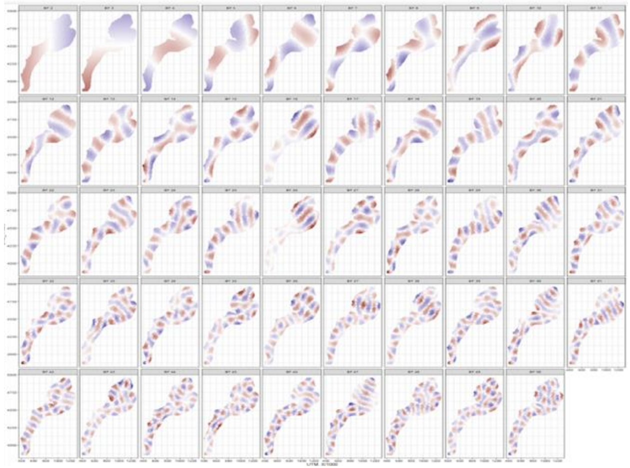
Joint SDMS: Making More of Model Residuals

- In single-species SDMs, **residuals = "error"**
- In a multi-species context, **residual patterns across species may contain information** about underlying processes (i.e., missing predictors, dispersal, interactions)
- Joint SDMs model residual covariance & exploit it to produce **more realistic estimates of species assemblages**



CBFM: Community-level Basis Function model

- **Related to GAMS**
  - Basis functions (BF) model covariance in space & time



Spatio-Temporal Joint Species Distribution Modeling:
A Community-Level Basis Function Approach

Francis K.C. Hui*[1], David I. Warton[2], Scott D. Foster[3], Nicole A. Hill[4], and Christopher R. Haak[5]

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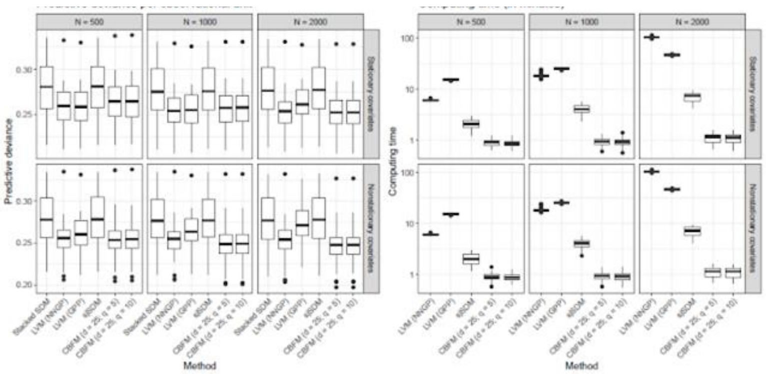


- **Methods Manuscript** w/ Simulation Studies
- **R package** (Github repository, June public release)

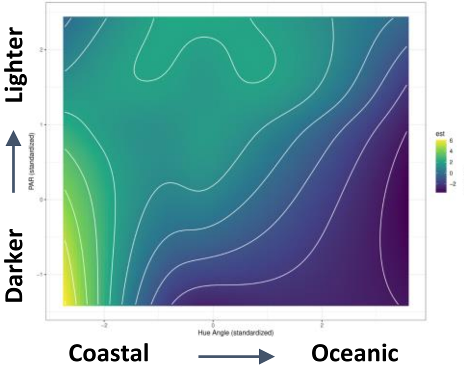
GitHub

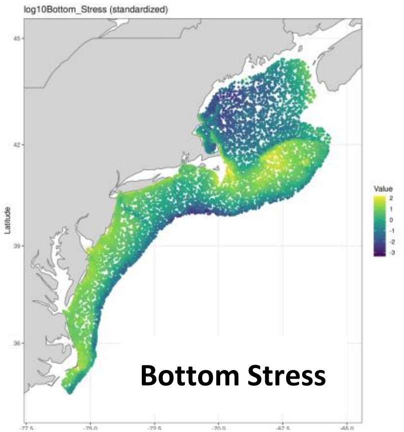
CBFM: NRHA Application

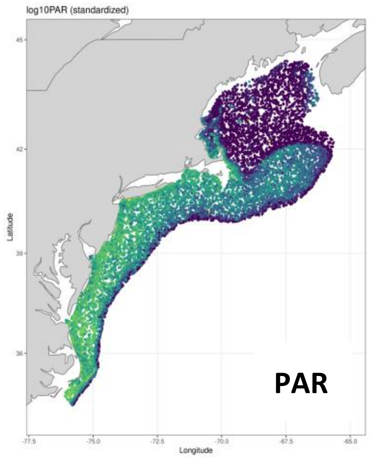
- **97 spp-stages** from NMFS bottom-trawl surveys
  - Demersal & pelagic spp., managed, common, & prey
  - Training 2000-2014 (n > 9000 obs)
  - Testing 2015-2019 (n > 3000 obs)
- Combined **Spring & Fall** surveys
- 13 Predictor variables
  - Surface & bottom **temperature** (monthly & annual min/max), **salinity** (surface & bottom), **sea surface height**, correlates of depth (**optical environment, hydrodynamic stress**)
- **Hurdle model** (presence/absence & count conditional on presence)
- Spatiotemporal Basis Functions (intra-year) & random effect of year

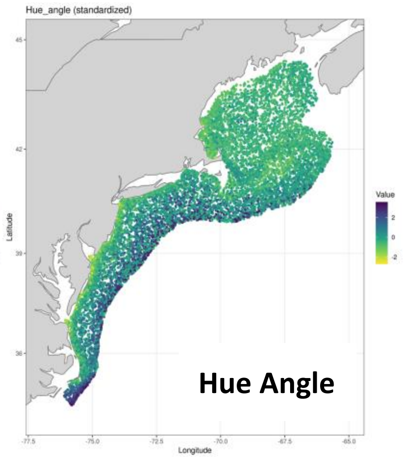
Predictor Variables: Correlates of Depth

- Depth is an informative predictor, but mostly a proxy for other factors
  - Spp may alter use of depth as they track other causal factors (e.g., **temperature**)
- **Bottom Stress**
  - Strength of wave & current-driven water movement at the seabed
- **PAR = Intensity** of underwater light
  - Light → Dark (shallow → deep)
- **Hue Angle = Spectral distribution** (i.e., color) of light
  - Red → Blue (coastal → oceanic)



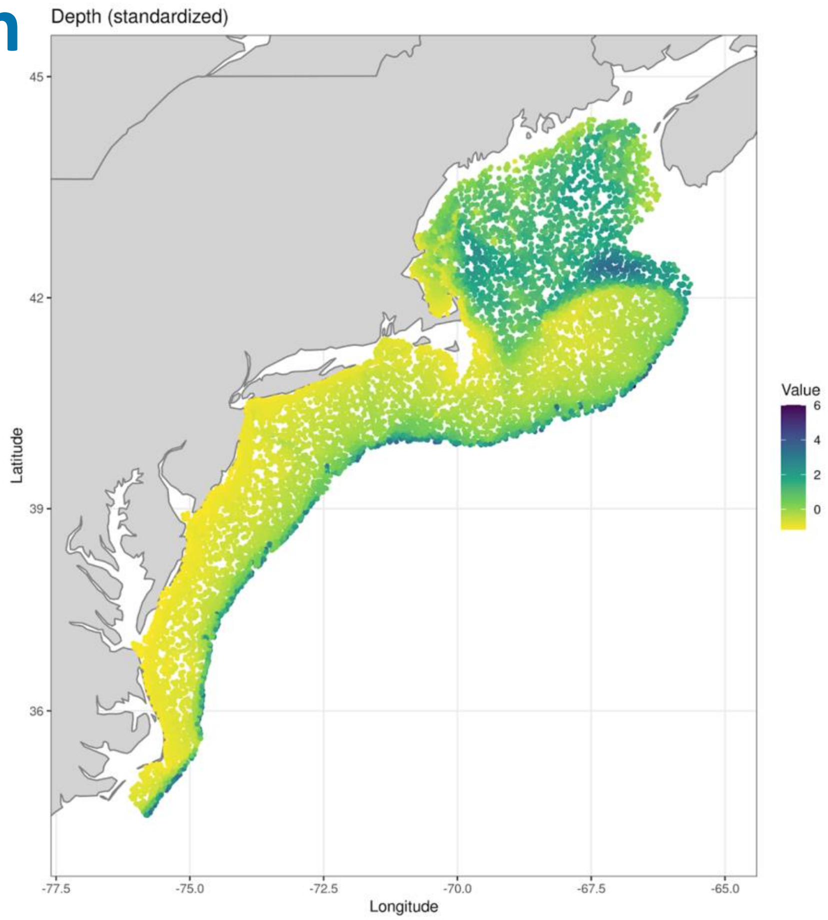






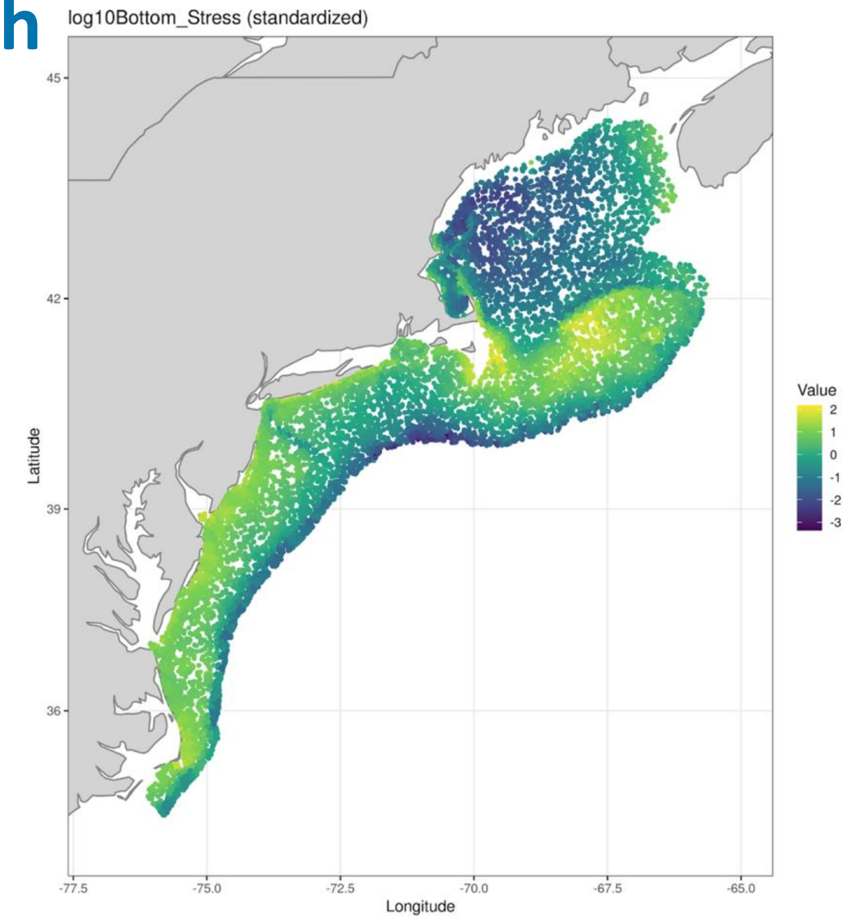
Covariates: Correlates of Depth

- Depth is an informative predictor, but is largely a proxy for other factors
  - Spp may alter use of depth as they track causal factors (e.g., temperature)
- Correlates of depth with more direct ecological relevance:
  - **Temperature** (physiology)
  - **Optical environment** (navigation, predator-prey interactions)
  - **Water movement** (locomotion, energetic costs)



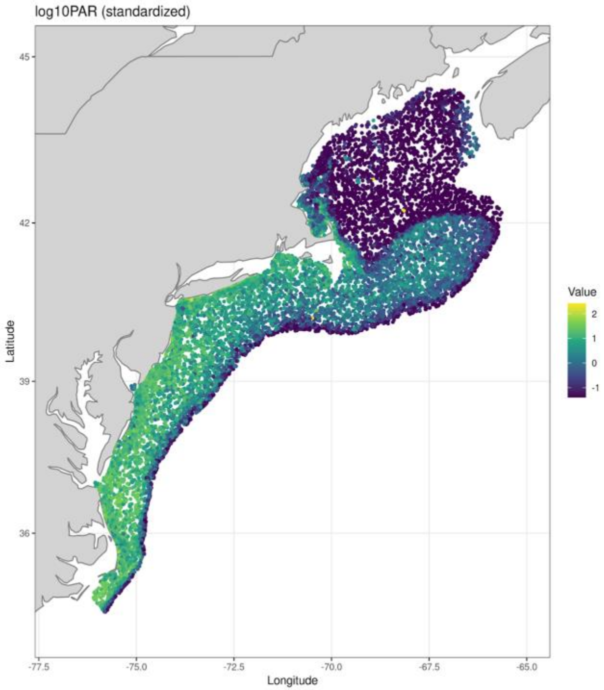
Covariates: Correlates of Depth

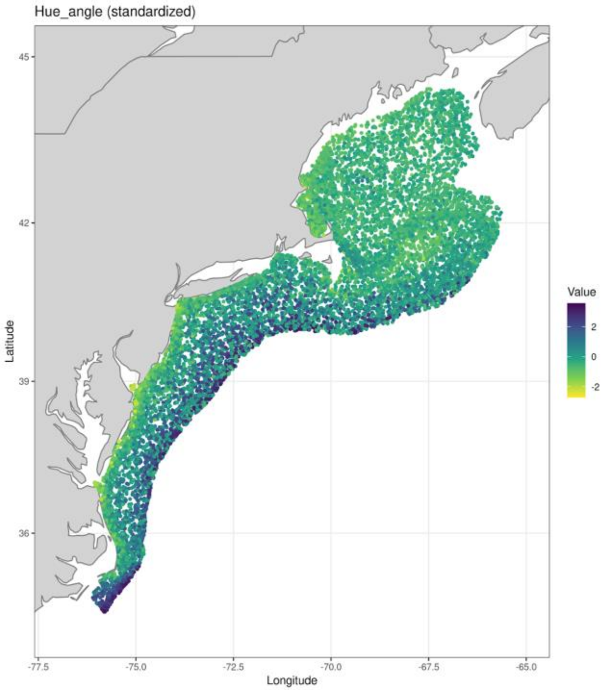
- **Bottom Stress**
- Intensity of hydrodynamic stress at the seabed due to waves & currents
- Inversely related to depth
- 95th quantile (extreme events)
- USGS Seabed Stress & Sediment Mobility Database



Covariates: Correlates of Depth

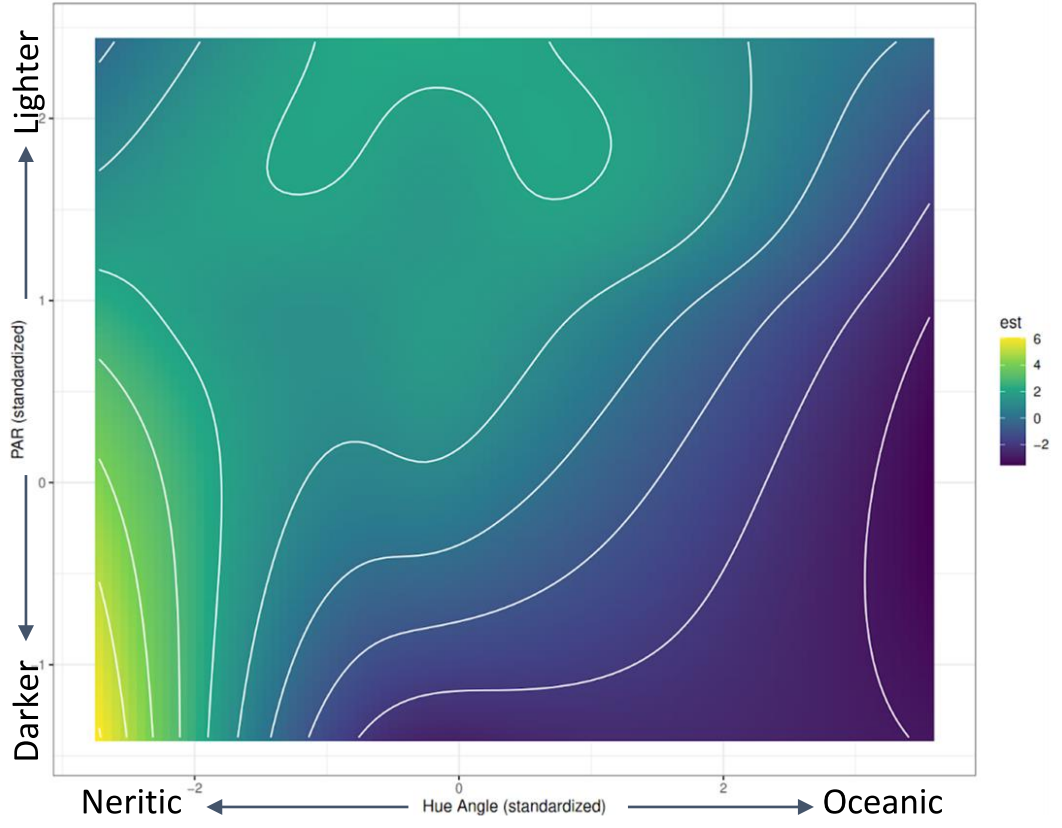
- **PAR = Intensity** of downwelling light
  - Light → Dark
  - (Shallow → Deep)
- **Hue Angle = Spectral distribution** (color) of downwelling light
  - Red → Blue
  - (Coastal → Oceanic)
- @ 0.5 * depth





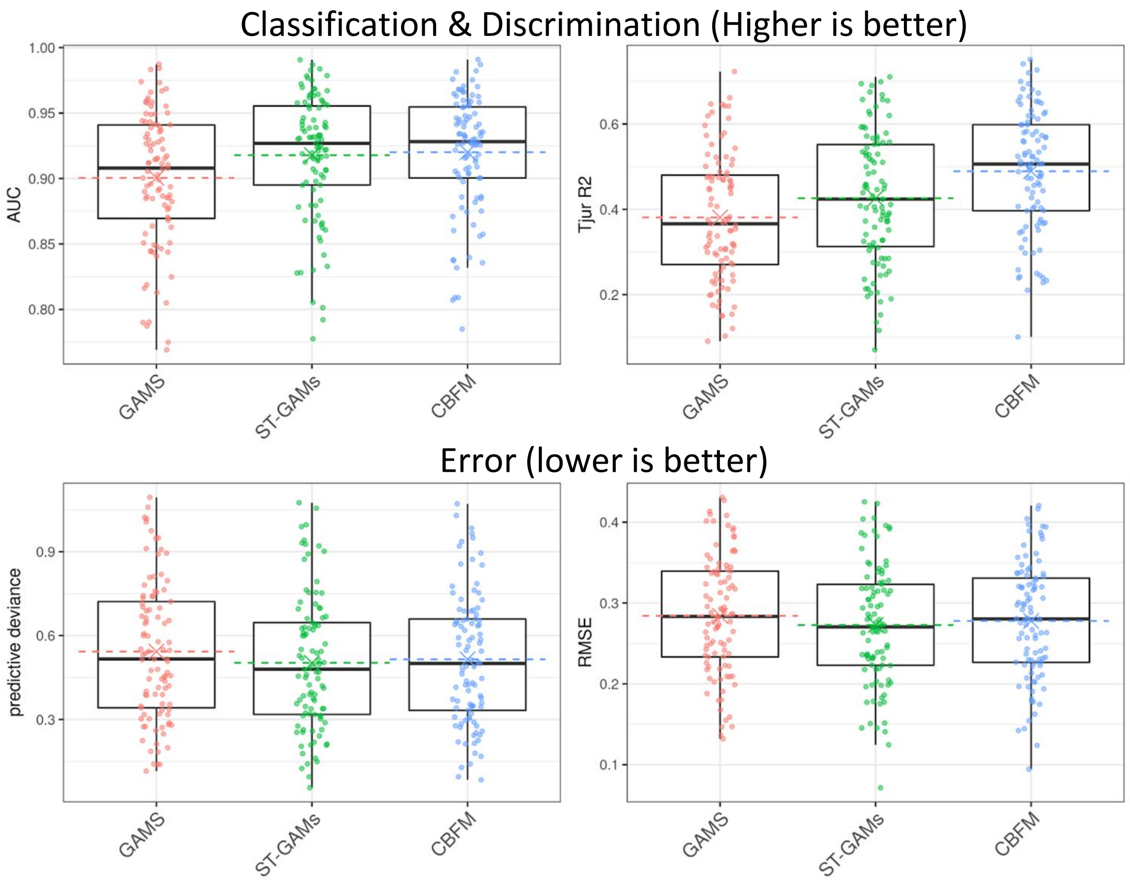
Covariates: Correlates of Depth

- Interaction of **PAR** and **Hue Angle** (tensor product)
- Basic quality of underwater optical environment
  - Neritic-oceanic gradients
  - Depth gradients
  - Productivity gradients (Chl)
- Dynamic
  - Season, terrestrial inputs, circulation patterns (e.g., gulfstream position)



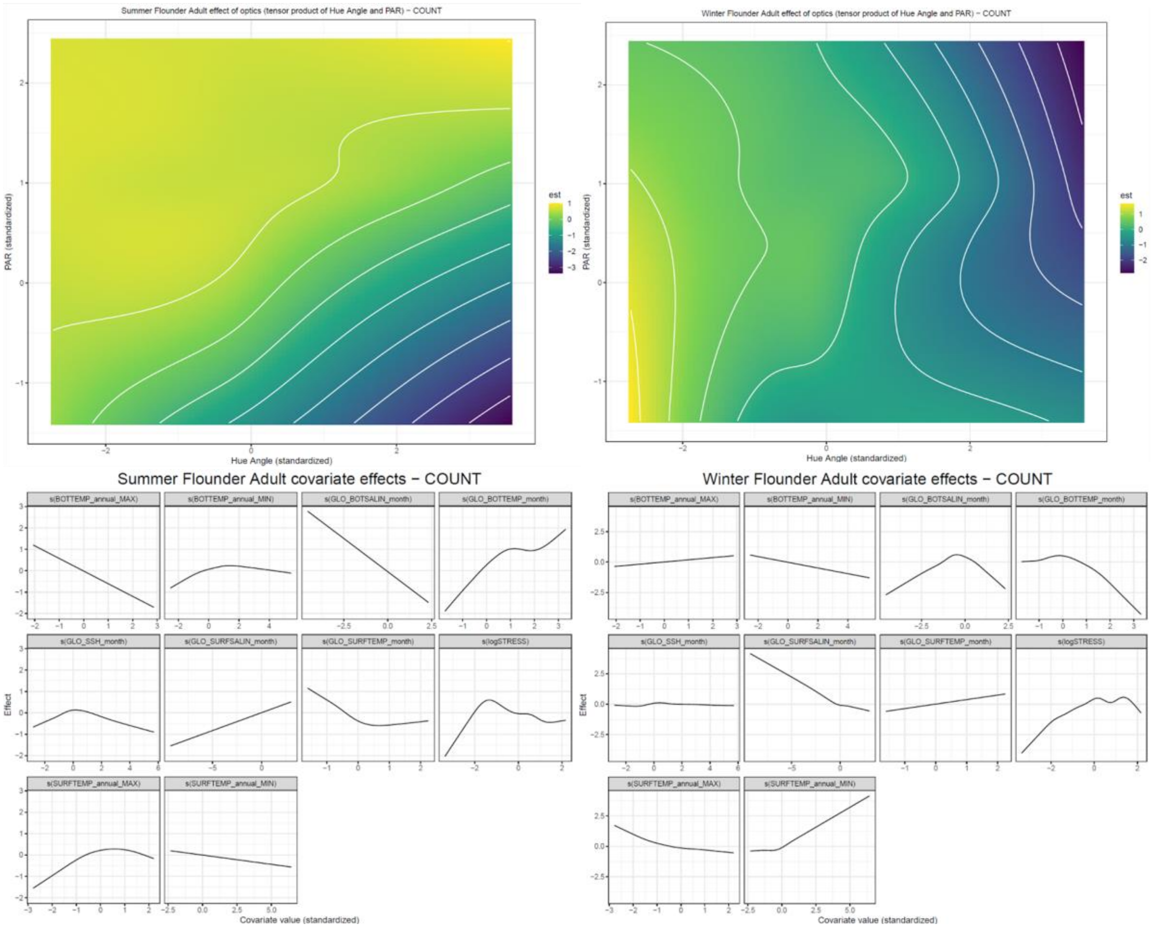
NRHA Application: Predictive Performance

- Out-of-sample prediction: (extrapolated to years 2015 -2019)
  - Median AUC = 0.93 (range from 0.78 - 0.99)
  - Median Tjur R^2 = 0.50 (0.1 - 0.75),
  - Median RMSE = 0.28 (0.09 - 0.42)
- Outperforms stacked (i.e., single-species) spatiotemporal GAMS



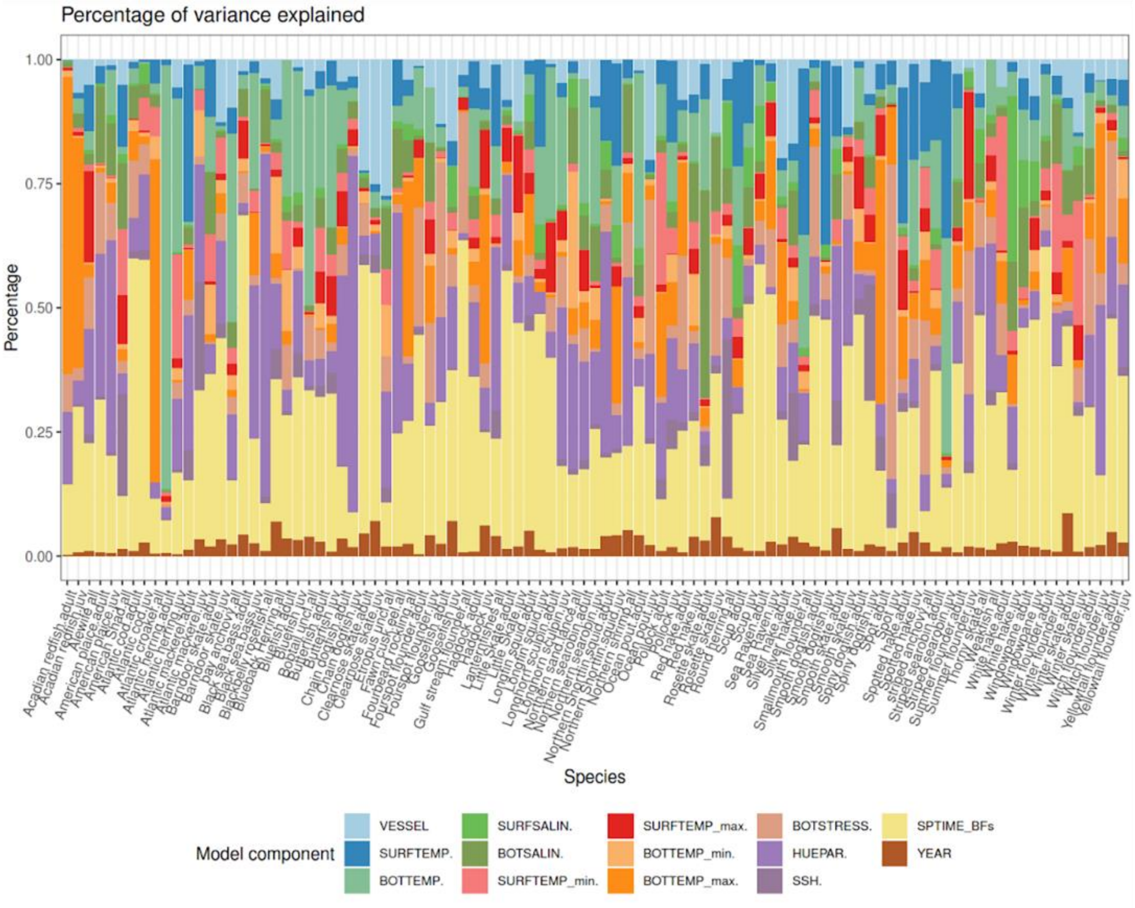
Response to Predictors: Flounders

- Relationship b/w abundance or P/A & environmental predictor variables; "**habitat niche**"
- Summer Flounder (left) vs Winter Flounder (right) "optical niche"
- SF spans both coastal & more oceanic waters, WF confined to more coastal



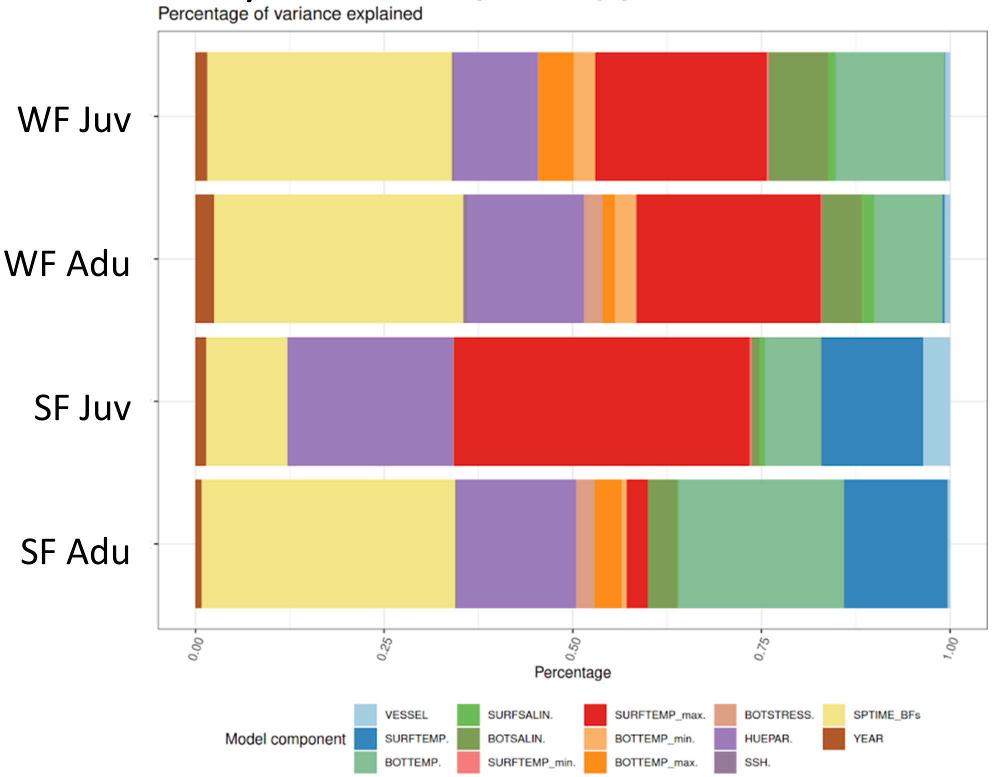
Predictor Importance

- **% variance** explained by each predictor (and spatiotemporal BFs & year effect)
- **What factors are most influential** in driving habitat use of a spp?



Predictor Importance: Summer and Winter Flounders

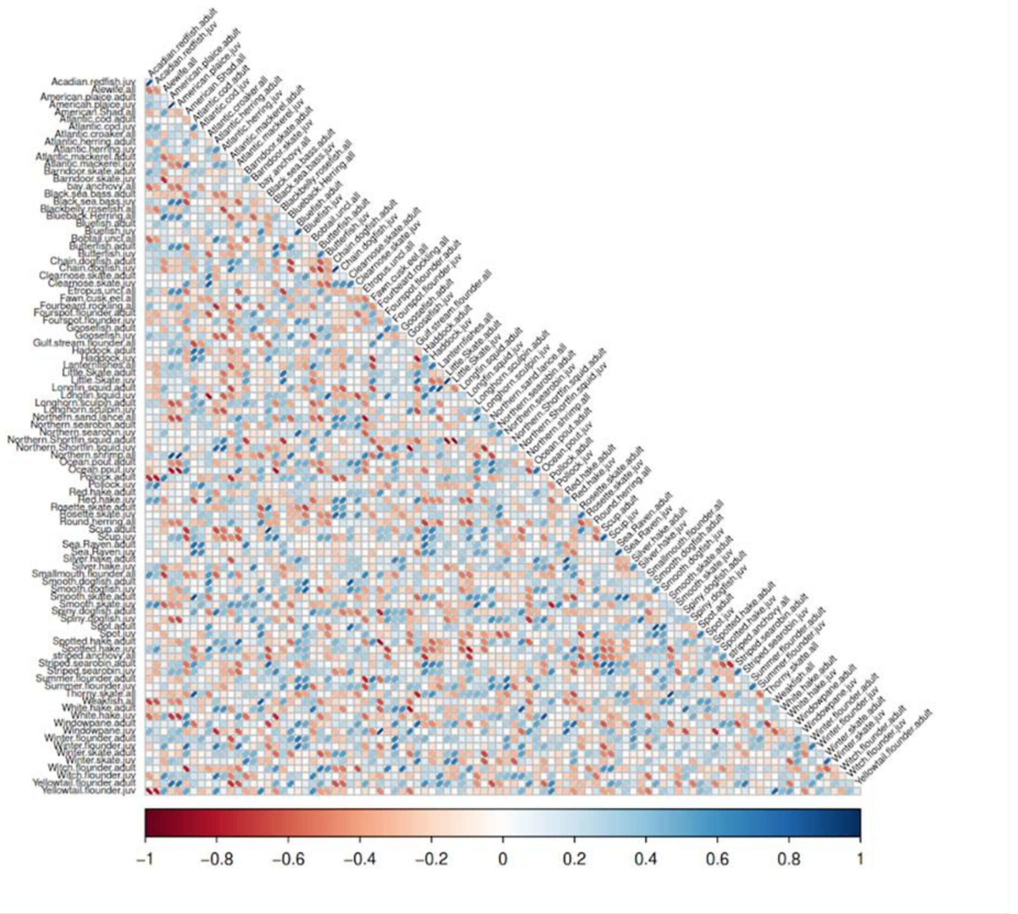
Pres/abs model



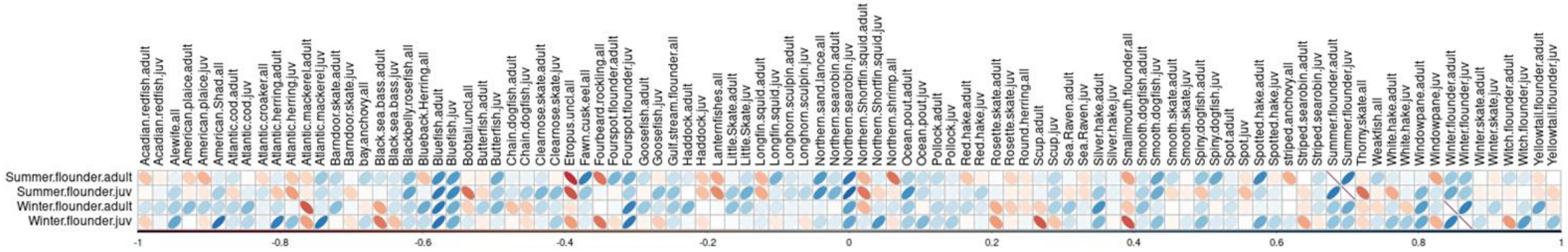
- **Bottom temp, annual max surface temp, & optical parameters** influential
- Surface temp more important for SF, salinity more important for WF
- Similar patterns for juvs and adults

Residual (Partial) Correlations

- Correlation b/w spp. that is *not* explained by measured predictors
- May be evidence of:
  - **Biotic interactions?**
  - Responses to **“missing” covariates**?
  - **Dispersal** effects
- Partial correlations control for “indirect” interactions (e.g., shared avoidance of a predator)

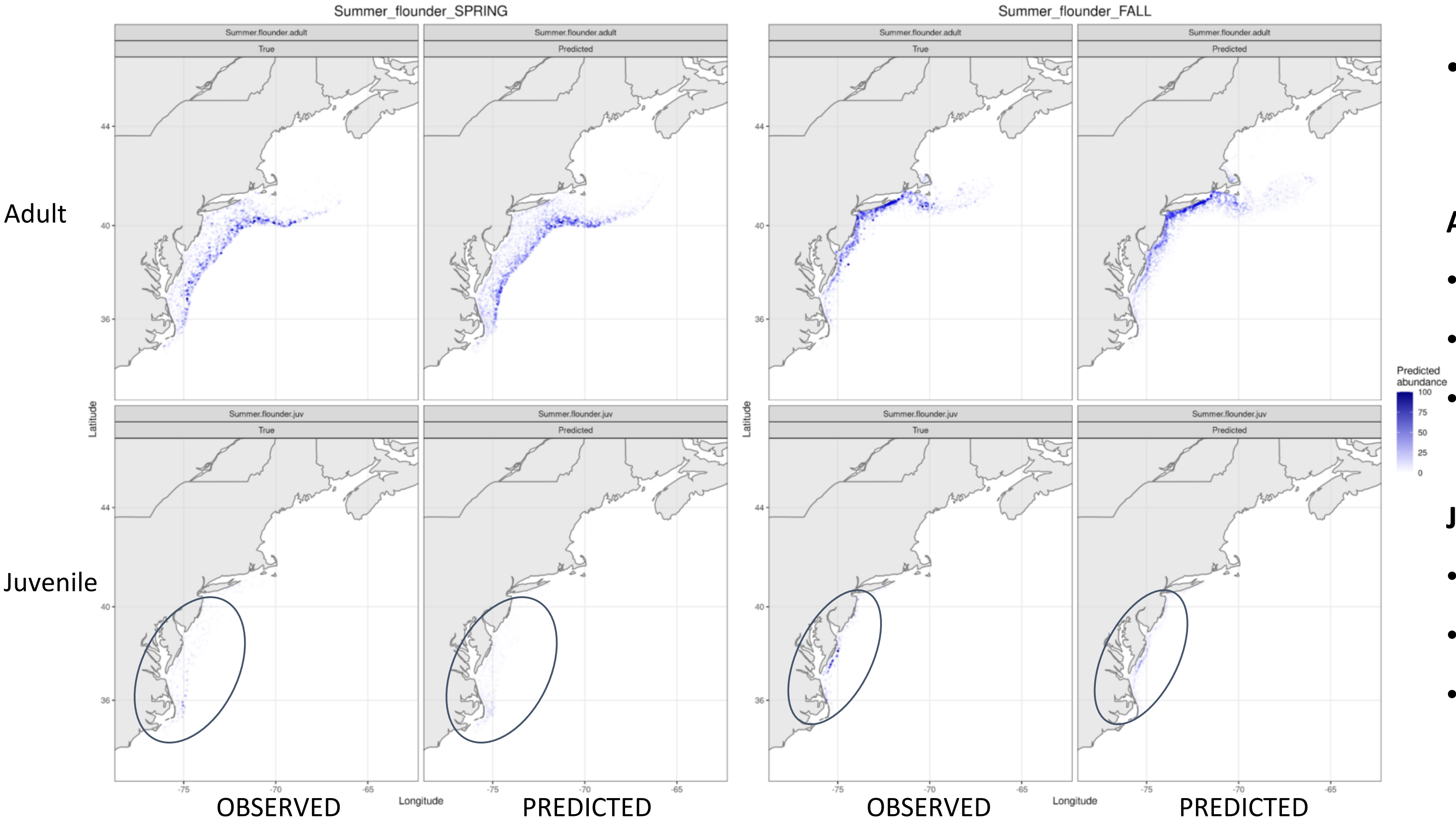


Residual (Partial) Correlations: Flounders



- **Strong +** corrs b/w adults and juveniles within species (dispersal?)
- Weaker **+** Corrs w/ each other (Summer & Winter)
- **+** Corrs w/ Bluefish and Northern Searobin?
- **-** Corrs w/ Etropus & Smallmouth flounders

Predictions: Summer flounder



- **Seasonal & stage-specific differences**

Adults

- AUC = 0.94
- TjurR^2 = 0.62
- RMSE = 0.34

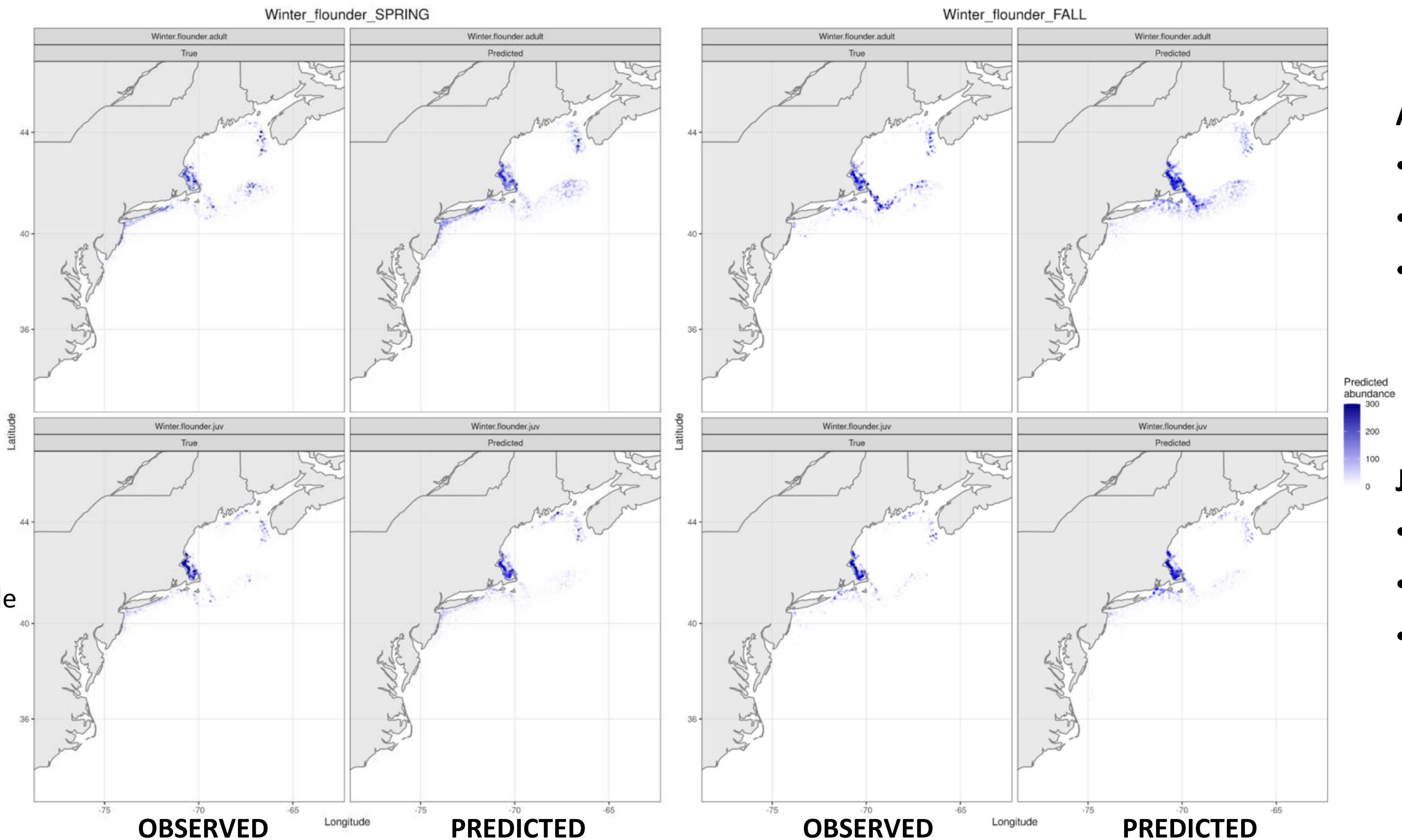
Juveniles

- AUC = 0.93
- TjurR^2 = 0.30
- RMSE = 0.22

Predictions: Winter flounder

Adult

Juvenile



OBSERVED PREDICTED OBSERVED PREDICTED

Adults

- AUC = 0.95
- TjurR^2 = 0.66
- RMSE = 0.30

Juveniles

- AUC = 0.96
- TjurR^2 = 0.65
- RMSE = 0.26

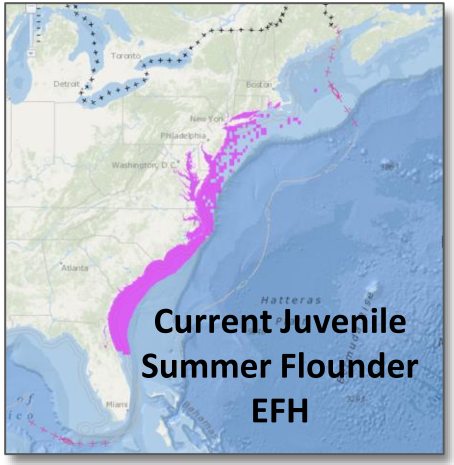
Next Steps

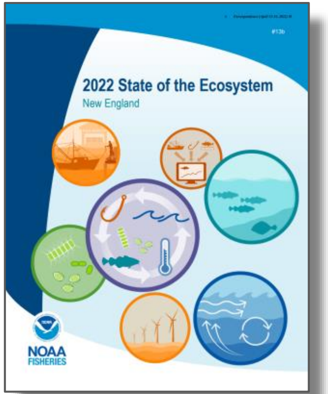
- Expand predictor variables to include benthic habitat characteristics (e.g., BPI, topographic complexity, sediment type)
- Visualize final results & make available via NRHA Data Explorer and regional data portals
- Also considering:
  - Developing long-term projections of changes in habitat use, driven by climate model outputs
  - Including response data from additional surveys (e.g., NEAMAP) to improve coverage in the nearshore

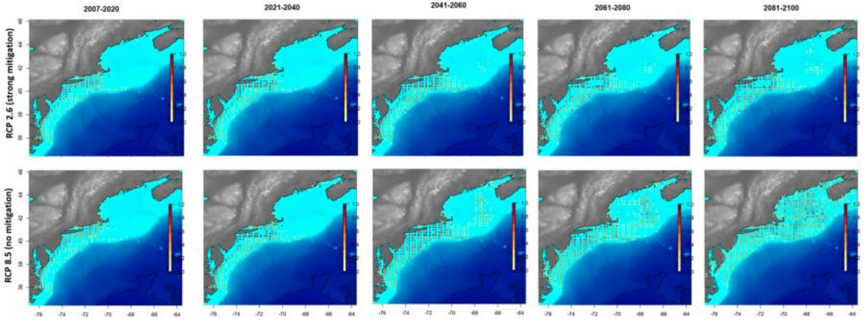
Selected applications for NRHA products

Applications for NRHA Products

- **Essential Fish Habitat:** NRHA provides more specificity on which environmental factors influence species distribution.
  - EFH text descriptions and maps
  - Habitat area of particular concern (HAPC) designations
  - Potential for shifts due to climate change and adaptive approach with automated updates
- **State of the Ecosystem Reports:** NRHA provides habitat and climate change information on managed species
- **Single Species Assessments:** Addresses Ecosystem TORs (e.g. butterfish 2022)
  - NRHA provides historic distributions and projected distributions due to climate change
  - Links between environmental drivers and stock health and recruitment

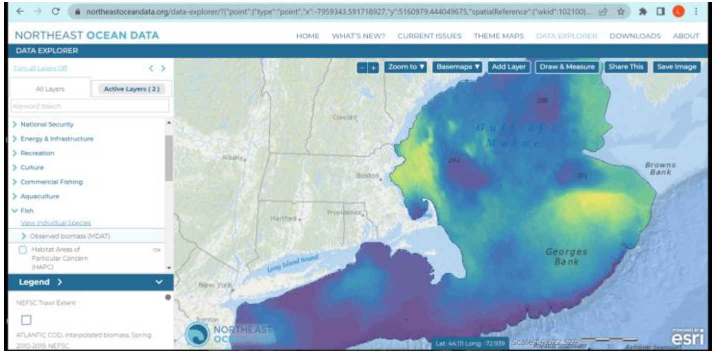


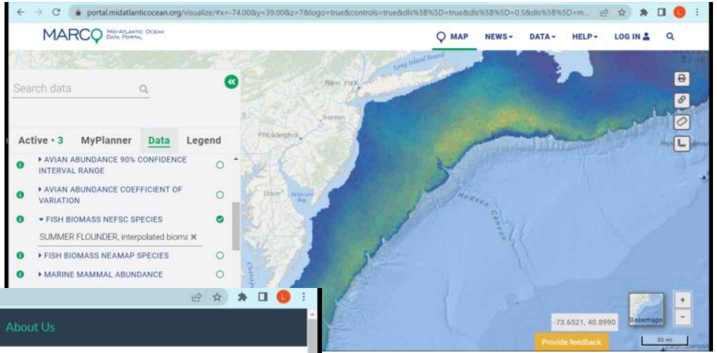


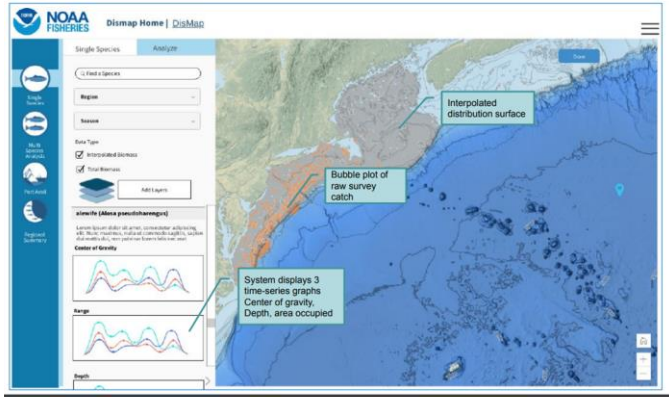


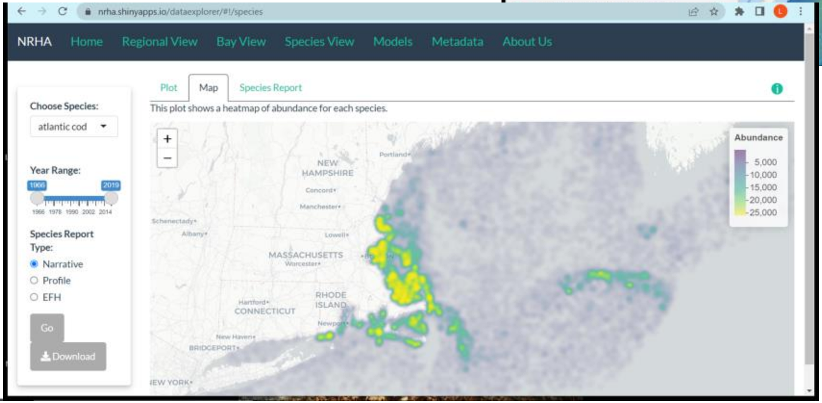
Publicly Available Data Portals

- Intent is to make NRHA products as widely available as possible
- Northeast Ocean Data Portal
- Mid-Atlantic Ocean Data Portal (MARCO)
- NMFS Distribution Mapping and Analysis Portal (DisMAP)
- NRHA Data Explorer (R-Shiny)



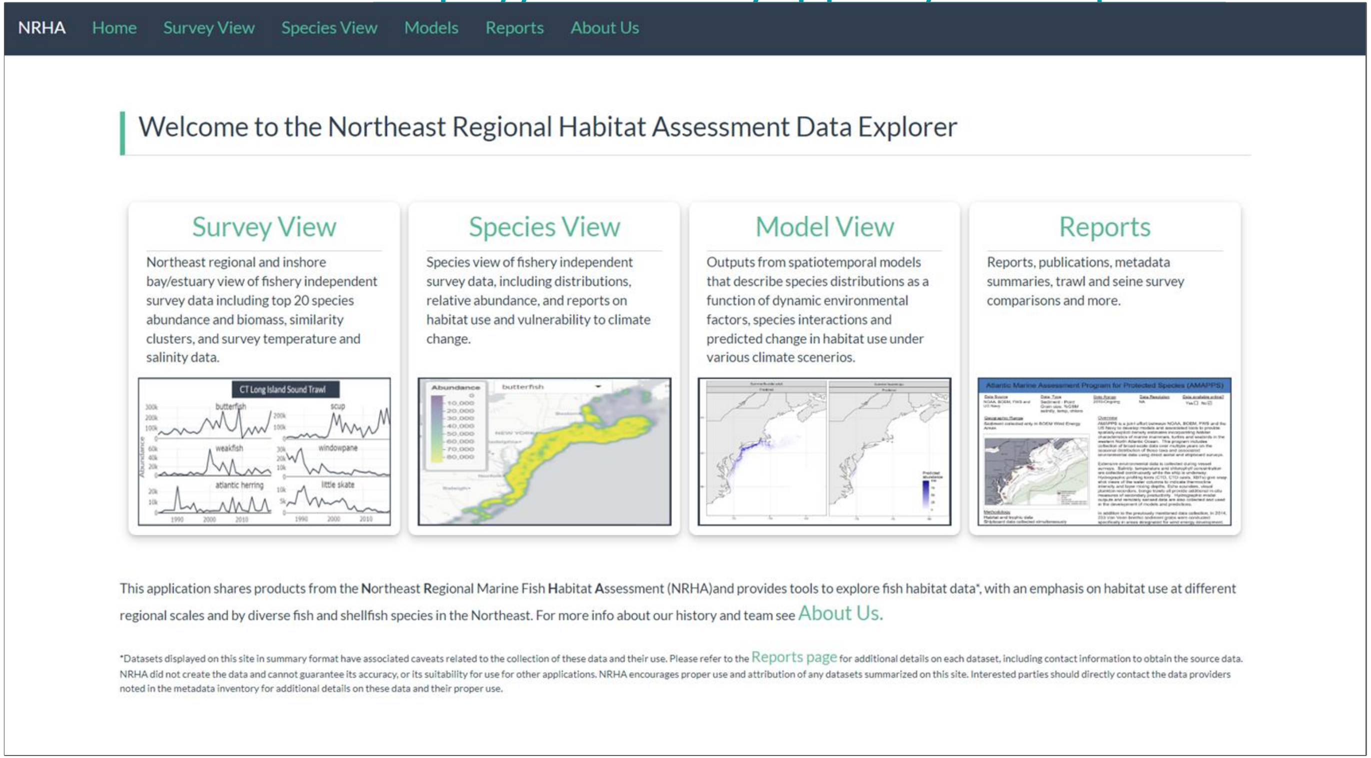






NRHA Data Explorer Demonstration

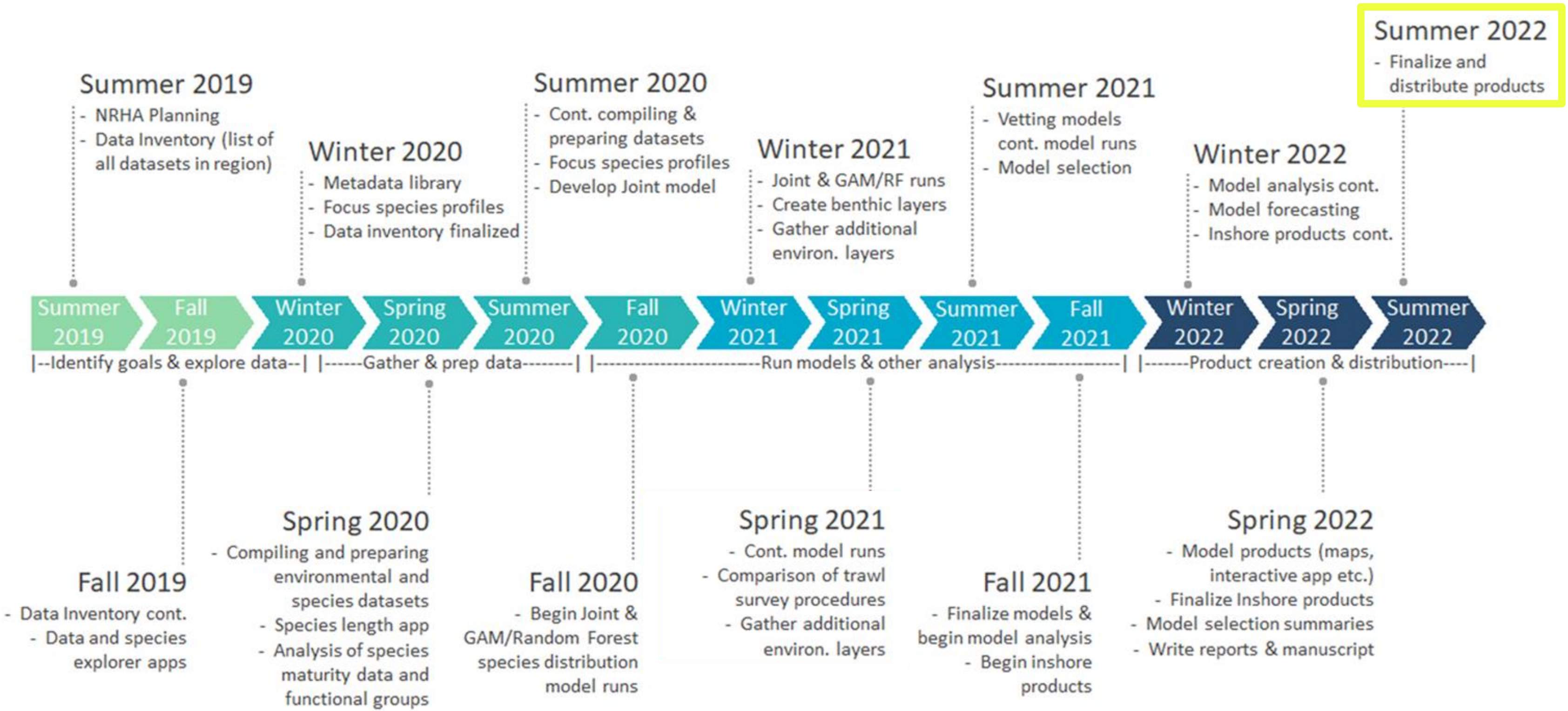
Available here: https://nrha.shinyapps.io/dataexplorer



Northeast Regional Habitat Assessment:

Describe and characterize estuarine, coastal, and offshore fish habitat distribution, abundance, and quality in the Northeast

NRHA Timeline



MAFMC/NEFMC
SSC Sub-Panel
Review of NRHA Products

Dr. Samuel Truesdell
Massachusetts Division of Marine Fisheries,
NEFMC SSC member

TOR 1 - Review products

- Clarify catchability assumptions in multispecies context and how differences among species may impact modeling results
- Model replaces depth with mechanistic variables (e.g., hydrodynamic stress, underwater light characteristics) – suggest also including depth at least in parallel models
- Additional covariates: sediment type, production-associated variables such as chlorophyll-a and annual integrated production
- Inclusion of benthic invertebrates – additional predictive info
- Only federal trawl survey data employed – results less relevant to agencies responsible for inshore waters (i.e., ASMFC, states); nearshore/estuarine areas can be important spawning/nursery habitats
- NRHA Data Explorer (R-Shiny app decision support tool) - generally found to be very useful
    - Suggested mapping species distribution by life stage, describing mapping methods
    - Thorough explanation of assumptions used in creating time series and distribution maps – ensure accurate interpretation

TOR 2 - Provide input on model results

- Species responses to predictor variables, between-species relationships and spatial distributions generally consistent with expectations
- Interesting result: surface temperature sometimes more important than bottom temperature for demersal sp (?)
- Adult distributions sometimes more realistic than juvenile
- Model artifacts on the shelf break for certain species
- Suggestions:
    - Time-varying component for correlations among species
    - Include frequency of coastal storms (enhance predictions)

TOR 3 - Comment on utility and applications

- Supportive of NRHA work: relevant to variety of management applications
- Useful supplement to allocation discussions (projects species co-occurrence given future environmental conditions)
- Help inform stock structure and predict dynamic habitat
- Downscaled climate predictions could help the multi-species model answer smaller-scale research questions
- How will survey data inputs and model outputs reconcile with EFH material?
  - NRHA information broad in scale but much EFH content is granular; synthesizing info sources may be challenging

TOR 4 - Consider communication approach

- Appreciative that the framework incorporates ecological processes in a management context – different than information typically presented
- Important to consider audience when preparing material
  - Overly-technical communications can discourage stakeholders and limit appetite to apply results to management
- Many caveats associated with modeling: essential these are outlined in communications with stakeholders – ensure results used effectively and as intended

Acknowledgments

The Steering Committee:
Mid-Atlantic Fishery Management Council - Christopher Moore
New England Fishery Management Council - Thomas Nies
Atlantic Coast Fish Habitat Partnership - Lisa Havel
Atlantic States Marine Fisheries Commission - Bob Beal (designee Patrick Campfield)
Duke University, Marine Spatial Ecology - Patrick Halpin
Monmouth University, Urban Coast Institute - Tony McDonald
National Fish Habitat Partnership, Science and Data Committee - Gary Whelan
NOAA Fisheries Offices of Habitat Conservation - Kara Meckley, Lou Chiarella
NOAA NCCOS Marine Spatial Ecology Division - Mark Monaco
NOAA Fisheries Office of Science and Technology - Peg Brady, Tony Marshak
NOAA Northeast Fisheries Science Center - Thomas Noji (retired), Dan Wieczorak
The Nature Conservancy - Kate Wilke

Action Teams:
Gulf of Maine Research Institute - Kathy Mills
Maryland DNR - Marek Topolski
Massachusetts DMF - Mark Rousseau
NOAA Fisheries GARFO - David Stevenson, Alison Verkade,
NOAA Fisheries NEFSC - Kevin Friedland, Donna Johnson, Ryan Morse, Dave Packer, Vince Saba, Harvey Walsh
NOAA NCCOS - Andrew Leight
The Nature Conservancy - Bryan DeAngelis, Rich Bell, Marta Ribera
The PEW Charitable Trusts - Zack Greenberg
Rhode Island DEM - Eric Schneider
US Fish and Wildlife Service - Julie Devers
US Geologic Service - Stephen Faulkner
Virginia Institute of Marine Sciences - Robert Latour

NRHA/FSCVA/HCVA Crosswalk: UMass/SMAST Gavin Fay and Madeleine Guyant, and Project CoPIs, Mike Johnson, Tauna Rankin, Wendy Morrison (NOAA Fisheries)

Other Collaborators: David (Moe) Nelson (NOAA NOS), Aaron Kornbluth (PEW), Lisa Havel and Pat Campfield (ASMFC/ACFHP), Karl Vilacoba, Emily Shumchenia, and Nick Napoli (MARCO/NROC), Sarah Gaichas and Kim Hyde (NOAA Fisheries NEFSC), and Emily Farr.

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