A Community-Level Model for Marine Fish Habitat on the NE Shelf

Community-level Basis Function Model (CBFM)

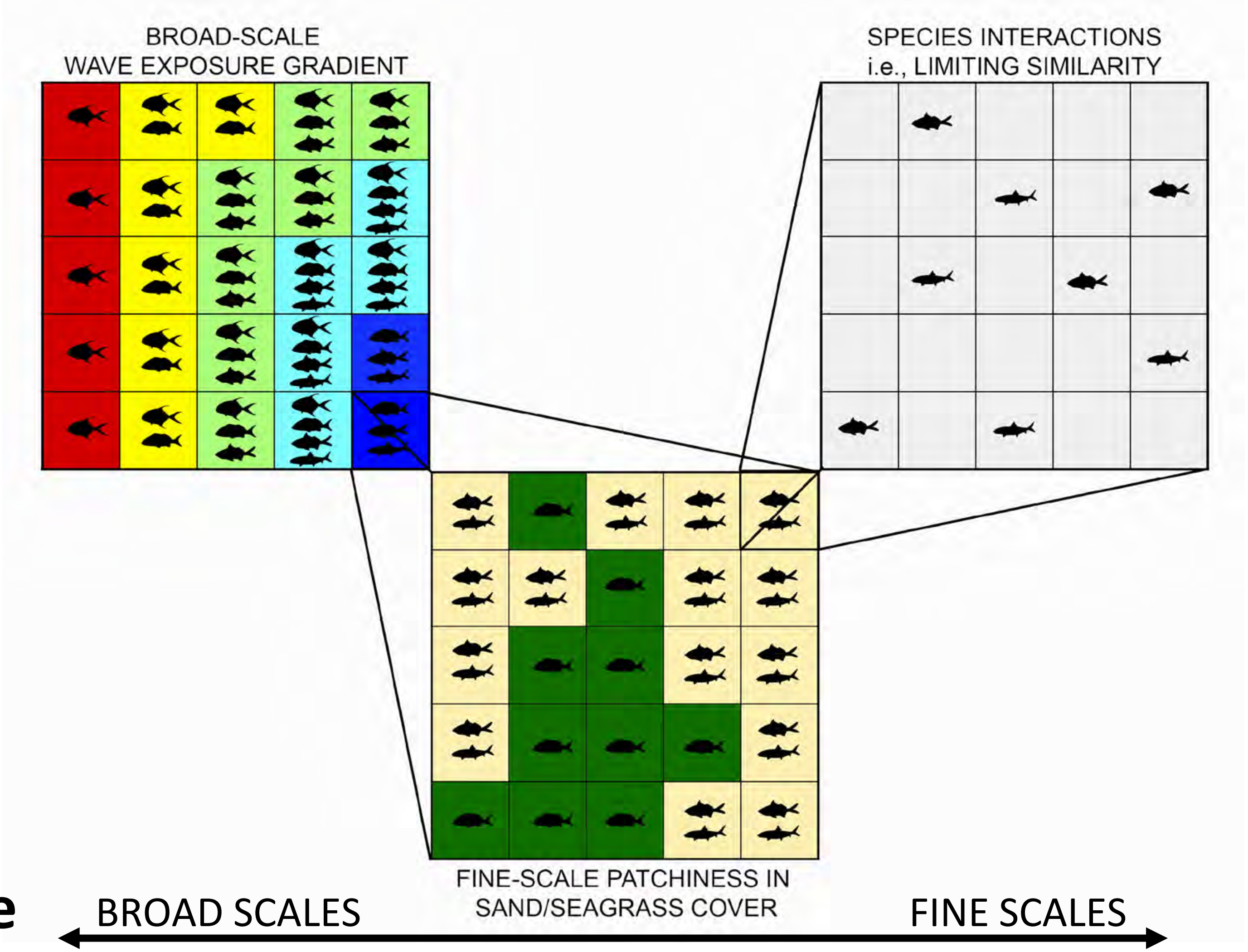
What is Fish Habitat?

- **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
  - Multiple life stages (often with differing requirements)
  - ***Dynamic*** factors that fluctuate over time

We generally infer habitat suitability based on species distributions; (i.e., if fish are there, they like something about that place)

Habitat Use & Community Ecology

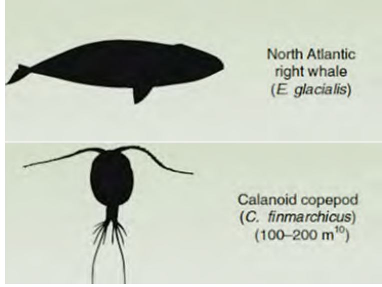
- Habitat use patterns are shaped by multiple processes:
  1. **“Environmental filtering” -** Are abiotic conditions compatible with the limitations of the animal?
  2. **Biotic interactions –** Animals act upon one another, influencing their use of space
  - **Induce (+) or (-) correlations in spp pres/abs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

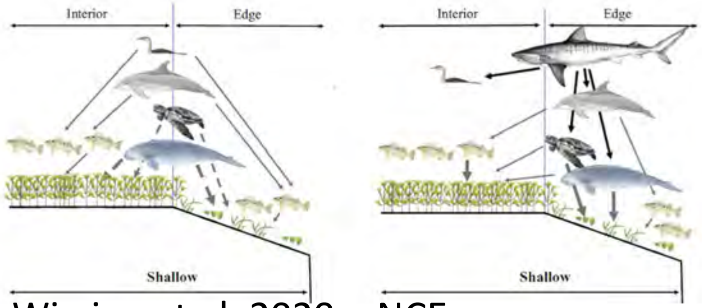


How Can Biotic Interactions Affect Habitat Use?

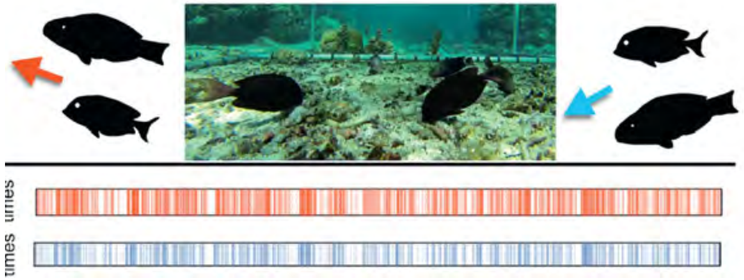
- **Competition: (-)** Species with similar niches may exclude each other
- **Migratory coupling: (+)** Movement of a consumer is driven by that of its prey
- **Non-consumptive effects: (-)** “Fear” of predators alters use of space by prey
- **Social interactions: (+)** Information exchange b/w species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


Connel 1961 – Competition

Furey et al. 2018 – Migratory coupling


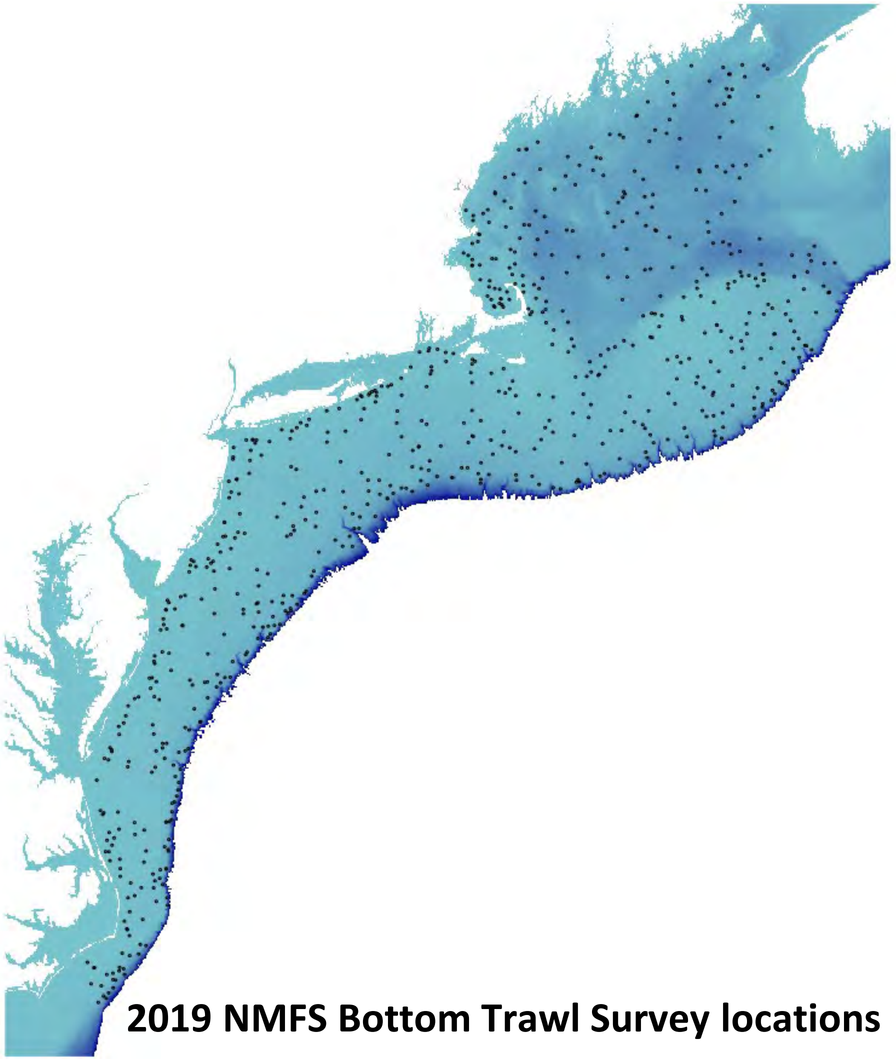


Wirsing et al. 2020 – NCEs


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 use make use of such sparse, discrete data?**

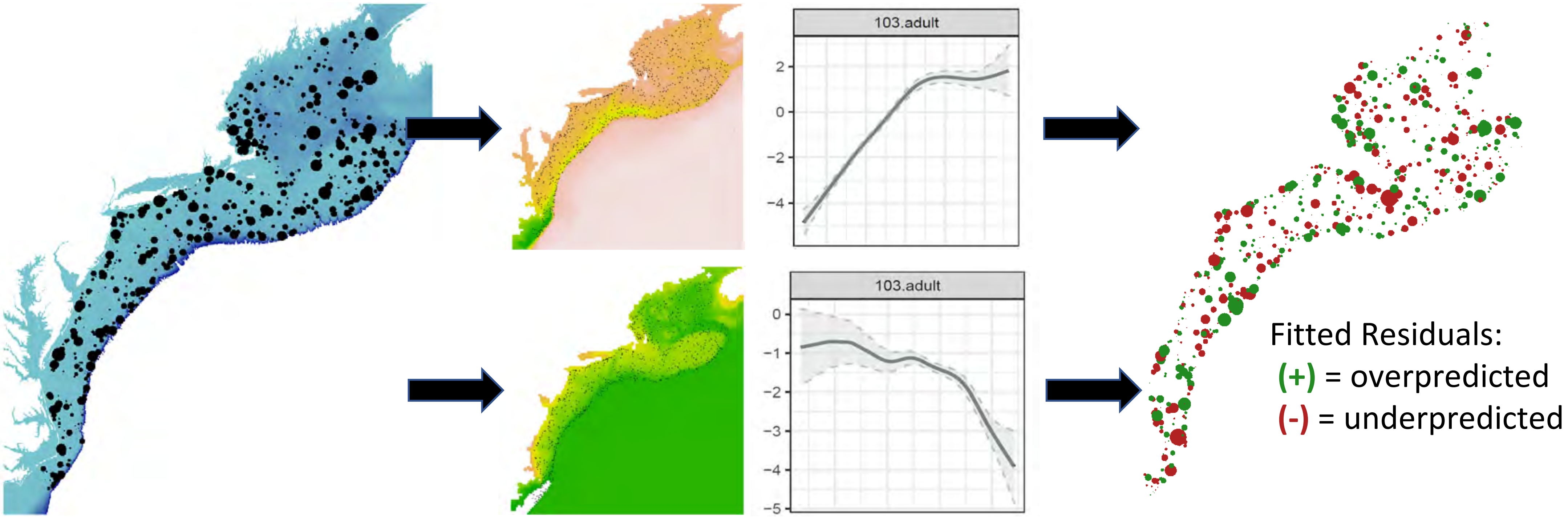


2019 NMFS Bottom Trawl Survey locations

SDMs: A More Mechanistic View of Habitat?

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

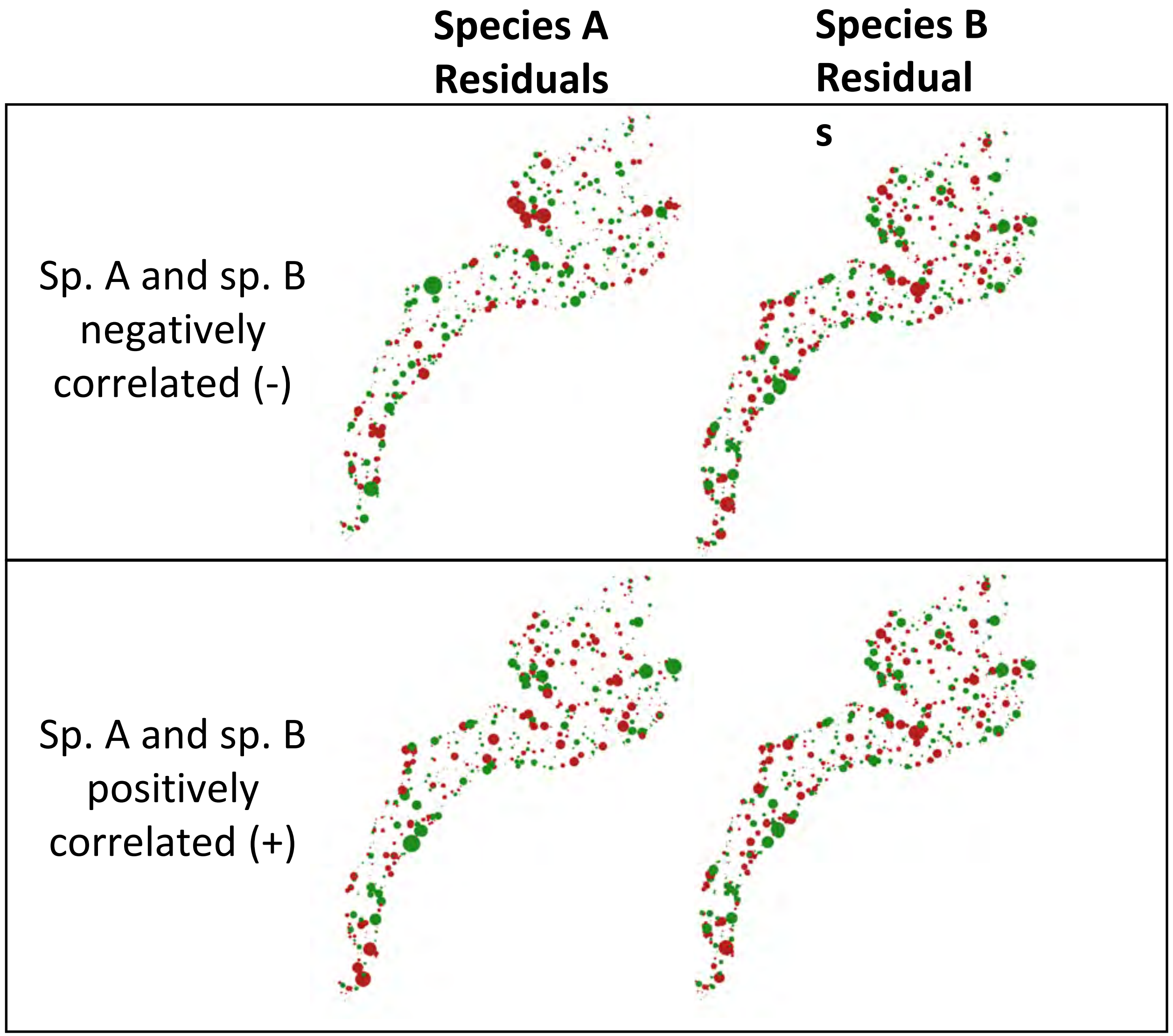
"Environmental filters"



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

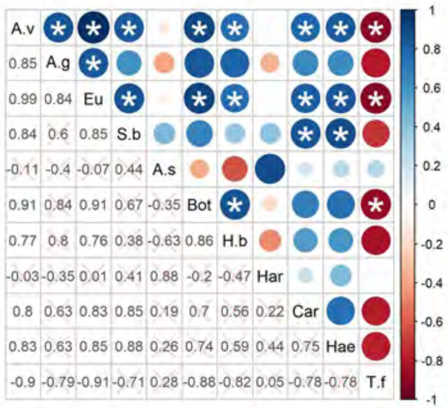
Joint SDMS: Making More of Model Residuals

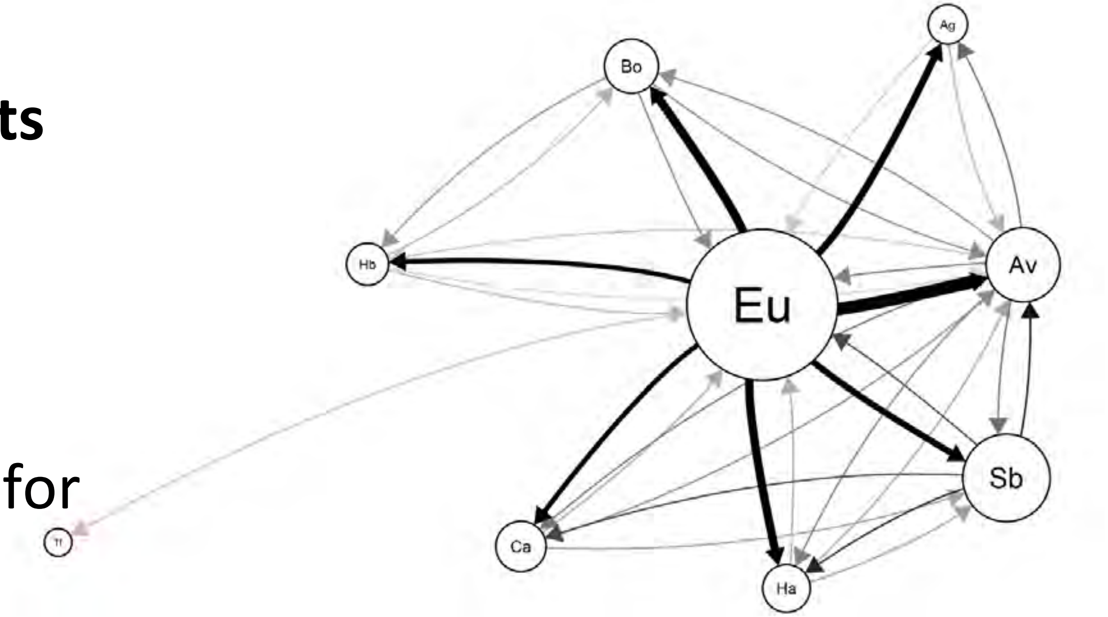
- In single-species SDMs, **residuals = “error”**
- In a multi-species context, the **residual patterns across species contain information**
- Strong correlations in the residuals b/w species may reflect underlying processes (i.e., biotic interactions, missing predictors)
- Joint SDMs model this residual covariance



Joint-species distribution models (JSDMs)

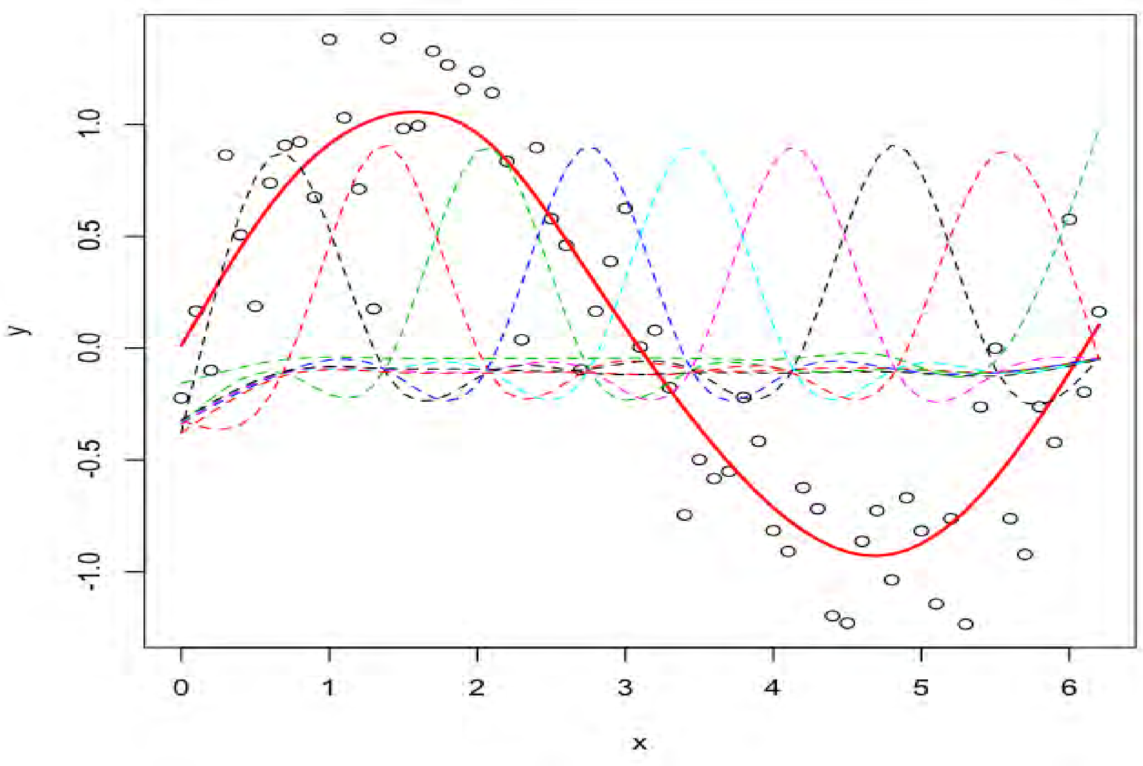
- JSDMs model groups of species together, simultaneously estimating:
  1. Species-environment relationships ("**environmental filtering**")
  2. Species covariation with each other (evidence of **biotic interactions** or **"missing" predictors**)
- **Improved predictions & ecological insights**
  - Better propagation of uncertainty
  - Pooling of information across species to aid estimation
- Computationally expensive – not feasible for large datasets

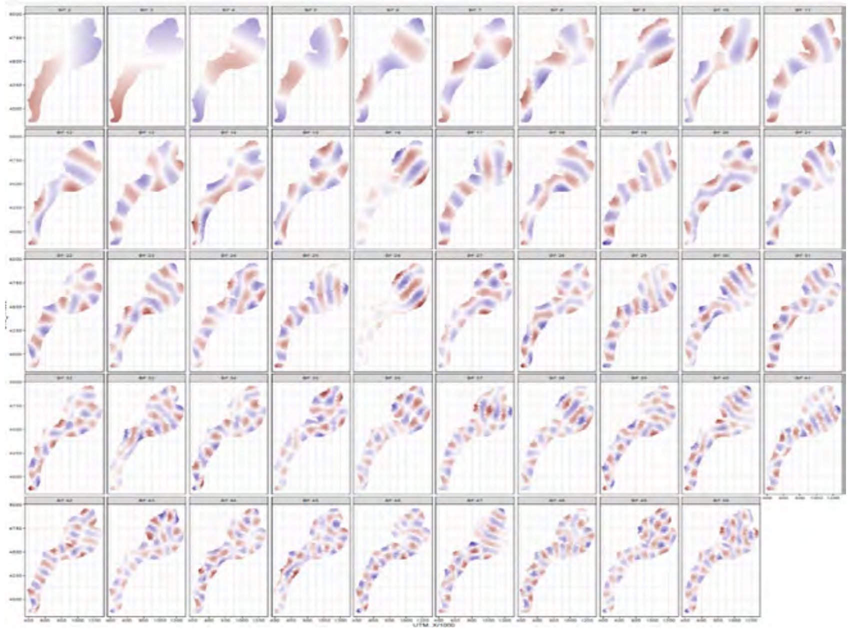




Community-Level Basis Function Model (CBFM)

- **GAMs** model complex species relationships with environmental variables as a linear combination of basis functions ("building blocks")





- CBFM exploits the same "machinery" that GAMs use to model species responses to the environment, but also to (flexibly and efficiently) model covariance in space and time

CBFM: Development & Proof of Concept

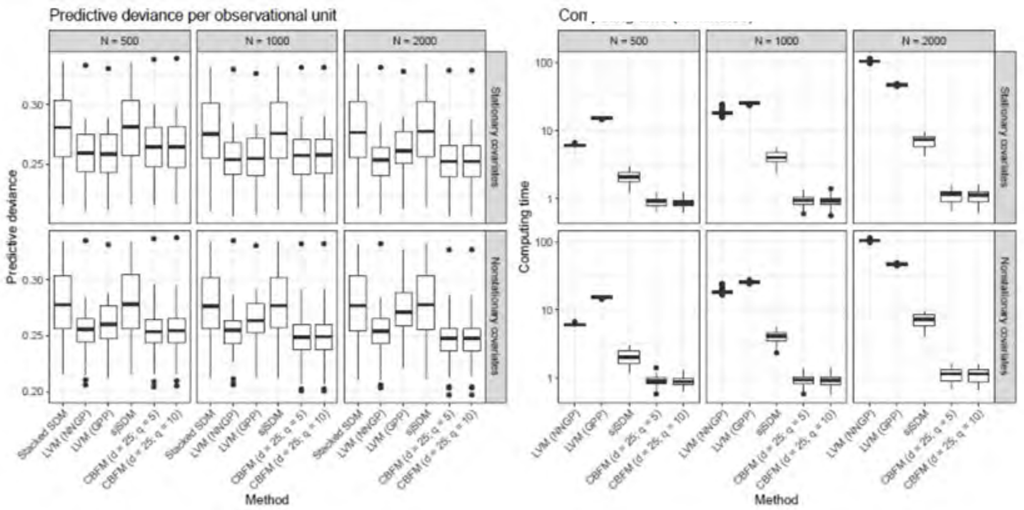
- **Methods manuscript** (MEE)
  - Simulation studies
- **R package**
  - Github repository
  - June Public release

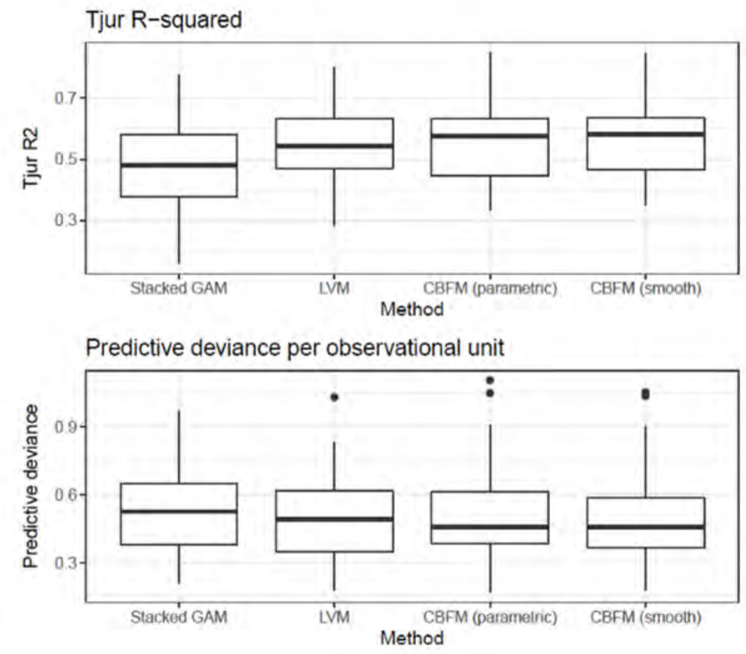
GitHub

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]

[1]Research School of Finance, Actuarial Studies and Statistics, The Australian National University, Canberra, Australia
[2]School of Mathematics and Statistics, The University of New South Wales, Sydney, Australia
[3]Data61, Commonwealth Scientific and Industrial Research Organization, Hobart, Australia
[4]Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, Australia
[5]Northeast Fisheries Science Centre, National Oceanic and Atmospheric Administration, Highlands NJ, USA

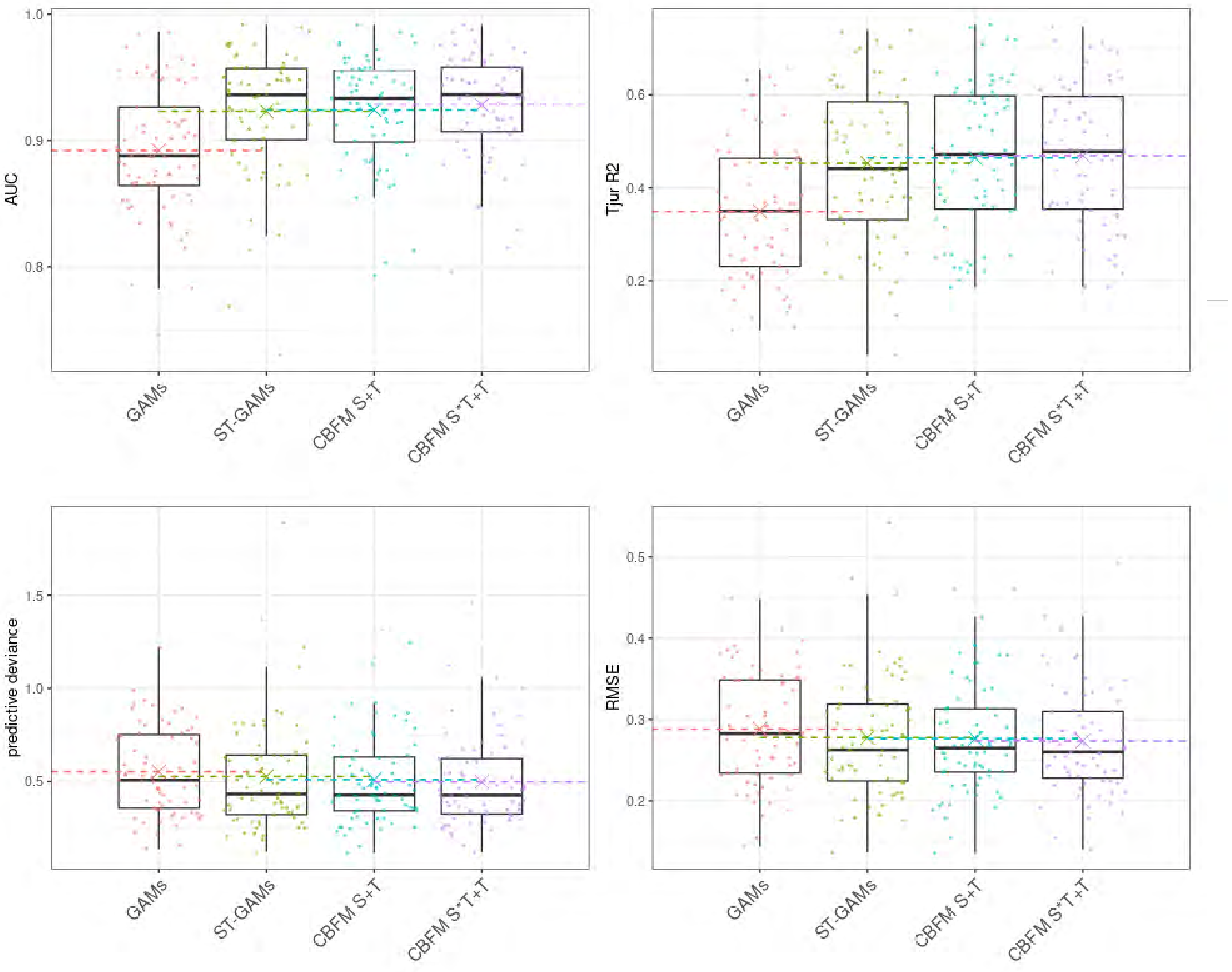




- Performs as well or better than existing methods, but with drastic speed improvements

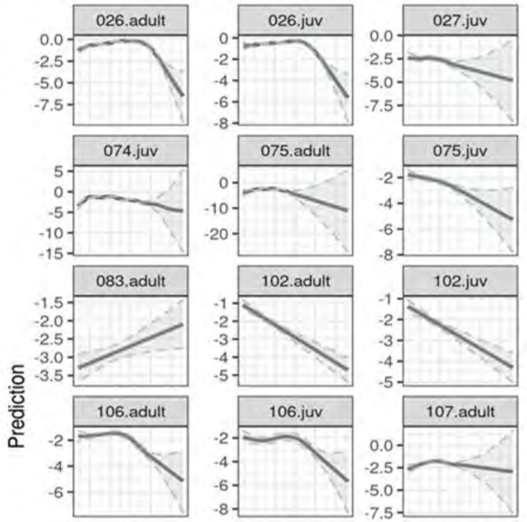
CBFM: NRHA Application

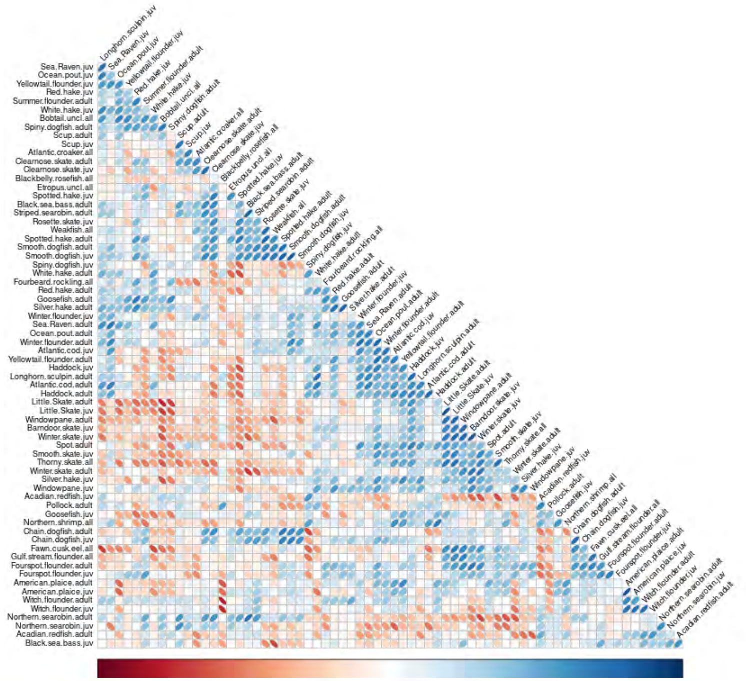
- Abundance of 91 spp-stages from NMFS-BTS (Spring & Fall)
  - Demersals & pelagics, managed, common, & prey
  - Training 2000-2014 (n > 9000)
  - Testing 2015-2019 (n > 2000)
- 14 predictor variables
- Outperforms stacked single-species GAMS in out-of-sample prediction
  - Biggest gains are for lower-performing species

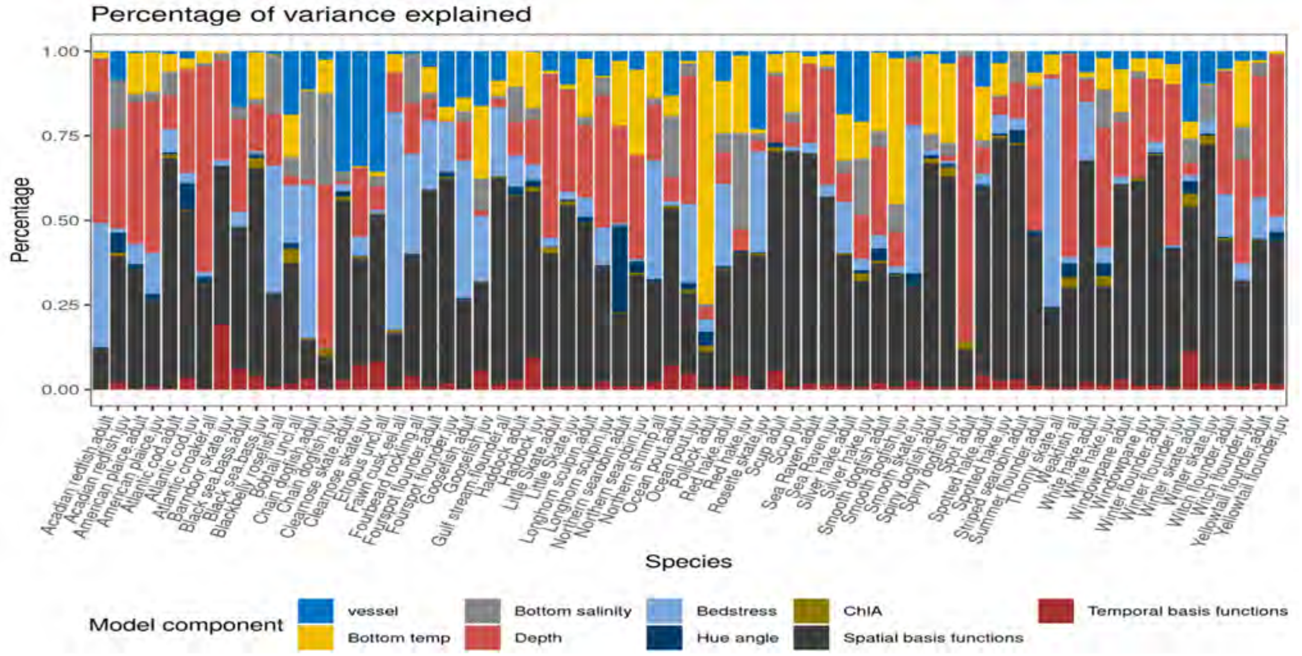


CBFM: NRHA Application - Products

- Community-level predictions
  - Conditional on other spp
- Niche estimates
- Identify the relative importance of different predictors for each species
- Residual correlations b/w species that may help to understand underlying ecosystem dynamics







CBFM: Next Steps

- Visualize results and share with stakeholders via online portals
- Apply projections from climate models to explore potential long-term shifts in habitat use and changes to local assemblage structure
- Aggregate response data from multiple surveys (NMFS, NEAMAP, DFO) to improve models for poorly-sampled or rare species and expand spatial coverage
- Further develop modeling framework to include time-varying BFs with autoregressive structure (to infer non-symmetric correlations?)

Thanks to Francis K.C. Hui and the whole NRHA team