NOAA FISHERIES

NEFSC

Climate induced shifts in historical and future distributions of marine species on the Northeast Shelf

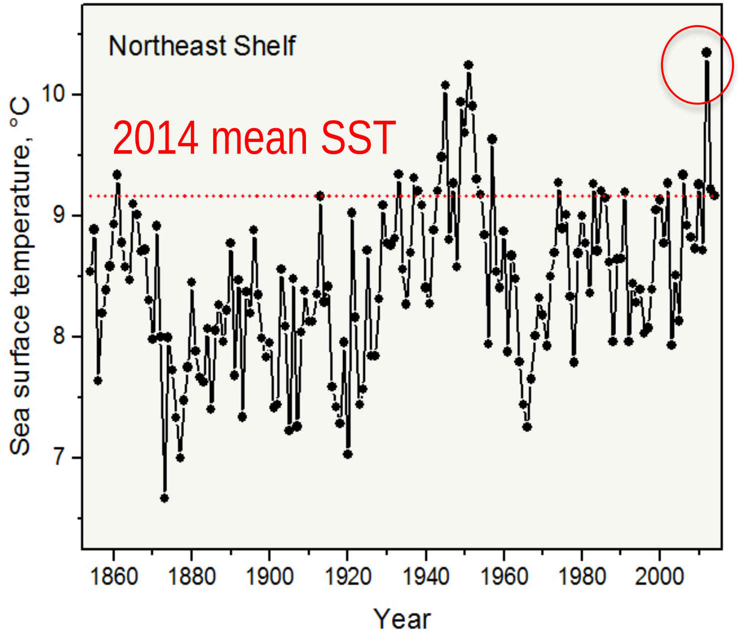
Kristin M. Kleisner

NEFSC Ecosystem and Climate Science Program Review

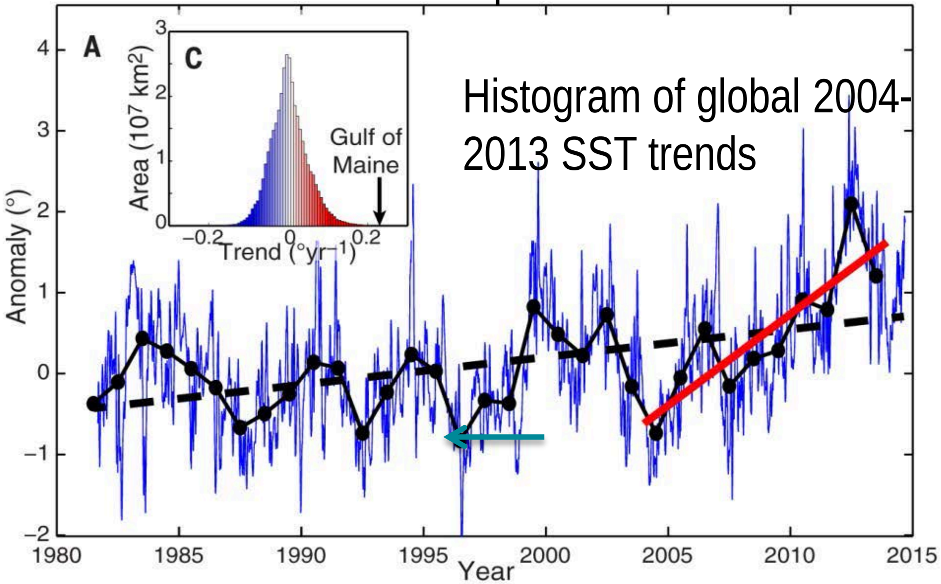
Climate Research Session

June 7, 2016

Climate on the NE Shelf: Things are warm…

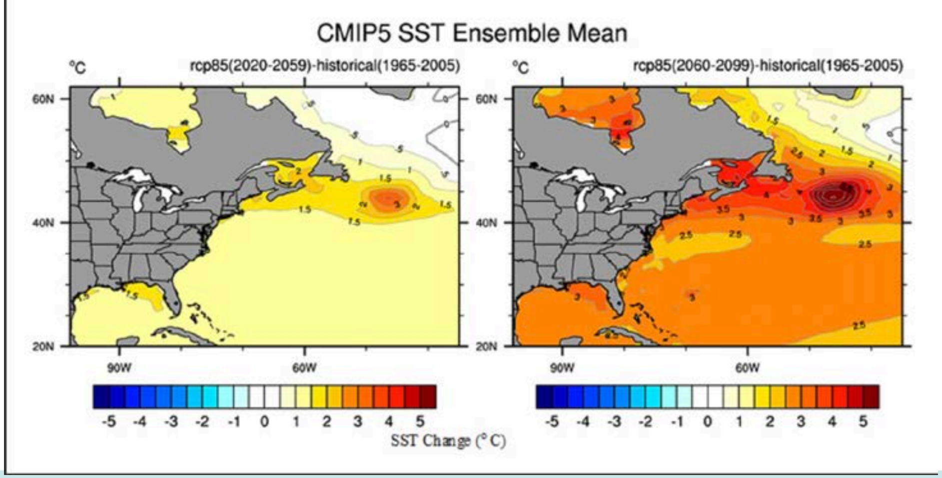


Gulf of Maine temperatures



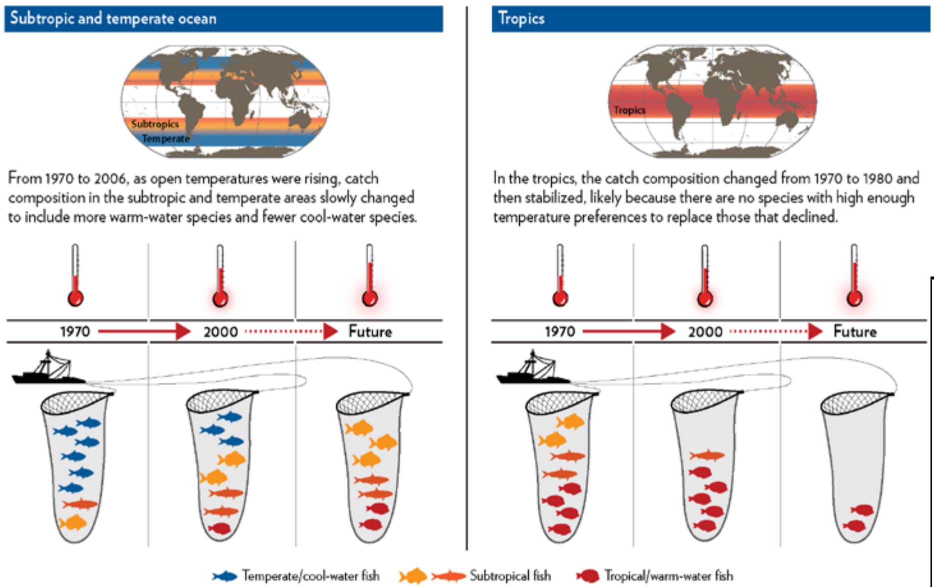
Credit: Pershing et al. 2015, *Science*

…and predicted to get warmer



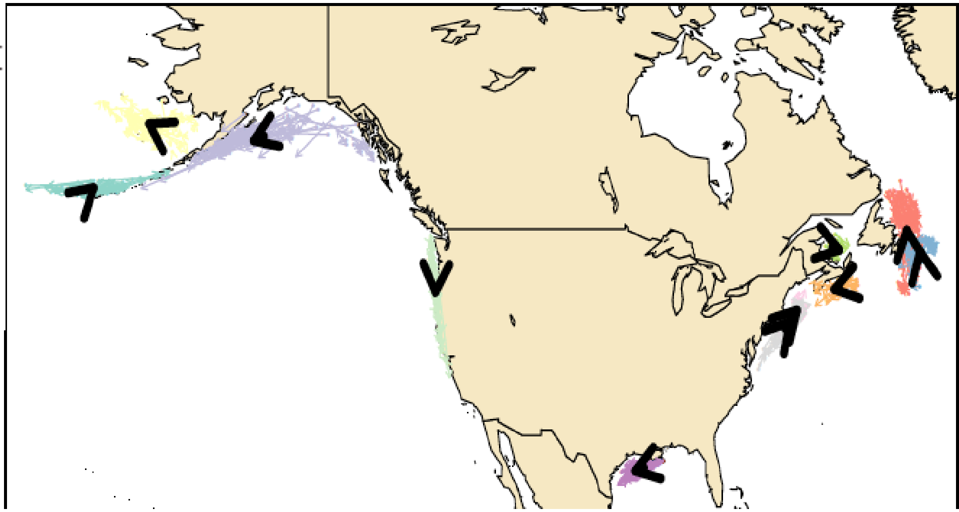
Wide variation in range shift direction

On average, many poleward shifts noted



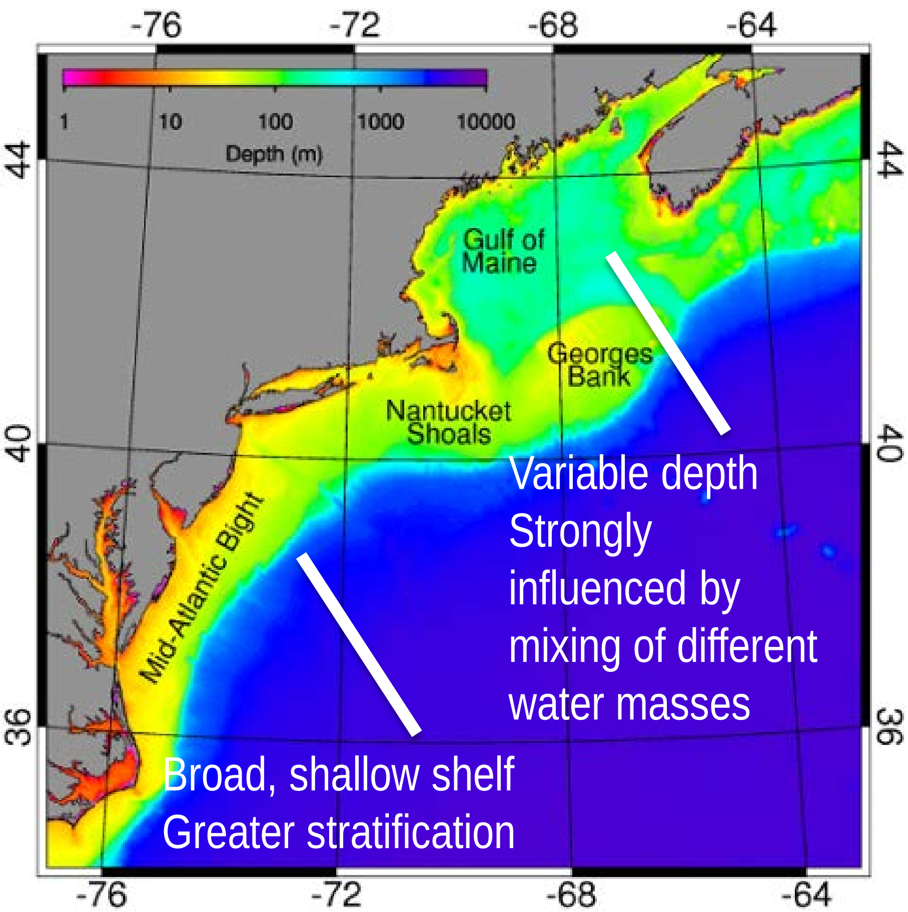
Credit: Cheung et al. 2013, *Nature*

But, regionally, patterns may vary



Credit: Pinsky et al. 2013, *Science*

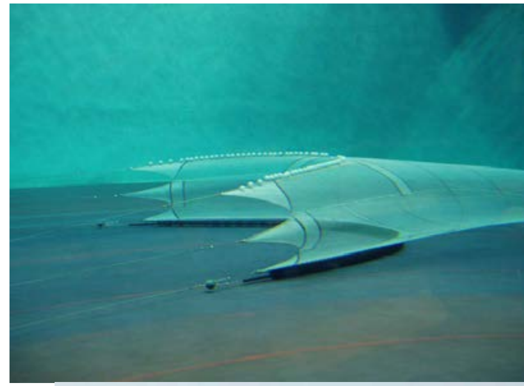
Project goals



- Phase I: Kleisner et al. 2016, *Plos One*
  - Define assemblages of demersal species based on 'realized' niche → habitat/oceanographic conditions
  - Looked at the Gulf of Maine versus southern NE Shelf
  - Explore shifts of species assemblages over the trawl survey time period
  - Explore how species assemblages track the shift of temperature isotherms: "climate velocity"
- Phase II: Kleisner et al. In Prep.
  - Forecast species suitable thermal habitat across the NE Shelf using a high resolution climate model to explore patterns

Data Source: NEFSC Bottom trawl surveys

- Long (almost 50 year) sample taken in spring and autumn
  - 1968-2013
  - Approx. 80 species
  - Surface and bottom temps/salinity
  - Lat/Long and depth
- Stratified Random Design
  - Random stations within geographic strata defined by depth and habitat



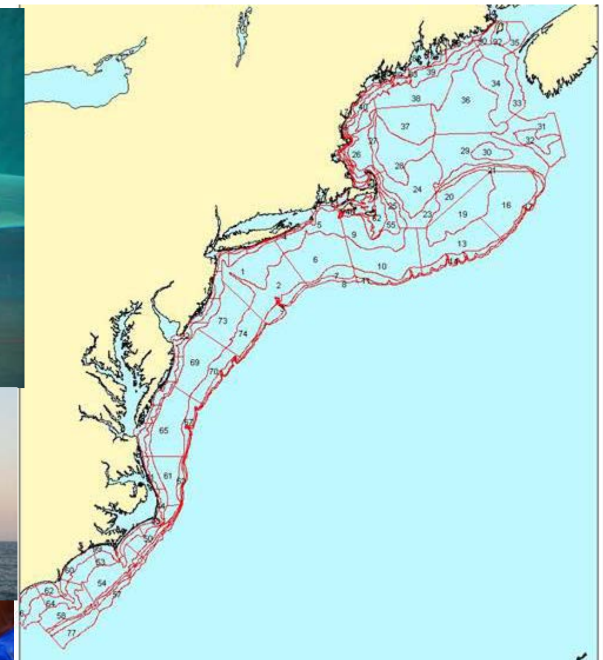
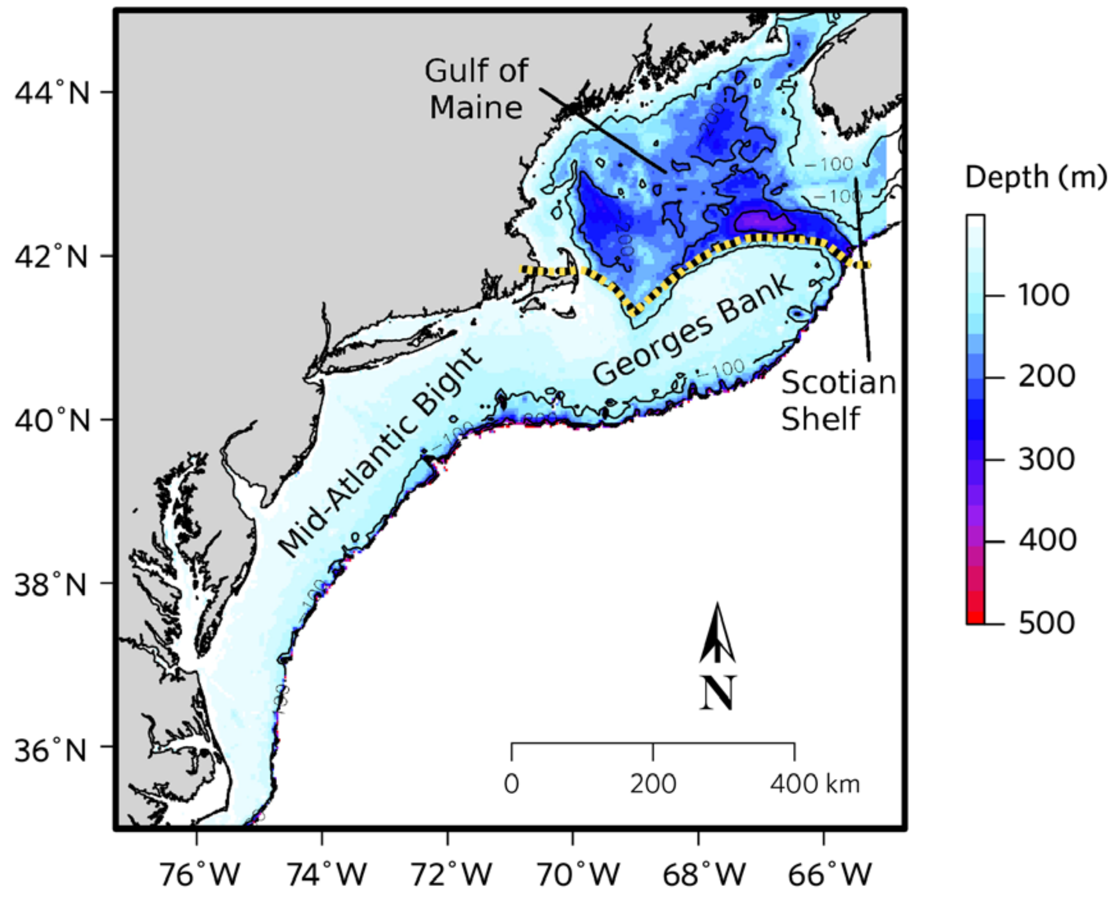


Photo credits: NEFSC/NOAA

Study region

- *North*: Gulf of Maine (GOM)
  - Variable depth, strong mixing
- *South*: Georges Bank (GB) and Mid-Atlantic Bight (MAB)
  - Broad shallow shelf, stratified, warmer waters
- Define 4 assemblages per season and region for 4 time periods
  - 1968-1978, 1979-1989, 1990-2000, 2001-2012
  - Bottom and surface temperature and depth



Core species—north

'Core' species: cluster together by both methods in at least three of the four periods

Assemblage 1

Shallow/warm water:
- Alewife
- American lobster
- Atlantic mackerel
- Blueback herring
- Little skate
- Longfin squid
- Scup
- Windowpane flounder
- Winter flounder
- Winter skate
- Yellowtail flounder

Assemblage 2

Coastal/offshore waters:
- American plaice
- American shad
- Haddock
- Red hake
- Spiny dogfish
- Wolffish

Assemblage 3

Mid- to deep waters over soft bottom:
- Barndoor skate
- Monkfish
- Silver hake
- White hake
- Witch flounder

Assemblage 4

Bathypelagic (deep) and cold water:
- Blackbelly rosefish
- Smooth skate

Deeper and colder

Core species—south

Shallow/warm water:

Atlantic croaker
Banded drum
Black seabass
Bluefish
Bluntnose stingray
Bullnose stingray
Clearnose skate
Cownose ray
Cravelle jack
Northern kingfish
Northern puffer
Northern sea robin
Pig fish
Pin fish
Roughtail stingray
Scup
Sharpnose shark
Smooth dogfish
Southern stingray
Spiny butterfly ray
Spot
Striped burrfish
Striped sea robin
Summer flounder
Tautog
Weakfish
Windopane flounder

Coastal/offshore waters:

Alewife
American shad
Atlantic cod
Atlantic herring
Barndoor skate
Butterfish
Fourspot flounder
Longhorn sculpin
Red hake
Sea raven
Sea scallop
Silver hake
Spiny dogfish
Wolffish

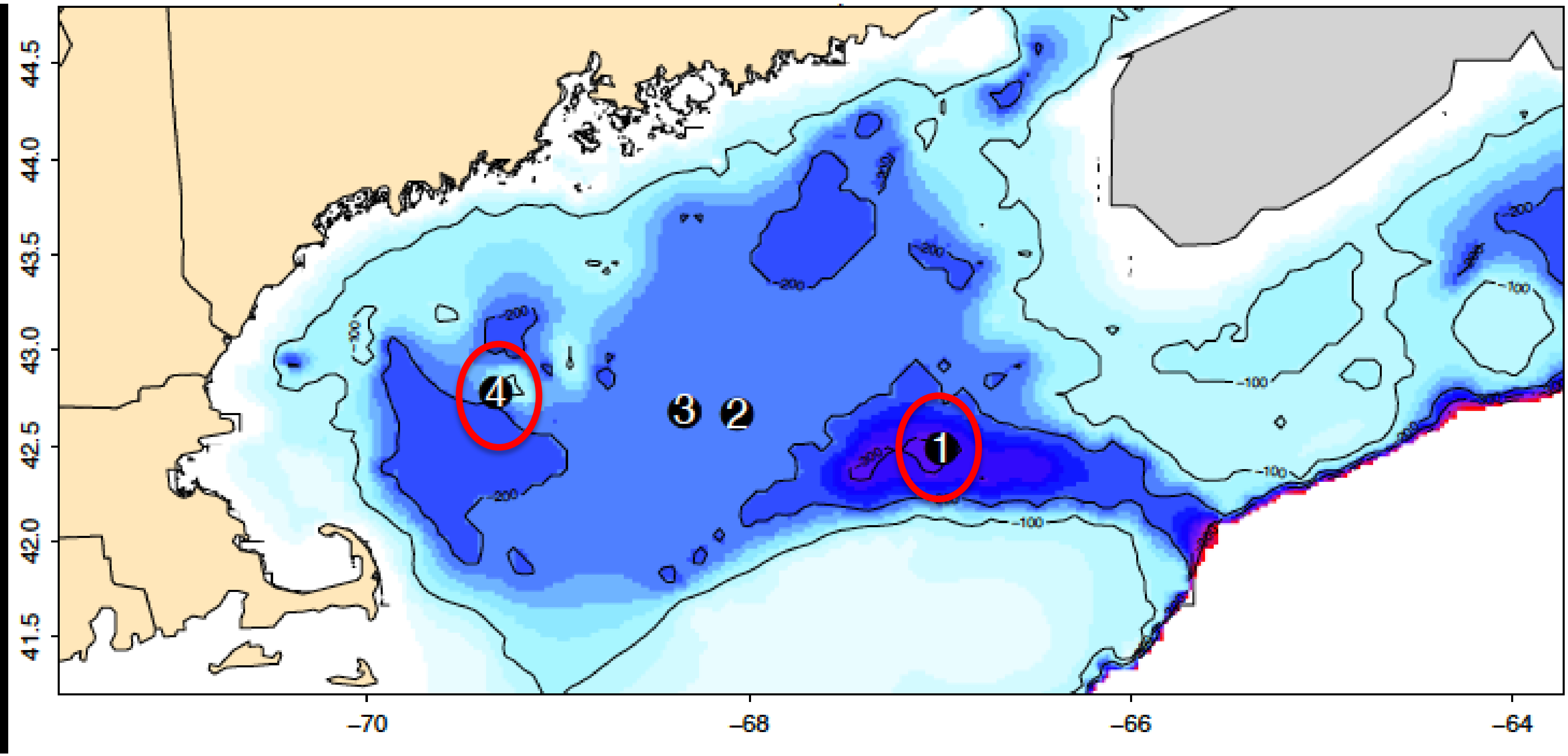
Mid- to deep waters over soft bottom:

American lobster
American plaice
Monkfish
Rosette skate
Shortfin squid
Thorney skate
White hake

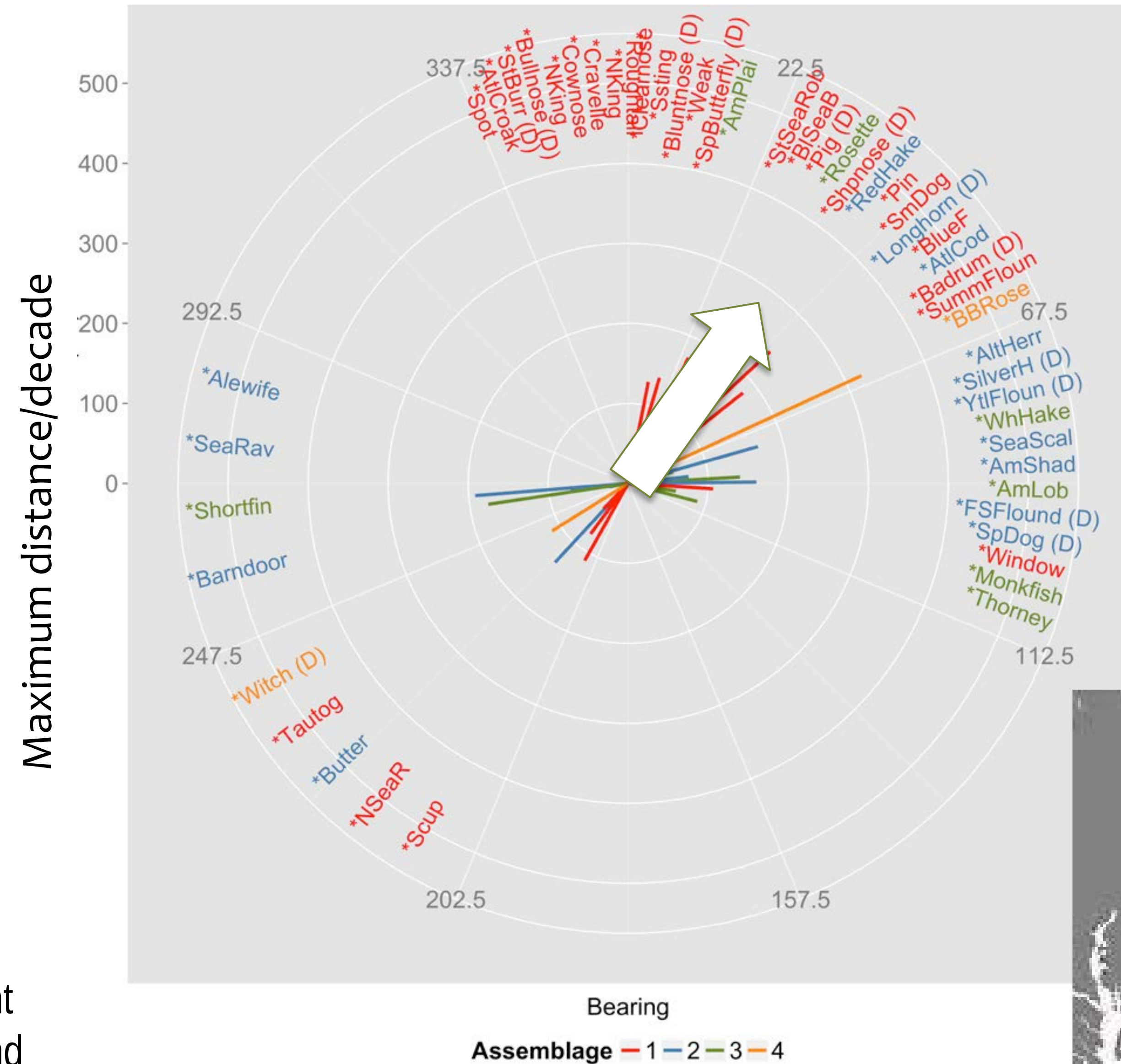
Deep and cold water:

Blackbelly rosefish
Witch flounder

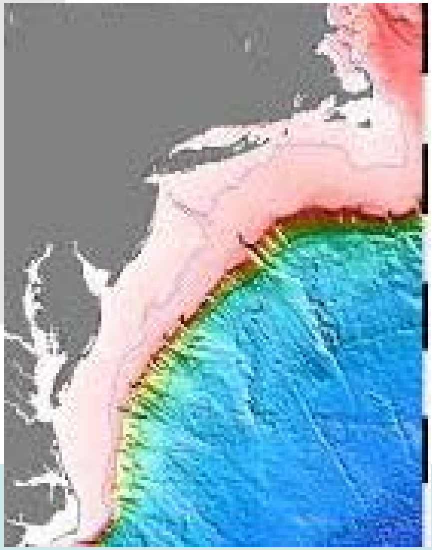
Identifying COBs over time: biomass-weighted mean lat-long



Fall, Mid-Atlantic Bight/Georges Bank



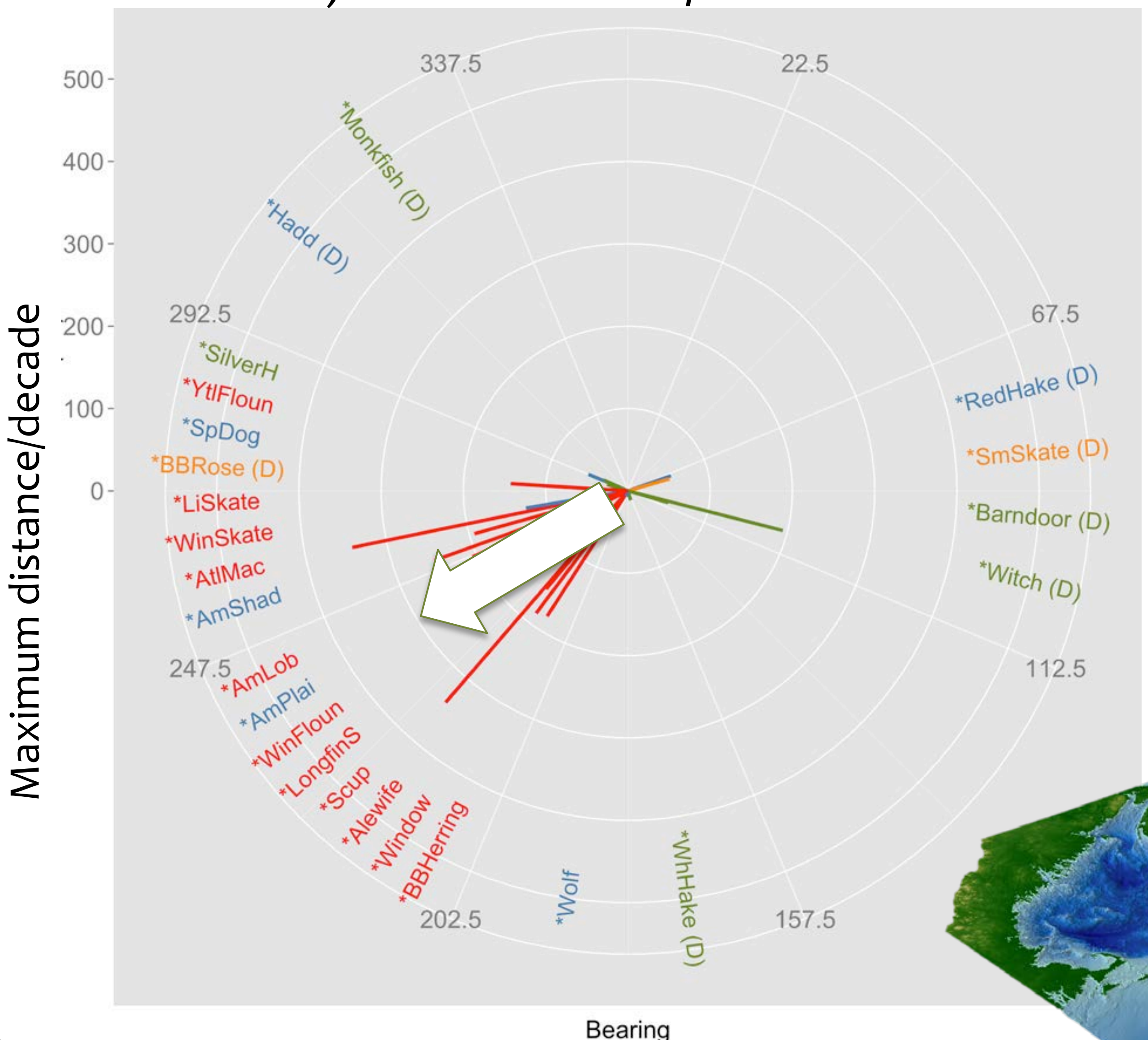
(D) = significant deepening trend

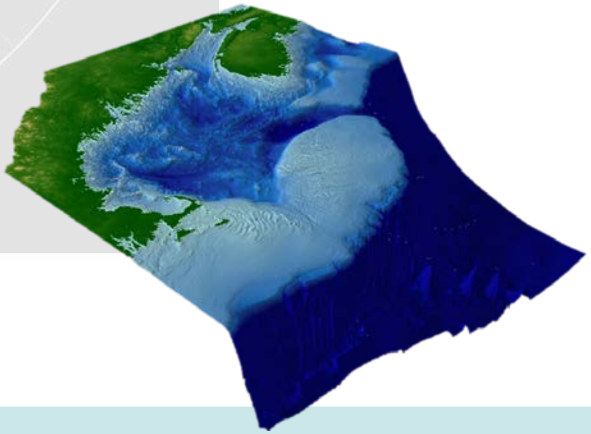


Average vector direction: 38 (NE)

NOAA FISHERIES

Fall, Gulf of Maine/Scotian Shelf





(D) = significant deepening trend

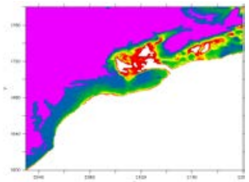
Average vector direction: 238 (WSW)

Phase II

Goal: make (relatively) long-term projections of species distributions based on climate scenarios from a high resolution model

Climate Modeling

High resolution Climate model



Downscaling

Surface and bottom temps

Species Niche Modeling

Occurrence

Niche model: GAM

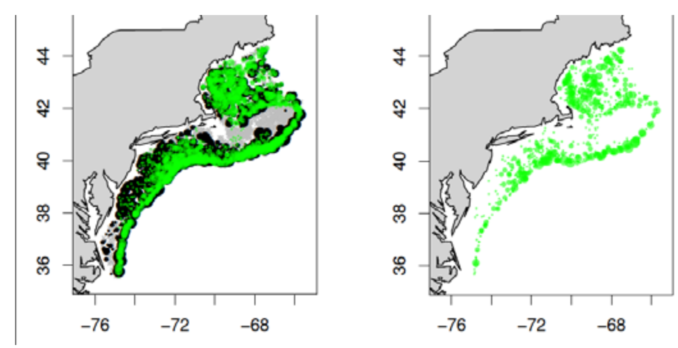
Strata & mean abundance

Projections

Projections: dynamic and static fields

Analysis

Assess impacts to assemblage distribution

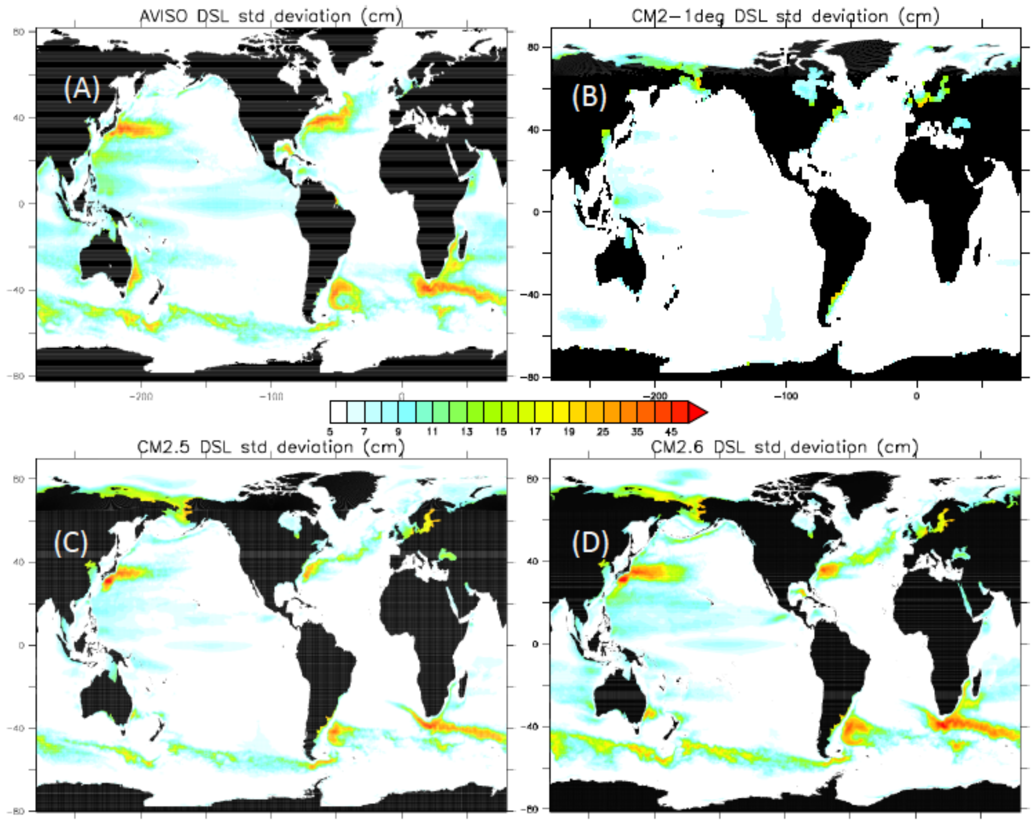


GFDL climate model suite

Temporal standard deviation in dynamic sea level (DSL)

AVISO (Archiving, Validation, and Interpolation of Satellite Oceanography)

CM 2.1



CM 2.5

CM 2.6

Griffies et al. 2015

Model	Ocean (ice)	Atmosphere (land)
CM 2.1	1°	2°
CM 2.5 FLOR	1°	0.5°
CM 2.5	0.25°	0.5°
CM 2.6	0.1°	0.5°

Niche models: GAMs

Delta log-normal model—2 component models—calculated GAMs for each species:

Suitable thermal habitat:

P(Presence/Absence) ~

s(Bottom temperature) +
s(Surface temperature) +
depth +
stratum +
rugosity* +

e ~ Binomial(n,p)

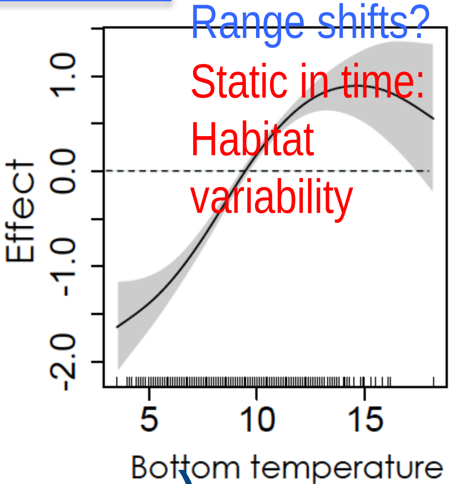
E(log(Biomass|Presence) ~

s(Bottom temperature) +
s(Surface temperature) +
depth +
stratum +
rugosity* +

e ~ Gaussian()

Dynamic temperature variables: Range shifts?

Static in time: Habitat variability



P(presence/absence) x E(log(biomass|presence)

*Riley et al 1999: Terrain Ruggedness Index

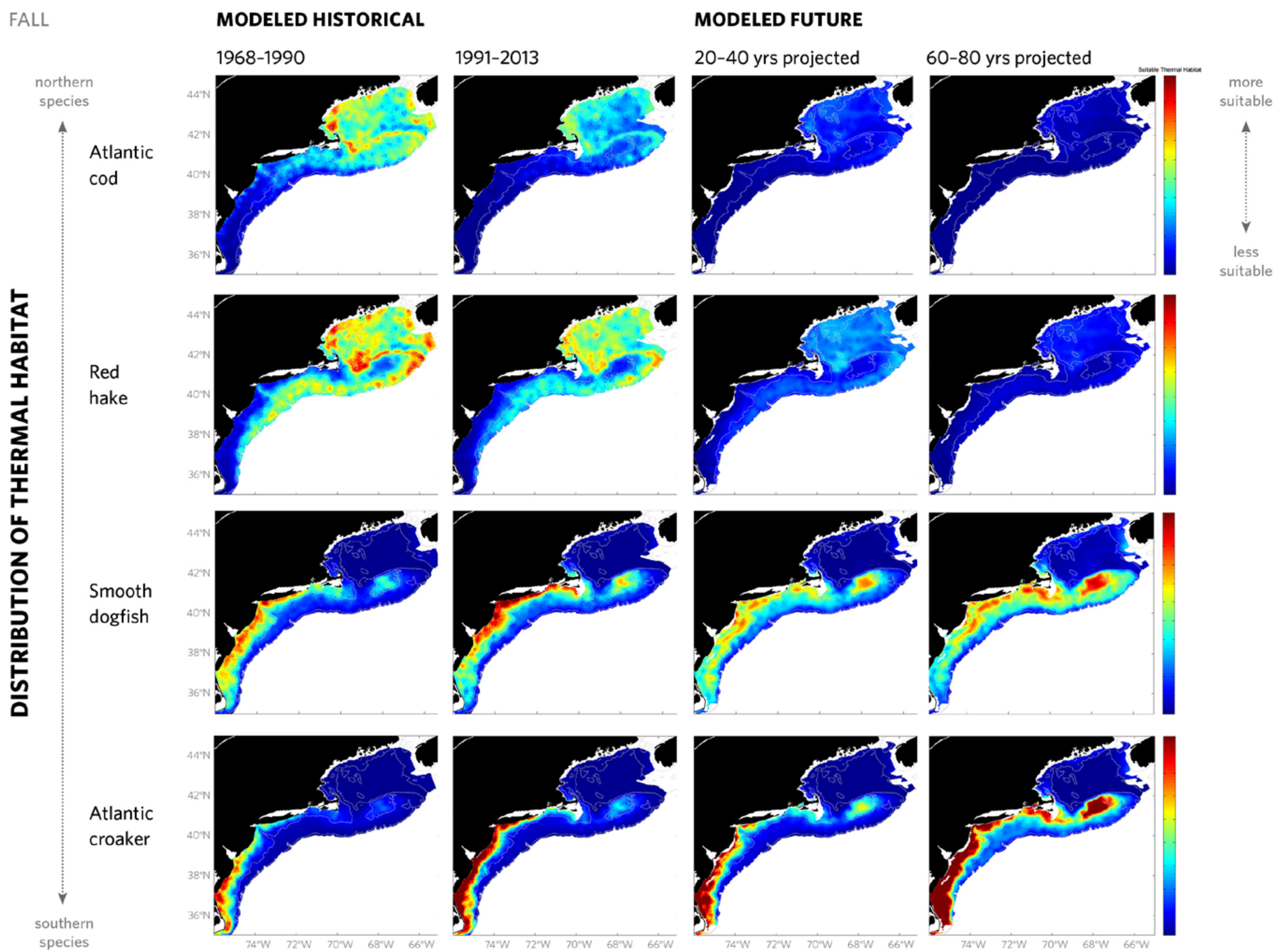
Thermal 'envelope' from GAMs

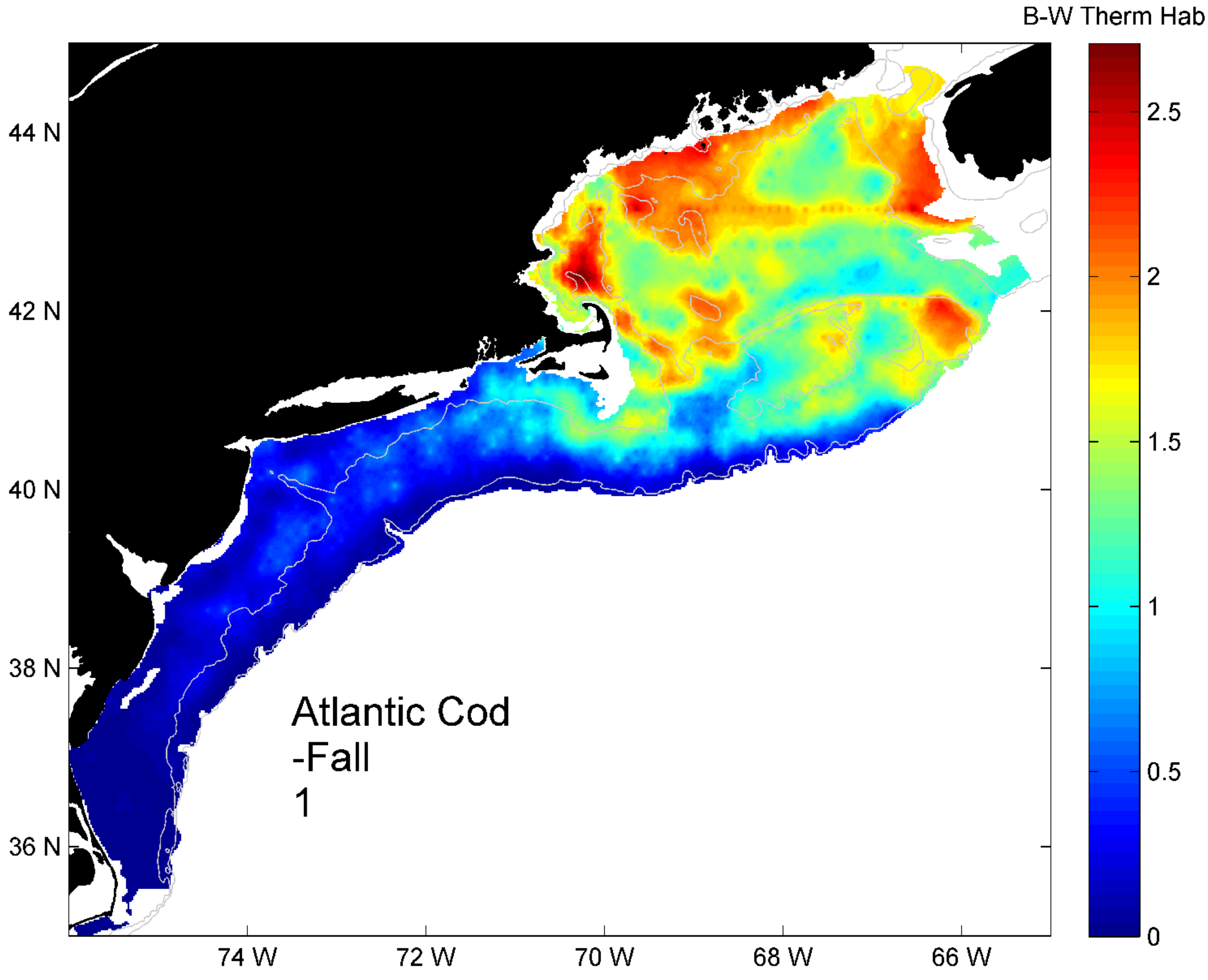
Do GAMs with environmental variables give better long-term predictions than naive models?

- Naïve model: random walk model with drift
- Split observed time series:
  - Training set (1968 – 2001)
  - Test set (2002 – 2013)
- First use training set to fit naïve model and GAM over training period
- If good fit, then use the training set to predict the test set
- How well do the predictions match our observed values in 2002 through 2013?

Assumptions

- Can only assess changes in distributions that may be likely due to temperature changes under CM scenario of doubling CO_2 in 70 years
- We assume:
  - No changes in fishing effort
  - No changes in habitat quality
  - No changes in species interactions
  - …
- Only looking at change potential given changes in temperature
- Forecasts useful for understanding general patterns and for informing adaptive management strategies


FALL
MODELED HISTORICAL
MODELED FUTURE
1968-1990
1991-2013
20-40 yrs projected
60-80 yrs projected
northern species
southern species
DISTRIBUTION OF THERMAL HABITAT
Atlantic cod
Red hake
Smooth dogfish
Atlantic croaker
more suitable
less suitable
44°N
42°N
40°N
38°N
36°N
74°W
72°W
70°W
68°W
66°W


B-W Therm Hab
2.5
2
1.5
1
0.5
0
44 N
42 N
40 N
38 N
36 N
74 W
72 W
70 W
68 W
66 W
Atlantic Cod
-Fall
1

Overall patterns

- Historical:
  - Exploring the assemblages on a regional basis highlights some different patterns:
    - NE shift in the GB/MAB may be indicative of species shifting poleward to cooler waters
    - SW shift in the GOM/SS may be due to cooler bottom temps in the SW GOM
- Future:
  - Climate winners and losers?
    - Southern species shifting north and increases in suitable thermal habitat
    - Northern species show greater declines in suitable thermal habitat
  - Potentially significant implications for fishing communities as species distributions shift further from traditional fishing locations

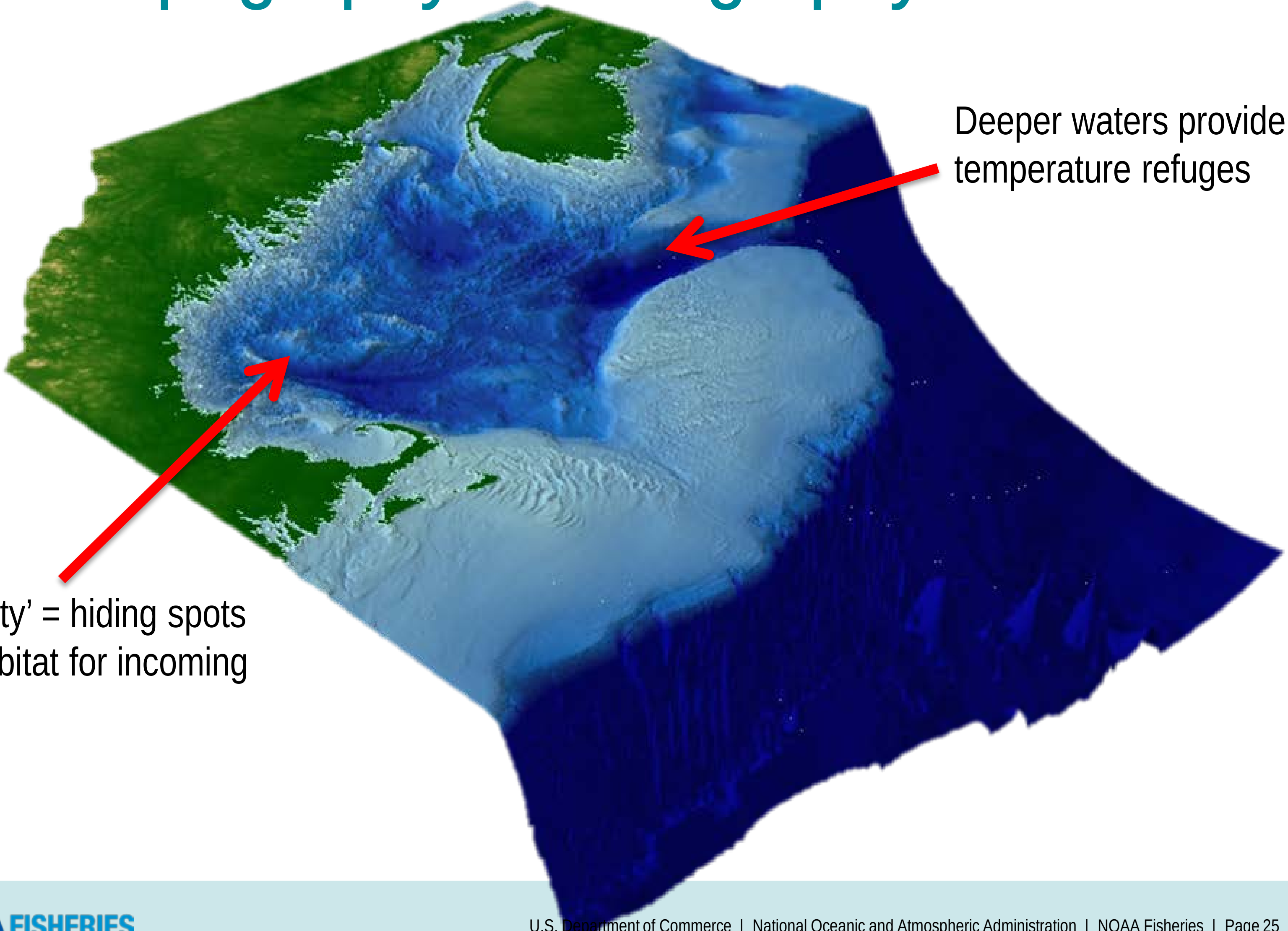
Results are useful for:

- Understanding projected impacts of climate change on distributions of vulnerable fish species
  - Identification of biomass hotspots and areas of high fish biodiversity
- Assessing implications for developing spatial protection strategies in response to climate change
- Evaluating socio-economic and management implications of climate change

Questions?

Co-authors: Mike Fogarty, Sally McGee, Analie Barnett, Paula Fratantoni, Jennifer Greene, Jonathan A. Hare, Sean Lucey, Christopher McGuire, Jay Odell, Charles Peretti, Vincent S. Saba, Laurel Smith, Katherine J. Weaver, Malin L. Pinsky

GOM Species are constrained by geography & variable topography/oceanography



Deeper waters provide temperature refuges

High 'rugosity' = hiding spots and new habitat for incoming species

‘Forecastability’

- Based on the ability of the GAM to predict test samples, use the GAMs to forecast based on temperature projections
- Mean Absolute Scaled Error (MASE): a measure of the accuracy of forecasts used to determine which of the GAMs have forecast potential

$$MASE = \frac{1}{n}\sum_{t=1}^{n}\left(\frac{\left|Y_t - F_t\right|}{\frac{1}{n-1}\sum_{i=2}^{n}\left|Y_i - Y_{i-1}\right|}\right)$$

How good is the forecast?

How good is the naïve prediction?

Assemblage characteristics

Depth and bottom temperature most important for defining assemblages

Assemblage 1 (red): warmer/shallower → Assemblage 4 (yellow): cooler/deeper