Climate-induced shifts in phenology: Case studies of fish, whales, and seabirds in the Gulf of Maine

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USGS science for a changing world

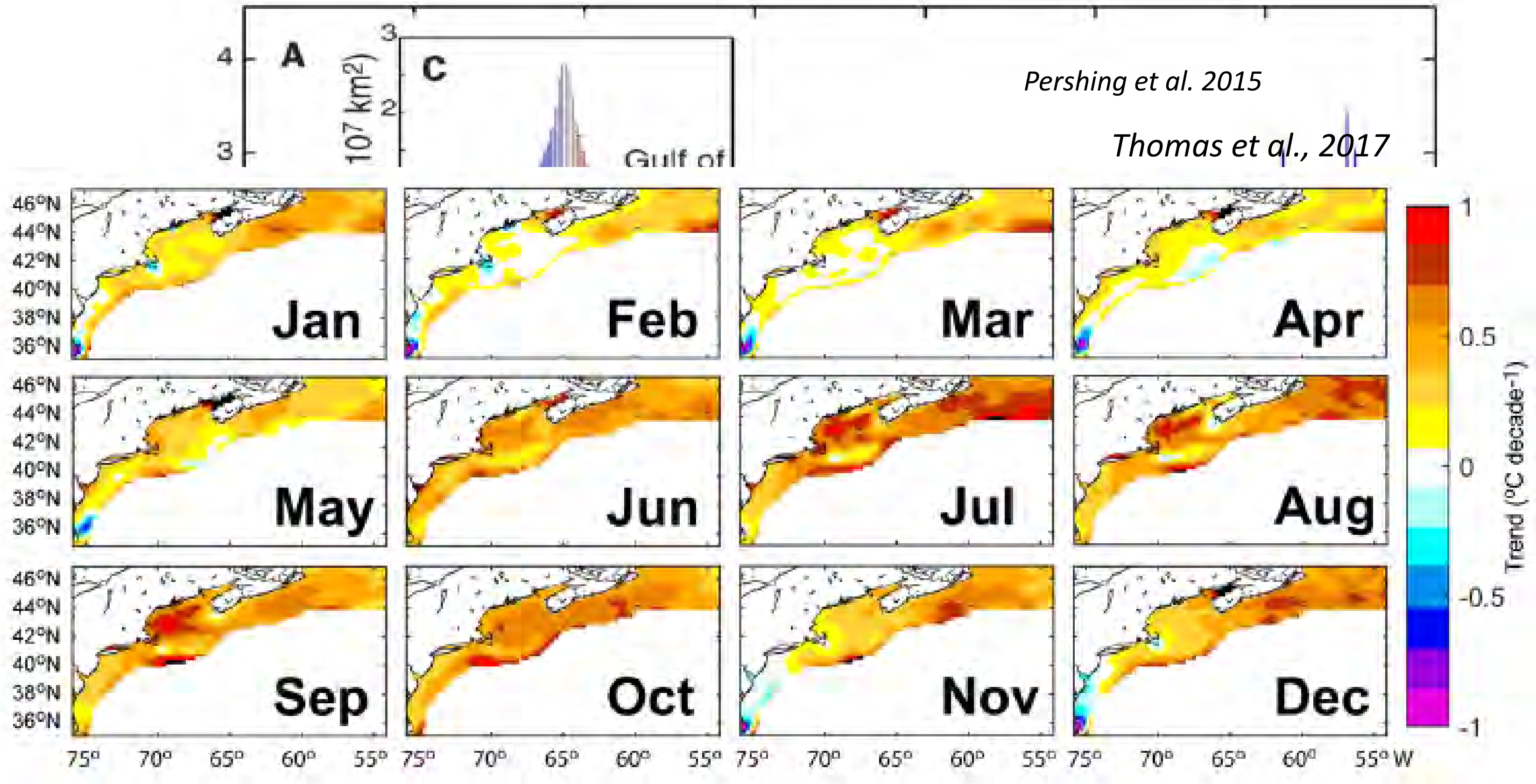
NECSC Northeast Climate Science Center

UMASS AMHERST

Anderson Cabot Center for Ocean Life at the New England Aquarium

Seasonal Warming Trends in the Gulf of Maine

- Warming during all seasons
- Strongest rates in summer (~1.0°C/dec)
- Increased variability in seasonal stratification onset
- Changes in seasonal water mass inputs from NE Channel



Pershing et al. 2015

Thomas et al., 2017

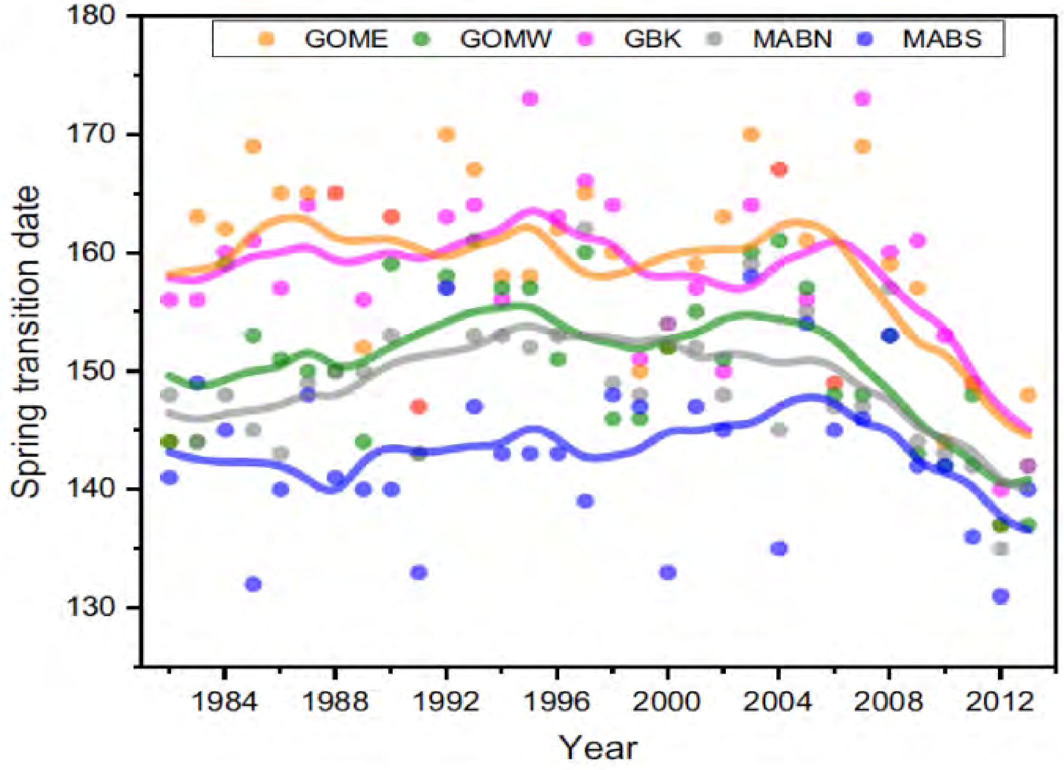
Trends in Seasonal Transitions

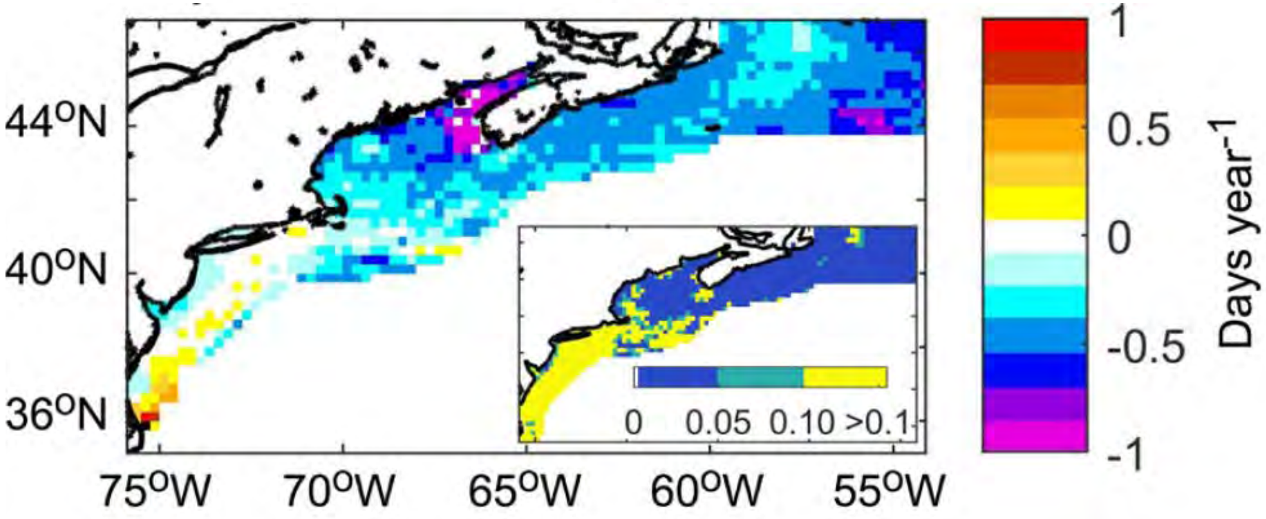
Shifting seasons in the GOM

- Earlier onset of spring (~1 d/yr)
- Earlier summer (~1 d/yr)
- Later fall transition → increased summer duration (>2 d/yr) → decreased winter duration

Primary drivers in seasonal phenology trends:

- NAO
- Gulf Stream position
- Atmospheric pressure
- Air temperatures





Friedland et al. 2015; Thomas et al. 2017

Why Study Phenology in the Gulf of Maine?

- Mismatches/asynchronies
- Altered fitness & productivity
- Population dynamics
- Ecosystem function

- Hotspot of warming
- Highly seasonal system
- Seasonal foraging and breeding/spawning area

Project Objectives

❖ Improve understanding of climate-induced shifts in phenology in the Gulf of Maine

1) **Spring spawning** migration of anadromous alewife (*Alosa pseudoharengus*)
2) **Spring-summer foraging** conditions of nesting seabirds (*Sterna* sp.)
3) **Spring migration** to **foraging** habitats for North Atlantic right (*Eubalaena glacialis*) and fin (*Balaenoptera physalus*) whales

Are earlier springs or other seasonal variables causing shifts in species' phenology?


M. Devine


K. Yakola

Case Study 1: Alewife (*Alosa pseudoharengus*)

Objectives

1) Test for changes in migration timing

2) Identify key drivers of movement patterns

Factors influencing Climate Vulnerability

Climate Vulnerability

Ranking: Highly Vulnerable
Confidence: High
Region: NE Atlantic shelf
Climate scenario: RCP 8.5
Time period: 2005-2055

- Increasing SST and air T
- Ocean acidification

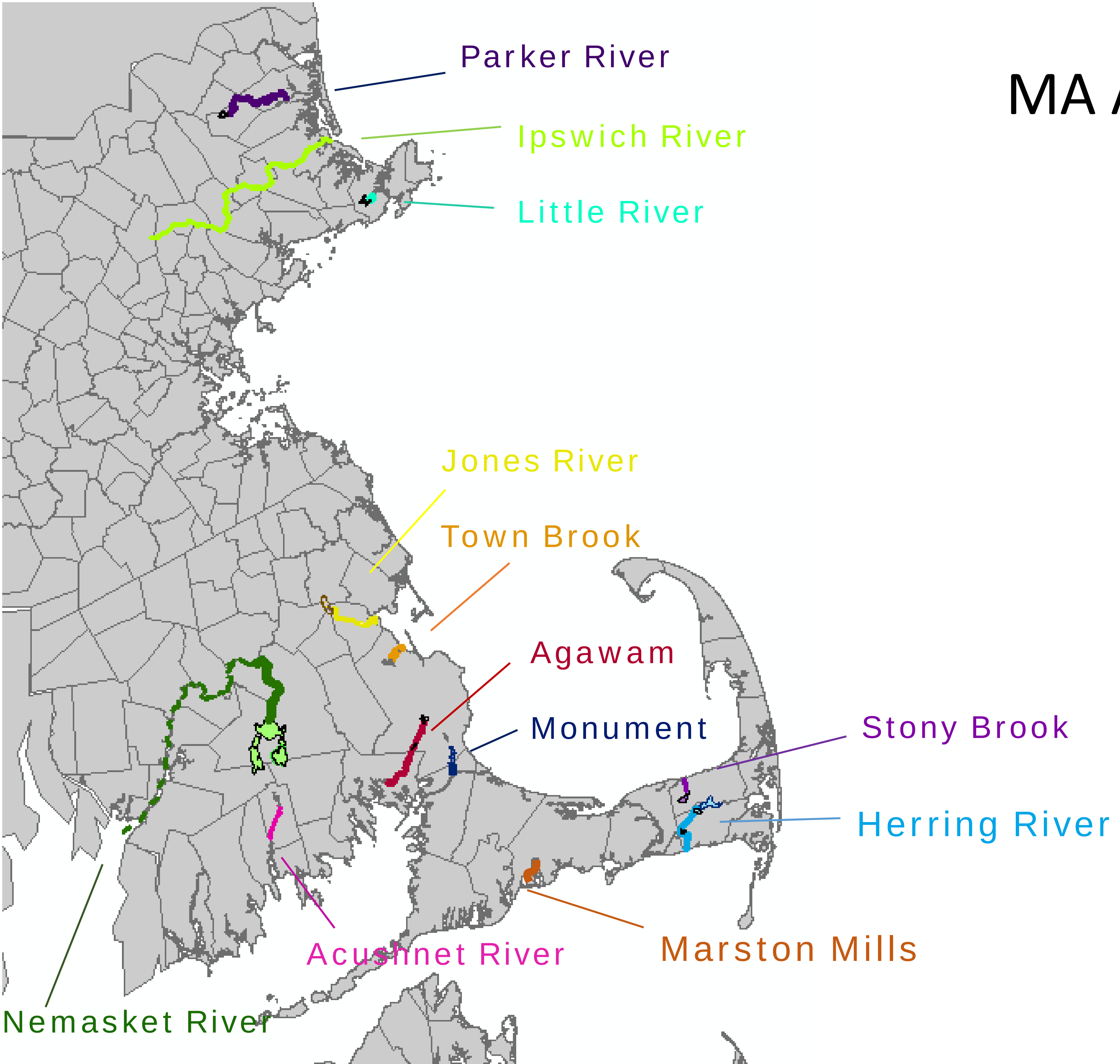
Exposure

- Complex spawning cycle
- Early life history, dispersal requirements

Sensitivity

Attributes from Hare et al. 2016

MA Alewife Spawning Runs



- Daily fish counts, river temps
- 12 locations
- March – June
- 1990 – 2017

Approach

Analyses:

- Linear mixed models (lmerMod) → JD Run initiation

Run initiation ~ Environmental Parameters + annualcount + (1|loc) + (1|year)

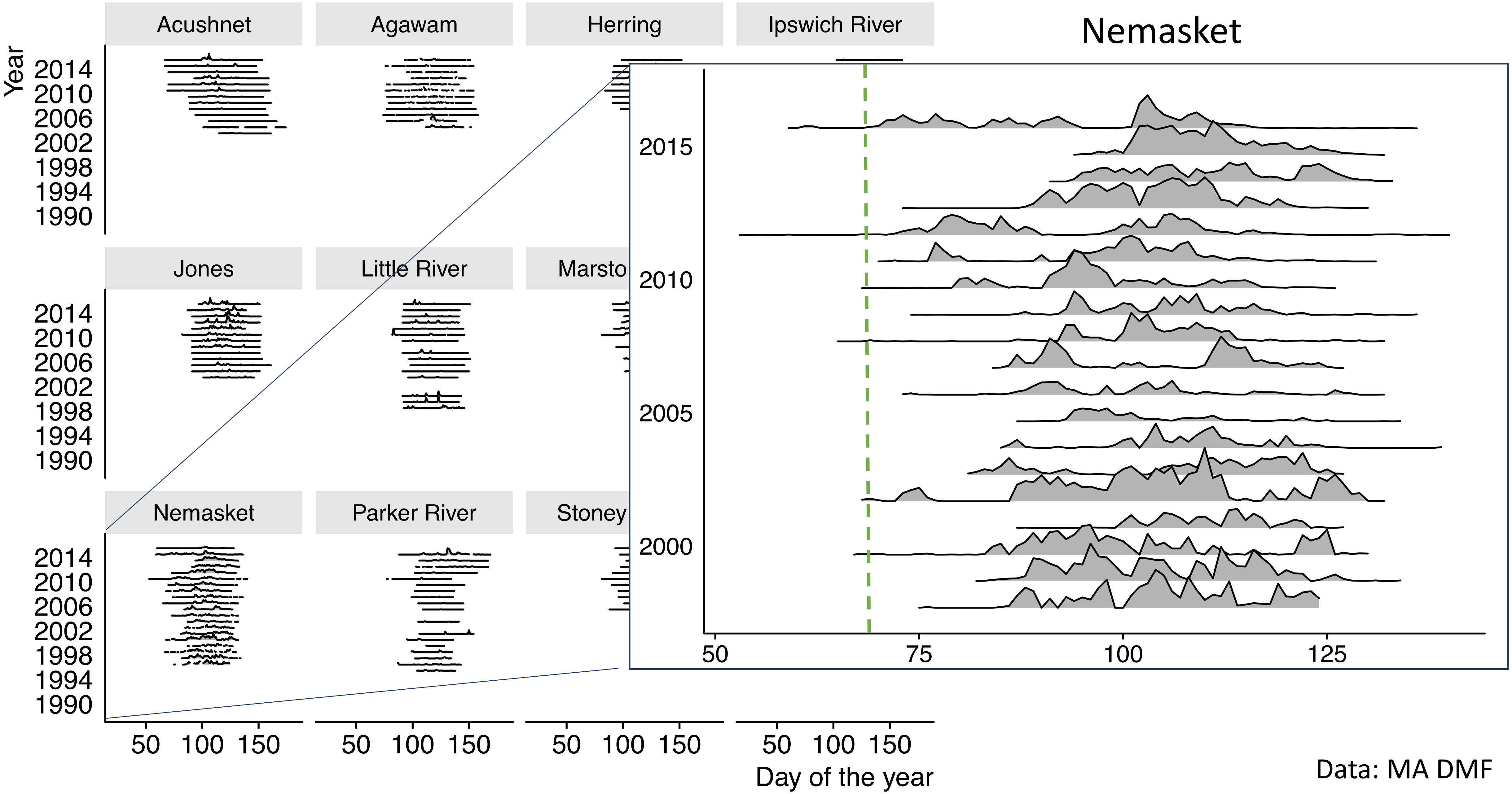
Environmental Parameters ↓
Spring and Fall TDs
Daily T (stream, estuary, ocean)
Daily stream flow
Max T (JD)
Lunar phase
Annual NAO

annualcount ↓
Run strength

(1|loc) ↓
12 sites

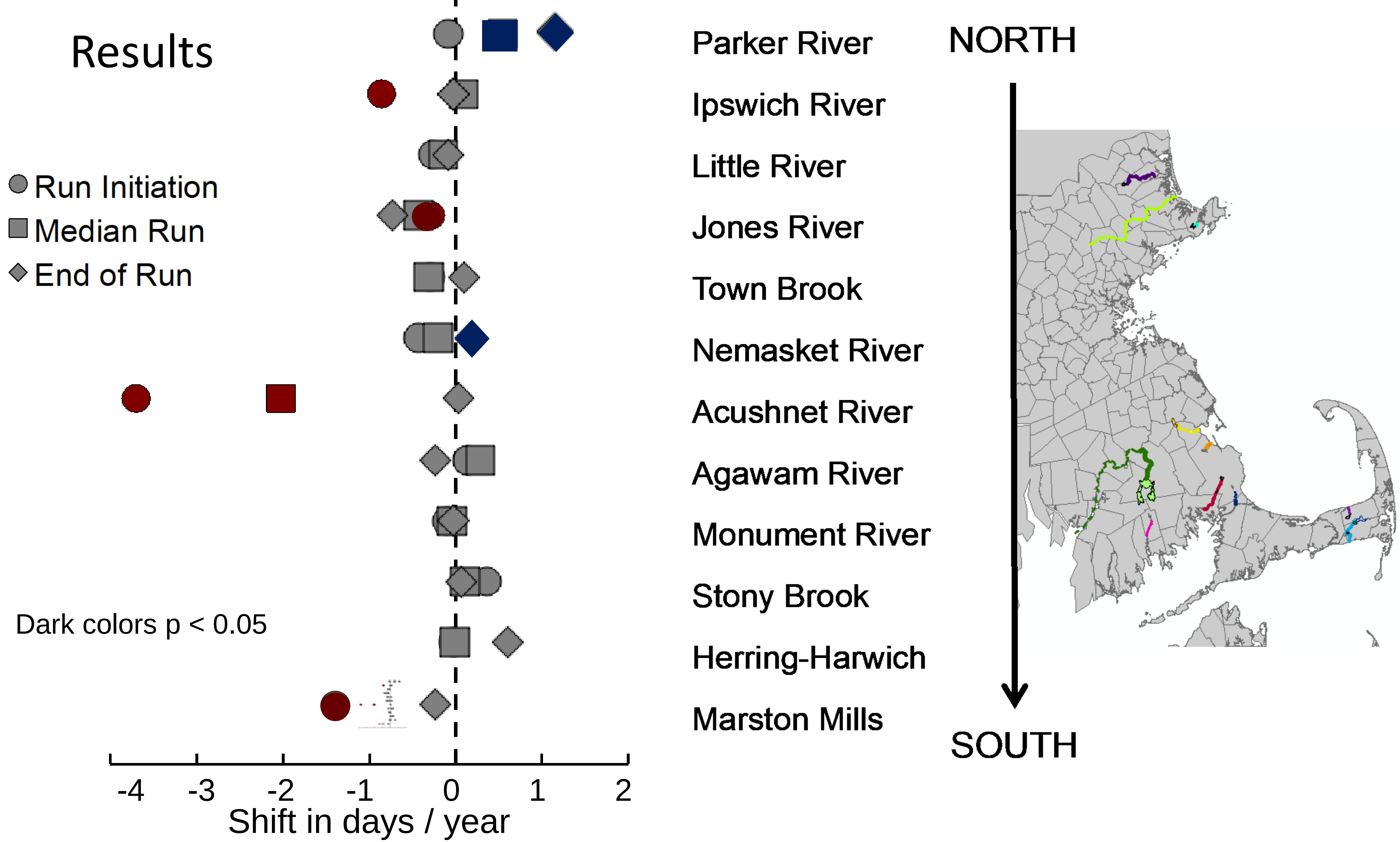
(1|year) ↓
1990 – 2017

Annual Counts



Data: MA DMF

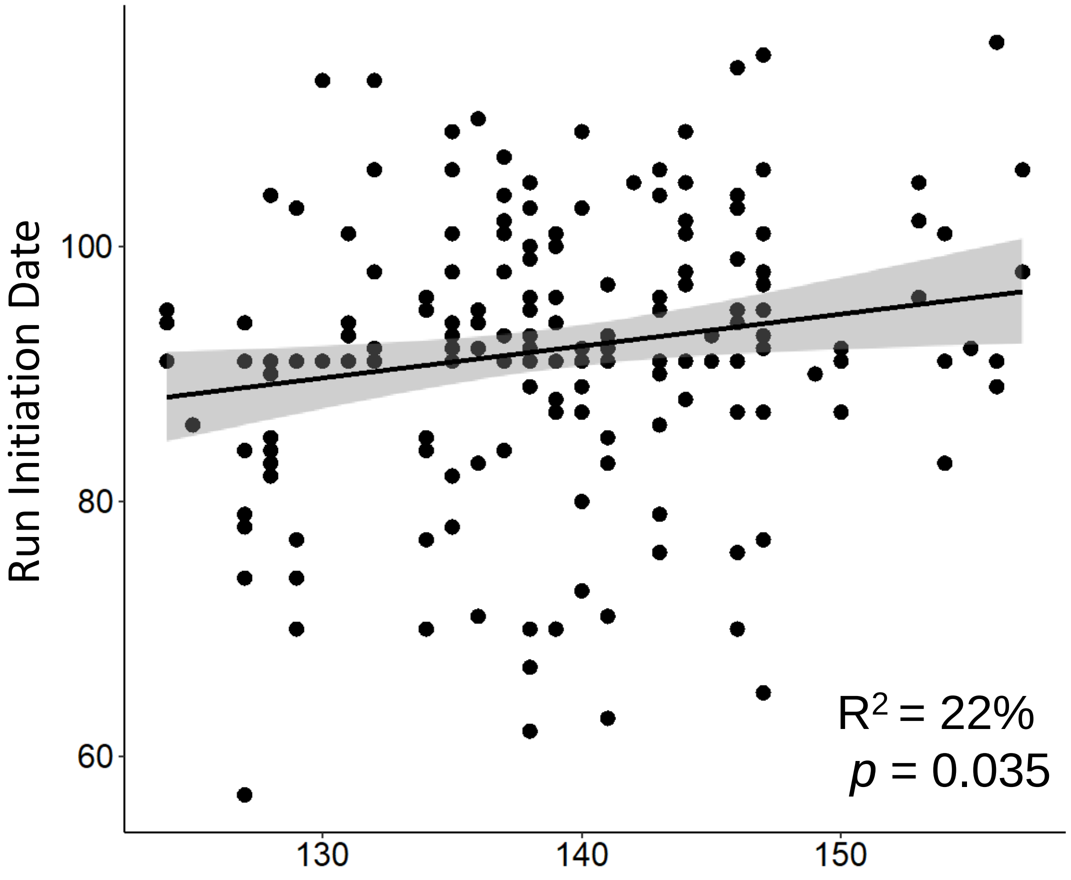
Results



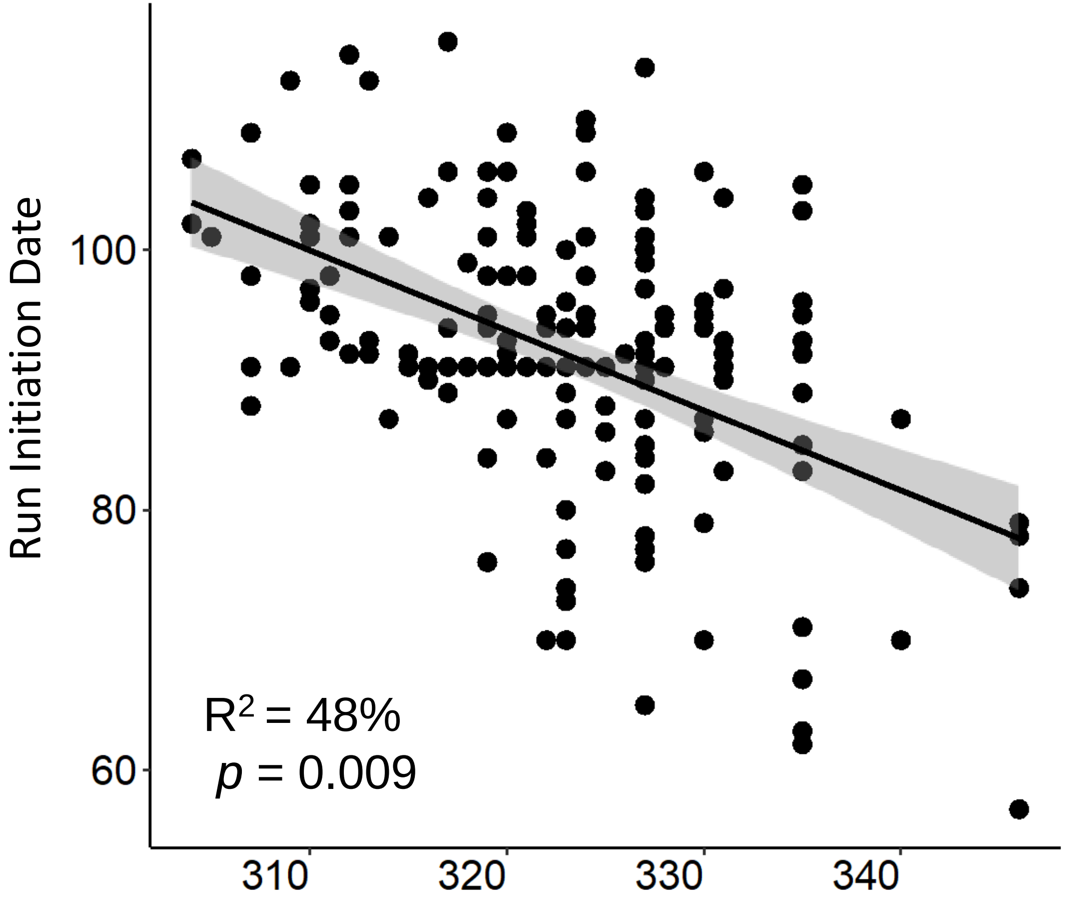
Run Initiation
Median Run
End of Run
Dark colors p < 0.05
-4
-3
-2
-1
0
1
2
Shift in days / year
Parker River
Ipswich River
Little River
Jones River
Town Brook
Nemasket River
Acushnet River
Agawam River
Monument River
Stony Brook
Herring-Harwich
Marston Mills
NORTH
SOUTH

Results

Run initiation ~ std + ftd** + nao + annualcount + (1|loc) + (1|year)



Early May
Spring Transition Date
Early June



Early Nov
Fall Transition Date (previous year)
Mid-Dec

Alewife Summary and Next Steps

- High variability in phenological responses among runs
- Lag in seasonal response to fall transition…..or winter duration (~severity?)
- Daily count model to explain within season drivers of movement

Case study 2: Colonial nesting seabirds (*Sterna* sp.)

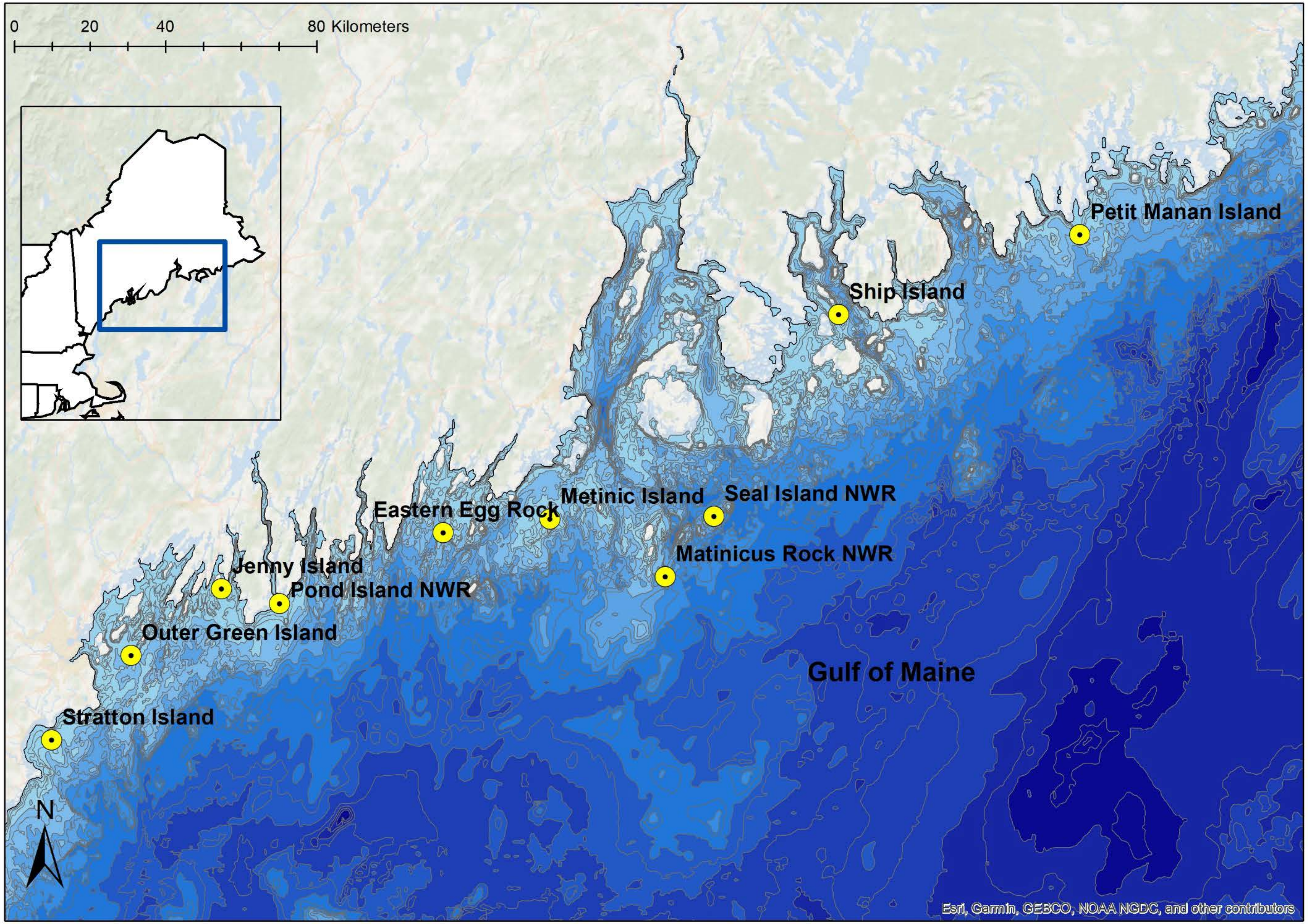
Objectives

1) Describe long-term trends in diet

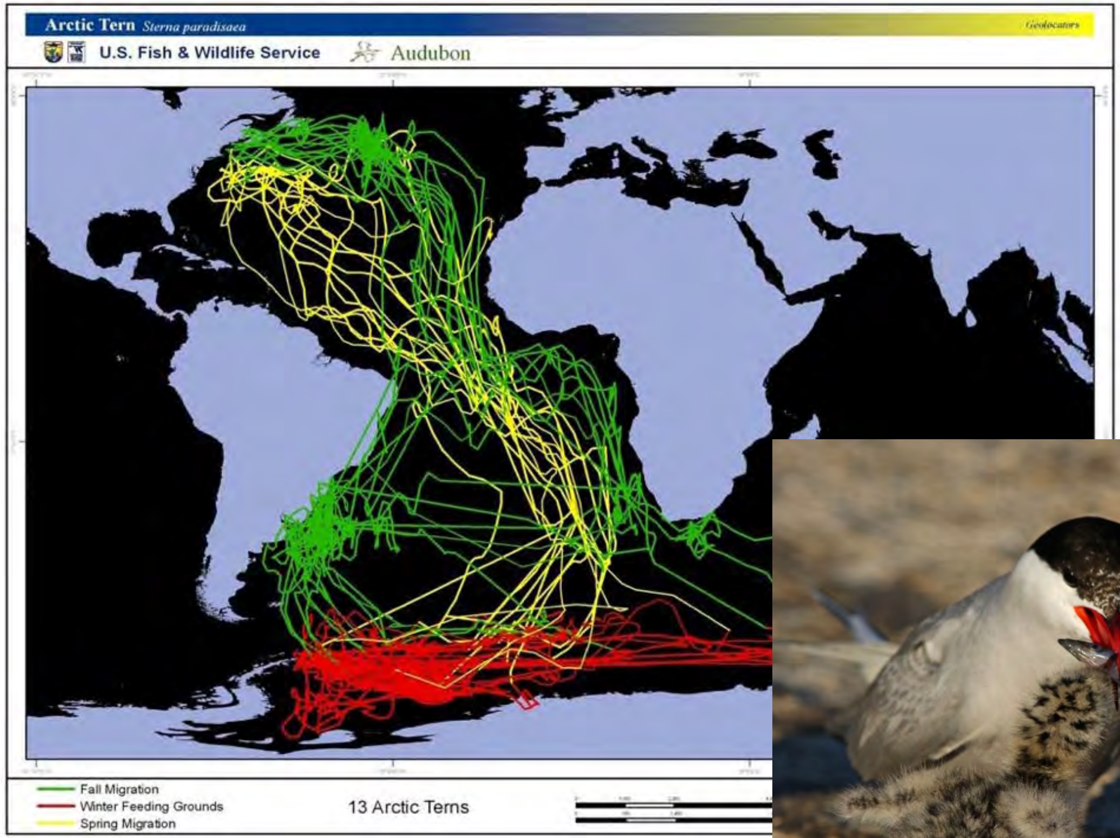
2) Identify drivers of major prey in tern diets

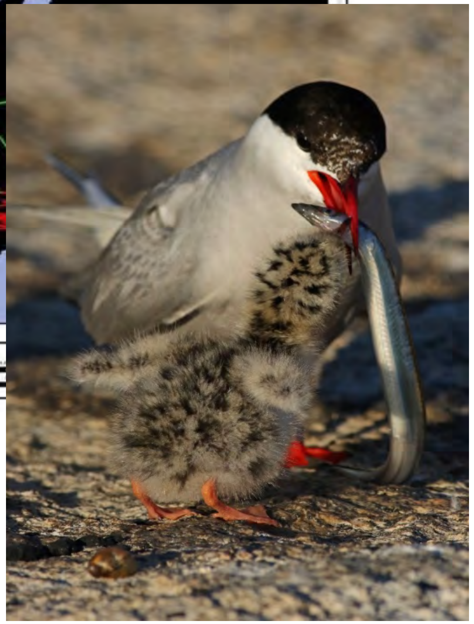
3) Relate fluctuations in diet to productivity

Maine Coastal Islands National Wildlife Refuge



Factors influencing Climate Vulnerability





Climate Vulnerability

Ranking: Highly – Moderately Vulnerable
Region: Northeastern United States
Climate scenario: SRES A1B
Time period: 2050, 2080

- Habitat loss
- Increasing air temperatures

} Exposure

- Dietary specialization
- Resource mismatches

} Sensitivity

Attributes from ASGSCCC 2010; Whitman et al. 2013, Sneddon and Hammerson 2014

Approach

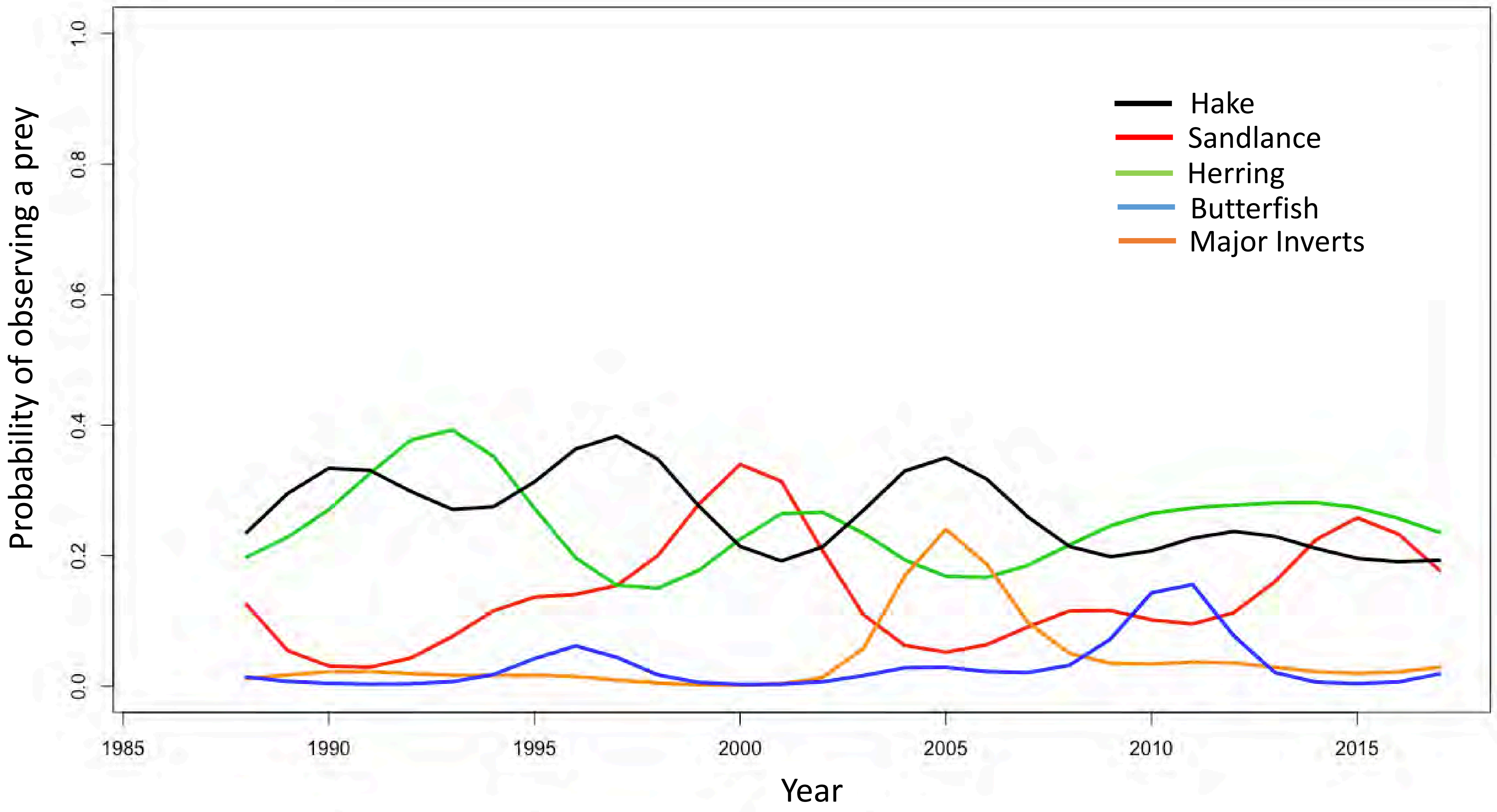
Analysis:

- **Species level**: Binomial Generalized Additive Models (1988-2017)
- **Regional level**: Binomial Generalized Linear Models (1998-2017)

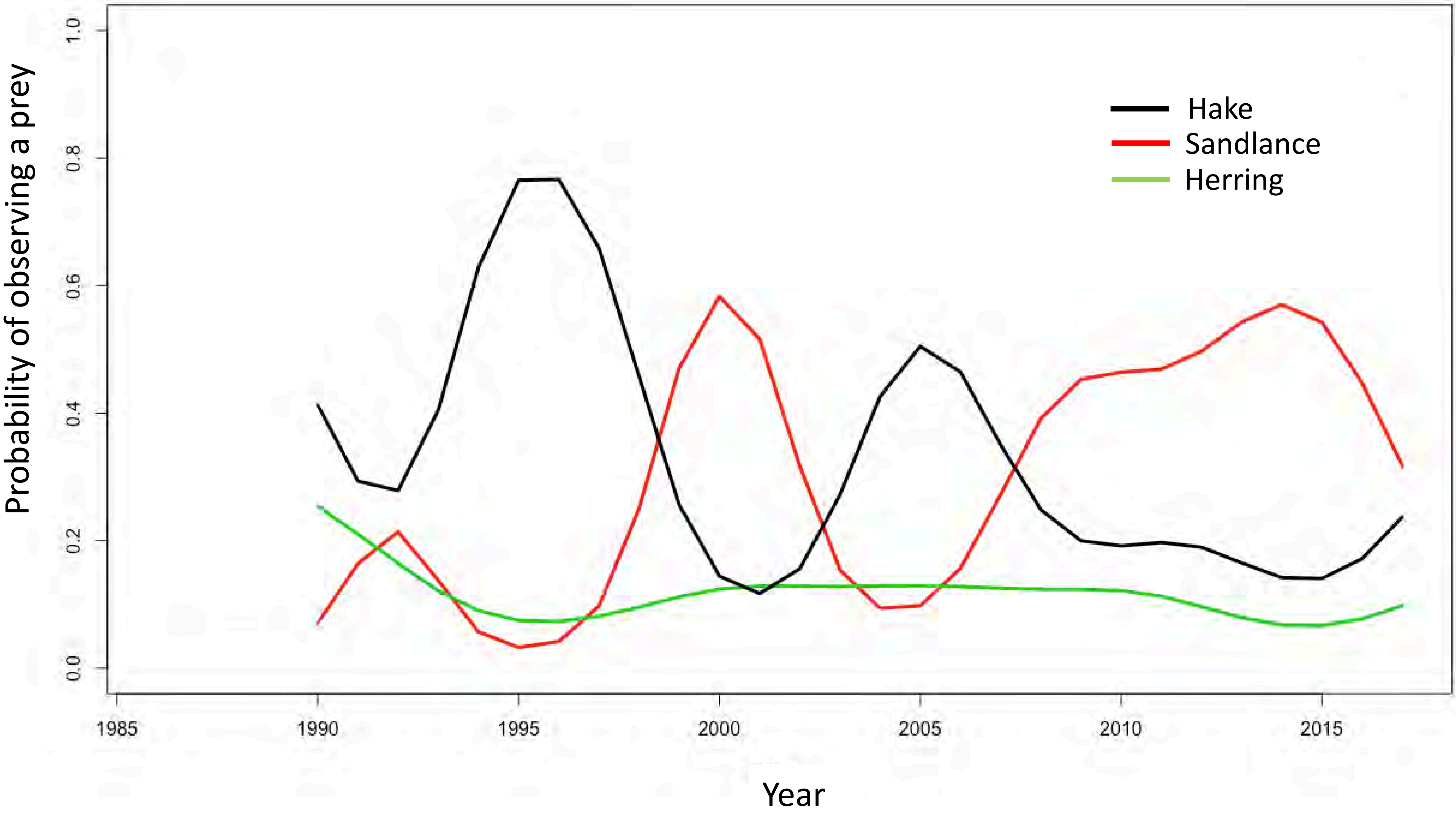
Prey ~ Environmental Parameters + Island + Species + (1|Nest)

- Prey → Hake, Herring, Sandlance, Butterfish
- Environmental Parameters → Spring and fall SSTs, Chl concentration, Transition Dates
- Island → 7 islands
- Species → Common, Arctic, Roseate, Least
- (1|Nest) → 3,618

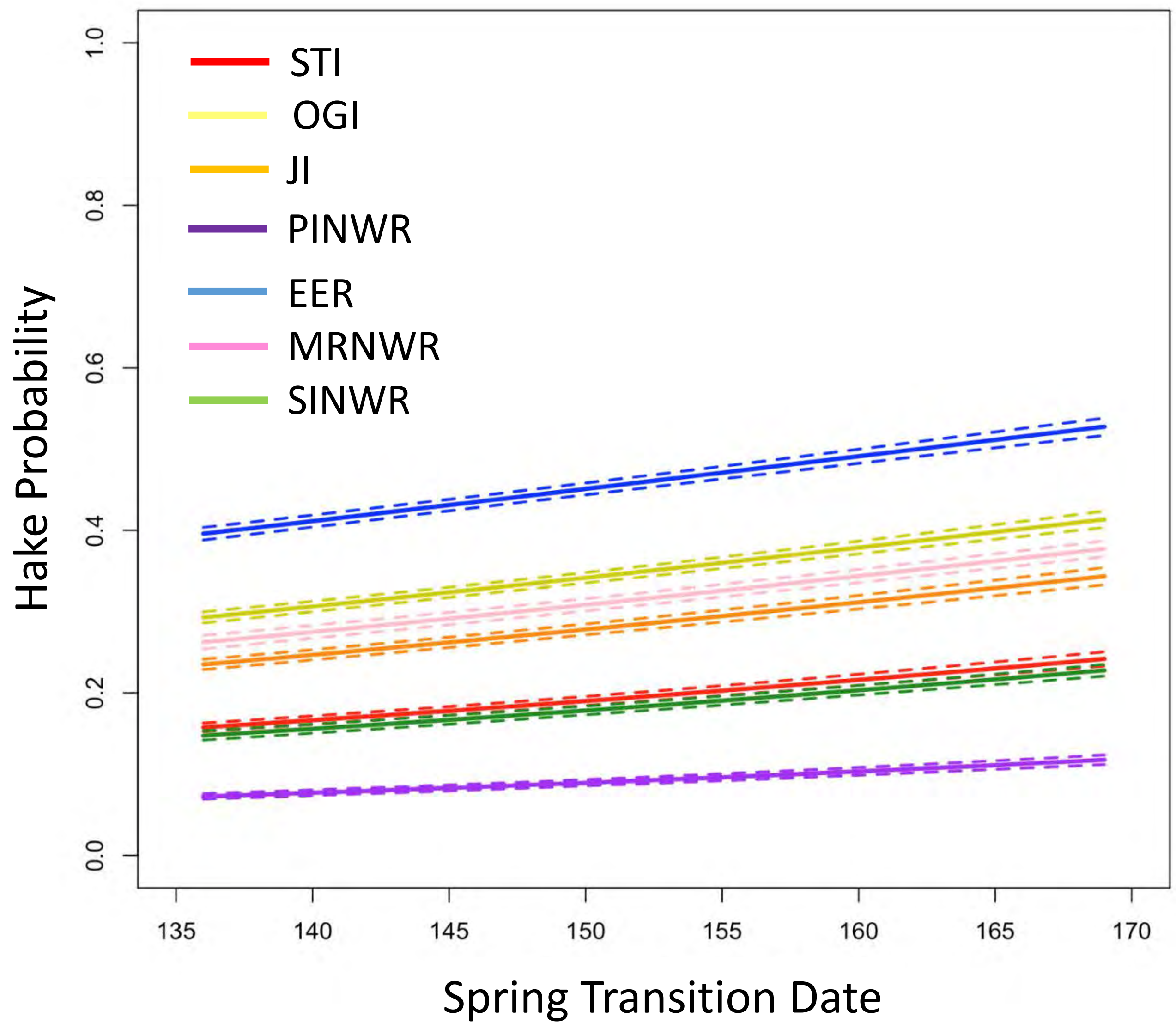
Long-term Cycles in Common Tern Diet



Long-term Cycles in Roseate Tern Diet



Does Spring Transition Date Predict Prey Probabilities?



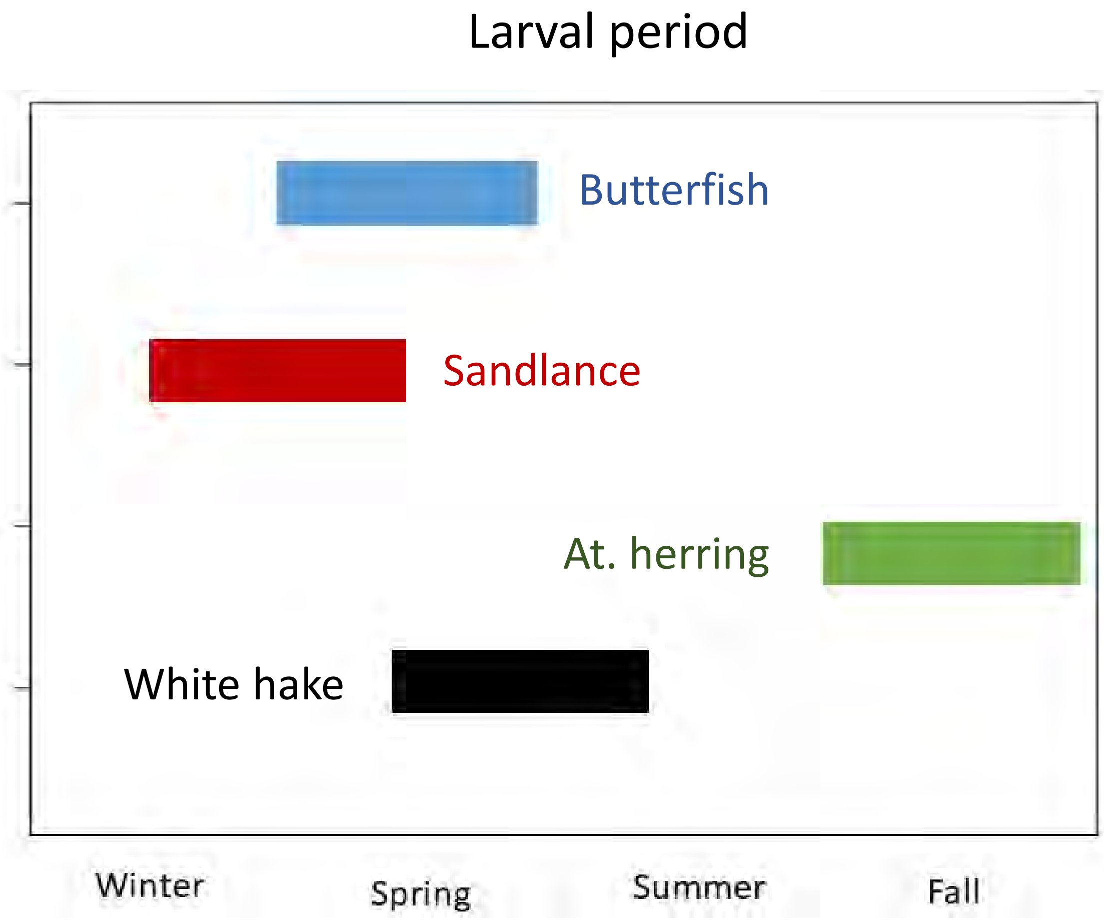
Significant predictors:

- **Hake**: Spring Chl, **STD**
- **Herring**: Spring Chl, SST

- **Sandlance**: Fall **FTD**, SST
- **Butterfish**: Fall **FTD**, SST; spring Chl

Seabird Summary and Next Steps

- Terns diets are largely focused on YOY and juvenile fishes
- Integrate all seasonal (winter) environmental variables into models
- Evaluate relationship between prey cycles relative to tern productivity

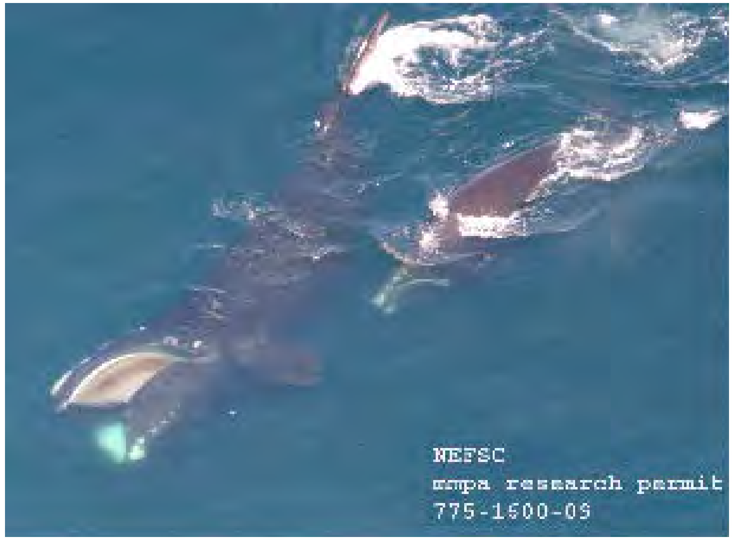


Case study 3: North Atlantic right (*Eubalaena glacialis*) and fin (*Balaenoptera physalus*) whales

Objectives

1) Test for changes in migration phenology

2) Estimate timing of peak habitat use relative to environmental drivers



Factors influencing Climate Vulnerability

Bay of Fundy & Roseway Basin
Aug – Sept

Great South Channel
May – July

Cape Cod Bay
December – May

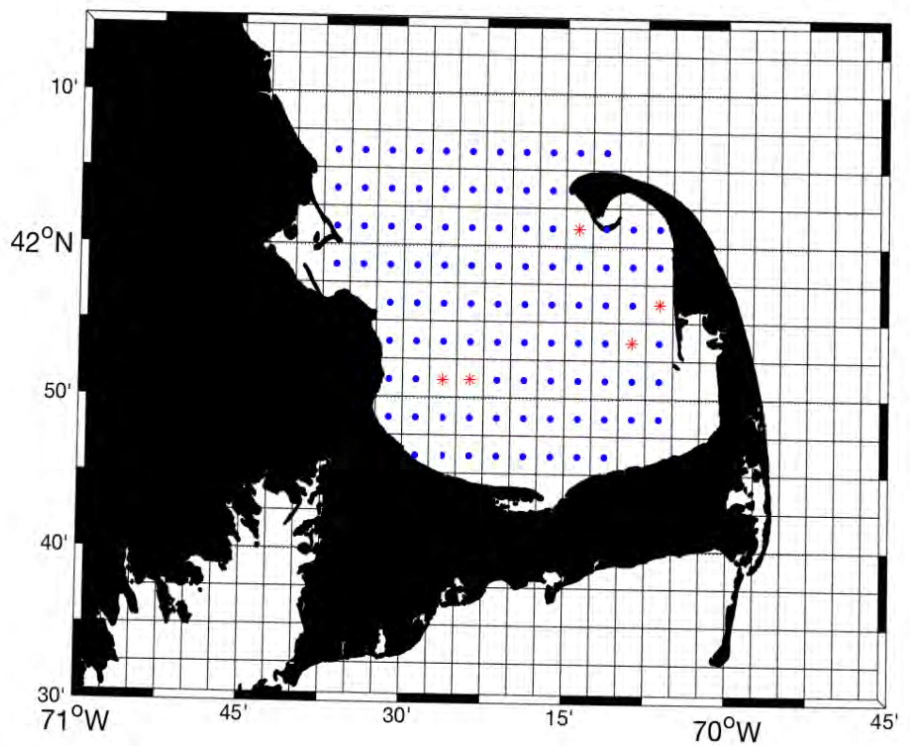
Southeast US
November – February

Protected Species Climate Vulnerability Assessment: *In progress*

- Unknown impact of warming on whales
- Recent abandonment of traditional habitats in GOM; exception of CCB
- Females are especially vulnerable to entanglement in fishing gear

Approach

Cape Cod Bay



Response variables

- Right and fin whale occurrence

Environmental parameters

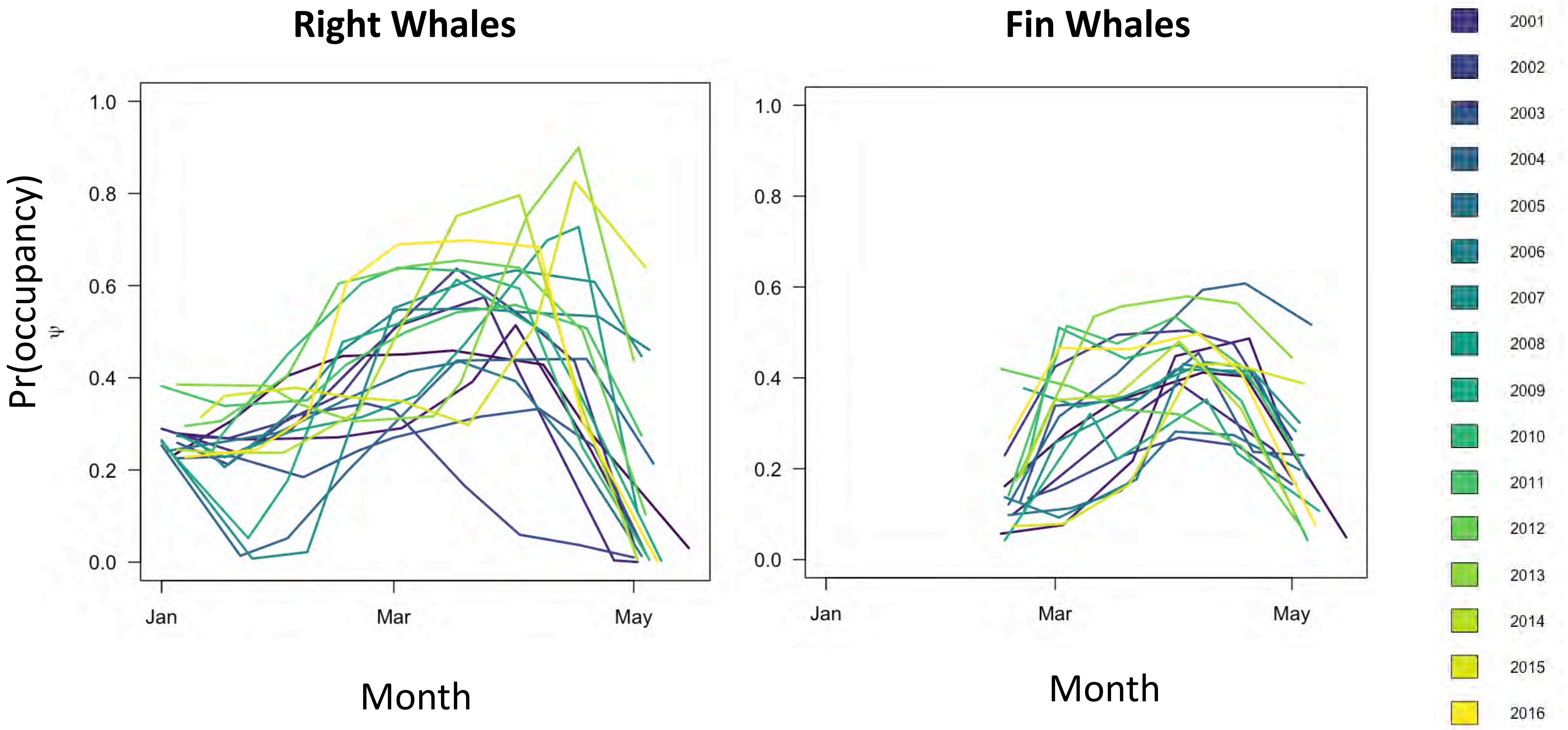
- SST
- Chl
- Bathymetry

Analysis:
Multi-season occupancy models
~state-space hierarchal model

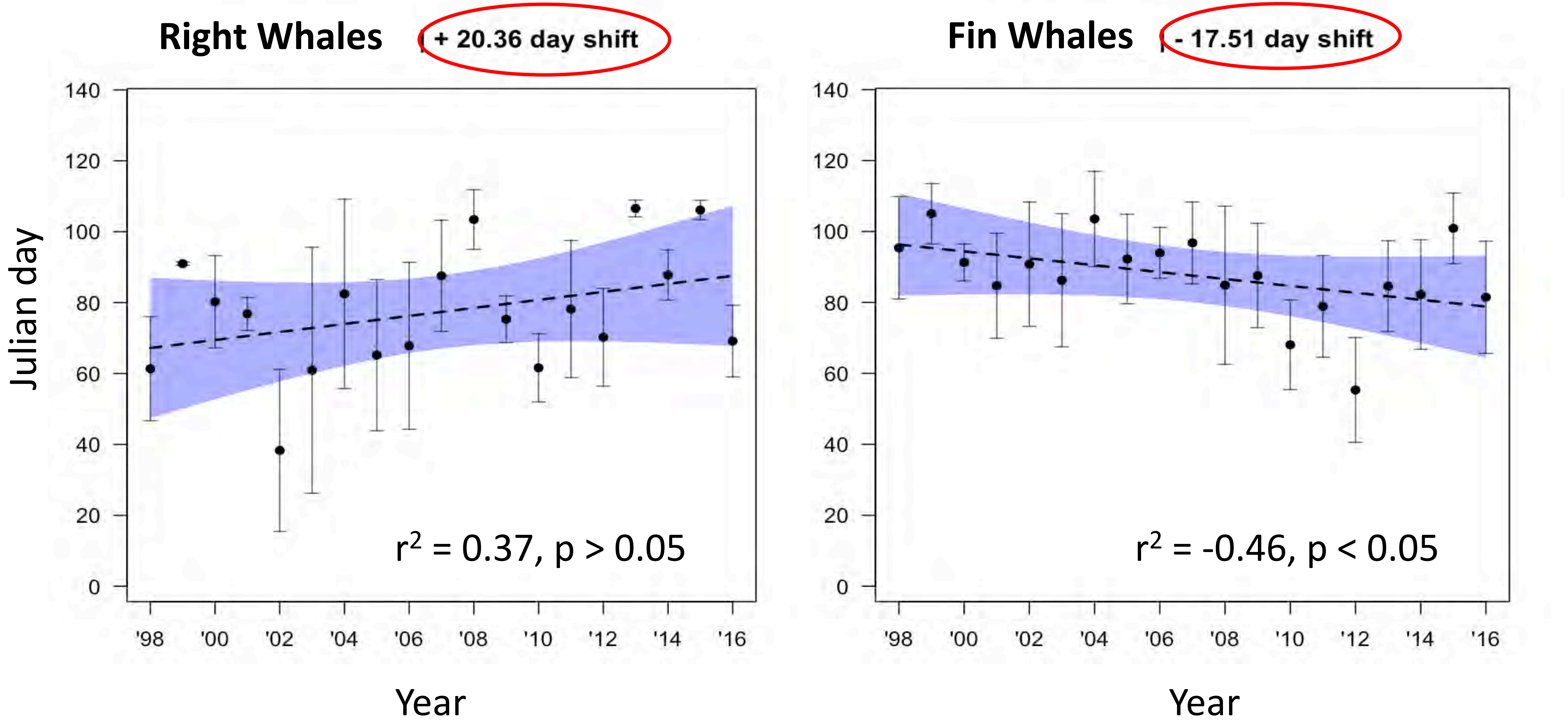
Spatio-temporal resolution

- 1998 – 2016
- Jan – May
- 4.6 km square sites

Annual Occupancy Dynamics

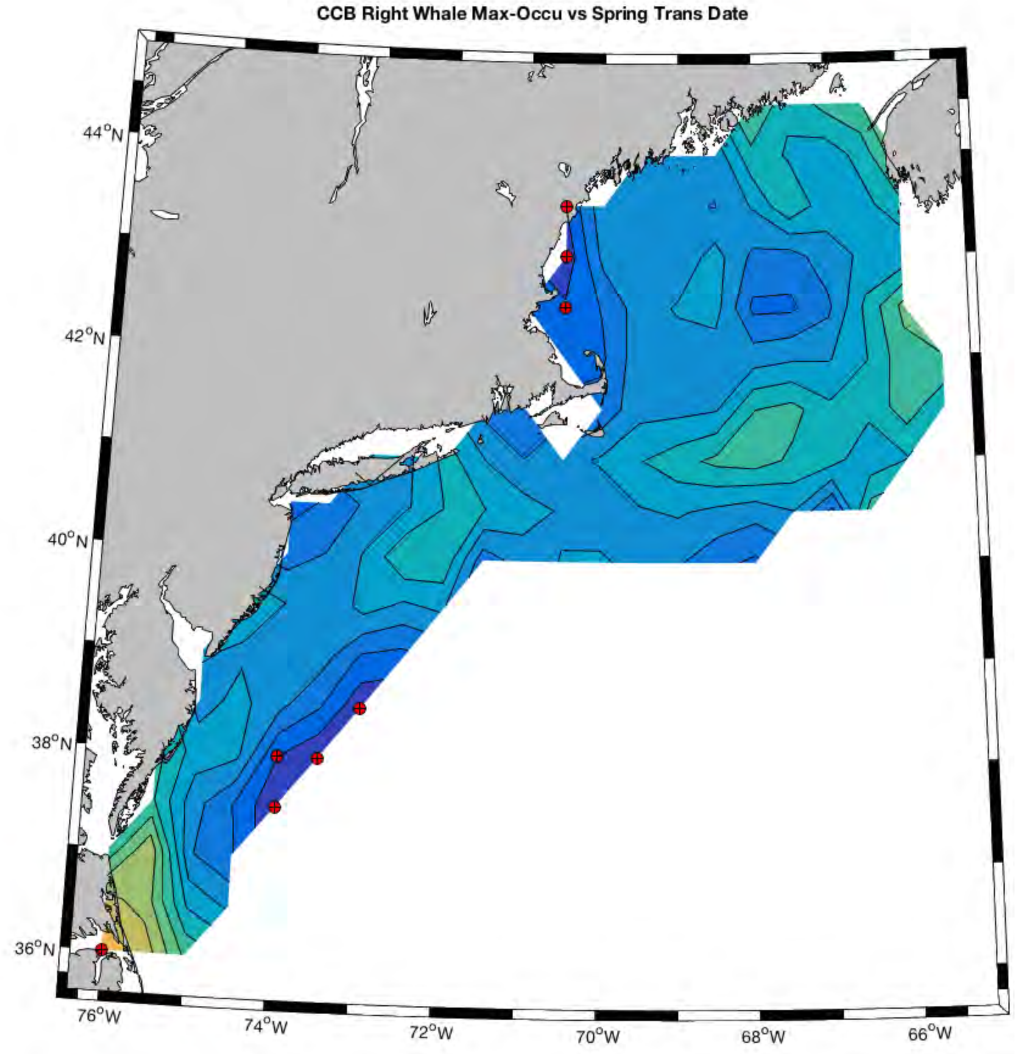


Estimated day of Maximum Occupancy

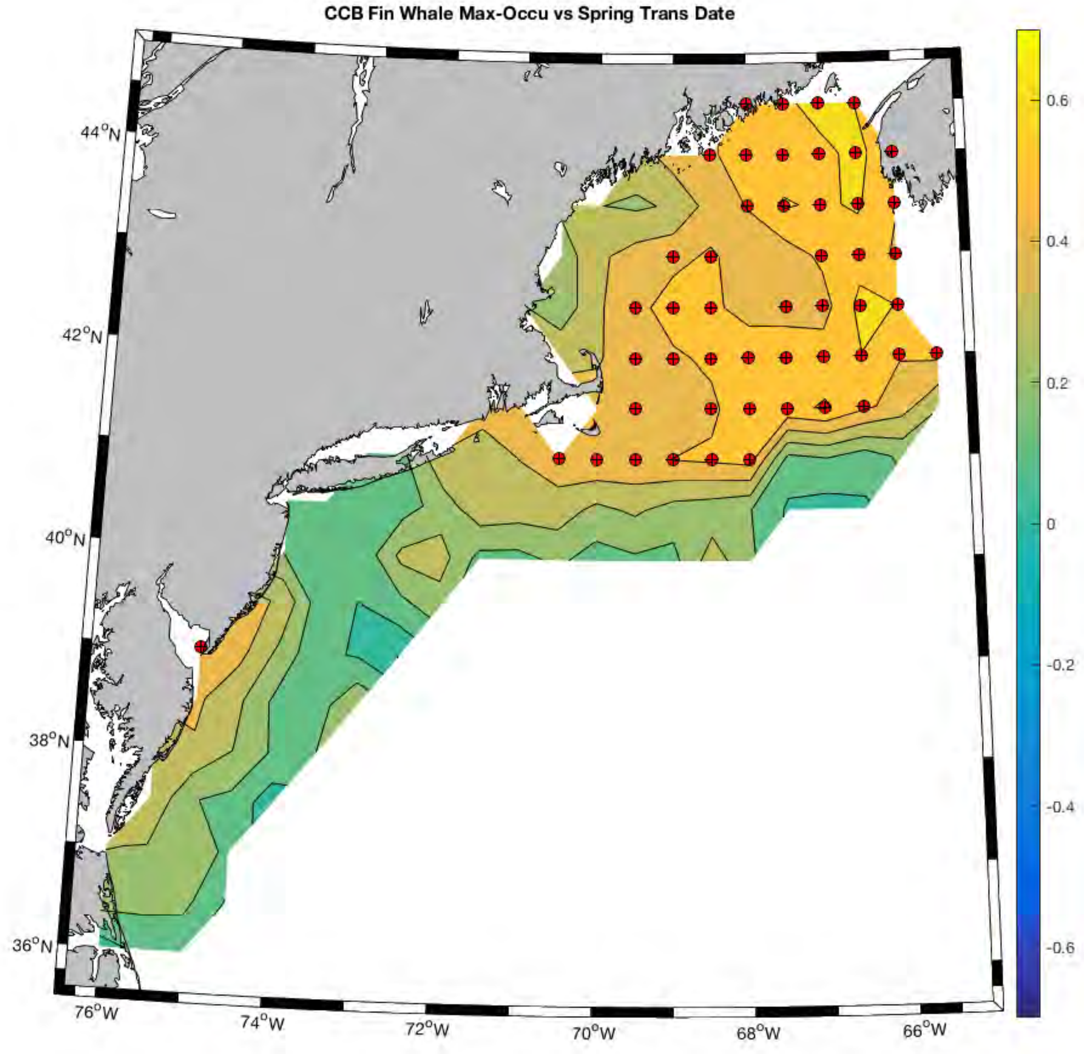


CCB Maximum Occupancy vs. Spring TD

Right Whales



Fin Whales



Whale Summary and Next Steps

- Right and fin whales occupancy appears to have undergone substantial opposite temporal shifts

- Tight coupling between species response and physical changes proportional to
  - Regional warming
  - Advancement of spring

- Evaluate shifts in occupancy of CCB relative to human activities

Overall Summary and Conclusions

- Understanding shifts in phenology is complex
- Responses are inconsistent across species
- Within season environmental events (e.g., Spring TD) don’t fully explain timing of biological events → seasonal lags likely important for many species

❖ Understanding where **AND *when*** they are responding to environmental drivers have implications for population dynamics, interactions with human activities (water withdraws, fishing, shipping), and management decisions

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