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

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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
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?
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  
- Complex spawning cycle  
- Early life history, dispersal requirements

**Exposure**  
**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)

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

- Run strength
- 12 sites
- 1990 – 2017
Results

- Run Initiation
- Median Run
- End of Run

Dark colors $p < 0.05$

Shift in days / year

-4 -3 -2 -1 0 1 2

NORTH

- Parker River
- Ipswich River
- Little River
- Jones River
- Town Brook
- Nemasket River
- Acushnet River
- Agawam River
- Monument River
- Stony Brook
- Herring-Harwich
- Marston Mills

SOUTH
Results

Run initiation \sim \text{std} + \text{ftd}** + \text{nao} + \text{annualcount} + (1|\text{loc}) + (1|\text{year})

- **Spring Transition Date**
  - Run initiation \sim \text{std} + \text{ftd}** + \text{nao} + \text{annualcount} + (1|\text{loc}) + (1|\text{year})
  - $R^2 = 22\%$
  - $p = 0.035$

- **Fall Transition Date**
  - Run initiation \sim \text{std} + \text{ftd}** + \text{nao} + \text{annualcount} + (1|\text{loc}) + (1|\text{year})
  - $R^2 = 48\%$
  - $p = 0.009$
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
- Dietary specialization
- Resource mismatches

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

Analysis:

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

- Hake
- Herring
- Sandlance
- Butterfish
- Spring and fall SSTs
- Chl concentration
- Transition Dates
- 7 islands
- Common
- Arctic
- Roseate
- Least
- 3,618
Long-term Cycles in Common Tern Diet

- Hake
- Sandlance
- Herring
- Butterfish
- Major Inverts

Probability of observing a prey over time.
Long-term Cycles in Roseate Tern Diet

Probability of observing a prey

Year

Herring
Sandlance
Hake


Hake
Sandlance
Herring
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
Southeast US
November – February

Bay of Fundy & Roseway Basin
Aug – Sept

Great South Channel
May – July

Cape Cod Bay
December – May

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

Factors influencing Climate Vulnerability
Approach

Response variables
- Right and fin whale occurrence

Environmental parameters
- SST
- Chl
- Bathymetry

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

Spatio-temporal resolution
- Jan – May
- 4.6 km square sites
Annual Occupancy Dynamics

Right Whales

Fin Whales

Month

Month
Estimated day of Maximum Occupancy

Right Whales: + 20.36 day shift
- 17.51 day shift

$r^2 = 0.37, p > 0.05$

$r^2 = -0.46, p < 0.05$
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
  o Regional warming
  o 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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