SECTION 1. ADMINISTRATIVE INFORMATION:

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Agency or Institution of the recipient: Department of Environmental Conservation, University of Massachusetts Amherst

Project title: Ecological and management implications of climate change induced shifts in phenology of coastal fish and wildlife species in the Northeast CSC region

Agreement number: G14AC00441

Date of the report: October 1, 2019

Period of time covered by the report: October 1, 2014 – September 30, 2019

Actual total cost of the project: $229,880.80

SECTION 2. PUBLIC SUMMARY

Climate change is causing species to shift their phenology, or the timing of recurring life events such as migration and reproduction. This can potentially result in mismatches with food and habitat resources that negatively impact species and ecosystems. Numerous studies have evaluated phenological shifts in terrestrial species, particularly birds and plants, yet far fewer evaluations have been conducted for marine animals. This project sought to improve understanding of shifts in timing at the ecosystem-scale across the Gulf of Maine as well as by exploring marine species-specific case studies. Through stakeholder engagement and outreach across the Northeast region we formed an interdisciplinary working group that developed a regional synthesis of how the timing of biological and human activities were shifting in the Gulf of Maine. We also identified two high priority case studies to focus evaluations and deeper analyses of factors contributing to observed shifts: 1) anadromous river herring in Massachusetts coastal streams, and 2) nesting seabirds across the Maine Coastal Islands National Wildlife Refuge. We used a combined approach of synthesis and modeling to determine the direction, magnitude and extent of spatial shifts, as well as identify data gaps and future research needs. The results pointed to complex and location-specific phenological

responses to climate-linked variables, but capacity for adaptive strategies to minimize risks to species. Project results are anticipated to increase the efficacy of management and planning tools which can be compromised when target species experience shifts in the timing of life history events.

SECTION 3. PROJECT SUMMARY

The overall objectives of this project were to increase our understanding of shifting phenology on fish and wildlife species that inhabit Northeast coastal habitats and evaluate the implications of those shifts on community dynamics and ecosystem services. Results provide decision support information to assist natural resource managers with development of regional climate change adaptation and conservation plans. This was accomplished through exploration of the following objectives: 1) synthesize available knowledge and datasets of key fish and wildlife species that inhabit Northeast coastal habitats to assess shifts in phenology; 2) evaluate ecological and management implications of shifting phenology and residence time of key fish and wildlife species that inhabit Northeast coastal habitats. Where sufficient long-term species observations and environmental monitoring data existed we explored the questions: 1) can we detect phenological shifts of key coastal fish and wildlife species? 2) What environmental variables are the observed shifts in phenology correlated with? 3) If shifts in phenology are detected, how have these shifts affected the ecosystem services that these species provide in the region and what are the potential future risks? In general, many biological and management surveys, particularly bi-annual surveys, do not collect data appropriate for testing phenological shifts. Where appropriate data were collected, complex and location-specific phenological responses to climate-linked variables were observed. Broad scale environmental variables representative of winter severity as well as site-specific conditions such as run size and restoration actions affected phenological patterns of anadromous river herring migrations into Massachusetts coastal streams. Seabird diets responded to seasonal signals in prey, modified by climate variables. Management and planning tools can be developed from the results of this effort, adjusting time-at-place regulations and developing strategies for maximizing the likelihood of success in conservation goals.

Purpose and Objectives:

Climate change is causing species to shift their phenology, or the timing of recurring life events, in variable and complex ways. This can potentially result in mismatches or asynchronies in food and habitat resources that impact individual fitness, population dynamics, and ecosystem function. This project sought to improve our understanding of climate-induced shifts in the seasonal timing of migration, spawning or breeding, and rates of biological development in coastal fishes, marine mammals, and seabirds along the U.S Atlantic coast, with a focus on the Gulf of Maine. Long-term biological observations and environmental monitoring data were

identified and assembled to evaluate the spatial and temporal scales at which phenological shifts are occurring, the primary environmental variables driving shifts, and to identify shared biological attributes that influenced observed responses. Comparisons of phenological shifts among taxa and trophic levels helps characterize the adaptive capacity and vulnerability of individual species and regional sub-populations to changing environmental conditions. Such analyses also help identify where potential trophic mismatches may occur due to rapid climate change and reveal gaps in monitoring networks intended to detect such responses among species of commercial, ecological, and conservation importance.

Organization and approach:

1. ***Initial stakeholder outreach and engagement and literature review.***

For the initial scoping of this project we brought on Karen Alexander, a historical ecologist, to conduct preliminary and comprehensive literature and data searches to identify key studies and datasets about the current state of knowledge of how phenology is shifting in global marine ecosystems (**Figure 1**). Once this task was complete we had a good sense of the taxa-specific and regional work that had been completed to date in our region. Quite fortuitously, in 2015, the Regional Association for Research on the Gulf of Maine (RARGOM) focused their annual meeting theme on "How is the timing of all things changing in the Gulf of Maine?". This conference provided an ideal gathering of regional experts and managers with interests in phenology to seek potential collaborators and partners on this project. Indeed, we presented our project objectives and initial findings, which launched a working group comprised of the meeting's presenters. Additional interest was gained from the contacts and relationships formed at the RARGOM meeting and led to additional presentations and engagement activities at a range of stakeholder meetings including: the annual Roseate tern recovery working group meeting, the Center for Coastal Studies, and the New England Aquarium, Anderson Cabot Center for Ocean Life, annual meeting of the River Herring Network. Further targeted conversations with staff and scientists from state, federal, and non-profit organizations including the Massachusetts Department of Marine Fisheries, the USFWS Marine Coastal Islands NWR and Migratory Birds divisions, National Audubon Seabird Restoration Program and Project Puffin revealed additional opportunities for the project to pursue. Stakeholder engagement with these entities helped us identify high-priority regional case studies with sufficient long-term data collected at a temporal resolution that allowed us to evaluate phenological responses. We also identified research partners from these organizations who helped us evaluate emerging species-specific case studies and are outlined below.

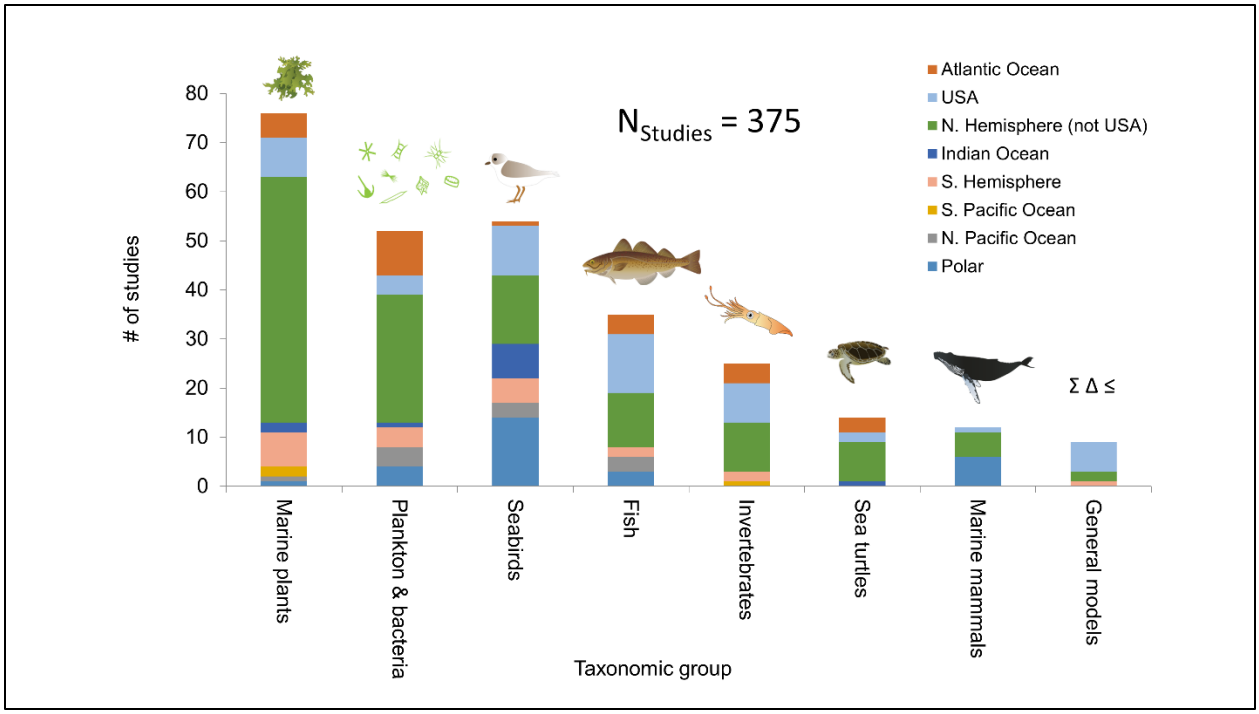

***Figure 1**: Results of a comprehensive literature search which served as the basis for understanding existing global studies and research needs. A total of 375 studies were found in the peer reviewed literature. This was further refined to focus on the Northwest Atlantic Ocean.*

2. Regional analyses and species-specific case studies

a) *Tambora's influence on historical fisheries*.

Global warming has increased the frequency of extreme climate events, yet responses of biological and human communities are poorly understood, particularly for aquatic ecosystems and fisheries. Retrospective analysis of known outcomes may provide insights into the nature of adaptations and trajectory of subsequent conditions. We consider the 1815 eruption of the Indonesian volcano Tambora and its impact on Gulf of Maine coastal and riparian fisheries in 1816. Applying complex adaptive systems theory with historical methods, we analyzed fish export data and contemporary climate records to disclose human and piscine responses to Tambora's extreme weather at different spatial and temporal scales while also considering sociopolitical influences.

b) *Regional assessment of shifting phenology in the Gulf of Maine*.

The primary goals of this regional synthesis were to summarize the current knowledge in the Gulf of Maine on: 1) key seasonal ecological and environmental processes, patterns, and events; 2) direct evidence for shifts in timing across the ecosystem; 3) implications of

phenological responses for linked ecological-human systems; and 4) potential phenology-focused adaptation strategies and actions. Results provide a comprehensive perspective on shifting phenology in the Gulf of Maine, with case studies that span from the bottom of the food chain to higher level consumers as well as human activities, including fishing and recreation. We synthesized contributions from the 2015 Regional Association for Research on the Gulf of Maine (RARGOM) Annual Science Meeting "How is the timing of all things changing in the Gulf of Maine?", outputs of an expert workshop, which we organized and held in 2016 at the Gulf of Maine Research Institute, results from a comprehensive literature review, and expert input from an international working group composed of 26 authors representing 17 organizations, including multiple federal agencies, non-profit organizations, and academic institutions.

c) *River herring*.

Diadromous fishes are critical to ecosystems because they transport marine-derived nutrients between freshwater and ocean environments (Durbin et al. 1979). They are subject to strong seasonal cycles because they utilize disparate habitats and may be impacted significantly by phenological mismatches between these habitats. Alewife (*Alosa psuedoherengus*), one of the two species of river herring, were well suited for this study because they have been identified as highly vulnerable to climate change due to their sensitivity and exposure to climate stressors (Hare et al. 2016), their passage points in Massachusetts are well monitored, and it is a species of conservation concern to state and federal agencies as well as tribal nations. Working collaboratively with the MA DMF, we examined how climate change affected the timing of the spring spawning migration in MA by asking the following questions: 1) Has adult migration timing shifted over recent decades? 2) How does the direction and magnitude of phenological shifts vary across the region? and 3) What regional-scale environmental factors best predict migration timing across spawning runs?

Using a series of linear mixed-effects regressions (LMMs) and linear models (LMs) we determined the extent of phenological shifts in the timing of adult alewife migration in 12 coastal streams in Massachusetts (**Figure 2**). We evaluated migration timing across coastal streams relative to regional-scale seasonal environmental predictors including spring and fall transition timing, winter duration, sea surface temperature (SST), North Atlantic Oscillation index (NAO), and Gulf Stream index.

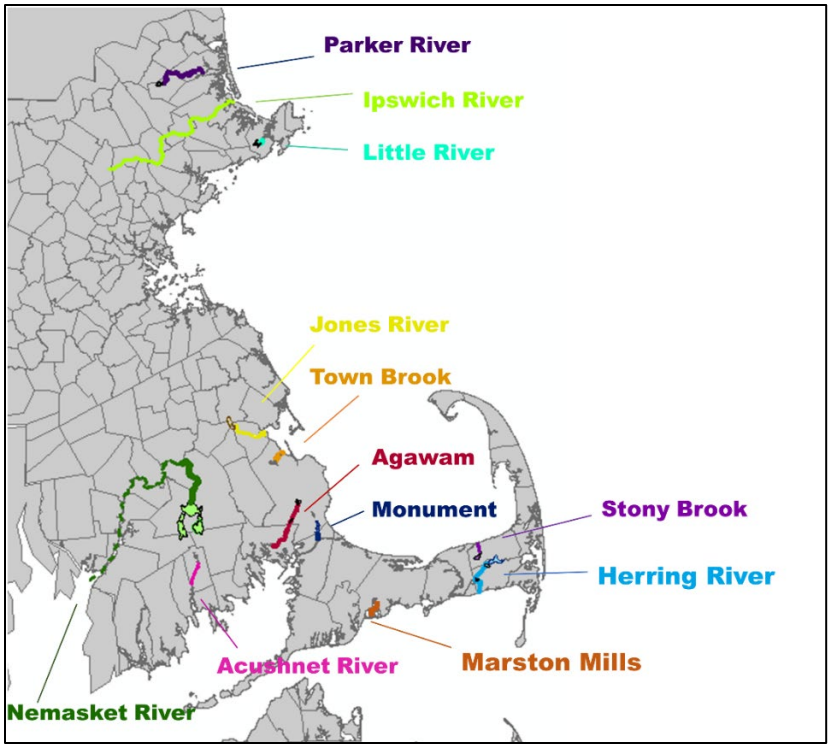

Figure 2: *Map of monitoring locations and sites where spring adult alewife migration timing was evaluated in Massachusetts. Data were collected by the Massachusetts Division of Marine Fisheries and partnering organizations.*

Seabird foraging ecology.

The Gulf of Maine, USA is home to four different species of nesting terns: the Least tern (*Sternula antillarum*), Common tern (*Sterna hirundo*), Arctic tern (*S. paradisaea*), and Roseate tern (*S. dougalii*). As the Gulf of Maine is an incredibly dynamic ecosystem with rapidly warming sea surface temperatures (SSTs), it is vital to understand how diet varies over time, space, and among tern species that use this region for seasonal nesting and rearing of young. The Least and Roseate tern are considered endangered in the state of Maine while Arctic terns are considered threatened. Furthermore, Least, Arctic and Roseate terns are also considered to be highly vulnerable to climate change due to habitat specialization, reduction of nesting and loafing habitat, and reduction of prey due to shifting food webs (Whitman et al. 2013). Working in collaboration with the National Audubon Seabird Restoration Program, Project Puffin and USFWS, we 1) digitized historical data of tern chick diets, 2) quantified and compared differences in chick diet among tern species and across seven islands over a 32-year period, 3) characterized long-term trends in common tern chick diets across the region, 4) assessed how prey composition in chick diet shifted over the course of the nesting period, 5) quantified how warming sea surface temperatures and shifting thermal phenology in the region impacted dietary composition and long-term trends.

Diets were summarized and evaluated across the four tern species, seven nesting colonies (**Figure 3**) and over a 31 year time period using a variety of multivariate statistical techniques including cluster and principal components analyses. Trends in diet were evaluated using generalized additive models (GAMs) and Generalized linear mixed models (GLMMs).

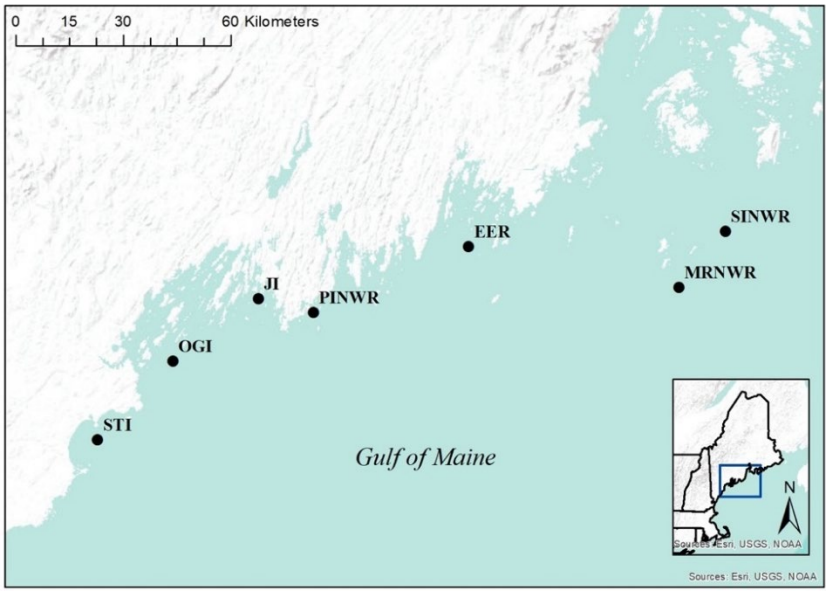

***Figure 3**: Study area map with inset of the Gulf of Maine coastline in the northeastern portion of the United States. Stratton Island (STI), Outer Green Island (OGI), Jenny Island (JI), and Eastern Egg Rock (EER) are managed by the National Audubon Seabird Restoration Program. Pond Island National Wildlife Refuge (PI NWR), Matinicus Rock (MR), and Seal Island NWR (SINWR) are managed in collaboration with and owned by the USFWS Maine Coastal Islands NWR.*

Project Results, Analysis and Findings:

a) Tambora's influence on historical fisheries.

We identified a tipping point in Gulf of Maine fisheries induced by concatenating social and biological responses to extreme weather. Abnormal daily temperatures selectively affected targeted fish species—alewives, shad, herring, and mackerel—according to their migration and spawning phenologies and temperature tolerances. First to arrive, alewives suffered the worst. Crop failure and incipient famine intensified fishing pressure, especially in heavily settled regions where dams already compromised watersheds. Insufficient alewife runs led fishers to target mackerel, the next species appearing in abundance along the coast; thus, 1816 became the "mackerel year." Critically, the shift from riparian to marine fisheries persisted and expanded after temperatures moderated and alewives recovered. We conclude that contingent human adaptations to extraordinary weather permanently altered this complex system. Understanding how adaptive responses to extreme events can trigger unintended

consequences may advance long-term planning for resilience in an uncertain future. The full results are summarized in a published paper in Science Advances (Alexander et al., 2019).

b) Regional assessment of shifting phenology in the Gulf of Maine.

A surprisingly small number of studies (N = 20) showed direct evidence of shifts in timing in biotic and abiotic events in the Gulf of Maine ecosystem. Similar to previous research in terrestrial systems, the most common phenological responses found in the Gulf of Maine were earlier timing of key events. These included earlier spring onset (the day of year when sea surface temperatures exceed a thermal threshold), earlier and higher spring river flows that deliver freshwater runoff to coastal habitats, earlier and higher peaks in abundance of zooplankton, earlier occurrence of larval stages of benthic fishes (haddock, winter flounder, wolffishes, rock gunnel), and anadromous fish migrations occurring earlier in the year. Later timing was observed in fall onset (the day of year when sea surface temperatures descend below a thermal threshold), spring and fall phytoplankton blooms, occurrence of several larval benthic and pelagic fishes (sand lance, pollock, offshore hake, Atlantic mackerel), as well as reproduction and fledging of Atlantic puffins. Changes in the duration of certain events generally increased, including longer abundance peaks in zooplankton, the spawning/early life history period of macro-invertebrates including Northern shrimp and an intertidal nudibranch, and the high-landings period in the Maine lobster fishery. Ice-affected streamflow was the only seasonal event exhibiting a reduction in duration. Few studies to date have focused on how the timing of events may change in the future, but two studies projected decreased overwintering (diapause) duration for a key zooplankton species, *Calanus finmarchicus*.

Overall, rates of phenological shifts were species- and event-specific, and responses varied depending on the environmental driver and the spatial and temporal scales evaluated. Results reveal a need for increased emphasis on documenting and understanding phenological shifts in the region. The paper identifies opportunities for future research and consideration of phenological changes in adaptation efforts.

The full results are summarized in a published paper in Fisheries Oceanography (Staudinger et al., 2019).

c) River herring.

Our approach showed a general trend towards earlier spring migration timing of adult alewife into coastal freshwater streams between 1990-2017; however, these shifts varied widely among individual systems. Many streams showed earlier timing in phenology metrics, but we only detected significant trends at a subset of streams that have also undergone significant restoration activities in recent years. Restored sites showed population increases (Acushnet River in particular) and undoubtedly influenced migration timing, as larger runs were associated

with earlier migration. When we examined the relationship between region-wide environmental drivers and migration timing and accounted for population size, a combination of several seasonal factors was found to influence run initiation dates. This included warmer minimum spring SST, a seasonal lag-effect of later fall transition dates from the previous year, as well as positive winter and negative spring NAO indices. Later fall transition dates were strongly correlated with shorter winter duration, and when considered in combination with the positive phase of the winter NAO index and warmer spring minimum SSTs, results suggest aspects of winter severity influenced migration behavior in alewife. Our combined results lead us to hypothesize that during warmer, shorter, and wetter winters, alewife move inshore and test the system earlier in comparison to longer, colder (more severe) winters with less precipitation, where they may remain offshore in search of (warmer) thermal refuge found in deeper waters (Lynch et al., 2014). Warmer minimum spring SST and a negative spring NAO index characterized the regional conditions effecting within-season regional movements by alewife.

This work was executed by a visiting scholar from Duke University (Rebecca Dalton) through the NSF INTERN program. Full details of methodology and results are summarized in an NSF final report, a dissertation chapter, and a manuscript submitted to Canadian Journal of Fisheries and Aquatic Sciences (Dalton et al., In review).

d) Seabird foraging ecology.

Results represent the longest published dietary time-series of multiple tern species in the northwest Atlantic and the first comprehensive study of Least tern diet in the region. We found that although diet varies across tern species and to some extent nesting islands, three forage groups - hake, herring and sand lance - dominate diets across the region. The hake group includes an unknown mixture of fourbearded rockling (*Enchelyopus cimbrius*), red hake (*Urophcis chuss*), offshore hake (*Merluccius bilinearis*), and white hake (*Uropycis tenuis*); with white hake believed to be the most common of the hake species in chick diets. The herring group is dominated by Atlantic herring (*Clupea harengus*), though closely related anadromous species, alewife and blueback herring (*A. aestivalis*) may also be provisioned in uncertain amounts. Two species of sand lance, Northern (*Ammodytes dubius*) and American (*A. americanus*) are known to occur in the region. Overall, a strong reliance on such few prey species likely increases tern vulnerability to climate change and other stressors that influence prey distribution and population dynamics.

In addition, we found that the hake prey group has shown a declining trend in common tern chick diets across the 31-year time series. In contrast, sand lance has increased in chick diets at all islands, though in varying magnitudes, over the past decade. Many of the trends in focal prey groups appear to be cyclical in nature with peaks and troughs occurring concurrently at multiple islands. Annual within-season phenological shifts in chick diet found that hake and sand lance were more important in the beginning of the chick rearing period (mid-June), while

herring, butterfish (a warm-water associated species) and other fishes increased in importance as the nesting season progressed (early August). Hake also exhibited steeper within-season declines during years in which the thermal spring transition date occurred earlier, indicating phenological sensitivity to changes in seasonal timing. The occurrence of hake in chick diets was negatively related to warming SSTs while the other fish group showed a positive relationship. This result has important implications for the future availability and composition of chick diets given observed and projected warming in the region (Saba et al. 2016, Alexander et al. 2018). Declines or shifts in timing of hake availability could force Common terns, and other seabirds to seek alternative prey, potentially of lower energetic value. The ramifications of these dietary shifts on seabird productivity (e.g. nesting success and chick growth) and adult condition are still unknown, and are an outstanding research priority.

This work was performed by Keenan Yakola as part of a Masters degree at the University of Massachusetts Amherst. Full details of methodology and results are summarized in the Masters Thesis and two anticipated manuscripts (Yakola 2019; Yakola at al., In review).

Conclusions and Recommendations:

Like other temperate marine ecosystems, the Gulf of Maine is characterized by a strong seasonal cycle, which drives the region's ecology. Changes in the timing of seasonal features have the potential to impact individual species, food webs, and overall ecosystem productivity through trophic mismatches and asynchronies in linked food and habitat resources, and eventually delivery of ecosystem services. The efficacy of management and planning tools such as fishing seasons, catch limits, and time-area closures may be compromised when target resources shift in time. For example, spatiotemporal closures have been used to protect spawning aggregations of commercially-important fish; however, temporal closures are typically set to predetermined dates and may need to be adjusted if spawning times change. Adaptation strategies could better account for phenological changes through expanded, coordinated, and high-resolution monitoring programs (to track changes), vulnerability assessments (to prioritize focus areas or species), as well as forecast models and dynamic management tools that consider ongoing and projected temporal system changes (to improve decision-making). These actions can help managers better prepare for phenological shifts that may impact resources of conservation concern or human activities dependent on the ocean. Information that provides advanced warning of events that may disrupt other activities or industries may be needed if phenology shifts become more widespread in the region in the future. Many gaps in knowledge remain in the Gulf of Maine. Additional research and monitoring that focuses specifically on temporal shifts is needed to improve understanding of the risks and opportunities in the region.

Results and stakeholder engagement activities stemming from this project have led to additional inquiries that are being pursued as part of the NE CASC project "How and why is the timing and occurrence of seasonal migrants in the Gulf of Maine changing due to climate?". This subsequent effort is expanding and applying the results found here to pursue threat

assessments of shipping activities with North Atlantic right whale interactions in a changing climate and ecosystem assessments of the trophic role of key forage fishes, sand lances (*Ammodytes* sp.).

Finally, this project brought numerous stakeholders to the table over the past 5 years, including tribal, state and federal agencies, NGOs and other interested stakeholders. Through these efforts, and by leading a regional synthetic working group, the team has helped make phenology an important area of research in the region and provided significant exposure for the NE CASC and the University of Massachusetts Amherst. The results of each independent project, and the sum-total, have provided management implications of shifting phenology to numerous agencies and recommendations for adaptation to climate change.

Outreach and Products:

Publications:

1) Yakola, Keenan, Adrian Jordaan, Steven Kress, Paula Shannon, and Michelle Staudinger. In preparation. Inter and intraspecific comparisons of tern chick diet across seven nesting colonies in the Gulf of Maine, USA. Anticipated submission to The Auk October 2019.
2) Dalton, Rebecca, John Sheppard, Jack Finn, Adrian Jordaan, and Michelle Staudinger. In review. Climate-induced shifts in phenology: spring spawning migration patterns in adult alewife (*Alosa pseudoharengus*). Submitted to Canadian Journal of Fisheries and Aquatic Sciences October 2019.
3) Staudinger, Michelle D., Mills Katherine E., Stamieszkin Karen, Record Nicholas R., Hudak Christine A., Allyn Andrew, Diamond Antony, Friedland Kevin D., Golet Walt, Henderson Meghan Elisabeth, Hernandez Christina M., Huntington Thomas G., Ji Rubao, Johnson Catherine L., Johnson David Samuel, Jordaan Adrian, Kocik John, Li Yun, Liebman Matthew, Nichols Owen C., Pendleton Daniel, R. Richards Anne, Robben Thomas, Thomas Andrew C., Walsh Harvey J., Yakola Keenan (2019) It's about time: A synthesis of changing phenology in the Gulf of Maine ecosystem, Fisheries Oceanography DOI 10.1111/fog.12429
4) Alexander, Karen E., William B. Leavenworth, Theodore V. Willis, Carolyn Hall, Steven Mattocks, Steven M. Bittner, Emily Klein, Michelle Staudinger, Alexander Bryan, Julianne Rosset, Benjamin H. Carr, Adrian Jordaan. 2017. Tambora and the mackerel year: Phenology and fisheries during an extreme climate event. Science Advances.18 Jan, 2017

Theses and reports:

- Yakola, K. 2019. An examination of tern diets in a changing Gulf of Maine. University of Massachusetts Amherst. Masters Thesis. 104 p. https://scholarworks.umass.edu/masters_theses_2/
- Dalton, R. 2018. Climate Change, Phenological Shifts, and Species Interactions: Case Studies in Subalpine Plant and Migratory Fish Populations. Duke University PhD Dissertation. 127 p.
- Dalton, R. 2018. Climate-induced shifts in phenology of marine ecosystems: A case study on migration patterns in *Alosa psuedoherengus*. Final report to the National Science Foundation Graduate Research Internship Program. 12 p.

Conference Presentations:

2019 Staudinger, M.D., C. Hudak, O. Nichols. *It's about time: A synthesis of changing phenology in the Gulf of Maine Ecosystem.* State of Wellfleet Harbor Conference.

2019 Sheppard, J., R. Dalton, M.D. Staudinger. *Shifts in phenology of the spring spawning of adult alewife (Alosa pseudoharengus): Impacts of climate and population recovery.* Symposium: If the Time is Right: Phenology Match and Mismatches Across Ecosystems. AFS Annual Meeting.

2019 Staudinger, M.D., R. Dalton, H. Leggett, J. Sheppard. *Shifts in spring migration patterns by adult alewife (Alosa pseudoharengus): impacts of climate and population recovery.* GOM2050 Conference. Poster presentation.

2019 Yakola, K. A. Jordaan, P. Shannon, S. Kress, and M. D. Staudinger. *Long-term Trends and Potential Drivers of Dietary Variability in Tern Diet in the Gulf of Maine, USA.* Pacific Seabird Working Group Meeting. Oral presentation.

2018 Jordaan, A. and Staudinger, M.D. *Ecological and Management Implications of Climate Change Induced Shifts in Species' Phenologies*. 9th National Summit on Coastal and Estuarine Restoration and Management. Poster presentation.

2018 Dalton, R. "Phenological shifts in adult alewife migration in Massachusetts", Duke University Biology Department Population Biology Seminar.

2018 Staudinger, M.D. *Climate-induced shifts in phenology: Case studies of fish, whales, and seabirds in the Gulf of Maine.* School of Marine Science and Technology, UMass Dartmouth, Departmental Seminar.

2018 Staudinger, M.D. *Time is of the Essence: Climate-Induced Shifts in Phenology.* Monsters of Climate Science Workshop, AFS Annual Meeting.

2018 Staudinger, M.D., D. Pendleton, and A. Jordaan. *Climate-induced shifts in phenology: Case studies of fish, whales, and seabirds in the Gulf of Maine.* 4th International Symposium on the Effects of Climate Change on the World's Oceans, Session 8 - Understanding the impact of Abrupt Ocean Warming and Continental Scale Connections

on marine productivity and food security via Western Boundary Currents. Washington DC. Oral presentation.

2017 Staudinger, M.D., A. Davis, M. Devine, L. Deegan, and A. Jordaan. *Climate change induced shifts in migration timing of adult alewife (Alosa psuedoherengus) in Massachusetts natal streams*. AFS Annual Meeting, Tampa FL. Oral presentation.

2015 Jordaan, A., M. Staudinger, and K. Alexander. *Ecological and management implications of climate change induced shifts in phenology of coastal fish and wildlife species in the Northeast region*. RARGOM Annual Science Meeting, Portsmouth, NH. Oral presentation.

2015 Staudinger, MD, K. Alexander, and A. Jordaan. *Ecological and management implications of climate change induced shifts in phenology of coastal fish and wildlife species in the Northeast*. American Fisheries Society Meeting, August 17, 2015. Poster

Stakeholder outreach presentations:

2019 Staudinger, M.D. *Shifts in timing of the spring spawning run: Implications of climate change and population recovery*. River Herring Network Annual Meeting.

2019 Staudinger, M.D. Climate-induced shifts in phenology in the Gulf of Maine: Implications and potential adaptation strategies. Acadia National Park Staff Seminar.

2019 Staudinger, M.D. *Timing is everything: how fish and wildlife are responding to climate change through shifts in phenology in the Gulf of Maine*. Schoodic Institute at Acadia National Park public seminar.

2019 Staudinger, M.D. *Changes in Alewife Spring Spawning Migration*. Facilitated discussion with New England tribal nations. Organized in conjunction with Casey Thornbrugh.

2019 Staudinger, M.D. *Climate Adaptation Science for Coastal Habitats, Species, and Ecosystems*. NE CASC Seminar Series.

2017 Staudinger, M.D. *Evaluating shifts in phenology in river herring in New England Watersheds*. River Herring Technical Expert Working Group (TEWG). Oral presentation.

2017 Yakola, K., M. Staudinger, A. Jordaan, S. Kress, and P. Shannon. Preliminary exploration of long-term trends in Sterna sp. chick diet in the Gulf of Maine. Roseate Tern Recovery WG meeting, Westborough MA. Oral presentation.

2017 Jordaan, A. How changing climate can lead to changes in species phenology and climate effects primer. NOAA Climate Stewards and Connecticut Sea Grant, Educator Professional Development Workshop “Resilience: It’s Not Just Surviving the Zombie Apocalypse”. Connecticut Sea Grant, University of Connecticut - Avery Point campus Keynote oral presentation.

2016 Staudinger, M.D. *How vulnerable are river herring to climate change?* River Herring Network Annual Meeting. Oral presentation.

2016 Staudinger, M.D., and A. Jordaan. *The times they are a changing: Shifting phenology in Northeast coastal ecosystems.* NE CASC Seminar Series. Co-presented oral webinar..

Workshops:

- RARGOM phenology Working group meeting, Gulf of Maine Research Institute, Portland ME. August 1-2, 2017. 20 participants.

Awards:

- Keenan Yakola's paper, "Long-Term Trends and Potential Drivers of Chick Diet in Four Tern Species in the Gulf of Maine, USA", won the Best Student Paper Award at the 46th annual Pacific Seabird Group held in Kaua'i, Hawaii, USA from 27 Feb to 2 Mar 2019.
- Sam Stettiner was awarded an Undergraduate Sustainability Research Award from the UMass Amherst Libraries for his project "Ecological and management implications of climate change induced shifts in phenology of alewife", March, 2016.

Public outreach and media coverage:

- News New Publication: Its About Time April 23rd 2019
- News: New Study Compiles Gulf of Maine Seasonal Wildlife Timing Shifts, Urges Broader Use of Marine Data in Understanding Climate Change UMass Amherst April 23 2019
- News: NE CASC Fellow Awarded by Pacific Seabird Group Mar. 11 2019
- Report: National Science Foundation Graduate Research Internship Program -Project Summary-Rebecca M. Dalton 1-May-2018
- Blog: "What do fish and flowers have in common?" 18 December 2017
- News: How the Timing of Physical and Biological Processes are Changing in the Gulf of Maine August 10, 2016
- Blog: Maine's First State Record of Ancient Murrelet: How it's vagrancy could be a warning Climate Change, July 20, 2016
- News: Notes From the Field: Don't Count All Your Eggs Until They Hatch July 14, 2016
- News: Puffin Cams are Live on Seal Island, Maine! June 14, 2016
- UMass Undergraduate Intern, Sam Stettiner, received accolades for "Ecological and management implications of climate change induced shifts in phenology of alewife" in the UMass Amherst Libraries Undergraduate Sustainability Research Awards, March 12, 2016.
- News: Climate Change Impacts on Marine Species of Conservation Concern March 10, 2016
- News: Secretary Jewell Announces new Wildlife and Climate Studies at the NE CASC. December 18, 2014.

Communications with decision-makers:

- Attendance and break-out sessions at the Roseate tern Recovery WG annual meeting (2015-2018)
- New England Aquarium – initial outreach meeting Jan 12, 2016, ~10 attendees to discuss phenology research needs and collaboration potential
- Center for Coastal Studies – initial outreach meeting Feb 19, 2015, 10-15 attendees to discuss phenology research needs and collaboration potential
- 2015 and 2016 annual meetings of the Regional Association for Research on the Gulf of Maine (RARGOM) -Initial outreach at the 2015 meeting "*How is the timing of all things changing in the Gulf of Maine?*"; update presentation at 2016 meeting on working group progress

Citations

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