Developing Indices of Climate and Trophic Linkages of Euphausiids and Atlantic Herring in the Gulf of Maine Ecosystem

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Project Duration: 2 years

Total Funding Request: $100,173
Year 1 Request: $46,394
Year 2 Request: $53,779

Year 1: NEFSC: $3,000; WHOI: $43,394
Year 2: NEFSC: $4,000; WHOI: $49,779

Note to Reviewers:

In response to the insightful comments from reviewers of a previous version of this proposal submitted to the FATE program last year, we have made a number of changes here:

- The overall cost of the proposal has been reduced substantially (cut in half) by reducing travel costs and the amount of funds requested in support of postdoc/co-PI Lowe.
- The analyses of the linkages between herring, euphausiid prey, and oceanographic conditions have been put into a more hypothesis-driven framework.
- The deliverables and benefits have been clarified.

Background

The goals of this proposal are to quantify climate-driven interactions between euphausiids (i.e., krill) and Atlantic herring (*Clupea harengus*) in the Gulf of Maine/Georges Bank (GOM/GB) region using new acoustically derived indices of euphausiid density and biomass and to quantify the effects of both euphausiid consumption and environmental variability on Atlantic herring stock metrics and production. As described further in the benefits section, the motivation for this work is driven largely by input from Northeast Fisheries Science Center (NEFSC) personnel and the NEFSC's Strategic Science Plan for 2016-2021. The proposed work will fill several major information gaps in our understanding of drivers of euphausiid biomass, the overall importance of this under-studied prey group to Atlantic herring stocks, the uncertainty associated with key trophic nodes in mass-balance ecosystem models, and connections between the climate of the North Atlantic region and the oceanography of the deep basins in the Gulf of Maine.

Atlantic herring are at the nexus of ecosystem structure and function in the Northeast U.S. Shelf Large Marine Ecosystem (NES-LME; Overholtz & Link 2009), support a large commercial fishery that in turn augments the lucrative New England lobster fishery (Lowther, 2012), and are strongly influenced by the environment. Atlantic herring have a broad diet spectrum throughout their life history with adults feeding primarily on copepods, chaetognaths, and euphausiids (Bigelow & Schroeder 1953; Maurer, 1976). Adult diet composition across the NES-LME is highly variable in both space (Reid et al. 1999) and time: ongoing work by PIs Lowe and Lawson shows that euphausiids periodically constitute 50-80% of adult herring diets immediately following the fall spawn in the GOM/GB (Fig. 1). However, there is a periodicity in euphausiid consumption by herring that may relate to euphausiid availability, species composition, and associated environmental and climate drivers.

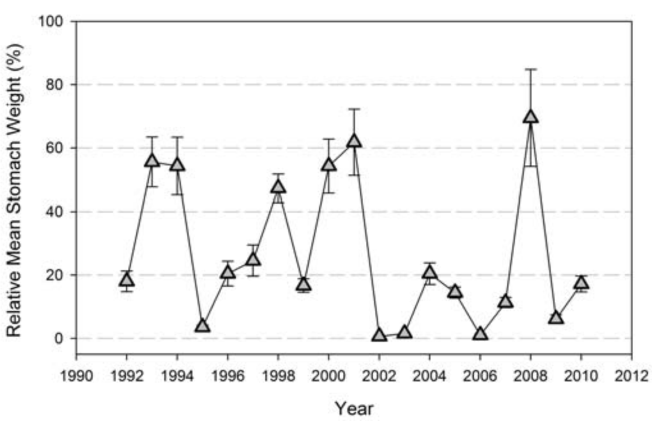

Figure 1. Mean annual (1992-2012) percentage of pre-spawn Atlantic herring diets that is euphausiid in the GOM/GB spawning area. Data derived from the NEFSC fall bottom trawl survey and food habits programs.

Like Atlantic herring, euphausiids are also an important component of pelagic marine ecosystems (Cochrane et al. 2000) and are highly susceptible to oceanographic variability. Yet surprisingly little information is available on their spatial and temporal patterns of distribution, biomass, and their trophic role in the GOM/GB region. The NEFSC is aggressively building mass-balance ecosystem models for the GOM that aggregate euphausiids into a single, poorly resolved “micronekton” node (Link et al. 2008) and enthusiastically supports the development of improved biomass indices for this under-sampled prey group.

Currently, euphausiid density, biomass, and production estimates are derived from shelf-wide, systematic zooplankton surveys conducted by the NEFSC (i.e., Ecosystem Monitoring program (ECOMON)). This survey uses inadequate sampling gear (i.e., bongo nets) for collecting euphausiids (Napp et al. 2002) and samples to a maximum depth of 200 m, above the preferred daytime habitat for vertically migrating euphausiids. Though they provide a useful indicator of temporal and spatial patterns of relative density (Lowe et al. *in prep*A), these data likely underestimate true euphausiid densities in ways that may vary between species and geographic regions. Multi-frequency acoustics, on the other hand, are standard on NEFSC survey vessels and have emerged as a powerful tool for assessing the abundance and spatial distribution of euphausiids (Lawson et al. 2008; Ressler et al. 2012).

The deep basins of the GOM/GB region are oceanographically complex and defined largely by variations in circulation, heat transport and water column properties (Mountain & Jessen 1987). These properties are important drivers of ecosystem structure (Greene & Pershing 2007; Head & Pepin 2010). Further complicating these drivers, there has been unprecedented freshening, increased water temperature, and changes in bottom water composition in the GOM that have been accompanied by changes in the zooplankton community (Kane 2007, 2009; Greene & Pershing 2007). The changing properties of the pelagic environment are likely to exert a strong influence on the distribution and abundance of euphausiids in the GOM/GB region.

There is growing body of evidence suggesting that euphausiids are a critical component of the NES-LME ecosystem and provide an important forage base for numerous commercially important fishes (e.g., Atlantic herring, silver hake *Merluccius bilinearis*, and Acadian redfish *Sebastes fasciatus*; Lowe et al. *in prep*B). Developing a holistic understanding of the interrelationships among euphausiids, Atlantic herring, and the environment is not only important for managing the GOM/GB Atlantic herring complex within an integrated ecosystem framework but is likely to be an important step in resolving our understanding of euphausiid interactions with other species as well.

Approach:
We propose to examine climate- and environment-related drivers of euphausiid distribution and abundance, as well as their trophic importance to Atlantic herring using a combination of existing data collected by NEFSC. These include multi-frequency acoustic data from dedicated surveys, long-term bottom trawl and food habits data, and associated oceanographic data from surveys covering the entire pre-spawning concentration of Atlantic herring in the GOM/GB region (Fig. 2). The proposed work will address the following objectives.

<u>Objective 1</u>: Develop a time-series (1999-2012) of euphausiid density, biomass, and distribution for the GOM/GB region using the acoustic survey data. The NEFSC’s annual fall (Sept. through mid-Oct.) acoustic survey for Atlantic herring, conducted from 1999-2012, was designed to enumerate pre-spawning herring in pelagic habitats in the GOM/GB region. The frequencies employed during the survey (18, 38, and 120 kHz) are appropriate for making concurrent acoustic observations of euphausiids, in addition to their original use for the herring assessment. The survey data have already been fully post-processed (e.g., noise and bottom signal removed) and backscatter attributable to herring has been identified and used to derive herring abundance estimates (Jech & Sullivan 2014). Acoustic scattering in the Gulf of Maine arises from many sources (Lavery et al., 2007) but in the herring acoustic survey region the dominant scatterers are herring and euphausiids (Jech and Michaels 2006; Lawson, Jech unpublished data), allowing for euphausiids to be discriminated in the acoustic record on the basis of the frequency dependence of their scattering. We will assess and extend, as necessary, multi-frequency methods available in the literature, in order to develop a suitable protocol for discriminating euphausiids from other scatterers (e.g., gas-bearing organisms like fish, and smaller zooplankton like copepods) on the basis of their frequency response (i.e., threshold approach, Jech & Michaels 2006; “dB-differencing” combined with thresholds, Kang et al. 2002, Lawson et al. 2008; “Z-score”, De Robertis et al. 2010; and Trenkel/Berger method, Trenkel and Berger 2013). Additionally, in the fall of 2010, PI Lawson collected depth-stratified net samples to ground-truth acoustic data in a separate cruise within the same study region. These data will be used to parameterize euphausiid acoustic scattering models (Lawson et al. 2006) that will be applied first to the 2010 survey data, and then extended to the remainder of the acoustic survey data to develop a 14 year time series of euphausiid distribution and abundance. Given the accuracy of the scattering models and acoustic resolution, we may be able to estimate euphausiid mean length.

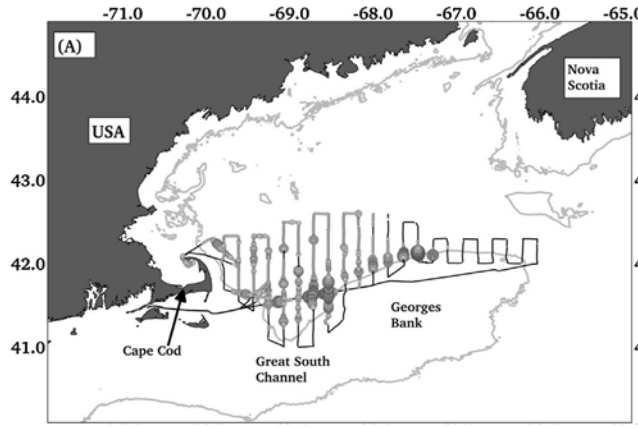

Figure 2. Map of fall acoustic survey area with acoustic transect from 2010 (Jech & Michaels 2014).

<u>Objective 2</u>**: Develop a suite of environmental and oceanographic indicators for the deepwater basins of the GOM where euphausiids (especially the large species *Meganyctiphanes norvegica*) are abundant and overlap with known spawning areas for Atlantic herring.** Oceanographic and atmospheric data specific to the acoustic survey area will be derived from all of the applicable surveys in the NEFSC’s database (ECOMON, multispecies bottom trawl surveys, and acoustic surveys), and NOAA’s International Comprehensive Ocean-Atmosphere Data Set (ICODAS). Large-scale climate indices (e.g., NAO and AMO) will be obtained from the NOAA Climate Prediction Center. We will investigate the relationships among oceanographic data and large-scale climate indices to develop a suite of physical indicators of climate attributes that are specific to the survey area and deep basins (e.g., Franklin, Wilkinson, and Georges) in the GOM. Previous work indicates a strong relationship between the wintertime North Atlantic Oscillation index and bottom water properties in the GOM (NEFSC’s Ecosystem Assessment Program 2012). We will explicitly examine the relationship between water column properties (i.e., bottom temperature, salinity, stratification, etc.) in the GOM/GB and a suite of large-scale climate indices.

<u>Objective 3</u>: Quantify the relationships among euphausiid distribution, abundance, and consumption by herring, as well as with environmental and oceanographic indicators. Atlantic herring stomach contents, obtained from the NEFSC food habits database, will be used to directly assess the trophic importance of euphausiids, other micronekton, and the zooplankton community to adult herring in the GOM/GB directly after the fall spawning event. The relevant fall stomach samples were collected from the fall bottom trawl surveys and hence provide a random sample of typical adult herring diet. Gut evacuation models will be used to estimate fall euphausiid consumption in the GOM/GB by scaling *per capita* consumption rate to acoustic estimates of Atlantic herring abundance. PIs Lowe and Lawson are using the same approach to estimate euphausiid consumption across a much larger area (Lowe et al. *in prep*B). However, that work uses swept-area abundance indices from the entire bottom trawl survey to derive euphausiid consumption estimates; such indices are better suited for groundfish stocks and problematic for pelagic species like herring (Overholtz et al. 2006). Using acoustic-based estimates of herring abundance in the model will provide a more accurate estimate of euphausiid consumption in the GOM. In addition, a multivariate framework, using the full diet spectra of Atlantic herring from the survey area, will be used to not only quantify inter-annual differences in diet composition, but also identify environmental and oceanographic drivers of diet variability (e.g., Lowe & Peterson 2013). A Generalized Additive Model framework, which allows for the inclusion of both non-linear relationships and spatial structure, will be used to test the hypotheses that 1) herring predation on euphausiids fluctuates with euphausiid availability, 2) inter-annual variability in euphausiid density is associated with different water characteristics in the deep basins, and 3) these variations are associated with basin-scale climate indices (i.e., NAO and AMO). In addition, we will also explore lags in euphausiid consumption by comparing our derived biomass estimates to readily available spring Atlantic herring diet data. Further, we will use this same framework to quantify the relationships between euphausiid consumption and Atlantic herring body condition and spawning stock biomass. Such information can be used to assess the degree to which these prey support and/or limit the GOM/GB/GOM herring complex.

<u>Objective 4</u>: Resolve our understanding of energy flow through the lower trophic levels via ecosystem modeling incorporating the new indices of euphausiid biomass. PI Lucey is currently developing new mass balance models for the region and will segregate the euphausiids from other micronekton. Existing mass balance models for the region, for example EMAX (Link et al. 2006, 2008), currently aggregate euphausiids with amphipods, mysid shrimp, and other decapods into a common micronekton node. This node is viewed as poorly resolved. Therefore, the goal is to run two mass balance models for the herring survey area: one using the poorly resolved “micronekton” node and one that incorporates the new data. This approach allows us to quantify the uncertainty in model outputs with the expectation that improved model inputs should result in better projections and assure that the model will not rely on ecologically unsupported estimates of prey biomass.

Benefits:
The outcomes of this work will provide the basis for integrated scientific advice to managers by addressing a persistent gap in our understanding of the influence of climate, habitat factors, and species interactions on Atlantic herring bioenergetics and population dynamics. This work is directly aligned with Focus F in the NEFSC Strategic Science Plan under the theme Science in Support of Ecosystem-Based Fisheries Management.

This project facilitates and advances center-wide communication and collaboration by drawing on the expertise of NEFSC personnel from the Advanced Sampling Technologies (PI Jech), Oceanography Branch (PI Fratantoni), and Ecosystem Assessment Program (PI Lucey) together with personnel from the Biology department at Woods Hole Oceanographic Institution (PIs Lawson and Lowe). This collaboration supports the goals of the NEFSC Strategic Science Plan under the theme of Organizational Excellence.

Our proposed work meets the requirements of FATE research priorities #1 and 3. We specifically address research priority #1 by utilizing newly derived prey (i.e., krill) density and biomass indices, environmental and oceanographic indicators specific to the deep basins of the GOM, and long-term food habits data to test the overarching hypothesis that herring predation on euphausiids fluctuates with euphausiid availability through inter-annual variability in water characteristics in the deep basins of the GOM and that krill, through trophic interactions, support the GB/GOM management unit of the Northwest Atlantic herring stock. To that end, the Coastal Pelagics Task Group in the NEFSC Population Dynamics Branch has expressed interest in incorporating an improved prey index and environmental indicators into the Atlantic herring stock assessment model to improve forecast capabilities and better inform catch advice.

In addition, our work also addresses research priority #3 by incorporating our improved estimates of euphausiid density and biomass into mass-balance ecosystem models currently being developed the NEFSC's Ecosystem Assessment Program and examining how model performance affects management strategies. Further, all indicators derived from this work will be made available to the Ecosystem, Protected Species, and Population Biology Branches at the NEFSC can be used for risk analyses exploring the potential impacts of climate change to the deep basins of the GOM (e.g., Gaichas et al. 2012).

Deliverables

- Fourteen-year time series of the euphausiids biomass that will be incorporated into existing mass balance models for the region and the annual Ecosystem Status Report.
- Detailed information on how the Atlantic herring stock responds to euphausiid consumption, prey availability, the environment, and large-scale climate transients in the deep water basins within the GOM/GB region.
- Acoustic method for estimating euphausiid abundance that can be ported to other regional surveys (ECOMON, multispecies bottom trawl survey, and Integrated Pelagics Survey) and used to estimate euphausiid biomass at larger spatial and temporal scales.
- Environmental and oceanographic indicators that are specific to the deepwater basins of the GOM and can be used to monitor trends at the ecosystem level that are associated with climate change and ocean acidification.
- Multiple peer-reviewed publications and presentations at regional, national, and international meetings, such as regional fisheries council meetings, FATE annual meeting, ICES WGNARS (Working Group for the North Atlantic Regional Seas), and ICES WGFAST (Fisheries Acoustic Science and Technology).

Statement of Previous FATE Results

Ji, Chen, Fratantoni, Hare - Stratification indices for stock and ecosystem assessments from a data assimilative circulation model FY12-FY14. The goal of this project was to develop stratification indices for the Northeast U.S. shelf ecosystem based on the 33-year reanalysis product of a data assimilative circulation model. Spatially explicit stratification indices were constructed, characterizing the spatio-temporal variability and scales of stratification on the Northeast US shelf. Indices were examined on seasonal and interannual time scales, with the focus on the joint and respective effects of warming and freshening on the magnitude and timing of stratification development and breakdown. The interannual variation of the timing of stratification onset was related to the phenology of phytoplankton blooms across the region. Results from this project are presented in two published papers and one manuscript in preparation.

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Budget

Personnel	Months	Year 1 1/1/16 - 12/31/16 Salary	Months	Year 2 1/1/17 - 12/31/17 Salary	Months	Total Salary
G. Lawson	0.5	$ 4,742	1	$ 9,816	1.5	$ 14,558
A. Brown	0.11	$ 572	0.11	$ 592	0.22	$ 1,164
Fringe (37.80%)		$ 1,875		$ 3,671		$ 5,546
Travel		$ 2,500		$ 3,500		$ 6,000
Equipment		$ -		$ -		$ -
Supplies		$ 3,600		$ 1,100		$ 4,700
Contractual		$ 26,408		$ 19,174		$ 45,582
Other Direct Costs						
Publications		$ -		$ 3,000		$ 3,000
Communications		$ 50		$ 50		$ 100
Duplicating		$ 50		$ 50		$ 100
Shipping		$ 100		$ 100		$ 200
Total Direct Costs		$ 39,897		$ 41,053		$ 80,950
Indirect Costs[1]						
Lab Costs (54.69%)		$ 3,867		$ 7,575		$ 11,442
General & Administrative (35.88%)		$ 2,630		$ 5,151		$ 7,781
Totals		$ 46,394		$ 53,779		$ 100,173

[1]Rate applied to salary and fringe benefits