LTER: Scales of Variability in Ecosystem Dynamics and Production on the Changing Northeast U.S. Shelf (NES II)

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Overview
The Northwest Atlantic, renowned for its fisheries, is rapidly warming and experiencing other climate-related impacts. It will also see the largest development of coastal wind farms in the U.S. to date. The Northeast U.S. Shelf Long-Term Ecological Research program (NES-LTER) was designed to improve our ability to predict how climate change will affect the dynamics of the shelf's planktonic food webs and their ability to support the productivity of higher trophic levels. The PIs propose to extend the NES-LTER to a second phase (NES II). The focus of NES I was on seasonal time scales for evaluating and understanding shifts between communities, associated food webs, and the resulting energy flow. While NES I findings supported hypotheses about the large amplitude of seasonal variability, the project's participants also found striking levels of interannual and cross-shelf variability. These findings highlight the need for long-term observations and motivate new directions for NES II.

Intellectual Merit
Patterns of ecosystem change over seasons to decades have been documented in this region, but the key mechanisms linking changes in the physical environment, planktonic food webs, and higher trophic levels remain poorly understood. As a result, predictive capability is limited and management strategies are largely reactive. To address these needs, NES II not only maintains the long-term NES I strategy—which combines observations that provide regional-scale context, process cruises along a high gradient cross-shelf transect, high-frequency time series at an inner-shelf location, coupled biological-physical food web models, and targeted population models—but also increases our attention to ecosystem responses to disturbance. In particular, the PIs will investigate the impacts on community structure and trophic transfer of (i) increasing prevalence of heat waves, (ii) intrusions of offshore water associated with increasing instability in the Gulf Stream, and (iii) offshore wind farms now under construction on the NES. The long-term research plan is guided by an overarching science question: "How is climate change impacting the pelagic NES ecosystem and, in particular, affecting the relationship between compositional (e.g., species diversity and size structure) and aggregate (e.g., rates of primary production, and transfer of energy to higher trophic levels) variability?" The PIs will assess the extent to which the NES ecosystem possesses a biodiversity reservoir that is resilient to dramatic changes in the environment and that will allow the ecosystem to maintain overall productivity.

The intersection of human activities, environmental variability, and climate change in the NES has complex effects on ecosystem dynamics. There are indications that the pace of change is accelerating and a systematic approach to observe multiscale changes with sufficient detail is critical to understand the underlying causes and implications. NES II will leverage the foundational knowledge of NES I to gain a predictive understanding of how future ecosystem productivity will be influenced by the interplay of disturbance, interannual variability, seasonal forcing, and long-term environmental trends as they act on communities and the physiology of the species they comprise.

Broader Impacts
The Northeast U.S. shelf provides an array of ecosystem services including energy development, shipping, recreation, and conservation; its integrity is critical to the health of the Northeast U.S. economy. In the face of climate change and increasing human utilization of the coastal ocean, sustaining these ecosystem services and protecting endangered species will require effective management, which requires understanding of ecosystem dynamics and functioning that the NES II project will provide. To this end, the project will continue close collaborations with NOAA scientists. NES II will also conduct education and outreach via three main components: (1) training and mentoring for undergraduate and graduate students and postdoctoral researchers in LTER research; (2) an LTER Schoolyard program that engages middle and high school teachers and students; and (3) public outreach through targeted events, our website, and social media channels. The co-PIs will infuse all of these activities with attention to justice, equity, diversity and inclusion (JEDI). The NES JEDI Committee has developed an action plan to continue to enhance and sustain diversity within our project, foster a sense of belonging and equity, and nurture and guide team members.

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Project Description Table of Contents

1. Brief NES History and Conceptual Framework

NES LTER history. The Northeast U.S. Shelf (NES) is a highly productive temperate ecosystem in a coastal biome (Fig. 1). Human activities, environmental variability, and climate change intersect to have complex effects on NES ecosystem dynamics. The NES provides an array of ecosystem services including fishing, energy development, shipping, waste disposal, recreation, and conservation of iconic threatened species including Atlantic salmon, the North Atlantic right whale, and the Roseate tern. The region is rapidly warming and experiencing other climate-related impacts. Furthermore, there are indications that the pace of change is accelerating, emphasizing the need for the NES LTER program's systematic approach to observe multiscale changes with sufficient detail to develop understanding of the underlying causes and implications.

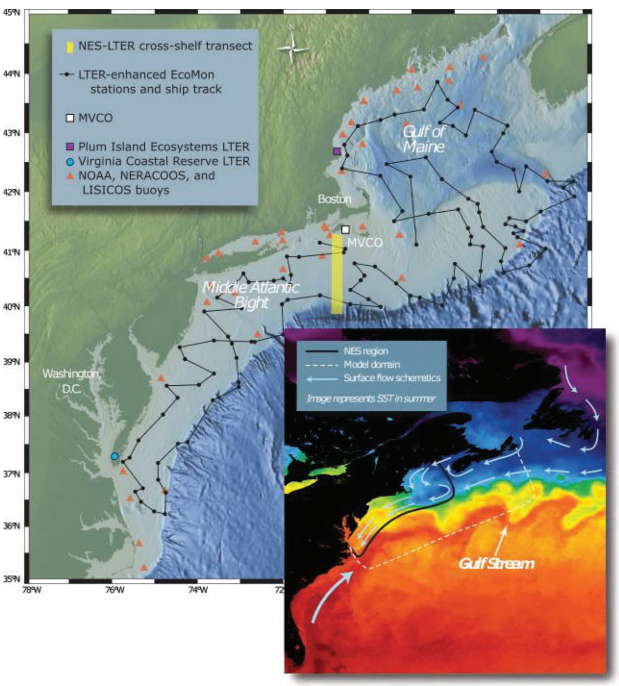


Fig. 1. Multi-scale observations and modeling are used to address LTER core areas within the NES site, spanning the continental shelf from North Carolina to Maine. Multi-decade high temporal resolution observations at a nearshore observatory (MVCO) are complemented by process observations focused along a seasonally occupied cross-shelf transect extending from MVCO to upper slope waters. Quarterly EcoMon surveys (example cruise track shown) and biannual trawl surveys by NOAA colleagues, along with NES-specific enhancements to these cruises, provide select information at broad spatial scales and a greater contextual understanding of changes occurring in the NES ecosystem. Regional observing system components, including NOAA buoys, also provide context. Multi-scale modeling addresses impacts of high latitude processes and basin-scale forcing in this highly advective system by encompassing a domain that extends beyond the NES (lower right, with example SST).

The overarching goal of NES LTER is to understand and predict how the composition and structure of planktonic food webs change through space and time in response to changes in the physical environment and how those changes impact ecosystem productivity across trophic levels. By conducting long-term studies of shelf-wide pelagic dynamics on the NES, our goals are to (1) characterize food web structure and function; (2) identify the mechanisms that link shifts in communities with changes in organic matter flows and trophic transfer pathways; and (3) understand the linkages and transfer of energy from the phytoplankton to pelagic forage fish. During the initial phase of the NES LTER project (NES I) we have also begun characterizing and understanding the relationship between variability in species composition and variability in aggregate properties such as total biomass and production across a range of space and time scales, as well as how this relationship may be influenced by climate change and other forms of disturbance. The overarching question guiding the NES research program remains:

> *How is climate change impacting the pelagic NES ecosystem and, in particular, affecting the relationship between compositional (e.g., species diversity and size structure) and aggregate (e.g., rates of primary production, and transfer of energy to higher trophic levels) variability?*

Conceptual and Theoretical Frameworks. Exactly how communities operate in any ecosystem depends on the nature of the environmental drivers and the composition of each community. Both the environmental conditions and the community composition are highly dynamic on the NES, and both are changing rapidly. As we transition to Phase II, a core element of the NES conceptual framework remains to quantify the range of physical conditions and processes that drive NES environmental variability on scales from days to decades (Fig. 2, top). Along-shelf advection and diverse processes at the shelf break lead to nutrient inputs, and processes controlling stratification affect vertical distribution. These and other processes also affect important factors such as light availability and temperature distribution.

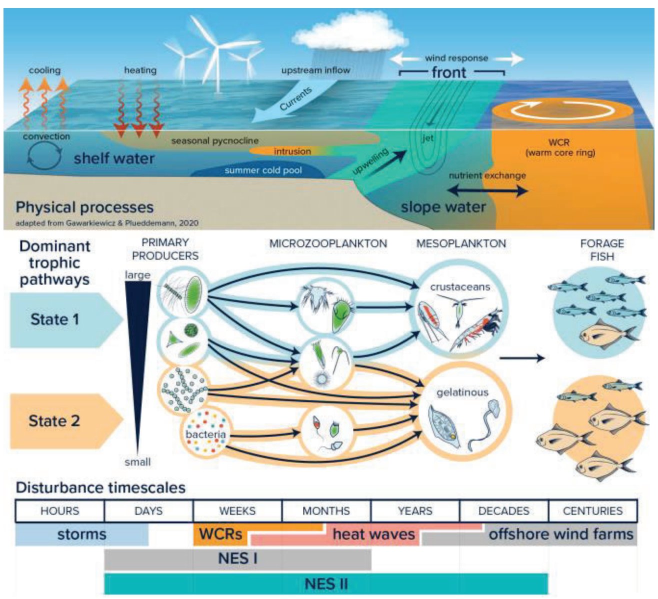


Fig. 2. Conceptual framework characterizing links among LTER core areas at the NES site. Top: Conceptual diagram of physical processes across the shelf. Middle: Simplified food web connections emphasizing the structuring role of cell size at lower trophic levels. Bottom: Time-space scales of interactions among dynamic forcings, disturbances, and ecological processes drive shifts across a spectrum of community structure and food web states. The framework highlights State 1 conditions when large-celled primary producers are abundant, which may occur both seasonally (common in NES winter) and in response to disturbances that shift resource availability or competition; and State 2, exemplifying a system with primary producers dominated by small cells and important pathways to higher trophic levels involving gelatinous consumers that may in turn select for specialists in the forage fish community.

Living in this dynamic environment are diverse plankton communities that support variable production pathways. During NES I, we evaluated hypotheses that linked important aspects of trophic pathways to the intense seasonal changes in environmental conditions on the shelf. Aspects of those hypotheses were supported, while others were challenged in intriguing ways (see Sec. 2). In response to Phase I insights, we have modified our NES conceptual framework to reflect a composite food web schema encompassing major hypothesized pathways of energy transfer (Fig. 2, middle) and to emphasize changes of the physical-biological system over different time scales. We continue to emphasize the importance of changes in the composition of the phytoplankton, but now also consider how energy and organic matter pathways vary in relative importance in response to forcing at scales including seasons, disturbance events, and multi-year trends. Our approach continues to build from ecological theory regarding two important types of variability that ecological communities exhibit in response to environmental variation: compositional and aggregate. Our observational and modeling approaches address both compositional variability (as reflected in changes in the relative abundance of component taxa) and aggregate variability (as reflected in changes in summary properties such as total abundance, biomass, and production). We aim to understand both of these aspects of community variability, including the extent to which they exhibit synchrony, asynchrony, or compensatory dynamics, which are critical to predict the responses of community structure and function to physical and/or biological perturbations.

The focus of NES I was initially on seasonal time scales for evaluating and understanding shifts between communities, associated food webs, and the resulting energy flow and net community production. While NES I findings largely supported our hypotheses about the large amplitude of seasonal variability, we also found striking levels of interannual and cross-shelf variability. These findings highlight the need for long term observations and motivate new directions for NES II. Ultimately, we seek to develop mechanistic understanding that can be extended to predictions about the effects of ongoing climate change punctuated by disturbances across a range of scales (Fig. 2, bottom).

2. Overview of NES II New Directions and Foci

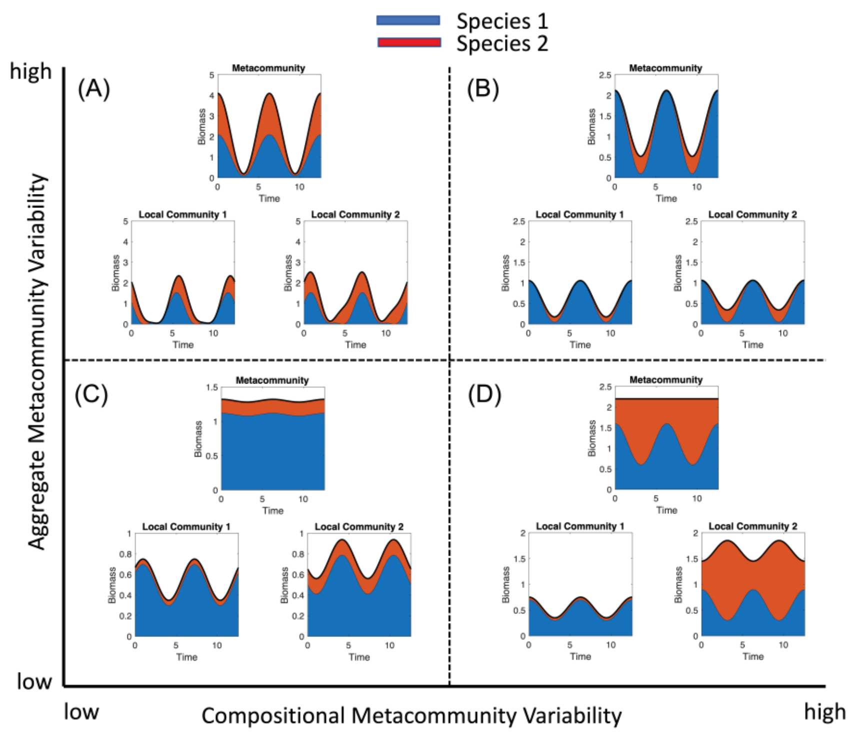
NES I time series, process cruise observations, and ecosystem models have generated important insights that relate to each of the LTER core research areas, including the spatial and temporal variability in physical forcing, distributions of inorganic nutrients and organic matter pools, taxonomic and size structure of plankton and fish communities, structure of food webs and trophic transfer pathways, and rates of primary and community production (Fig. 2). As we predicted, seasonal variability has proved to be especially high and has provided a means to explore hypotheses about mechanisms and ecosystem consequences of changes in the plankton (see Sec. 3).

The extent to which this variability is linked to specific mechanisms of disturbance and their patterns of occurrence at event- to multi-year scales remains unresolved and motivates new foci for NES II. We will continue efforts to characterize seasonal ecosystem changes, with new emphasis on evaluating hypotheses about grazing control and links between food web pathways and phytoplankton community structure. We updated our conceptual model (Fig. 2) and introduced new questions and approaches to evaluate hypotheses about the ways key disturbance mechanisms perturb expectations from seasonal climatologies. The combination of observations and modeling conducted during NES I have brought forward the importance of three types of disturbance: (1) increasingly frequent marine heat waves (MHWs) at local, regional, and basin scales; (2) intrusions of offshore waters linked to phenomena such as changes in instabilities of the Gulf Stream and more warm-core rings; and (3) emerging installation of extensive offshore wind infrastructure on the NES. Along with the conceptual model, a theoretical framework helped guide our work during NES I. That framework, inspired by Micheli et al. (1999), continues to provide a useful scaffold for organizing our data collection, analysis, and modeling work. Motivated by preliminary discoveries in NES I, we will augment this framework to accomplish NES II goals.

Micheli et al. (1999) pointed out that the temporal variability of an ecological community responding to environmental variation could be thought of as having two aspects: compositional variability—reflecting changes in the relative abundance of component species—and aggregate variability—reflecting changes in summary properties, such as total abundance, biomass, or production. Theoretical and experimental work (Gonzalez and Loreau 2009) has suggested that a combination of high compositional variability and low aggregate variability (a.k.a., compensatory dynamics) may confer resilience to community function in the face of disturbance or longer-timescale changes (e.g., associated with changing climate). In contrast, conventional wisdom holds that synchronous communities, which exhibit low levels of compositional variability and high levels of aggregate variability are relatively fragile. A mechanistic understanding of the drivers of both compositional and aggregate variability will be critical for predicting the responses of community structure and function to physical and/or biological disturbance.

In Sec. 5.2, we report on intriguing preliminary results that indicate a spatial gradient in the synchrony of community dynamics, at least for some taxa. While our computational models have always explicitly represented spatial dispersal processes (via advection) and spatial heterogeneity (in, e.g., salinity, temperature, and nutrients), the NES I theoretical framework does not have a spatial component. We propose to add spatial complexity to our framework in NES II, in a way that remains conceptually (and mathematically) useful. A simplifying abstraction of space that has proven powerful in terrestrial and freshwater community ecology is the *metacommunity* (Liebhold et al. 2004)—a group of distinct habitat patches, hosting several potentially interacting species, connected by the dispersal of individuals. The metacommunity concept is a simplification for the dynamic and spatially continuous NES; nevertheless, this simplification provides us powerful mathematical tractability for generating hypotheses, the validity of which we can explore with more complicated computational models.

Recently, Lamy et al. (2021) described a framework—and importantly, a set of diagnostic statistics that can be directly applied to the NES transect and EcoMon time series—that generalizes and extends the Micheli et al. (1999) framework to metacommunities (Box 1). The framework, which we will adopt, "highlights the importance of *spatial* synchrony [or compensation] in the *compositional* trajectories of local communities and sheds light on the underlying processes structuring metacommunities" (emphasis added). Just as temporal compensation in community dynamics can be expected to confer resilience, we expect that so too will spatial compensation in community composition.



Box 1. A theoretical framework for understanding spatiotemporal community variability (after Lamy et al. 2021), illustrated with a simplified metacommunity comprising two species (red and blue) living in two local communities connected by dispersal. In each panel (A-D), bottom two graphs illustrate the total biomass and relative species composition over time in the two local communities. These sum to form the metacommunity dynamic in the top central graph. Metacommunity variability through time has two aspects: aggregate and compositional. When aggregate metacommunity variability is high, there are relatively large variations in total biomass (A, B top graphs). These swings can be accompanied by changes in the relative abundance of species that are either small (A) or large (B). In contrast, the metacommunity may exhibit low aggregate variability, with approximately constant total biomass through time (C, D top graphs), again accompanied either by small (C) or large (D) changes in the relative abundance of the two species. If aggregate biomass changes synchronously in both localities, metapopulation aggregate variability is enhanced (A, B); if, on the other hand, oscillations in the aggregate are out of phase in the two locations (C, D), those oscillations are averaged out in the metacommunity sum. Compositional synchrony in space (B, D) favors compositional variability in the metacommunity, while out-of-phase compositional changes in space (i.e., compositional compensation; A, C) favors low metacommunity compositional variability.

3. Results from Prior Support

NES I research focused on three cross-disciplinary questions. The first centered on the interplay between the environment and spatial and temporal patterns of plankton species composition and biological production (Q1). Shifts in the plankton were then linked to variability in the feeding, condition, and distribution of pelagic forage fish (Q2). These two questions were foundational to Q3, which addresses vulnerability and resilience in the ecosystem in light of rapid climate change.

NES I Q1: *What are the main factors controlling spatial and temporal patterns of plankton species composition and biological production?*

NES I Q2: *How is variability in the feeding, condition, and distribution of pelagic forage fish linked to interannual variability and multi-year trends in plankton size structure and species composition and the ratio of export to total primary production?*

NES I Q3: *Is the NES ecosystem (and the services it provides) vulnerable to dramatic transformations in the face of rapid climate-induced environmental changes? Or does the diversity of species confer resilience providing a buffer against dramatic changes in overall productivity via shifts in species composition?*

In the remainder of this section, we first highlight ten peer-reviewed publications that address these three questions and then summarize in more detail NES I findings that motivate the refined research questions that structure NES II (see Sec. 5).

3.1. 10 significant publications from NES I

Food web structure and function. Marrec et al. (2021a L&O) quantified rates of primary production and herbivorous grazing losses along the NES cross-shelf transect. These process studies showed seasonal patterns with strong shifts in trophic transfer coupling from high in winter to lower in summer. Relationships between seasonal shifts in ecosystem structure and functional differences in organic matter transfer emphasize links between production rates and their environmental and ecological drivers. (Q1)

Drivers of seasonality in *Synechococcus* population dynamics on the NES. Hunter-Cevera et al. (2020 L&O) used a 16-yr hourly time series and a mathematical model to examine the factors that determine abundance patterns and provide a framework for understanding seasonal controls on *Synechococcus* at the Martha's Vineyard Coastal Observatory (MVCO). They found that drivers of cell division vary with season: cells are temperature-limited in winter and spring, but light-limited in the fall. (Q1)

Functional diversity in phytoplankton. Fowler et al. (2020a PNAS) used multi-decade high resolution time-series observations of single cells coupled with a matrix population model to examine seasonal and interannual dynamics in small phytoplankton. Eukaryotes reproduce much more rapidly than other picophytoplankton and appear to be preferred prey of the micrograzer community and so contribute more to the region's primary productivity than would be inferred from their abundance alone. (Q1)

Conditions of an unusual spring phytoplankton bloom. Smith et al. (2021 JGR) used transect cruises and high-resolution time series observations to document an unusual winter-spring bloom of *Phaeocystis pouchetii* in shallow shelf waters. The bloom contributed significantly to spatiotemporal variability, overall productivity, and regional ecology during the winter/spring transition. (Q1)

Spring dynamics at the shelf break. Combining in-situ and remote-sensing data and a numerical model, Oliver et al. (2022 JGR) examined the dynamics of how wind forcing affects productivity at the shelf break front. Springtime Ekman restratification driven by upfront winds drives ephemerally enhanced chlorophyll at the shelf break front and is linked to strong temporal variability of productivity. (Q1)

Nutrients and temperature drive seasonality. Zang et al. (2021 ICES JMS) used a high-resolution coupled biological-physical model to assess the seasonality of phytoplankton dynamics and the underlying mechanisms modulating spatial heterogeneity. The model captured observed spatiotemporal patterns and suggested that differences in seasonality between the Mid-Atlantic Bight and the Gulf of Maine result from the interplay between nutrient and temperature effects. (Q1)

Mechanisms of synchrony in zooplankton. Ji et al. (2021 ICES JMS) applied model-based scaling and sensitivity analyses to a 40-year plankton dataset from the Gulf of Maine. Spatial synchrony patterns in *Calanus finmarchicus* were shown to be season-dependent, with patterns largely driven by internal population dynamics in spring and both internal mortality and external dilution loss in fall. (Q2)

Linking zooplankton and forage fish variability. Suca et al. (2021b ICES JMS) combined stomach and lipid content with growth analyses to understand the population dynamics of sand lance and to construct an abundance regression model. *C. finmarchicus* abundance influences sand lance parental condition and recruitment (Fig. 3), directly driving interannual population variability. (Q2)

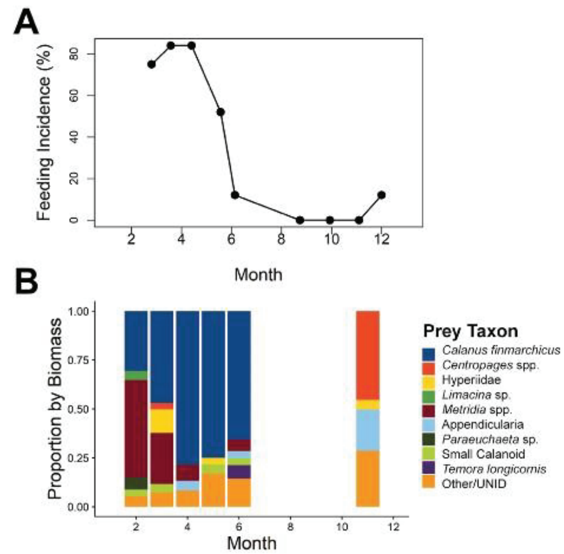


Fig. 3. Phenology and trophic connections in sand lance feeding ecology show importance of the lipid-rich copepod *C. finmarchicus* to diet (B) especially in spring (A). Suca et al. (2021b).

Spatial patterns in forage fish communities. Suca et al. (2021a ICES JMS) used species distribution models to assess the environmental drivers responsible for changes in the forage fish community's shelf occupancy. For some forage fishes, mean depth and latitude of shelf occupancy has trended deeper and northward with time, with some changes linked to habitat suitability associated with environmental conditions (e.g., warming) and others indicating more complex mechanisms. (Q2, Q3)

Offshore transport of organic matter, nutrients, and plankton. Zhang et al. (2023 Prog Oceanogr) analyzed in-situ and remote-sensing data to quantify the exchange of physical and biological materials between the shelf and neighboring slope sea. Disturbance from Gulf Stream rings can induce substantial transport across the shelf break and strong multi-faceted impacts on the shelf ecosystem. (Q3)

3.2. Mechanisms driving spatial and temporal variability in representative taxa from phytoplankton to fish

During NES I, we paired surveys of planktonic species diversity with focused investigations of particular taxa to advance mechanistic understanding of the drivers of spatial and temporal variability in populations and communities (Q1). For our taxon-focused work, we selected representatives of critical aspects of our conceptual model, linking functional or ecological diversity and spanning trophic levels from primary producers to forage fish. Insights from these studies highlight the importance of seasonality across trophic levels; the ubiquitous significance of temperature variability in regulating organismal responses (i.e., physiology, behavior) and ecological interactions (e.g., predation, grazing, parasitism); and the complexity and range of relevant physical processes.

To examine spatial and temporal patterns of diversity in phytoplankton communities, we sequenced the 18S rDNA of biomass collected on cross-shelf transect cruises. Furthermore, we sampled size-fractionated biomass to examine diversity and its drivers in more detail. Overall, species richness in surface waters was somewhat higher in summer than winter and increased by about 2-fold from on- to offshore stations, mostly driven by increases in the <5 µm size class, regardless of season (Fig. 4). Overall, the <5 µm size class was most species rich, consistent with findings for other regions (de Vargas et al. 2015). Species composition shifted with both season and distance from shore (Fig. 5) suggesting that these communities are closely tied to particular environmental conditions that support their growth, such as temperature, light and inorganic nitrogen, as has been observed in other planktonic communities (Anderson et al. 2022). The results raise new questions about the resilience of seasonally distinct communities to disturbance and the drivers of interannual variability (Sec. 5.1, 5.2). The sequencing effort is providing detailed information about phytoplankton communities. For example, we have identified over 200 species of the globally important diatom genus *Chaetoceros* inhabiting the NES. This number of species far exceeds what could be identified with microscopy allowing us to tease apart seasonal and disturbance signals in the growing time series with a high level of sensitivity.

The smallest primary producers in NES waters are numerically dominated by the genus *Synechococcus*. These picocyanobacteria (~1 µm) are ubiquitous in temperate coastal ecosystems worldwide and important in 'State 2' food webs (Fig. 2). Our time series observations at MVCO (2003-present) have shown that *Synechococcus* population dynamics are highly seasonal with temperature playing a major role in driving bloom timing within and between years (Hunter-Cevera et al. 2014, 2016, 2020). During NES I, we documented similar seasonal dynamics for picoeukaryotic phytoplankton (Fowler et al. 2020a). We hypothesized that *Synechococus* and other small cell types dominate the primary producers across the NES transect in warm stratified regimes, such as those that occur naturally in summer or could be caused by increasingly frequent MHWs. The findings of Stevens et al. (revised) support this hypothesis, showing that the same physiological controls on division rate (e.g., temperature limitation in cold conditions) control *Synechococcus* populations at MVCO and across the transect (Fig. 6). Evidence points to some differences, such as earlier spring bloom timing offshore compared to MVCO, but these are also consistent with earlier seasonal warming on the outer shelf, further emphasizing the robustness of our understanding of temperature as a driver for picoplankton dynamics.

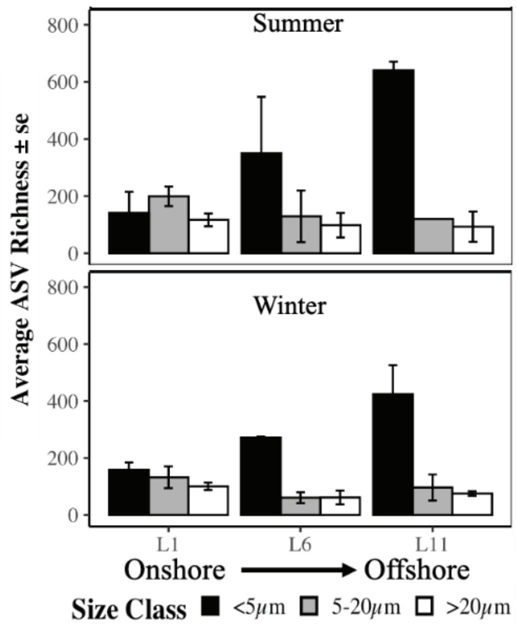


Fig. 4. Richness of 18S rDNA amplicon sequence variants (ASV) from surface waters in three size classes across the main transect in summer (top) and winter (bottom).

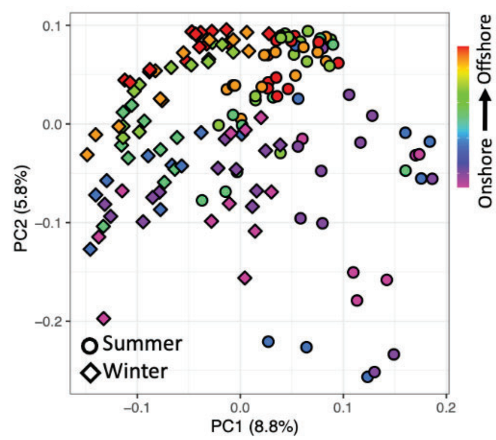


Fig. 5. Principal component analysis of phytoplankton community composition (from 18S rDNA amplicon sequencing) in summer (circles) and winter (diamonds) and with distance from shore (symbol colors).

The largest primary producers in NES waters are dominated by chain-forming diatoms, comprising numerous species and important in 'State 1' food webs (Fig. 2). Our observations of diatoms at MVCO (2006-present) highlight *Guinardia delicatula* as the top contributor to microplankton biomass across all seasons and years (Peacock et al. 2014). Observations on NES transect and broadscale cruises have confirmed the hypothesis that this species is important not only at MVCO but also throughout the region (Fig, 7). Furthermore, we have been able to show that broad patterns in the timing and location of blooms are consistent with our hypotheses about population dynamics being controlled by the interacting effects of temperature and mortality associated with parasitism. In Catlett et al. (subm.), we used machine learning classification combined with automated plankton imaging from 23 NES broadscale cruises since 2013 to elucidate abundance and parasitic infection dynamics of *G. delicatula*, showing seasonality found at MVCO is evident across the region (Fig. 7). Our results are consistent with hypotheses that temperature indirectly regulates diatom abundance via direct suppression of parasitism, and further that ongoing warming may enable parasitic infection to occur throughout the year, driving shifts in this important diatom's abundance dynamics with potential cascading effects on the NES ecosystem.

The lipid-rich calanoid copepod, *Calanus finmarchicus*, plays a critical role in the NES food web, especially in transfer of energy to fish in 'State 1' pathways (Fig. 2). A fundamental question regarding the variability of *C. finmarchicus* is the relative importance of biologically driven population growth vs. physically driven population exchanges over their multi-month life histories. Our model-based scaling

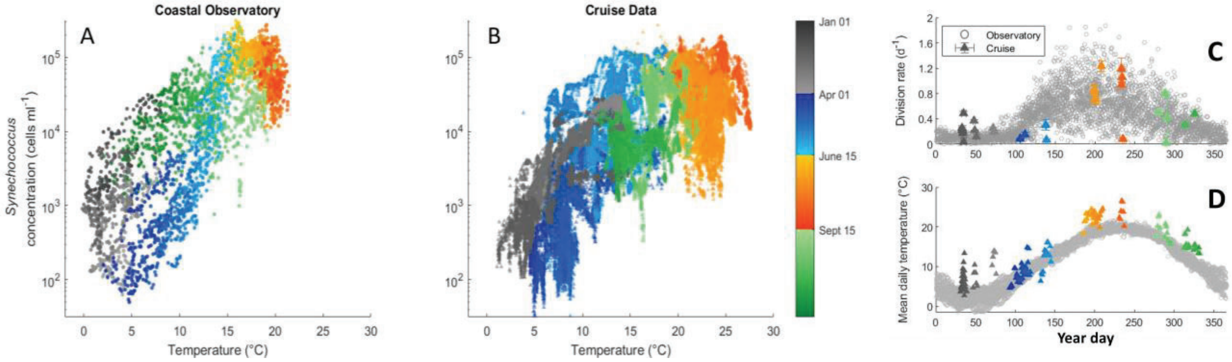


Fig. 6. Relationships between temperature and *Synechococcus* concentration (A, B) and *Synechococcus* division rate (C, D) are similar at MVCO and across a larger spatial scale sampled during cruises along the NES transect from MVCO to upper slope waters. The color of each point indicates time of year. MVCO values are daily averages over 2003-2019; cruise data are for each individual sample (2-min intervals) and reflect the combination of seasonal and spatial variability on 21 NES I cruises across 2018-2022. Stevens et al. (revised).

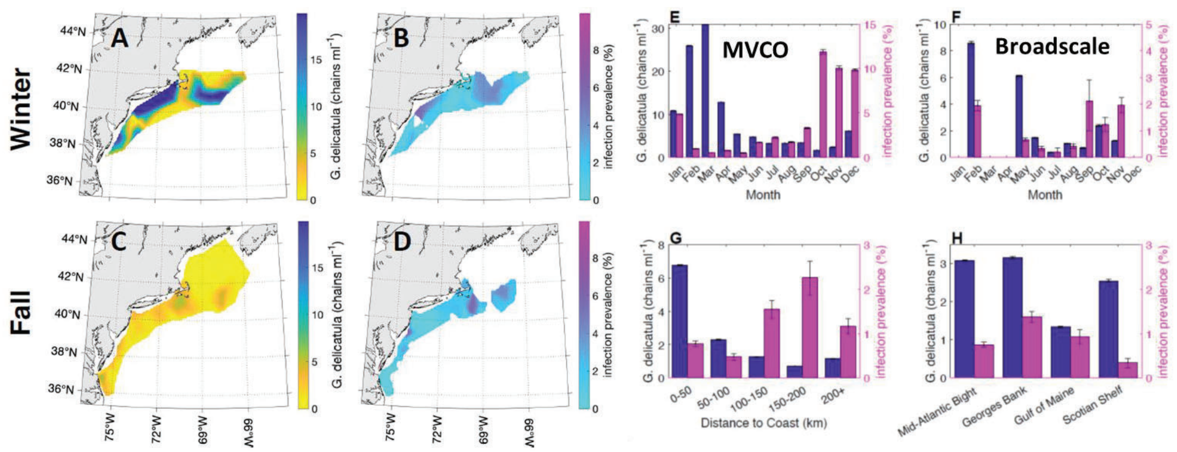


Fig. 7. Example composite maps for fall and winter (2013-2021) for *G. delicatula* concentration (A, C) and parasitoid infection prevalence (B, D) across the NES broadscale emphasizing similar bloom dynamics as previously documented for MVCO. Largest diatom blooms are found in cold winter waters while highest infection rates occur in warmer conditions during fall and further offshore (E-H). Catlett et al. (subm.).

showed distinct drivers in different seasons (Ji et al., 2021). In spring, there is strong synchrony of interannual variability, largely driven by internal population dynamics (growth vs mortality loss). In fall, the synchrony weakens, and variability is influenced by both internal mortality and external dilution loss (Ji et al. 2021; Wiebe et al. 2022). These results are consistent with *C. finmarchicus* synchrony patterns across the NES (Honda et al. in revision). Follow-up studies on the detailed spatial scales and associated drivers are currently on-going and will continue in NES II, including extending to other copepod species.

Northern sand lance (*Ammodytes dubius*) is an important lipid-rich forage fish species throughout the NES. Together with Atlantic herring (*Clupea harengus*), they dominate as critical prey for numerous top predators (Staudinger et al. 2020; Silva et al. 2021). In contrast to Atlantic herring, however, little previous work existed on sand lance to uncover drivers of their huge spatial and temporal abundance fluctuations. We examined the seasonal progression of sand lance diet, growth, and condition to explain annual variability in abundance (Suca et al. 2021b). Our observations showed that they feed, grow, and accumulate lipids in the late winter through summer, predominantly consuming the copepod *Calanus finmarchicus* (Fig. 3). Sand lance then cease feeding, utilize lipids, and begin gonad development in the fall. The abundance of *C. finmarchicus* is critical to recruitment and Atlantic herring can have a notable top-down effect on sand lance—muting the *Calanus* effect—through intra-guild predation upon larval sand lance (Fig. 8). Hydrography further impacts sand lance abundance as increases in warm slope water coming into the region decrease overwintering survival of adults. These results are contributing to understanding of changes in forage fish habitat (Suca et al. 2021a) and generating new hypotheses about potential long term impacts on NES forage fish communities.

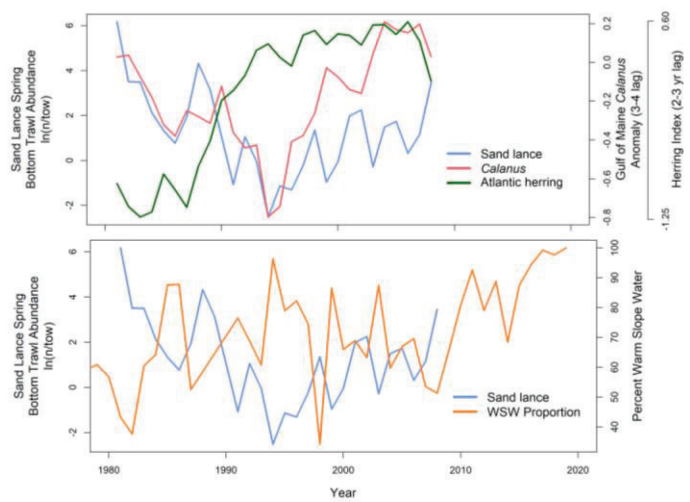


Fig. 8. Environmental drivers of sand lance abundance include (upper) *C. finmarchicus* winter-summer abundance anomaly (3- to 4-y lagged), Atlantic herring abundance index (2- to 3-y lagged), and (lower) warm slope water (WSW) proportion entering the region from offshore. From Suca et al. 2021b.

3.3. Seasonal and spatial patterns in primary production, trophic transfer, and food web pathways

Despite the ecological and economic importance of the NES, process studies that measure rates of organic matter production and flow are rare (Sibunka and Silverman 1989; Balch et al. 2007; Mannino et al. 2012). In NES, we measure gross primary production (GPP), net primary production (NPP=GPP minus phytoplankton respiration), and net community production (NCP= GPP-community respiration), as well as rates of herbivory. We combine multiple approaches, ranging from small volume deck board incubations to chemical tracers measured over tens of kilometers, to integrate field observations with biogeochemical models to yield a multi-faceted view of production and trophic transfer. With long term observations that span from cell physiology to large scale patterns in productivity, we are beginning to disentangle the role of environmental conditions, phytoplankton size structure, and trophic transfer rates and are moving toward quantitative and predictive understanding of energy and matter flow in NES food webs.

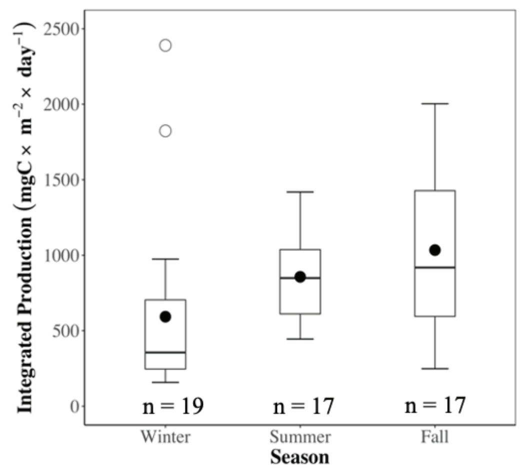


Fig. 9. Observed seasonal variability in depth-integrated NPP across the NES transect over 4 years of ^{13}C incubations.

Seasonal and spatial patterns of primary production: By combining measures of production made using isotope (^{13}C), chl-a generation (dilution), and triple oxygen isotope tracer methods, we confirmed our hypothesis that cross-shelf production is generally higher in summer than winter for (Fig. 9), likely due to light and temperature effects. We also found cross-shelf gradients. NPP, for example, decreased from near- to offshore in both winter and summer (Fig. 10A, B). NCP shows similar spatial patterns to NPP but has larger seasonal and interannual variability, especially during winter (Fig. 11). In contrast to NPP which showed spatial variations in both seasons, GPP did not show consistent spatial variation across the shelf in winter, suggesting differences in the response of autotrophic respiration to seasonal drivers (Fig. 11). These gradients will be exploited in NES II for hypothesis driven examinations of the relative importance of nutrient supplies, hydrography, temperature, and species composition of producers and consumers in setting primary production rates (see Sec. 5.1). In particular, NES I results suggest that temperature control plays a large role in GPP variations, with lower values in warmer summers. Interestingly, NCP is much less sensitive to temperature than GPP while the temperature dependence of NPP has yet to be examined. Given the increasing prevalence of MHWs, the temperature dependence on production will be explored in NES II (Sec 5.3).

Effects of phytoplankton size structure on primary production: The strong seasonality in chl-a biomass on the NES was associated with systematic shifts in phytoplankton size structure between summer and winter, with small (<5 µm) phytoplankton biomass dominant in summer and large (>20 µm) in winter. We found that the relative contribution to NPP by the different size classes mirrored their relative contribution to biomass. In winter, large cells generated > 50% of NPP at coastal and mid-shelf stations reflecting the importance of the winter diatom community to organic matter production across most of the shelf (Fig. 10A, B). The pattern was reversed in summer when the smallest cells generated at least 50% of NPP, reflecting the importance of cyanobacteria and small eukaryotes. Surprisingly, when rates of NPP were normalized to chl-a, the 5-20 µm size class had by far the largest NPP in both seasons (Fig. 10C, D). Persistently high chl-specific NPP rates for this size class suggest that it may be grazed more heavily than other size classes and thus make an outsized and unexpected contribution to energy flow on the NES regardless of season. Our biological model analyses suggest that higher phytoplankton growth rate due to warmer temperature is responsible for higher biomass-specific NPP in summer despite lower nutrient availability (Fig. 12). We will investigate these initial findings in NES II (Sec. 5.2).

NES I yielded intriguing results showing that individual species may drive production rates. For example, during particularly warm summer transect conditions in 2019, diatoms (>20 µm) were dominant and NPP, NCP, GOP and microzooplankton grazing rates were highest of any summer—suggesting that species composition and by extension size structure can be important controls on rates (Castillo Cieza, in prep). Consequently, in NES II, we will explore size structure effects further (Sec. 5.2).

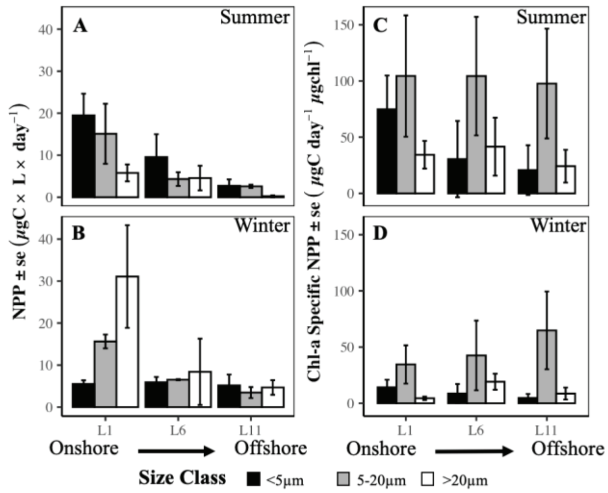


Fig. 10. Variability in size-fractionated surface NPP ([13]C incubation) over 4 years showing large seasonal shifts in which size fraction dominates NPP (A, B) but not in which fraction dominates chl-specific NPP (C, D).

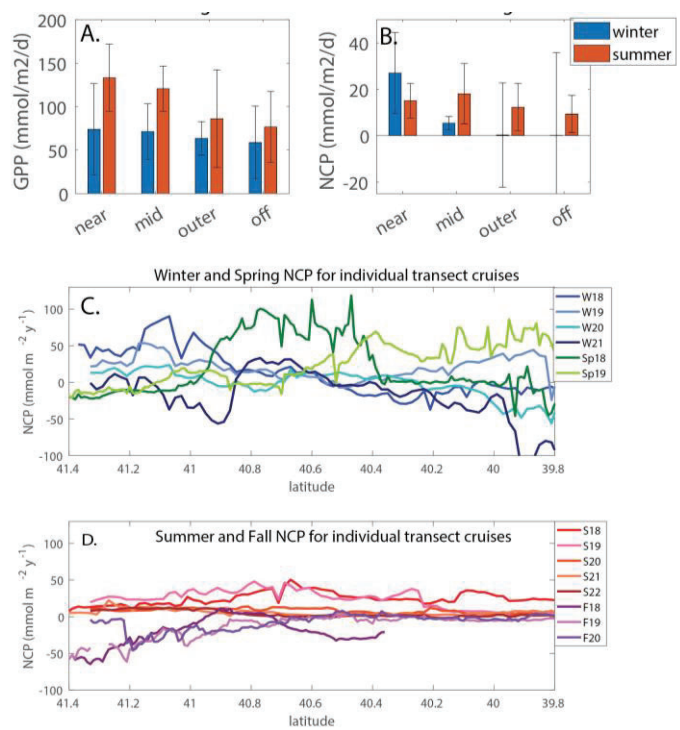


Fig. 11. Rates of GPP (A) and NCP (B), averaged over all transect cruises by region and season, show spatial and seasonal patterns consistent with those found in NPP and phytoplankton composition, with higher values typically nearshore and in summer. Near (<50m water depth), mid (50-100 m), outer (100-500 m) and off (>500 m) cross-shelf regions are shown. Error bars reflect the observed variability in high resolution rates, as can be seen in interannual and spatial variability in rates of NCP at measured at 2-km resolution (C, D) on NES transect cruises. Sp and F denote spring and fall.

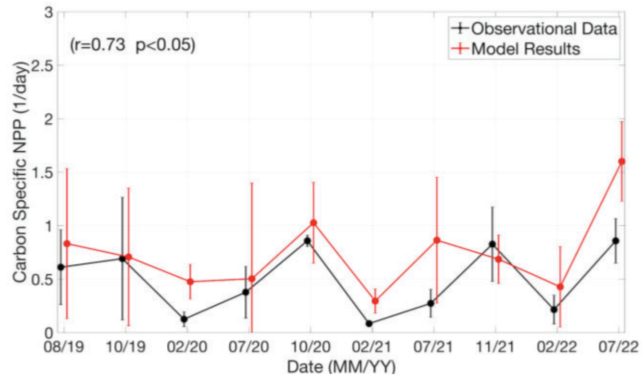


Fig. 12. Comparison of model-computed (red) and observed (black) carbon-specific NPP in surface waters over 10 NES transect cruises, showing mean and standard deviation over the cross-shelf locations.

Microzooplankton grazing and trophic transfer: Concurrently analyzing phytoplankton production and herbivorous consumption on transect cruises has allowed us to explore the fate and flow of organic matter. Herbivorous consumption by microzooplankton is the primary fate of marine primary production globally, directing matter and energy either to higher trophic levels or towards export and remineralization (Steinberg and Landry 2017). The strong seasonal and spatial gradients across the NES, accompanied by shifts in phytoplankton size structure, allowed us to document contrasting herbivory rates and pathways (Fig. 13). Herbivorous removal of phytoplankton by microzooplankton was high in winter (>50%) but surprisingly near absent in summer (<20%) (Marrec et al. 2021a). The very low microzooplankton grazing rates observed in summer contradicted our initial NES I hypotheses, led to changes in our conceptual framework for summertime trophic transfer (Fig. 2), and motivated NES II hypotheses about food web pathways involving mesozooplankton consumers (see Sec. 5.2).

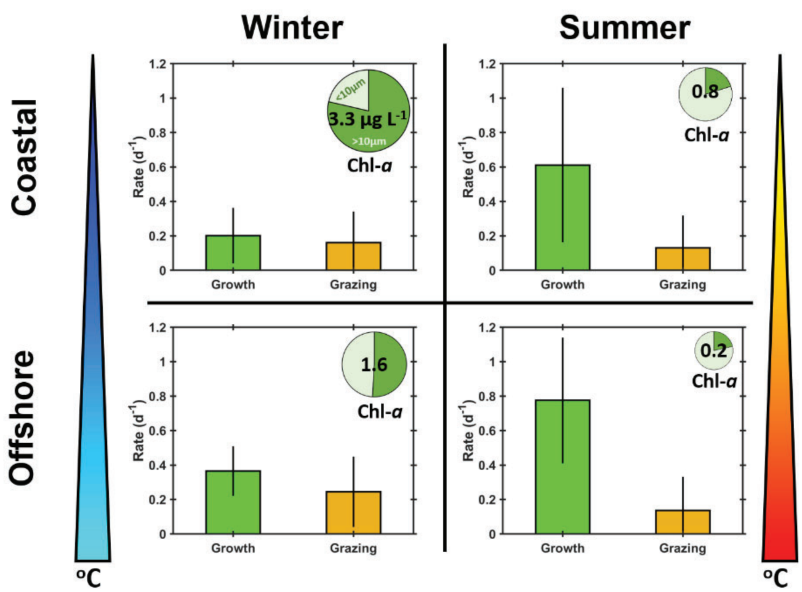


Fig. 13. Seasonal and spatial patterns in phytoplankton growth and microzooplankton herbivory observed during NES I. Inset circles indicate Chl a concentration (µg L^{-1}) in <10µm (light green) and >10µm (dark green) size fractions. After Marrec et al. (2021) but updated through 2022. Summertime enhancement of phytoplankton growth vastly outpaces microzooplankton grazing, which is higher when larger phytoplankton dominate.

3.4. Processes impacting temperature, light availability, and transport of nutrients, organic matter, and plankton

The Mid-Atlantic Bight continental shelf is characterized by seasonal formation of a cold pool, a body of cold water surrounded by vertical stratification above and a shelf break front offshore (Lentz 2017), and strong tidal- and wind-driven currents (Chen et al. 2011; Sun et al. 2016). Physical and biogeochemical properties differ drastically from those offshore (e.g., Hales et al. 2009). The shelf break front has strong temporal and spatial variability and serves as a barrier to contain the productive waters of the shelf. In winter, strong mixing deepens the surface mixed layer on both sides of the front, which suppresses light availability and thus overall production on the outer shelf. In early spring, we have found that weakening of mixing allows frontal isopycnals to relax and episodic westerlies drive the surface part of the front offshore through Ekman transport, creating a shallow surface mixed layer, increasing light levels, and stimulating phytoplankton blooms (Oliver et al. 2022). This ephemeral increase in production is likely a major part of the enhanced chlorophyll observed at the outer shelf in spring (Ryan et al. 1999). Instability of the shelf break front can develop into large-amplitude frontal meanders and eddies with enhanced upwelling and downwelling flows (Zhang and Gawarkiewicz 2015a). Our latest analyses indicate that upwelling associated with the frontal eddies can bring up nutrient-rich subsurface water to the nutrient-depleted euphotic zone in summer and stimulate local production, consistent with hotspots of enhanced surface chlorophyll on the outer NES (Hirzel 2023).

Our work has emphasized that the shelf break front is a leaky barrier, and physical processes, such as impinging Gulf Stream warm-core rings, can break the barrier and drive substantial exchange of water, nutrients, and biota across the shelf break (Zhang et al. 2023). Episodic events of warm-core ring impingement on the shelf are a major driver of the overall exchange between the shelf and open ocean. Impingement of rings can push the warm, salty ring water of Gulf Stream origin directly onto the shelf, changing the shelf habitat. These onshore intrusions can take different forms, including surface intrusion (Zhang and Gawarkiewicz 2015b), high-salinity water thermocline (mid-depth) intrusion, i.e., so-called S-max intrusion, (Lentz 2003; Gawarkiewicz et al. 2022), and bottom intrusion (Ullman et al. 2014; Chen et al. 2022). In keeping with growing evidence of their frequency and intensity, we have updated our conceptual framework for NES II to incorporate these forms of intrusion, which can change vertical distribution of the warm waters and have different impacts on the shelf communities and productivity. Meanwhile, the exact origin of the intrusion water in the Gulf Stream also affects its nutrient concentration and in turn its impact on productivity. *Surface* Gulf Stream water is nutrient depleted, and its intrusion likely suppresses shelf productivity. *Subsurface* Gulf Stream water is nutrient-rich, and Oliver et al. (2022) have shown its intrusion can lead to enhanced biological productivity on the outer shelf. At the same time, ring impingement can draw a substantial amount of shelf water into the slope sea, representing a major transport of shelf biological communities (Zhang et al. 2023). Deciphering the ecological impact of these different processes will be a focus for NES II (see Sec. 5.3).

In addition to shelf break frontal dynamics, many other physical processes affect hydrographic and biogeochemical properties on the NES. Since the production regime is different both latitudinally (e.g., Gulf of Maine vs. Mid-Atlantic Bight) and across the shelf (Zang et al. 2021), responses to environmental forcings also differ. Episodic extreme events such as storms can significantly impact offshore water intrusion and on-shelf stratification (Li et al. 2020; Li and Chen 2022), directly altering nutrient supply and phytoplankton bloom dynamics. The intrusion of warm salty water from offshore, facilitated by more frequently occurring MHWs, has potential to seed or promote anomalous blooms of otherwise uncommon plankton species such as *Hemiaulus*, *Trichodesmium* and subtropical dinoflagellates. We have shown that localized nearshore phytoplankton blooms can also be advected offshore, leading to a spatially extensive impact on nutrient and organic matter cycling on the shelf (Smith et al. 2021). Additionally, our synthesis of observations and model results has shown that deep water intrusion through the Northeast Channel (connecting shelf and slope) affects nutrient supply and production (Zang et al. 2022b) and also directly impacts variability of critical populations such as *Calanus finmarchicus* (Ji et al. 2021; Suca et al. 2021a).

3.5. Unusual blooms promoted by interplay of biological adaptations, physical processes, and disturbance mechanisms

Seasonal observations along the NES transect revealed a set of striking phytoplankton bloom events that stand out in having both distinct taxonomic (typically low diversity) composition and accumulated biomass exceeding typical seasonal levels (Fig. 14). While specific blooms are well known phenomena in coastal waters and were expected to be part of NES ecology, it is surprising to have encountered so many such events during our limited sampling to date (~4-5 1-week cruises annually over 5.5 years). Also remarkable is the scope of physical conditions and bloom ecology encountered. For example, in spring 2018, we encountered a dense bloom of the colony-forming prymnesiophyte *Phaeocystis* on the inner shelf*;* in summer 2019, a massive near-monospecific mid-shelf bloom of the chain-forming diatom *Hemiaulus* occurred; and in spring 2022, high biomass of mixed diatoms was found in offshore waters, co-occurring with elevated levels of microzooplankton (Fig. 14). Nanoplankton-sized *Phaeocystis* cells have distinct physiology and ecological roles linked to their mucus-producing colony formation and associated food web impacts; the 2018 bloom initiated in tidally mixed waters over Nantucket Shoals and was advected across the shelf (Smith et al. 2021). Imaging of *Hemiaulus* during the 2019 bloom confirmed the presence of the diatom's nitrogen-fixing symbionts, which appear to have provided a competitive advantage over the typical summer nanoplankton communities during a period with high temperatures and vertical stratification, and depleted nutrients (Castillo Cieza et al. in prep). The presence of this summer diatom bloom also revealed strong microzooplankton grazing pressure that is typically absent in pico-plankton dominated summertime communities. A warm-core ring was present near the shelf break in spring 2022, likely stimulating the diatom bloom triggered by a combination of available light and upwelled nutrients (Oliver et al. 2021). Taken together, the dramatic phytoplankton bloom events observed during NES I paint a picture of multi-faceted disturbance mechanisms interacting with resident biodiversity to trigger strong responses at the base of the food web. Our NES I conceptual framework had a focus on seasonal food web transitions, but now, armed with greater knowledge of the range of disturbances that can cause similar magnitude but more rapid 'State 2' to 'State 1' transitions, we have updated our framework accordingly (Fig. 2) and incorporated new hypotheses about likely ecosystem impacts of increasingly frequent disturbances such as heat waves and intrusion of offshore water onto the shelf.

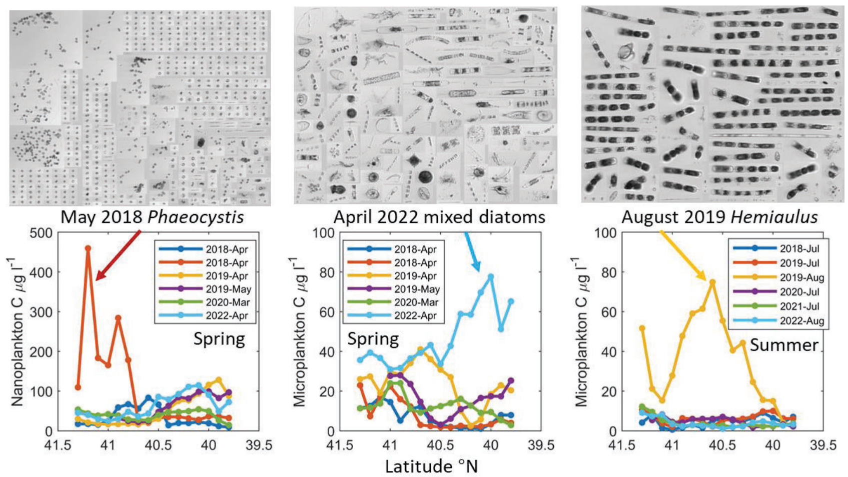


Fig. 14. During NES I transect cruises (2018-2022), typical cross-shelf seasonal distributions of phytoplankton size classes (cruise means in 0.1-degree latitude bins) were disrupted by extreme bloom events dominated by particular taxa as documented by automated imaging with IFCB (upper row: example IFCB images for each highlighted event). Examples include (left) a bloom of the colony-forming prymnesiophyte *Phaeocystis* in spring 2018, during which very high concentrations of single *Phaeocystis* cells dominated the nanoplankton); (middle) an August 2019 mid-shelf bloom of chain-forming diatoms of the genus *Hemiaulus*, documented in IFCB images to be growing with nitrogen-fixing symbionts, dominating the microplankton; and (right) an intense mixed species diatom bloom in offshore waters during April 2022, dominating the microplankton.

3.6. Synchronous vs. compensatory community dynamics within trophic levels

In NES I, we began the collection of data and analyses of models that would allow us to improve our understanding of the relationship between variability in species composition of a community and variability in aggregate properties of the community such as total biomass or production in the NES ecosystem, as well as how these relationships may be influenced by climate change. Quantifying a community's location on the synchrony-compensation spectrum is important for understanding its potential fragility in the face of a changing climate.

Our thinking was motivated by Micheli et al. (1999) who pointed out that community dynamics can fall into one of four categories that depend on the levels of compositional and aggregate variability: (1) In a *synchronous* community the populations that comprise it exhibit correlated fluctuations that produce fluctuations in the aggregate; (2) in an *asynchronous* community, populations vary in an uncorrelated fashion while still generating variability in the aggregate; (3) when populations exhibit negatively correlated variation, and as a result stabilize the aggregate, we say the community is *compensatory*; finally, (4) when the components, and hence the aggregate show only small variation, we say the community is *static*. Both pre-existing data and our observations allow us to eliminate stasis as a characterization of the highly dynamic NES. Modeling, experiments, and field observations suggest that compensatory communities are more stable and resilient than synchronous communities (Gonzalez and Loreau 2009; Valencia et al. 2020). (Asynchronous communities would fall somewhere in the middle of this resilience spectrum.)

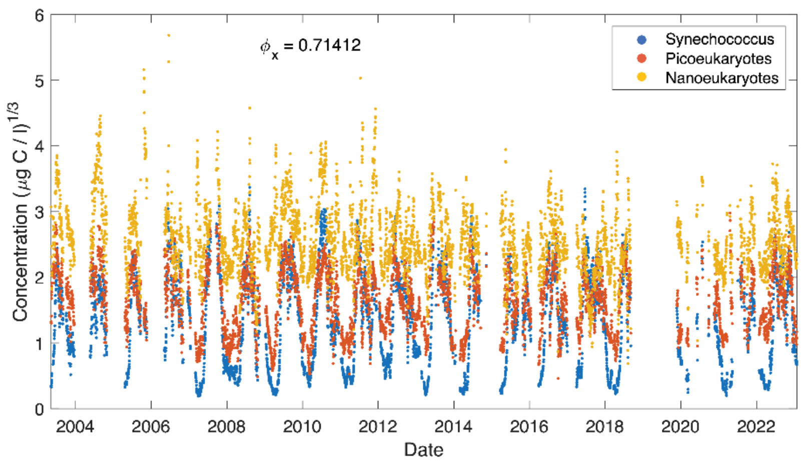


Fig. 15. Observed daily carbon concentration (cube root scaled) in three phytoplankton groups (*Synechococcus*, picoeukaryotes, and 2-10 μm nano-eukaryotes) at MVCO, 2003-2023.

One way to quantify the relationship between community and population variability is with a variance ratio test proposed by Loreau and de Mazancourt (2008). If $x_i(t)$ is a measure of population abundance for population *i* at time *t*, $x_T(t) = \sum_{i=1}^{N} x_i(t)$ is the time series of total population size, and σ_i^2 and σ_T^2 are the corresponding temporal variances, then $\varphi_x = \sigma_T^2 \,/\, (\sum\sigma_i)^2$ is a variance ratio that measures community synchrony. φ_x varies between 0 and 1. If the community components fluctuate in an uncorrelated fashion, $\varphi_x \approx 1/N$. A value of φ_x near its maximum value of 1 indicates synchrony; a value near 0 indicates compensatory community dynamics, with components exhibiting negative correlations.

By applying this variance ratio to the continuing time series of the abundance of the phytoplankton types that comprise the community at MVCO, we find that three groups of small phytoplankton exhibit synchronous dynamics (Fig. 15). While this synchronicity largely reflects the similar response of different groups of small cells to the seasonal cycle of temperature, a deeper analysis (with generalized additive models to extract variability at different timescales) reveals that the dynamics are synchronous at interannual scales as well.

The conclusions that we draw from these time series (Fig. 15) are limited by their lack of spatial coverage; however, with data collected on NES I cruises, Stevens et al. (revised) showed that the population dynamics of *Synechococcus* at MVCO approximate their dynamics across the shelf. Our preliminary analyses indicate that MVCO is also representative of the *community* dynamics across the shelf, at least in terms of synchrony. At each station along the NES transect, the variance ratio of the three phytoplankton groups falls between 0.4 and 0.78, indicating moderate synchrony. Discovering if there is spatial structure in community synchrony on the NES, understanding the potential drivers of that structure, and the spatiotemporal scales over which those drivers operate, are among the goals of NES II. These objectives require the new theoretical framework we will adopt (Sec. 2) and motivate new hypotheses to evaluate (Sec. 5).

3.7. Results of Broader Impacts

Training & Mentoring, including Research Experiences for Undergraduates (REUs). During NES I, we provided opportunities for training and mentoring for 12 postdoctoral researchers, 30 graduate students, and 51 undergraduate students. Each summer, the NES project sponsored an REU student through the Woods Hole Partnership Education Program (PEP), a 10-week program designed primarily for college juniors and seniors from underrepresented groups in marine and ocean sciences. We also sponsored an REU student through WHOI's Summer Student Fellow program and mentored students through URI's SURFO program and Wellesley's summer research program, all of which actively recruit underrepresented minorities. Almost half of the undergraduate women from Wellesley College who participated are from underrepresented groups, often getting involved in NES research as freshman through the Wellesley's First Year Apprentice Program.

Schoolyard and Data Jam. The NES-LTER Schoolyard program had at least 25 teachers registered each year, including teachers from Boston and New Bedford, MA, helping to increase participation of underrepresented minorities in STEM. Schoolyard teachers are regularly provided with curriculum content connections, tools for data analysis and interpretation, Data Jam resources, and professional development workshops including online Ask a Scientist webinars. Each year we held a Data Jam competition for grade 6-12 students to explore NES datasets and creatively communicate their interpretations, reaching >100 students annually and involving >15 NES team members as judges. Data Jam winners are offered field trips to WHOI. Four teachers had Research Experience for teachers (RET) opportunities, with three as active participants on project transect cruises.

Outreach. We have conducted local, regional, national, and online outreach activities. Workshops have been presented at annual educator conferences such as the Massachusetts Assoc. of Science Teachers as well as Massachusetts Marine Educators. Team members (PIs, graduate students, technicians, and the EO coordinator) have hosted activity tables at community events such as "Party for the Planet" at the zoo in New Bedford, MA to reach families and the general public. We used social media to share the events and accomplishments of team members and the project along the way.

Justice, Equity, Diversity, and Inclusion (JEDI). During NES I, we created a JEDI Action Plan for our site as a living document, as well as a land and water acknowledgment and Code of Conduct. Our JEDI committee includes a PI-level representative from each academic institution (WHOI, URI, Wellesley, and UMass-Dartmouth), as well as undergraduate and graduate students, postdocs, and technical staff. NES I co-PI Llopiz played a leadership role with the national LTER Network JEDI committee, including serving as their representative on the LTER Executive Board. A different NES team member starts each monthly all-hands meeting by contributing a "JEDI moment" to increase awareness and foster inclusive perspectives. Through our Schoolyard program, we have partnered with teachers in several major urban areas that are 30-85% non-white and 33-75% economically disadvantaged. The Schoolyard program is broadly accessible, and has included participants from public schools in Fairhaven, MA, a public STEM program in Baltimore, MD, and a tuition-free all-girls school in New Bedford, MA. We have mentored 19 undergraduate students from underrepresented minorities in the sciences through the Woods Hole PEP, URI SURFO, and Wellesley First Year Apprentice, POSSE, Luce, and McNair programs. We launched a Mentorship Program focused on providing a sense of belonging and safety to project participants at all levels, especially during field research. Members of the NES leadership team have worked to learn about and adopt interaction approaches that are inclusive across the team.

Engagement with management agencies and regional observing programs. NES I fostered strong connections with partner organizations including the Northeast Fisheries Science Center (NEFSC) and the operators of regional observing system components including the NSF-funded Ocean Observatories Initiative (OOI) and NOAA-funded Northeastern Regional Association of Coastal Observing Systems (NERACOOS).

3.8. Results of Supplemental Support

RAPID award. The NES team received a RAPID award in late 2020 that supported a special cross-shelf transect cruise during the fall season to observe plankton composition, primary production, growth and grazing rates, and food web transfers, as well as environmental conditions such as temperature, salinity, and nutrient concentrations. The added cruise allowed us to offset impacts of the COVID-19 pandemic (which caused a truncated summer transect in 2020) and explore new aspects of the seasonal progression of ecosystem impacts of an especially warm summer followed by fall heat wave conditions throughout much of the NES (Northeast Fisheries Science Center (U.S.) 2021). In addition to generating new knowledge about seasonal transitions, the supported cruise made it possible to provide training opportunities for students and postdoctoral researchers who would otherwise have not been able to participate in field work during the pandemic.

Equipment Supplement. NES received an equipment supplement in 2022 that enabled the acquisition of instrumentation critical for on-ongoing time series and process cruise observations. A SUNA nitrate sensor was delivered in July 2022 and integrated with the Stingray towed vehicle in time for the summer 2022 transect cruise. An Imaging FlowCytobot was delivered in December 2022 and will be used for plankton characterization on cruises starting in 2023.

Year 6 supplement. NES received funding to extend observations, modeling, and synthesis for an additional Phase I year. The original NSF-prescribed 5-year duration for NES I was intended to synchronize NES with LTER-wide renewal cycles, but the duration proved impractical in the face of pandemic-related delays in mid-term reviews. Funding enabled continuity in time series observations and seasonal cruises, responses to mid-term review recommendations (see Sec. 4), and completion of several studies synthesizing NES I findings (Zhang et al. 2023; Catlett et al. subm.; Stevens et al. revised).

Career-Life Balance Supplement. NES received approval for a CLB supplement in early 2023 to mitigate impacts associated with a sudden and unexpected long-term approved leave for an NES I co-PI. The supplement has supported integration of a new co-PI (Sato) with the team, including participation in process cruises and taking on project responsibilities in areas related to population, community, and food web dynamics associated with zooplankton and forage fish. This ensures continuity in these important LTER core research areas and provides new complementary intellectual directions for NES II.

3.9. Report on Data Availability

As a supplementary document, we provide a table of datasets exported from the NES-LTER Data Catalog publicly available as collection "NES-LTER Data Products" (Beaulieu and Sosik 2023). The table includes ongoing, long-term as well as completed datasets, highlights associations to LTER core areas, and indicates datasets used in the 10 significant publications from NES I (Sec. 3.1). Datasets have been deposited into the Environmental Data Initiative (EDI) or other public repositories, including the National Center for Biotechnology Information (NCBI) and NASA Ocean Biology DAAC (SeaBASS). Products from NES (data sets, publications) are annotated in the Reference Cited section.

4. Response to Mid-Term Review

The mid-term review committee highlighted a number of NES-LTER strengths, in particular noting that: *"site personnel have been highly productive in terms of recruitment, publication, and outreach, and have established active collaborations in the region and with other LTER sites"*; *"NES-LTER science is truly interdisciplinary bringing together experimentalists, observationalists, and modelers, and spanning physics to plankton to fish"; "the site incorporates many exciting and innovative technologies"*; and *"the NES-LTER team is diverse and efforts to broaden participation of underrepresented groups are targeted, well-informed, and already showing signs of success at several levels within the project participants"*. The committee provided us with six recommendations. Some of these we addressed immediately, and some are addressed in this renewal.

(1) Clarify core area connections. The review team highlighted a need for clarity in how core areas are defined and connected with the NES conceptual framework. They drew specific attention to the roles of disturbance and export production in our NES I framework. We formed interdisciplinary working groups (see details next point *2*) to focus on these topics, integrate perspectives, synthesize knowledge gained during NES I, and highlight priorities for NES II. Working group efforts directly informed evolution of the NES conceptual framework, which has been updated to incorporate critical disturbance mechanisms and to reflect our evolving view of trophic transfer pathways (which we now emphasize in place of our previously ambiguous use of "export production"). Our refined definitions and thinking about connections among core areas are reflected in the questions and hypotheses in this renewal (Sec. 5). In particular, Q2 brings focus on community structure and trophic transfer impacts of three prioritized types

of disturbance: (i) increasing prevalence of heat waves, (ii) intrusions of offshore water associated with increasing instability in the Gulf Stream, and (iii) offshore wind farms now under construction on the NES. We also immediately implemented the specific recommendation to make direct dissolved organic matter measurements and plan to continue those in NES II so that we can more comprehensively address the organic matter core area.

(2) Integrate across project components. The review team recommended that we take steps to increase integration among groups (e.g., observationalists and modelers) and across research areas (e.g., biological processes and environmental context) by leveraging the conceptual model, core areas, and theoretical framework. Immediately following the review, we formed several new working groups focused on meeting this challenge through such activities as collaborative literature review, synthesis of NES I findings, and prioritizing specific integration objectives. During the last 18 months, working group foci have included (i) ecosystem impacts of disturbances; (ii) data-model integration, particularly in regard to planktonic communities and processes; (iii) spatiotemporal variability in interactions among food web structure, nutrient availability, and fate of organic matter; and (iv) temporal synchrony and compositional vs. aggregate variability in plankton and fish communities, considering both theoretical and empirical findings. While the full impacts are still unfolding, the process has certainly stimulated more interaction and is likely to lead to more synthetic insights. The working group outcomes contributed extensively to the evolution of the conceptual framework and prioritization of questions for this renewal. We will continue this valuable working group process in NES II.

We note that the review team felt that early NES research emphasized within trophic level understanding at the expense of broader perspectives. We carefully considered this critique as we prioritized integrative science questions for NES II. Each question is cross-cutting in terms of ecosystem components and levels of organization, with Q1 targeting deeper knowledge of typical seasonal and cross-shelf patterns, Q2 focusing on three critical disturbance mechanisms (see response above) expected to cause perturbations from climatological states, and Q3 exploring larger scale implications for resilience and stability. As a final note, we believe there is already a trajectory of increased integration across components as our project matures; for example, work led by graduate students shows new findings from integration of observations with habitat models (Suca et al. 2021a), matrix population models (Stevens et al. revised), and non-linear mixing models (Honda et al. in revision).

(3) Clarify ideas for advancing ecological theory. We welcomed the external review committee's recommendation to clarify our ideas about the NES I theoretical framework, which "contrasts synchronous versus compensatory time dynamics, and their relationship to resilience." In response, we formed a working group (see above) whose members continue to study the expanding literature on the subject. (Much of this literature was produced by an LTER Working Group formed coincidentally at the start of NES.) Working group meetings have already inspired new theoretical results, including a study on how zooplankton grazing behavior affects synchrony and food web stability (Archibald et al. in revision), and another about how synchrony in metacommunity models can depend sensitively on the mathematical description of dispersal (Neubert and van Daalen in prep). In addition, we have responded to the committee's recommendation to begin applying our theoretical framework to NES datasets by standardizing our time series data at multiple taxonomic levels and beginning to assess community synchrony at the NES site with combinations of computational models and newly developed statistical approaches (e.g., Honda et al. in revision; see also our preliminary results in Sec. 3.6 and 5.2).

(4) Enhance communication. We followed the review team's recommendation to enhance our use of committees and formalize regular meeting schedules to target project goals. Since the mid-term review, our NES JEDI committee has met monthly focusing on our JEDI plan action items; we have held full NES team meetings monthly to share updates and opportunities, build community and JEDI awareness, and solicit broad input and feedback about project needs and challenges; and the NES Steering Committee has met at least twice monthly, often weekly. In addition, as noted above, we formed several science working groups focused on integration and within-project synthesis. Working group participants

span all project roles (PIs, technicians, students, etc.), reflect diverse composition in areas of interest and expertise, including an IM team member, and each group is co-led by an early career investor and a co-PI. Working groups met regularly, interacted asynchronously on identified objectives, and reported out and solicited broad input at full team meetings. We continue to leverage these efforts to push forward on cross-group synthesis of findings and generation of new hypotheses linked to our conceptual framework.

(5) Prioritize data publication. Priorities of the NES team are fully aligned with the review team's emphasis on the need to submit data packages on a timeline that meets the LTER Network Data Policy. After launching an ambitious multi-faceted observational program and grappling with COVID challenges, we acknowledged a need to catch up by redirecting and prioritizing IM efforts. We expanded the IM team, refocused support provided through WHOI's Information Services group toward streamlining pipelines, and thoroughly engaged research team members in data package prioritization and preparation. As a result of these steps, we substantially increased the pace of data submission and, as of this writing, we have met the requirement to deposit data within 2 years of collection for ongoing, long-term data packages spanning all 5 LTER core areas (see Sec. 3.9).

(6) Create data catalog. We followed the review team's advice to provide a centralized data catalog available from our website, pioneering the use of a bibliographic cloud platform (Zotero; Beaulieu and Sosik 2023). Entries in this catalog are tagged by relevant core area(s) and include DOIs and repository access points. The goal of this catalog is to help users discover datasets and their associated access points in multiple community repositories. A secondary consideration was ease of catalog design and maintenance for the NES IM and team members.

5. Proposed Research

5.1. Overview NES context and strategy

During NES II, we propose to maintain the long-term NES I strategy that combines observations providing regional-scale context, process cruises along a high gradient cross-shelf transect, high-frequency time series at an inner-shelf location, coupled biological-physical food web models, and targeted population models (Fig. 1). At the same time, we will increase our attention to ecosystem responses to disturbance. The findings from NES I (Sec. 3) emphasize the ways we have characterized organic matter flow in the NES ecosystem by linking large scale modeling studies, in situ production rates at multiple trophic levels, and surveys of abundance and community composition from primary producers to forage fish. NES I results revealed major forms of disturbance in the region, their temporal and spatial scales and potential biological and ecological impacts, as well as key observational and modeling next steps required to understand the impacts. These insights motivate questions and hypotheses for NES II and set the stage for more in-depth exploration of patterns and mechanisms as our time series grow. Broadly, the three questions we propose to address concern (1) the typical or "climatological" seasonal and cross-shelf patterns in ecosystem structure and function; (2) processes and drivers that generate departures from climatologies (i.e., disturbances); and (3) long-term trends linked to climate change and other anthropogenic influences.

5.2. (Q1) What are the mechanisms that drive the dominant seasonal and interannual patterns of variability in community composition, food web pathways, and productivity at spatial scales characteristic of the NES (10s - 100s of kms)?

A notable characteristic of NES I results described above is extensive seasonal and interannual variability. Understanding the mechanisms that drive variability and how variability influences key linkages in the NES food web is a main goal of NES II and requires extending time series observations, adjusting our sampling approach, adding to process-based studies, and conducting model-based attribution analyses to assess the contribution of individual drivers to the variability at seasonal and interannual scales.

H1.1 Cross-shelf seasonal and interannual variability in the distribution, abundance and productivity of organisms is caused by hydrographic conditions on the shelf and at the shelf break front.

During NES I, we characterized seasonal changes in hydrographic features on the inner- and mid-shelf and at the shelf break front (e.g., Smith et al. 2021; Oliver et al. 2022). Seasonality on the shallow inner shelf is characterized by dramatic temperature changes over the entire water column (Lentz 2008), while at the mid-shelf, the largest seasonal variations occur in vertical stratification, where the winter water column is cold and well-mixed and the summer water column is strongly stratified with a warm, nutrient-depleted surface layer overlaid on a cold subsurface layer of relatively high nutrient concentrations (Zhang et al. 2013). At the shelf break front on the outer shelf, canonical seasonal variations are most dynamic and include changes in frontal location, frontal isopycnal steepness, strong subsurface temperature gradients across the front in the summer, and springtime frontal relaxation (Linder and Gawarkiewicz 1998; Zhang et al. 2011; Oliver et al. 2022).

We will use our emerging time series to examine how changes in temperature, stratification, and frontal dynamics are linked to organism distribution, abundance, and productivity. Temperature is a well-documented driver of organism distributions because growth and reproduction are often temperature dependent (Pörtner and Knust 2007). For example, the thermal growth responses of phytoplankton differ significantly among functional groups (e.g., cyanobacteria, diatoms, dinoflagellates) suggesting that temperature alone can alter community composition by altering relative growth rates among taxa (Anderson et al. 2021). Our high-spatial resolution analyses of phytoplankton communities and biological production rates across the shelf will allow us to connect seasonal shifts in temperature with effects on community composition and production. Furthermore, with our growing time series, we will characterize thermal niches across the food web (Rynearson et al. 2020) and correlate those with variability in community composition.

In the summer, thermal stratification develops on the shelf and reduces nutrient supply to surface waters. A subsurface chl-a maximum develops on the mid-shelf in response to thermal stratification in summer (Zhang et al. 2013), and we are just beginning to discover the implications for production. In NES II, we will use our growing time series to examine whether the mid-shelf subsurface chl-a maximum is (1) a primary production hotspot, (2) a result of photoacclimation, or (3) driven by light-mediated zooplankton grazing (Moeller et al. 2019; Cornec et al. 2021).

In addition to strong seasonality, physical, biogeochemical, and biological processes on the shelf change from year to year. Interannual variation in water temperature on the NES (Fig. 16a) is influenced by changes in atmospheric, upstream ocean, and open ocean conditions. NES I observations documented corresponding interannual variability in plankton communities that could have dramatic impacts on productivity. For example, the intense bloom of a diatom with a nitrogen-fixing symbiont unexpectedly encountered mid-shelf in summer 2019 (Fig. 14) was tightly coupled with high NCP (Fig. 17) and also associated with perturbations in typical summer food web pathways. Our analyses have suggested warm shelf water, associated stratification, and nutrient depletion in setting conditions where a diatom with nitrogen fixing symbionts could outcompete more typical summer flora. Ongoing warming trends may lead to more frequent occurrences as in 2019. Assessing the generality of these mechanisms and impacts on nutrient and energy flows in the ecosystem depend in large

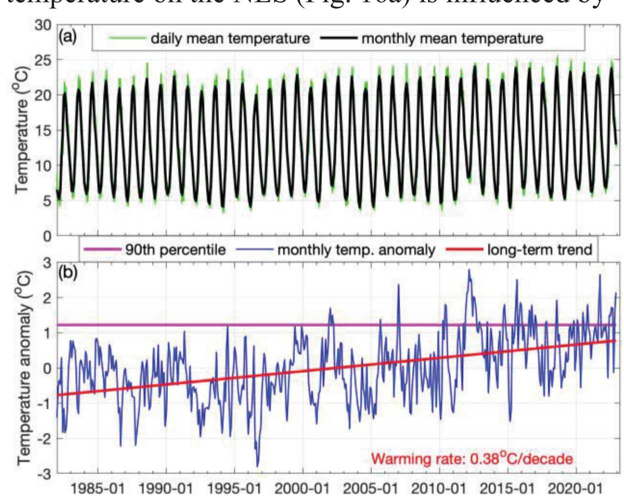


Fig. 16. Satellite-measured SST (a) and SST anomaly (b) time series for the NES, 1982-2022. In (b), the red line is a least-squares fit to the monthly anomaly, showing the long-term warming trend; and the magenta line is the 90th percentile in anomaly, periods above which are defined as MHWs (Hobday et al, 2016).

part on longer time series as proposed for NES II to capture a wider spectrum of seasonal bloom occurrences and their conditions.

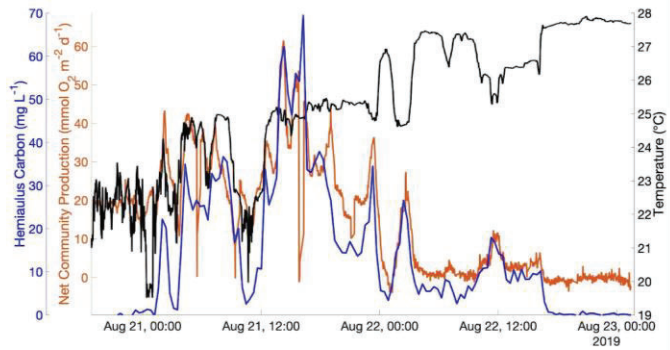


Fig. 17. Biomass of the diatom *Hemiaulus* (blue), as estimated from IFCB data, shows a strong positive correspondence with NCP (orange) and a negative correlation with SST (black) during the August 2019 cross-shelf transect cruise. Castillo Cieza et al. (in prep)

The hydrographically dynamic shelf-break front plays an important role in separating biological communities in offshore and on-shelf waters, primarily through steep gradients in temperature and nutrients (Cox and Wiebe 1979; Sato et al. 2018). For many plankton and fish species, steep gradients at the front may serve as a physiological boundary limiting their access to habitat on the shelf (Worm et al. 2005; Tittensor et al. 2010). We hypothesize that fish primarily remain in warm slope waters and modify their distributions based on temporal and spatial changes in frontal features. Preliminary observations support this hypothesis, and our focus will be on documenting and understanding how variability in frontal features (e.g., front sharpness, width, slope, location, and frontal eddies) modifies temperature-dependent animal behaviors. We also hypothesize that forage fish aggregate at the front where their zooplankton and/or phytoplankton prey are abundant. Interestingly, our preliminary data collected across the shelf show the aggregation of scattering layers along the front (Fig. 18). We have already shown that phytoplankton accumulate at the front in spring because of frontal re-stratification (Oliver et al. 2022), and now hypothesize that phytoplankton accumulate at the front in other seasons as well, because of frontal-eddy induced upward injection of subsurface nutrient-rich water, or because surface convergence of the frontal flow can retain nutrient-enhanced biomass from primary production. Increased primary production could cause zooplankton to aggregate at the front where their food is abundant.

For NES II, we propose to combine acoustics, optical imaging, water and net sampling, incubations and physical measurements collected during NES cruises and NOAA bottom trawl surveys, along with model runs to test H1.1. Standard core measurements made on transect cruises will be important. New for NES II, we will add the assessment of high spatial resolution zooplankton and fish distributions with multifrequency echosounders (with community composition verified by net and trawl samples), as well as

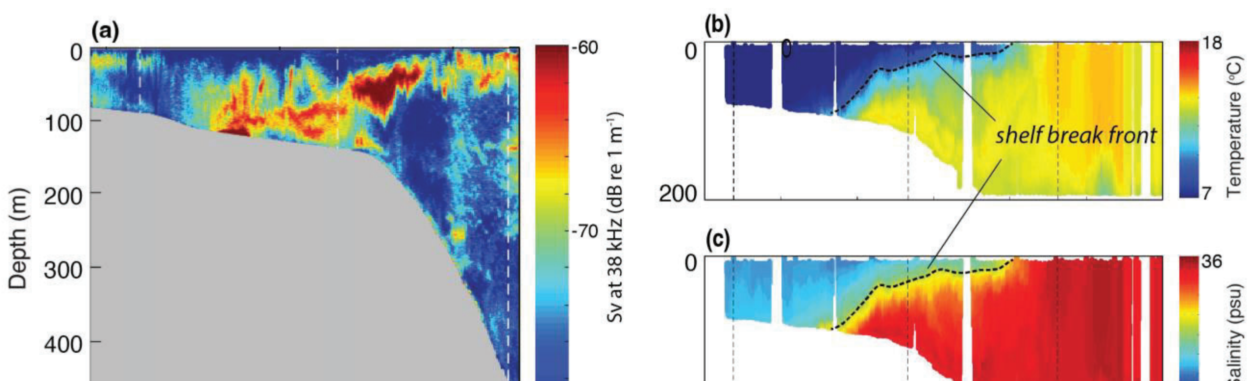


Fig. 18. Example ship-based echograms of scattering layer responses across the NES shelf break in March 2018. Fine-scale acoustic measurements indicate fish movement across the thermohaline front. Temperature (b) and salinity (c) profiles observed by a nearby OOI glider in February 2018; black dashed lines highlight the front.

distributions of gelatinous organisms assessed with high resolution in situ shadowgraph imaging on our towed sled. Frontal variability during cruises will be assessed from CTD profiles at stations and from our undulating towed sled (~4-5 kt ship speed, ~20 m min^{-1} vertical). Response of biological production to the front will be assessed with 2-km scale resolution rates of NCP derived from a shipboard mass spectrometer. Satellite-measured SST and chl-a will provide larger-scale context since unique surface characteristics of rings, slope and shelf waters allow us to distinguish different water masses (e.g., Zhang and Gawarkiewicz 2015b). These data will inform how spatial scales and physical features are linked to observed biological distributions and modeled patterns.

H1.2 Synchronous community dynamics dominate when the temporal and spatial scales of variability in drivers are commensurate with life history time scales.

The 20-yr time series at MVCO combined with data collected on over 20 NES cruises transecting the shelf represent the beginning of a robust seasonal time series that will be used to examine patterns of aggregate and compositional variability in the plankton (both locally and in the NES "metacommunity" cf. Box 1), the drivers of that variability, and their temporal and spatial scales. In NES II, we will examine how patterns of synchrony vary spatially and to what extent they depend upon taxonomic resolution and trophic level. Preliminary analyses suggest this will be a productive approach. For example, we find the synchrony observed among populations of *Synechococcus* and small eukaryotes at MVCO (Fig. 15) extends across the shelf, with variance ratios of 0.4-0.8, indicating moderate synchrony (Sec. 3.6). This pattern of cross-shelf synchrony depends, however, upon the components of the community that we include. For a broader range of size classes (pico-, nano-, and micro-plankton), community dynamics are approximately asynchronous (or mildly compensatory) nearshore but show a steady increase in synchrony with distance from shore (Fig. 19). Intriguingly, we have uncovered a similar, but less steep spatial gradient in local synchrony in the three dominant species of mesozooplankton: *Calanus finmarchicus*, *Pseudocalanus spp*., and *Centropages typicus* (Fig. 19).

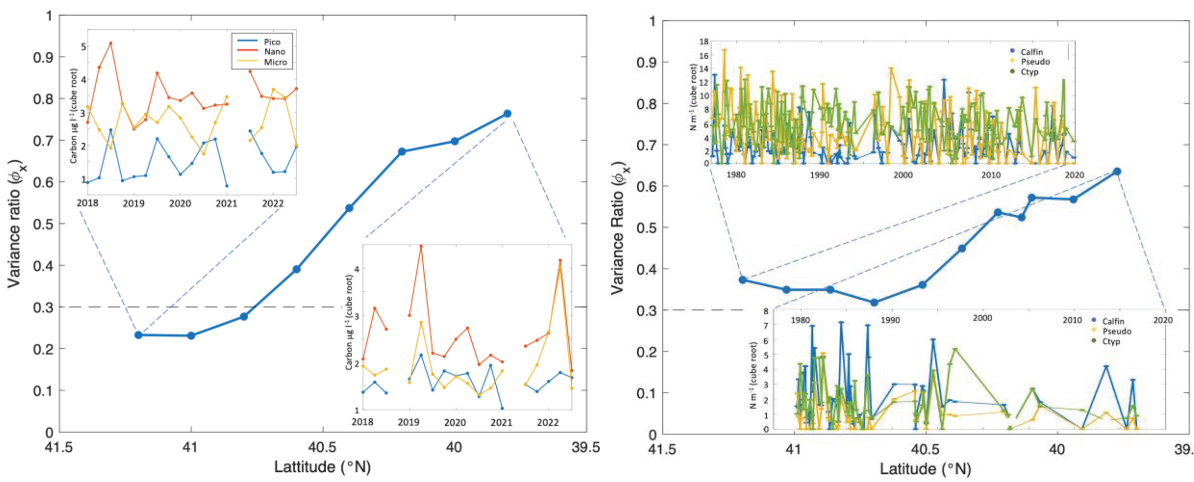


Fig. 19. The variance ratio of three phytoplankton size classes (left) and three populations of zooplankton (*Calanus finmarchicus*, blue; *Pseudocalanus spp.*, yellow; and *Centropages typicus*, green) across the NES transect (inshore to offshore, left to right), along with examples of the time series from which they were calculated. For these 3-component communities, $\phi_x = 1/3$ marks the threshold between synchrony and compensation. In both cases, the community is approximately asynchronous nearshore, and exhibits increasing synchrony with distance from shore.

These preliminary results, and what we have learned during NES I (Ji et al. 2021; Honda et al. in revision) lead us to hypothesize that the cross-shelf gradients in synchrony (Fig. 19) are generated by offshore environmental variability (including variability generated by environmental disturbance) that operates more coherently, over longer timescales and larger spatial scales, than it does nearshore, where we expect such variability to be more random. We also expect that synchrony will emerge at larger spatial and temporal scales at higher trophic levels (e.g., Suca et al. 2021b). In addition, we expect to see the signature of compensatory dynamics emerge when the components of the metacommunities that we analyze are more finely resolved, and the effects of competition and niche differentiation become apparent (See H3.2 for diversity-compensatory relationships). Our analyses will use established statistical approaches for examining community synchrony (e.g., Schluter 1984; Loreau and de Mazancourt 2008; Gonzalez and Loreau 2009) and recent developments that allow for decomposition of time-scale specific contributions via spectral representation (e.g., Zhao et al. 2020; Shoemaker et al. 2022). Because our theoretical framework emphasizes changes in community composition across space and time (a type of β diversity, Anderson et al. 2011), we will also use methods for partitioning compositional variability provided by Lamy et al. (2021).

H1.3 Temporal variations in plankton size structure and community composition alter the flow of carbon through food webs, influencing community productivity and the energy available to higher trophic levels.

During NES I, we found that the size structure and taxonomic composition of NES planktonic populations undergo dramatic changes both seasonally and across the shelf (Fig. 15; Marrec et al. 2021a; Smith et al. 2021; Sterling et al. 2022) and are now beginning to examine the consequences for trophic transfer. In NES II, we will evaluate the hypothesis that interannual variation in plankton communities leads to interannual variation in community productivity via shifts in the flow of carbon through food webs. An alternative hypothesis is that shifts in composition and size structure of primary producers are dampened by the feeding ecology of progressively higher trophic levels leading to annually consistent flows of carbon through the NES food web.

We will test these hypotheses with a variety of integrated approaches. A primary approach will be to determine phytoplankton composition and size structure as a function of spatial, temporal, and environmental conditions and examine how changes in composition influence productivity and predation on transect cruises. Connections among trophic levels will be examined with both ongoing and new approaches. Continuation of microzooplankton grazing rate incubations will be amended with addition of non-protist mesozooplankton, such as copepods, krill and gelatinous filter-feeders on select cruises and stations. Salps, in particular, can play a key role in energy transfer by directly feeding on small-sized phytoplankton (Stukel et al. 2021). We have evidence from summer 2022 that salps indeed were major consumers of picophytoplankton (Menden-Deuer & Steinberg in prep). Gelatinous consumers in the NES food web could lead to a significant shift in our conceptual understanding of the summer ecosystem particularly since microzooplankton enhance trophic transfer to higher trophic levels and ultimately fish, whereas consumption by gelatinous zooplankton is generally viewed as limiting higher order production.

To understand feeding ecology and its interannual variability at higher trophic levels, we will continue to determine the gut contents of forage fish and the isotopic composition of fish and zooplankton. We will begin to examine copepod gut contents on selected stations from a subset of transect cruises. We will extend our food web investigation to right whales by leveraging a NOAA pilot grant to examine their feeding ecology on the NES. Finally, we will use ecosystem models to test hypothesis H1.3 by altering the magnitude and pathways of carbon flow through the food web. Changes in plankton community structure and productivity will be assessed after reconfiguring model parameters for prey preference and switching parameters. Finally, data from empirical and modeling approaches will be integrated to examine shifts in carbon flows over space and time and determine how those changes are related to shifts in phytoplankton composition.

5.3. (Q2) How do community composition, food web pathways, and productivity respond to ecosystem disturbance at scales associated with MHWs, intrusions of offshore water onto the shelf, and renewable energy infrastructure?

The NES environment is subject to a several major natural and anthropogenic disturbances. The influences of MHWs, offshore water intrusions, and offshore wind farms on shelf ecosystem dynamics and species composition will be new focal areas for NES II.

H2.1 Episodic intrusions of offshore waters onto the shelf increase spatial and temporal variability in the biological productivity and community composition and suppress overall productivity of the NES.

The Gulf Stream has become more unstable in recent years (Andres 2016). Concurrently, more warm-core rings have been shed into the slope sea off the NES (Gangopadhyay et al. 2020). This can lead to more pronounced offshore influence through more frequent impingement of rings on the shelf edge. Bottom-intrusion of the warm offshore water onto the shelf (Ullman et al. 2014; Chen et al. 2022) and increased occurrence of thermocline intrusion of the high salinity offshore water (Gawarkiewicz et al. 2022) onto the NES have been well documented. Because offshore slope and ring waters have drastically different properties (e.g., Joyce et al. 1992; Zhang et al. 2023), more frequent intrusions onto the shelf are expected to lead to substantial changes in the NES ecosystem.

We propose to explore specific predictions about these changes. (i) More frequent intrusion of offshore waters will alter the shelf physical environment and thus important habitat characteristics. (ii) Onshore intrusions induce more variability in primary productivity on the shelf, because of high variability in source waters; surface slope and ring waters have lower nutrient concentrations than the shelf, while deep slope and ring waters have higher concentrations. (iii) Overall shelf productivity will be suppressed by these disturbances because surface slope and ring water intrusions are more common. (iv) Intrusion of offshore waters will transport offshore organisms and alter species composition on the shelf. (v) Onshore intrusion facilitates the foraging migration of warm water animals into productive shelf water and enhances the energy transfer to them. (The impact of the onshore intrusion on the energy transfer across trophic levels could be strong at lower trophic levels but may diminish at higher trophic levels due to the mismatch of spatio-temporal scales associated with the biological and physical processes.)

We will combine in situ and remote-sensing data with biophysical modeling to test these predictions. Individual ring water intrusions will be identified with satellite data. When available, in situ measurements will be analyzed to examine the influence of the intrusion events on nutrient availability, productivity, species composition and energy transfer. To the extent possible during transect cruises (within constraints of weather and time series priorities), we will incorporate some adaptive sampling to target offshore water intrusion. For instance, if an intrusion event is identified, we will use any flexible cruise time to investigate its spatial scale and biological characteristics. We will use our existing numerical models to examine large-scale influences of intrusion events. The cumulative impact of consecutive intrusion events on habitat, nutrient budgets, overall productivity, species composition and ecosystem change over interannual to multi-year scales, will also be investigated by synthesizing cruise data, time series data, and modeling results.

H2.2 The impact of MHWs on the NES ecosystem is scale- and trophic level- dependent, with responses of species composition and productivity strongest at the base of the food web, and declining at higher trophic levels due to the scale mismatch between biological processes and MHW disturbances.

Seawater temperatures have been rising throughout the NES in recent decades at a faster pace than most other ocean regions (Pershing et al. 2015) (Fig. 16). In addition to the general warming trend, extreme and prolonged positive temperature anomalies or MHWs (Hobday et al. 2016), have been occurring frequently in the recent decade (Scannell et al. 2016; Pershing et al. 2018). MHWs are expected to be even more frequent in the foreseeable future on the NES (Saba et al. 2016). Notably MHWs can be triggered by different mechanisms, including variability in atmospheric forcing (e.g., jet stream, Chen et al. 2014), changes in ocean advection such as Gulf-Stream ring or slope water intrusions (Saba et al. 2016), and eddy-induced warm-water transport (Chen et al. 2022). The resulting MHWs could exhibit different timing, locations and magnitudes, which in turn could have different ecological consequences.

MHWs may have significant impacts across trophic levels. Our studies before and during NES I have shown the sensitivities of the ecosystem to warming. Among primary producers, picophytoplankton including both *Synechococcus* and eukaryotic picoplankton exhibit strong responses to temperature changes in terms of concentration and division rate, both seasonally and interannually (Hunter-Cevera et al. 2016, 2020; Fowler et al. 2020a). Diatoms, important contributors to microphytoplankton biomass, have more complicated temperature and seasonal responses that likely reflect the combined effects of direct thermal impacts, stratification-mediated changes in light and nutrients, and temperature-sensitive trophic impacts through grazing and parasitism (e.g., Peacock et al. 2014; Catlett et al. subm.). During NES I, we found an anomalous summer diatom bloom associated with warmer shelf waters suggesting that, under some conditions, MHWs may trigger a rapid transition from typical summer 'State 2' conditions to a 'State 1' food web with large primary producers (Fig. 14), low trophic transfer to microzooplankton (Fig. 13), and high NCP (Fig. 17).

The impacts of MHWs on higher trophic levels are complex due to differences in the spatiotemporal scales between MHW disturbances and biological responses. Higher trophic level organisms have longer life cycles (e.g., months for mesozooplankton, years for fish) and thus experience environments over a more expansive spatial domain, both horizontally and vertically. MHWs are considered to be episodic and constrained in their spatial domain. This scale mismatch exists, at least for now, although MHWs could be more frequent in time and expansive in space in the future climate scenario (see Sec. 5.4). If prolonged and widespread MHWs lead to a new baseline, changes to the marine habitat could become semi-permanent, and organisms at higher trophic levels are likely to be severely impacted. Consequently, the structure and function of the regional food web will be altered, leading to a potential regime shift.

For NES II, we propose the following approaches to assess the impact of MHWs, with a special consideration of scale mismatch as described above. We will continue core observations of communities and food-web responses along the NES transect. With more frequent MHWs expected, we anticipate encountering MHW events in different seasons. This will allow us to monitor detailed responses in rates, community structure, and overall productivity. These observations will provide critical information for model sensitivity analyses and hypothesis testing. We will also conduct model-based sensitivity analysis focusing on the following: (i) identifying years with known MHW events and comparing against 'normal' years or climatological conditions in terms of biomass and productivity across trophic levels; (ii) perturbing the model system with idealized MHW events (with different timing, location and magnitude), and assessing model responses in terms of community structure and productivity at different trophic levels; and (iii) modifying the modeled food web configuration (incorporating results from experiments and observations) to evaluate responses of energy transfer pathways and efficiency. This can be achieved by adding novel food web components, adjusting temperature-dependent functions, and/or modifying interactions among different food web components.

H2.3 Large-scale installation of wind energy turbines will impact the NES ecosystem through altered circulation and mixing processes, nutrients fluxes, light availability, and offshore transport of organic matter and plankton.

Offshore wind is considered a critical component of the global shift towards renewable energy. The Bureau of Ocean Energy Management (BOEM) has issued a large number of leases for commercial renewable energy development along the Mid-Atlantic Bight and initial construction has begun (Fig. 20). Exactly how this development will affect the ecosystem remains unknown, but given the extent of lease areas and planned number of turbines, impacts are expected (Hooper et al. 2017; Galparsoro et al. 2022) and are newly added to our conceptual framework for NES II (Fig. 2).

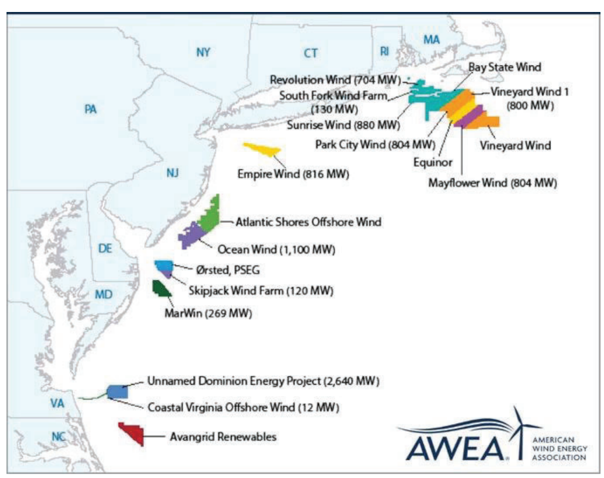


Fig. 20. U.S. east coast offshore wind projects and lease areas approved by BOEM.

We expect that the structures supporting wind turbines will influence regional ocean circulation, the planktonic ecosystem, and fisheries. Locally, increased mixing associated with unsteady vortices generated by turbine monopiles can alter water column stratification, the transport of nutrients and planktonic organisms (including larvae of commercially important fish), and impact primary production (e.g., Chen et al. 2020a).

During NES II, we propose exploratory research on this topic leveraging new multi-agency wind farm monitoring programs in the region, in conjunction with NES observations and modeling. NES transect observations will occur before, during, and after wind turbine installation, ideally continuing during their multi-decade planned operations. In addition to continuing relevant observational time series during NES II, we will carry out model simulations focusing on the impact of wind turbines on the production and distributions of planktonic organisms. For modeling approaches, we will follow Chen et al. (2020a) to explore how wind turbines could impact physical conditions and associated ecosystem properties. In particular, we will focus on how the offshore transport of water is influenced by the turbine-induced vorticity field in the water, associated momentum losses, and lateral/vertical mixing. We will also test how large-scale wind turbine installations could change the wind field within the region and in turn affect stratification, nutrient distributions, and primary production. To do this, we will conduct numerical experiments similar to those by Daewel et al. (2022), but with an expansion to include the impact on the along- and cross-shelf transport of nutrients and organic matter. The results from model simulations will also be used to inform site selection and data interpretation associated with our observational efforts. Into the future, wind energy infrastructure will be a long-term feature of the NES seascape and our exploratory efforts in NES II will set the stage for more in-depth study and understanding of the impacts.

5.4. (Q3) Is the NES ecosystem (and the services it provides) vulnerable to dramatic transformations in the face of climate-induced environmental changes? Or does diversity confer resilience and provide a buffer against dramatic changes in aggregate productivity via shifts in composition?

The NES ecosystem is at the forefront of climate-induced environmental changes, signified by prolonged and widespread MHWs and other long-term disturbances. We will continue to document ecosystem responses and uncover underlying mechanisms responsible for ecosystem vulnerability and resilience as we obtain longer time series during NES II.

H3.1 Chronic MHWs associated with climate trends alter phenological and biogeographic patterns of organisms on the NES, leading to changes in community structure.

When MHWs occur frequently and become chronic, the baseline thermal regime will be shifted. SST anomalies have crossed the MHW threshold frequently in the most recent decade (Fig. 16b). This NES warming trend is projected to continue. Consequently, the resident organisms are susceptible to warming, with linked alterations to ecosystem structure and function as emphasized in a recent synthesis across LTER marine pelagic sites including NES (Ducklow et al. 2022). Some of the first consequences of climate warming and global change are often seen in altered species phenology and in altered geographical distribution limits (Ji et al. 2010).

In an open and dispersive system such as the NES with low spatial restriction, environmental changes continually impact the life cycles of species. As a result, populations respond over time adjusting their optimum position within bioclimatic envelopes. Plankton, with their short life cycles and ranges largely free of geographical barriers, are capable of quickly tracking changing bioclimatic envelopes, whether within a temporal niche as in seasonal succession (observed as a phenological response) or an overall spatial niche (observed as a geographical movement in a population) (Ji et al. 2010). At higher trophic levels (e.g., fish), organisms with high mobility can respond to warming by moving to areas within their temperature range for which physiological performance is maximized (in many cases northward or to deeper depths for NES species); whereas organisms with low mobility will experience high mortality due to thermal stress, resulting in population decline at the southern extent of their range and potentially leading to population growth in the northern extent (Fogarty et al. 2008; Nye et al. 2009). Thus, warming-induced biogeographic shifts could be a result of either direct movement or the integrated population response to changes in growth, mortality and recruitment at individual levels (Pörtner and Peck 2010). Since different species have different thermal preferences, species within a community are likely to be reshuffled, leading to changes in community structure in a new thermal regime.

To test hypothesis H3.1, we will continue our sampling program to extend existing time series, and couple these with data-driven statistical and dynamic modeling analyses. Phenology analysis often requires high resolution time-series data. We will rely on in-situ observations (such as MVCO) for single-location species-specific phytoplankton phenology analyses (following Hunter-Cevera et al. 2016), and ocean color satellite data for bloom phenology analyses across the entire NES region (following Song et al. 2010). Numerical experiments with the lower trophic level food web model developed in NES I (Zang et al. 2021) will be used to examine mechanisms linking warming and phenological shifts in different subregions of the NES. For zooplankton phenology analysis, we will focus on ecologically prominent copepods (e.g., *Calanus finmarchicus*) and gelatinous groups (e.g., ctenophores, salps, and appendicularians). The analysis will rely on data collected through NOAA EcoMon surveys and on NES transect cruises. As new data becomes available during NES II, comparisons will be made with historical phenological patterns as described in Staudinger et al. (2019) to further assess the role of warming in the shifts of multiple phenological parameters such as abundance peak, stage composition, diapause timing. For fish phenology, a follow-up analysis will be conducted in collaboration with our NOAA collaborators to evaluate whether and how the phenological shifts of multiple fish species on the NES (described by Walsh et al. 2015; Staudinger et al. 2019) might change as the warming continues.

Our proposed assessment of biogeographic boundary shifts will be focused on zooplankton and fish species. We will adopt a widely used mean temperature of catch method (MTC; Cheung et al. 2013) to detect warming impacts on distributions. Recognizing the limitations of the MTC method (Agiadi et al. 2022), we intend to use it to detect large scale patterns, and will complement it by computing additional distributional parameters (e.g., center of biomass, max/min latitudes, and mean depth of occurrence) as described by Nye et al. (2009). Our NES cross-shelf transect, strategically located at the boundary between the Gulf of Maine and Mid-Atlantic Bight, will allow us to detect the absence/presence of indicator species that are sensitive to warming. Additionally, our on-going observations will help validate and improve habitat models for zooplankton (e.g., Chust et al. 2014) and fish (e.g., Suca et al. 2022b).

H3.2. The impact of abiotic forcing on NES productivity could be buffered through compensatory dynamics in the planktonic communities, thus dampening variability of energy transfer to higher trophic levels over longer time scales.

Environmental fluctuations may negatively impact certain species in a community, causing compensatory increases for other species due to the release of competition or predation pressure from stress-intolerant species. This type of compensatory dynamic has long been hypothesized as an important mechanism to support community stability and ecosystem resilience (e.g., Patten 1975; McNaughton 1977). Numerous theoretic studies considered in a review by Gonzalez & Loreau (2009) have demonstrated that compensatory fluctuations at the population level could have a stabilizing effect at the community level, and this effect is likely enhanced as species diversity increases. A counter argument suggests that compensatory dynamics are rare in natural ecological communities, as shown in a synthesis study of 41 natural communities from terrestrial and freshwater systems (Houlahan et al. 2007). A compensatory dynamic is often the result of internal density-dependency in a community, whereas the lack of it implies abiotic environmental factors as the primary drivers of population fluctuations. Most of these debates are based on analyses of terrestrial and freshwater systems, which differ from marine pelagic systems in scale, diversity, food-web structure, and driver-response relationships.

We hypothesize that compensatory dynamics in marine plankton communities reduce aggregate variability and support maintenance of ecosystem function at the community or metacommunity level. A high-diversity community is more resilient to environmental disturbance than a low-diversity community through compensatory effects (Fig. 21). Preliminary analyses from NES I illustrate this with zooplankton observations along the NES cross-shelf transect. A community composed of three dominant species (two cold water species, *Calanus finmarchicus* and *Pseudocalanus* spp. and one warm water species, *Centropages typicus*) show compensation nearshore and more synchrony offshore (Fig. 19). Removing the warm water species (*C. typicus*) from the community shows the remaining copepods have synchronous dynamics, with a variance ratio close to 0.8 across the entire transect (results not shown in the figure). This relationship between diversity and aggregate variability due to compensation matches the theoretical analysis by Yachi and Loreau (1999). The NES forage fish also show compensatory effects between sand lance and herring over the last few decades (Suca et al. 2021a). Furthermore, our preliminary analyses of carbon stable isotope composition of NES forage fish suggest aspects of functional redundancy and food web flexibility. In particular, a consistent seasonal fluctuation in $\delta^{13}C$ across 5 different species (blueback herring *Alosa aestivalis*; alewife *Alosa pseudoharengus*; Atlantic herring *Clupea harengus*; Atlantic butterfish *Peprilus triacanthus*; and Atlantic mackerel *Scomber scombrus*) shows evidence of temporal variability at the food web base and likely a similar seasonal diet shift by either the forage fishes themselves or the lower trophic levels (Fig. 22). Compensatory effects have been documented in the California Current Ecosystem (Lindegren et al. 2016), where mesozooplankton and small pelagic fishes demonstrate stable aggregate dynamics. Lindgren et al. (2016) suggested possible reasons for compensatory dynamics in ocean systems including shorter generation time relative to the characteristic timescale of environmental variability; and adaptations to drivers with higher variance at lower frequencies. The dispersive nature of shelf seas could also be important as species with compensational functional traits can be dispersed and occupy disturbed habitats.

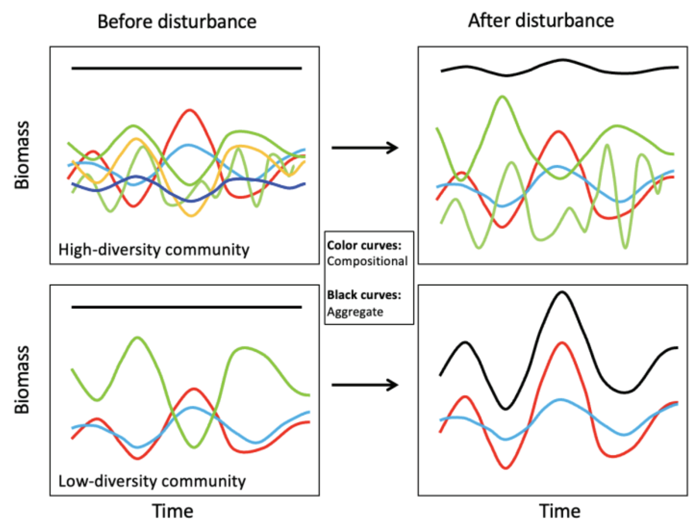


Fig. 21. A conceptual illustration of high- vs. low-diversity communities responding to disturbance. In a low-diversity community, disturbance-induced loss of diversity reduces compensatory effects, resulting in higher aggregate variability; whereas in a high-diversity community, aggregate variability is less affected by disturbance due to compensatory effects.

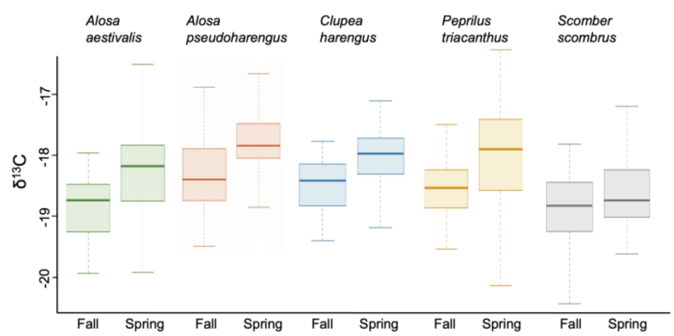


Fig. 22. Comparison of fall and spring δ13C across 5 species of NES forage fish. All species showing higher spring values suggests base-of-food-web variability tied to a coherent seasonal diet shift in the fishes themselves or the lower trophic levels. This is consistent with a hypothesis of more diatom-dominated food webs (State 1) in late winter/spring.

We propose to assess the compensatory dynamics of zooplankton and forage fish communities on the NES by combining both data analysis and modeling approaches. We will rely on the NOAA plankton and fish survey data for long-term shelf-wide analyses. Statistical indices (like those described in Sec. 3.6) will be applied for community synchrony/compensation detection. Additionally, the lower trophic level food web model developed for NES I (Zang et al. 2021) will be adapted to test the responses of zooplankton communities within different size classes to changes in primary production regime. The focus will be on how prey-switching behavior can alter the energy transfer pathway and buffer the impact of changing phytoplankton size structure and productivity. Synchrony indices will also be computed for seasonal- to decadal-scale changes in zooplankton biomass of different size classes across the entire NES region. Through the extension of time series data during NES II, we will be better positioned to detect compensatory signals at a longer time scale, while the numerical experiments will allow us to explore mechanisms that contribute to compensatory effects under different disturbance scenarios. A cross-site comparison with the California Current Ecosystem will be conducted with principal component analyses similar to Lindegren et al. (2016), along with the variance ratio calculations.

5.5. LTER core areas and approaches

Many NES II approaches will closely follow those from NES I to produce longer term observations and results from process and experimental studies that we will continue to integrate with a variety of models. We use a range of approaches that span the LTER core research areas and provide the information needed to address our guiding questions (Table 1). The overview here is complemented by more method details provided as metadata in our published data sets (see Supplementary Table of Data Products).

Table 1. LTER core areas and observational approaches during NES I and continuing or planned for NES II. Bolded approaches are those with new or enhanced focus in NES II.

Approach	**Primary production**	**Population dynamics**	**Organic matter movement**	**Inorganic matter movement**	**Patterns of disturbance**
Physical and hydrographic observations			X	X	X
Nutrients, **dissolved** & particulate C and N			X	X	X
Flow cytometry & imaging		X	X		
Chlorophyll, including size fractions	X	X	X		
DNA sequencing, incl. size fractions		X	X		
Zooplankton net tows		X	X		
Zooplankton imaging		X	X		
O_2/Ar gas tracers & triple O_2 isotopes	X	X	X	X	
^{13}C incubations	X	X	X		
Microzooplankton grazing experiments	X	X	X		
Macrozooplankton grazer addition exp'ts		X	X		
Stable isotope analysis		X	X		
Forage fish abundance		X			
Forage fish diet		X	X		
Bioacoustics		X	X		X
Population models	X	X	X		
Biological-physical coupled models	X	X	X	X	X
Forage fish abundance		X			
Forage fish diet		X	X		
Stable isotope analysis		X	X		

Primary Production: We will continue to measure and model aspects of primary production at multiple temporal and spatial scales. On transect cruises, we will use ship-board incubations to quantify rates of size-fractionated NPP (^{13}C incorporation) and phytoplankton growth (dilution experiments). For more spatial detail, we will use a shipboard mass spectrometer to measure rates of NCP at km-scale resolution throughout the entire cruise - producing thousands of rates on a single cruise. We will also use triple oxygen isotopes, measured from CTD casts and the underway system, to quantify GPP. We have seen good agreement and complementary information between the different methods, showing that we can use these methods to assess production on multiple scales. With our biogeochemical models, we will continue to examine NPP and NCP patterns, diagnose mechanisms underlying spatiotemporal variability, and synthesize model and observational results to test hypotheses.

Population Dynamics: We will continue to assess population dynamics of phytoplankton, zooplankton, and fish with a range of methods from NES I, along with some additions. We will characterize the abundance, biomass, and species composition of phytoplankton and heterotrophic protists with five complementary approaches: conventional flow cytometry, imaging flow cytometry, size-fractionated chlorophyll a, microscopy, and DNA sequencing. We will maintain FlowCytobot (FCB) and Imaging FlowCytobot (IFCB) deployments at MVCO, IFCBs for underway sampling during broadscale and transect cruises, underway automated flow cytometry (Attune NxT) on transects, and discrete sample enumeration of heterotrophic bacteria with flow cytometry from transect and MVCO cruises. For protist and bacterial diversity, size-fractionated samples will be collected from two transect cruises annually, and DNA extracted from high priority water samples. We will measure microzooplankton grazing rates with shipboard dilution experiments. *New for NES II, when possible, given logistical and sampling constraints on ~one cruise annually, we propose to conduct targeted dilution experiments with mesozooplankton grazer additions at an adaptively selected station.* Mesozooplankton and forage fish observations will continue to leverage our partnership with NOAA colleagues, benefiting from their on-going EcoMon surveys, their spring and fall trawl surveys to obtain forage fish specimens for diet analyses (at WHOI), and shared cost and time for zooplankton abundance/composition analyses for NES transect net samples. In addition to microscopy, net samples will be analyzed for metabarcoding and stable isotopes. *During NES II, we propose to increase resolution of spatiotemporal patterns in zooplankton and fish with new focus on (1) in situ shadowgraph imaging (towed system, initially deployed during NES I and to continue) and (2) bioacoustics (leveraging historical transect and broadscale datasets and new observations in NES II), as well as to add a midwater trawl on transect cruises to characterize larval fish.* Numerical modeling will be continued with the intermediate-complexity model implemented during NES I to simulate lower trophic level food web dynamics.

Organic Matter Movement: Much of the NES organic matter movement is mediated by biological activity and our approaches listed above that characterize the abundance and movement of phytoplankton, zooplankton, and fish will therefore give important data on the biological aspect of organic matter movement. In addition, we will measure particulate organic carbon at multiple depths on our transect cruises. *At the end of NES I, we also started measuring dissolved organic carbon and we will continue to do so in NES II.* Our modeling efforts will provide valuable constraints on organic matter movement as they provide organic matter estimates in the forms of various plankton functional groups and detrital pools, as well as estimates of transfers among pools. Additionally, models will allow us to test how physical processes are changing organic matter movement and how this in turn affects the ecosystem.

Inorganic Matter Movement: We will continue to collect a broad range of physical and chemical observations. This includes temperature, salinity, wind speed, water velocity, and discrete samples for nutrients, oxygen, and dissolved inorganic carbon. Modeling efforts will continue hindcasts with high spatial and temporal resolution for temperature, salinity, and nutrients. To examine the temporal and spatial variation and disturbance patterns of inorganic matter, we will integrate a variety of observational data sets collected on the shelf and in the neighboring slope sea.

Patterns of Disturbance: In NES I, we established detailed information on many of the baseline patterns of the other four core areas. Additionally, we already saw some instances of disturbance such as unusual diatom blooms that occurred in an extremely warm summer and under spring conditions with strong offshore influence over the outer shelf. In NES II, we will focus one of our central questions on disturbance (Q2) and will use the observational data and modeling methods described above to understand how our system responds to disturbances ranging from warm core rings and heat waves to offshore wind infrastructure now under construction in our site.

6. Related Research Projects, Regional and Cross-site Collaboration and Synthesis

NES research will continue to require strong connections with partner organizations and the operators of regional observing system components. Critical elements include regional ship-based surveys operated by the Northeast Fisheries Science Center (NEFSC, NOAA National Marine Fisheries Service) for ecosystem monitoring, stock assessment, and protected species management. We will continue to achieve NES broadscale sampling objectives by adding observations to these cruises and our overall research objectives benefit greatly from the valuable multi-decade datasets collected by NESFC. On the nearshore end of the focal transect, high resolution time series will continue to be made possible due to our partnership with the MVCO, operated by WHOI. We will continue to maintain automated plankton observations and other water column sampling that complement the core environmental properties measured at MVCO. Other important regional assets include NODC weather buoys and IOOS components in the Gulf of Maine (NERACOOS) and Mid-Atlantic Bight (MARACOOS). The NES team is actively involved in complementary networks such as the Integrated Sentinel Monitoring Network (ISMN), the Rhode Island EPSCOR C-AIM program, and a variety of affiliated research projects. NES II education and outreach activities will continue to benefit from strong partnerships with existing programs, including several long-running programs: Summer Student Fellowships at WHOI, Partnership Education Program (NOAA/NMFS, WHOI), Summer Undergraduate Research Fellowships in Oceanography at URI, and Sophomore Early Research Program and Science Center Summer Research Program at Wellesley. In turn, our activities will benefit these programs directly including through funding of students and engagement in training.

The proposed research described above will be funded as part of NES II and not contingent on other funding. NES II investigators are involved, however, in several on-going projects that will extend the research proposed here and accelerate the pace of analytical and synthetic activities. In particular, (1) Sosik leads research funded by the Simons Foundation to advance imaging technologies and associated big data challenges for plankton studies, as well as support students and postdoctoral investigators who use NES datasets in their research; (2) Catlett has been awarded an NSF Ocean Sciences Postdoctoral Research Fellowship for in-depth analysis of impacts of parasitism on diatoms at the NES site; (3) Sato has been awarded a NOAA CINAR fellowship to study distributions of Northern shortfin squid in NES waters with acoustic methods; (4) Ji and Llopiz have been awarded a NOAA CPO project to evaluate zooplankton changes in the Gulf of Maine in support of the Stellwagen Bank National Marine Sanctuary; (5) Rynearson has been awarded NOAA CINAR funds to investigate the diet composition of right whales from scat samples using DNA metabarcoding; (6) Rynearson has been awarded NSF funds to investigate the physiology and thermal tolerance of the bloom-forming diatom-diazotroph association *Hemiaulus-Rhizosolenia* observed on the NES in summer 2019; (6) Rynearson continues to lead the Narragansett Bay long-term plankton time series allowing us to extend some of our investigations from the shelf into the adjacent Narragansett Bay estuary; (7) NES investigators will be engaged with the newly funded "Pelagic Community Structure" LTER synthesis working group focused on cross-site synthesis and testing of conceptual models across a global latitudinal gradient and (8) NES investigators are leading the newly funded "Producers, Consumers and Disturbance" LTER synthesis working group focused on understanding how disturbances and environmental change across timescales are altering the production and transfer of organic matter from primary producers to herbivores.

7. Broader Impacts

All project team members will be encouraged to be involved with broader impacts inclusive of education and outreach (E&O), JEDI efforts, and engagement with management agencies. As in NES I, our E&O plan will provide opportunities for a broad range of learners, and our continued close collaboration with the NOAA NEFSC will improve knowledge of ecosystem services of the NES Large Marine Ecosystem. In NES II we are enhancing both our JEDI efforts and our connection to management agencies regarding the wind farm industry.

Education and Outreach (E&O). NES E&O has three main components: (1) training and mentoring for undergraduate and graduate students and postdoctoral researchers; (2) an LTER Schoolyard program that engages Middle and High School teachers and students; and (3) public outreach through targeted events, our website, and established social media channels. Our goals continue to align with growing efforts to incorporate publicly available Earth and life science data into formal and informal educational activities to advance science, technology, engineering, and mathematics (STEM) literacy (e.g., Bader et al. 2016).

Training & Mentoring, including Research Experiences for Undergraduates (REUs). We will involve undergraduate and graduate students and postdoctoral researchers directly in NES research, and they will gain valuable training in not only field, lab, data management, and analytical skills, but also in collaborating in a multi-investigator/multi-disciplinary project. Over the course of the 5-year grant period, we will offer research experiences for undergraduates (REUs), including 10 sponsored by NES at WHOI, 5+ at the University of Rhode Island (URI), and 10+ at Wellesley College. The NES REUs at WHOI will be coordinated with the Woods Hole Partnership in Education Program (PEP; see letter from O. Scott Price), a multi-institutional effort to promote diversity in the Woods Hole science community, and WHOI's Summer Student Fellow (SSF) program. At URI, 1-2 undergraduates each summer will be incorporated into the NSF-sponsored undergraduate research fellowship in Oceanography (SURFO). At Wellesley, at least one undergraduate each summer and at least one during the academic year will be sponsored by programs engaging students from underrepresented minority groups (described in Facilities statement). We will support graduate students at WHOI and UMD and a postdoctoral researcher at WHOI (see Mentoring Plan), with leveraged funding expected for additional participants. New enhancements for our training in NES II include peer mentoring for cruise participants, working group leadership roles for early-career researchers, and direct involvement with our Schoolyard as described below.

LTER Schoolyard. As in NES I, our proposed LTER Schoolyard program will continue to focus on Middle (MS) and High School (HS) curricula supporting introductory to advanced data analysis, e.g., change over time, ecological similarities/differences in marine vs. terrestrial systems, making claims supported by evidence and reasoning. We will engage teachers from the region (i.e., Massachusetts, Rhode Island, Maine, New Hampshire) to participate in professional development (PD) workshops and in research experiences such as the seasonal transect cruises, a successful part of NES I. We will engage the students of these teachers in curriculum use, classroom research, and using data/visuals on laptop or tablet-based applications (adapting to technology available in different schools). Curriculum content and a framework for student and teacher research experiences will be developed and aligned to Next Generation Science Standards (NGSS) including Disciplinary Core Ideas and Science and Engineering Practices for both MS and HS. Components of the Schoolyard program are: **(1)** Teacher PD workshops will be offered two to three times each year, led by Brickley with project graduate students/postdocs to support student data literacy skill development, enhance Claim-Evidence-Reasoning communication skills (McNeill and Berland 2017), and make the relevant NES research accessible. Involving graduate students/postdocs in PD with Brickley is a deliberate component of training for future Broader Impacts work. Additional teacher PD will be conducted in coordination with the Massachusetts Marine Educators (MME), National Marine Educators Association (NMEA), and Massachusetts Association of Science Teachers (MAST). Brickley's active participation with these organizations facilitates connections to teachers in MA, RI and beyond. **(2)** Research experiences for teachers (RET) will include teacher-at-sea opportunities to participate and share their experience with students, and through the Ask-a-Scientist webinars and social media. **(3)** Students (MS, HS) will learn from the project through the NES Data Jam, where they access real project data, are guided to build data literacy and communication skills, and connect with the NES team as project judges. **(4)** Selected student groups demonstrating curiosity through the Data Jam will earn a full-day field trip, including the WHOI Visitors and Exhibit Centers, lab experience/tours, and NOAA's Woods Hole Science Aquarium. We will continue to work with the Network Office and other sites to adopt an effective and attainable approach to assessment for each of the components.

Outreach. Outreach will be aimed at targeted audiences and the public. While Schoolyard activities are designed for curricular use by students and teachers, outreach activities are aimed to increase awareness and engage curiosity about our research and the people and opportunities behind it. Brickley will attend events (MME, MAST, NMEA) to share data literacy ideas and content linked to NES research. Brickley will also share at youth-focused events such as the Falmouth Public Schools STEAM Fair and the MME High School Marine Science Symposium (HSMSS). Aligned with NES JEDI goals, the HSMSS is held in Boston each year as a professional-style symposium designed to encourage and engage youth (particularly the underserved population in Boston Public Schools) in marine science. Activity tables at public events, such as the "Party for the Planet" Earth Day event at the Buttonwood Park Zoo, will build local awareness of NES research in the largely underserved community of New Bedford, MA. Each of these avenues will be publicized and documented for further reach through the NES website and social media channels on YouTube and Twitter. Posts and shares will focus on giving the public audience direct connections to the people on the NES team, engage curiosity, help themselves see career opportunities, and promote JEDI in ocean science and engineering. We are positioned to share more about how our research benefits local communities such as the fishing community of New Bedford, which has a long heritage connecting BIPOC families to the industry.

Justice, Equity, Diversity, and Inclusion (JEDI) efforts. Growth of JEDI activities and deliberate action towards diversification, equity and inclusion during NES I, led by NES co-PIs with engagement from the whole NES community, have set the stage through learning and experience to formulate and implement goals from our JEDI Action Plan. The Action Plan is centered around three foci: recruit, retain and promote, recognizing these three elements as key steps to democratize effort and level representation of perspectives in scientific teams. NES II activities will build on these three focal areas so that we continue to enhance and sustain diversity within our project, foster a sense of belonging and equity, and nurture and guide team members. While the NES leadership team already reflects gender, ethnic, and other aspects of diversity to some extent, we are mindful of being continually vigilant on this issue through stages of recruitment and succession planning. We will continue the successful engagement of diverse undergraduates from our respective institution's summer programs.

Whole team JEDI activities will continue to include our monthly 'JEDI moments' where team members share resources or insights from their self-study of structural inequities and barriers to inclusivity. JEDI moments will continue to be contributed by NES team members at all career stages, highlighting how our community learns together across project roles. To further increase retention of individuals in our project and in STEM more broadly, the JEDI Committee will take actions to strengthen our network through the sharing of resources between team members before, during, and after their participation in the NES project. We will continue to develop orientation materials and best-practices for onboarding to welcome new participants to the team. Our at-sea mentoring program has been so well received that we now plan during NES II to implement a similar program for our shore-based teams. To enhance the sense of belonging across the team, we will continue our listening sessions where co-PIs are available in small group meetings, listening to ideas, concerns, and discussion of suggestions including implementation strategies. Supporting and promoting the personal and professional growth of team members will include such strategies as recruiting promising REUs to graduate school, providing within-project opportunities to develop leadership, and engaging students and technical staff in authoring publications and presentations. The JEDI Committee will maintain communication with past participants to track their career progress, and, when appropriate, leverage the growing networks of individuals as we continue to recruit new scientists to the project.

Engagement with management agencies. Our on-going collaboration with NOAA NEFSC aligns with efforts towards end-to-end modeling being conducted as part of the multispecies, ecosystem-based management on the NES. Our LTER research will improve knowledge of supporting and regulating services (e.g., primary production, nutrient and carbon cycling) that underpin fisheries as a provisioning ecosystem service. New in NES II will be enhancing our connection with the Wind Team at NEFSC with regard to potential effects of offshore wind infrastructure on ecosystem dynamics and services. The NES team has engaged with the licensees of wind farm projects. This engagement is nascent, a major developer has indicated an interest in substantive engagement. We highlight how our 5+ years of insights into the drivers of ecosystem function and their possible responses to disturbances can serve as a critical baseline for management of the essential services the NES region provides to the blue economy.

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* Denotes NES product

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FACILITIES, EQUIPMENT AND OTHER RESOURCES

WHOI

The Woods Hole Oceanographic Institution (WHOI) is the largest independent, not-for-profit, oceanographic research institution in the world. Founded in 1930 in the village of Woods Hole, Massachusetts, the Institution's facilities have grown to encompass 219 acres of land and waterfront and 58 buildings and laboratories. The paid staff numbers about 900, with more than half involved directly in scientific research. The Institution's higher education programs enroll about 125 students in graduate-level studies and about 35 in undergraduate summer fellowships. A wide range of shop services and facilities are available to WHOI staff including a precision machine shop, carpentry shop, and graphics services.

Instrumentation and observatory access: WHOI operates the Martha's Vineyard Coastal Observatory (MVCO) facility, to which we will have full access for instrument deployments and core environmental data (http://www.whoi.edu/mvco). WHOI operates the 60-foot coastal boat R/V Tioga (https://www.whoi.edu/main/ships/tioga), available for research projects at a fixed day rate. Funds for this boat time (to access the MVCO site, 1.5 h from WHOI) are requested in this proposal. WHOI has complete facilities to support the diving operations needed to deploy and maintain the in situ instrumentation involved in the proposed research.

Sosik and collaborators at WHOI maintain a series of automated submersible flow cytometers (FlowCytobot and Imaging FlowCytobot series), including several Imaging FlowCytobot (McLane Research Laboratories, Inc.) units optimized for measuring and imaging microplankton. One or more of these instruments will be available for the continued fieldwork at MVCO for the duration of this project. The Sosik laboratory also maintains a ZooSCAN (Hydroptic) system for high resolution digital imaging of net tow samples, two SUNA (SeaBird Electronics) optical nitrate sensors, and a custom Stingray towed sled (Bellamare, LLC.) equipped with a high speed shadowgraph imager (optimized for mesozooplankton, 15 Hz, 2.3 liter/frame imaged volume, ~40 micron pixel) and sensors for CTD, fluorescence, optical backscattering, oxygen, PAR sensor, and nitrate. In the Sosik laboratory, the PIs will have access to facilities and equipment to support maintenance and evaluation of instruments for the proposed field deployments. These include a wide variety of electrical, optical, electronic equipment and testing devices, including power supplies, function generators, digital oscilloscopes, diode lasers, LEDs, photomultipliers, amplifiers, and PIC microprocessor systems.

The Sato laboratory at WHOI has multifrequency shipboard echosounders (Simrad EK80s; 38, 70, 120, and 200 kHz, Mini: 38 and 200 kHz), access to Echoview software for acoustic data analysis, as well as an Isaacs-Kidd Midwater trawl (4-m^2 mouth opening, 3.2-mm black mesh) and real-time depth sensor (Simrad PX sensor). Simrad EK80s (portable systems) will be available for the cruises when the vessels are not equipped with echosounders but have the capacity to install them (i.e., transducer well). Electronics of the Simrad Mini will be integrated into Sosik's Stingray towed sled during this project. Sato's laboratory includes space for testing and preparation of sensitive equipment, as well as analyzing zooplankton and fish samples including a hood with ventilation system.

Sampling and analytical facilities: In their laboratories and within shared-use institutional resources, the PIs have the facilities required to carry out the proposed work. These include incubators, microscopes equipped for phase contrast, epifluorescence and transmitted light microscopy, high-powered stereomicroscopes, an Attune NxT flow cytometer, spectrophotometers, refrigerators, -20°C and -80°C freezers, balances, centrifuges, plankton nets, laminar flow hoods, and fume hoods. Equipment involved in the isolation and amplification of nucleic acids is also available, including microcentrifuges, PCR machines, agarose gel electrophoresis equipment, and an imager for gel documentation. At WHOI, there is a Thermofisher 253 Isotope Ratio Mass Spectrometer configured for measuring triple oxygen isotopes and O_2/Ar ratios. The attached automated processing line makes use of a custom-made cryogenic trap, Neslab recirculating chillers, GC column, refrigerated bath, turbomolecular pumps, and mechanical pumps. The entire system is under automated control and can be checked from the internet.

Clinical and Animal: N/A

Computing: The Information Management (IM) component of the NES LTER project will be located at WHOI, with the data center for physical research data storage (RDS) on premises at the Quissett Campus. Information Services (IS) support will be provided by the WHOI IS pool of technical experts, with specialists in system and database administration and applications programming. WHOI IS provides a range of free and at-cost services for all WHOI researchers, students, and staff, including desktop, server, and software support. WHOI IS Security provides several functions, including managing firewalls, analyzing network traffic, providing network level antivirus and vulnerability protection, and identity and password management, to ensure that systems are protected by a multilayered defense strategy, while safely allowing outside access to public services. The NES LTER uses virtual machines and network-attached storage appliances for high volume and high frequency data. WHOI IS also provides data backup (on and off site) and disaster recovery services. The WHOI data center is equipped with backup power/cooling and physically secured with electronic locks. Additional support for data curation and archiving will be available from specialists at the MBLWHOI Library, in particular for minting DOIs for data sets and implementing data access through the Woods Hole Open Access Server (WHOAS). Cloud storage for file sharing across institutions is enabled by WHOI's Google Drive services. WHOI IS maintains the WordPress server used for our project website and an organizational account on GitHub to facilitate our IM code development.

For routine computing, all PIs have computers and peripherals in their laboratories, including an automated daily back-up system (administered by WHOI IS). Computational infrastructure available in the Sosik laboratory includes three Dell Precision T7500/7600 six core workstations with more than 30TB network attached storage for routine data analysis and access; and, for more demanding image analysis and classification tasks, two Dell R710 PowerEdge servers, each with two 6-core Xeon X5660s 2.8GHz processors, 72 GB of RAM, and 5TB of local disk space. WHOI has a dedicated high-memory server for high throughput sequence data analysis, with 1 TB RAM, and 40 (80 hyperthreaded) processors.

We also have access to an institutional high-performance compute cluster connected to the RDS repository via 100Gb/s Infiniband EDR. The cluster operates on a fair share policy and is administered by the slurm scheduler. The cluster is currently composed of 85 standard notes (192GB RAM, 36 cores per node), 1 shared-memory node (3 TB RAM and 80 cores), and one GPU node (4 Nvidia Volta V100 GPUs connected via NVLINK). The cluster users share 200TB of scratch space to run compute jobs. For NES II we have dedicated access to 100 TB of storage on this system and the ability to purchase additional space if needed. Additional computing resources will be made available for this project through WHOI's Information Services department (see other resources described below).

WHOI maintains a site license for MATLAB and the MATLAB toolboxes, which will be used in the proposed research. WHOI's Graphics Services department offers expertise in animations, web design, and video processing, including post-production video editing valuable for outreach activities.

Office: All PIs have their own laboratories equipped with personal computers, office space for students and visitors, meeting space, and all necessary peripherals. Office space and computational resources for graduate students and summer undergraduate fellows will be provided in their labs.

Other resources, personnel: Dr. Joel Llopiz led the zooplankton, fish ecology, and trophic dynamics components of NES I. Dr. Llopiz is an expert in forage fish ecology and his role greatly contributed to the success of NES 1. Dr. Llopiz is currently on extended approved leave with an uncertain return. When Dr. Llopiz is able to return to active status he will continue to advise on the fish ecology, zooplankton ecology, and food web dynamics aspects of the project.

Other resources: We anticipate recruiting several REUs who will be sponsored through WHOI's long-running, endowed Summer Student Fellowship program. Through its institutional Information Services (IS) group, WHOI will provide resources needed to maintain the NES-LTER data and information system, including computational infrastructure, data storage, and support staff (programmers, system administrators). Further, WHOI is finalizing the establishment of a formal, institutional Project Management program. While the timing of full implementation remains under discussion, support for NES LTER project coordination and management figures prominently in institutional prioritization.

UNIVERSITY OF RHODE ISLAND

PIs Menden-Deuer & Rynearson are both faculty members at the Graduate School of Oceanography, the University of Rhode Island. They each hold a 9-month state supported faculty position.

Live culture and molecular facilities: PI Rynearson has three laboratory spaces to allow for separate handling of 1) live cultures, 2) fixatives and DNA stains and 3) general molecular biology reagents and procedures. The laboratory for handling live cultures contains 2 Percival incubators (30 ft^3), a HEPA Class 100 UV laminar flow bench, an Olympus dissecting scope and standard glass and plasticware for media preparation and culturing live cells. The lab maintains a Guava Flow cytometer (Luminex) for analysis of the abundance, size and optical properties of pico- and nanoplankton. A separate dark room is used for fixatives and DNA stains and includes gel electrophoresis equipment for both agarose and polyacrylamide gels and a Syngene Gbox HR for high resolution gel imaging. A third laboratory space is equipped with instrumentation for standard molecular analysis and includes an Eppendorf EPMotion BioRobot for high throughput liquid handling, 2 x 96-well PCR thermocyclers, refrigerated centrifuges, microcentrifuges, refrigerator, freezer, two –80ºC freezers for sample storage, liquid nitrogen dewars and dry shippers, pipettors (both single and multi-channel, manual and electronic), balances and standard glassware and plasticware. PI Rynearson has access to additional microscopes at GSO including three Nikon microscopes: an Eclipse 800 for video and photography, a Diaphot 300 with epifluorescence, and a second Olympus dissecting scope for isolating live cells.

PI Menden-Deuer has two adjacent laboratory spaces to allow for separate handling of live experiments and toxin related work. There is a separate facility with independent generator support that houses two 30 ft^3 light and temperature-controlled incubators. The laboratory for handling live cultures contains a laminar flow workbench for sterile manipulation of cultures and a Coulter Counter for enumeration and size classification of plankton cultures. Menden-Deuer has three Nikon microscopes: an Eclipse 800 for video and photography, a Diaphot 300 with epifluorescence, and a SMZ-U dissecting scope for isolating live cells. The lab is equipped with standard glass and plasticware for media preparation and culturing live cells. An autoclave is available adjacent to the lab for sterilizing materials. Menden-Deuer maintains an active seagoing operation to study plankton population dynamics in situ and has deckboard incubators along with the necessary hardware to incubate plankton samples under simulated in situ light and temperature conditions. PI Menden-Deuer has access to 4 walk-in incubators for culturing isolates in the basement of the same building as the labs and access to a separate EPSCOR marine life sciences core facility on the GSO campus (see below).

Clinical and Animal: N/A

Computing: PIs Rynearson and Menden-Deuer and their lab members have access to desktop and laptop computers that will be used to remotely access compute clusters for data analysis (see major facilities below) and will be used locally for less intensive data analysis and manuscript preparation.

Offices: The PIs, student and technician offices are located at the Graduate School of Oceanography. For students conducting experimental work, their offices are located adjacent to their respective laboratory spaces.

Major Equipment and Facilities: The University of Rhode Island has excellent facilities and equipment for physiological and genomics work related to aquatic ecosystems. The staffed Center of

Excellence in Marine Life Sciences contains a Satlantic FIRe system for measuring variable fluorescence, a BD Influx sorting flow cytometer, a flowcam (Fluid Imaging), a Turner fluorometer, Lachat nutrient analyzer, a Stratagene MX3005P real time PCR machine, a fiber–optic oxygen meter (PreSens), a laminar flow bench, pipettors, thermocyclers, a nanodrop, a running seawater facility and 3 walk-in incubators. All equipment can be used by the co-PIs following the published fee structure.

The main campus of the University of Rhode Island has excellent facilities and equipment for molecular work related to aquatic ecosystems. URI houses a staffed RI INBRE center that contains: an Applied Biosystems 3130xl sequencer, a MiSeq Illumina sequencing platform, two Stratagene MX4000 quantitative PCR systems, a MJ research PCR thermocycler, a refrigerated centrifuge, a DNA SpeedVac, a Zeiss LSM 5 PASCAL confocal imaging system, and Zeiss AxioPlan 2 imaging system, which are available for use by the PIs and personnel on this project.

Research computing resources at URI are provided by the Center for Computational Research at no charge to URI researchers. The data center is configured with emergency power supplies and high-speed internet access through the URI central power and network connections. Central cooling is provided to maintain a climate-controlled environment for the operation of HPC systems. Dedicated IT staff provide operation, management and monitoring support to ensure the smooth operation of the data center facility.

Bluewaves high-performance computing cluster *Bluewaves* HPC cluster contains 62 standard computer nodes [20 physical cores; 128 GB (60), 256 GB (1), or 512 GB (1) memory, 2TB local storage], two large memory nodes (24 physical cores, 512 GB memory, 4TB local storage), and over 1.1 PB hard disk spaces for fast I/O and secondary storage. The storage disks are configured with RAID 6 protection. The computer nodes are connected with InfiniBand QDR network cables and switches and are assembled in three 42U racks. The cluster is in its seventh year of operation. The cluster, while still operating, is near the end of its life cycle and has limits for further expansion.

Andromeda high-performance computing cluster The *Andromeda* HPC cluster is a similar scale cluster that largely serves groups of contributing users with some support for the broader URI user community. It was established with contributions from individual researchers and currently has 47 nodes, providing 1704 cores with nodes having 64GB (8), 128GB (29), 256GB (3), 512GB (4), or 768GB (1) memory. These are connected via an Omni-Path 100Gbps network, with shared storage to the 1.1 PB hard disk on *Bluewaves*.

PI Rynearson also maintains a lab account on the Brown University IBM computer cluster. This IBM iDataPlex system contains >450 nodes and >13,000 cores with both CPU and GPU (>40) nodes and ~3.2 PB of storage via GPFS. A variety of genomics analysis programs (assembly algorithms, CLC genomics workbench, etc) are compiled on the cluster at present and additional software will be added at our request.

Other basics: We have access to the internet, email support, phones, copiers, scanners, and printers. URI provides basic software licenses such as Microsoft Office and MATLAB.

Other resources: GSO/URI will contribute support toward the NES-LTER. We are not permitted to quantify this information in this proposal, but this support comes in several forms: (1) support for 1-2 summer research experiences for undergraduates (SURFO/REU) in each year of the proposal and (2) because both PIs are supported by 9 month institutional salary support they request only minimal salary support as part of this NES-LTER and can devote a greater than requested effort to the NES-LTER. GSO/URI recognizes the NES-LTER and is willing to make a substantial, long term commitment in support of the NES-LTER.

UNIVERSITY OF MASSACHUSETTS, DARTMOUTH

Laboratory: The Marine Ecosystem Dynamics Modeling Laboratory (MEDM-Lab), the University of Massachusetts-Dartmouth, is an active research group with a focus on 1) FVCOM development, 2) ocean modeling, and 3) ecosystem process studies. The laboratory is equipped with a super performance Linux cluster with a total of 3,784 processors.

Clinical and Animal: N/A

Computing: A super performance Linux cluster. The cluster includes 6 generation nodes, with a total of 3,784 processors, 2304 of which are from the latest upgrade done in June 2020. The Latest processors are 32-core 2.9 GHz Intel Cascade Lake with a total of 96 GB of RAM.

Office: MEDML has two permanent laboratory spaces that include offices for research scientists, postdoctoral researchers, research associates, and graduate students. All offices are equipped with the Internet, phones, workstations, and PCs/MACs. MEDML also has a model display room equipped with three 56in TVs to display real-time NECOFS forecast animations through the NECOFS Web Map Server.

Major equipment: A super-performance Linux cluster and multiple workstations.

Other resources, personnel: Dr. Changsheng Chen is an expert in numerical modeling of ocean physics. He oversees the FVCOM simulations that support NES research and has been involved in the NES-LTER project since the start. Dr. Chen will continue to contribute to the project through his faculty advising position for the graduate student supported at UMD.

Other resources: N/A

WELLESLEY COLLEGE

Sampling and Analytical Facilities: PI Stanley is an associate professor at Wellesley College. Her laboratory has three field-deployable equilibrator mass spectrometers, configured for measuring a suite of noble gas mole ratios. The systems contain Hiden or Pfeiffer quadrupole mass spectrometers, Agilent compact pumping stations with turbomolecular pumps, VICI switching valves for automated calibration, hot and cold zirconium-iron-vanadaium getters, Membrana Extra-Flow equilibrator cartridge, and an assortment of gear pumps, flow meters, filters, fused silica capillary, and tubing. The instruments measure ratios of the noble gases (Ne, Ar, Kr and Xe) in air or water depending on the position of the VICI switching valve. Water (from a tank or an underway system of a ship or a coastal embayment) is pumped through the Membrane Extra-Flow where the gas equilibrates with the headspace in the cartridge. In order to aid equilibration, a small pump recirculates the air in the headspace through two drying cartridges. A 0.05 mm ID fused silica capillary carries gas from the headspace of the cartridge, or from the air directly, through the getters and into the QMS. No carrier gas is used since the presence of other gases in the QMS is minimized in order to prevent competition of ions within the QMS. A system similar to these but without the getters will be used for this project to measure O2/Ar from the underway systems on ships to constrain net community production. Stanley's lab at Wellesley also contains a convection oven for drying bottles, and a variety of other small lab equipment. Additionally, Wellesley College has a machine shop with welding capabilities, and limited free technical support available to all professors.

Clinical and Animal: N/A

Computing: Stanley has access to multiple desktop and laptop computers which will be more than sufficient for calculating rates of production from the gas data obtained as part of the LTER. If required, she has access to workstations at Wellesley College.

Office: Stanley has an office near her laboratory.

Other resources: The proposed work will be enabled through the generous student support offered by Wellesley College. Wellesley has a vibrant research program. Endowed funds and internal fellowships will support a summer student on this project each year. During the semester, students will do research on this project for credit and also one will be sponsored by the college's Sophomore Early Research Program, the Clare Luce Boothe Fellow program, or the McNair program, all of which provide funds for students from underrepresented minority groups to perform research in labs.

NSF BIOGRAPHICAL SKETCH

Provide the following information for the Senior personnel.
Follow this format for each person. **DO NOT EXCEED 3 PAGES.**

IDENTIFYING INFORMATION:

NAME: Sosik, Heidi M

ORCID: 0000-0002-4591-2842

POSITION TITLE: Senior Scientist

ORGANIZATION AND LOCATION: Woods Hole Oceanographic Institution

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	DATE RECEIVED	FIELD OF STUDY
Woods Hole Oceanographic Institution, Woods Hole, MA, United States	Postdoctoral Fellow	1993 - 1996	Oceanography
University of California, San Diego, Scripps Institution of Oceanography, La Jolla, CA	PHD	1993	Oceanography
MIT, Cambridge, MA	BS	1987	Civil Engineering
MIT, Cambridge, MA	MS	1987	Civil Engineering

Appointments and Positions

2008 - present Senior Scientist, Woods Hole Oceanographic Institution
1999 - 2008 Associate Scientist, Woods Hole Oceanographic Institution
1994 - 1999 Assistant Scientist, Woods Hole Oceanographic Institution
1993 - 1996 Postdoctoral Scholar, Woods Hole Oceanographic Institution

Products

Products Most Closely Related to the Proposed Project

1. Fowler BL, Neubert MG, Hunter-Cevera KR, Olson RJ, Shalapyonok A, Solow AR, Sosik HM. Dynamics and functional diversity of the smallest phytoplankton on the Northeast US Shelf. Proc Natl Acad Sci U S A. 2020 Jun 2;117(22):12215-12221. PubMed Central PMCID: PMC7275697.
2. Hunter-Cevera KR, Neubert MG, Olson RJ, Shalapyonok A, Solow AR, Sosik HM. Seasons of *Syn*. Limnol Oceanogr. 2020 May;65(5):1085-1102. PubMed Central PMCID: PMC7319482.
3. Oliver H, Zhang WG, Smith WO, Alatalo P, Chappell P, Hirzel AJ, Selden CR, Sosik HM, Stanley RHR, Zhu Y, McGillicuddy DJ. Diatom hotspots driven by western boundary current instability. Geophysical research letters. 2021 May 11; 48(11):e2020GL091943. Available from: https://doi.org/10.1029/2020GL091943 DOI: 10.1029/2020GL091943
4. Ducklow H, Cimino M, Dunton KO, Fraser W, Hopcroft R, Ji R, Miller A, Ohman MD, Sosik

HM. Marine coastal pelagic ecosystem responses to climate variability and change. BioScience. 2022; 72:827-850. ORCID: 10.1093/biosci/biac050

5. Zhang WG, Alatalo P, Crockford ET, Hirzel AJ, Meyer MG, Oliver H, Peacock E, Petipas CM, Sandwith Z, Smith WO, Sosik HM, Stanley RHR, Stevens BLF, Turner JT, McGillicuddy DJ. Cross-shelf exchange associated with a shelf-water streamer at the Mid-Atlantic Bight shelf edge. Progress in Oceanography. 2023; 210:102931. DOI: 10.1016/j.pocean.2022.102931.

Other Significant Products, Whether or Not Related to the Proposed Project

1. Peacock EE, Olson RJ, Sosik HM. Parasitic infection of the diatom *Guinardia delicatula*, a recurrent and ecologically important phenomenon on the New England Shelf. Marine Ecology Progress Series. 2014; 503:1-10.
2. Smith WO, Zhang WG, Hirzel A, Stanley RHR, Meyer M, Sosik HM, Alatalo P, Oliver H, Sandwith Z, Crockford T, Peacock E, Mehta A, McGillicuddy DJ. A Regional, Early spring bloom of *Phaeocystis pouchetii* on the New England continental shelf. Journal of geophysical research. Oceans. 2021; 126(2):2020JC016856. Available from: https://doi.org/10.1029/2020JC016856 DOI: 2020JC016856
3. Hunter-Cevera KR, Hamilton BR, Neubert MG, Sosik HM. Seasonal environmental variability drives microdiversity within a coastal Synechococcus population. Environ Microbiol. 2021 Aug;23(8):4689-4705. PubMed Central PMCID: PMC8456951.
4. Galaz-García C, Bagstad K, Brun J, Chaplin-Kramer R, Dhu T, Murray NJ, Nolan CJ, Ricketts TH, Sosik HM, Sousa D, Willard G, Halpern B. The future of ecosystem assessments is automation, collaboration, and artificial intelligence. Environmental Research Letters. 2023; 18:011003. DOI: 10.1088/1748-9326/acab19
5. Oliver H, Zhang WG, Archibald KM, Hirzel AJ, Smith WO, Sosik HM, Stanley RHR, McGillicuddy DJ. Ephemeral surface chlorophyll enhancement at the New England shelf break driven by Ekman restratification. Journal of Geophysical Research. 2021; 127:e2021JC017715. DOI: 10.1029/2021JC017715

Synergistic Activities

1. Associate Editor / Editorial Board service for several journals including Limnology and Oceanography (2003-2021).
2. American Geophysical Union, Secretary of Ocean Sciences Section (2015-2019), with responsibilities including AGU Fall Meeting Planning Committee.
3. Co-development of automated submersible image-in-flow cytometer, Imaging FlowCytobot, licensed for commercial production (McLane Research Laboratories, Inc.), leading to growing worldwide user community.
4. Development and active support of open source analysis and data access software for the Imaging FlowCytobot (IFCB) worldwide user community, including IFCB-analysis GitHub repository (https://github.com/hsosik/ifcb-analysis/wiki).
5. Chief Scientist of the Martha's Vineyard Coastal Observatory (2006-2019); http://www.whoi.edu/mvco.

Certification:

When the individual signs the certification on behalf of themselves, they are certifying that the information is current, accurate, and complete. This includes, but is not limited to, information related to domestic and foreign appointments and positions. Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Sosik, Heidi M in SciENcv on 2023-02-14 17:31:17

NSF BIOGRAPHICAL SKETCH

Provide the following information for the Senior personnel.
Follow this format for each person. **DO NOT EXCEED 3 PAGES.**

IDENTIFYING INFORMATION:

NAME: Ji, Rubao

POSITION TITLE: Senior Scientist

ORGANIZATION AND LOCATION: Woods Hole Oceanographic Institution, Woods Hole, MA, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	DATE RECEIVED	FIELD OF STUDY
University of Georgia, Athens, GA, United States	PHD	2003	Biological Oceanography
University of Georgia, Athens, GA, United States	MS	2002	Computer Science
Ocean University of China, Qingdao, China	MS	1994	Marine Ecology
Ocean University of China, Qingdao, China	BS	1991	Marine Biology

Appointments and Positions

2019 - present Senior Scientist, Woods Hole Oceanographic Institution, Woods Hole, MA, United States

2013 - 2019 Associate Scientist w/ Tenure, Woods Hole Oceanographic Institution, Woods Hole, MA, United States

2009 - 2013 Associate Scientist, Woods Hole Oceanographic Institution, Woods Hole, MA, United States

2005 - 2009 Assistant Scientist, Woods Hole Oceanographic Institution, Woods Hole, MA, United States

2004 - 2005 Postdoctoral scholar, Woods Hole Oceanographic Institution, Woods Hole, MA, United States

2003 - 2004 Research Associate, University of Massachusetts Dartmouth, Dartmouth, MA, United States

1999 - 2003 Research Assistant, University of Massachusetts Dartmouth, Dartmouth, MA, United States

1994 - 1998 Associate Scientist, First Institute of Oceanography, China, Qingdao, Not Applicable, N/A, China

Products

Products Most Closely Related to the Proposed Project

1. Ji R, Feng Z, Jones BT, Thompson C, Chen C, Record NR, Runge JA. Coastal amplification of

supply and transport (CAST): a new hypothesis about the persistence of Calanus finmarchicus in the Gulf of Maine. ICES journal of marine science. 2017. DOI: doi:10.1093/icesjms/fsw253

2. Ji R, Stegert C, Davis C. Sensitivity of copepod populations to bottom-up and top-down forcing: a modeling study in the Gulf of Maine region. Journal of plankton research. 2012; 35(1):66-79.
3. Ji R, Franks PJS. Vertical migration of dinoflagellates: model analysis of strategies, growth, and vertical distribution patterns. Marine Ecology Progress Series. 2007; 344:49-61. Available from: https://doi.org/10.3354/meps06952
4. Ji R, Runge A, Davis CS, Wiebe PH. Drivers of variability of Calanus finmarchicus in the Gulf of Maine: roles of internal production and external exchange. ICES Journal of Marine Science. 2021. Available from: https://doi.org/10.1093/icesjms/fsab147
5. Zang Z, Ji R, Feng Z, Chen C, Li S, Davis CS. Spatially varying phytoplankton seasonality on the Northwest Atlantic Shelf: a model-based assessment of patterns, drivers, and implications. ICES Journal of Marine Science. 2021 August; 78(5):1920. Available from: https://doi.org/10.1093/icesjms/fsab102

Other Significant Products, Whether or Not Related to the Proposed Project

1. Ji R, Jin M, Varpe Ø. Sea ice phenology and timing of primary production pulses in the Arctic Ocean. Glob Chang Biol. 2013 Mar;19(3):734-41. PubMed PMID: 23504831.
2. Ji R, Edwards M, Mackas DL, Runge JA, Thomas AC. Marine plankton phenology and life history in a changing climate: current research and future directions. J Plankton Res. 2010 Oct;32(10):1355-1368. PubMed Central PMCID: PMC2933132.
3. Li Y, Fratantoni PS, Chen C, Hare JA, Sun Y, Beardsley RC, Ji R. Spatio-temporal patterns of stratification on the Northwest Atlantic shelf. Progress in oceanography. 2015. DOI: 10.1016/j.pocean.2015.01.003
4. Ji R, Ashjian C, Campbell R, Chen C, Gao G, Davis C, Cowles G, Beardsley R. Life history and biogeography of Calanus copepods in the Arctic Ocean: An individual-based modeling study. Progress in Oceanography. 2012; 96(1):40-56. DOI: 10.1016/j.pocean.2011.10.001
5. Ji R, Davis C, Chen C, Beardsley R. Life history traits and spatio-temporal distribution of copepods in the Gulf of Maine-Georges Bank region. Marine ecology progress series. 2009; 384:187-205.

Synergistic Activities

1. Awarded as a Fellow for Cooperative Institute for the North Atlantic Region (CINAR) from 2013-2016.
2. PI or co-PI of 45 research projects over the last 17 years on developing and applying numerical models to understand biological-physical interactions in various ocean systems.
3. Published 95 peer-reviewed research articles as lead- or co-author on topics such as biological-physical coupled modeling, plankton dynamics and food web dynamics.
4. Co-chaired an ICES modeling working group (2012-2015) to lead an international group of researchers for model development and applications.
5. Serving as a Review Editor for ICES Journal of Marine Sciences for 8 years (2014- present).

Certification:

When the individual signs the certification on behalf of themselves, they are certifying that the information is current, accurate, and complete. This includes, but is not limited to, information related to domestic and foreign appointments and positions. Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Ji, Rubao in SciENcv on 2023-02-14 09:21:48

NSF BIOGRAPHICAL SKETCH

Provide the following information for the Senior personnel.
Follow this format for each person. **DO NOT EXCEED 3 PAGES.**

IDENTIFYING INFORMATION:

NAME: Neubert, Michael G.

POSITION TITLE: Senior Scientist, Biology Department

ORGANIZATION AND LOCATION: Woods Hole Oceanographic Institution, Woods Hole, MA, USA

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	DATE RECEIVED	FIELD OF STUDY
Woods Hole Oceanographic Institution, Woods Hole, MA, USA	Postdoctoral Fellow	1994 - 1996	Mathematical Ecology
Univ. of Washington, Seattle, WA, USA	PHD	1994	Applied Mathematics
Univ. of Washington, Seattle, WA, USA	MS	1990	Applied Mathematics
Brown University, Providence, RI, USA	BS	1988	Applied Mathematics/Biology

Appointments and Positions

2015 - present Senior Scientist, Biology Department, Woods Hole Oceanographic Institution, Woods Hole, MA, USA

2018 - 2022 Director, Marine Policy Center, Woods Hole Oceanographic Institution, Woods Hole, MA, USA

2013 - 2014 Chair, Joint Committee on Biological Oceanography, MIT-WHOI Joint Program in Oceanography, Woods Hole, MA, USA

2007 - 2012 J. Seward Johnson Chair in Oceanography (Education Coordinator), Woods Hole Oceanographic Institution, Woods Hole, MA, USA

2000 - 2015 Associate Scientist, Biology Department, Woods Hole Oceanographic Institution, Woods Hole, MA, USA

1996 - 2000 Assistant Scientist, Biology Department, Woods Hole Oceanographic Institution, Woods Hole, MA, USA

Products

Products Most Closely Related to the Proposed Project

1. Hunter-Cevera KR, Neubert MG, Olson RJ, Solow AR, Shalapyonok A, Sosik HM. Physiological and ecological drivers of early spring blooms of a coastal phytoplankter. Science. 2016 Oct 21;354(6310):326-329. PubMed PMID: 27846565.
2. Hunter-Cevera KR, Neubert MG, Solow AR, Olson RJ, Shalapyonok A, Sosik HM. Diel size distributions reveal seasonal growth dynamics of a coastal phytoplankter. Proc Natl Acad Sci U

S A. 2014 Jul 8;111(27):9852-7. PubMed Central PMCID: PMC4103375.

3. Fowler B, Neubert M, Hunter-Cevera K, Olson R, Shalapyonok A, Solow A, Sosik H. Dynamics and functional diversity of the smallest phytoplankton on the Northeast US Shelf. Proceedings of the National Academy of Sciences. 2020 June 02; 117(22):12215-12221. Available from: http://www.pnas.org/lookup/doi/10.1073/pnas.1918439117 DOI: 10.1073/pnas.1918439117
4. Moeller H, Neubert M, Johnson M. Intraguild predation enables coexistence of competing phytoplankton in a well-mixed water column. Ecology. 2019 September 24; 100(12):-. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1002/ecy.2874 DOI: 10.1002/ecy.2874
5. Hunter-Cevera K, Neubert M, Olson R, Shalapyonok A, Solow A, Sosik H. Seasons of Syn. Limnology and Oceanography. 2019 November 19; 65(5):1085-1102. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1002/lno.11374 DOI: 10.1002/lno.11374

Other Significant Products, Whether or Not Related to the Proposed Project

1. Pascual M, Neubert M, Acuña J, Solow A, Dominguez-Carrió C, Salvador J, Olariaga A, Fuentes V. Environmental drivers of salp Thalia democratica population dynamics from in situ observations. Marine Ecology Progress Series. 2016; 561:189-201.
2. Hernández C, van Daalen S, Caswell H, Neubert M, Gribble K. A demographic and evolutionary analysis of maternal effect senescence. Proceedings of the National Academy of Sciences. 2020 July 14; 117(28):16431-16437. Available from: http://www.pnas.org/lookup/doi/10.1073/pnas.1919988117 DOI: 10.1073/pnas.1919988117
3. Neubert M, Caswell H. Alternatives to Resilience for Measuring the Responses of Ecological Systems to Perturbations. Ecology. 1997 April; 78(3):653-. Available from: http://www.jstor.org/stable/2266047?origin=crossref DOI: 10.2307/2266047
4. Sullivan L, Li B, Miller T, Neubert M, Shaw A. Density dependence in demography and dispersal generates fluctuating invasion speeds. Proceedings of the National Academy of Sciences. 2017 May 09; 114(19):5053-5058. Available from: http://www.pnas.org/lookup/doi/10.1073/pnas.1618744114 DOI: 10.1073/pnas.1618744114
5. Moeller H, Peltomaa E, Johnson M, Neubert M. Acquired phototrophy stabilises coexistence and shapes intrinsic dynamics of an intraguild predator and its prey. Ecology Letters. 2016 April; 19(4):393-402. Available from: http://doi.wiley.com/10.1111/ele.12572 DOI: 10.1111/ele.12572

Synergistic Activities

1. Associate Editor, *Theoretical Ecology* (2013 - present).
2. Co-Organizer (with Paul Armsworth) *Managing Ecological Systems at Multiple Scales: The Role of Institutions and Stakeholder Interactions*. Organized oral session, Annual Meeting of the Ecological Society of America, Louisville (2019).
3. Co-Organizer (with H. Moeller and M. Granados) *Transcending Guilds: Mixotrophs and Omnivores as Regulators of Ecosystem Function*. Organized Oral Session, Annual Meeting of the Ecological Society of America, Portland, OR (2017).
4. Scientific Advisory Committee, *Sixth International Conference on Mathematical Modeling and*

Analysis of Populations in Biological Systems, University of Arizona, Tucson (2017).

5. Chair,Theoretical Ecology Section, Ecological Society of America (2004 - 2005).

Certification:

When the individual signs the certification on behalf of themselves, they are certifying that the information is current, accurate, and complete. This includes, but is not limited to, information related to domestic and foreign appointments and positions. Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

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NSF BIOGRAPHICAL SKETCH

Provide the following information for the Senior personnel.
Follow this format for each person. **DO NOT EXCEED 3 PAGES.**

IDENTIFYING INFORMATION:

NAME: Sato, Mei

POSITION TITLE: Assistant Scientist

ORGANIZATION AND LOCATION: Woods Hole Oceanographic Institution, Woods Hole, MA, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	DATE RECEIVED	FIELD OF STUDY
Oregon State University, Corvallis, OR, United States	Other training	2015 - 2017	Postdoctoral Research Associate
University of Washington, Seattle, WA, United States	Other training	2013 - 2015	Postdoctoral Research Associate
University of Victoria, Victoria, BC, Canada	PHD	2013	Oceanography
University of Maine, Orono, ME, United States	MS	2006	Oceanography
Tokyo University of Fisheries, Tokyo, Japan	BS	2004	Aquatic Biosciences

Appointments and Positions

2021 - present Assistant Scientist, Woods Hole Oceanographic Institution, Woods Hole, MA, United States

2019 - 2021 Guest Investigator, Woods Hole Oceanographic Institution, Woods Hole, MA, United States

2018 - 2020 Research Associate, University of British Columbia, Vancouver, British Columbia, Canada

2015 - 2017 Postdoctoral Research Associate, Oregon State University, Corvallis, OR, United States

2013 - 2015 Postdoctoral Research Associate, University of Washington, Seattle, WA, United States

2009 - 2013 Research Assistant, University of Victoria, Victoria, British Columbia, Canada

2007 - 2009 Acoustic Data Analyst/ Project Coordinator, Sonic Corporation Co., Ltd., Tokyo, Not Applicable, N/A, Japan

2004 - 2006 Research Assistant, University of Maine, Orono, ME, United States

Products

Products Most Closely Related to the Proposed Project

1. Sato M, Barth JA, Benoit-Bird KJ, Pierce SD, Cowles TJ, Brodeur RD, Peterson WT. Coastal

upwelling fronts as a boundary for planktivorous fish distributions. Marine Ecology Progress Series. 2018; 995:171-186.

2. Sato M, Benoit-Bird KJ. Spatial variability of deep scattering layers shapes the Bahamian mesopelagic ecosystem. Marine Ecology Progress Series. 2017; 580:69-82.
3. Sato M, Dower J, Kunze E, Dewey R. Second-order seasonal variability in diel vertical migration timing of euphausiids in a coastal inlet. Marine Ecology Progress Series. 2013; 480:39-56.
4. Sato M, Jumars PA. Seasonal and vertical variations in emergence behaviors of Neomysis americana. Limnology and Oceanography. 2008; 53:1665-1677.
5. Sato M, Trites AW, Gauthier S. Southern resident killer whales encounter higher prey densities than northern resident killer whales during summer. Canadian Journal of Fisheries and Aquatic Sciences. 2021 October; 78:1732-1743.

Other Significant Products, Whether or Not Related to the Proposed Project

1. Sato M, Horne JK, Parker-Stetter SL, Essington TE, Keister JE, Moriarty PE, Li L, Newton J. Impacts of moderate hypoxia on fish and zooplankton prey distributions in a coastal fjord. Marine Ecology Progress Series. 2016; 560:57-72.
2. Benoit-Bird KJ, Welch TP, Waluk CM, Barth JA, Wangen I, McGill P, Okuda C, Hollinger GA, Sato M, McCammon S. Equipping an underwater glider with a new echosounder to explore ocean ecosystems. Limnology and Oceanography: Methods. 2018; 16:734-749.
3. Sato M, Horne JK, Parker-Stetter SL, Keister JE. Acoustic classification of coexisting taxa in a coastal ecosystem. Fisheries Research. 2015; 172:130-136.
4. Sato M, Klymak JM, Kunze E, Dewey R, Dower JF. Turbulence and internal waves in Patricia Bay, Saanich Inlet, British Columbia. Continental Shelf Research. 2014; 85:153-167.
5. Sato M, Yamazaki H. Estimating micro-scale intermittency of fluorescence fields from conventional CTD measurements. Journal of Marine Systems. 2008; 70:240-247.

Synergistic Activities

1. Subject Matter Expert for the bioacoustic sensors of the Ocean Observatories Initiatives (OOI), advising sampling protocol, conducting calibrations, and QA/QC of the data. 08/16 - present
2. Reviewer for journals: Limnology and Oceanography, Marine Ecology Progress Series, Journal of Plankton Research, Deep-Sea Research II, ICES Journal of Marine Sciences, Progress in Oceanography, Fisheries Research, Aquatic Living Resources, Invertebrate Reproduction and Development; Reviewer for proposals: NSF Ocean Technology and Interdisciplinary Coordination Program, NSF Biological Oceanography Program, NOAA Northwest Fisheries Science Center Internal Grant
3. Workshop co-organizer (Synthesis of bio-acoustics programs for monitoring zooplankton and fisheries in the North Pacific) at PICES 2019 Annual Meeting. 10/19
4. Co-organizer of workshops with stake holders (sport fishing guides/whale watching boat owners) in British Columbia, Canada, designed to foster interactions and collaborations to study endangered southern resident killer whales. 03/18 – 06/18

Certification:

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Certified by Sato, Mei in SciENcv on 2023-02-13 13:41:33

NSF BIOGRAPHICAL SKETCH

Provide the following information for the Senior personnel.
Follow this format for each person. **DO NOT EXCEED 3 PAGES.**

IDENTIFYING INFORMATION:

NAME: Zhang, Weifeng (Gordon)

NSF ID: 000559007@nsf.gov
ORCID: 0000-0002-2819-1780

POSITION TITLE: Associate Scientist with Tenure

ORGANIZATION AND LOCATION: Woods Hole Oceanographic Institution, Woods Hole, MA, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	DATE RECEIVED	FIELD OF STUDY
Rutgers, The State University of New Jersey, New Brunswick, New Jersey, United States	PHD	2009	Oceanography
Zhejiang University, Hangzhou, Zhejiang, China	MENG	2003	Fluid Mechanics
Zhejiang University, Hangzhou, Zhejiang, China	BS	2000	Engineering Mechanics

Appointments and Positions

2018 - present Associate Scientist with Tenure, Woods Hole Oceanographic Institution, Woods Hole, MA, United States

2015 - 2018 Associate Scientist, Woods Hole Oceanographic Institution, Woods Hole, MA, United States

2011 - 2015 Assistant Scientist, Woods Hole Oceanographic Institution, Woods Hole, MA, United States

2009 - 2011 Post-doctoral Scholar, Woods Hole Oceanographic Institution, Woods Hole, MA, United States

2004 - 2009 Research Assistant, Rutgers, The State University of New Jersey, New Brunswick, NJ, United States

Products

Products Most Closely Related to the Proposed Project

1. Zhang WG., Lentz SJ.. Wind-driven circulation in a shelf valley. Part I: Mechanism of the asymmetrical response to along-shelf winds in opposite directions. Journal of Physical Oceanography. 2017 December; 47:2927-2947. DOI: 10.1175/JPO-D-17-0083.1
2. Zhang WG., McGillicuddy DJ., Gawarkiewicz GG.. Is biological productivity enhanced at the New England Shelfbreak Front?. Journal of Geophysical Research - Oceans. 2013 January;

118:517-535. DOI: 2169-9275/13/10.1002/jgrc.20068

3. Oliver H, Zhang WG, Smith WO, Alatalo P, Chappell PD, Hirzel A, Selden CR, Sosik HM, Stanley HR, Zhu Y, McGillicuddy D. Extradordinary diatom blooms driven by western boundary current instability. Geophysical Research Letter. 2021; 48. DOI: 10.1029/2020GL091943
4. Oliver H, Zhang WG, Archibald KM, Hirzel AJ, Smith WO, Sosik HM, Stanley RH.R., McGillicuddy DJ. Ephemeral Surface Chlorophyll Enhancement at the New England Shelf Break Driven by Ekman Restratification. Journal of geophysical research. Oceans. 2022 January; 127(1):e2021JC017715. Available from: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2021JC017715 DOI: 10.1029/2021JC017715
5. Zhang WG, Alatalo P, Crockford T, Hirzel AJ, Meyer MG, Oliver H, Peacock E, Petitpas CM, Sandwith Z, Smith WO, Sosik HM, Stanley RHR, Stevens BLF, Turner JT, McGillicuddy DJ. Cross-shelf exchange associated with a shelf-water streamer at the Mid-Atlantic Bight shelf edge. Progress in Oceanography. 2023 January; 210:102931. Available from: https://doi.org/10.1016/j.pocean.2022.102931 DOI: 10.1016/j.pocean.2022.102931

Other Significant Products, Whether or Not Related to the Proposed Project

1. Zhang WG., Gawarkiewicz GG.. Dynamics of the direct intrusion of Gulf Stream ring water onto the Mid-Atlantic Bight shelf. Geophysical Research Letters. 2015 September 30; 42:7687-7695. DOI: 10.1002/ 2015GL065530
2. Zhang WG, Gawarkiewicz GG. Length-scale of the finite-amplitude meanders of shelfbreak fronts. Journal of Physical Oceanography. 2015 October; 45:2598-2620. DOI: 10.1175/JPO-D-14-0249.1
3. Zhang WG, McGillicuddy DJ. Warm Spiral Streamers over Gulf Stream Warm-Core Rings. Journal of Physical Oceanography. 2020; 50(3331):3351. DOI: 10.1175/JPO-D-20-0035.1
4. Du J, Zhang WG, Li Y. Variability of deep water in Jordan Basin of the Gulf of Maine: Influence of Gulf Stream Warm Core Rings and the Nova Scotia Current. Journal of Geophysical Research - Oceans. 2021; 126. DOI: 10.1029/2020JC017136
5. Li X, Zhang W, Rong Z. The Interaction Between Warm-Core Rings and Submarine Canyons and Its Influence on the Onshore Transport of Offshore Waters. Journal of Geophysical Research: Oceans. 2021 December 13; 126(12):e2021JC017989. Available from: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2021JC017989 DOI: 10.1029/2021JC017989

Synergistic Activities

1. Mentoring undergraduate students, graduate students and postdocs through the WHOI Summer Student Fellow and Guest Student Programs, the MIT-WHOI Joint Program and the WHOI postdoc scholar and investigator program
2. Member of an NSF OCE Physical Oceanography Program proposal review panel
3. Invited to and participated in the NSF Ocean Observatory Initiative Cyber-Infrastructure Beta Test and Coastal Arrays Workshop, and Pioneer Array Relocation Innovation Lab workshop; Contribution to the NSF Ocean Observatory Initiative online data streaming and data quality

control

4. Co-chair of the Gordon Research Conference - Coastal Ocean Dynamics in June 2023
5. Associate Editor of the journal Frontiers in Marine Science - Physical Oceanography Section.

Certification:

When the individual signs the certification on behalf of themselves, they are certifying that the information is current, accurate, and complete. This includes, but is not limited to, information related to domestic and foreign appointments and positions. Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Zhang, Weifeng (Gordon) in SciENcv on 2023-02-09 16:51:07

NSF BIOGRAPHICAL SKETCH

Provide the following information for the Senior personnel.
Follow this format for each person. **DO NOT EXCEED 3 PAGES.**

IDENTIFYING INFORMATION:

NAME: Llopiz, Joel

ORCID: 0000-0002-7584-7471

POSITION TITLE: Associate Scientist (tenure-track faculty)

ORGANIZATION AND LOCATION: Woods Hole Oceanographic Institution

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	DATE RECEIVED	FIELD OF STUDY
Woods Hole Oceanographic Institution, Woods Hole, MA	Postdoctoral Fellow	2010 - 2012	Biological Oceanography
University of Miami/RSMAS, Miami, FL	Postdoctoral Fellow	2008 - 2010	Biological Oceanography
University of Miami/RSMAS, Miami, FL	PHD	2008	Marine Biology and Fisheries
Eckerd College, St. Petersburg, FL	BS	2000	Marine Science

Appointments and Positions

2017 - present	Associate Scientist (tenure-track faculty), Woods Hole Oceanographic Institution
2012 - 2017	Assistant Scientist (tenure-track faculty), Woods Hole Oceanographic Institution
2011 - 2013	Instructor, Massachusetts Marine Studies Consortium
2010 - 2012	Postdoctoral Scholar, Woods Hole Oceanographic Institution
2008 - 2010	Postdoctoral Associate, University of Miami/RSMAS
2005 - 2008	Graduate Research and Teaching Assistant, University of Miami/RSMAS
2002 - 2005	Graduate Research Fellow, University of Miami/RSMAS
2000 - 2002	Fisheries Biologist, Florida Fish and Wildlife Research Institute

Products

Products Most Closely Related to the Proposed Project

1. Suca JJ, Pringle JW, Knorek ZR, Hamilton SL, Richardson DR, Llopiz JK. Feeding dynamics of Northwest Atlantic small pelagic fishes. Progress in Oceanography. 2018; 165:52-62.
2. Llopiz JK, Richardson DE, Shiroza A, Smith SL, Cowen RK. Distinctions in the diets and distributions of larval tunas and the important role of appendicularians. Limnology and Oceanography. 2010; 55:983-996.
3. Suca JJ, Wiley DN, Silva TL, Robuck AR, Richardson DE, Glancy SG, Clancey E, Giandonato T, Solow AR, Thompson MA, Hong P, Baumann H, Kaufman L, Llopiz JK. Sensitivity of sand lance to shifting prey and hydrography indicates forthcoming change to the northeast US shelf

forage fish complex. ICES Journal of Marine Science. 2021; fsaa251. DOI: 10.1093/icesjms/fsaa251

4. Govindarajan A, Francolini R, Jech JM, Lavery AC, Llopiz JK, Wiebe PH, Zhang WG. Exploring the use of environmental DNA (eDNA) to detect animal taxa in the mesopelagic zone. Frontiers in Ecology and Evolution. 2021; 9:574877. DOI: 10.3389/fevo.2021.574877
5. Caiger PE, Lefebvre LS, Llopiz JK. Growth and reproduction in mesopelagic fishes: a literature synthesis. ICES Journal of Marine Science. 2021; fsaa247. DOI: 10.1093/icesjms/fsaa247

Other Significant Products, Whether or Not Related to the Proposed Project

1. Llopiz JK, Cowen RK, Hauff MJ, Ji R, Munday PL, Muhling BA, Peck MA, Richardson DE, Sogard S, Sponaugle S. Early life history and fisheries oceanography: New questions in a changing world. Oceanography. 2014; 27(4):26-41.
2. Llopiz JK, Hobday AJ. A global comparative analysis of the feeding dynamics and environmental conditions of larval tunas, mackerels, and billfishes. Deep Sea Research II. 2015; 113:113-124.
3. Llopiz JK. Latitudinal and taxonomic patterns in the feeding dynamics of fish larvae: A literature synthesis. Journal of Marine Systems. 2013; 109-110:69-77.
4. Llopiz JK, Cowen RK. Variability in the trophic role of coral reef fish larvae in the oceanic plankton. Marine Ecology Progress Series. 2009; 381:259-272.
5. Hernandez CM, Witting J, Willis C, Thorrold SR, Llopiz JK, Rotjan RD. Evidence and patterns of tuna spawning inside a large no-take marine protected area. Scientific Reports. 2019; 9:10772. DOI: 10.1038/s41598-019-47161-0

Synergistic Activities

1. Mentored 18 undergraduate researchers in 9 yrs as a WHOI scientist
2. Co-chair of WHOI's Committee for Diversity, Equity, and Inclusion
3. Developed and taught 5 graduate-level courses for the MIT-WHOI Joint Program and an undergraduate fish biology course for the Marine Studies Consortium (students from Tufts, Wellesley, Northeastern, Wheaton, and Stonehill)
4. Co-chair of IMBER-associated CLIOTOP (Climate Impacts on Top Predators) program
5. Former (2016-2019) chair of the Regional Association for Research on the Gulf of Maine (RARGOM)

Certification:

When the individual signs the certification on behalf of themselves, they are certifying that the information is current, accurate, and complete. This includes, but is not limited to, information related to domestic and foreign appointments and positions. Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

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Effective 01/30/2023 **NSF BIOGRAPHICAL SKETCH** **OMB-3145-0058**

*NAME Changsheng Chen *Required fields

ORCID ID (Optional) 0000-0001-8715-6101

*POSITION TITLE Montgomery Charter Chair Professor

*PRIMARY ORGANIZATION & LOCATION University of Massachusetts-Dartmouth, New Bedford

***PROFESSIONAL PREPARATION - (see PAPPG Chapter II.D.2.h.i.a.3)**

PREVIOUS ORGANIZATION(S) & LOCATION(S)	DEGREE (if applicable)	RECEIPT DATE* (MM/YYYY)	FIELD OF STUDY
Ocean University of China, Qingdao, China	Diplima	07/1979	Marine Meteorology
Ocean University of China, Qingdao, China	M.S.	08/1983	Marine Meteorology
Massachusetts Institute of Technology (MIT)/Woods Hole Oceanographic Institution (WHOI) Joint Program, Cambridge, MA, USA	M.S.	09/1989	Physical Oceanography
MIT/WHOI Joint Program, Cambridge, MA, USA	Ph.D.	06/1992	Physical Oceanography

Note - For Fellowship applicants only, please include the start date of the Fellowship.

***APPOINTMENTS AND POSITIONS - (see PAPPG Chapter II.D.2.h.i.a.4)**

Start Date - End Date	Appointment or Position Title, Organization, and Location
2014-Present	Montgomery Charter Chair Professor, School for Marine Science and Technology (SMAST), University of Massachusetts-Dartmouth (UMASS-D), New Bedford, MA, USA
2022: 9-11	Guest Professor, School of Frontier Sciences, The University of Tokyo, Kashiwa, Japan
2001-2019	Adjunct Scientist, Department of Physical Oceanography, Woods Hole Oceanographic Institution, Woods Hole, MA, USA
2001-2014	Professor, SMAST/UMASS-D, New Bedford, MA, USA
199-2001	Associate Professor with tenure, Department of Marine Sciences (DMS), University of Georgia (UGA), Athens, GA, USA
1994-1999	DMS/UGA, Athens, USA
1992-1994	Assistant Research Scientist, Department of Oceanography, Texas A&M University, College Station, TX, USA
1985-1986	Lecturer, Department of Marine Meteorology and Oceanography, Ocean
1983-1985	University of China, Qingdao, China
	Assistant Lecturer, Department of Marine Meteorology and Oceanography, Ocean University of China, Qingdao, China
1979-1980	Assistant Engineer, , Meteorological Bureau of Guangxi Providence, Weather Forecast Center
1975-1976	Weather Forecast Assistant, Meteorological Bureau of Guangxi Providence, Weather Forecast Center

***PRODUCTS - (see PAPPG Chapter II.D.2.h.i.a.5) Products Most Closely Related to the Proposed Project**

Li., S. and C. Chen, 2022. Air-sea Interaction Processes during Hurricane Sandy: Coupled WRF-FVCOM Model Simulation. Progress in Oceanography, 206, 102855. doi: http://doi.org/10.1016/ j.pocean.2022.102855.
Chen, C. L. Zhao, S. Gallager, R. Ji, P. He, C. Davis, R. C. Beardsley, D. Hart, W. C. Gentleman, L. Wang, S. Li, H. Lin, K. Stokesbury, D. Bethoney, 2021. Impact of larval behaviors on dispersal and connectivity of sea scallop larvae over the northeast U.S. shelf. Progress in Oceanography, 195, 102604, https://doi.org/10.1016/ j.pocean.202
Chen, C., Z. Lin, R. C. Beardsley, T. Shyka, Y, Zhang, Q. Xu, J. Qi, H. Lin, and D. Xu, 2021. Impacts of sea-level rise on future storm-induced coastal inundations over Massachusetts coast. Natural Hazard, https://doi.org/10.1007/s11069-020-04467-x.
Qi, J., C. Chen, and R. C. Beardsley, 2018. FVCOM one-way and two-way nesting using ESMF: development and validation. Ocean Modelling, 124, 94-110. https: //doi.org/10. 1016/j.ocemod.2018.02.007.
Li, S., C. Chen, Z. Wu, R. C. Beardsley, and M. Li, 2020. Impacts of oceanic mixing layer on hurricanes: a simulation experiment with Hurricane Sandy. Journal of Geophysical Research-Oceans, 125, e2019JC015851 doi: 10.1029/2020JC0811.

Other Significant Products, Whether or Not Related to the Proposed Project (see PAPPG Chapter II.D.2.h.i.a.5)

Zang, Z., R. Ji,1Y. Liu, C. Chen, Y. Li, S. Li, and C. S. Davis, 2022. Remote silicate supply regulates spring phytoplankton bloom magnitude in the Gulf of Maine. Limnology and Oceanography, Letters, 1-9, doi: 10.1002/lol2.10245.
Zang, Z., R. Ji, Z. Feng, C. Chen, S. Li, and Cabell S. Davis. 2021. Spatially varying phytoplankton seasonality on the Northwest Atlantic Shelf: a model-based assessment of patterns, drivers, and implication. ICES Journal of Marine Science. 78(5), 1920–1934.
Li, R., C. Chen, W. Dong, R. C. Beardsley, Z. Wu, W. Gong, Y. Liu, T. Liu, and D. Xu, 2021. Slope-intensified storm-induced near-inertial oscillations in the South China Sea. Journal of Geophysical Research-Oceans, 125, e2019JC015851. https:/doi.org/10. 1029/2020 JC016713.
Zhang, Y, C. Chen, P. Xue, R. C. Beardsley, and P. J. S. Franks, 2020. A view of physical mechanisms for transporting harmful algal blooms to Massachusetts Bay. Marine Pollution Bulletin, 154, 111048. https://doi.org/10.1016/j.marpolbul.2020.111048.
Zhang, Z., C. Chen. R. C. Beardsley. S. Li, Q. Xu, Z. Song, D. Zhang, D. Hu, F. Guo, 2020. A FVCOM study of the potential coastal flooding in Apponagansett Bay and Clarks Cove, Dartmouth Town (MA), Natural Hazard, https:// https://doi.org/10.1007/ s11069-020-04102-9.

***Synergistic Activities** - (**see PAPPG Chapter II.D.2.h.(i)(a)(6)**)

• Leader of the development team of unstructured-grid Finite-Volume Community Ocean Model (FVCOM), FVCOM has widely used ocean communities with applications to academic research and coastal environmental managements
• Leader of the development team of the Northeast Coastal Ocean Forecast System (NECOFS)
• Leader of the development team of Northeast Biogeochemical and Ecosystem Model (NeBEM)
• Developed Global and Arctic Ocean FVCOM nested model system (Global-FVCOM/AO-FVCOM)
• Completed and working on multi-research projects on multi-scale global-basin-shelf-estuarine modeling, ocean-ice interactions in the Arctic, tsunamis, coastal inundations and acidification, and impacts of climate changes

***Certification**:

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Signature
(Please type out full name):

Date: 02/13/2023

NSF BIOGRAPHICAL SKETCH

Provide the following information for the Senior personnel.
Follow this format for each person. **DO NOT EXCEED 3 PAGES.**

IDENTIFYING INFORMATION:

NAME: Stanley, Rachel

POSITION TITLE: Associate Professor

ORGANIZATION AND LOCATION: Wellesley College, Wellesley, MA, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	DATE RECEIVED	FIELD OF STUDY
Princeton University, Princeton, New Jersey, United States	Postdoctoral Fellow	2007 - 2009	NOAA Climate and Global Change and Hess Postdoctoral Fellow
MIT/WHOI Joint Program, Cambridge and Woods Hole, MA, United States	PHD	2007	Chemical Oceanography
National Oceanography Centre, Southampton, Hampshire County, United Kingdrom	Fellow	2000 - 2001	Fulbright Fellowship
Masschusetts Institute of Technology, Cambridge, Massachusetts, United States	BS	2000	Chemistry

Appointments and Positions

2020 - present Associate Professor, Wellesley College, Chemistry Department, Wellesley, MA, United States

2016 - present Adjunct Scientist, Woods Hole Oceanographic Institution, Department of Marine Chemistry and Geochemistry, Woods Hole, MA, United States

2015 - 2020 Assistant Professor, Wellesley College, Department of Chemistry, Wellesley, MA, United States

2009 - 2014 Assistant Scientist, Woods Hole Oceanographic Institution, Department of Marine Chemistry and Geochemistry, Woods Hole, United States

Products

Products Most Closely Related to the Proposed Project

1. Oliver H, Zhang WG., Smith Jr. WO., Philip A, Chappell PD, Selden CR., Sosik HM., Stanley RH.R., Zhu Y, McGillicuddy Jr. DJ.. Diatom Hotspots Driven by Western Boundary Current Instability. Geophysical research letters. 2021; 48:2020GL091943. Available from: https://doi. org/10.1029/2020GL091943 DOI: https://doi. org/10.1029/2020GL091943
2. Oliver H, Zhang WG., Archibald KM., Hirzel AJ., Smith WO., Sosik HM., Stanley RH.R., McGillicuddy Jr. DJ.. Ephemeral Surface Chlorophyll Enhancement at the New England Shelf Break Driven by Ekman Restratification. JGR Oceans. 2022; 127:e2021JC017715. Available

from: https://doi.org/10.1029/2021JC017715 DOI: https://doi.org/10.1029/2021JC017715

3. Smith WO, Zhang WG, Hirzel A, Stanley RH.R., Meyer MG., Sosik H, Alatalo P, Sandwith ZO., Crockford T, Peacock EA, Mehta A, McGillicuddy DJ. A regional bloom of Phaeocystis on the New England continental shelf. Journal of Geophysical Research: Oceans. 2021; 126:e2020JC016856. Available from: https://doi. org/10.1029/2020JC016856 DOI: 10.1029/2020JC016856
4. Ji BY, Sandwith ZO, Williams WJ, Diaconescu O, Ji R, Li Y, Van Scoy E, Yamamoto-Kawai M, Zimmerman S, Stanley RH.R.. Variations in Rates of Biological Production in the Beaufort Gyre as the Arctic Changes: Rates from 2011 to 2016. Journal of Geophysical Research: Oceans. 2019. DOI: . doi: 10.1029/2018JC014805
5. Manning CC, Stanley RH. R., Nicholson DP, Loose B, Lovely A, Schlosser P, Hatcher BG. Changes in gross oxygen production, net oxygen production, and air-water gas exchange during seasonal ice melt in Whycocomagh Bay, a Canadian estuary in the Bras d'Or Lake system. Biogeosciences,. 2019; 16(17):3341-3376. DOI: https://doi.org/10.5194/bg-16-3351-2019

Other Significant Products, Whether or Not Related to the Proposed Project

1. Seltzer AM., Nicholson DP., Smethie WM., Tyne RL., LeRoy E, Stanley RH.R., Stute M, Barry PH., McPaul K, Davidson PW., Chang BX., Rafter PA., Lethaby P, Johnson R, Khatiwala S, Jenkins WJ.. Dissolved gases track deep ocean ventilation processes in the deep North Atlantic. Proceedings of the National Academy of Science (PNAS). Forthcoming.
2. Stanley RH.R., Kinjo L, Smith AW., Aldrett D, Alt H, Kopp E, Krevanko C, Cahill K, Haus BK.. Gas Fluxes and Steady State Saturation Anomalies at Very High Wind Speeds. JGR Oceans. 2022; 127. Available from: https://doi. org/10.1029/2021JC018387 DOI: https://doi. org/10.1029/2021JC018387
3. Smith AW., Haus BK., Stanley RH.R.. ubble-Turbulence Dynamics and Dissipation Beneath Laboratory Breaking Waves. Journal of Physical Oceanography. 2022; 52(9):2159-2181. DOI: DOI: 10.1175/JPO-D-21-0209.1
4. Howard EM, Spivak AC, Karolewski JS, Gosselin KM, Sandwith ZO, Manning CC, Stanley RH.R.. Oxygen and Triple Oxygen Isotope Measurements Provide Different Insights into Gross Oxygen Production in a Shallow Salt Marsh Pond. Estuaries and Coasts.. 2020. DOI: doi.org/10.1007/s12237-020-00757-6
5. Stanley RH. R., McGillicuddy DJ, Sandwith ZO, Pleskow HM. Submesoscale Hotspots of Productivity and Respiration: Insights from High-Resolution Oxygen and Fluorescence Sections. Deep Sea Research I. 2017; 130:1-11.

Synergistic Activities

1. Currently serving as the United States Representative to the international research initiative Surface Ocean Lower Atmosphere Study (SOLAS)
2. Currently serving as chair of the Ocean Carbon and Biogeochemistry Air-Sea Interaction committee and as such, organized a national workshop on identifying US priorities in air-sea interaction research
3. Serving/served on the scientific committee of the Gas Transfer at Water Surfaces symposium in 2015, 2020 and 2025

4. Mentored 43 undergraduate students so far at Wellesley college (in 8 years) and 2 graduate, 4 undergraduate and 3 high school students while at Woods Hole Oceanographic Institution.
5. Teaches classes at Wellesley College on Aquatic Chemistry, Advanced Inorganic Chemistry, Communicating Chemistry, Environmental Chemistry, and General Chemistry

Certification:

When the individual signs the certification on behalf of themselves, they are certifying that the information is current, accurate, and complete. This includes, but is not limited to, information related to domestic and foreign appointments and positions. Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

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NSF BIOGRAPHICAL SKETCH

Provide the following information for the Senior personnel.
Follow this format for each person. **DO NOT EXCEED 3 PAGES.**

IDENTIFYING INFORMATION:

NAME: Rynearson, Tatiana

NSF ID: 000269532@nsf.gov
ORCID: 0000-0003-2951-0066

POSITION TITLE: Professor

ORGANIZATION AND LOCATION: University of Rhode Island, Narragansett, RI, USA

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	DATE RECEIVED	FIELD OF STUDY
University of Washington, Seattle, WA, USA	Postdoctoral Fellow	2003 - 2005	Marine Genomics
University of Washington, Seattle, WA, USA	PHD	2003	Oceanography
University of Washington, Seattle, WA, USA	MS	1998	Oceanography
Brown University, Providence, RI, USA	BS	1994	Aquatic Sciences

Appointments and Positions

2016 - present Professor, University of Rhode Island, Graduate School of Oceanography, Narragansett, RI, USA

2011 - 2016 Associate Professor, University of Rhode Island, Graduate School of Oceanography, Narragansett, RI, USA

2005 - 2011 Assistant Professor, University of Rhode Island, Graduate School of Oceanography, Narragansett, RI, USA

Products

Products Most Closely Related to the Proposed Project

1. Anderson S, Barton A, Clayton S, Dutkiewicz S, Rynearson T. Marine phytoplankton functional types exhibit diverse responses to thermal change. Nature Communications. 2021 November 05; 12(1):-. Available from: https://www.nature.com/articles/s41467-021-26651-8 DOI: 10.1038/s41467-021-26651-8
2. Rynearson T, Flickinger S, Fontaine D. Metabarcoding Reveals Temporal Patterns of Community Composition and Realized Thermal Niches of Thalassiosira Spp. (Bacillariophyceae) from the Narragansett Bay Long-Term Plankton Time Series. Biology. 2020 January 16; 9(1):19-. Available from: https://www.mdpi.com/2079-7737/9/1/19 DOI: 10.3390/biology9010019
3. Canesi K, Rynearson T. Temporal variation of Skeletonema community composition from a long-term time series in Narragansett Bay identified using high-throughput DNA sequencing. Marine Ecology Progress Series. 2016 September 08; 556:1-16. Available from: http://www.int-

res.com/abstracts/meps/v556/p1-16/ DOI: 10.3354/meps11843

4. Sterling A, Kirk R, Bertin M, Rynearson T, Borkman D, Caponi M, Carney J, Hubbard K, King M, Maranda L, McDermith E, Santos N, Strock J, Tully E, Vaverka S, Wilson P, Jenkins B. Emerging harmful algal blooms caused by distinct seasonal assemblages of a toxic diatom. Limnology and Oceanography. 2022 October 07; 67(11):2341-2359. Available from: https://onlinelibrary.wiley.com/doi/10.1002/lno.12189 DOI: 10.1002/lno.12189
5. Alison C. Cleary, Edward G. Durbin, Tatiana A. Rynearson, Jennifer Bailey. Feeding by Pseudocalanus copepods in the Bering Sea: Trophic linkages and a potential mechanism of niche partitioning. Deep Sea Research Part II: Topical Studies in Oceanography. 2016; 134:181-189. Available from: https://www.sciencedirect.com/science/article/pii/S0967064515001046 issn: 0967-0645

Other Significant Products, Whether or Not Related to the Proposed Project

1. Bishop IW, Anderson SI, Collins S, Rynearson TA. Thermal trait variation may buffer Southern Ocean phytoplankton from anthropogenic warming. Glob Chang Biol. 2022 Oct;28(19):5755-5767. PubMed PMID: 35785458.
2. Anderson S, Franzè G, Kling J, Wilburn P, Kremer C, Menden-Deuer S, Litchman E, Hutchins D, Rynearson T. The interactive effects of temperature and nutrients on a spring phytoplankton community. Limnology and Oceanography. 2022 February 08; 67(3):634-645. Available from: https://onlinelibrary.wiley.com/doi/10.1002/lno.12023 DOI: 10.1002/lno.12023
3. Menden-Deuer S, Rowlett J, Nursultanov M, Collins S, Rynearson T. Biodiversity of marine microbes is safeguarded by phenotypic heterogeneity in ecological traits. PLoS One. 2021;16(8):e0254799. PubMed Central PMCID: PMC8336841.
4. McNair H, Morison F, Graff J, Rynearson T, Menden-Deuer S. Microzooplankton grazing constrains pathways of carbon export in the subarctic North Pacific. Limnology and Oceanography. 2021 May 03; 66(7):2697-2711. Available from: https://onlinelibrary.wiley.com/doi/10.1002/lno.11783 DOI: 10.1002/lno.11783
5. Anderson S, Rynearson T. Variability approaching the thermal limits can drive diatom community dynamics. Limnology and Oceanography. 2020 March 02; 65(9):1961-1973. Available from: https://onlinelibrary.wiley.com/doi/10.1002/lno.11430 DOI: 10.1002/lno.11430

Synergistic Activities

1. 2006-present Director, Narragansett Bay Long-Term Plankton Time Series. This is the longest running time series of its kind with physical, chemical and plankton species composition data beginning in 1959. http://www.gso.uri.edu/phytoplankton
2. Associate Editor-Limnology and Oceanography, Review editor-Frontiers in Marine Science, reviewer for 26 journals, 8 private and federal funding agencies
3. Faculty advisor since 2007 for the National Science Foundation-funded "SURFO" program (Summer Undergraduate Research Fellowships in Oceanography) at GSO, including an emphasis on recruiting students with diverse backgrounds.
4. 2020- present Board Member, Save the Bay, Largest non-profit environmental organization in Rhode Island, committed to protecting and improving estuarine and coastal waters of RI.
5. 2009-2018 Science Director (to 2015) and board member, Metcalf Institute for Marine and

Environmental Reporting. Designed science immersion workshops for journalists, including annual workshop for early-career minority journalists; raised funds from both private foundations and federal agencies to teach marine and environmental sciences to journalists; built bridges between scientists and journalists and from 2009-2012 included assisting with the judging the annual Grantham prize, the largest prize ($75K) for environmental reporting in the USA.

Certification:

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Certified by Rynearson, Tatiana in SciENcv on 2023-02-02 08:18:49

NSF BIOGRAPHICAL SKETCH

Provide the following information for the Senior personnel.
Follow this format for each person. **DO NOT EXCEED 3 PAGES.**

IDENTIFYING INFORMATION:

NAME: Menden-Deuer, Susanne

NSF ID: 000433035@nsf.gov
ORCID: 0000-0002-8434-4251

POSITION TITLE: Professor of Oceanography

ORGANIZATION AND LOCATION: University of Rhode Island, Kingston, RI, USA

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	DATE RECEIVED	FIELD OF STUDY
University of Washington, Seattle, Washington, USA	PHD	2004	Oceanography
University of Washington, Seattle, Washington, USA	MS	1998	Oceanography
Friedrich Wilhelms Universität, Bonn, North Rhine Westphalia, Germany	MS	1996	Biology

Appointments and Positions

2017 - present	Professor of Oceanography, University of Rhode Island, Kingston, RI, USA
2012 - 2017	Associate Professor of Oceanography, University of Rhode Island, Kingston, RI, USA
2008 - 2012	Assistant Professor, University of Rhode Island, Kingston, RI, USA
2006 - 2007	Research Fellow, Princeton Univ., Ecology & Evolutionary Biology, Princeton, NJ, USA
2004 - 2006	Lecturer, Western Washington University, Anacortes, WA, USA

Products

Products Most Closely Related to the Proposed Project

1. Marrec P, McNair H, Franzè G, Morison F, Strock J, Menden-Deuer S. Seasonal variability in planktonic food web structure and function of the Northeast U.S. Shelf. Limnology and Oceanography. 2021 January 20; 66(4):1440-1458. Available from: https://onlinelibrary.wiley.com/doi/10.1002/lno.11696 DOI: 10.1002/lno.11696
2. Mcnair H, Hammond C, Menden-Deuer S. Phytoplankton carbon and nitrogen biomass estimates are robust to volume measurement method and growth environment. Journal of Plankton Research. 2021 March; 43(2):103-112. Available from: https://academic.oup.com/plankt/article/43/2/103/6171200 DOI: 10.1093/plankt/fbab014
3. Franzè G, Anderson S, Kling J, Wilburn P, Hutchins D, Litchman E, Rynearson T, Menden-Deuer S. Interactive effects of nutrients and temperature on herbivorous predation in a coastal plankton community. Limnology and Oceanography. 2022 December 30; :-. Available from:

https://onlinelibrary.wiley.com/doi/10.1002/lno.12289 DOI: 10.1002/lno.12289

4. Xenopoulos M, Downing J, Kumar M, Menden-Deuer S, Voss M. Headwaters to oceans: Ecological and biogeochemical contrasts across the aquatic continuum. Limnology and Oceanography. 2017 November; 62(S1):S3-S14. Available from: https://onlinelibrary.wiley.com/doi/10.1002/lno.10721 DOI: 10.1002/lno.10721
5. Menden-Deuer S, Rowlett J, Nursultanov M, Collins S, Rynearson T. Biodiversity of marine microbes is safeguarded by phenotypic heterogeneity in ecological traits. PLOS ONE. 2021; 16(8):e0254799-. Available from: https://dx.plos.org/10.1371/journal.pone.0254799 DOI: 10.1371/journal.pone.0254799

Other Significant Products, Whether or Not Related to the Proposed Project

1. Strock J, Menden-Deuer S. Temperature acclimation alters phytoplankton growth and production rates. Limnology and Oceanography. 2020 October 26; 66(3):740-752. Available from: https://onlinelibrary.wiley.com/doi/10.1002/lno.11637 DOI: 10.1002/lno.11637
2. Rynearson T, Menden-Deuer S. Drivers That Structure Biodiversity in the Plankton. In: Glibert P, Kana T, editors. Aquatic Microbial Ecology and Biogeochemistry: A Dual Perspective [Internet] Cham: Springer International Publishing; 2016. Chapter Chapter 213-24p. Available from: http://link.springer.com/10.1007/978-3-319-30259-1_2 DOI: 10.1007/978-3-319-30259-1_2
3. Grear J, Rynearson T, Montalbano A, Govenar B, Menden-Deuer S. pCO2 effects on species composition and growth of an estuarine phytoplankton community. Estuarine, Coastal and Shelf Science. 2017 May; 190:40-49. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0272771416307077 DOI: 10.1016/j.ecss.2017.03.016
4. Menden-Deuer S, Montalbano A. Bloom formation potential in the harmful dinoflagellate Akashiwo sanguinea: Clues from movement behaviors and growth characteristics. Harmful Algae. 2015 July; 47:75-85. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1568988315000931 DOI: 10.1016/j.hal.2015.06.001
5. Anderson S, Menden-Deuer S. Growth, Grazing, and Starvation Survival in Three Heterotrophic Dinoflagellate Species. Journal of Eukaryotic Microbiology. 2016 September 19; 64(2):213-225. Available from: https://onlinelibrary.wiley.com/doi/10.1111/jeu.12353 DOI: 10.1111/jeu.12353

Synergistic Activities

1. Efforts to enhance diversity in and exposure to marine sciences: e.g. Women in Marine Science, ASLO-Multicultural Program, Volvo Ocean Races, MPOWIR Group Mentor for LGBTQ+ scientists
2. Undergraduate experiential research mentor: - advised >30 undergraduate students in independent research projects, including aboard R/V Endeavor.
3. Past Associate Editor or editorial board for Limnology & Oceanography and Ecosystems, Journal of Plankton Research, Guest Editor Frontiers in Marine Science, Reviewer for >30 Scientific Journals, 9 national and international funding agencies and 3 publishers.

4. Past or Current President-elect ASLO, Member of the Board of Directors ASLO, National Harmful Algal Bloom Committee, chair ASLO Early Career Enhancement committee, Ocean Carbon and Biogeochemistry Scientific Steering Committee
5. Science Definition Team, NASA EXPORTS, Multiple Session co-organizer Aquatic and Ocean Sciences Meeting, LTER annual meeting, Session-lead Ocean Carbon Biogeochemistry Summer workshop

Certification:

When the individual signs the certification on behalf of themselves, they are certifying that the information is current, accurate, and complete. This includes, but is not limited to, information related to domestic and foreign appointments and positions. Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Menden-Deuer, Susanne in SciENcv on 2023-02-07 15:32:56

ANNETTE L. BRICKLEY
107R Marion Rd
Mattapoisett, MA 02739
tel: (207) 951-6273
email: abrickley.edu@gmail.com

A. PROFESSIONAL PREPARATION

Kenyon College	Chemistry	B.A.	May 1988
Scripps Institution of Oceanography	Oceanography	N/A	Sep 1989-Jun 1990
University of Maine	Oceanography	M.S.	May 1995

B. APPOINTMENTS

Education Outreach.	*EO Coordinator for NES-LTER* (NSF-WHOI), Woods Hole, MA	2017-present
Evaluator.	*External evaluator for Whales Today curriculum project* (IMLS-NBWM), New Bedford, MA	2020
Education Outreach.	*EO for Metacommunity Dynamics at Hydrothermal Vents* (NSF-WHOI) Woods Hole, MA	2016-2019
Facilitator/ Curriculum Development.	*National Network of Ocean &Climate Change Interpreters* (NSF-New England Aquarium), Boston, MA	2014-2019
Professional Development.	*NSF TEACH! Southcoast* (NSF-UMassD), Dartmouth, MA	2012-2017
Content Development.	*Visualizing Change* (NOAA-New England Aquarium), Boston, MA	2014-2016
Education Director.	*Ocean Explorium at New Bedford Seaport*, New Bedford, MA	2012- 2014
Instructional Designer.	*Challenger Center for Space Science Education*, (NASA-CCSSE, NOAA-CCSSE) Alexandria, VA	2010- 2012
Director.	*Challenger Learning Center of Maine,* Professional Development Director, Center Director, Bangor, ME	2003- 2010

C. PRODUCTS & PUBLICATIONS

(i) Products most closely related to the proposed project

1) Northeast U.S. Ecosystems Data Jam: outreach product/site to build student data literacy skills & practices.
2) Science On a Sphere® products: Shark Tracks, Deep-Sea Vents: Animals on the Move, Deep-Sea Vents: Life Without Sunlight, Deep-Sea Vents: Smoke and Fire Underwater, Oxygen Minimum Zones, Visualizing Change.
3) NSF TEACH! Southcoast, 6 year NSF Robert Noyce Teacher Scholarship Program, UMass Dartmouth, STEM Professional Development and Graduate Coursework for teachers g.7-12.
4) STEMming the Gap, 5-part, 7-day workshop series on teaching with inquiry and uncovering student misconceptions, for teachers g.5-12, funded by Maine Dept. of Educ.
5) Connecting Climate to Curriculum, Project Director and Principal Developer for 3-year State MSP project for teachers g.6-12, 120+ hours content and content integration

(ii) Publications related to the proposed project

1) Beaulieu, S.E., M. Emery, **A. Brickley**, A. Spargo, K. Patterson, K. Joyce, T. Silva, and K. Madin (2015) Using digital globes to explore the deep sea and advance public literacy in Earth system science. *Journal of Geoscience Education,* 63, 332-343; doi: 10.5408/14-067.1
2) Laursen, S. L., & **A. Brickley** (2011). Focusing the camera lens on the nature of science: Evidence for the effectiveness of documentary film as a Broader Impacts strategy. *Journal of Geoscience Education* 59, 126-138; doi:10.5408/1.3604825
3) Laursen, S., & **A. Brickley** (2011). “A scientist has many things to do”: E/O strategies that focus on the processes of science. In J.B. Jensen, J.G. Manning, & M. Gibbs (eds.), *Earth and Space Science: Making Connections in Education and Public Outreach*, ASP Conference Series vol. 443, 116-124

Data Management Plan: As instructed in the solicitation, this information is being submitted as Other Supplementary Documentation.

POSTDOCTORAL RESEARCHER MENTORING PLAN

The NES II co-PIs will support a postdoctoral researcher at WHOI to work on a project that integrates across NES II components. The postdoc will be jointly advised by co-PIs Ji, Neubert, and Zhang, who will be responsible for ensuring that the mentoring plan laid out here is implemented. This arrangement will allow the postdoc to gain experience with a diversity of approaches, ranging from ecological theory to computational coupled biological-physical models. The postdoc will have a unique opportunity to interact with a multidisciplinary team of oceanographers, ecologists, modelers, and theoreticians. They will further develop their skills in data production, analysis, and interpretation; preparation of presentations and publications; and building and sustaining effective research collaborations. Active engagement in teaching and public outreach activities will be encouraged through participation in the Broader Impacts activities, as well as through invited lectures in courses at the participating institutions.

The proposed project offers excellent opportunities for professional development and interdisciplinary research through close collaboration with the researchers, staff, and students at WHOI, URI, UMass and Wellesley College. In addition to the formal training programs at WHOI (described below), all postdoctoral researchers will be encouraged to lead working groups within our project, participate in the national LTER network, and as permissible, contribute to synthesis workshops, participate in the All Scientists Meeting and develop connections with other LTER scientists.

At the beginning of their appointment, and at least annually thereafter, the postdoctoral researcher will complete an individual development plan and review it with their supervisor(s). We will use a plan developed by the Federation of American Societies for Experimental Biology, and the associated web-based tool developed by AAAS (Fuhrmann et al., 2011). As described on the AAAS website, the tool is designed to help postdoctoral researchers: (1) evaluate their skills, values, and interests, (2) use this self-assessment as a guide for exploring and evaluating career opportunities and identifying their preferred career (3) set specific goals to prepare them for the career paths to which they aspire, and (4) discuss these goals and outline strategies with their primary mentor to put the plan into place.

Finally, WHOI has mentoring programs at both institutional and departmental levels. At the institutional level, WHOI hosts a "Writing a Better Proposal" workshop twice a year; regular meetings for postdocs with visiting federal agency program managers to discuss funding opportunities; workshops for responsible conduct of research training; career development forums; a Postdoctoral Symposium every fall; and the annual Postdoctoral Breakfast Reception which convenes postdoctoral researchers, their institutional sponsors, and representatives from WHOI's leadership to discuss issues of potential importance to postdoctoral scientists, including the federal funding outlook. Incoming postdoctoral researchers are provided with the document *Guidelines for Discussing Advisor-Postdoc Expectations and Responsibilities*. The Biology Department Postdoctoral Mentoring Committee at WHOI reviews each postdoctoral researcher's progress every six months and meets with the postdoc to provide an objective assessment of progress and an expanded network of support for both the postdoctoral researcher and their sponsor. The mentoring committee is available to review job application materials such as cover letters and research / teaching statements for each postdoctoral researcher.

TABLE OF DATA PRODUCTS

Table of datasets exported from the NES-LTER Data Catalog publicly available as collection "NES-LTER Data Products" (Beaulieu and Sosik 2023). The table is organized to list first the 31 ongoing, long-term datasets (listed alphabetically by creator), then our 36 completed datasets, then several partner datasets. The left-most columns indicate the association of each data product to the five core areas, abbreviated as pr (primary production), po (population dynamics), or (organic matter), in (inorganic matter), and di (disturbances). Shading indicates those datasets associated with the 10 significant publications from NES I (journal articles in Section 3.1). These datasets have been deposited into the Environmental Data Initiative (EDI) or other public data repositories, including the National Center for Biotechnology Information (NCBI) and NASA Ocean Biology DAAC (SeaBASS). We provide the creator name(s), year of publication, dataset title, repository, and Digital Object Identifier (DOI); if a DOI is not available, we provide the web address (URL) for public access as of February 2023.

Core Areas					**Creators, year of publication, dataset title, repository**	**DOI or web address**
Ongoing, long-term						
pr		or			Fontaine, D. N., & Rynearson, T. A. (2023). Size-fractionated net primary productivity (NPP) estimates based on 13C uptake during cruises along the Northeast U.S. Shelf Long Term Ecological Research (NES-LTER) Transect, ongoing since 2019. Environmental Data Initiative.	10.6073/PASTA/D1A7D072AFCA4D6BFC0E54F44C6982AE
	po	or			Glancy, S. G., & Llopiz, J. K. (2023). Zooplankton sample inventory for Northeast U.S. Shelf Long Term Ecological Research (NES-LTER) Transect cruises, ongoing since 2017. Environmental Data Initiative.	10.6073/PASTA/F68B449C7551FBE38DDD8E85C8F0DA9F
	po				Glancy, S. G., Suca, J. J., & Llopiz, J. K. (2022). Diet composition for small pelagic fishes across the Northeast U.S. Continental Shelf for NES-LTER, ongoing since 2013. Environmental Data Initiative.	10.6073/PASTA/E48FEF01A8BB7AE3C443D57DE83BED2E
pr	po				Marrec, P. (2019). Phytoplankton growth and microzooplankton grazing rates from NES-LTER transect cruises EN608, EN617, EN627. Environmental Data Initiative.	10.6073/PASTA/D0FB2B369AEE56E0E60BB796C698C9E9
pr	po	or			Menden-Deuer, S., Marrec, P., & Herbst, A. (2022). Underway discrete chlorophyll and post-calibrated underway fluorometer data during NES-LTER Transect cruises, ongoing since 2019. Environmental Data Initiative.	10.6073/PASTA/16C8E5937A860C882B524FDA73408BAF

pr	po	or	in	di	Northeast U.S. Shelf LTER, & Sosik, H. M. (2022). Event logs from Northeast U.S. Shelf Long Term Ecological Research (NES-LTER) Transect cruises, ongoing since 2017. Environmental Data Initiative.	10.6073/PASTA/E5289F602FACB4579F825CFC71ACEDDD
	po				Rynearson, T., McKenzie, M., & Fontaine, D. (2022). NES-LTER Transect eukaryote 18S V4 amplicon raw sequence reads 2018-2021. National Center for Biotechnology Information.	https://www.ncbi.nlm.nih.gov/bioproject/PRJNA900219/
		or	in		Sosik, H. (2015). MVCO discrete absorption (particles, CDOM). NASA Ocean Biology DAAC.	10.5067/SEABASS/MVCO/DATA001
pr	po	or			Sosik, H. (2016). MVCO discrete HPLC. NASA Ocean Biology DAAC.	10.5067/SEABASS/MVCO/DATA001
pr	po	or			Sosik, H. (2019). NES-LTER transect discrete HPLC. NASA Ocean Biology DAAC.	10.5067/SEABASS/NES-LTER/DATA001
	po				Sosik, H. (2020). MVCO eukaryote 18S V4 amplicon raw sequence reads time series 2013-2017. National Center for Biotechnology Information.	https://www.ncbi.nlm.nih.gov/bioproject/PRJNA504617
	po				Sosik, H. (2021). MVCO bacteria 16S V6-V8 amplicon raw sequence reads time series 2010-2018. National Center for Biotechnology Information.	https://www.ncbi.nlm.nih.gov/bioproject/?term=PRJNA725036
				di	Sosik, H. (2022). CTD (Conductivity, Temperature, Depth) data collected during day cruises onboard the coastal research vessel Tioga.	https://dlacruisedata.whoi.edu/tioga/cruise/
	po				Sosik, H. M. (2022). IFCB Dashboard NES-LTER Broadscale. Woods Hole Oceanographic Institution.	https://ifcb-data.whoi.edu/timeline?dataset=NESLTER_broadscale
	po				Sosik, H. M. (2022). IFCB Dashboard NES-LTER Transect. Woods Hole Oceanographic Institution.	https://ifcb-data.whoi.edu/timeline?dataset=NESLTER_transect
				di	Sosik, H. M. (2023). AERONET Aerosol Optical Depth Data from CIMEL SeaPRISM sun photometer at MVCO. NASA AERONET.	https://aeronet.gsfc.nasa.gov/cgi-bin/data_display_aod_v3?site=MVCO&nachal=2&aero_water=0&level=1&if_day=0&year_or_month=0
	po				Sosik, H. M., & Olson, R. J. (2022). Abundance of eukaryote picophytoplankton and Synechococcus from a moored submersible flow cytometer at Martha's Vineyard Coastal Observatory, ongoing since 2003 (NES-LTER since 2017). Environmental Data Initiative.	10.6073/PASTA/99F139F2DBDEA0B09DBA02DFEAD1FFDC

			in		Sosik, H. M., Crockford, E. T., & Peacock, E. (2021). Dissolved inorganic nutrients from NES-LTER Transect cruises, including 4 macro-nutrients from water column bottle samples, ongoing since 2017. Environmental Data Initiative.	10.6073/PASTA/EC6E5C76C7AD4E0DA0A8D1CEC84FA3F5
			in		Sosik, H. M., Crockford, E. T., & Peacock, E. (2022). Dissolved inorganic nutrients from the Martha's Vineyard Coastal Observatory (MVCO), including 4 macro-nutrients from water column bottle samples, ongoing since 2003 (NES-LTER since 2017). Environmental Data Initiative.	10.6073/PASTA/CA34BE7554DDC67C9FA0F8DEA01F375B
pr	po	or			Sosik, H. M., Crockford, E. T., & Peacock, E. (2022). Size-fractionated chlorophyll from the Martha's Vineyard Coastal Observatory (MVCO), ongoing since 2003 (NES-LTER since 2017). Environmental Data Initiative.	10.6073/PASTA/29ECB409988F09597EE268D6926E1CD9
		or			Sosik, H. M., Crockford, E. T., & Peacock, E. (2022). Dissolved Organic Carbon (DOC) and Dissolved Total Nitrogen (DTN) from Northeast U.S. Shelf Long Term Ecological Research (NES-LTER) Transect cruises, ongoing since 2022. Environmental Data Initiative.	10.6073/PASTA/38216FE6DA85D04A005FEA279CD579A5
		or			Sosik, H. M., Crockford, E. T., & Peacock, E. (2023). Particulate organic carbon and nitrogen from Northeast U.S. Shelf Long Term Ecological Research (NES-LTER) Transect cruises, ongoing since 2017. Environmental Data Initiative.	10.6073/PASTA/055CDC8078781AE5BAF7B1B5CABFEE2C
pr	po	or	in	di	Sosik, H. M., Llopiz, J. K., Crockford, E. T., & Peacock, E. (2023). Event logs from Northeast U.S. Shelf Long Term Ecological Research (NES-LTER) cruises to the Martha's Vineyard Coastal Observatory (MVCO) ongoing since 2017. Environmental Data Initiative.	10.6073/PASTA/80C39B9B09F267F413065B7FBCA83E96
					Sosik, H. M., Peacock, E., & Brownlee, E. (2014). WHOI-Plankton: Annotated Plankton Images - Data Set for Developing and Evaluating Classification Methods. Woods Hole Open Access Server.	10.1575/1912/7341
pr	po	or			Sosik, H. M., Rynearson, T., Menden-Deuer, S., & OOI CGSN Data Team. (2021). Size-fractionated chlorophyll from water column bottle samples collected during NES-LTER Transect cruises, ongoing since 2017. Environmental Data Initiative.	10.6073/PASTA/798BDA0E9DDFEBA20F2266E64CF4DD40
	po				Sosik, H. M., Futrelle, J., Crockford, E. T., Peacock, E. E., Shalapyonok, A., & Olson, R. J. (2023). IFCB Plankton Image Time Series at the Martha's Vineyard Coastal Observatory (MVCO). Woods Hole Oceanographic Institution.	10.26025/9Q7Z-A148

pr			in		Stanley, R. H. R. (2022). Oxygen-argon dissolved gas ratios using Equilibrator Inlet Mass Spectrometry (EIMS) and triple oxygen isotopes (TOI) from NES-LTER Transect cruises, ongoing since 2018. Environmental Data Initiative.	10.6073/PASTA/1294C7E1FCDA0B8DDD8C5C1C8CECF855
pr			in		Stanley, R. H. R., Mehta, A., & Aldrett, D. (2022). Net community production (NCP) and gross oxygen production (GOP), based on oxygen-argon ratios and triple oxygen isotopes, from seasonal NES-LTER Transect cruises in 2018. Environmental Data Initiative.	10.6073/PASTA/A03FCB9FDFCA8DB00C48ABB514715C83
pr			in		Stanley, R. H. R., Mehta, A., & Aldrett, D. (2022). Net community production (NCP) and gross oxygen production (GOP), based on oxygen-argon ratios and triple oxygen isotopes, from seasonal NES-LTER Transect cruises in 2019. Environmental Data Initiative.	10.6073/PASTA/2A5EB6DFBB56E338C14FAD88DECDB776
	po	or			Stevens, B., Sosik, H. M., Peacock, E., & Crockford, E. T. (2023). Abundance, biovolume, and biomass of Synechococcus and eukaryote pico- and nano- plankton from continuous underway flow cytometry during NES-LTER Transect cruises, ongoing since 2018. Environmental Data Initiative.	10.6073/PASTA/127DD033E69D0E1A3F4900D47254D425
	po				Suca, J. J. (2019). Stable Isotope Data for Small Pelagic Fishes across the Northeast U.S. Continental Shelf from 2013-2015. Environmental Data Initiative.	10.6073/PASTA/DB87ADC18BDB57B618AD067CC918735C
Completed						
pr	po				Fowler, B., Neubert, M. G., Hunter-Cevera, K. R., Olson, R. J., Shalapyonok, A., Andrew. R. Solow, & Sosik, H. M. (2020). Division rate model for picoeukaryotes at Martha's Vineyard Coastal Observatory (Version v.1.0). Zenodo.	10.5281/ZENODO.3708062
pr	po				Hunter-Cevera, K. R., Neubert, M. G., Olson, R. J., Solow, A. R., Shalapyonok, A., & Sosik, H. M. (2017). Data from: Physiological and ecological drivers of early spring blooms of a coastal phytoplankter. Dryad.	10.5061/DRYAD.JM8S7
					Rolling Deck To Repository. (2018). Cruise EN608 on RV Endeavor. Underway data sets and products processed by Rolling Deck To Repository.	10.7284/908133
					Rolling Deck To Repository. (2018). Cruise EN617 on RV Endeavor. Underway data sets and products processed by Rolling Deck To Repository.	10.7284/908140
					Rolling Deck To Repository. (2019). Cruise EN627 on RV Endeavor. Underway data sets and products processed by Rolling Deck To Repository.	10.7284/908390

					Rolling Deck To Repository. (2019). Cruise EN644 on RV Endeavor. Underway data sets and products processed by Rolling Deck To Repository.	10.7284/908413
					Rolling Deck To Repository. (2020). Cruise EN649 on RV Endeavor. Underway data sets and products processed by Rolling Deck To Repository.	10.7284/908429
					Rolling Deck To Repository. (2020). Cruise EN655 on RV Endeavor. Underway data sets and products processed by Rolling Deck To Repository.	10.7284/908982
					Rolling Deck To Repository. (2020). Cruise EN657 on RV Endeavor. Underway data sets and products processed by Rolling Deck To Repository.	10.7284/908984
					Rolling Deck To Repository. (2021). Cruise EN661 on RV Endeavor. Underway data sets and products processed by Rolling Deck To Repository.	10.7284/908987
					Rolling Deck To Repository. (2021). Cruise EN668 on RV Endeavor. Underway data sets and products processed by Rolling Deck To Repository.	10.7284/909169
					Rolling Deck To Repository. (2022). Cruise AT46 on RV Atlantis. Underway data sets and products processed by Rolling Deck To Repository.	10.7284/909585
					Rolling Deck To Repository. (2022). Cruise EN687 on RV Endeavor. Underway data sets and products processed by Rolling Deck To Repository.	10.7284/909791
			in	di	Sosik, H. (2018). ADCP (Acoustic Doppler Current Profiler) data collected during research cruise EN608 using a Hawaii UHDAS instrument system onboard the platform RV Endeavor. Rolling Deck to Repository (R2R) Program.	10.7284/131327
				di	Sosik, H. (2018). CTD (Conductivity, Temperature, Depth) data collected during research cruise EN608 using a SeaBird SBE-911+ instrument system onboard the platform RV Endeavor. Rolling Deck to Repository (R2R) Program.	10.7284/131328
			in	di	Sosik, H. (2018). ADCP (Acoustic Doppler Current Profiler) data collected during research cruise EN617 using a Hawaii UHDAS instrument system onboard the platform RV Endeavor. Rolling Deck to Repository (R2R) Program.	10.7284/131466
				di	Sosik, H. (2018). CTD (Conductivity, Temperature, Depth) data collected during research cruise EN617 using a SeaBird SBE-911+ instrument system onboard the platform RV Endeavor. Rolling Deck to Repository (R2R) Program.	10.7284/131467

			in	di	Sosik, H. (2019). ADCP (Acoustic Doppler Current Profiler) data collected during research cruise EN627 using a Hawaii UHDAS instrument system onboard the platform RV Endeavor. Rolling Deck to Repository (R2R) Program.	10.7284/133842
				di	Sosik, H. (2019). CTD (Conductivity, Temperature, Depth) data collected during research cruise EN627 using a SeaBird SBE-911+ instrument system onboard the platform RV Endeavor. Rolling Deck to Repository (R2R) Program.	10.7284/133843
			in	di	Sosik, H. (2019). ADCP (Acoustic Doppler Current Profiler) data collected during research cruise EN644 using a Hawaii UHDAS instrument system onboard the platform RV Endeavor. Rolling Deck to Repository (R2R) Program.	10.7284/133983
				di	Sosik, H. (2019). CTD (Conductivity, Temperature, Depth) data collected during research cruise EN644 using a Sea-Bird SBE-911+ instrument system onboard the platform RV Endeavor. Rolling Deck to Repository (R2R) Program.	10.7284/133984
			in	di	Sosik, H. (2020). ADCP (Acoustic Doppler Current Profiler) data collected during research cruise EN649 using a Hawaii UHDAS instrument system onboard the platform RV Endeavor. Rolling Deck to Repository (R2R) Program.	10.7284/140232
				di	Sosik, H. (2020). CTD (Conductivity, Temperature, Depth) data collected during research cruise EN649 using a SeaBird SBE-911+ instrument system onboard the platform RV Endeavor. Rolling Deck to Repository (R2R) Program.	10.7284/140233
			in	di	Sosik, H. (2020). ADCP (Acoustic Doppler Current Profiler) data collected during research cruise EN655 using a Hawaii UHDAS instrument system onboard the platform RV Endeavor. Rolling Deck to Repository (R2R) Program.	10.7284/140342
				di	Sosik, H. (2020). CTD (Conductivity, Temperature, Depth) data collected during research cruise EN655 using a SeaBird SBE-911+ instrument system onboard the platform RV Endeavor. Rolling Deck to Repository (R2R) Program.	10.7284/140343
			in	di	Sosik, H. (2020). ADCP (Acoustic Doppler Current Profiler) data collected during research cruise EN657 using a Hawaii UHDAS instrument system onboard the platform RV Endeavor. Rolling Deck to Repository (R2R) Program.	10.7284/141675

				di	Sosik, H. (2020). CTD (Conductivity, Temperature, Depth) data collected during research cruise EN657 using a SeaBird SBE-911+ instrument system onboard the platform RV Endeavor. Rolling Deck to Repository (R2R) Program.	10.7284/141676
			in	di	Sosik, H. (2021). ADCP (Acoustic Doppler Current Profiler) data collected during research cruise EN661 using a Hawaii UHDAS instrument system onboard the platform RV Endeavor. Rolling Deck to Repository (R2R) Program.	10.7284/146037
			in	di	Sosik, H. (2021). ADCP (Acoustic Doppler Current Profiler) data collected during research cruise EN668 using a Hawaii UHDAS instrument system onboard the platform RV Endeavor. Rolling Deck to Repository (R2R) Program.	10.7284/146125
				di	Sosik, H. (2021). CTD (Conductivity, Temperature, Depth) data collected during research cruise EN668 using a SeaBird SBE-911+ instrument system onboard the platform RV Endeavor. Rolling Deck to Repository (R2R) Program.	10.7284/146129
	po				Sosik, H. M., Peacock, E., & Santos, M. (2020). Abundance and biovolume of taxonomically-resolved phytoplankton and microzooplankton imaged continuously underway with an Imaging FlowCytobot along the NES-LTER Transect in winter 2018. Environmental Data Initiative.	10.6073/PASTA/74775C4AF51C237F2A20E4A8C011BC53
	po				Suca, J. J., Ji, R., Baumann, H., Pham, K., Silva, T. L., Wiley, D. N., et al. (2022). Larval transport pathways from three prominent sand lance habitats in the Gulf of Maine: otolith data, model data, and post-processed model data products. Environmental Data Initiative.	10.6073/PASTA/7FD3A9B61626BC0647B041E9F8340FD5
	po				Zang, Z. (2021). Chlorophyll and phytoplankton composition climatological data on the Northwest Atlantic Shelf from 1978 to 2014: post-processed model data. Environmental Data Initiative.	10.6073/PASTA/ADB6741BB880EC450DC8FC333CE6BDF8
pr		or			Zang, Z. (2021). MARMAP EcoMon bimonthly phytoplankton size structure data. Woods Hole Oceanographic Institution.	http://ulysse2.whoi.edu:8080/thredds/catalog/data/zzang/MARMAP_bimonth/catalog.html
pr		or			Zang, Z. (2021). DINEOF reconstructed MODIS-terra 8-day composite of surface chlorophyll data. Zenodo.	10.5281/ZENODO.5077173
	po			di	Zang, Z. (2022). Atlantic sea scallop energy budget data on the Northeast U.S. Shelf, monthly in 2010 and 2012. Environmental Data Initiative.	10.6073/PASTA/665DDFC326826DF5740ECA24194529FE

Ongoing, long-term from partner NEFSC						
					Northeast Fisheries Science Center. (2022). Bottom Trawl Surveys. NOAA National Centers for Environmental Information.	https://www.fisheries.noaa.gov/inport/item/22557
					Northeast Fisheries Science Center. (2022). Dissolved inorganic carbon, total alkalinity, nutrients, and other variables collected from profile and discrete observations during NOAA Ship cruises. NOAA National Centers for Environmental Information.	https://www.ncei.noaa.gov/access/ocean-carbon-acidification-data-system-portal/
					Northeast Fisheries Science Center. (2022). Oceanography Branch Hydrographic Database. NOAA National Centers for Environmental Information.	https://www.fisheries.noaa.gov/inport/item/25147
					Northeast Fisheries Science Center. (2022). Zooplankton and ichthyoplankton abundance and distribution in the North Atlantic collected by the Ecosystem Monitoring (EcoMon) Project from 1977-02-13 to 2019-11-11 (NCEI Accession 0187513). NOAA National Centers for Environmental Information.	https://www.ncei.noaa.gov/archive/accession/0187513

Data Management Plan NES-LTER Phase II

This data management plan is organized first to summarize how the NES LTER information management (IM) team supports the full data lifecycle and then to step through the DMPTool template provided by NSF's Biological and Chemical Oceanography Data Management Office (BCO-DMO). Our IM team includes a lead Information Manager, a technical staff member who serves as 'at-sea' data lead, a technical staff member to facilitate hydrographic data processing, and staff in WHOI's Information Services (IS; as described in the Facilities Statement).

Infrastructure to support the full data lifecycle

A primary goal of NES LTER IM is to support the project's research activities by facilitating the data lifecycle (Fig. DMP 1).

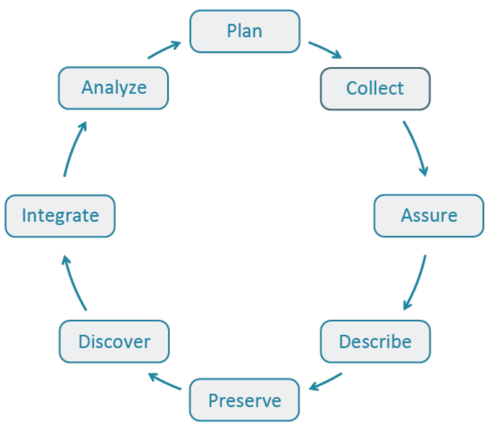

Fig. DMP 1. DataONE Research Data Lifecycle Diagram.

- Plan - Our IM team participates in science planning meetings, coordinates data acquisition prior to and following cruises, and trains project teammates in best practices for data management.
- Collect - Our project collects "Big Data" in terms of *volume, variety, and velocity,* requiring a complex infrastructure described below.
- Assure - To address *veracity* our IM team employs quality assurance in our data product workflows including IODE (International Oceanographic Data and Information Exchange) quality flags for some products.
- Describe, Preserve, Discover - To contribute FAIR (Findable, Accessible, Interoperable, Reusable) data products to DataONE and other community repositories, our IM team uses non-proprietary data formats, standardizes metadata, and promotes the use of controlled vocabularies.
- Integrate and Analyze - Our web-based REST API (representational state transfer application programming interface) for cruise data and our sharing code online in GitHub allow our project team to quickly build workflows for data integration, analysis, and visualization.

Our infrastructure must balance the project participants' need to have efficient access to large volumes of data with the additional goal of providing public access to data products. Our solution involves components spread between on-premises and cloud providers (Fig. DMP 2, Table DMP 1). By mid-year 6 of our project, our IM team stores ~60 TB of data (~55 on premises and ~5 cloud). For WHOI's institutional research data storage (RDS) on premises, we have >40 TB to share within WHOI a subset of our towed plankton imaging data, 12 TB for a subset of our coupled physical-biological model output, and 1 TB for (low-volume) data products including those served by our web-based REST API. However, additional storage is required for plankton imagery (e.g., PI Sosik's network attached storage serving ~10 TB publicly available IFCB data), acoustic data collected by vessels and Stingray towed vehicle, and physical and coupled biological-physical model output; these and some other high-volume data types (e.g., high throughput sequencing data) are necessarily managed by PIs. Much of the high-volume data needs to be proximate to high-performance computing resources. Cloud storage is used for Google Drive, GitHub, and Zotero (in decreasing order of total data volume). Google Drive is our primary means of sharing files among project participants across institutions and is used to store some raw data and internal documentation. GitHub is used to store IM-related software including data package assembly for community repositories, and we maintain a list of project participants also using GitHub to share code. Zotero is used to organize our project's products including published articles, data, and conference presentations for citation.

Many of the IM-managed components are intended to effectively handle and distribute the data collected during transect cruises (and post-cruise from samples collected). Once we obtain the external drives from these cruises, the IM copies ship- and PI-provided data into Google Drive and conducts initial quality assurance prior to uploading a subset of data types into WHOI's RDS for scientists and students to be able to use our web-based REST API to integrate cleaned data into their data visualization and analysis workflows. The API provides the ability to read data directly into code and is language agnostic to accommodate the use of a variety of programming languages (Matlab, Python, R). The IM team uses the API when compiling core long-term data products for curation and submitting to community repositories. IM-managed data products for our REST API and the project website are housed on a suite of virtual servers maintained by WHOI IS.

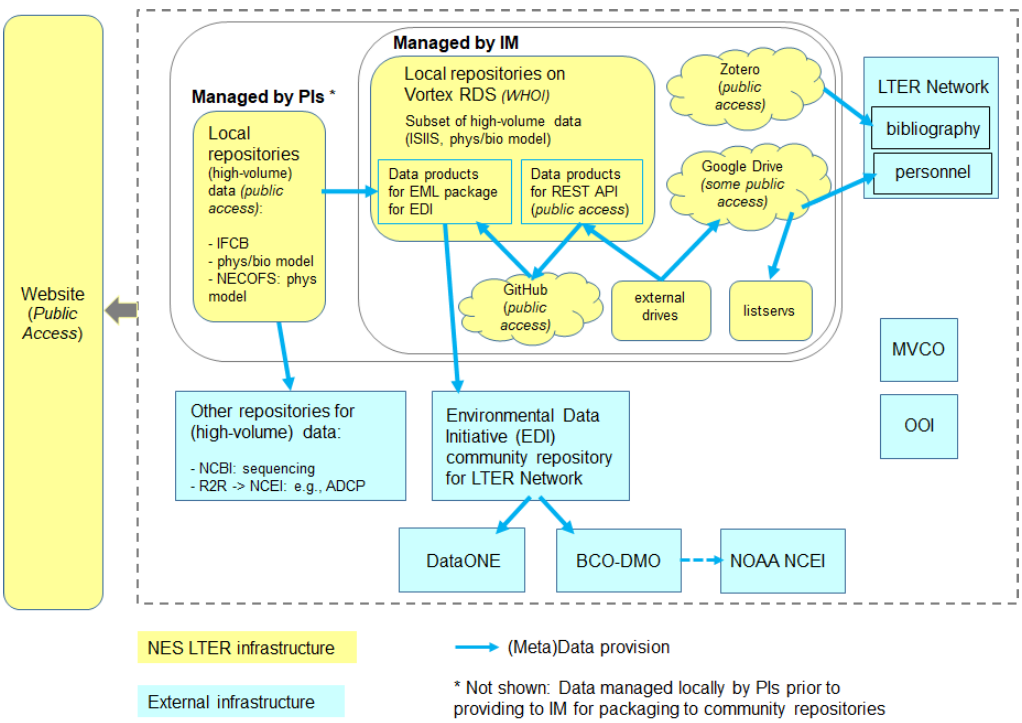

Fig. DMP 2. Major NES LTER information management system (IMS) features, with arrows indicating the flow of (meta)data to repositories for public access. Not shown: Provision of metadata from external repositories to our Zotero data catalog; Trello (cloud service) used by IM to document data packaging.

Table DMP 1. Major NES LTER information management system (IMS) features. [1]Feature required by all LTER sites; [2]further described in text; [3]provided by WHOI Information Services. Note: most of our data products served publicly through NES LTER REST API are incorporated into long-term core data products published to community repositories.

Type	Feature	Implementation
Website, catalogs, and/or directories	[1] https://NES LTER.whoi.edu/; [1] Bibliography and [1] Data catalog; [1] Personnel directory and listservs; [1] Protocols	[3] WordPress; Zotero; Google sheet > csv > LTER Network and 6 listservs; Google Drive
Data products published to DataONE community repositories	[1] 52 data products publicly available through DataONE repositories (as of February 2023)	EDI; R2R; NCEI; Dryad; data in EDI and R2R linked to BCO-DMO
Data products served by other repositories	15 data products publicly available through other community, institution, and local repositories	NCBI; SeaBASS; [2] PI-managed high-volume datasets with public access
Servers and user accounts	Cloud file system across institutions for project team; On-premises institution file system for sharing within WHOI	[3] Google Drive; [3] Vortex RDS
Code repository, Issue tracking	Code storage with version control for REST API and EML package production	GitHub; Trello

DMPTool template from BCO-DMO

Data Policy Compliance

Our project will comply with the data management policies described in the NSF PAPPG (NSF 23-1) Chapter XI.D.4 “Dissemination and Sharing of Research Results,” the NSF Division of Ocean Sciences (OCE) Sample and Data Policy, and the Long Term Ecological Research (LTER) Network Data Access Policy.

Pre-Cruise Planning

Our project involves research cruises on vessels within and external to the University-National Oceanographic Laboratory System (UNOLS) fleet. For UNOLS cruises: pre-cruise planning will be done via teleconferencing. Detailed plans for station locations, instrument deployment, and water sampling strategy will be written up as a cruise plan. The actual sampling events will be recorded in a digital event log using the R2R event logger application, and any paper logsheets will be scanned into PDF documents.

Description of Data Types

We will produce observational data, experimental data, derived data products, and model data. Observational data will be obtained in near-real-time from moored underwater instruments, underway and from sampling on research cruises, and post-cruise with laboratory analyses of physical samples including water samples, filters, plankton net samples, and fish specimens. Experimental data will be generated from incubation experiments conducted during research cruises. Derived data products will include rates calculated from observational and/or experimental data. Model data and post-processed model data products will result from coupled biophysical modeling. Data products will be categorized into the 5 LTER core areas, as in the table of datasets from NES-LTER Phase I (supplementary document).

Data and Metadata Formats and Standards

Data products provided to DataONE repositories will be in non-proprietary formats when applicable, e.g., comma separated values (CSV); “raw” data in formats as collected will also be provided when applicable. Metadata will be provided to the EDI repository in the Ecological Metadata Language (EML) standard. Our primary means of curating data with EML metadata uses the emlassemblyline R package for “ongoing” data packages, with utility functions and a spreadsheet template to streamline the incorporation of metadata contributed by lab groups; for “completed” data packages, we use the ezEML tool. We strive to meet FAIR data standards with effort towards high quality metadata and method details for each dataset. Other data and metadata standards may apply to some high-volume and/or high-frequency data. For example, high-throughput sequencing data will be formatted for the National Center for Biotechnology Information (NCBI), and model data will utilize data and metadata formats familiar to the U.S. Integrated Ocean Observing System (IOOS) community (e.g., NetCDF format). We select attribute names from controlled vocabularies including those served by the British Oceanographic Data Centre (NERC Vocabulary Server). We employ IODE (International Oceanographic Data and Information Exchange) primary quality flags. We select dataset keywords from controlled vocabularies including the LTER Controlled Vocabulary.

Data Storage and Access During the Project

As detailed in the section above (“Infrastructure to support the full data lifecycle”), data storage and access during the project differ depending on data type and volume. In general we strive to use resources that enable sharing data across institutions - thus, our use of Google Drive and other cloud resources, and our REST API for a subset of transect cruise data in WHOI’s Research Data Storage (RDS), as shown in Fig. DMP 2. Some of our high-volume data types are locally served with public endpoints (e.g., IFCB data); however, other high-volume data types are stored in infrastructure local to respective institutions, also shown in Fig. DMP 2. The IM will ensure regular backup of shared cloud resources (e.g., to external drive); backup for the IM-managed storage on WHOI’s RDS is provided through Commvault to either tape storage or Amazon Deep Glacier in the cloud. PIs are responsible for backup as described in each institution’s Facilities Statement.

Our full data catalog is implemented in Zotero, linked from our project website’s Data page, where we also provide a suggested order in which to find and access NES LTER data (in decreasing order of curation): (1) Check to see if data are curated and published at EDI (or another community repository); if not yet, then (2) check to see if data are available through our REST API; and if not in that subset of data products, then (3) for project participants, access data in our project Google Drive.

Mechanisms and Policies for Access, Sharing, Re-use and Re-distribution

With regard to public access to (meta)data and other relevant digital products, we aim to publish our data products through DataONE community repositories, with some products (e.g., high-volume data from images or models) served by other repositories (Table DMP 1). We provide long-term datasets to the LTER Network's repository—the Environmental Data Initiative (EDI) repository—with some exceptions, e.g., if another community repository in the ocean sciences is more often used for a particular type of data. NES-LTER data will be made freely and publicly available following guidelines from the LTER Network Data Access Policy for Type I data. To meet the time frame of release within 2 years from collection, the IM team maintains a data publishing 'priorities' sheet and has regular meetings to iterate ongoing packages and document completed packages. We also have engaged software engineers to assist with automation and to engage in technical discussions (e.g., with EDI) to develop streamlined ways of dealing with data variety and volume. Some high-volume and/or high-frequency data will be provided through other community, institutional, or local repositories. For example, high-throughput sequencing data will be provided to NCBI; underway data from UNOLS cruises will be provided through the Rolling Deck to Repository (R2R); underway data from Tioga coastal vessel day cruises will be provided through WHOI's institutional repository. Our project landing page at NSF OCE's BCO-DMO points to our data packages in EDI as well as our cruise data in R2R. With regard to licensing data for re-use, we recommend Creative Commons CC0 – No Rights Reserved or CC BY – Attribution when possible as recommended in the LTER Network Data Access Policy. Type II data restrictions might apply to products from remote-sensing data if covered under prior licensing.

Plans for Archiving

We will facilitate the archiving of data with NOAA NCEI when possible, and with WHOI's Data Library and Archives when applicable. For those data provided to other community repositories, archiving plans of those repositories apply. Local repositories at WHOI's data center will include backup and disaster recovery as described in the Facilities Statement. PIs will archive voucher specimens in their labs.

Roles and Responsibilities

Each PI will be responsible for sharing his/her subset of data among the project participants in a timely fashion. The lead Information Manager, supervised by Lead PI Sosik, will coordinate the submission of ongoing (long-term) data products to the EDI repository and will facilitate and document other data products submitted by project participants to appropriate repositories.

PROJECT MANAGEMENT PLAN

1. Overview and structure

Project management for the NES-LTER is inclusive of personnel, fiscal, administrative, institutional, and logistical components. The NES-LTER is based at the Woods Hole Oceanographic Institution (WHOI). Heidi Sosik is the lead PI, providing overall scientific leadership, budget oversight, and communication with the LTER Network, as well as working closely with the Project Coordinator, Information Manager, and Education and Outreach Coordinator to prioritize activities, track progress, and ensure timely and effective reporting. Three additional institutions are represented with co-PIs (University of Massachusetts, Dartmouth; University of Rhode Island; and Wellesley College). The NES LTER Steering Committee is composed of the funded co-PIs, two NOAA/NMFS scientists, the Information Manager, Project Coordinator, and Education and Outreach Coordinator (Fig. PMP 1). This steering group shares responsibility for project priorities: (1) coordinating activities across the core research areas, including full data life cycles (approving protocols, overseeing data and metadata collection, ensuring quality, and making products accessible); (2) setting and participating in education and outreach objectives; and (3) promoting collaborative and inclusive team dynamics. The steering group meets regularly to discuss high level priorities, opportunities, and project-level decisions, communicates by email for routine issues, and operates principally by consensus, with excellent rapport within the group and investment in open communication to promote diverse perspectives.

Functioning of the NES team depends on a dedicated group of technicians, supervised by the PI/co-PIs mainly at WHOI and URI. While each NES technician has primary specialization in one area, they are expected to contribute substantially across the major activities associated with field research, lab research, and information management (Fig. PMP 1). This cross-activity continuity in staff helps promote quality, accountability, and teamwork. Involvement of K-12 teachers, students from diverse backgrounds and early-career researchers in project activities is actively encouraged in a variety of ways.

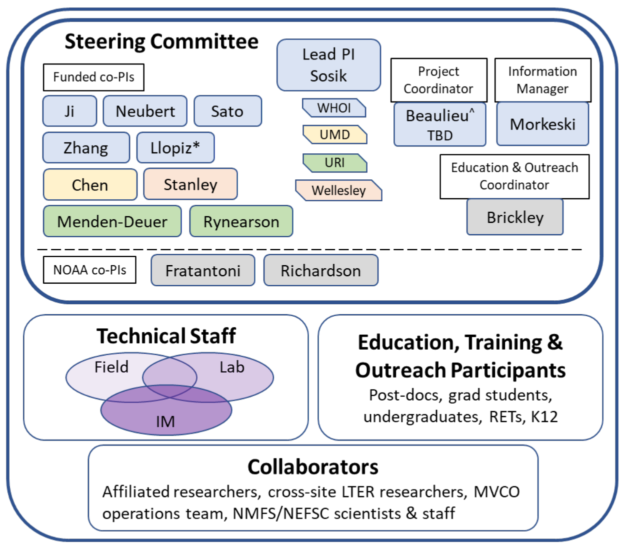

Figure PMP 1. NES team structure
*NES I co-PI on extended leave; ^Year 1 only

2. Personnel roles

During NES II, the project will continue to be managed by Lead PI Sosik, who will implement funding and research decisions in consultation with the Steering Committee. Sosik will supervise the Information Manager, project coordinator, and administrative professionals (as described below), as well as project personnel conducting sampling on NOAA-supported regional survey cruises and LTER-supported cross-shelf transect cruises. Sosik will also be the point-of-contact with other collaborators and affiliated researchers who would like to initiate new research in association with NES. Leading into the NES II mid-term review, co-PI Ji will take on a Co-Lead PI role working alongside Sosik, with the expectation that Ji will lead NES III.

There have been several leadership changes for this renewal. NES I co-PI Lentz has retired, co-PI Beaulieu plans to leave the project for other priorities after Year 1, and NES I co-PI Llopiz is on extended approved leave. Co-PIs new for NES II are W. Gordon Zhang and Mei Sato, both at WHOI, and engaged from among our group of Affiliated Investigators to cover priority areas for NES II. Zhang brings highly collaborative expertise in physical oceanography of the NES including characterization of disturbance patterns and understanding their biogeochemical impacts. Sato's research focuses on biological-physical coupling with emphasis on use of acoustics to assess dynamics in zooplankton and fish. Sato's work and expertise are highly complementary with those of Llopiz. While the return of Llopiz to active status remains uncertain, he will be eagerly welcomed back, and Sato will collaborate closely with him. During Llopiz' leave, Sosik and Sato are sharing responsibility for maintaining core area observations related to food webs, trophic dynamics, and community composition in zooplankton and fish.

During NES II, Research Associate Kate Morkeski will step into the half-time Information Manager position at WHOI and will be point-of-contact for sharing data and metadata and coordinating with other IMs at the LTER Network level (see Data Management Plan). Morkeski will work closely with WHOI Information Services (see Facilities statement) and other IM team members, setting priorities and guiding their IM contributions. Morkeski has been an integral part of the NES I IM team for several years and is being actively trained for IM leadership by NES I IM Lead Stace Beaulieu. In Year 1, a WHOI team member (E. Peacock or new hire in WHOI's project management investment) will step into the Project Coordinator role. Beaulieu will remain active with NES II for one year to ensure a smooth transition; she will also remain a resource through her leadership of the Data and Informatics Initiative at WHOI.

Leadership continuity between NES I and NES II covers major areas of research emphasis for NES II: Chen (physical modeling), Ji (coupled biological-physical modeling and numerical ecosystem simulations), Menden-Deuer (protist ecology, plankton dynamics and rate processes), Neubert (theoretical and mathematical ecology), Rynearson (molecular diversity characterization across major domains of life), Sosik (plankton community composition and phytoplankton ecology), and Stanley (gas tracer biogeochemistry, rate process, and productivity). The partnership with NOAA's Northeast Fisheries Science Center was solidified as a foundational collaboration in NES I and will continue in NES II (see Letter of Collaboration from Dr. Paula Fratantoni, Chief Oceans and Climate Branch, NEFSC).

Annette Brickley (STEMming the Gaps, Science Education Consultant) will continue as Education and Outreach Coordinator, with oversight by co-PI Ji. Brickley will coordinate the LTER Schoolyard program, inclusive of Research Experiences for Teachers. WHOI technician, Taylor Crockford, will continue to serve as logistics manager for field research, including point-of-contact for cruise preparation; Crockford is also an IM team member, focused on data management at sea and curation of metadata for data sets. Ship and observatory-based field work will continue to be conducted with support from an experienced team of technical professionals, many of whom have been with the project since inception.

Through a combination of NES II and leveraged funding, we anticipate engaging at least 2 postdoctoral researchers, 3 graduate students, and 7 undergraduate students each year in NES research and outreach activities. LTER-supported REU students will be coordinated through well-supported existing programs: the Woods Hole Partnership Education Program (PEP) (see Letter of Collaboration from Onjale Scott Price, PEP Director), WHOI's Summer Student Fellow program, Wellesley's Sophomore Early Research and STEM POSSE programs, and URI's Summer Undergraduate Research Fellowship in Oceanography.

3. Committees and Working Groups

Justice, Equity, Diversity and Inclusion (JEDI)–During NES I we launched a standing JEDI committee which will continue through NES II. The JEDI Committee (currently co-led by Stanley and Menden-Deuer) includes PI representation from WHOI (including Sosik), Wellesley, URI, and UMD, as well as student, postdoc, technical staff members. The committee meets monthly (virtually for participation across institutions) and communicates on objectives and progress through shared documents and an email list. The committee produced a written JEDI Action Plan and will continue to focus on promoting progress on actionable objectives. They also regularly (at least annually) evaluate, and update as needed, living documents (e.g., NES Code of Conduct and Safe and Inclusive Work Environments Plan), and on-going activities (e.g., cruise-based mentoring for new participants). The JEDI committee regularly reports at full team meetings and communicates with the full team with targeted emails.

Topical Working Groups–Acting on NES I mid-term review feedback, we launched a set of five topical working groups aimed at cross-disciplinary synthesis of findings and generation of new questions and hypotheses. We will continue this productive approach in NES II. We expect some topics, such as integration of observations and models for plankton processes, to continue on their current path, while others may shift focus (e.g., from synthesis guiding conceptual framework updates to synthesis evaluating NES II hypotheses). Working group topics are selected by the Steering Committee after full team input is gathered with inclusive participation and communication strategies. Working groups are co-led by an early career researcher and a senior investigator, and participants span all project personnel categories.

4. Fiscal, administrative, and institutional components

The NES-LTER site is based at WHOI with lead PI Sosik overseeing the project budget, administration, and representation in the national LTER Science Council. Sosik implements funding and research decisions in consultation with co-PIs. The funds within NES-LTER are distributed according to needs for each sub-point in the project timeline, rather than proportionally to individual PIs. Each WHOI co-PI is responsible for monitoring his/her respective budget sub-point. Three additional institutions with subawards are represented with co-PIs from UMass Dartmouth, University of Rhode Island, and Wellesley College. Each co-PI with a subaward is responsible for monitoring his/her respective budget with regular reporting to WHOI and invoice approvals by Sosik. Sosik will be assisted in providing these support activities by a to-be-hired part-time Project Coordinator supported through a leveraged WHOI initiative (see Facilities statement). We anticipate this person bringing appropriately scaled elements of formal project management to NES and helping to ease the Lead PI task load.

5. Project Communication and Coordination

For efficient within-team communication and integration, we utilize a range of organizational and collaboration tools that are in broad use across the NES team at all levels from co-PIs to undergraduates. Cloud storage and collaborative document and file sharing (Google Drive) are especially important and effective due to careful initial design and ongoing curation during NES I. Other important tools include WordPress, Zotero, Trello, and our custom REST APIs. A full-team in person science meeting is held annually in Woods Hole. Standing committees meet once (JEDI) or twice (Steering) per month. In addition, we hold one-hour full-team meetings monthly to share news, opportunities, and promote wide-ranging discussions that foster idea exchange and synthesis. The annual meetings are in person, but the others are virtual to ensure broad participation, including our REU interns even after they have returned to their home institutions. All-hands pre-cruise meetings are held each season, with most cruise planning streamlined through our online resources. Day-to-day communications are facilitated by several email listserv (full team, early career only, PIs only). The Information Manager attends the annual LTER IM Meeting. At least 4 NES participants will attend the LTER All Scientists Meetings.

6. Managing field site disruptions

Lead PI Sosik and the NES Steering Committee continue to be actively engaged in responding to field site disruptions. An important emphasis for the transition to NES II is relocation of the OOI Pioneer Array, formerly located at the offshore end of our focal transect. To mitigate the loss of spring/fall observations that formerly leveraged OOI cruises, we have now included shiptime requests for those seasons with this proposal, and will be seeking leveraged support and taking the opportunity to build an extended network of affiliated researchers with sea-going interests to help effectively manage the added cruise commitments. Sosik and other co-PIs will continue to work with WHOI leadership to seek leveraged investments that can replace key components for long-term observations near the shelf break. In the meantime, we will rely on satellite data for aspects of physical disturbance characterization. In another development important for NES II, construction of wind turbines in new offshore wind energy lease areas is already underway in NES waters adjacent to our focal transect. We are managing both the challenge and the opportunity presented by this large-scale long-term disturbance. NES II foci include exploring this scientifically. Sosik has met with wind industry representatives to mitigate logistical impediments for NES observations and to begin a promising dialog about observing partnerships that may leverage offshore structures. The NES Steering Committee will continue this proactive engagement and management for project goals and leveraging.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Northeast Fisheries Science Center
166 Water Street
Woods Hole, MA 02543-1026

23 February 2023

To: NSF Biological Oceanography Program, Directorate for Geosciences

If the proposal submitted by Dr. Heidi Sosik, entitled "LTER: Scales of variability in ecosystem dynamics and production on the changing Northeast U.S. Shelf (NES II)" is selected for funding by NSF, it is my intent to collaborate and/or commit resources as detailed in the Project Description or the Facilities, Equipment and Other Resources section of the proposal.

Sincerely,

Paula Fratantoni
Chief, Oceans and Climate Branch
Northeast Fisheries Science Center

THE WOODS HOLE
Partnership
Education
Program

23 February 2023

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Onjalé Scott Price

Onjalé Scott Price
Director, The Woods Hole Partnership Education Program (PEP)