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RAPID: Effect of a Very Low NAO Event on the Abundance of the Lipid-Rich Planktonic Copepod, Calanus Finmarchicus, in the Gulf of Maine

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Federal Agency and Organization Element to Which Report is Submitted:	4900
Federal Grant or Other Identifying Number Assigned by Agency:	1235920
Project Title:	RAPID: Effect of a Very Low NAO Event on the Abundance of the Lipid-Rich Planktonic Copepod, Calanus Finmarchicus, in the Gulf of Maine
PD/PI Name:	Jeffrey Runge, Principal Investigator
Recipient Organization:	University of Maine
Project/Grant Period:	04/01/2012 - 03/31/2014
Reporting Period:	04/01/2013 - 03/31/2014
Submitting Official (if other than PD\PI):	Jeffrey Runge Principal Investigator
Submission Date:	08/28/2014
Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	Jeffrey Runge

Accomplishments

*** What are the major goals of the project?**

1. Test the hypothesis that a distinctly lower abundance of the planktonic copepod, *Calanus finmarchicus* in the Gulf of Maine follows the occurrence of very negative winter phases of the North Atlantic Oscillation (NAO). In 2010,

the station-based winter NAO index was -4.64, even more intense than the negative (-3.78) 1996 NAO winter index. If a two-year lagged relationship between very negative NAO winter indices and *Calanus* abundance in the Gulf of Maine is valid, cooler water from the Labrabdor Sea should replace Atlantic Temperate Slope Water in the GoM in 2012, inducing a major climatic ecosystem event on the New England shelf, one manifestation of which would be dramatically lower *Calanus* abundances in the Gulf of Maine basins.

2. Collect data on demography, abundance and characteristics of body size and composition of the *Calanus finmarchicus* in Wilkinson Basin during a period of extreme warming in the Gulf of Maine. These date will provide evidence for development of hypotheses about the sources and fate of C. finmarchicus in the Guf of Maine in the context of climate forcing of the region's coastal ecosystems.

*** What was accomplished under these goals (you must provide information for at least one of the 4 categories below)?**

Major Activities: This reporting period covers the no cost extension of the award.

1. We completed analysis of plankton samples collected at two time series stations, the Coastal Maine Time Series (CMTS) station in the Maine Coastal Current off the Damariscotta Estuary and the Wilkinson Basin Time Series Station (WBTS) in Wilkiinson Basin.

2. We have published or submitted 4 research articles related to the subject of the award. One (Runge et al. submitted) report and interprets the results of the sampling activities in the Gulf of Maine (Wilkinson Basin) in 2012-13 that were the focus of this RAPID award.

3. The dataset from the Wilkinson Basin Time Series Station between April 2012 - May 2013, the collection of samples from which was fully supported from this award, has been submitted to the NSF BCO-DMO for archiving. BCO-DMO will also ensure that these data are permanently archived at the National Oceanographic Data Center (NODC).

4. The results of the award activities are the foundation for a new research proposal, to be submitted to the NSF BioOce proposal, to investigate a new hypothesis about the mechanisms sustaining persistence of this key planktonic species in the Gulf of Maine under rapid warming in the region.

5. The results were presented at the Ocean Sciences Meeting held in Honolulu in Feb. 2014.

6. J. Runge served as co-chair of the NERACOOS/NROC Ocean and Coastal Health Committee and a co-chair, with M. Cote (US EPA) and Brian Thompson (Conn. Dept. Env. and Energy Protection), of the Integrated Sentinel Monitoring Project (http://www.neracoos.org/sentinelmonitoring). This project is a multi agency and institution effort to coordinate observing of the Northeast US shelf ecosystem during climate change. Because it is the foundation of the Gulf of Maine pelagic food web, C. finmarchicus has been designated as a sentinel variabile for future observing activities.

Specific Objectives: 1. Conduct time series sampling (1-2 times per month) at a prescribed fixed station in Wilkinson Basin using standard protocols for monitoring Calanus in NW Atlantic waters.

2. Sample C. finmarchicus along a transect in Wilkinson Basin during a research cruise on the R/V Cape Hatteras in Sept-Oct., 2012.

3. Analyze samples for abundance of C. finmarchicus life stages and for body size and lipid volume of stage CV. Conduct a preliminary analysis of carbon and

nitrogen and fatty acid composition of stage CV.

4. Write up results of analyses with respect to hypotheses about factors controlling the sustained high abundance of C. finmarchicus in the Gulf of Maine

Significant Results: C. finmarchicus abundance in Wilkinson Basin remained at high levels in 2012, contrary to predictions based on the occurrence of the very low 2010 NAO. The fixed station time series and the transect across Wilkinson Basin in late September both show stage CV abundances that make the GoM among the regions with the highest abundances (in terms of numbers m-2) across the subarctic range of the species.

A new hypothesis has been developed to explain the mechanism sustaining C. finmarchicus in the Gulf of Maine. The processes involved include supply from Canadian sources from the Scotian Shelf, local egg production, southwesterly transport of growing copepodid stages in the cold and phytoplankton-rich Maine Coastal Current, and accumulation of the dormant, preadult stage CV in deep water, particularly Wilkinson Basin in the western Gulf of Maine. The magnitude of *C. finmarchicus* abundance in the southern and western Gulf of Maine during the succeeding spring is expected to vary according to the match or mismatch of the temperature-dependent emergence from dormancy in late winter with the timing of the winter-spring phytoplankton bloom in Wilkinson Basin.

Key outcomes or Other achievements: 1. Successful completion of a time series in Wilkinson Basin, the major center of C. finmarchicus abundance in the western Gulf of Maine, during 2012, the warmest year on record in the Gulf of Maine. This sampling effort fulfills the RAPID goal of providing funds for quick-response research on significant and unanticipated natural or anthropogenic events.

2. The research disproved a longstanding prediction that dramatic change in abundance of C. finmarchicus in Wilkinson Basin is correlated with the state of the North Atlantic Oscillation

3. A new hypothesis explaining the mechanism sustaining C. fimnarchicus in the Gulf of Maine during climate change was introduced in a research article to be published in the Journal of Plankton Research. The hypothesis repesents a specific case of the general hypothesis that *the interaction between upstream source supply, advection and local production contributes significantly to persistence of planktonic populations on continental shelves despite environmental changes associated with climate warming.*

*** What opportunities for training and professional development has the project provided?**

This project represents a 1-year RAPID award with an additional 1-year no cost extension. It contributed to the development of reserch skills in sample collection and analysis for UMaine research associate, Cameron Thompson. University of Maine undergraduate students participated in sample collection at the Coastal Maine Observing station and received training in methods in zooplankton ecology and basic principles of biological oceanography.

*** How have the results been disseminated to communities of interest?**

The results will be published in the Journal of Plankton Research, a research journal with broad dissemination to the research community. Please see attached PDF file.

The results have been disseminated through presentations and discussions with colleagues in the Gulf of Maine observing community, through the Integrated Sentinel Monitoring Project (http://www.neracoos.org/sentinelmonitoring).

The results have also been disseminated through interviews with the media, including the Associated Press, Boston Globe, Huffinton Post, Portland Press Herald and NBC Nightly News, on 8 occassions since 2012.

Products

Books

Book Chapters

Conference Papers and Presentations

Inventions

Journals

Batchelder, H., K. Daly, C. Davis, R. Ji, M. Ohman, W. Peterson, and J. Runge. (2013). Climate impacts on animal populations and communities in coastal marine systems: towards forecasting change through mechanistic understanding of population dynamics.. *Oceanography*. 26 (4), 34-51. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Fields, D. M., J. A. Runge, C. Thompson, S. Shema, R. Bjelland, A. B. Skiftesvik, and H. Browman. (2014). Infection of the planktonic copepod Calanus finmarchicus by the parasitic dinoflagellate, Blastodinium spp.: effects on grazing, respiration, fecundity, and fecal pellet production.. *Journal of Plankton Research*. . Status = ACCEPTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Preziosi, B. M. and J. A. Runge (2014). The effect of warm temperatures on hatching success of the marine planktonic copepod, Calanus finmarchicus. *Journal of Plankton Research*. . Status = ACCEPTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Runge, J.A., R. Ji, C. Thompson, N. Record, C. Chen, D. Vandemark, J. Salisbury and F. Maps. (2014). Persistence of Calanus finmarchicus in the western Gulf of Maine during recent extreme warming.. *Journal of Plankton Research*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Licenses

Other Products

Databases.

Data collected at the Wilkinson Basin Time Series Station (WBTS) have been submitted to the NSF BCO-DMO (http://www.bco-dmo.org/project/523621). BCO-DMO will ensure that these data are permanently archived at NODC.

The dataset includes the following:

- Time Series metadata: date/time, location, depth, event log

- Zooplankton species abundance and composition

- *C. finmarchicus* demographic data

- CTD and profile data

- Chlorophyll a concentrations at selected depths (size fractionated)

A quantitative subsample (1/2 split) of the plankton samples collected with the vertical ring net at WBTS is preserved in 4% formaldehyde and presently archived at the sample storage site located at the Gulf of Maine Research Institute.

Other Publications

Patents

Technologies or Techniques

Thesis/Dissertations

Websites

Participants/Organizations

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Runge, Jeffrey	PD/PI	4
Thompson, Cameron	Technician	3

Full details of individuals who have worked on the project:

Jeffrey Albert Runge
Email: jeffrey.runge@maine.edu
Most Senior Project Role: PD/PI
Nearest Person Month Worked: 4

Contribution to the Project: J. Runge is project leader. He participated in the collection and analysis of data and the reporting and interpretation of results in four research articles. He supervised research associate, Cameron Thompson, who was supported in this project for collection of samples and analysis of data.

Funding Support: Salary for J. Runge was supported by the Unversity of Maine

International Collaboration: No
International Travel: No

Cameron S. Thompson
Email: cameronsthompson@gmail.com
Most Senior Project Role: Technician
Nearest Person Month Worked: 3

Contribution to the Project: C. Thompson was responsible for the collection of data at monthly intervals at two time series stations in the Gulf of Maine, identification and enumeration of plankon samples, and analysis of data

Funding Support: No other funding suppor

International Collaboration: No
International Travel: No

What other organizations have been involved as partners?

Name	Type of Partner Organization	Location
University of New Hampshire	Academic Institution	Durham, NH

Full details of organizations that have been involved as partners:

University of New Hampshire

Organization Type: Academic Institution
Organization Location: Durham, NH

Partner's Contribution to the Project:
In-Kind Support

More Detail on Partner and Contribution: Dr. Joseph Salisbury and Douglas Vandemark, Ocean Process Analysis Laboratory, UNH. Sharing of vessel time and analysis of phytoplankton samples

What other collaborators or contacts have been involved?

NO

Impacts

What is the impact on the development of the principal discipline(s) of the project?

These finding contribute to understanding of the factors sustaining the abundance of a key zooplankton species in a regional coastal ecosystem. They lead to development of an alternative hypothesis, that the high abundance of C. finmarchicus in the Gulf of Maine is sustained by transport of individuals from the surface Nova Scotia current in combination with local production in the Maine Coastal Current. This hypothesis opposes published predictions that the species will disappear from the Gulf of Maine due to global warming.

The hypothesis developed provide a mechanism for persistence of C. finmarchicus in the Gulf of Maine, involving the interaction between advection and local production, can be applied to understand species range boundary shifts in other coastal and continental shelf oceans.

What is the impact on other disciplines?

The findings have implications for study of global change biology, in particular for the understanding and prediction of species distribution shifts due to global change. With increasing frequency, statistical habitat models are used to predict effects of environmental habitat on species distribution. The results of this research support the hypothesis that advective transport (in this case from colder habitats to the north) may locally mitigate predictions from basin scale statistical models describing species habitat.

What is the impact on the development of human resources?
Nothing to report.

What is the impact on physical resources that form infrastructure?
Nothing to report.

What is the impact on institutional resources that form infrastructure?
Nothing to report.

What is the impact on information resources that form infrastructure?
Nothing to report.

What is the impact on technology transfer?

The research hypothesis developed in this project represents the foundation for new coupled physical biological modeling approaches that can be used by state and federal agencies to understand impacts of climate change on coastal ecosystems, informing adaptive management decisions as climate forced changes affect coastal ecosystems.

What is the impact on society beyond science and technology?

The Northeast Regional Ocean Council and the Northeast Regional Association for Ocean Observing Systems are presently developing a strategy for integrated sentinel monitoring of the Northeast marine ecosystems. The network would inform researchers, managers, and the public about ecosystem vulnerabilities and impacts, and support an ecosystem-approach to management framework that promotes human and ecosystem resiliency from climate change and related stressors. This research contributes to an understanding of factors sustaining the abundance of a key species in the Gulf of Maine ecosystem and will provide information for society decisions about what and how to monitor regional ecosystems for impacts of climate change.

Changes/Problems

Changes in approach and reason for change
Nothing to report.

Actual or Anticipated problems or delays and actions or plans to resolve them
Nothing to report.

Changes that have a significant impact on expenditures
Nothing to report.

Significant changes in use or care of human subjects
Nothing to report.

Significant changes in use or care of vertebrate animals
Nothing to report.

Significant changes in use or care of biohazards
Nothing to report.

RSR Award Detail

Research Spending & Results

Award Detail

Awardee:	UNIVERSITY OF MAINE SYSTEM
Doing Business As Name:	University of Maine
PD/PI:	Jeffrey Runge (207) 228-1652 jeffrey.runge@maine.edu
Award Date:	03/28/2012
Estimated Total Award Amount:	$ 122,566
Funds Obligated to Date:	$ 122,566 FY 2012=$122,566
Start Date:	04/01/2012
End Date:	03/31/2014
Transaction Type:	Grant
Agency:	NSF
Awarding Agency Code:	4900
Funding Agency Code:	4900
CFDA Number:	47.050
Primary Program Source:	490100 NSF RESEARCH & RELATED ACTIVIT
Award Title or Description:	RAPID: Effect of a Very Low NAO Event on the Abundance of the Lipid-Rich Planktonic Copepod, Calanus Finmarchicus, in the Gulf of Maine
Federal Award ID Number:	1235920
DUNS ID:	186875787
Parent DUNS ID:	071750426
Program:	BIOLOGICAL OCEANOGRAPHY
Program Officer:	David L. Garrison (703) 292-8582 dgarriso@nsf.gov

Awardee Location

Street:	5717 Corbett Hall
City:	ORONO
State:	ME
ZIP:	04469-5717
County:	Orono
Country:	US
Awardee Cong. District:	02

Primary Place of Performance

Organization Name:	Gulf of Maine Research Institute
Street:	350 Commercial Street
City:	Portland
State:	ME
ZIP:	04101-2557
County:	Portland
Country:	US
Cong. District:	01

Abstract at Time of Award

The copepod, Calanus finmarchicus, is a dominant member of the plankton in the Gulf of Maine, (GoM), despite its location at the southern edge of the species' subarctic range. Wilkinson Basin, one of the three deep basins in the GoM, harbors very high concentrations of the early developmental stages of C. finmarchicus in the summer through winter and serves as a source of C. finmarchicus to GoM coastal ledges and banks. A recent study based on C. finmarchicus habitat characteristics across the North Atlantic predicts that climate-driven change will force the distribution of C. finmarchicus northward out of the GoM over the next several decades. However, the oceanographic and life history responses of C. finmarchicus to environmental variability in the Gulf are complex and largely unknown. The research in this RAPID proposal takes advantage of a rare opportunity to test a hypothesis about the control of C. finmarchicus abundance in the GoM from climate change related external forcing. The hypothesis states that a distinctly lower C. finmarchicus abundance follows, with a two-year lag, the occurrence of a very negative North Atlantic Oscillation (NAO). The specific processes that causally connect low C. finmarchicus with the NAO are not known. The research here tests the prediction that C. finmarchicus abundance will be very low in Wilkinson Basin in 2012, two years after one of the most negative NAOs on record, dating back to the 1860?s. Field observations in the form of a time series of measurements of hydrography, food availability and C. finmarchicus stage abundance will be taken at a fixed station in Wilkinson Basin and in the Maine coastal region, supported by measurements taken on the Scotian Shelf. A research survey, coordinated with a scheduled cruise in the Gulf of Maine in September, 2012, will take additional collections in Wilkinson Basin and throughout the GoM. Frozen and ethanol preserved samples of C. finmarchicus will also be collected for population genetic studies. The abundance results will be compared with historical time series and survey data collected over the past two decades, confirming or refuting the expectation of extreme NAO influence on GoM C. finmarchicus populations.

The lipid-rich early developmental stages of C. finmarchicus represent a particularly important energy source for planktivorous fish such as herring, mackerel and sand lance, supporting coastal fisheries as well as the summer resident populations of the endangered North Atlantic right whale, which feeds on C. finmarchicus directly. This RAPID research provides information needed to understand sources of variability in C. finmarchicus supply to the GoM ecosystem and the data will be used to support the development of coupled physical-biological models of responses of the C. finmarchicus population to the NAO and other sources of external forcing. Archived samples will be used for genetic analyses addressing research questions about shelf-basin connectivity developed by the ocean sciences community in the U.S. BASIN Implementation Plan. The project contributes to the implementation of the observing subsystem for the Northeast Association for Coastal Ocean Observing Systems (NERACOOS), which has identified the need for observing change in zooplankton diversity as part of its regional build-out planning. It will also contribute to development of the story of C. finmarchicus as an asset for teaching marine science to K-12 students, through COSEE curriculum resources and the Cohen Center for Interactive Learning at the Gulf of Maine Research Institute.

Project Outcomes Report

Disclaimer

The planktonic copepod, *Calanus finmarchicus*, is a dominant member of the zooplankton across the North Atlantic Ocean. In the northwest Atlantic, the southern edge of its reproductively active range is the Gulf of Maine. Despite its location at the southern boundary, the Gulf of Maine harbors extremely abundant concentrations of *C. finmarchicus*, which plays a fundamental role in the region's marine ecosystem. Of particular importance to predators and to the region's fishing economy are the lipid-rich (with fatty acids), late preadult stages (CIV-CV) that dominate the zooplankton biomass in late spring and summer. These stages serve as a primary source of energy either directly (northern right whales) or indirectly (via consumption by primary consumers such as herring, mackerel and sandlance) for the ecosystem's top predators, including groundfish, tuna, marine mammals, many seabirds and even lobsters.

Over the past decade, sea surface temperature (SST) in the Gulf of Maine has warmed at a rate (0.2°C yr^{-1}) that is more than ten times greater than the 100 yr rate. In 2012, a record warm year, SST in summer was as much as 5°C higher than the long term average. The mean annual SST has exceeded 10°C in the western Gulf of Maine since 2006 and in the eastern Gulf of Maine since 2012.. This temperature landmark has ecological significance as a biogeographic transition zone in the North Atlantic. Statistical-based modeling of *C. finmarchicus* habitat, for which SST is an important variable, combined with forecasts with an atmosphere-ocean climate model predict that climate driven ocean warming will force distribution of the species northward out of the Gulf of Maine over the next several decades.

Because zooplankton diversity in the Gulf of Maine is low and there is no other obvious candidate to replace the production of energy rich lipids for higher trophic levels, significant declines or fluctuations in the abundance of C. finmarchicus will likely have important implications for management of the regions resources and social and economic adaptation to environmental change.

This research, funded under the NSF RAPID program designed to support quick-response research to significant and unanticipated events, investigated the population response of *C.finmarchicus* to record warming in the Gulf of Maine in 2012. Population data from two time series stations and a plankton survey conducted in the Gulf of Maine in early autumn, 2012, showed that *C. finmarchicus* abundance in the western Gulf of Maine was within the normal range and did not show signs of decline. On the contrary, a new cohort, likely originating from early egg production during a winter phytoplankton bloom in early spring, 2013, was the most abundant ever recorded in the eight-years for which there are time series data.

To explain why C. finmarchicus persists in the Gulf of Maine despite the recent warming trend, a new hypothesis that implicates transport in currents from colder waters in the Gulf of St. Lawrence and Nova Scotia Shelf, where the species is abundant as well transport of C. finmarchicus in the Maine Coastal Current, a relatively cold, southwesterly flowing current along the coast of the Gulf of Maine. In contrast to the central Gulf of Maine, the Maine Coastal Current is rich in phytoplankton throughout the summer months, providing a source of food for the species to reproduce and grow. These individuals that grow up and become filled with fat during the late spring and summer are delivered by the Maine Coastal Current to the southern and western parts of the Gulf of Maine, where they spend the winter in diapause.

Recognizing the importance of *C. finmarchicus*, the Northeast Regional Association of Coastal and Ocean Observing Systems (NERACOOS) and the Northeast Region Ocean Council (NROC), two regional associations of representing federal and state agencies as well as universities and non-profit organizations, have identified it as a key sentinel species for climate change in plans for an Integrated Sentinel Monitoring Network (ISMN- http://www.neracoos.org/sentinelmonitoring) for the Northeast shelf ecosystem. The research results of this project provide the foundation for development of computer models combining knowledge of the currents and biology of the species into analysis and forecasting tools. These tools will advance the capacity of the ISMN to interpret observing data for the Northeast pelagic ecosystem and to develop information products for managers and users of Northeast ecosystem services to adapt to change.

Last Modified: 08/15/2014
Modified by: Jeffrey Runge

For specific questions or comments about this information including the NSF Project Outcomes Report, contact us.