Northeast Consortium Cooperative Research

PULSE:
A Cooperative Partnership for Coastal Ocean Ecosystem Monitoring in the Gulf of Maine

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Abstract

This project demonstrates a successful partnership for a cooperative, industry-based contribution to monitoring of the pelagic ecosystem in the Gulf of Maine. The need for long-term biological data collection in the Gulf of Maine becomes critical in light of the potential for change in climate at both the regional and global scale. It is increasingly important for the fishing industry as decisions about fishery management shift from a single or multi-species to an ecosystem-based approach. In this final report, we describe the structure of the partnership and major results of a three year time series, between 2003-2005, of hydrographic and biological data from a fixed station at GoMOOS buoy "B" and on Jeffreys Ledge. This is the first recorded time series for the western Gulf of Maine showing both seasonal and interannual variability in phytoplankton and zooplankton biomass. It indicates a marked reduction of abundance of *Calanus finmarchicus*, a dominant Gulf of Maine planktonic copepod that is a primary prey for adult herring and the northern Right Whales, in 2004-2005, particularly in summer on Jeffreys Ledge. In addition to providing indicators of seasonal and interannual variations in abundance of plankton, the time series results serve fundamental data needs for coupled physical biological models investigating coupling between climate forcing, physical circulation and mixing, plankton production and recruitment processes in the western Gulf of Maine. Recommendations for future research and steps to continue the partnership and maintain an industry-based contribution to the regional observing system are proposed.

Introduction

The overall goal of this project was to design and develop a cooperative, industry-based contribution to monitoring of the pelagic ecosystem in the Gulf of Maine. The need for long-term biological data collection in the Gulf of Maine becomes critical in light of the potential for change in climate at both the regional and global scale. It is increasingly important for the fishing industry as decisions about fishery management shift from a single or multi-species to an ecosystem-based approach. The project has involved the expertise and resources of the local fishing community in the process of learning more about the natural and man-made variability of the Gulf of Maine marine ecosystem.

In this final report we demonstrate that a cooperative, industry-based contribution to monitoring is logistically feasible. We present highlights from a three-year time series of observing data on interannual and seasonal variability in phytoplankton and zooplankton biomass and species composition from two fixed stations sampled off Portsmouth between 2003-2005. The fishing industry provided vessels and participated in collection of samples at weekly to semi-monthly intervals. The sampling involved relatively inexpensive, "low-tech" techniques and equipment that can be readily learned and routinely deployed on fishing vessels. The sample analysis was carried out in the laboratory at the University of New Hampshire.

Why monitor the pelagic ecosystem in the Gulf of Maine?

The earth system, which includes the atmosphere and the oceans and all life that inhabits them, is a dynamic balance that is subject to change. Over the past 50 years, the world's oceans have been warming (Levitus et al. 2000), in a trend well correlated with the observed increase in average temperature in the lower atmosphere (Albritton, Meira Fiho et al. 2001). Paleoclimatologists have recently discovered that when the earth system is being forced, as in the emergence from the last ice age, large, abrupt climate shifts have occurred, locally reaching as much as a 10 °C change in 10 years (Cuffey and Clow 1997; Alley 2000). The implication for the present, when climate is being forced by increasing greenhouse gases, has motivated a group of earth system scientists to announce the possibility of abrupt climate change in the foreseeable future (Alley et al. 2002).

Superimposed on the recent trend in warming over the past century are fluctuations of atmospheric and ocean processes (including fishing) at smaller scales that in some instances have led to a rapid transition to a different oceanographic ecological states ("regime shifts"). These regime shifts are associated with major changes in abundance and composition of fish stocks (e.g. Steele 1998). Examples include the oscillations of anchovy and sardine populations in the California Current ecosystem, the collapse of North Sea herring populations in the Middle Ages, fluctuations in herring, salmon and halibut catches off British Columbia associated with climate shifts in the North Pacific, the shift from gadoids to pelagics in the North Sea in the 1960's and 70's and the collapse of the northern cod off the Canadian coast in the early 1990's, which was accompanied by an increase in shrimp and crab (see references in Mann 2000; Dower et al. 2000; Frank et al. 2005).

In many of these cases, there is evidence that ecological regime shifts are driven by changes in the dynamics of phytoplankton and zooplankton at the base of the pelagic food web (e.g. Mann 2000; Pershing et al. submitted) occurring faster than a fish stock's capability to adapt to them. A characteristic of many of the recorded collapses in fish stocks is that heavy fishing pressure continued after a series of recruitment failures caused by adverse environmental conditions (Larkin 1996; Cushing 1996).

In their report to the National Academy of Sciences, the international committee on Abrupt Climate Change points out that human and natural systems have survived abrupt changes in the past; the best way for effective response is for increased knowledge to reduce the vulnerability to consequences and increase the capacity to adapt. They argue for better monitoring activities, including tracking of oceanic regimes of intense biological activity, particularly near the coasts. Similarly, many in the fisheries oceanography research community argue for increased monitoring of oceanic ecosystems as a necessary step for fisheries management strategies in the context of the potential for change (e.g. Sharp 2000; Dower et al. 2000).

The potential for climate change is predicted to affect the pattern of New England's weather (New England Regional Assessment Group 2001). The average air temperature is predicted to increase by 3-5°C and snow fall and precipitation levels may change, with implications for patterns of river runoff into the Gulf of Maine. An increasing trend in surface temperature in winter along the northeastern U. S. coast, including the Gulf of Maine, at a rate of about 2°C per 100 years, has recently been documented (Shearman et al. 2004). At the same time, change is occurring in the level of human activity along the Gulf of Maine coast. The southern coast of Maine, in particular, is predicted to become increasingly urbanized over the next few decades.

What effects, if any, these potential regional changes would have on circulation and water temperature in the Gulf of Maine and on the productivity of its ecosystems and fisheries, is not at present predictable, although recent developments in coupled physical-biological modelling of the Gulf of Maine- Georges Bank system (e.g. Miller et al. 1998; Lynch et al. 1998) promise new levels of understanding of connections between ocean circulation and temperature and plankton productivity and distribution. Common sense dictates that it would be advantageous to know whether change is occurring in the Gulf of Maine oceanic ecosystem, with its potential consequences for the recruitment and distribution of fish stocks, in order to better prepare for it. The Gulf of Maine now has a Closed Area, in the vicinity of Jeffrey's Ledge, the main purpose of which is to protect the habitat and spawning stocks of Gulf of Maine groundfish. Knowledge of whether the structure and productivity of planktonic communities is changing will contribute to accurate assessment of the effectiveness of the Closed Area , and of any future Marine Protected Area that may be designated in the Gulf of Maine (Anon. 2001).

The Canadian Atlantic Zonal Monitoring Program (AZMP)
Shortly after the collapse of the northern cod stocks in the early 1990's, the Fisheries Research Conservation Council, composed of government and university scientists and members of the fishing sector, recommended that the Department of Fisheries and

Oceans increase the monitoring capacity for the biological environment in waters of Atlantic Canada. The Department responded with a proposal for a Zonal Monitoring Program (Therriault et al. 1998) to meet the needs of the FRCC for more information about variability, trends and the possibilities for regime shifts in Atlantic waters supporting the fisheries. The biological observation program comprises a number of components, including section sampling for plankton during existing fish surveys, remote sensing, Continuous Plankton Recorder measurements, and toxic algae monitoring. Most of these components were already in place. A new and cornerstone activity of the AZMP is the establishment of six fixed stations located in the Bay of Fundy, Scotian Shelf and Gulf of St. Lawrence. The fixed stations are intended to complement the coarser temporal resolution of other monitoring components with higher-frequency data on seasonal patterns of phytoplankton and zooplankton at accessible yet strategic locations across the zone. After over a year of inter-regional meetings and discussions a list of key biological variables and protocols were defined and sampling commenced in 1999. A description and summary of the results of the program are provided by Therriault (2001).

IOOS: National program for regional coastal ocean observing
A number of monitoring and observing programs are currently conducted in the Gulf of Maine (Chandler 2001). While these programs address numerous aspects of the Gulf of Maine system, very few sample the planktonic ecosystem in the water column away from the nearshore environment. GoMOOS (Gulf of Maine Ocean Observing System: http://www.gomoos.org) focuses on providing real or near real time information on ocean temperature, currents, waves, wind and other oceanographic parameters using moorings and seaward looking shore-based high-frequency radar. Several of the buoys, including buoy "B" now measure chlorophyll at 3 and 18 m as well as light levels. The Northeast Fisheries Science Center (National Marine Fisheries Service) conducts the ECOMON surveys (formerly MARMAP:Marine Resources Monitoring, Assessment and Prediction; Sherman et al. 2002) program, which includes four to six surveys a year since 1977, presently at about 30 stations sited randomly across the Gulf of Maine. NMFS also supports a Continuous Plankton Recorder transect that measures relative abundance of zooplankton at the surface in the deep, central Gulf of Maine at monthly intervals (e.g. Pershing et al. 2005).

In 2002, the Coastal Ocean Observing Center (COOA: Center of Excellence in Coastal Ocean Observation and Analysis) was established at the University of New Hampshire (http://www.cooa.unh.edu). The Coastal Observing Center conducts sampling at monthly intervals along two transects, one extending from Portsmouth Harbor to Wilkinson Basin and the other from Portsmouth along the coast to the Kennebec Estuary. The measurements include hydrography, optical properties of seawater, chlorophyll and microplankton composition and zooplankton abundance. The Coastal Observing Center is also involved in the development of analytical tools for the interpretation and synthesis of the observing data. The Center draws on results of an international program (GLOBEC: Global Ocean Ecosystems Dynamics) dedicated to the development of quantitative models for analysis of how change in ocean physics (winds, currents, temperature) and pelagic ecosystem dynamics influence the marine ecosystems and processes contributing to fish recruitment; see for example, the journal Oceanography (2002; Volume 15, No. 2).

These and perhaps other sampling programs in the Gulf of Maine form a foundation for development of a regional observing system that would be part of the national Integrated Ocean Observing System (IOOS). When fully funded, the regional observing system will be overseen by a Regional Association with headquarters presently at the University of Southern Maine.

PULSE: A contribution to the regional observing system by the local fishing communities
We have named our Northeast Consortium cooperative project *PULSE*, to connote the ability to track the health of the Gulf of Maine ecosystem by tracking plankton populations. Similar to the AZMP program, this tracking is done at fixed stations at a relatively high frequency (weekly to semi monthly intervals). This sampling frequency is not achieved by other sampling programs. especially for zooplankton. PULSE therefore has provided a necessary complement to the existing Gulf of Maine monitoring activities. It has provided much-needed observations of seasonal and interannual production cycles of phytoplankton and zooplankton. These data are extremely useful to coupled physical-biological model development, as they would document the timing of biological events in two separate years and could be used to test model predictions. A longer time series is even more valuable, as it would provide insight not only into the extent of interannual variability and trends in plankton biomass and species abundance and ecosystem structure but also in the timing of biological events in the inshore pelagic ecosystem.These observations meet the need for coastal fixed station observations (e.g. RARGOM, 2005), which the once-monthly Coastal Observing Center or seasonal collection in the NOAA ECOMON and CPR surveys cannot provide. The measurements of seasonal cycles in the Gulf of Maine plankton will be useful for the interpretation of the NOAA plankton survey data,

Project objectives
The overarching objectives were to (A) provide a framework for a cooperative partnership between the fishing and scientific research communities for collection of time series data showing seasonal, interannual and longer-term variation in plankton and hydrography and (B) demonstrate its feasibility in a pilot two-year time series at two stations in coastal waters off Portsmouth, New Hampshire. Specific objectives were established as follows:

1. Establish a Steering Committee (the Monitoring Panel) to guide the design, implementation, and analysis of industry participation in a pilot program. Goals will include: a) identification of monitoring activities and habitats of interest to all stakeholders, b) examination of cost effectiveness of industry leadership in monitoring efforts, c) leadership and industry infrastructure and partnership considerations.

2. Create a process to encourage broad industry participation, and to select

fishermen and fishing vessels for participation in the collection of time series samples.

3. Establish a laboratory at the University of New Hampshire for the analysis of oceanographic field samples for ecosystem monitoring, using standard biological oceanographic procedures. Obtain necessary field and laboratory equipment for data and sample analysis.

4. Establish procedures for data collection, quality control, database management, and analysis of results.

5. Coordinate with ongoing research and monitoring efforts by local, state, regional, and national programs and agencies

6. Organize training workshops and seminars for commercial fishermen in oceanographic and ecosystem processes.

7. Implement a two-year project to collect and analyze samples at the two fixed stations (because the frequency of sampling was somewhat less than originally planned, the time series was extended for 10 months of a third year)

Project participants

Project Principal Investigators: Jeffrey Runge (UNH) and Rebecca J. Jones (UNH)

Project assistance: Rebecca Love (UNH: 2002).

***Monitoring Advisory Panel*:** R. Barnaby (UNH), C. Goudey (MIT Sea Grant), S. Meeker (UNH Sea Grant Extension), L. Mercer (Maine DMR), D. Mountain (NMFS, Woods Hole), C. Pendleton (NAMA), D. Townsend (U Maine)

Industry participants: Members of the Yankee Fisherman's Coop and Portsmouth Fisherman's Coop.:

F/V Lady Regena
Owner: George Littlefield
H= 603-772-8326
Cell= 603-216-7401

F/V Chutzpah and F/V Karen Lynn II
Owner: Jeremy and Karen Davis
207-439-2460
Cell= 207-475-6084

F/V Lynn Allison (sold)
Owner: Lee Stevens
H= 603-926-7177

F/V Marion Mae
Owner: Craig Mavrikis
H= 207-439-5604
Boat= 207-361-8053

F/V Kelly Rose & F/V Elizabeth Ann
Owner: Peter Kendall
H= 603-964-7824
Cell= 207-475-5447

F/V Rhiannon Rae
Owner: Bud Fernandez
Cell= 498-2951

F/V Julie Ann II
Owner: Dennis Robillard
H= 207-439-4794
Cell= 207-252-3388

F/V Kris N Kev
Owner: Eric Anderson
H= 603-431-1779
Cell= 603-234-7038

F/V Special K
Owner: Alan Vangile
H= 603-436-5031
Cell= 603-205-5140

Data

The data include files and figures showing measurements of temperature, salinity, chlorophyll a (at 6 depths), nutrients (phosphate, nitrate, ammonium), zooplankton biomass, abundance and composition at each station (total of 93 stations at Buoy "B" and 87 stations at Jeffreys Ledge over 3 years).

The data from 2003-2004 are served on the PULSE website (www.pulse.unh.edu) which is linked to the Northeast Consortium Database. Methodology and protocols for collection and analysis of samples are provided on the website. Entry of all data into the database is in progress, under the supervision of R. Jones.

Presentation of the scientific results of the 3-year time series collection is in preparation for publication of a peer-reviewed research article. Consequently, only highlights of the results are presented in this report, pending acceptance of the research publication.

Results and conclusions

This section is organized by the specific project objectives presented above.

1. Interactions with a Steering Committee (the Monitoring Panel) to guide the design, implementation, and analysis of industry participation in a pilot program.

- Three annual meetings of the Monitoring Panel established station locations, refined protocols and provided feedback, insights and perspectives during the development of the partnership. The Panel contributed to the selection of the two fixed stations, GoMoos Buoy "B" and New Scantum on southern Jeffreys Ledge. These two stations represented a compromise between what is feasibly possible in terms of boat speeds available in the industry and the requirements of the sampling protocols. Specific protocols and techniques were discussed and subsequently modified to ensure the quality of the data being collected.
- Additions of higher technology sampling gear were considered, including the FlowCam, Laser Optical Plankton Counter and acoustics. In the end it was decided to stay with the simpler, lower cost technologies.
- An examination of the cost-effectiveness of industry leadership in the monitoring efforts was undertaken. In future partnerships, we propose that the industry take responsibility for collection of samples, without on board assistance from UNH in the laboratory.

2. Create a process to encourage broad industry participation, and to select fishermen and fishing vessels for participation in the collection of time series samples.

- To contribute to the monitoring program, boats had to meet specific criteria. These criteria were made as broad as possible to allow participation of a diversity of fishing vessel while ensuring that the goals of the program would be met. The criteria included minimum vessel cruising speed, deck space, davit for the block for the winch wire and offshore safety equipment. Eight vessels from Portsmouth COOP and one from the Seabrook COOP participated over the three year study. These vessels include lobster, gillnet and trawling vessels. At all times the industry partners have been consulted for improvements and many changes have been made based on their suggestions for efficiency. This program has proven to be very beneficial to participating fishermen during periods of management area closures because it provides a source of dependable income. For socio-economic reasons it has been decided that a specific boat will be the partner for a period of 2-4 weeks at a time, whichever is beneficial to both the program or the fisherman.

3. Establish a laboratory at the University of New Hampshire for the analysis of oceanographic field samples for ecosystem monitoring, using standard biological oceanographic procedures. Obtain necessary field and laboratory equipment for data and sample analysis. Provide training workshops to provide general and hands-on experience for commercial fishermen in the laboratory protocols

- A laboratory at UNH was made functional in all aspects of sample analysis required for this program.

4. Establish procedures for data collection, quality control, database management, and analysis of results.

- On several occasions in 2002 prior to the initiation of the time series in January, 2003, samples were collected and analyzed from a transect of stations off Portsmouth Harbor. The data from these samples provided background information that aided in the development of sampling procedures and fixed station locations. Valuable lessons were learned regarding handling of equipment, for example alterations to the winch to make it more suitable for specific project's needs including refinements to the winch speed control and getting it to start on the coldest of days in the winter. In this first year of the project, we learned how to outfit certain boats for the deck operations and the specific criteria needed to make the program work, such as a minimum ship cruising speed of 8 knots, a running wash down hose and overhead structure for hanging the winch wire block. We also learned that certain boat speeds are more suitable for the winter months when the weather windows are more narrow and marginal. Faster boats were slated for those months and slower boats were used during the summer months.

- Quality control was of utmost importance. Sample collection and analyses were periodically checked in order to ensure accuracy of the data and integrity of the time series. For example, Chlorophyll-a samples have undergone quality control of collection and analysis methods. Replicate chl-a samples were taken to make sure the procedures are still functioning appropriately. Duplicate zooplankton samples were taken as a safety precaution. If something happened to one sample, such as snagging of the winch wire in the block during rough sea, the duplicate served as a backup. R. Campbell, a zooplankton ecologist at the University of Rhode Island who is knowledgeable in zooplankton taxonomy, was consulted and served as a quality control checks of random zooplankton samples by confirming species and stage identifications.

- Descriptions of the protocols are provided on the PULSE website (www.pulse.unh.edu). A detailed description of methodology will be provided as part of the research article reporting project results for publication in a scientific journal.

5. Coordinate with ongoing research and monitoring efforts by local, state, regional, and national programs.

- By focusing on weekly sampling at fixed stations, the Northeast Consortium program has complemented the existing Gulf of Maine monitoring activities, providing relatively high temporal frequency of observations of seasonal production cycles of phytoplankton and especially zooplankton, for which there is not another data source in the western Gulf of Maine. These data are extremely useful to coupled physical-biological model development, as they would document the timing of biological events that can be used to test model predictions and provide insight not only into the extent of interannual variability and trends in plankton biomass and structure but also in the timing of biological events in the pelagic ecosystem. The measurements of seasonal cycles in the Gulf of Maine plankton should prove useful for the interpretation of and the NMFS ECOMON and CPR plankton survey data.

- A website has been created that will allow stakeholders to access the data through a program designed by the Woods Hole Oceanographic Institute that is also used by NEC (http://www.pulse.unh.edu). Any information regarding the program and announcements will be posted there as well.

- J. Runge was in a position to represent the partnership and its contribution at several meetings of agencies and programs involved in Gulf of Maine monitoring efforts. He is the UNH representative and presently chairman of RARGOM, the Regional Association for Research on the Gulf of Maine. He is one of the RARGOM representatives on the Advisory Board for the Gulf of Maine Regional Association. He serves as chair of the Gulf of Maine Census of Marine Life Working Group on Plankton and Pelagic Nekton. He is currently on the Executive Committee of the U.S. GLOBEC Northwest Atlantic/Georges Bank program and was a member of a Gulf of Maine Zooplankton Working Group sponsored by GoMOOS.

- Dr. Runge participates as a Principal Investigator in the U.S. GLOBEC Northwest Atlantic/Georges Bank Program funded by NOAA and the National Science Foundation on projects related to the development of coupled biological-physical models of plankton dynamics for the Gulf of Maine/Georges Bank. This research requires long time series of data such as the dataset that will be collected by the Northeast Consortium. He is the editor of a RARGOM theme workshop report on the role of modeling and data needs for the Gulf of Maine Observing System (Runge and Braasch 2005). In this report, the need for establishment of fixed stations in the Gulf of Maine is identified.

6. Organization of training workshops and seminars for commercial fishermen.

- Training workshops were provided at sea during trips for sample collection. Data from the time series were regularly discussed with fishermen and they were invited to learn about the process of the data collection and subsequent laboratory analysis.

- Through the Coastal Observing Center at the University of New Hampshire in collaboration with the Northwest Atlantic Marine Alliance (NAMA), J. Runge and H. Deese organized information exchange sessions with local area fishermen. The goal was to facilitate knowledge exchange between the scientific research and fishing communities in order to (1) develop new conceptual understanding of the application of coastal observation and analysis tools in fisheries management and (2) work toward mutual understanding in the two communities of ecosystem concepts that should be part of ecosystem-based approaches. The NAMA-UNH Coastal Ocean Observing Center partnership succeeded in bringing together small groups of local fishermen and scientists in focused exchanges. In addition to the three meetings that were planned in the original proposal, the project participants also organized a special session at the Maine Fishermen's Forum, an event that attracted approximately seventy participants from fishing-related businesses and occupations, government agencies, universities and public and non-profit organizations. This provided exposure of the project's themes to a broad spectrum of the region's fisheries community

7. The scientific results: Implementation of a two-year project to collect and analyze samples at the two fixed stations

Difficult winter weather prevented sampling at the fixed stations on the four times a month schedule that was originally planned for the project. The actual sampling frequency was approximately three times a month on average.

Year	Total Number Sample Days
2003	38
2004	44
2005 (to November only)	36

Because of the fewer number of days sampled per year, we were able to sample for an additional 10 months into 2005. Hence the originally planned two year time series was extended into 2005 through an additional spring, summer and fall season.

The sample collections were carried out at two fixed stations off the coast of Portsmouth, New Hampshire: GoMOOS Buoy “B” and New Scantum on Jeffreys Ledge (Fig. 1).

Examples and highlights of the results of the three year study are shown in Figures 2-8. CTD profiles of temperature, salinity and density show characteristic deep mixing in winter and stratification in spring at the two stations (e.g. Fig. 2-3). Contours of temperature and salinity over the 3 year study show timing of stratification and subsequent warming of surface waters in May-June, with both spring warming and fall cooling occurring substantially earlier in 2003 than in 2005. The distribution of chlorophyll a with depth shows low, relatively uniformly mixed values in winter and high surface or subsurface values representing the spring phytoplankton bloom after stratification (Fig. 4b). The time series plot of chlorophyll a standing stock integrated over the upper 50 m of the water column shows the variable timing of stratification and the spring bloom. The horizontal line in figure 4b represents the chlorophyll levels at which growth and reproduction of the dominant planktonic copepod, *Calanus finmarchicus* has been empirically determined to be maximal.

The time series of zooplankton biomass (Fig. 6) over the three year period is the first record of seasonal and interannual variation in zooplankton biomass for the Gulf of Maine. It shows maximal biomass levels during summer on Jeffreys Ledge and bimodal maxima of biomass in spring and summer at the nearshore station (Buoy "B"). A mid-year minimum in zooplankton biomass occurs in June in all three years at this station. In 2004 and 2005, there is a marked crash in biomass starting in late August and continuing to early November on Jeffreys Ledge. Analyses (not shown here) indicate that the abundance of late stage *C. finmarchicus* is the primary determinant of the zooplankton biomass on Jeffreys Ledge, but not necessarily at the inshore station where other copepods are also important contributors to the total biomass (e.g. Fig. 7). This conclusion is corroborated by the time series of *C. finmarchicus* abundance, which indicate remarkably low abundance on Jeffreys Ledge in September of 2004 and 2005 and at the Buoy B station after mid August in 2005 (Fig. 8). The abundance of *C. finmarchicus* is notably low during the entire year in 2005, relative to the preceding two years.

Calanus finmarchicus is a primary prey for adult herring and northern Right Whales in the western Gulf of Maine. We hypothesize that aggregations of adult herring that occur in late summer at the base of Jeffreys Ledge and just south of Jeffreys Basin represent the response of herring to large concentrations of lipid-rich, late stage *Calanus* that concentrate at the head of Jeffreys Basin and overflow onto the ledges. We are presently investigating whether the low, late summer *C. finmarchicus* abundances at the Jeffreys Ledge station are the consequence of high predation by herring on the species in this region or represent much lower production of the species recently in the western Gulf of Maine. The lower production of *Calanus* may be related to warmer temperatures in deep waters of the Gulf of Maine in fall, which is hypothesized to disrupt the diapause component of the life cycle of this species. We anticipate that new coupled *Calanus*-circulation modeling will provide insight into the underlying controls on population dynamics of *Calanus* and distribution of feeding aggregations of herring in this region.

Figure 1: Location of fixed stations sampled approximately 3 times per month between Jan. 2003 and Nov. 2005.

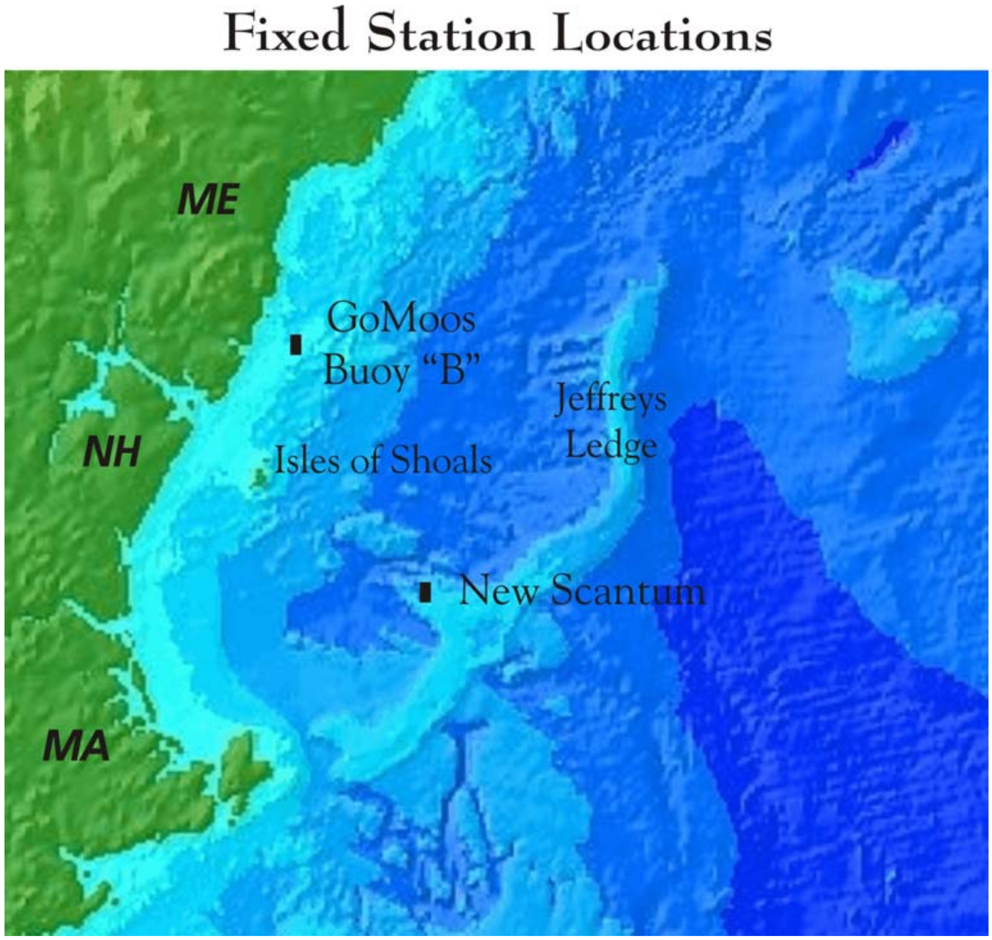


Figure 2. Examples of hydrography (temperature, salinity and density as a function of station depth) profiles for selected dates in 2003 at Station B.

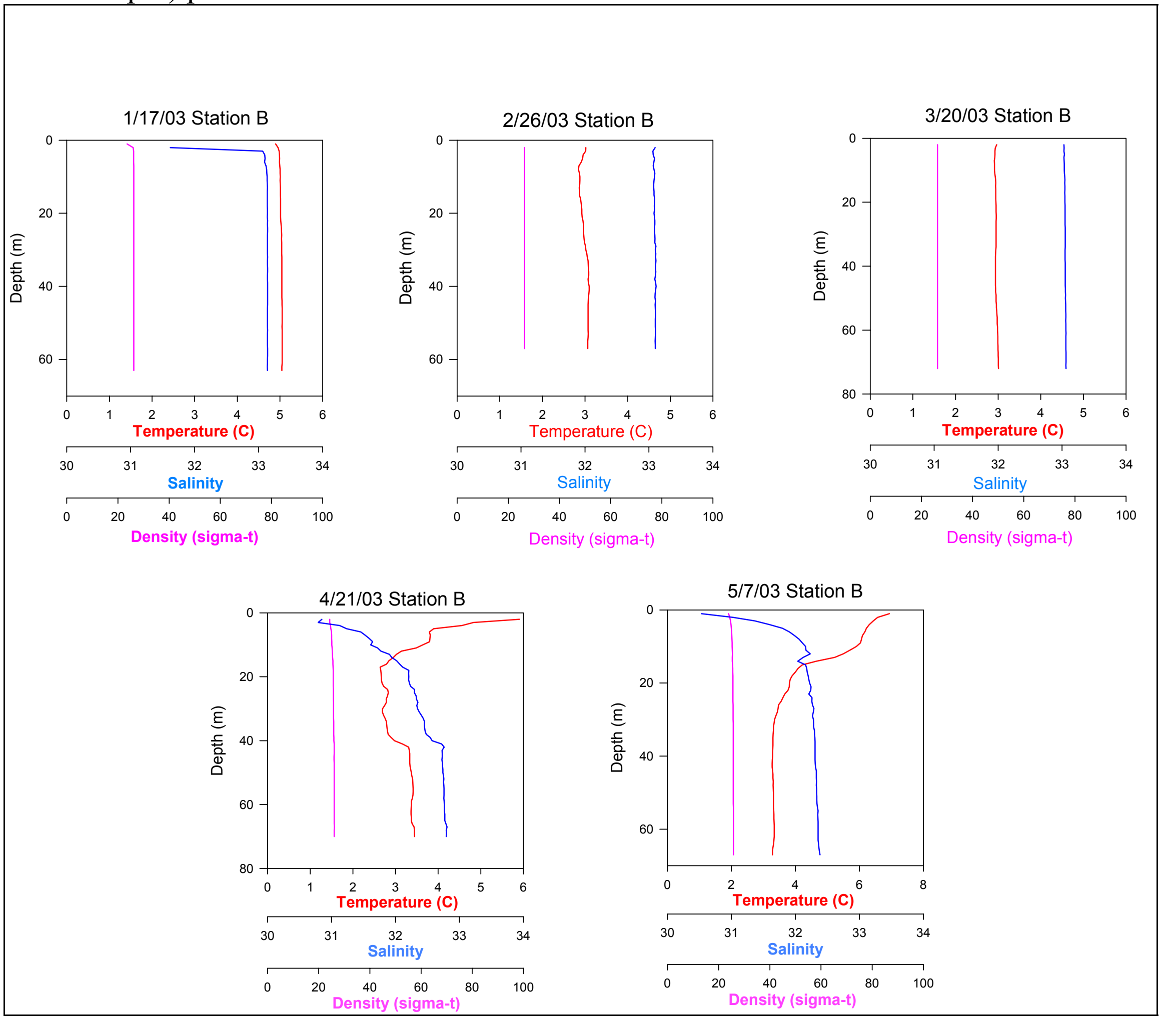


Figure 3: Examples of hydrography (temperature, salinity and density as a function of station depth) profiles for selected dates in 2003 at Station S on Jeffreys Ledge.

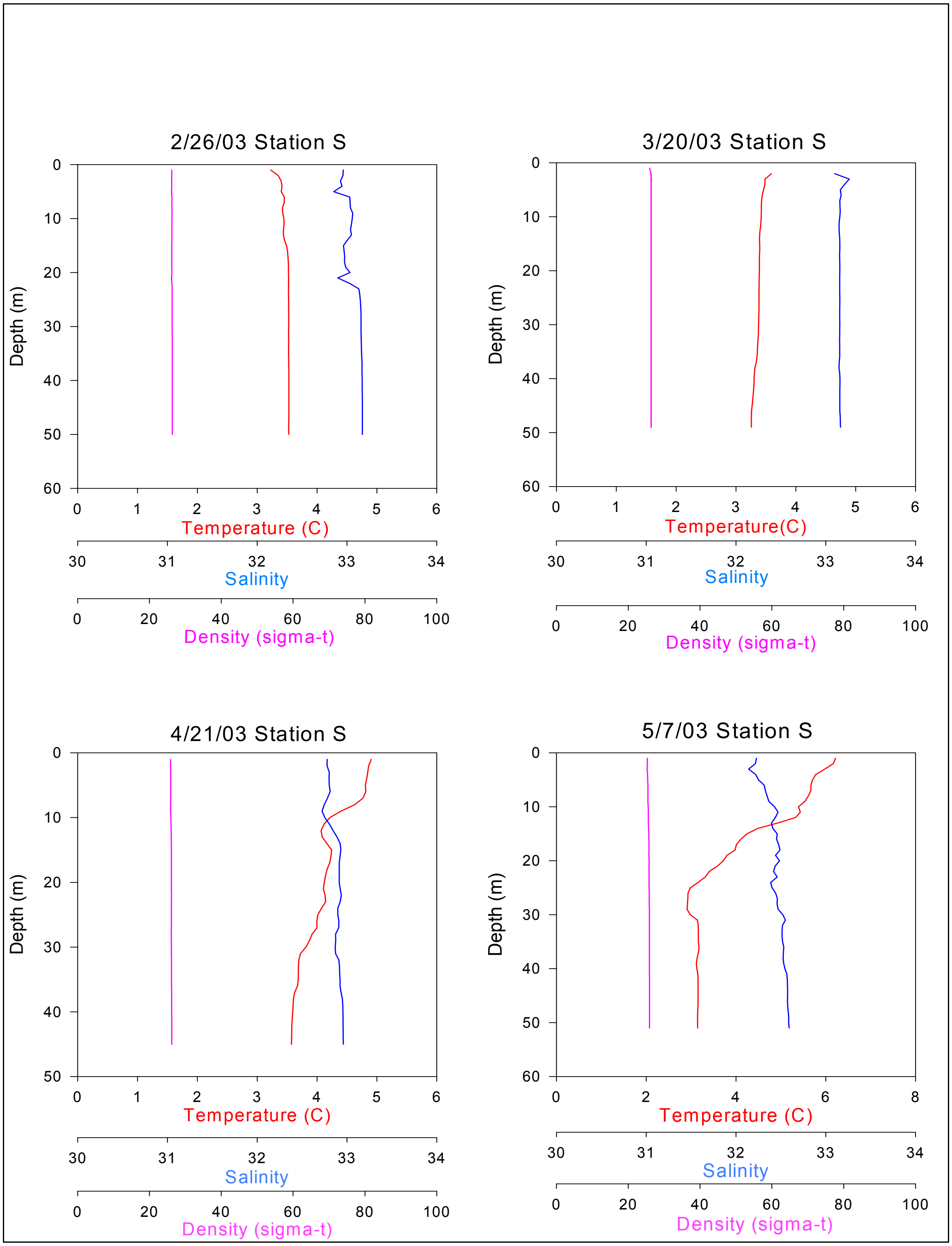
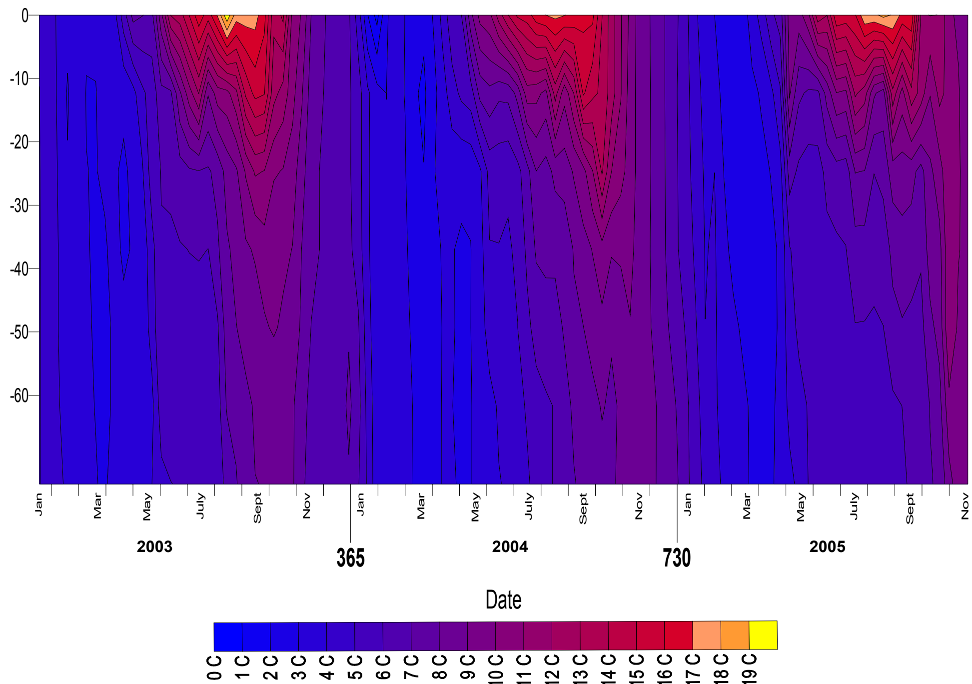
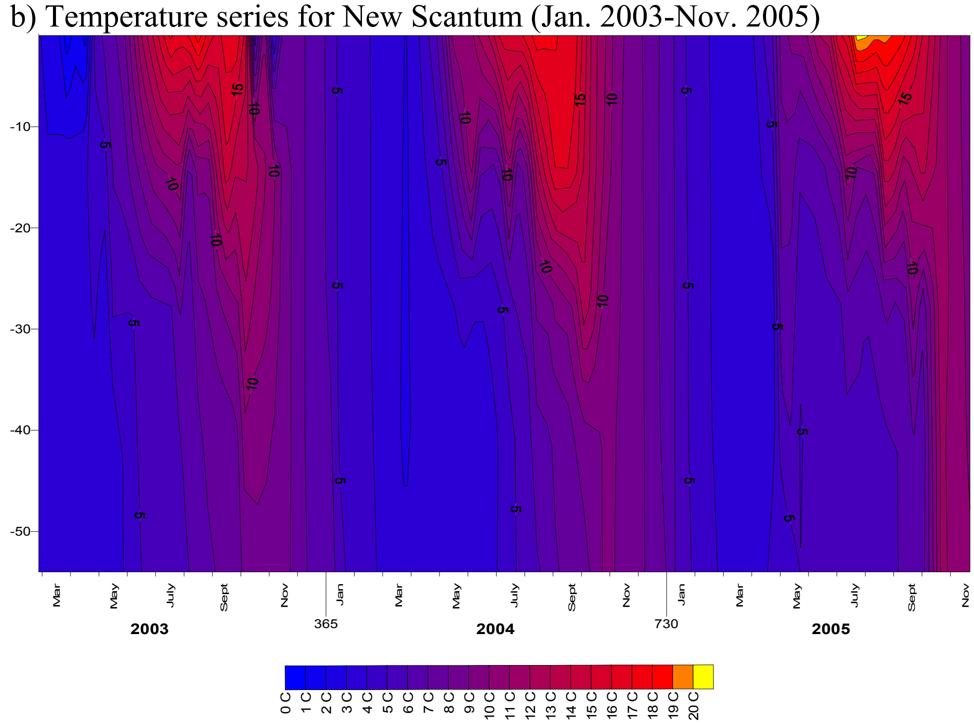


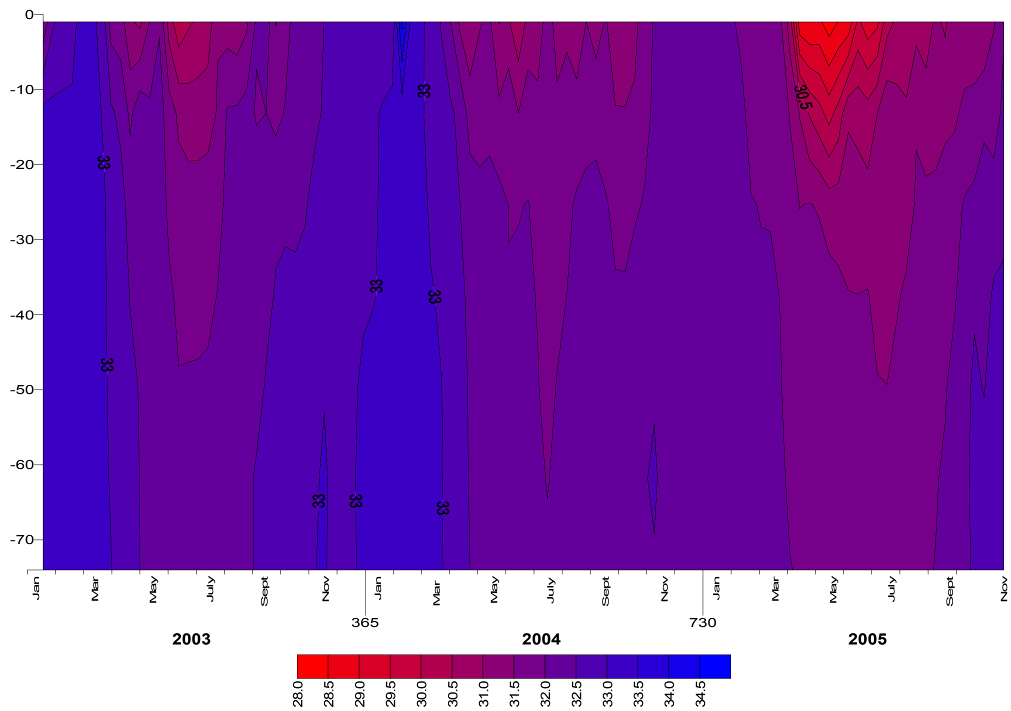
Figure 4. Seasonal change in 1m temperature (°C) and salinity on GoMOOS Buoy "B" (a,c) and Jeffreys Ledge (b, d) during the three year sampling period (note different start date for the two series).

a) Temperature series for GoMOOS Buoy "B" (Jan. 2003-Nov. 2005)

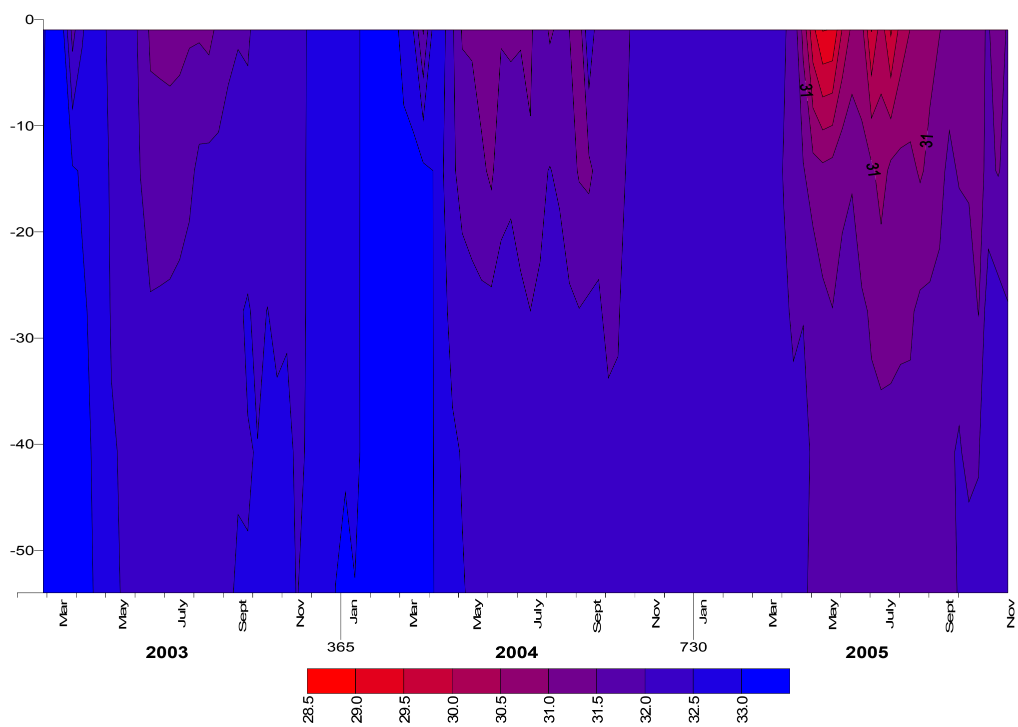


b) Temperature series for New Scantum (Jan. 2003-Nov. 2005)





c) Salinity (psu) at GoMOOS Buoy "B" (2003-2005)



d) Salinity (psu) at New Scantum (2003-2005)

Figure 5a. Examples of Chlorophyll-a concentrations as a function of for separate selected dates in 2003 at the two fixed stations. Note the scale change for chl-a during April and May.

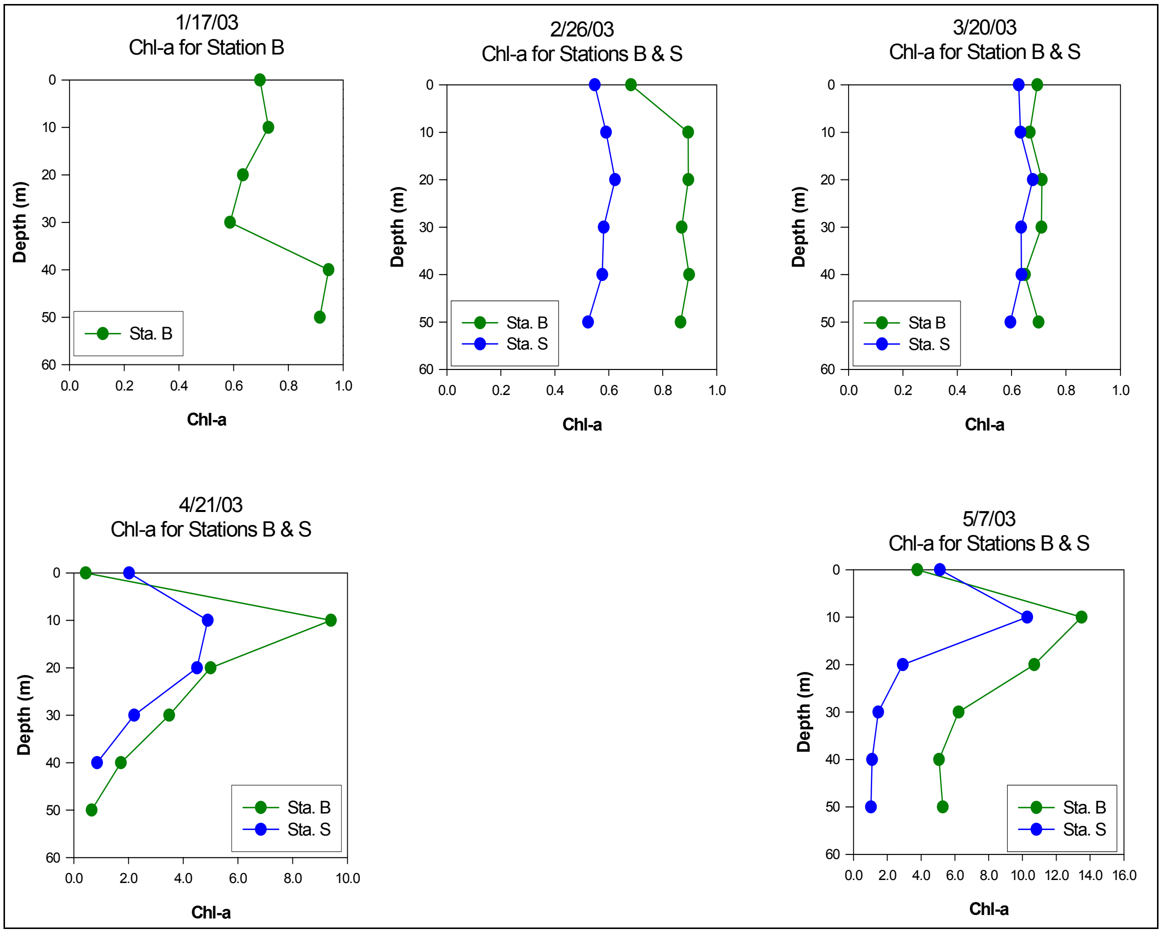


Fig. 5b. Time series of chlorophyll a standing stock at the two fixed stations, 2003-2005.

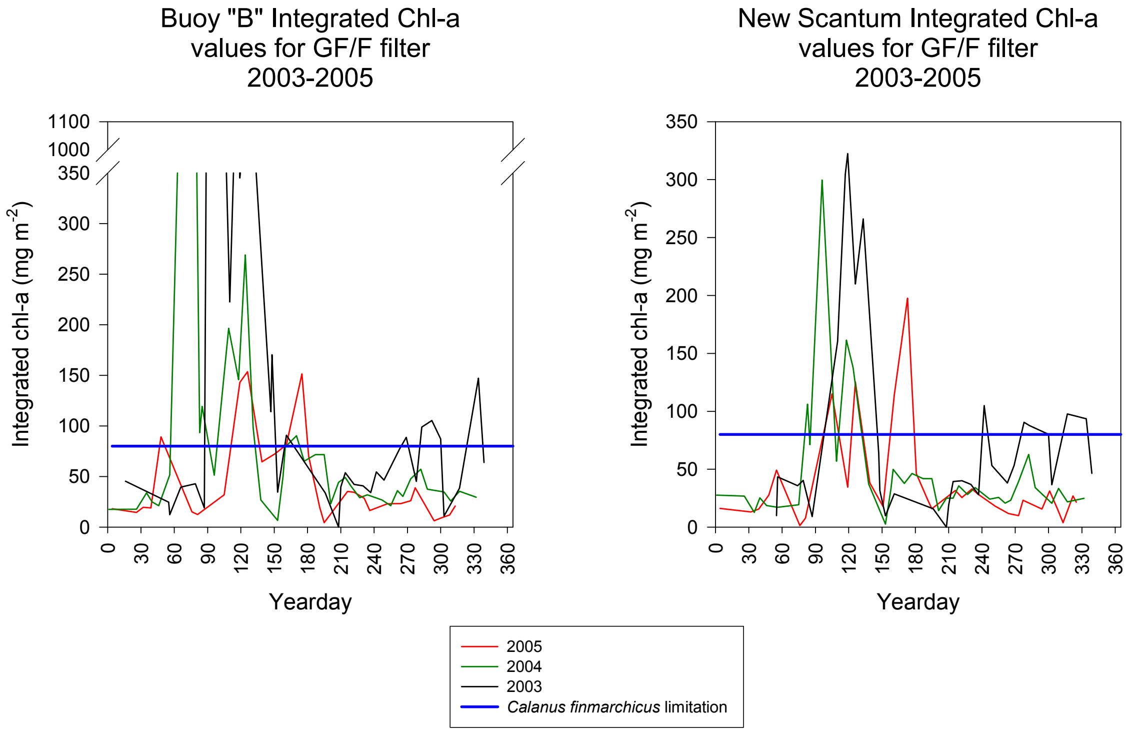


Figure 6. Results of 3-yr time series of zooplankton dry weight biomass at the two fixed stations.

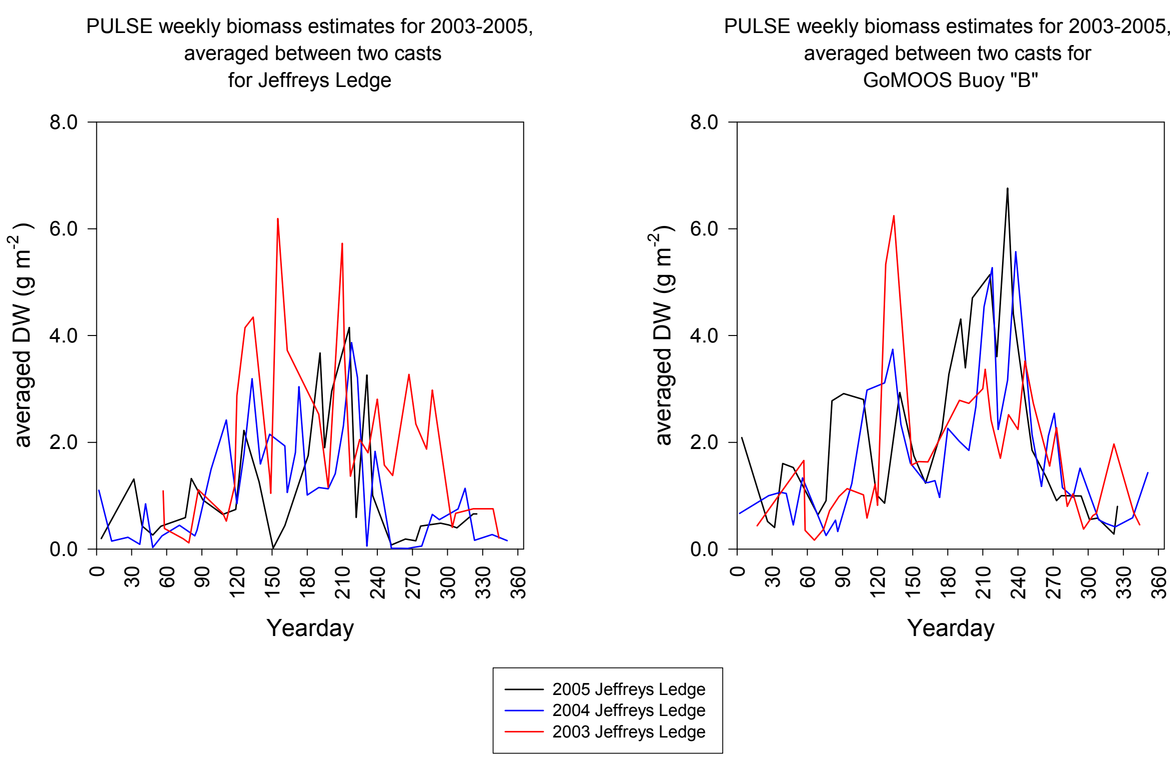


Figure 7. Zooplankton species abundance and composition at the two fixed stations in 2003.

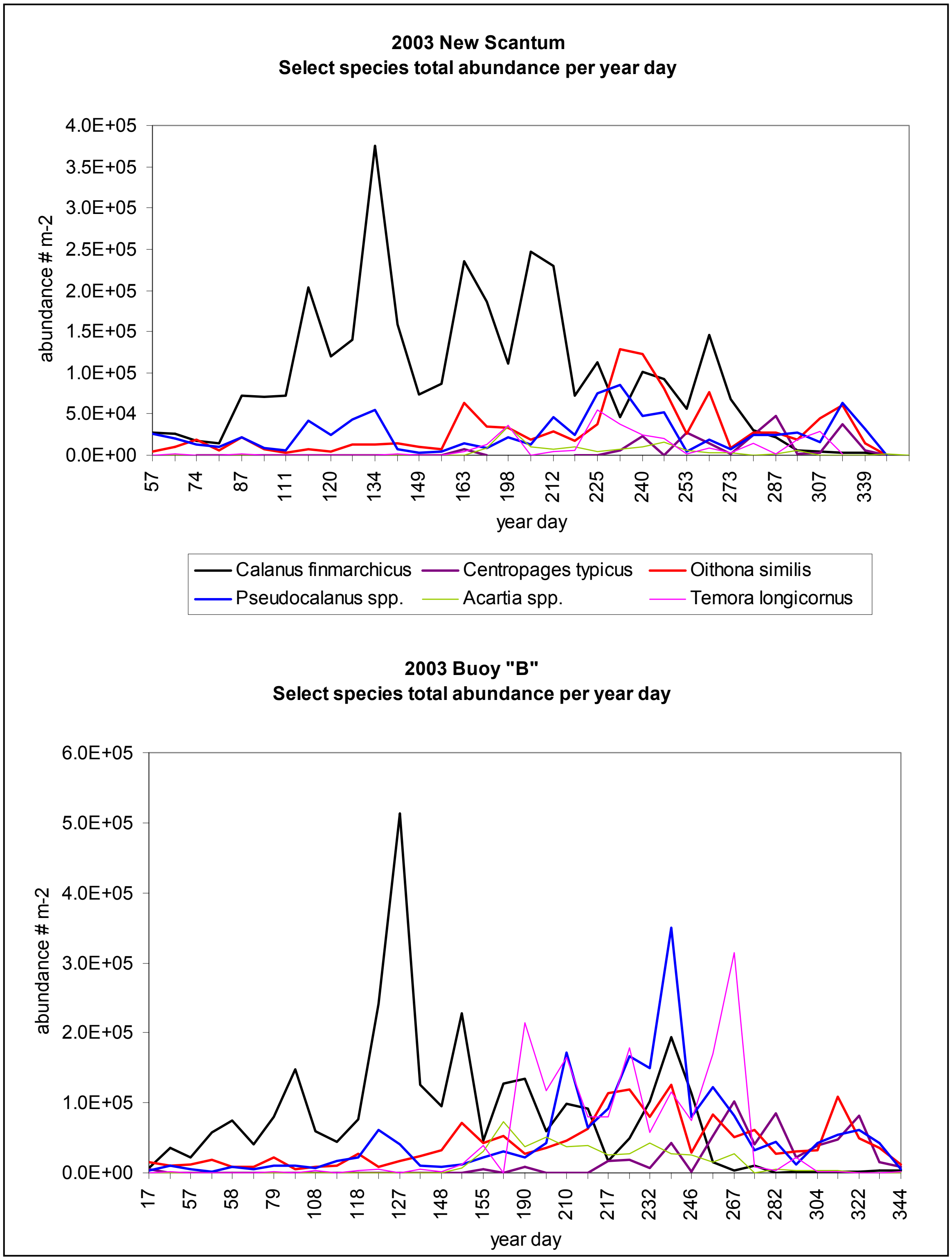
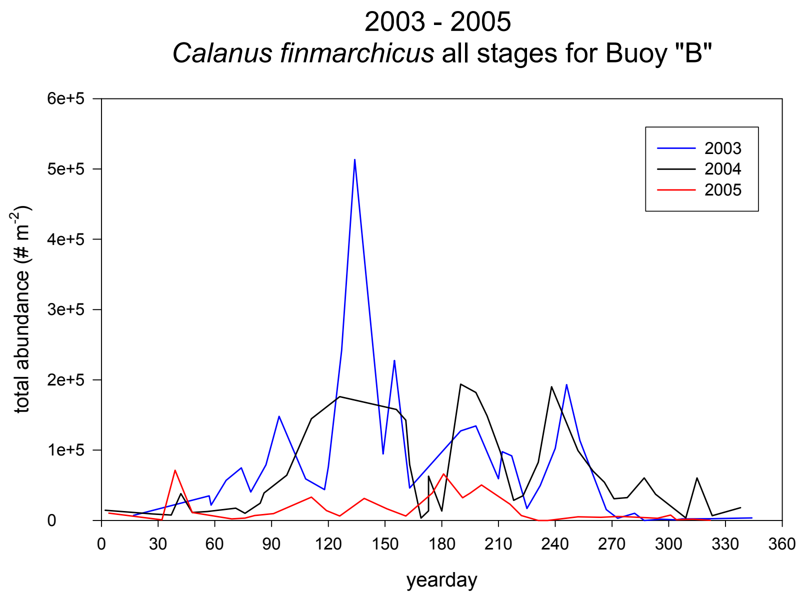
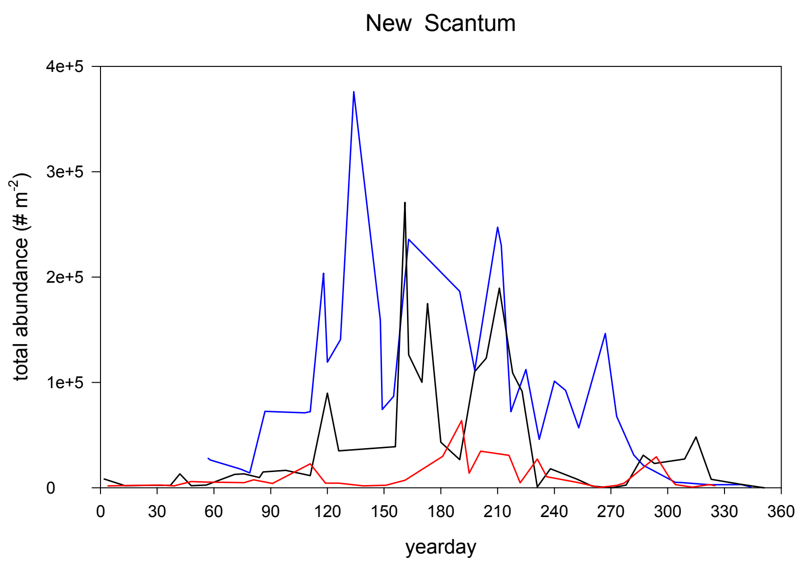


Figure 8. Time series abundance of Calanus finmarchicus at the two fixed stations for the three study years.





Partnerships
This is a successful project that received enthusiastic and responsible participation from the fishing industry. All fishermen involved have been very helpful and receptive to the idea of this cooperative monitoring project being available for the long-term. The project has been well supported by the industry as a means of supplemental income during the seasons of large area closures and has been well supported during the fishing season as well. Many improvements have been made to make the data collection procedures efficient, data analysis of good consistent quality and data widely available

Impacts and applications
The scientific results and demonstrated success of this approach for acquiring high frequency time series data on zooplankton populations will strongly support inclusion of fixed stations in the regional plan for an observing system in the Gulf of Maine.

Related projects

- This project was leveraged by grants from the NOAA Coastal Services Center (to the UNH Coastal Observing Center). The Coastal Observing Center funding contributed significantly to salary of Rebecca Jones in 2004 and 2005. It contributed salary to J. Runge during this time period to cover costs for supervision and analyses associated with the project. The Coastal Observing Center also purchased a FlowCam and Laser Optical Particle Counter, two instruments used in the observing program that were also evaluated for use in PULSE, but considered not feasible for routine implementation at this time. The Coastal Observing Center is now funding a continuation of the high frequency time series (although at different stations and not in partnership with the industry, for reasons provided in the future steps section below).
- This project was leveraged by an outreach grant from the University of New Hampshire Vice President's Office to hold information exchange meetings with local fishermen in collaboration with the Northwest Atlantic Marine Alliance (NAMA) in 2004-2005.
- Time series results were used to leverage funding of three research grants (two awarded and one pending) from the National Science Foundation:
    - C. Davis, R. Beardsley, R. Ji, E. Durbin, J. Runge, C. Flagg and J. Lerczak. *Processes controlling abundance of dominant copepod species on Georges Bank: Local dynamics and large-scale forcing*. Awarded 2005
    - J. Runge and A. Leising. *Effects of climate variability on Calanus dormancy patterns and population dynamics in the Northwest Atlantic.* Awarded 2005.
    - A. Pershing, F. Chai, J. Pringle and J. Runge. *Understanding interannual ecosystem variability in the Gulf of Maine: A combined modeling and field study.* Award Pending.

Presentations

- The project was presented as a poster at the 2002-2004 Annual Meetings of the Northeast Consortium.

The project was presented at the Maine Fisherman's Forum (2003-2006) as follows: as a poster in 2003 Meeting of the Maine Fisherman's Forum, in 2005 as an oral presentation given by J. Runge at the NAMA Ecosystem based management session and in 2006 at the GoMOOS session as part of an oral presentation about the role of the observing system in predicting environment and ecosystem influences on fisheries in the Gulf of Maine.

Student participants
Meghan Deeney, undergraduate student at UNH, participated in the summer and fall, 2004.

Published reports and paper

- A summary of the time series results, including hydrography, chlorophyll a concentrations and zooplankton biomass, abundance and composition is found on the PULSE website (www. pulse.unh.edu).
- A research article that describes the methodology and presents and interprets the three-year time series of PULSE data is in preparation for submission to a peer-reviewed journal
- A report of the results of the information exchange meetings conducted in collaboration with NAMA (Runge and Deese 2005)
- A workshop report in which the need for fixed stations as part of a regional observing strategy has been published (Runge and Braasch 2005) and is available as a pdf document on the RARGOM website (www.rargom.org).

Images
Images are provided on the pulse website and a greater set of images will be made available to the Northeast Consortium by R. Jones.

Future research/ future steps
This project has demonstrated the feasibility of a cooperative partnership between the fishing and scientific research communities that contributes to monitoring of the pelagic ecosystem in the Gulf of Maine. The partnership has involved participation of a number of fishing boats that rotate in the collection of samples approximately 3 times a month. The participating fishermen have assisted Rebecca Jones with the sampling at sea, and she has either conducted or supervised analysis of the samples in the laboratory at the University of New Hampshire.

A planning letter to the Northeast Consortium to continue this partnership beyond the initial two-year period was declined in 2004. There was perceived reluctance by the Northeast Consortium advisory committee to commit the program to a long term observing project, and concern that the industry partners weren't participating in the scientific analysis of the samples.

To continue a sampling program at coastal fixed stations off New Hampshire, J. Runge made arrangements to merge the sampling protocol with the Coastal Observing Center (COAA) sampling program. The COOA program samples on a monthly basis at stations along a line extending from the mouth of Portsmouth Harbor to Wilkinson Basin. A second monthly collection, at a reduced effort that focuses on sampling using the AZMP protocols, was added in order to obtain a higher frequency needed to more adequately describe the temporal changes in zooplankton abundance and composition. The sampling is carried out on the R/V Gulf Challenger by COOA technical staff, including R. Jones. The speed of the Gulf Challenger makes possible sampling at a station in Wilkinson Basin, representing the central Gulf of Maine, which was not possible on daily trips with fishing vessels. However, in order to take advantage of the COOA program, the PULSE stations had to be replaced with the COOA stations, located to the south of Buoy "B" and north of the Scantum station on Jeffreys Ledge. Sampling at Buoy "B" is nevertheless maintained on a monthly basis as part of the other COOA coastal transect. The merger took place in the fall of 2005.

While the new arrangement continues an important time series, it has several drawbacks. There is no longer any sampling at the Scantum station on Jeffreys Ledge. It is not certain that the new sampling design will capture the dramatic decline in biomass and abundance of late stage *C. finmarchicus* that occurred on Jeffreys Ledge in late summer, 2004 and in 2005. Documentation of this event may prove valuable in the explanation of patterns of herring and tuna distribution on Jeffreys Ledge. A second drawback is that the scheduling for the R/V Gulf Challenger does not have the flexibility that was enjoyed in the cooperative partnership. The flexibility of fishermen to reschedule cancelled trips to the fixed station due to weather ensured the viability of a high frequency (i.e. three times a month) time series. Maintaining a high frequency with the Gulf Challenger alone is problematic.

It is therefore recommended that new arrangements be explored for renewal of the cooperative partnership with Northeast Consortium assistance. A new partnership might include sampling at the Jeffreys Ledge station and at the second monthly COOA stations to ensure a high frequency of sampling. Sampling should also include bongo tows for ichthyoplankton. A greater participation of industry, for example in the supervision, collection and quality control of samples at the fixed stations,as well as in sample analysis, should also be explored. Finally, there is a need for at least two other time series sites in the Gulf of Maine, with the most likely candidates being a station in Massachusetts Bay near Buoy "A" and a station in the eastern Gulf of Maine off Penobscot Bay.

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