Northeast Fisheries Science Center
Fisheries Climate Research Program

A Research Program to Investigate Climatic Effects on Biological Productivity and Sustainable Fisheries in the Northeast U.S. Continental Shelf Large Marine Ecosystem

Northeast Fisheries Science Center (NEFSC)

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1 Forward

Acknowledging growing concerns about the effects of long-term climate change on our living marine resources and the need to provide pertinent advice to managers, in 2007 the Northeast Fisheries Science Center began drafting a 5-year fisheries research plan with a focus on climate change. The current document provides a description of the priority research activities and implementation plans to address climate-change effects on fisheries in the Northeast.

NOAA has several climate-related goals, including understanding and predicting how climate is changing; predicting the impacts these changes are having and will have on ocean and coastal resources and communities; assisting NOAA and non-NOAA collaborators to assess risks and implement mitigation and/or adaptation strategies; and monitoring and assessing impacts of climate change and our responses over time[1]. The NEFSC proposes to address these NOAA-wide goals with a focus on fisheries in the Northeast U.S. Continental Shelf Large Marine Ecosystem.

Notably, the research envisioned addresses both regionally specific concerns and underlying fundamental ecosystems processes. Therefore, although our focus is on climate change, the proposed research supports a comprehensive integrated ecosystems approach, the results of which will find application for numerous spatial management issues including Marine Protected Areas, Essential Fish Habitat, meeting growing energy needs, and aquaculture. Accordingly, this research plan directly supports the NOAA Fisheries mission to "Protect, Restore, and Manage the Use of Coastal and Ocean Resources through an Ecosystem Approach to Management" as well as Programs within the NOAA Ecosystem Goal and the Climate Goal.

2 Global and Regional Considerations

Recent global increases in atmospheric CO_2 concentrations and Earth's surface temperatures have been documented during the industrial age and are predicted to increase over the next decades. Projections from the International Panel on Climate Change (IPCC) indicate a potential doubling of atmospheric CO_2 by the end of the century with a concomitant increase in global temperatures of 2-3 ^{o}C. This increase in temperature will cause warming oceans, melting of the polar ice caps, rises in sea level, increased incidence of coastal storms, and increased precipitation. These effects will in turn force a broad range of physical and chemical changes throughout the world's oceans including changes in sea surface temperature, sea surface salinity, water column stratification, ocean heat content, and oceanic circulation and currents. In addition, the increases in atmospheric CO_2 will alter the carbon inventories in the ocean and result in increased ocean acidification.

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[1] As identified during the *NOAA Climate and Living Marine Resources Workshop Pacific Marine Environmental Laboratory, Seattle, Washington May 14-15, 2008.*

Changing physical and chemical conditions in the oceans will have strong effects on ocean productivity and success of living marine resources. These effects will differ from region to region, yet include changes in the timing and magnitude of productivity of plankton and higher trophic levels, shifts in distribution of species, and large-scale changes in species recruitment. Cumulatively, these will alter the population dynamics of living marine resources, as well as the structure of ecosystems that support these resources. There is growing justifiable concern that the seafood industry and communities supported by this industry will be dramatically affected by climate change (see Figure 1).

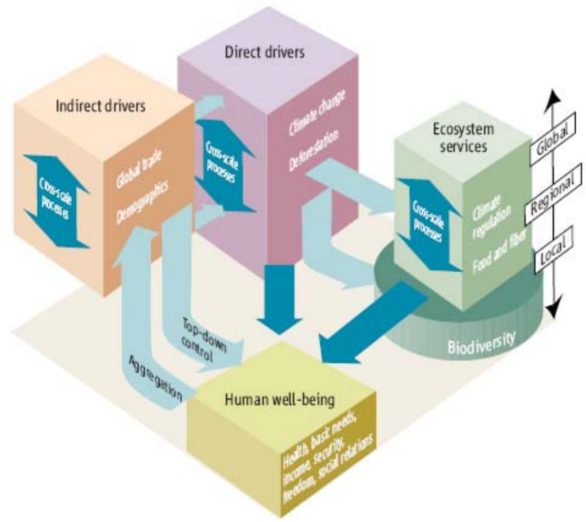


Figure 1. The Millennium Ecosystem Assessment conceptual framework, modified to illustrate connections among local, regional, and global scales for a few processes. Light blue arrows indicate actions that are amenable to policy interventions. Carpenter *et al.* 2006. Science 314: 257 – 258.

3 Challenges for the Northeast Fisheries

On the Northeast U.S. continental shelf, a number of exploited species are over-fished and a number of protected species remain endangered. Current management plans strive to rebuild fisheries to sustainable levels and to return protected species from the brink of extinction. Yet these management strategies assume that the ecosystems on which these species depend are at equilibrium – variable but with no long-term trends. Research shows that this assumption is not valid: ecosystems are not static and long-term changes related to warming and increased atmospheric CO_2 are happening now.

Predicting the effects of climate changes on habitats and marine species is critical for resource management in the Northeast, if a vibrant and resilient socioeconomy is to be maintained over the next decades. However, this is no easy task due to the multiple spatial and temporal scales of factors regulating marine habitats and ecosystems, as well as to the complexity of the processes affected by changing climate (Figure 2). Relevant spatiotemporal scales range from local hydrographic conditions typified by coastal fronts operating on scales of days and several kilometers to basin-scale phenomena operating on scales of several decades.

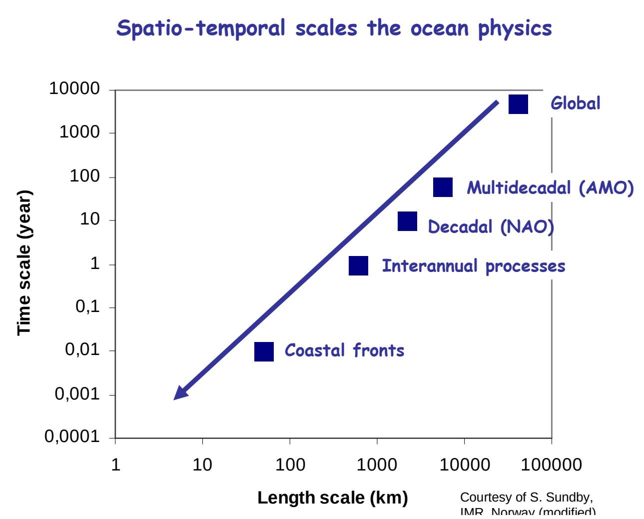


Figure 2. Spatiotemporal scales influencing species success. Courtesy of S. Sundby (IMR Norway).

To exemplify the complexity of the task, consider the following question. As global warming proceeds, will the mean temperature of the water above Georges Bank increase or decrease? This seems a simple question. Yet, whereas the current generation of General Circulation Models predicts an increase in sea surface temperature in this region, observations indicate that increasing temperatures in the Arctic are resulting in an influx of colder melt water. This dichotomy of projections for Georges Bank temperatures will be associated with equally contrasting responses in primary and secondary productivity, pelagic recycling and benthic-pelagic coupling. Thus minimizing uncertainty in forecasts of climate-change effects on marine habitats and biota is critical for providing reasonable advice to resource managers and spatial planners.

Evidence on the effects of climate on marine ecosystems is growing. For example, on the Scotian Shelf broad-scale meteorological changes are associated with changes in the timing of the spring bloom and the survival of haddock larvae. There is evidence from the Gulf of Maine for a link between climatic effects and plankton production. Further, zooplankton composition and biomass seem to play an important role in determining success of individual groundfish species in the Gulf of Maine. The processes causing these relationships remain unknown and this Climate Research Program aims to elucidate the causality behind the field data.

Changes in temperature will also have direct effects on the dynamics of living marine resources. The distribution of fish spawning in the Northeast is linked to ocean temperatures and changes in spawning locations may influence subsequent recruitment. Additionally, the mass mortality of surf clams in the late 1990s in the Mid-Atlantic was attributed to decadal scale rising temperatures (Figure 3). Warming will benefit more southern species, for example increased recruitment of Atlantic croaker is related to warming winters.

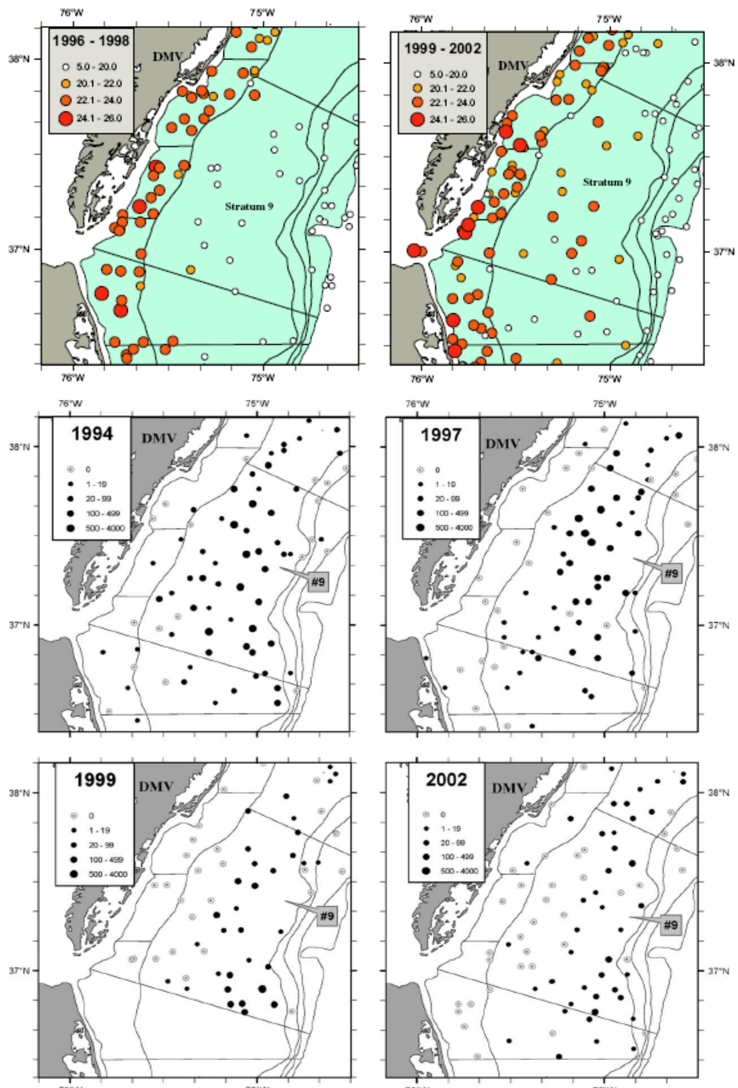


Figure 3. As bottom water on the Mid-Atlantic Shelf became warmer from 1996 to 2002 (upper panel), the abundance of surf clams decreased (lower panel, no. per tow). From Weinberg 2005. ICES Journal of Marine Science 2005 62(7):1444-1453.

Notably and most recently, a growing number of publications have described negative effects of acidification on calcifying marine invertebrates. This is of particular concern for the thriving scallop industry in the Northeast; higher carbonate concentrations could disrupt the life cycle of scallops. But, ocean acidification is of broader concern for all managed species, potentially affecting basic physiological processes. Although the effects are potentially large, very little is known and filling this information gap is a priority research topic of this Plan.

North Atlantic and Atlantic Multidecadal Oscillations

Although it is clear that climate changes will affect species, habitats, and the overall productivity of the ecosystem, differentiating between anthropogenic and natural changes is a significant challenge to marine scientists and of particular interest to ocean managers and legislators. In the North Atlantic, climate change will interact with at least two natural climate cycles: the North Atlantic Oscillation (NAO) and the Atlantic Multidecadal Oscillation (AMO) (Figure 4).

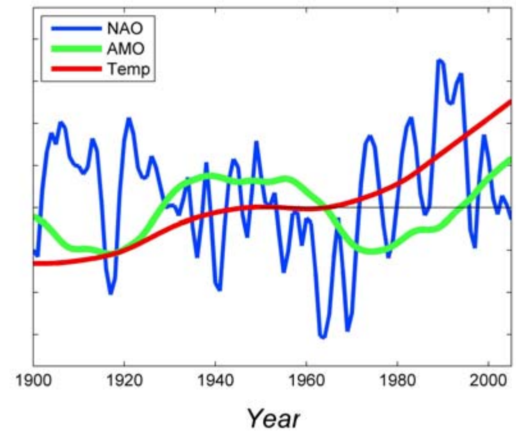


Figure 4. Global air temperature is inceasing (Temp). This warming will interact with the 30-60 year Atlantic Multidecadal Oscillation (AMO) and the 3-8 year North Atlantic Oscillation (NAO).

The NAO is the anomalous difference in air pressure between the polar low and the subtropical high during the winter. The Positive NAO index phase shows a stronger than usual difference in pressures, and these are associated with more and stronger winter storms crossing the Atlantic Ocean on a more northerly track. In the Northeast Continental Shelf Large Marine Ecosystem, positive NAO indices are associated with warmer waters, lower salinities and larger water masses with these properties over the shelf. These conditions can extend down to the shelf floor. The surf-clam mortality event of the late 1990s may have been at least partially attributed to the NAO. The Atlantic Multidecadal Oscillation or AMO is a more recently discovered natural cycle of warm and cold ocean temperatures with a periodicity of 30-60 years. Historical data from the multidecadal warming of the positive AMO phases may provide insight into the long-term effects of global warming on marine habitats and marine species. Disentangling these effects of these natural oscillations and the long-term warming is necessary for improving reliability of forecasts of climate-effects.

Minimizing Uncertainty in Support of Management

It must be our goal to collect the information and perform the analyses needed to reduce the uncertainly of predictions of effects of climate-change (including ocean acidification) on habitats and biota to a level which significantly promotes successful management of living marine resources in the Northeast. To this end, we must:

- improve our understanding of the effects of changes in climate-relevant environmental factors (e.g. temperature, salinity, pH, turbidity, siltation) on habitats and species reproduction, feeding, growth and survival;
- establish laboratory and field programs to identify and monitor indicators of climate-change effects on key habitats and species;

- synthesize the knowledge and data in coupled physical - chemical - biological models; and
- deliver advice and tools to inform managers of climate impacts on habitats and managed species.

The proposed Climate Research Program promotes research that will enable scientists to develop regional-scale ecological models and link these with the regional-scale climate models. This plan then supports activities to apply the resulting forecasts to managers with the goal of improving marine resource management in the face of climate change.

4 Research Goal and Key Research Questions

Goal

The overarching goal of this Research Program is to identify and understand the dynamic properties of the Northeast U.S. Continental Shelf Large Marine Ecosystem in response to climatic changes, in order to predict within prescribed errors future conditions affecting biological productivity and fisheries sustainability.

Questions

This Climate Research Program is designed to answer several key research questions. Although simple in nature, the questions are extremely complex and answering them will require an extensive integrated multidisciplinary ecosystems approach. The six questions with highest priority are:

1) How will overall productivity of the region respond to climate change?
2) How will individual fish and shellfish stocks respond to climate change?
3) Can changes in fish and shellfish stocks be predicted on timescales meaningful to fisheries managers?
4) What are the most important factors required for modeling climate-change effects on fisheries, and what research is required to identify and understand those factors?
5) How should the environment and biota be monitored to support research programs and provide early warning signs to managers?
6) Are we prepared to respond to urgent climate-related observations or predictions, such as effects of ocean acidification?

Focal Species

There are more than 50 managed fishery species that inhabit the Northeast U.S. continental shelf. To address the overall research goal and to answer the six questions across all managed species in the ecosystem would dilute our effort and reduce the synergistic effect of process studies, monitoring, and modeling focusing on the same species. Thus, we will focus efforts on 14 species during the first iteration of the Climate Science Program (Table 1). These species are chosen to contrast northern and southern species representative of several important groups (e.g., finfish, shellfish, and crustaceans), several important feeding strategies (e.g., planktivore, omnivore, piscivore), and several different life histories (e.g. pelagic, flounder, groundfish). Research will be concentrated on these species and will be

Table 1. List of focal species of the NEFSC Climate Research Program

Species	Category	Northern / Southern Range
Atlantic herring	Pelagic planktivore	Northern
Atlantic menhaden	Pelagic planktivore	Southern
Pollock	Pelagic piscivore	Northern
Bluefish	Pelagic piscivore	Southern
Yellowtail flounder	Flounder	Northern
Winter flounder	Flounder	Northern
Summer flounder	Flounder	Southern
Atlantic cod	Groundfish	Northern
Haddock	Groundfish	Northern
Black sea bass	Groundfish	Southern
Atlantic sea scallop	Shellfish	Northern
Atlantic surfclam	Shellfish	Northern
Ocean quahog	Shellfish	Southern
American lobster	Crustacean	Northern
Blue crab	Crustacean	Southern

focused on the contrasts in species range, feeding, life history. The information gained will then serve as a first approximation of the response of similar species to climate change.

5 Program Organization

To answer the six key questions and coordinate a comprehensive yet targeted fisheries research program with a focus on the effects of climate change, a coordinated hierarchical management structure is proposed (Figure 5). The activities in this Program will be conducted largely by thematic multidisciplinary teams organized in six Work Groups (WGs). These are: Process Studies (WG1), Monitoring (WG2), Modeling (WG3), Ocean Acidification (WG4), Advice (WG5), and Program and Data Management (WG6).

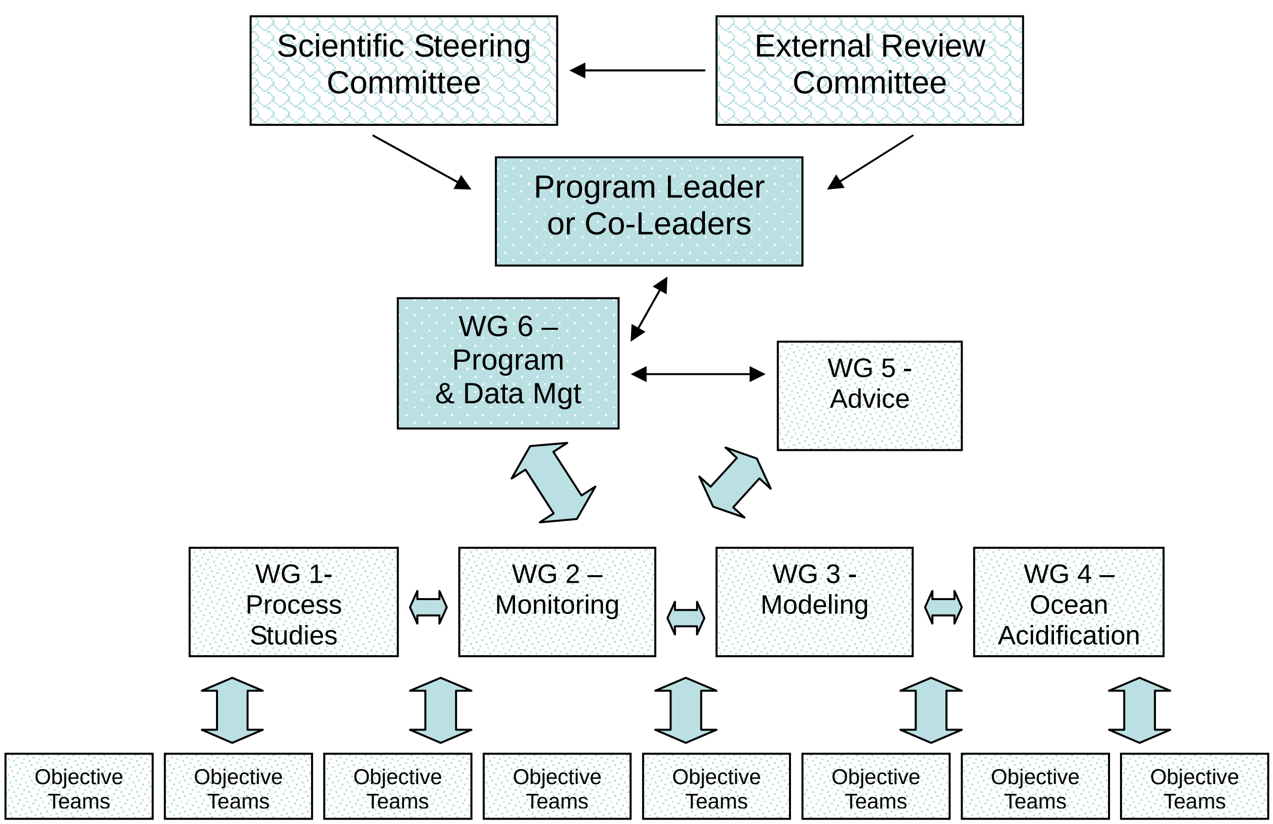


Figure 5. Proposed hierarchical management structure for NEFSC Climate Research Program

Brief descriptions of the goals and objectives for each Work Group are provided below. For detailed implementation plans for each Work Group, see Appendices 1-6. Program resource requests are provided in Appendix 7.

WG 1: Process Studies

The goal of WG 1 is to quantify the effect of the environment and habitat dynamics on key population processes (reproduction, feeding, growth, survival) and develop mechanistic hypotheses for the effects of the environment on LMR dynamics.

Our research approach involves retrospective analyses, laboratory studies and process-oriented field work. This research will be conducted with the goal of providing a mechanistic understanding of the factors limiting production on the Northeast U.S. shelf. This mechanistic understanding will be developed through the iterative use of process studies (WG 1), monitoring (WG 2) and modeling (WG 3). The resulting information will be incorporated into coupled population-climate models (WG 5) to forecast the effect of climate change on living marine resources in the Northeast U.S. continental shelf.

Specifically, for this part of the NEFSC Climate Research Program, we will address two objectives:

- quantify direct effects of environmental variability on vital rates; and
- quantify the indirect effects of environmental variability on vital rates through species interactions.

See Appendix 1 for implementation plan and Appendix 7 for requested resource needs.

WG 2: Monitoring

The goal of WG 2 is to use monitoring of physical, chemical, and biological indicators to validate and refine modeling simulations as well as to provide early warnings to managers.

The monitoring WG will integrate observations with field (WG 1) and modeling (WG 3) studies to develop a mechanistic understanding of the effects of environmental change on living marine resources. Further this WG will collect operational data for use in developing climate assessments and providing early warning of environmental changes with potentially strong impacts on fisheries (WG 5). The monitoring activities proposed in this plan are directed at parameters that are critical to understanding the effect of climate change on the ecosystem that are not currently part of NEFSC programs. This effort will build on existing resources and platforms; for the inclusion of other technologies (e.g. HF Radar) and platforms (e.g. moorings), we will collaborate with regional ocean observing activities and work to make all relevant data available (WG 6) to researchers, assessment scientists, and the public.

Specifically, for this part of the NEFSC Climate Research Program, we will address four objectives.

- augment current Ecosystem Monitoring surveys with additional measurements relevant to understanding and forecasting the effects of climate change;
- initiate a benthic monitoring program as part of current clam and scallop resource surveys and potentially as part of an Integrated Benthic Survey program;

- support remote sensing capabilities to provide synoptic value-added products for examining the effect of climate change on the Northeast U.S. shelf ecosystem; and
- build a data center for serving NEFSC Climate Monitoring data and value-added data products

See Appendix 2 for implementation plan and Appendix 7 for requested resource needs.

WG 3: Modeling

The goal of WG3 is to develop coupled climate-environment-population models based on mechanistic hypotheses to forecast the effect of environmental change in LMR dynamics and status

This WG shall synthesize and improve our understanding of the effect on environmental variability (WG 2) on population processes (WG 1) and also use these same models – coupled to the output of climate models – to forecast the effect on climate change on resource species in the Northeast U.S. continental shelf ecosystem. The results of these forecast models will be used as the basis of advice provided to managers (WG 5)

Based on this goal, we have three specific objectives:

- develop ecological models for studying the effect of climate change on fishery and ecosystem productivity;
- link ecological models to climate-change models and develop ecological climate assessments and forecasts; and
- develop risk assessment framework to evaluate the effects of changes in living marine resources and their habitats in terms of economic, social and cultural impacts.

See Appendix 3 for implementation plan and Appendix 7 for requested resource needs.

WG 4 – Ocean Acidification

The goal of WG 4 is to develop baselines for ocean acidification indicators and assess the effects of acidification on living marine species.

WG 4 will focus on ocean acidification. The WG will perform an assessment of the effect of ocean acidification on the living marine resources of the Northeast U.S. Continental Shelf Large Marine Ecosystem. This work draws upon three other elements of this Climate Science Program. Process-oriented research (WG 1), monitoring (WG 2), and modeling (WG 3) will be used to develop assessments of the impact of ocean acidification. We chose to identify ocean acidification as a priority topic, because the great sense of urgency to quickly predict the impact of this phenomenon. The potential effects are severe and widespread, and we know little about acidification effects on resource species. Laboratory and field efforts will be directed at collecting specific information for the parameterization of single species and ecosystem models, which will be used to assess the effect of acidification on commercially and recreationally important species and overall ecosystem productivity.

This WG has five specific objectives:

- develop a monitoring program to assess the current state of ocean acidification and monitor its development in the Northeast U.S. Continental Shelf Large Marine Ecosystem;
- conduct laboratory and targeted field studies to quantify the impact of ocean acidification on primary producers, which form the basis of fisheries productivity in the ecosystem;
- conduct laboratory and targeted field studies to quantify the impact of ocean acidification on resource species including both direct effects on calcification and indirect effects on physiology, growth and mortality;
- develop and implement modeling approaches to assess the effects of ocean acidification on single-species dynamics and overall ecosystem productivity; and
- provide a first integrated assessment of the effects of ocean acidification on the Northeast U.S. continental shelf ecosystem.

See Appendix 4 for implementation plan and Appendix 7 for requested resource needs.

WG 5 – Advice

The goal of WG 5 is to will synthesize products from the Climate Research Program to develop products to support fisheries and ecosystem-based management.

Keeping in mind that the overall goal of the proposed Climate Research Program is to provide assessments of the effect of climate change on habitats and biota and to communicate these results to managers, the Advisory WG will integrate discrete research products to provide fisheries advice to NEFSC clients including the New England and Mid-Atlantic Fishery Councils, Atlantic States Marine Fisheries Commission and various State fisheries and environmental agencies. Other potential customers include the NOAA Ecosystem and Climate Goal Teams, academic institutions, non-profit organizations, and industry groups. The products will take many forms, but we will emphasize tailoring the advice to the needs of resource managers, with the overall goal of informing managers of the possible consequences of climate change including gradual and dramatic shifts in abundance, distribution and production of living marine resources, changes in essential fish habitat (EFH), changes to the status of protected species, and changes in overall productivity and trophic structure in the Northeast U.S. Continental Shelf Large Marine Ecosystem.

Specifically, this WG will coordinate the development of three types of products:

- ecosystem status reports and Integrated Ecosystem Assessments (IEA);
- climate forecasts for specific managed stocks incorporated into the stock assessment process; and
- regional climate impacts reports.

See Appendix 5 for implementation plan and Appendix 7 for requested resource needs.

WG 6 – Program and Data Management

The goal of WG 6 is to manage activities within the Climate Research Program to ensure that research, monitoring, modeling and provision of advice are synergistic and coordinated.

The Climate Research Program is a large complex scientific effort with participation throughout the NEFSC including multiple divisions and laboratories. Coordination of activities through proper management of this program will be indispensable for success. We propose a hierarchical approach with defined deliverables. Program and Data Management will be responsible not only for coordinating research but for ensuring there are proper communications both internally and with external partners and clients. Further, data management will be a key responsibility of this WG. This will be achieved through a dedicated Program database and links to existing NEFSC and other data repositories.

The management structure will consist of:

- program leader or co-leaders;
- work group leaders;
- objective leaders within WGs;
- scientific steering committee; and
- external review committee.

See Appendix 6 for implementation plan and Appendix 7 for requested resource needs.

6 Potential to Expand the Scope of this Regional Research Program

The proposed Research Program to Investigate Climatic Effects on Biological Productivity and Sustainable Fisheries in the Northeast U.S. Continental Shelf Large Marine Ecosystem was developed specifically for research within the NEFSC. The Program is intended to be adaptive and as such will evolve according to management needs, scientific results, and research opportunities. Therefore the current iteration should be considered as the starting point for a continually evolving Program.

The implementation of Climate Research Program calls for considerable collaboration with agency and non-agency partners. Many of the collaborations will be with scientists outside of the Northeast region. In this proposed Climate Research Program, we describe fundamental processes and management concerns applicable to all NOAA Fisheries management regions of the USA. Further, the scientific approach, methodologies and technologies proposed in this plan can easily be applied nationally. Therefore, we hope that this Program may serve as a pilot for broader national application in the future.

7 Appendices - Implementation Plans

The Climate Science Program is composed of six work elements: Process Studies (Appendix 1), Monitoring (Appendix.2), Modeling (Appendix 3), Ocean Acidification (Appendix 4), Advice (Appendix 5), and Program and Data Management (Appendix 6).For each work element, the implementation plan provides background, objectives and statement of work.

7.1 Appendix 1. Process Studies – Work Group 1

Background

The production of a population is constrained by limiting factors. These factors affect the population's vital rates (e.g., metabolism, recruitment, growth, mortality, maturity, immigration, emigration, phenology), which in turn influence the distribution, abundance, and productivity of the population. Most marine species have complex life histories, in which different stages (typically egg, larvae, juvenile, adult) exhibit contrasting morphological, behavioral, physiological and ecological attributes. Typically, the larvae of most marine species are pelagic, regardless if the adults are pelagic or benthic. Limiting factors act differently on these discrete stages and the productivity of a population is typically limited by a subset of factors acting on a subset of stages. Further the limiting factors controlling productivity can vary among populations within a species and over time as abundance and distribution of the population changes.

These limiting factors can be classified into two categories: direct and indirect effects. Direct effects are environmental factors that directly influence the vital rates of a population. Direct effects can be thought of in isolation (e.g., temperature effects on juvenile survival) or in combination (salinity and dissolved oxygen effects on adult distribution or pH effects of shell calcification and metabolism). Indirect effects involve environmental effects on species that interact with the species in question. These species interactions include predation, feeding, competition, and habitat. For example, predation risk of winter flounder juveniles is greater at higher temperatures and salinities because there is a greater spatial and temporal overlap with predators.

Climate change will alter a number of limiting factors and thereby have wide ranging effects on resource species, as well as their prey and predators. These effects are occurring concurrently with exploitation and changes in habitat and the combination of these factors is going to change the productivity of populations on the northeast U.S. shelf ecosystem. To assess and forecast the effect of climate change on resource species, we need to develop a mechanistic understanding of the limiting factors acting on populations in the ecosystem.

Objectives

The goal of WG 1 is to quantify the effect of the environment and habitat dynamics on key population processes (reproduction, feeding, growth, survival) and develop mechanistic hypotheses for the effects of the environment on LMR dynamics.

Our research approach involves retrospective analyses, laboratory studies and process-oriented field work. This research will be conducted with the goal of providing a mechanistic understanding of the factors limiting production on the Northeast U.S. shelf. This mechanistic understanding will be developed through the iterative use of process studies (WG 1), monitoring (WG 2) and modeling (WG 3). The resulting information will be incorporated into coupled population-climate models (WG 3 and 5) to forecast the affect of climate change on living marine resources in the Northeast U.S. continental shelf.

Specifically, for this part of the NEFSC Climate Research Program, we will address two objectives:

- quantify direct effects of environmental variability on vital rates; and
- quantify the indirect effects of environmental variability on vital rates through species interactions.

Statement of Work

Objective 1 –Direct Effects of Climate Change

Retrospective Analyses

There is abundant information regarding the effect of environmental parameters on the abundance, distribution, and vital rates of our focal species in the northeast U.S. shelf ecosystem. There also is relevant information available from other ecosystems and for related species. Our first step is a retrospective analysis of available information for environmental effects on the focal species. Environmental variables include temperature, salinity, carbon dioxide and dissolved oxygen. Population parameters include abundance, distribution, growth, mortality, maturity, immigration, emigration, and phenology. Each life history stage will be treated separately. One aspect of this retrospective analysis involves a thorough examination of the literature. A second aspect involves analysis of extant NEFSC databases. Some analyses have already been conducted, for example, changes have been documented in distribution of ~20 species from the spring trawl survey in relation to bottom water temperature. Similar analyses will be conducted for other population parameters and environmental factors using the trawl survey database for juvenile and adult stages and the EcoMon database for pelagic larval stages. The resulting information will be used to i) establish preliminary models of the effect of climate change on resource species, ii) perform a gap analysis to help direct laboratory and field studies, and iii) identify potentially critical factors that need to be examined in more detail in field and laboratory.

Laboratory Studies

Laboratory-based studies will be used to fill in the information required for the focal species with regard to environmental effects on various vital rates for different life history stages. Initial work would focus on early life stages, since limiting factors during these stages often have a disproportionately large effect on the population as a whole. Experiments would first be conducted to define minimal and maximal tolerances of survival relative to environmental factors (Figure 6). These experiments would be followed by studies to quantify vital rates over the viable range of environmental parameters. These studies would first be performed with individual environmental variables examining single

Figure 6. Laboratory setup at the NEFSC Sandy Hook Laboratory used for examination of environmental effects on fish vital rates.

population responses. Subsequently, studies would evaluate the effect of single environmental variables on multiple population responses with an emphasis on quantifying the covariance between vital rates at the individual level. Finally the research will examine combined effects of environmental variables on population vital rates.

Laboratory efforts would also be directed at adult stages, but these will take more time simply owing to the relative duration of adult stages (years) compared to larval (weeks) and juvenile (months) stages. Work on adult stages would focus on fecundity and egg quality since recent studies have indicated parental effects may also have a large influence on overall population production. The sequence of experiments would follow those described above: single factor-single response, single factor-multiple response, and multiple factor-single response, and multiple factor-multiple response.

Field Work

In addition to the laboratory work, we also propose targeted field sampling to use the documented spatial variability in temperature, salinity, pH, and dissolved oxygen to evaluate the relationship between vital rates and environmental conditions. We will perform surveys that focus on finer space-time scales than examined in the trawl surveys. These finer-scale studies will be designed based on available oceanographic data from our own monitoring programs and from collaborations with the IOOS Regional Associations. Demersal fish-habitat surveys will be conducted using optics, acoustics and other sensors, and will be ground truthed using traditional gear. Benthic grab samples will also be made to collect the potential prey of demersal fishes. Pelagic sampling with multiple opening and closing nets will be stratified using real time satellite and HF radar imagery of surface convergences/divergences, as well as shipboard CTD, ADCP and fisheries hydroacoustics to describe vertical structure. In addition to measuring distribution and abundance, we will estimate recent vital rates using otolith and scale growth patterns, measures of condition, measures of feeding, and measures of reproductive output. These targeted collections will be made in two locales representing different environments on the northeast U.S. shelf: the New York Bight region and Georges Bank (these areas are termed seascapes). Both have a long-history of field studies providing an excellent context for targeted field studies.

To address the issue of migration, we will use acoustic, traditional and natural tags to quantify the timing, extent and rate of juvenile and adult movements. We will also use the field collected data to parameterize larval transport model. These data include depth-discrete vertical sampling coupled with laboratory experiments to define the depth preferences of larvae and passive and active vertical movement rates (see Modeling Component of the NEFSC Climate Science Plan). Finally, we will conduct laboratory work to define the horizontal swimming capabilities of early stage fishes and attempt to verify these estimates in the field using visual or acoustic techniques. The goal of this work will be to parameterize movement throughout the life history of our focal species.

Objective 2 – Indirect Effects of Climate Change

Retrospective Analyses

Information regarding species interactions is more limited, but a similar approach will be used as described for the retrospective analysis for Objective 1. The first step will involve an examination of available information for environmental effects on species interactions on the focal species.

Interactions will include prey, predators, competitors, and habitat. Environmental variables include temperature, salinity, carbon dioxide and dissolved oxygen. Population parameters include abundance, distribution, growth, mortality, maturity, immigration, emigration, and phenology. Each life history stage will be treated separately. One aspect involves a thorough examination of the literature – this has already been completed to an extent through the development of Essential Fish Habitat Source Documents, however, this process will be revisited for each focal species. A second aspect involves determining the important species-interactions in the system. One source of data for this analysis will be the Food Habitats Database. Another source will be a literature review of species interactions in the system. These analyses will allow construction of models that incorporate variability in species interactions. The next step will be to parameterize the effect of environmental variability on species interactions and habitat distributions. These can then be used to identify gaps where further research is necessary and to develop preliminary climate forecasts based on available information.

Laboratory Studies

Laboratory studies will be essential to target specific processes under controlled conditions. Two types of laboratory studies will be performed. First, much of our understanding of predatory interactions comes from food habitats data. Interpretations from these data, however, are complicated by variability in consumption rates, digestion rates and energetic value across prey species and environmental conditions. For the focal species, these parameters will be measured for dominant prey in as identified in the NEFSC food habitats database. The effect of environmental variability on these rates will then be quantified. Second, specific interactions will be studied in the laboratory with an emphasis of quantifying the effect of environmental variability on the interaction. For our focal species, the dominant predators will be identified in the retrospective analysis. Predator-prey experiments over a range of environmental conditions will than be conducted. Owing to the time consuming nature of multispecies experiments, we will make no attempt to thoroughly document the effect of the environment on all species interactions; rather we will focus on specific interactions for which there is some evidence. One interaction we will examine early on is the effect of environmental variability on scallop predation by starfish. Another interaction we will examine is fish predation on juvenile winter flounder and juvenile black sea bass. We will also examine haddock predation of benthic fauna. Subsequent experiments will be determined based on the results of the retrospective analyses and preliminary results from the field programs.

Field Work

We also propose targeted field sampling to investigate the effect of environmental variability on species interactions. Using the field work described for Objective 1 as context, we will investigate temporal and spatial differences in predation and competition over relatively small scales and relate these to environmental and habitat variability. Efforts will examine both benthic and pelagic habitats and include bentho-pelagic coupling. We will focus on the prey and predators of the focal species in the two different seascapes: Mid-Atlantic Bight and Georges Bank. One aspect of this work will be to conduct intensive food habitats analysis on collected species. These will be used to identify predatory and potentially competitive interactions. This work will be correlative but will be used to corroborate laboratory and retrospective results. Another aspect of this work will be to develop statistical habitat models that include both biotic and abiotic factors with various population responses.

7.2 Appendix 2. Monitoring – Work Group 2

Background

Monitoring plays an important role in the assessment of stock and ecosystem status. Long-term observations provide times series of indicators that can be analyzed in exploratory analyses to develop hypotheses and to evaluate the merits of competing hypotheses. These analyses can then be coupled with process-oriented lab and field studies and modeling studies to understand the mechanisms by which the environment affects population vital rates. For example, the recent finding of a strong relationship between haddock recruitment on Georges Bank and the magnitude of the fall bloom was dependent on monitoring time series of haddock recruitment derived in part from the NEFSC trawl survey and time series of ocean color data from the SeaWIFS satellite. The form of the ocean color data was a derived variable representing bloom dynamics that was generated by the NEFSC with the intent of providing a remotely-sensed indicator in a form amenable to fisheries analyses. Another example involves a correlation between changes in zooplankton community structure and changes in salinity on the shelf. This relationship has been key in understanding the trophic effects of Arctic melt in this region and could only have been found with the long-term zooplankton and hydrographic monitoring conducted by the NEFSC.

Monitoring can also be used to supply data for the operational assessments conducted for fisheries management. Most of the assessments in the northeast region utilize age-specific abundance estimates from the trawl survey. In addition, time series of a range of indicators are being collated and used to understand and assess the state of the northeast U.S. shelf ecosystem as an initial step in implementing Ecosystem-Based Management in the region. NEFSC has maintained a long-standing commitment to ecosystem monitoring and analysis. The elements of the current ecosystem monitoring programs encompass physical oceanography, lower trophic processes, living marine resource dynamics, habitat ecology, and protected resource dynamics. These activities are performed to meet current management needs. However, it is clear that the breadth of monitoring activities needs to increase and that both *in situ* and remotely sensed data need to be analyzed in combination to study the links between climate change and resource dynamics and to provide data for developing management advice regarding the effects of climate change. Additionally, cooperation is required with other observing institutions (state and federal agencies, universities, IOOS Regional Associations) to provide as a holistic view of the ecosystem as possible.

Objectives

The goal of WG 2 is to use monitoring of physical, chemical, and biological indicators to validate and refine modeling simulations as well as to provide early warnings to managers.

The monitoring WG will integrate observations with field (WG 1) and modeling (WG 3) studies to develop a mechanistic understanding of the effects of environmental change on living marine resources. Further this WG will collect operational data for use in developing climate assessments and providing early warning of environmental changes with potentially strong impacts on fisheries (WG 5). The monitoring activities proposed in this plan are directed at parameters that are critical to understanding the effect of climate change on the ecosystem that are not currently part of NEFSC programs. This effort will build on existing resources and platforms; for the inclusion of other technologies (e.g. HF Radar) and platforms (e.g. moorings), we will collaborate with regional ocean observing activities and work to make all relevant data available (WG 6) to researchers, assessment scientists, and the public.

Specifically, for this part of the NEFSC Climate Research Program, we will address four objectives.

- augment current Ecosystem Monitoring surveys with additional measurements relevant to understanding and forecasting the effects of climate change;
- initiate a benthic monitoring program as part of current clam and scallop resource surveys and potentially as part of an Integrated Benthic Survey program;
- support remote sensing capabilities to provide synoptic value-added products for examining the effect of climate change on the Northeast U.S. shelf ecosystem; and
- build a data center for serving NEFSC Climate Monitoring data and value-added data products

Statement of Work

<u>Objective 1 – Augment Current EcoMon Surveys</u>

The EcoMon program currently collects ~2000 Conductivity, Temperature, and Depth (CTD) casts on the northeast U.S. continental shelf yearly (Figure 6). Close to half of these stations include plankton net tows for monitoring zooplankton and ichthyoplankton populations. The majority of the physical and biological data are collected on four dedicated monitoring cruises and as piggy-backed operations on the spring and fall bottom trawl surveys. This level of sampling allows for 6 "snapshots" of the northeast U.S. shelf annually. These surveys have been conducted in one form or another since the mid-1970's, providing a 30+ year time series of physical and biological oceanographic data. These data have been used extensively to characterize the inter-annual variability in hydrographic conditions and in the distribution and abundance of the lower trophic levels. In addition, these data have been used in physical and biological models of the northeast U.S. continental shelf ecosystem.

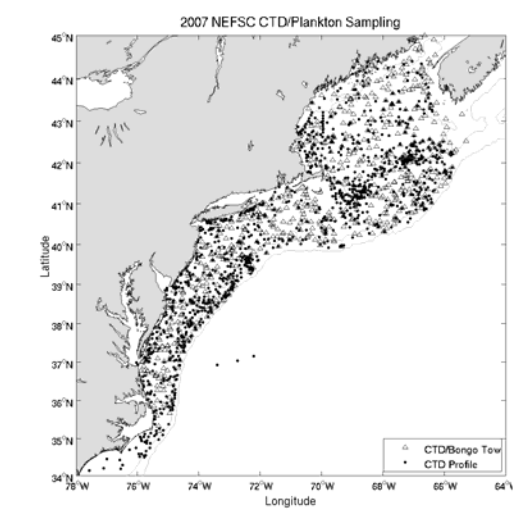


Figure 7. CTD/Plankton stations completed during the 2007 field season

We propose expanding the current EcoMon program to include more information on primary productivity, water column chemistry and the pelagic stages of resource species (Table 2). Primary productivity measurements will involve the purchase and deployment of the Fast Repetition Rate Fluorometer as part of CTD deployments. Resulting primary productivity estimates will be ground-truthed with traditional incubation-based estimates. Water column chemistry measurements will involve the purchase and deployment of wet-chemistry profilers which will also be deployed during CTD operations. These measurements will be ground-truthed using standard nutrient analyses of bottle-collected water samples. Water column chemistry will also include the measurement of the various components of carbonate chemistry. These analyses are described in more detail in the Ocean Acidification section. Water samples will be collected in bottles as part of the CTD deployments.

Table 2. Comparison of current and proposed ship-based sampling as part of the NEFSC climate monitoring activities

Current	**Proposed**
Temperature	Temperature
Salinity	Salinity
Density	Density
Zooplankton	Zooplankton
Ichthyoplankton (including Focal Species)	Ichthyoplankton (including Focal Species)
	Decapod crustacean and mollusk larvae of focal species
	Carbonate Chemistry (for pH determination)
	Oxygen (dissolved oxygen using CTD mounted sensor and O^{18} sampling from CTD bottle carousel)
	Nutrients (both based on water samples and deployable wet chemistry instruments)
	Chlorophyll (total and possibly size fractionated concentrations)
	In situ primary productivity (Fast Repetition Rate Fluorometer)

Finally, information about the pelagic early stages of our focal species will be based on extant plankton sampling. However, analysis of these samples will be augmented to include the identification of all our focal species including mollusks, decapod crustaceans, and teleosts. Some of this work will involve the use of traditional identification techniques and some will involve the novel application of genetic techniques (e.g., bar coding).

As new technologies and understandings emerge, the current sampling methods for the physics, biology, and chemistry will require updating. Biological sampling systems using video technology (VPR - Video Plankton Recorder, ISIIS – In situ Ichthyoplankton Imaging System) have recently been deployed on EcoMon cruises. The Office of Marine Ecosystem Studies (OMES) has carried out surveys of the Narragansett Bay estuary using a towed undulating instrument package. As these technologies approach operational status, they will be incorporated into our ecosystem monitoring activities.

Objective 2 – Benthic monitoring

Benthic invertebrates are major components of the marine food web and are directly preyed upon by many of our focal species. Biogenic structures such as tube fields result from the activities of benthic invertebrates and provide shelter (habitat) for juvenile stages of demersal fish. Environmental-driven change in the distribution of benthic species has been documented for Atlantic surf clam, but general surveys of benthic invertebrate fauna have not been conducted for over 20 years. Given the changes seen in finfish abundance and distribution, there are sure to be changes in the abundance and distribution of benthic invertebrates. These species are important prey and predators of our focal species and thus understanding the indirect effects of climate change through species interactions will involve documenting the long-term trends in abundance and distribution of benthic invertebrates.

Implementation of a comprehensive benthic monitoring program will involve testing and standardizing methodologies and technologies not broadly employed at the NEFSC or other science centers. The Marine Fisheries Habitat Assessment Improvement Plan (in preparation) provides a listing of instrumentation to be considered for habitat assessments. The Survey and Monitoring Task Force of the NEFSC also has submitted a rigorous analysis of instrumentation and platforms to be considered for sampling of discrete trophic levels.

The first step in developing a benthic monitoring program will involve repeating the summertime sampling conducted from 1978 through 1985. The overall goal of this sampling is to evaluate whether the benthic community structure has changed over time. This earlier program took 5 benthic grabs per station at 30 stations extending from Chesapeake Bay northward to the Gulf of Maine. We propose to repeat this sampling on the Clam and Scallop resource surveys to determine whether there have been changes in the summertime distribution and abundance of benthic invertebrates.
Sampling will also be repeated at locations in Closed Area II on Georges Bank and in the Hudson Canyon or another location in the New York Bight. Spatially limited benthic invertebrate sampling has been conducted at these locations in the past. This additional sampling will be conducted during the summer EcoMon cruise or during short cruises on smaller NOAA vessels or contract vessels.
The rationale for summer time sampling is two-fold. Firstly, the clam and scallop resource surveys occur during the summer providing a platform for most of the proposed sampling. Secondly, relatively large changes in summertime surface temperatures and production have been observed, and thus there is a good to opportunity to study benthic response to changes in food supply and to gain a much needed understanding of natural variability in regional benthic communities.

New technologies will also be deployed as part of our benthic monitoring activities. Several pieces of equipment are under development including the HabCam (Habitat Camera, WHOI) and sediment video profilers. As these technologies approach operational status, they will be incorporated into our benthic monitoring activities.

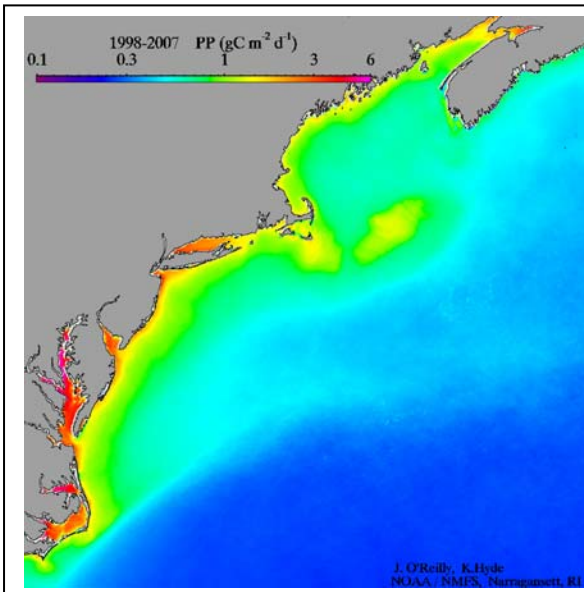


Figure 8. Primary productivity climatology for the northeast U.S. continental shelf ecosystem derived from OPAL, a model which includes chlorophyll, SST, photosynthetically active radiation, and other ocean color derived products.

<u>Objective 3 – Remote Sensing Activities</u>

Remote sensing has revolutionized our understanding of the ocean by providing synoptic views of the ocean's surface at spatial and temporal scales unattainable by ship-based sampling (Figure 7). Remotely-sensed data products have also made major contributions to understanding the effect of environmental variability on the dynamics of resource species. Studies have documented how pelagic species and stages move relative to the complex landscape of oceanographic features including fronts, eddies and currents. Relationships between system-wide primary productivity and fisheries productivity also have been documented and recruitment has been linked to the timing and magnitude of primary productivity. Yet these data have not been as widely utilized by the fisheries research community because it is spatially and temporally rich relative to fisheries data and it is not often in a familiar form.

Here we request support for a research and data processing group that will focus on the creation and provision of remote sensing data products of relevance to our work with fisheries, the ecosystem, and climate change. The intent is not to develop another group that serves raw data. Rather the group would concentrate on generating data products for use in research on the mechanisms of environmental effects of population vital rates and to provide operational data for use in assessment and forecasting models related to the effect of climate change. For example, instead of simply providing satellite sea surface temperature data, we would develop data features and condensations that would have biological meaning. These derived variables may include spatial and temporal extent of thermal habitats, the distribution of frontal probability, or the arrival dates of specific temperatures to evaluate effect of phenological changes in the ecosystem. The ocean color data used to show the distribution of plankton biomass would be aggregated into bloom indices specific to the ecosystem. The NEFSC is also uniquely positioned to provide both temperature and chlorophyll front formation data on a regional and global scale. In addition to these spatially explicit products, we will develop indicators that track important aspects of the ecosystem dynamics including the magnitude and timing of primary productivity and the seasonal temperature cycles. We will also work on developing blended products that combine remotely sensed data with in-situ data collected as part of the shipboard monitoring programs. As research continues and experience grows, we will add to the number and breadth of products provided but we will maintain the emphasis on value-added products that will contribute to understanding the effect of climate change on resource species in the northeast U.S. ecosystem.

Objective 4 – Environmental Monitoring Data Center

We proposed a dedicated data center for processing, displaying, and serving all of the research, monitoring, and modeling data generated as part of the Climate Science Plan. We also will serve data that are incorporated into our modeling and management activities, regardless if they are collected as part of this program or not. The purpose is to develop one source that provides the information collected as part of this program and to also provide direct support to the information needs for the development of the management products.

The data center will initially focus on remotely-sensed data: storage, automated product generation, and automated visualization tools. Other monitoring data will be added will be added incrementally and include data collected as part of this program and other relevant survey conducted by the NEFSC. There will be an emphasis on developing automated data processing and retrieval software for standard products that will be used in assessments resulting from this program. We will also incorporate the data and data products developed by other institutions but that are being used in the modeling and management activities.

7.3 Appendix 3. Modeling – Work Group 3

Background

Models form the integrative bridge from process-oriented research and monitoring to assessments and forecasts. Research models can be used to better understand the effect of the environment on resource species. These models are important for making predictions and testing hypotheses. In this form model are used iteratively with process-oriented research and monitoring to incrementally increase the mechanistic understanding of the effect of environmental change on resource species. Research models also serve as a synthetic tool to accumulate information and identify gaps to be filled through additional laboratory and field work.

These same models can be "operationalized" to form the basis of assessments and forecasts. Single-species management is based on a standard set of assessment models. No standards yet exist for developing ecological climate assessments. However, there have been some examples of forecasts of the effect of climate change on resource species and these studies can be used as guidance for the way forward.

For modelers to support fisheries and ecosystem-based management is the context of climate change, an integrated modeling framework must be developed that combines mechanistic population-level processes with climate model outputs. These models should incorporate information on direct effects of environmental variability on vital rates, as well as indirect effects of environmental variability on vital rates through species interactions. These ecological models must be linked to climate models that forecast the variables needed by the ecological models at the appropriate temporal and spatial scales. The outputs of this integrated modeling approach should provide the science needed for managers to develop more robust strategies for achieving and maintaining sustainability over the long-term. Finally, we develop a risk assessment framework to provide our climate forecasts with measures of uncertainty and probabilities that management objectives will not be met.

Objectives

The goal of WG3 is to develop coupled climate-environment-population models based on mechanistic hypotheses to forecast the effect of environmental change in LMR dynamics and status

This WG shall synthesize and improve our understanding of the effect on environmental variability (WG 2) on population processes (WG 1) and also use these same models – coupled to the output of climate models – to forecast the effect on climate change on resource species in the Northeast U.S. continental shelf ecosystem.

Based on this goal, we have three specific objectives:

- develop ecological models for studying the effect of climate change on fishery and ecosystem productivity;
- link ecological models to climate-change models and develop ecological climate assessments

and forecasts; and

- develop risk assessment framework to evaluate the effects of changes in living marine resources and their habitats in terms of economic, social and cultural impacts.

Statement of Work

Objective 1 - Develop Research Models

A wide variety of models could be used in researching the environmental effects on marine fish populations. We have selected four primary types that will be developed and implemented during the first five years of this program:

1) bioenergetic models to understand the effect of environmental variability on individual level energy allocation;
2) linked ocean circulation-individual-based models to understand the effect of the oceanic environment on the growth, mortality and movement of individuals and the effect of climate change on connectivity among habitats and populations;
3) delayed-difference population models to express the population-levels effects of climate change in terms familiar to stock assessment scientists and managers; and
4) trophic network models to examine climate impacts on overall energy flow in the system.

These model choices were made for largely pragmatic reasons; NEFSC staff already have experience with the models identified, thereby their implementation to developing climate forecasts can be immediate. This immediacy is justified by the recognition that climate change is affecting the northeast U.S. continental shelf ecosystem now, and to ensure sustainable management, it is imperative that climate effects on fisheries are identified, understood, and incorporated into the scientific advice provided to managers.

Bioenergetic models

Energy allocation affects a wide range of ecological processes. Bioenergetic models treat energy allocation as a simple function where energy consumed equals energy used for metabolism, activity, growth, and reproduction plus energy lost through excretion and egestion. A number of environmental parameters affect the metabolic rate of an individual. Most notably, as temperature increases, metabolic rate increases. In this circumstance, if consumption stays constant energy allocation must change through decreased activity, growth, or reproduction. These models will be parameterized from laboratory work described in the Process Studies section. In addition, field observations and monitoring data on reproductive output and growth will be analyzed in the context of bioenergetic models for the focal species. Although these models are simple, they have heuristic value for understanding the trade-offs that climate change imposes on an individual and they have practical value in allowing predictions to be made as to the effect of changing environment on different aspects of fish biology.

Ocean circulation-individual-based models

Through programs like GLOBEC and ECOHAB, several state-of-the-art circulation models have been generated for the northeast U.S. continental shelf region. NEFSC scientists have implemented these types of models previously, and we will build upon this experience here. Ocean circulation models will be coupled to individual based models (IBM), which include the spatial dynamics of multiple life stages. The IBMs will be parameterized with explicit, measurable, mechanistic responses of focal species to their environment. We will begin with a set of four simple IBMs describing spatio-temporal variability in: 1) adult spawning habitat and egg production, 2) larval transport, 3) juvenile survivorship, and 4) juvenile and adult migration. The goal is to develop individual-based, whole life cycle models that are coupled to oceanographic models and incorporate spatial-dynamics and environmental variability. The parameters for these models will be derived from the research and monitoring components of this research plan. In addition, predictions from these models will be evaluated with field collected data and monitoring data in an iterative cycle. We plan to use several circulation models (e.g., ROMs, FVCOM) to encourage an ensemble-based approach to forecasting the effect of environmental variability on the abundance, distribution, and production of our focal species.

Delayed-difference models

Relatively simple delayed-difference models will be used to capture the population-level effects of environmental variability on vital rates. These models are often used for making forecasts in stock assessments and thus, they are familiar to assessment scientists and modelers. Critical to the development of these models is an understanding of the effect of environmental variability on one or more of the components of the model: recruitment, growth, maturity, sex ratio, emigration/immigration. These models have been successfully used in single factor (temperature) - single response (recruitment) situations. As information is developed, these models will include multiple factors-multiple responses. Simple species interactions can also be included through effects on natural mortality rate (predation) or effects on growth (prey, competition). Simple spatial dynamics can also be included through the inclusion of simple spatial dynamics and emigration / immigration between habitats.

Trophic network models

The Energy Modeling and Analysis eXercise (*EMAX*) created an energy budget and network analysis for the northeast U.S. shelf ecosystem using EcoPath as the primary software tool. 36 nodes were defined in the network ranging from dissolved organic carbon to baleen whales, with more detail for exploited and protected species and less detail for lower trophic levels. This model will be revisited as additional biomass estimates are generated from the monitoring programs for components not well estimated previously (e.g., DOC). Presently, we are not proposing to link the EMAX model to the outputs of climate change scenarios. Rather, we will explore the effects of different scenarios that may result from climate change. One approach is to impose temperature dependent consumption rates – derived from laboratory experiments and used in the bioenergetic models - and then evaluate the changes in the flow of energy. In addition, we will examine climate change scenarios where forecasts of changes in species biomass derived from the delayed difference models are used in the EMAX model and the impacts on the overall system evaluated. These results will provide a large-scale view of potential climate effects on overall ecosystem structure and function.

Objective 2 - Link Ecological Models to Climate Models

An integrated modeling framework must be developed that combines mechanistic population-level processes with climate model outputs. Two steps will be taken to incorporate climate effects into the ecological models. 1) Fixed changes in environmental variables will be applied in the research models and the response of the population or ecosystem will be examined. This approach was used by to examine the effects of warming on cod recruitment. A recruitment-temperature relationship was derived from monitoring data and incorporated into a delayed-difference population model. Temperature was then changed incrementally to examine the effects of warming. 2) Ecological models will be coupled with climate models. This approach was used by Hare et al. (in review). Again, a recruitment-temperature relationship was derived from monitoring data and incorporated into a delayed-difference model. Temperature forecasts were then obtained from the output of two global climate models under three CO_2 emission scenarios. This second step allows direct coupling between global model predictions and forecasts of population and ecosystem-level responses. However, this only is operable for environmental variables that are forecasted by climate models (e.g., temperature).

To fully realize our integrated-modeling framework, it is essential that climate modelers and ecological modelers collaborate to ensure that climate models are forecasting the critical environmental variables needed for ecological response models at relevant time and space scales. One of the challenges will be to resolve the fact that the spatial-scale of global climate models is typically too coarse for fisheries and ecosystem applications. The climate modeling community is already working to develop regional-scale climate models, but there needs to be better coordination between the scientists developing the models and scientists using the models to make ecological forecasts. In addition, the regional climate models need to be better linked to regional ocean models. These efforts are already underway on the west coast and need to be initiated on the east coast.

The assessment products generated as part of this program are not going to address interannual variability in population abundance, distribution, and productivity. Rather, these forecasts will be made at three temporal scales: 5-20 years, 20-50 years, and 50-100 years. These scales are targeted for assessing rebuilding plans in the face of environmental variability, providing management councils and stakeholders with a projection of the fate of specific fisheries and fisheries production during the present generation, and a long-term projection to help understand the consequences of climate change. To achieve the shorter-term climate forecasts, data assimilative methods are required. To achieve the mid- and long-term forecasts, current global climate models are probably adequate but need to be regionalized.

Objective 3 – Develop Risk Analysis Framework

Explicit consideration of climate influences on productivity at the population, community, and ecosystem levels will necessarily add both complexity and uncertainty into the modeling frameworks outlined above. The inclusion of a broader suite of considerations related to climate influences will mean a expansion of the number of parameters to be estimated and the potential for increased propagation of error in projections of climate impacts. Broadly defined, the sources of uncertainty can be classified as those related to observation error (variance in the metrics included in the models), process-error (lack of fit in model performance), and model uncertainty (choice in model form and complexity). These sources of uncertainty translate into risk of achieving specified management objectives because thresholds and reference points may be exceeded without detection due to the uncertainty introduced by the sources noted above. It is also possible to define implementation uncertainty in which management objectives are compromised by an inability to completely control the outcome of management actions. Here, we define risk as the probability that a specified management objective is not met. We propose to quantify risk by explicitly incorporating uncertainty into the modeling frameworks described above and to simulate the consequences of the difference sources of error affecting the projections. Sensitivity analyses will be first conducted to identity critical parameters in each of the model types and special attention will be devoted to characterizing the uncertainty in these estimates. Each critical parameter will be characterized by an empirical probability distribution that will be used in Monte Carlo simulations. We will then quantify the probability that management objectives will not be met because of uncertainty in these estimates and the resulting detection problem.

7.4 Appendix 4. Ocean Acidification – Work Group 4

Background

Human activities, including the burning of fossil fuels, have released vast amounts of stored CO_2 into the atmosphere and approximately 40-50% of this released CO_2 has been absorbed by the ocean. Dissolved CO_2 is naturally occurring in aquatic systems and is used by a variety of marine organisms. Phytoplankton convert this dissolved inorganic carbon to organic carbon through photosynthesis, forming the basis for most marine food webs. In addition, calcifying organisms including some phytoplankton, zooplankton, molluscs, crustaceans, and fish combine the dissolved CO_2 with calcium to form their tests, shells and otoliths.

The oceanic uptake of anthropogenically released CO_2 is significantly impacting marine ecosystems. The dissolved form of CO_2 is carbonic acid and the uptake of CO_2 by the ocean has reduced oceanic pH by 0.1 units, which is equivalent to the ocean becoming 30% more acidic; this process is termed ocean acidification. Decreasing pH may interfere with the ability of organisms to form calcium carbonate structures: tests, shells, and otoliths. Also, changes in pH will alter the fundamental chemical balances in the ocean, potentially affecting the chemical speciation of phosphorus, nitrogen, and other elements that are critical to ocean life. These changes will affect the physiology of most, if not all marine species. Relationships between ocean acidification and hypoxia also have been described in some coastal systems, so organisms may face decreasing pH and decreasing dissolved oxygen. In all, ocean acidification has the potential to significantly affect marine organisms both directly and indirectly, as well as alter ecosystem structure, function and productivity. The direct impact of ocean acidification on living marine resources is largely unexplored and the resiliency of marine ecosystems to acidification is unknown. Given the social and economic importance of marine populations on the northeast U.S. continental shelf, the potential large scale and long-term impacts of ocean acidification must be evaluated.

Objectives

The goal of WG 4 is to develop baselines for ocean acidification indicators and assess the effects of acidification on living marine species.

WG 4 will focus on ocean acidification. The WG will perform an assessment of the effect of ocean acidification on the living marine resources of the Northeast U.S. Continental Shelf Large Marine Ecosystem. This work draws upon three other elements of this Climate Science Program. Process-oriented research (WG 1), monitoring (WG 2), and modeling (WG 3) will be used to develop assessments of the impact of ocean acidification. We chose to identify ocean acidification as a priority topic, because the great sense of urgency to quickly predict the impact of this phenomenon. The potential effects are severe and widespread, and we know little about acidification effects on resource species. Laboratory and field efforts will be directed at collecting specific information for the parameterization of single species and ecosystem models, which will be used to assess the effect of acidification on commercially and recreationally important species and overall ecosystem productivity.

This WG has five specific objectives:

- develop a monitoring program to assess the current state of ocean acidification and monitor its development in the Northeast U.S. Continental Shelf Large Marine Ecosystem;
- conduct laboratory and targeted field studies to quantify the impact of ocean acidification on primary producers, which form the basis of fisheries productivity in the ecosystem;
- conduct laboratory and targeted field studies to quantify the impact of ocean acidification on resource species including both direct effects on calcification and indirect effects on physiology, growth and mortality;
- develop and implement modeling approaches to assess the effects of ocean acidification on single-species dynamics and overall ecosystem productivity; and
- provide a first integrated assessment of the effects of ocean acidification on the Northeast U.S. continental shelf ecosystem.

Statement of Work

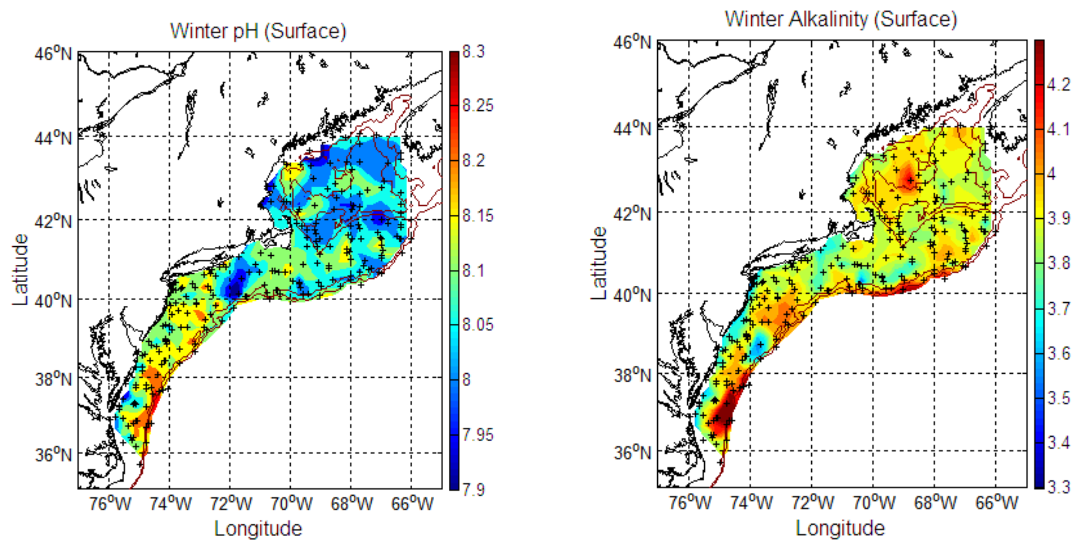
Objective 1 – Monitoring Ocean Acidification

The “state of ocean acidification” on the northeast U.S. shelf must be defined and potential changes in the carbonate chemistry need to be documented as part of larger ecosystem monitoring programs. The long-term monitoring data can then be coupled with forecast models to provide assessments of the effect of ocean acidification on marine resources. The monitoring data will also be used to direct field work and to provide a framework for the studies of the effect of ocean acidification on primary productivity and the dynamics of resource species.

Preliminary analysis of MARMAP data (1977-987, Figure 8) shows spatial variability in pH and total alkalinity, which indicates that measurements are needed over the entire ecosystem to assess the potential effect of ocean acidification on resource species. Further, these observations need to be made both at the surface and through the water column, since few marine species inhabit the surface and there is extensive stratification in different parts of the systems at different times of year.

We propose using the dedicated EcoMon surveys as the primary basis for water column monitoring of ocean acidification. A Seabird Electronics 911+ CTD system with bottle carousel and auxiliary oxygen sensor will be deployed at stations along transect lines extending from the coast to the shelf break (Figure 9). Surface, mid-depth, and bottom samples will be collected and prepared at sea for onshore determination of pH, dissolved inorganic carbon (DIC) and total alkalinity (TAlk). We will also measure a suite of other parameters at these stations to elucidate relationships between ocean acidification, nutrient availability, carbonate formation and dissolved oxygen. An additional 3 days of shiptime will be required for each EcoMon survey and an additional two staff members will be required with expertise to properly collect and prepare chemistry samples. This sampling design will then be re-evaluated after three years based on temporal and spatial variability observed and through a comparison with the MARMAP era data. Additionally, the need for continued sub-surface monitoring will be examined.

Figure 9. Winter climatology of surface layer pH (left) and total alkalinity (right) derived from MARMAP samples (1976-1984).



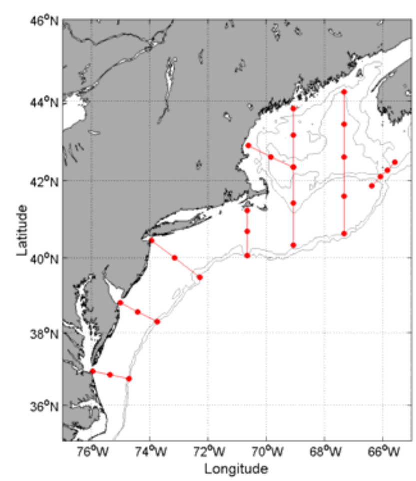


Figure 10. Preliminary sampling design for an ocean acidification monitoring program.

In addition to incorporating monitoring activities into the dedicated ecosystem monitoring cruises, we will coordinate with other researchers measuring dissolved CO_2 in the ecosystem. The goal of this coordination is to develop a merged dataset based on the various ocean acidification activities in the ecosystem. We are already working with AOML researchers who are measuring pCO_2 from vessels in the NEFSC Ship of Opportunity Program. University of New Hampshire has also been measuring pCO2 in the Gulf of Maine and we will work to coordinate these activities. The goal is to provide a comprehensive view of the spatial and temporal variability and long-term trends in dissolved CO_2 in the ecosystem and to use this information to guide field sampling and in the assessments evaluating the effect of ocean acidification on marine resources in the ecosystem.

Objective 2 - Effects on Primary Producers

Ocean acidification can affect primary productivity both directly and indirectly. Many marine phytoplankton are sensitive to changes in pH and temperature. We propose a progression of experiments that increase in complexity to quantify the interactive effects of pH and temperature on phytoplankton growth, physiology, and competition. These experiments will complemented by retrospective analysis of field-collected data and targeted comparative field sampling, with a specific goal of examining some of the effects and relationships observed in the laboratory.

We will start the laboratory experiments with single clonal cultures of marine phytoplankton species. These experiments will be conducted on 15 strains of phytoplankton from 11 classes selected from the over 200 strains that comprise the Milford Microalgal Culture Collection. We will add several calcifying strains (*Coccolithus huxleyi*; *Ochrosphaera neopolitana*) that will be acquired from the Provasoli-Guillard Center for the Culture of Marine Phytoplankton. Cells from each strain will be cultured at different pH's; pH will be manipulated via the addition of CO_2 and emphasis will be on Flow-cytometry will be used to quantify phytoplankton abundance at specified time intervals to estimate cell-division rate. Flow-cytometry will also be used to characterize selected physiological characteristics including nutrient status and internal pH. These experiments will be repeated iteratively with individual strains at different pH, temperature and irradiance levels, thereby constructing a three-dimensional, factorial grid of division rates and particulate-carbon assimilation rates at different pH, temperature, and irradiance levels.

The second stage of experiments will examine the competitive interactions between pairs of microalgal species under varying levels of pH. A factorial design will be used that permits statistical evaluation of both pH and initial population structure upon division rate and outcome of competition. It is impractical to conduct these competition experiments with all possible combinations of strains; therefore, we will select pairs to examine important ecological and physiological contrasts, e.g., calcifying and non-calcifying strains, two calcifying strains, a diatom and a dinoflagellate, a toxic and a non-toxic dinoflagellate, etc. These experiments will provide broad generalizations about likely shifts in phytoplankton community structure at the taxonomic Class level as a consequence of competition modified by ocean acidification. Similar to the single-species experiments, we will estimate cell division rates and percentages of each species at stationary phase, as well as analyze physiological status of both species in culture.

The third stage of experiments will be based on constructed phytoplankton communities with several cultured species (3-5) at equal initial population densities and subject these cultures to pH conditions at and below optima for component species. These experiments will be hypothesis-driven, in terms of ecological principles, e.g., does the presence of a calcifying species modify the interaction between diatom species. The analytical approaches of measuring cell division rates and physiological status will be as described above. These experiments will present a more-realistic simulation of how phytoplankton communities are likely to respond to ocean acidification, but still will be "artificial," in being constructed from pure cultures of species that may or may not co-occur in nature seasonally.

The final stage of experiments will examine the effect of pH on natural phytoplankton communities in the northeast U.S. continental shelf ecosystem. Communities will be studied in different regions across the ecosystem and in different season. These experiments will be piggy-backed on existing NEFSC ecosystem surveys. Small boats will be used to collect natural communities in more nearshore waters and experiments will be conducted at conveniently located facilities (e.g., the Navou will be used to sample coastal New Jersey and experiments will be conducted at the Sandy Hook Laboratory). The same experimental set-up used in the laboratory studies described above will be used for field-based studies, with necessary modifications. Division rates, physiological status and outcomes of competition at nutrient exhaustion will be determined for microalgal species present in these natural communities. These experiments will be much more challenging than the previous sections for several reasons: 1) resolving one species from another with the flow-cytometer may be difficult if co-occurring species have similar optical properties, 2) knowing which visualization on a cytogram is which species will require physical sorting of the samples, using a different instrument, 3) micro-grazers (protozoans) and bacteria will be present; their effects can be analyzed to some extent, but probably not completely, and 4) incubations will likely need to be done *in situ* (for shelf-based work) or near the site from which samples are collected(for more coastal work). Although these experiments will be challenging, they build upon the experience and knowledge gained using clonal cultures in the laboratory and will provide a more realistic view of the effect of acidification on primary producers in the sea.

We also propose retrospective analysis of monitoring data and targeted field collections to examine contrasts that are apparent from the laboratory work. The Ship of Opportunity Program has been collecting data on phytoplankton species composition since 1961. A detailed analysis of the species composition will be conducted and combined with available dissolved CO_2 measurements. This work will determine whether changes in phytoplankton species composition have occurred and evaluate the potential link to ocean acidification. In addition, the monitoring program described above will be used as a source of natural phytoplankton communities to evaluate contrasts that are brought forward by the experiments. There is spatial variability in pH throughout the system. Based on lab results, predictions will be made as to components of the phytoplankton community that should be observed in areas of differing dissolved CO_2. These natural contrasts will inform both future experiments and help in understanding the laboratory results in the context of the natural system.

Objective 3 - Effects on Resource Species

We will conduct experiments to evaluate the direct effects of ocean acidification on calcification of the shell in the Atlantic surf clam and the otolith in black sea bass and the indirect effects of acidification on physiology, growth, and predation of these two species. For invertebrates, shells are an important defense against predators and weaker, less calcified shells may results in increased predation. Also maintaining a shell at lower pH levels may have physiological costs in terms of reproductive output and somatic growth. For fish, the otolith is an important sensory organ and decreases in calcification may affect behavior including feeding and predator avoidance. Similar to Atlantic surf clam, maintaining otolith growth at lower pH may have physiological costs in terms of reproductive output and somatic growth. Atlantic surf clam and black sea bass were chosen to represent a shellfish and finfish species that is commercially harvested on the northeast U.S. shelf. The NEFSC has experience culturing these species, which will greatly facilitate the experimental work. The results of this research will be incorporated in the single species stock assessments through forecasts of the effect of acidification on future sustainable harvest levels.

For Atlantic surf clam, the effect of pH on shell formation, physiology, growth, and predation will be evaluated in culture. Predation effects will be evaluated since changes in shell growth may make Atlantic surf clam more susceptible to size-selective predation, and changes in shell rigidity may facilitate predation at all sizes. Culture techniques for the Atlantic surf clam were developed in the Milford Laboratory 20 years ago. This capability remains current in the Milford Lab. The initial experimental design is straightforward: newly hatched larvae, juveniles, and adults will be reared at varying levels of pH. In larvae, the formation and growth of the shell will be measured. In juveniles and adults, the growth of the shell will be measured. As hemocytes, or blood cells, in bivalves have been shown to participate actively in calcium dynamics and shell deposition, we also propose to conduct flow-cytometric analyses of hemocyte calcium status in clams exposed to experimental pH and temperature treatments. The next set of experiments will examine the effect of pH and temperature on shell formation and growth using a factorial design. The effects of acidification on physiology will then be quantified by measuring oxygen consumption (respiration rate) at varying pH and temperatures levels. These experiments will be coupled with measures of shell growth, somatic growth, energy storage, scope-for-growth, hemocyte calcium status, and reproductive growth (in the adults). We will also evaluate the effect of pH on predation by exposing Atlantic surf clam reared at different pH levels to natural starfish predators in the lab. The rate of predation will be evaluated. The duration of the experiments on early life stages will be shorter than adult life stages, thus the results for adults will come later than the results for larvae and juveniles.

For black sea bass, the effect of pH on otolith formation, growth and predation also will be evaluated in culture. Predation effects will be evaluated since changes in otolith formation may affect behavior and escape responses. The Milford Laboratory has experience culturing black sea bass, which will facilitate working with this species. The initial experiments again are straightforward. Females will be spawned over a range of pH and larvae will be reared. The effects on otolith formation and growth will be measured in larvae, juveniles, and adults. The next set of experiments will examine the effect of pH and temperature on otolith formation and growth using a factorial design. The effects of acidification on physiology will then be quantified by measuring oxygen consumption at varying pH and temperatures levels. These experiments will be coupled with measures of otolith growth, somatic growth, energy storage (condition), and reproductive growth (in the adults). We will use the measurements of growth to estimate mortality based on size-selective mortality theory. The duration of the experiments on early life stages will be shorter than adult life stages, thus the results for adults will come later than the results for larvae and juveniles.

In addition to the laboratory work, we also propose targeted field sampling to use the documented spatial variability in pH (Objective 1) to evaluate whether shell and otolith growth in Atlantic surf clam and black sea bass can be related to ambient pH and carbonate chemistry. These targeted collections will be made as part of the Ecology of Coastal Ocean Seascapes project ongoing at the Sandy Hook laboratory, as well as during the Center's standard resource surveys. Locations will be chosen based on dissolved CO_2 distribution resulting from the monitoring program. This work will include the collection of species of interest (Atlantic surf clam and black sea bass), as well as the collection of DIC and TAlk samples to verify chemical conditions at the time of collection. The purpose of this component it to evaluate whether there are already signals of the effect of pH among species in the ecosystem.

Also as part of this proposal, we will initiate a focused effort on culturing sea scallops. This species is notoriously difficult to culture, but is currently the most valuable fishery species in the United States. Studying Atlantic surf clam will provide first order information on the impact ocean acidification on marine shellfish, but an important need is understanding the effect of ocean acidification specifically on sea scallop. Once culturing methods are developed, a similar series of experiments described for surf clams will be conducted on sea scallops. Work with the adult stages should be possible by year 2 and work with early life stages may be possible by year 3 or 4.

<u>Objective 4 – Population and Ecosystem Modeling</u>

The results of the surf clam and black sea bass research will be used to parameterize population models for these two species relative to different levels of dissolved CO_2 in the system. From the experiments with adults, models will be parameterized with the effects of acidification on growth, reproductive output, and natural mortality. The experimental results from larvae and juveniles will be included in to population models as recruitment effects. These models will then be used to forecast population productivity under several acidification "scenarios" which will be developed based on IPCC carbon emission scenarios and resulting forecasts of dissolved CO_2 on the northeast U.S. shelf. Comparison of the MARMAP data with present day data will assist with estimating dissolved CO_2 from atmospheric CO_2. These forecasts will have a range of uncertainties, which we will try to capture, but the goal is to provide an initial assessment of the effect of ocean acidification of marine resource species over the coming decades and through the coming century.

The results of the research on phytoplankton will be used to assess the effect of ocean acidification on system-wide productivity and phytoplankton community structure, as food quality may be as important as bulk quantity. Fisheries productivity in any system is linked to primary productivity. Based on measures of primary productivity on the northeast U.S. shelf, estimates have been developed of total sustainable fishery extractions and these have been presented at the recent Groundfish Assessment Review Meeting (GARM). From the results of the experimental and field work, forecasts will be made of changes in the phytoplankton community resulting from decreasing pH. These forecasts will be used to estimate system-wide primary productivity, which will be converted to fishery production using the trophic-transfer approach applied in the GARM. Similar to the single species modeling, there will be a degree of uncertainly in this modeling exercise which we will include in the model formulation.

Additional modeling efforts will be developed as more information is generated during the course of laboratory and targeted field studies. The EMAX, Atlantis or NEMURO models could be used. However, our initial modeling efforts will be aimed at understanding the first-order effects of ocean acidification on a handful of resource species and on overall system productivity. As more information becomes available, more complicated (and realistic) models can be used to investigate the effect of acidification on northeast U.S. marine resources

Objective 5 – Assessment of the Effects of Ocean Acidification

The work described above is directed towards the development of an assessment of the effect of ocean acidification on the northeast U.S. continental shelf ecosystem. The audience of the assessment will be scientists and policy-makers alike. The form of the assessment will be similar to other Integrated Assessments produced within NOAA. The assessment will draw heavily on work done as part of this project, but will also incorporate the results of all research that is relevant. There are several groups that are working within the northeast U.S. shelf region (e.g., UNH, AOML, WHOI) and there will certainly be additional research conducted around the globe that will be relevant. This document will provide the first regionally-specific assessment of the effects of ocean acidification and serve as a tool for identifying critical gaps in our understanding and providing a basis for future research to fill these knowledge gaps. Importantly, this assessment will provide a quantitative framework describing the effects of ocean acidification on resource species in the northeast U.S. continental shelf ecosystem.

7.5 Appendix 5. Advice – Work Group 5

Background

Marine resource management is based on the explicit assumption that exploitation is the dominant factor shaping marine populations and the implicit assumption that ecosystems and the populations they support are at equilibrium over the long-term. The resulting management strategies emphasize that populations can be controlled through adjustments to fishing rate - 'recovery' is sought through reductions in effort. However, it is now generally accepted that the climate is changing and that these changes will have broad impacts on marine ecosystems. To successfully manage marine resources now and into the future, we need to accept not only that the climate is changing, but that it is the dynamic interplay between resulting ecosystem change and exploitation that will determine the productivity and sustainability of living marine resources.

Climate change will result in large and potentially irreversible changes in the marine environment, forcing us to accept that marine ecosystems are not at equilibrium. These changes include rising sea level, increased stratification, changing nutrient supply, increased acidification of ocean waters, alterations in physical forcing (large-scale ocean currents, local wind, precipitation), and the list goes on. These physical changes in the ecosystem will result in a cascade of effects that will directly and indirectly influence all living marine resources. Furthermore, these climate-related changes will exacerbate the impacts of habitat alteration and coastal eutrophication (*i.e.*, nutrient pollution), and may potentially alter the influences of natural long-term oscillations (e.g., El Niño, North Atlantic Oscillation) on productivity of marine systems.

On the northeast U.S. continental shelf, a number of exploited species is over-fished and a number of protected species remain endangered. Many current management plans strive to rebuild fisheries to sustainable levels and to return protected species from the brink of extinction. Yet these management strategies assume that the ecosystems on which these species depend are at equilibrium – variable but with no long-term trends. We know that this assumption is not valid: ecosystems are not static and unprecedented, long-term changes related to climate are happening now. Thus, we recognize an approaching dilemma - sustainable management could become unsustainable in the face of climate change.

We propose to develop an adaptive ecosystem-based strategy to sustain and rebuild populations of managed species in the northeast U.S. continental shelf ecosystem. This strategy will explicitly include the effects of climate change in single species and ecosystem assessments. Ultimately, this effort will promote the long-term, sustainable management of the region's living marine resources in the face of climate change.

Objectives

The goal of WG 5 is to synthesize products from the Climate Research Program to develop products to support fisheries and ecosystem-based management..

Keeping in mind that the overall goal of the proposed Climate Research Program is to provide assessments of the effect of climate change on habitats and biota and to communicate these results to managers, the Advisory WG will integrate discrete research products to provide fisheries advice to NEFSC clients including the New England and Mid-Atlantic Fishery Councils, Atlantic States Marine Fisheries Commission and various State fisheries and environmental agencies. Other potential customers include the NOAA Ecosystem and Climate Goal Teams, academic institutions, non-profit organizations, and industry groups. The products will take many forms, but we will emphasize tailoring the advice to the needs of resource managers, with the overall goal of informing managers of the possible consequences of climate change including gradual and dramatic shifts in abundance, distribution and production of living marine resources, changes in essential fish habitat (EFH), changes to the status of protected species, and changes in overall productivity and trophic structure in the Northeast U.S. Continental Shelf Large Marine Ecosystem.

Specifically, this WG will coordinate the development of three types of products:

- ecosystem status reports and Integrated Ecosystem Assessments (IEA);
- climate forecasts for specific managed stocks incorporated into the stock assessment process; and
- regional climate impacts reports.

Statement of Work

<u>Objective 1 – Ecosystem Status Reports & Integrated Ecosystem Assessments</u>

Climate change will impact the properties of the entire northeast U.S. continental shelf ecosystem including physical forcing, timing of migrations, susceptibility to invasive species, and overall productivity. These impacts will be simultaneous and complex, with numerous interactions and masking effects (e.g., influx of cold, fresh water from the melting ice in the north limiting the local warming signal). The Climate Research Program will work to incorporate an understanding of these complex processes into ecosystem-level information in support of Ecosystem Based Management.
To this end, the Climate Research Program will contribute to Ecosystem Status Reports (ESR) and Integrated Ecosystem Assessments (IEA), which are produced by Ecosystem Assessment Program (EcoAp). The ESR will provide an overview of the present state of the ecosystem from climate and human drivers, to physical pressures, to ecosystem state, to impacts on resources. An IEA, on the other hand, is a synthesis and analysis of relevant natural and socioeconomic factors, in relation to specified ecosystem management objectives. The ESR will provide information for use in the IEA, but the IEA is a formal assessment of resource and ecosystem status relative to stated management objectives.

Standard monitoring and modeling products from the Climate Research Program will be incorporated into the ESR and IEA process. This require close collaboration between the EcoAP group and scientists involved in the Climate Science Program, which will in part be achieved by the direct involvement of EcoAP staff in the Climate Science Program and vice versa. This will also be achieved, through the inclusion of climate drivers in the ESR and consideration of climate effects in the IEA. These steps will ensure that information and assessments generated in the Climate Science Program will be used in regional Ecosystem-Based Management.

Objective 2 – Single-species management advice

The current focus of NMFS is providing single species stock assessments. The results of the Climate Research Program will be incorporated into these assessments. As an example, temperature effects on recruitment and growth have been incorporated into a population model of Atlantic cod (Figure 9). This model predicted that maximum sustainable yield (MSY) of cod will decrease with climatic warming and these results imply that benchmarks set without the consideration of climate change may be too high and may lead unknowingly to unsustainable management practices even under stringent rebuilding plans. A counter example is provided by Hare et al. (submitted) working with Atlantic croaker. A mechanistic recruitment hypothesis was incorporated into a population model, which was then coupled to various climate scenarios. This coupled population-climate model predicted that with increasing warming, MSY of Atlantic croaker would increase and the range would extend northwards. This contrast between Atlantic cod and Atlantic croaker illustrates that in any region, some species will be positively affected while other species will be negatively affected by climate change.

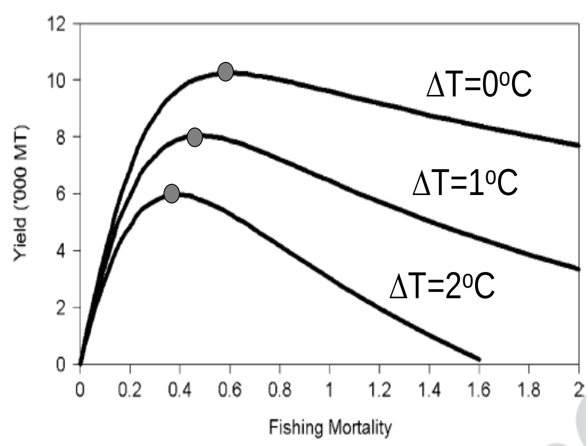


Figure 11. Yield curves for Gulf of Maine Atlantic cod under different warming scenarios including current conditions (ΔT=0°C), and changes of 1 and 2 °C. Maximum sustainable yield (MSY) is indicated by the circles. With temperatures increasing by 2°C, MSY decreases by ~ 40% and the Fishing rate at MSY decreases by 35%. Fogarty et al. 2008. Mitigation and Adaptation Strategies for Global Change 13: 453-466.

The forecasts of the above examples were developed based on a 50-100 year climate predictions, which have minimal relevance to near-term fisheries management. As stated in the modeling section, the Climate Science Program will work toward providing forecasts at three scales to assist fisheries managers in understanding the near-, mid-, and long-term effects of climate change.

These above examples are based on delayed-difference population models. The Climate Science Program will also work with other types of models to provide single-species management advice. A specific focus will be spatially-explicit population models based on our whole life-history-individual-based models. Simple spatially-explicit models demonstrate the importance of spatial processes to population dynamics (lobster, yellowtail flounder). Also, research studies indicate that fishery populations can have substantial spatial structure even if they are managed as one stock (weakfish) and that exploitation can have important spatial patterns as well (e.g., presence of closed areas on Georges Bank). However, the impacts of spatial dynamics are rarely included in stock assessment models. Further, the impacts of changing spatial dynamics resulting from climate change are largely unknown. We will work use our mechanistic understanding of the effect of climate change on populations to develop forecasts of changes in spatial dynamics. We will then use this information to build and parameterize whole life cycle models to examine the effect of spatial dynamics on the assessments of focal species and.

The forecasts of single-species dynamics will be provided to fishery managers through the standard stock assessment process. The Climate Science Program will work closely with the NEFSC stock assessment scientists to provide valuable additions to their scientific advice The focal species are managed by a range of fishery management councils, so the Climate Science Program will interact with fishery managers and management councils across the region.

Objective 3 – Regional Climate Impact Report

The first Regional Climate Impact Report was published in 2008 and includes regional descriptions for the entire nation including the northeast U.S. continental shelf ecosystem. The current state of the environment was described and the major effects of climate change on various components of the ecosystem were identified. This region-specific information will be updated and consolidated on an annual basis using information generated by the Climate Science Research Program. In one sense, this will serve as an Annual Report for the Climate Science Program and in another sense. In another sense, this report will serve as a summary of the current state of the climate and a synthesis of the anticipated impacts of climate change on resource species and ecosystem properties of the northeast U.S. shelf. We will also seek input from our stated customers as to how the report can be improved to better meet their needs. Thus, our climate assessment will be an adaptive document with the content changing as new information becomes available and as users seek new information regarding the effect of climate change on species and ecosystems.

7.6 Appendix 6. Program and Data Management – Work Group 6

Background

The Climate Science Program is a large scientific effort that is spread across the NEFSC including multiple Divisions and Laboratories. The Program will need to be well managed to be fully successful. Additionally there will need to be excellent communication within the program, between the program and other elements of the NEFSC, and with our external customers. The program is designed as top-down, with defined products. This is not to say that bottom-up ideas and input will not be considered; rather the top-down nature of this program recognizes that there are specific deliverables that must be met.

Objectives

The goal of WG 6 is to manage activities within the Climate Research Program to ensure that research, monitoring, modeling and provision of advice are synergistic and coordinated.

The Climate Research Program is a large complex scientific effort with participation throughout the NEFSC including multiple divisions and laboratories. Coordination of activities through proper management of this program will be indispensable for success. We propose a hierarchical approach with defined deliverables. Program and Data Management will be responsible not only for coordinating research but for ensuring there are proper communications both internally and with external partners and clients. Further, data management will be a key responsibility of this WG. This will be achieved through a dedicated Program database and links to existing NEFSC and other data repositories.

Proposed Management Structure

To fully achieve our objectives we propose five organizational units: .

1) Program Leader or co-leaders
    a) Main functions include:
        -Interface with Directorate and external clients.
        -Interface with Scientific Steering and Review Committees
        -Review and approve advice
        -Coordinate activities of the Work Groups

2) Work Group Leaders
    a) Main functions include:
        -Lead and coordinate activities within the Work Group
        -Coordinate work with related objectives in other Work Groups
        -Review and approve Work Group products
        -Ensure that data are quality controlled and available to all Program scientists
        -Identify emerging science priorities and communicate to the Program Leader

3) Objective Leaders
   a) Main functions include:
      -Lead and coordinate activities to achieve the research objective under a Work Group
      -Report to Work Group and Program Leaders
      -Identify emerging science priorities

4) Scientific Steering Committee
   a) Main functions include:
      -Provide general program oversight
      -Interface with Program Leader(s) to promote cooperation within the Program
      -Interface with Program Leader(s to identify and where possible provide resources to achieve unsupported tasks required to achieve Program goals and objective\
   b) Composed of Program Lead, Work Group Leaders, and some NEFSC Executive Staff

5) External Review Committee
   a) Main functions include:
      -Review products of the Program
      -Review efficiency of operations
      -Provide advice to improve program products
      -Conduct review of program for NEFSC Science Director
   b) Composed of five outside scientists with expertise reflective of Work Group goals

Proposed Communication Actions

To ensure communication within the Program and outside of the program, we propose three specific strategies

1) The Program Leader will meet with each work group every quarter. These meetings will focus on progress and problems as seen by all participants in the work group. These meetings will also help the Program Leader encourage links between work groups.

2) The Scientific Steering Committee will meet every quarter to review program progress and discuss problems. The SSC meetings will help maintain links between the Work Groups.

3) An Annual Science Workshop will be held to bring program participants together to present results, discuss ideas, and make connections. Outside scientists will also be asked to participate if they are involved in the related research, developing similar assessments, or are users of the products generated. External review will be conducted at this meeting.

4) Program scientists will give seminars at each NEFSC facility describing results from the Climate Science Program to assist with exchange within the NEFSC

5) Program scientists will be expected to present results at scientific, fisheries-management and other relevant workshops and meetings to ensure broad dissemination of correctly interpreted program results

6) Program participants will be expected to publish program results in scientific peer-reviewed journals

7.7 Appendix 7. Unsupported Resource Needs

Summary of unsupported needs by Work Group. Details for each Work Group are shown after the summary table, below.

				Year			
	in $1,000	**1**	**2**	**3**	**4**	**5**	**TOTAL**
WG 1	**Process Studies**	2,008	1,903	2,014	1,632	1,737	9,294
WG 2	**Monitoring**	2,752	2,391	2,527	2,687	2,842	13,200
WG 3	**Modeling**	1,588	1,636	1,742	1,856	1,983	8,805
WG 4	**Ocean Acidification**	1,349	933	941	951	1,001	5,174
WG 5	**Advice**	319	338	369	402	439	1,867
WG 6	**Prog & Data Mgt**	203	203	228	228	228	1,090
	Total	**8,219**	**7,404**	**7,821**	**7,757**	**8,230**	**39,430**

Work Group 1 – Process Studies

Budget (in $1,000's)

		in $1,000's	**Year**				
Objective	**Category**	**Details**	**1**	**2**	**3**	**4**	**5**
1	GS-6 (2) equiv	Retrospective Analyses $40k ea + 54% oh	124	130	137		
	NRC (2)	Retrospective Analyses	140	130	137		
	Computers		10				
	Supplies		6	6	6		
	GS-8 (2)	Laboratory Analysis Technician	118	130	143	157	173
	GS-13	Lead Laboratory Studies	111	122	134	148	163
	NRC (2)	Laboratory Studies	140	130	137	143	150
	Lab Equipment		100				
	Sample Analysis		50	50	50	50	50
	Lab Supplies		50	50	50	50	50
	GS-8 (3)	Field Technicians	177	195	214	236	259
	Field Equipment		50				
	Field Supplies		50	50	50	50	50
	Shiptime (40DAS)		200	200	200	200	200
	Subtotal		**1326**	**1193**	**1257**	**1034**	**1095**
2	GS-6 (1) equiv	Retrospective Analyses	54	57	60		
	NRC (1)	Retrospective Analyses	140	130	137		
	Computers		5				
	Supplies		3	3	3		
	GS-12	Laboratory Studies	94	103	114	125	138
	GS-8 (1)	Laboratory Technician	59	65	71	79	86
	Contractor	Laboratory Technician	74	78	82	86	90
	NRC (1)	Laboratory Analyses	70	65	68	72	75
	Computers		10				
	Lab Supplies		10	50	50	50	50
	Equipment		15				
	GS-8 (2)	Field Technicians	118	130	143	157	173
	Field Supplies		30	30	30	30	30
	Subtotal		**682**	**711**	**757**	**598**	**642**
	TOTAL		**2008**	**1903**	**2014**	**1632**	**1737**
	contractors	54% overhead, 5% annual inflation					
	FTEs	NY GS schedule, 23% benefits, 10% inflation					
	NRC	$45k starting salary, 20% benefits, PCS costs 1st year, $2k travel budget, add'l 1K for each year experience after PhD					

Objective 1

Retrospective Analysis – Two 3-year contract employees (GS-6 equivalents) to perform the literature searches. Two 3-year NRC post-docs to perform the retrospective analyses of extant databases. Funds for computer equipment in year 1 and supplies and miscellaneous expenses in year 1-3.

Laboratory Work - Two FTEs (GS-8 equivalents,) to participate in the experiments for the duration of the project, one FTE (GS 13 equivalent) and two NRC post-docs to participate in the experiments for the duration of the project, equipment and supplies to initiate experiments in year 1, and expendable laboratory supplies in each year.

Field Studies – Three term-employees (GS-8 equivalents) to participate in the field work and to analyze samples. Funds are also requested for initial equipment purchases, sample analyses, expendable supplies per year, and 40 days of shiptime on the Navuo and the Gloria Michele.

Objective 2

Retrospective Analysis – One 3-year contract employees (GS-6 equivalents) to perform the literature searches. 1 3-year NRC post-docs to perform the retrospective analyses of extant databases. Funds for computer equipment in year 1 and supplies and miscellaneous expenses in year 1-3.

Laboratory Work – One FTE (GS 12) to work on laboratory studies. One FTE (GS 8) and one contract employees (GS-8 equivalents) to participate in the experiments for the duration of the project, and one NRC post-docs to participate in the experiments for the duration of the project. Computers, equipment and supplies to initiate are requested for year 1. Expendable laboratory supplies are also requested for out-years.

Field Studies - Two term employees (GS-8 equivalents) to participate in the field work and to analyze samples. Funds are requested for expendable supplies per year.

Work Group 2 – Monitoring

Budget (in $1,000's)

			Year				
Objective	**Category**	**Details**	**1**	**2**	**3**	**4**	**5**
1	GS-14	Lead water chemistry and productivity	132	145	160	176	193
	GS-9 (2)	CTD rosette technicians	178	196	215	237	261
	FRFF		50				
	Nutrients		50				
	Supplies		50	50	50	50	50
	GS-13	invertebrate larvae scientist	111	122	134	148	163
	GS-7	invertebrate larvae technician	63	69	76	84	92
	Decapods	sorting and id costs	75	75	75	75	75
	Molluscs	sorting and id costs	75	75	75	75	75
	GS-9	fish larvae technician	65	72	79	87	95
	DAS		144	144	144	144	144
	Subtotal		**993**	**948**	**1008**	**1075**	**1148**
2	GS-7 (2)	benthic monitoring technicians	121	133	146	161	177
	Supplies		20	20	20	20	20
	DAS		168	168	168	168	168
	Sample		160	160	160	160	160
	Equipment	new technologies	150	150	150	150	150
	Subtotal		**619**	**631**	**644**	**659**	**675**
3	GS-9 (2)	Programmers	128	141	155	170	187
	GS-13 (1)	Fisheries / Satellite oceanographer	110	121	133	146	161
	Computers		10			10	
	Software		10	10	10	10	10
	Supplies		10	10	10	10	10
	Subtotal		**268**	**282**	**308**	**347**	**368**
4	GS-13	IT Specialist - Data Center Lead	110	121	133	146	161
	GS-9	Database Programmer	64	70	77	85	94
	GS-9	Programmer	64	70	77	85	94
	GS-12	Time series researcher	94	103	114	125	138
	Computers		300				
	Maintenance		25	25	25	25	25
	Upgrades		25	25	25	25	25
	Software		70	70	70	70	70
	Supplies		20	20	20	20	20
	Facilities		100	25	25	25	25
	Subtotal		**872**	**530**	**567**	**607**	**651**
	TOTAL		**2752**	**2391**	**2527**	**2687**	**2842**

Objective 1

For the primary productivity and water chemistry additions to the EcoMon program, we request a GS-14 to lead these efforts and two sea-going term employees (GS-9) to staff the cruises. These employees need to be trained in the operation of a CTD/rosette system and have the ability to analyze chemical samples at sea and in the laboratory. Additionally, we request funds for a wet chemistry nutrient profiler, Fast Repetition Rate Fluorometer and annual expendable supplies and maintenance. To add data on larval mollusks and decapod crustaceans, we request a GS-13 to lead and a term technician (GS-7 level) to support these efforts. In addition, funds for processing plankton samples for mollusks and decapod crustaceans annually are requested. For the ichthyoplankton component, a GS-9 technician is required to contribute to the identification of fish larvae to maintain quality control over the 30+ years of data. In addition, we request 3 extra days of ship time per cruise to support the added activities. It is also important to state that funding for the basic EcoMon program needs to remain at current levels.

Objective 2

We request two sea-going term technicians (GS-7) to support the Benthic Monitoring activities. The lead for this aspect of the project will come from current staff. We also request funds for 14 sea days in addition to participation on the clam and scallop surveys, annual expendable supplies and maintenance, and funds for annual processing of benthic samples. Annual improvements in instrumentation using advanced sampling technologies in years 1-5. Priorities include *in situ* video (year 1); side-scan sonar (year 3); shallow water multibeam echosounder (years 4 and 5); housing / sled for instrumentation) (year 2)

Objective 3

We request one GS-13 to participate in remote sensing activities and two programmers (GS-9) to aid in the development of value added products. We also request computer equipment, software licenses, and miscellaneous supplies.

Objective 4

We request 3 support positions and 1 scientific position to support the data center: one IT specialist (GS-13), one database programmer (GS-9), one programmer (GS-9) and one researcher (GS-12) to develop value added data products to bridge between the monitoring programs, and the research, modeling and assessment activities. In addition, we request computer systems to support the data center (in Y1) and annual costs for maintenance, upgrades, software licenses and miscellaneous supplies. Depending on the location of the data center facility upgrades may be necessary in terms of internet connectivity, cooling, and storage racks.

Work Group 3 – Modeling

Budget (in $1,000's)

			Year				
Objective	**Category**	**Details**	**1**	**2**	**3**	**4**	**5**
1	GS-12	IBM/Ocean Circulation Modeled	93	102	113	124	136
	GS-12 (2)	Ecological Modelers	186	205	225	248	272
	NRC	post-doc to support modelers	70	65	72	79	87
	Computer		10				
	Software Licenses		20	20	20	20	20
	Supplies		10	10	10	10	10
	Subtotal		**389**	**402**	**439**	**480**	**525**
2	NCAR	Support to NCAR for Climate Modeling	200	220	242	266	293
	GFDL	Support to GFDL for Climate Modeling	200	220	242	266	293
	NARCI	Support for CI Ocean Modeling	500	500	500	500	500
	GS-12	Climate/Ocean Modeler to Link	93	102	113	124	136
	Annual Workshop		50	50	50	50	50
	Supplies		5	5	5	5	5
	Subtotal		**1048**	**1097**	**1152**	**1211**	**1277**
3	NRC (2)	post-doc to preform Risk Analyses	140	130	144	158	174
	Computer		4				
	Software Licenses		5	5	5	5	5
	Supplies		2	2	2	2	2
	Subtotal		**151**	**137**	**151**	**165**	**181**
	TOTAL		**1588**	**1636**	**1742**	**1856**	**1983**
	FTEs	NY GS schedule, 23% benefits, 10% inflation					
	NRC	$45k starting salary, 20% benefits, PCS costs 1st year, $2k travel budget, add'l 1K for each year experience after PhD					

Objective 1

One FTE (GS-12) will be supported to participate in the IBM-ocean circulation modeling. The person will have expertise in the implementation of these models, not in the underlying physics. The expectation is to be able to layer the IBM components are archived flow fields from several circulation models. Support for two FTEs (GS 11-13) and one NRC post-doc is requested to be involved in the bioenergetic, delay-difference, and trophic transfer models. We also request funds for computers in year 1, annual software licenses, and annual expendable supplied.

Objective 2

To facilitate the development of climate modeling products for this effort, NCAR and GFDL will receive funding to support a PI and a technician. The use of both the NCAR and GFDL models with support the ensemble based approach advocated in the research plan. Funds are also requested for a grant to have research preformed into linking climate models and regional ocean circulation models; these funds will be expended through the North Atlantic Regional Cooperative Institute. A scientist (GS-12) will be hired at the NEFSC to make the links between climate model outputs and ecological models with the goal of developing forecasts and assessments. In addition, support for an annual workshop is requested to provide a venue for climate modelers, oceanographic modelers and ecological models to exchange information and ideas (50K per year). Supplies are also requested (5K).

Work Group 4 – Ocean Acidification

Budget (in $1,000's)

			Year				
Objective	**Category**	**Details**	**1**	**2**	**3**	**4**	**5**
1	DAS		144	144	144	144	144
	OT	for current employees	25	25	25	25	25
	CTD upgrades		30				
	CTD sensors		10				
	Sample processing		65	65	65	65	65
	Maintenance and Supplies		30	30	30	30	30
	Subtotal		**304**	**264**	**264**	**264**	**264**
2	Sorting Flow-cytometer		300				
	pH control system		30				
	Maintenance and Supplies		70	70	70	70	70
	Subtotal		**400**	**70**	**70**	**70**	**70**
3	Contractors (2)	Laboartory Technicians (GS-8 equa)	170	179	187	197	207
	NRC (2)	Laboratory Studies	160	160	160	160	160
	Equipment		50				
	Supplies		50	50	50	50	50
	Culture of Sea Scallops		100	100	100	100	100
	Subtotal		**530**	**489**	**497**	**507**	**517**
4	NRC (1)	Modeling	80	80	80	80	80
	Computers		5				
	Supplies		10	10	10	10	10
	Subtotal		**95**	**90**	**90**	**90**	**90**
5	Travel						10
	Outside Review						30
	Subtotal		**0**	**0**	**0**	**0**	**40**
6	Travel		18	18	18	18	18
	Supplies		2	2	2	2	2
	Subtotal		**20**	**20**	**20**	**20**	**20**
	TOTAL		**1349**	**933**	**941**	**951**	**1001**
	contractors	54% overhead, 5% annual inflation					
	FTEs	NY GS schedule, 23% benefits, 10% inflation					
	NRC	$45k starting salary, 20% benefits, PCS costs 1st year, $2k travel budget, add'l 1K for each year experience after PhD					

Objective 1

Costs include 3 extra days of ship time four time per year, overtime for two additional employees, upgrades and maintenance for the 911 CTD system in year 1, additional sensors for the 911 CTD system in year 1, DIC and Talk sampling processing at a NOAA-core facility under development, and funds for annual calibration of 911 systems, water bottle and collection supplies and software maintenance agreements.

Objective 2

Costs include a sorting flow-cytometer in year 1, a pH control system in year 1 and funds for supplies, maintenance agreements, and miscellaneous expenses in each of five years.

Objective 3

Costs include two contract employees to participate in the experiments for the duration of the project, and two NRC post-docs to participate in the experiments for the duration of the project, equipment and supplies to initiate experiments in year 1, expendable laboratory supplies in each year, and shiptime, supplies, and sample processing for targeted field work. In addition, we request funds to support an effort to culture sea scallops. The contract employees and post-docs will also be involved in this work.

Objective 4

Costs include an NRC post-doc to participate in the modeling, computer equipment for the post-doc in year 1, and miscellaneous supplies to support modeling activities through the duration of the project.

Objective 5

costs included travel for the PI’s to meet in the development of the assessment and funds to run a peer-review process similar to the GARM process.

Oversight

Includes travel for project investigators to meet and coordinate, to provide for travel to key scientific and policy meetings, and to pay for publication charges for papers resulting from the proposed research.

Work Group 5 – Advice

Budget (in $1,000's)

All participants in the Climate Science Program are expected to participate in the development of the assessments and forecasts. Thus, the costs associated with these element are fairly low and leverages from support to the other elements of the plan. By having the researchers, modelers, and observers involved and responsible for the development of these products, we hope to bring state-of-the-art science to our assessments and forecasts.

			Year				
Objective	**Category**	**Details**	**1**	**2**	**3**	**4**	**5**
1	GS-12 (1)	Ecosystem link to ESR and IEA	93	102	113	124	136
	Computer		3				
	Supplies		2	2	2	2	2
	Subtotal		**98**	**104**	**115**	**126**	**138**
2	GS-12 (2)	link to Single-species Assessments	186	205	225	248	272
	Computers		6				
	Supplies		4	4	4	4	4
	Travel		17	17	17	17	17
	Subtotal		**213**	**226**	**246**	**269**	**293**
3	Travel		5	5	5	5	5
	Supplies		3	3	3	3	3
	Subtotal		**8**	**8**	**8**	**8**	**8**
	TOTAL		**319**	**338**	**369**	**402**	**439**
	FTEs	NY GS schedule, 23% benefits, 10% inflation					

Objective 1
Support for 1 FTE (GS-12) is requested to link data from the Climate Science Program to the Ecosystem Status Reports and the Integrated Ecosystem Assessments. In addition, support is requested for a computer in year 1 and supplies annually.

Objective 2
Support for 2 FTEs (GS-12) is requested to work with the NEFSC Population Dynamics Branch with the goal of integrating the results of the Climate Science Program into single-species management advice. Funds for computers (in year 1), and annual supplies are also requested. In addition, a moderate travel budget is requested to ensure that the results of the Climate Science Program are communicated to the regional Fishery Management Councils.

Objective 3

The Climate Impacts Report will be created by a team of scientists that are part of the Climate Science Plan. The only additional costs are for annual travel to get this tea, together and supplies related to the development, production, and distribution of the report.

Work Group 6 – Program and Data Management

Budget (in $1,000's)

		Year				
Category	**Details**	**1**	**2**	**3**	**4**	**5**
WG Meetings		15	15	15	15	15
SSC Meetings		9	9	9	9	9
Annual Science Conference		100	100	100	100	100
External Review Committee		9	9	9	9	9
Laboratory Seminars		10	10	10	10	10
Scientific and Management Meetings		50	50	75	75	75
Publications		10	10	10	10	10
Subtotal		**203**	**203**	**228**	**228**	**228**