Proceedings of the ECOHAB/GLOBEC Gulf of Maine Modeling Workshop

Management and scientific informational needs for
harmful algal bloom and fisheries forecasting in the
Gulf of Maine

A framework for moving toward an
operational capability

Portland, Maine
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Executive Summary

The Center for Sponsored Coastal Ocean Research (CSCOR) held a workshop from June 17-18th, 2002 in Portland, Maine to facilitate the transfer of model-based research products into the hands of managers and stakeholders for environmental decision-making. Researchers in applied modeling activities and representatives of various public agencies met to discuss; 1) the current capabilities of biophysical models developed as part of ongoing ECOHAB and GLOBEC research efforts, 2) the information and decision needs of coastal resource managers concerned with harmful algal bloom and fishery resources in the Gulf of Maine and 3) the identification of areas to focus future research activities and resources around common model and management goals. Over the two-day workshop, presentations and discussions focused on the following two themes:

Model issues: What are the capabilities of the current models? What types of information can they produce? What types of data are needed to initialize and run the simulations? How might the models be used to make environmental decisions?

Management issues: What are the day-to-day decisions made by coastal resource and fisheries managers? What are the types of information needed to make these decisions? What key products or types of information would be beneficial? Is there a role for models or model output in the decision-making process?

The goal was to highlight the potential uses, information needs, and infrastructure necessary to transition these research models to the management community. Some of the key recommendations on how to proceed with this difficult and complex task are as follows:

Research: Continue basic research funding to fill in critical knowledge and data gaps especially with respect to physical-biological interactions, multispecies dynamics, and life history traits. By determining the dominant process for a given set of conditions, the appropriate model can be employed to address the question of interest.

Management: A list of potential model products needs to be defined that would be of interest to managers. This list can then be used to help define the type of forecast to be attempted (e.g. guidance vs. operational, daily vs. strategic), to determine the level of forecast accuracy and to identify realistic model products.

Model Development: Future development efforts should focus around a core group of models that represent a hierarchy capable of addressing a wide range of management issues. The simulation of near-shore hydrodynamics has to be improved so that problems of interest to coastal managers (e.g. bloom trajectory, larval transport) can be addressed with greater resolution and skill. Any models used for environmental decision-making have to be well documented (i.e. published), tested (i.e. a comprehensive assessment of model accuracy, error and uncertainty) and proven (i.e. success stories) so managers can make informed decisions fully aware of the limitations of model simulation results. A model interface standard should be developed to facilitate the use of multiple models and to allow comparisons between different model formulations.

Model Transition: The interactions between modelers and managers must be maintained throughout the transition process if the full potential of developed model products is to be realized. Model output should be user friendly and presented in a format that is interpretable and can be readily used by managers. Forecasting capacity for model products should be developed incrementally to build skill, confidence, familiarity and trust within the management community and public. Proposed forecasts should be supported by cost-benefit types of analyses to demonstrate societal benefits and to justify continued funding. An observational system to support proposed model forecasts that includes regional observing systems, ship transects, and field studies must be expanded upon.

Future workshops are planned to address some of these highlighted needs and issues. A logical next step would be for the model researchers, resource managers, and other interested stakeholders to meet and build upon the information presented at this workshop. Now that the ECOHAB and GLOBEC modelers have an idea of the management needs and the managers have an idea of the current model capabilities, these groups should define a "restricted" set of "realistic" model products that would be of interest to "both" communities. Which are the key model products that managers would like to see implemented and which ones could be addressed with the current model capabilities and within funding constraints. Some capacity for prediction already exists with the trajectory and physical transport models and these could be candidate projects for expansion.

This workshop has provided the foundation upon which to continue future model transition efforts in the Gulf of Maine. Because the research and management community do not interact often on a regular basis, getting the two groups to sit down and express their information needs and capabilities is a good first step. Judging by the long list of research and model needs there are obviously many hurdles that still need to be overcome. But this task is not impossible and if a model transition effort could be successful anywhere it would likely be in the Gulf of Maine (i.e. availability of extensive data sources, well-developed management structures, long history of basic research and problems of societal and economic importance). Hopefully, the ideas and issues presented at the workshop will frame the model transition pathway to be followed in the coming years and result in model products capable of providing ecological forecasting for the safeguarding of local economies and the public health.

Introduction

The Gulf of Maine is a large, semi-enclosed basin along the northeast coast of the United States covering approximately 130,000 km^2. The region supports a vast fishery resource from extensive shellfish and aquaculture operations along the coast and groundfish harvests from the highly productive Georges Bank region. Fluctuations in fish stocks (e.g. from harvesting and natural variability) and Paralytic Shellfish Poisoning (PSP) have a dramatic effect on the value of these resources, the sustainability of their natural populations and sometimes the public health (e.g. exposure to contaminated shellfish). Resource managers have the difficult task of having to allow harvesting while also protecting the public from shellfish contamination and the fishery stock from overharvesting. As a result, the Gulf of Maine has been the subject of several research efforts to better understand and fill knowledge gaps concerning these important management issues.

A number of long-term, regional research and monitoring programs are currently nearing completion in the Gulf of Maine. Some of these, such as Ecology and Oceanography of Harmful Algal Blooms (ECOHAB) and Global Ocean Ecosystem Dynamics (GLOBEC) are coupling well-defined 3-dimensional circulation models to ecosystem and species-specific population models. These models, initially conceptually based, are now being developed to provide realistic approximations of 'real world' conditions, whether predicting the occurrence of harmful algal blooms, the passive transport of pelagic larval species, or the density of prey organisms for harvested fish stocks.

NOAA, as a mission agency supporting ECOHAB and GLOBEC, expects models generated in basic research projects to become the foundation for 'operational' forecasting capabilities for identifiable user communities (i.e. stakeholders) in a region. Transitioning these research models to useful, user-friendly forecasting tools requires active interactions among researchers in the basic and applied sciences as well as with members of public agencies and private corporations. These groups often do not interact on a regular basis so maintaining a strong connection between all parties involved is vital to achieving a product of interest to both the research and management community.

For these reasons, the NOAA Center for Sponsored Coastal Ocean Research (CSCOR) recently supported a workshop to facilitate the transfer of model-based research products into the hands of managers and stakeholders for environmental decision-making. Researchers from multi-disciplinary teams currently developing linked physical-biological models, researchers in applied modeling activities, and representatives of various public agencies and institutions met to discuss progress and approaches in biological-physical modeling within the Gulf of Maine. Specific goals of the workshop were to; 1) Inform managers of the current capabilities of biophysical models developed as part of ongoing ECOHAB and GLOBEC research efforts, 2) obtain the informational and decision needs of coastal resource managers concerned with harmful algal bloom and fishery resources and 3) identify areas to focus future research activities and resources around common model and management goals.

By identifying the informational needs of managers and the capabilities of current models, future transition efforts can be organized around mutually beneficial goals and model products. Transitioning research models is a difficult task and CSCOR intends this workshop to be the first in a series aimed at building towards an "operational modeling framework" within the Gulf of Maine, capable of providing pro-active forecasting for the safeguarding of coastal living resources, local economies and the public health.

Ecology and Oceanography of Harmful Algal Blooms-Gulf of Maine (ECOHAB-GOM)

Harmful algal blooms (HABs) are one of the most significant coastal issues facing the nation. In the past, only a few regions of the U.S. were affected by HABs, but now virtually every coastal state has reported major blooms. HABs can cause human illness and death, alter marine habitats, adversely impact fish and other marine organisms, as well as close many coastal businesses. Presently, our limited understanding of the biological, physical, and chemical processes that regulate HABs is hindering our ability to address the expanding list of impacted coastal resources.

Five Federal agencies currently collaborate to sponsor the Ecology and Oceanography of Harmful Algal Blooms (ECOHAB), a national research program studying HABs in the coastal waters of the U.S that was created through the Harmful Algal Bloom and Hypoxia Research and Control Act (HABHRCA-P.L. 105-383). The agencies include the National Oceanic and Atmospheric Administration, National Science Foundation, U.S. Environmental Protection Agency, Office of Naval Research, and National Aeronautics and Space Administration. CSCOR takes the lead in coordinating this research program, as well as directly funding many of the participants. Through open competitions and peer review, the ECOHAB program provides research support towards developing a greater understanding of the physical and biological factors affecting the dynamics (e.g. growth, survival) of HAB species.

The sponsored research programs will be used to help guide the management of coastal resources in an effort to reduce HAB development, impacts, and future threats. One critical goal of the ECOHAB program is to develop reliable models to forecast bloom development, persistence, and toxicity. These models will be used to identify areas that may be susceptible to HAB outbreaks. This research will foster rapid response by monitoring agencies and health departments to safeguard public health, local economies, and fisheries. The identification of bloom-favorable conditions may also permit management of specific environmental factors to reduce bloom impacts.

To support these goals, the ECOHAB program funds a number of long-term, multi-disciplinary, regional studies. These studies focus on the biogeochemical, ecological, and physical processes that contribute to bloom formation and maintenance, and individual target studies that examine specific biological and physical processes that regulate the occurrence of HABs. One of the regional studies is located in the Gulf of Maine and focuses on one of the most toxic HAB-induced illnesses, Paralytic Shellfish Poisoning (PSP).

Dinoflagellates of the genus *Alexandrium* cause PSP, a potentially fatal neurological disorder that results from human ingestion of contaminated shellfish. Elevated levels of PSP toxin impact thousands of miles of U.S. coastline annually and the number of areas affected has expanded dramatically in the last two decades, especially in the Gulf of Maine. Although the organism rarely reaches bloom densities, typical of other HAB species, low concentrations of *Alexandrium* can accumulate in fish and shellfish to concentrations toxic for humans and marine mammals.

The ECOHAB-GOM project addresses several fundamental issues regarding *Alexandrium* blooms in the Gulf of Maine: 1) the source of the *Alexandrium* cells that appear in the fresh water plumes in the western Maine coastal current (WMCC); 2) *Alexandrium* cell distribution and dynamics in the eastern Maine coastal current (EMCC); and 3) linkages among blooms in the WMCC, the EMCC and on Georges Bank. Through an extensive field (hydrographic, chemical, and biological measurements, moorings, ship transects, drifters, satellite imagery) and modeling program (physical and biological models) the controls on *Alexandrium* population dynamics will be investigated. The program has been ongoing for five years and has been funded for an additional three-year synthesis and model transition stage.

These field and modeling studies have illustrated that a Gulf-wide modeling approach is necessary to capture the dynamics of *Alexandrium*. A biophysical model has been developed to study these dynamics and can include factors, which affect bloom initiation and transport, such as downwelling- and upwelling-favorable winds. The accuracy can be compared against previous studies (i.e. hindcasting), shellfish data, and buoy data. Surrogates such as remote sensing of water masses may allow the remote tracking of blooms and provide additional data sources for model validation. Small-scale regional studies can also be conducted. One of the big challenges is how to initialize the model runs and compare data and model output consistently. Despite these challenges, the coupled physical-biological models that have been developed for *Alexandrium* in the Gulf of Maine have progressed to a stage where it may be possible to use them to aid environmental decision-making.

Potential management applications for these models may allow coastal managers to better determine anthropogenic impacts on bloom frequency and extent. Results will yield specific information relevant to coping with and mitigating HABs in the Gulf of Maine. This information will also allow regulators and aquaculture farmers to make more informed decisions on siting of new shellfish and finfish farms. The model will be available as a product that may be used to explore the impacts of future environmental decisions regarding finfish and shellfish resources and nutrient loadings in the Gulf of Maine.

U.S. Global Ocean Ecosystems Dynamics Program-Georges Bank (GLOBEC-GB)

The U.S. Global Ocean Ecosystems Dynamics (GLOBEC) Program is a large multi-disciplinary, multi-year oceanographic effort jointly sponsored by the National Science Foundation (NSF) Division of Ocean Sciences and the National Oceanographic Atmospheric Administration (NOAA) Center for Sponsored Coastal Ocean Research. The National Marine Fisheries Service also provides support through ship time and salary funds for the participation of NMFS scientists. The objective of U.S. GLOBEC research is to understand how climate change and variability translate into changes in the structure and dynamics of marine ecosystems and fishery production. To understand these processes, modeling, process-oriented studies, broad-scale observations, and retrospective studies were utilized to gather important information on key physical and biological variables. These complementary efforts are a key element of the GLOBEC research strategy and will provide essential information over a broad spectrum of spatial and temporal scales. The program currently consists of four primary study sites selected to cover a range of ecosystem types. Each region exhibits characteristics likely to be affected by global climate change and specific target species were chosen for their ecological and economic importance. The region chosen for the first U.S. GLOBEC program was Georges Bank in the Gulf of Maine.

For centuries the Georges Bank region located off the New England coast has supported important commercial fisheries such as cod and haddock. The collapse of this fishery due to overharvesting and subsequent closures in 1993 and 1995 have focused attention of the management and science community on identifying and correcting critical gaps in knowledge in order to restore healthy populations. Some of the areas identified as needing further clarification were: developing a more robust criteria to define and open a species/area management unit to fishing; the management strategy needed for a multi-species ecosystem approach; the effect of trawling activity on the benthic food supply of commercially important species; and setting practical management objectives given the degree of environmental variability in the North Atlantic.

The U.S. GLOBEC Georges Bank Program was designed to address some of these questions. The main goal is to understand how oceanic variability and global climate change may affect population dynamics of key species on the Bank (i.e. cod, haddock, and two species of zooplankton) both in terms of their coupling to the physical environment and their predator/prey relationships. The ultimate goal is to predict changes in the distribution and abundance of these species as a result of changes in their physical (e.g. stratification, retentive circulation features, frontal zone exchanges, North Atlantic Oscillation) and biotic environment (e.g. predator/prey relationships, multispecies interactions). Changes in growth and survival of the target fish species due to changes in food supply and the physical environment have important implications for fisheries recruitment for these valuable species and directly affect the degree to which the species may be harvested.

The research effort is substantial, requiring information on many scales. Broad-scale cruises have described physical and biological conditions on the bank during January-June every year since 1995. Moorings have been in place continuously recording information over a long time series. Process studies focused both on the links between the target species and their physical environment, and the determination of fundamental aspects of their life history dynamics (birth rates, growth rates, death rates, etc). Equally important are the modeling efforts that are ongoing which seek to provide realistic predictions of the flow field and which utilize the life history information to produce an integrated view of the dynamics of the populations. Retrospective analysis has provided information over a longer time frame, and has helped to place the current study in historical context.

The GLOBEC Georges Bank program has had three years of extensive field process studies (1995, 1997, and 1999). Phase 1 (1994-1996) focused on stratification of the water column, and its effects on circulation around Georges Bank. Phase 2 (1996-1999) examined the sources, retention and loss processes affecting zooplankton populations on Georges Bank. Phase

3 (1999-2000) determined cross-frontal exchange process and how they influenced populations moving onto and off the bank. The final phase of GLOBEC Georges Bank is focusing on analysis and synthesis of the field results, with special attention to physical/biological modeling, climate effects, and development of indices to characterize environmental and ecosystem status and change.

Modeling studies have been an essential part of the effort to interpret and synthesize experimental and field measurements. These models were designed to capture the physical and biological processes that control the abundances and distribution of target species. To find the links between spatial changes in target species abundance and physical processes hind-cast and data assimilative techniques were employed for simulations involving individual- and bulk-based models. These coupled physical-biological models then become powerful means to separate the many interacting factors which affect the structure of observed population distributions.

Collectively, these studies are providing a more comprehensive picture of the population dynamics of the Bank and will provide insight and tools useful for fishery management. Key indices will be developed to monitor changes to the ecosystem. Models will provide new, ecosystem-based estimates of abundance and distribution for improved fishery forecasts and show promise as a useful tool to aid in the evaluation of Marine Protected Areas. Research results will be provided routinely to the NMFS Northeast Fisheries Science Center and to the New England Regional Fishery Management Council. Results have already been provided to the New England Fishery Management Council in their deliberations on the reopening of closed areas on Georges Bank to scalloping.

Workshop Particulars

The ECOHAB/GLOBEC Gulf of Maine modeling workshop was held June 17-18th in Portland, Maine. There was a diverse group of attendees (see Appendix 1), drawn from both the modeling and management community, covering a wide range of backgrounds and stakeholder groups (see Appendix 2). Over the two-day workshop (see Appendix 3), presentations and discussions focused around the following themes:

> Model issues: What are the capabilities of the current ECOHAB and GLOBEC models? What types of information can they produce? What types of data are needed to initialize and run the model simulations? How might the models be used to make environmental decisions?
>
> Management issues: What are the day-to-day decisions made by coastal resource and fishery managers? What are the types of information necessary to make these decisions? What key products or types of information would be beneficial? Is there a role for models or model output in the decision-making process?

The workshop started with introductions by Dr. Beth Turner (CSCOR), Dr. Donald Anderson (WHOI) and Dr. Michael Fogarty (NFSC). They discussed the need to use the workshop as a starting point for an active, ongoing dialogue between the model research and management community. What will be the best way to transition these research models to the management community to aid in day-to-day and long-term planning decisions for societal benefit? What information do managers need and what information can models provide? The Gulf of Maine is in a unique position for this difficult task because the infrastructure is already in place due to many years of research (e.g. GLOBEC, ECOHAB), a well-developed observational network (e.g. GoMOOS) and numerous management entities (e.g. Gulf of Maine Council, RARGOM). Hopefully, the obstacles, hurdles and lessons learned by this group can be used by other model transition efforts.

The first day consisted of talks by representatives from the ECOHAB and GLOBEC modeling community (John Quinlan (WHOI), Dr. Dennis McGillicuddy (WHOI), Dr. Changshen Chen (University of Massachusetts), Dr. Huijie Xue (University of Maine)) who highlighted the diverse mix of modeling approaches currently employed in the Gulf of Maine. These talks were following by presentations from representatives of the management community (Dr. David Pierce (Massachusetts Division of Marine Fisheries), Linda Mercer (Maine Department of Marine Resources), Paul Anderson (Maine Sea Grant), John Hurst (Maine Department of Marine Resources)) in charge of regulating shellfish, finfish, and fishery resources in Massachusetts and Maine.

On the second day, a presentation was made by Dr. Thomas Gross (Coast Survey Development Laboratory) on some of the issues (e.g. model, logistical, and legal) involved with setting up and maintaining an operational forecasting system. Dr. Phil Bogden gave a talk on the Gulf of Maine Ocean Observing System (GoMOOS) focusing on the components (goals, operational and user needs, partners and members, products) of the system and the types of data products (e.g. buoy, radar, satellite) available that may be useful for both modelers and managers.

The rest of the day was spent in a group breakout session. The particular issues facing the transition of ECOHAB models for the management of shellfish and finfish resources were debated followed by a discussion of the issues faced by transitioning the GLOBEC models for fishery management applications. Recommendations for model transition were put forth focusing around a set of models that would be necessary to address some of the management concerns and how the efforts of the ECOHAB and GLOBEC projects could be leveraged to facilitate model transition efforts. Discussions then concluded around the next steps with regard to research efforts and some possible topics for future workshops.

Focus Letter and Workshop Presentations

Several weeks before the start of the workshop the organizing committee sent out a reminder notice for the speakers. Attached to this reminder was a letter to help the speakers focus their talks for the workshop around some common theme areas (see Appendix 4). A summary of the talks as they pertain to the focus letter is described below as a composite for each of the groups. The summaries are not meant to be all-inclusive and are only a sample of the issues that are faced by managers and modelers in the Gulf of Maine.

Management: Presentations were made from several managers involved with the regulation of shellfish and fishery resources in the Gulf of Maine. Areas of focus included harmful algal bloom impacts on shellfish and finfish, regulation of inshore and offshore shellfish resources and the management of offshore fishery resources on the Georges Bank. A detailed list of each of the question areas below, which help to define the needs of resource managers in the Gulf of Maine, can be found in appendix 5.

1) Describe the management decisions that you must make

Coastal managers in the Gulf of Maine make short-term and strategic decisions on a number of important issues. While the specific issues are manager and location dependent, there were three broad areas (i.e. monitoring and assessment, fishery enhancement and control, public health and safety) identified where decisions are typically necessary to satisfy federal and state regulatory requirements (e.g. Biotoxin contingency plan, National Shellfish Sanitation Program, Atlantic States Marine Fisheries Commission, Magnusen Act).

Monitoring and assessment: In order to make informed decisions to safeguard public heath and biological resources environmental data is gathered through a network of monitoring programs. Some of these include water quality (e.g. nutrients, dissolved oxygen, pathogens), toxin levels (e.g. sediment, shellfish, water column), and abundance data (e.g. toxic algae, bacteria, regulated fish species). Biological data (e.g. age, growth, reproduction, recruitment, distribution, abundance) on important fishery resources is also monitored, along with information on catch landings, effort, composition, quotas, and value. In addition, resource managers may have to conduct assessments of natural resources, current/past activities or planned projects to evaluate potential impacts. Such activities can range from the identification of potential aquaculture sites (e.g. shellfish, finfish) and habitat characterization maps (e.g. eelgrass distribution, essential fish habitat) to the projected transport of oil spills and harmful algal bloom events.

Fishery enhancement and control: The Gulf of Maine supports a wide diversity of commercial and recreational shellfish and finfish species and a number of these (i.e. Cod, Haddock, Pollock, Dabs, White Hake, Silver Hake, Sea Herring, Mackerel, Skates, Monkfish, Red Hake, dogfish) are currently regulated through the NMFS and ASMFC management plans. These species are subject to fishery controls (i.e., size limits, harvest limits, gear restrictions, seasons, spawning closures) to balance harvest amounts and long-term sustainability. Additional decisions required by fishery managers involve how to minimize by-catch, the effects of fishing gear on habitat, measures to protect marine mammals, and recommendations for minimizing or preventing impacts of other human activities on the marine environment and fisheries. Increasingly these efforts are directed toward multi-species and ecosystem management types of frameworks. Aquaculture is rapidly expanding in the Gulf of Maine (e.g. finfish, seaweed, shellfish, sea urchins) and may require future regulations if deleterious environmental or ecosystem effects become apparent at higher site densities.

Public health and safety: Paralytic shellfish poisoning (PSP) is the greatest seafood safety threat in the Gulf of Maine. Resource managers are responsible for protecting the public health while allowing for the harvest of susceptible species of marine mollusks in areas not shown to be affected by contamination. Managers must make decisions about when and where to monitor, what species to test, when to close shellfish beds due to high toxin levels and when to remove shellfish from the market. Extensive and long-term monitoring efforts have been very successful in limiting the amount of public exposure to toxic shellfish by identifying the times and locations of highest toxicity, how individual species react to PSP exposure and the use of sentinel sites and organisms to provide an early warning capability. There is recent evidence, however, that domoic acid, amnesic (ASP) shellfish poisoning and diarrheic shellfish poisoning (DSP) may become future problem areas requiring enhanced effort and monitoring.

2) What are the types of information that you need to make these decisions

Both HAB and fishery managers need more baseline physical and biological data (e.g. from regional observing system, satellites, ongoing monitoring and regional research efforts). This data is vital to detect environmental and species trends, along with, initialization, calibration, verification, and data assimilation for models. Through long-term, spatially/temporally extensive data sets and biophysical models the extent to which broad-scale environmental factors (e.g. North Atlantic Oscillation, Gulf Stream rings, climate change) affect HABs, phytoplankton, zooplankton, larval survival and growth can be investigated. Additional information on meteorological, oceanography and life history factors should allow for even greater predictive modeling capability. The ability to predict the transport of suspended particles will also be beneficial for tracking contaminant spills (i.e. sewage, oil) and the transport of larval organisms.

For HAB managers the majority of this information will have to be at the sub-estuary level, the scale where many of the management decisions are made (e.g. monitoring locations, individual aquaculture and shellfish sites). Of particular interest would be information on the location, severity, and movement of HAB events. States and affected industries could use the knowledge to take appropriate management actions (e.g. close beach or shellfish bed, move finfish cages, harvest early). For monitoring, developing improved biotoxin detection methods that are field-based, reliable and affordable would be desirable especially if a larger area can be covered in greater detail and less cost. Enhanced data access, scientific communication, and a flexible regulatory structure to encourage the innovation/discovery of new methods would be useful to facilitate the ability to manage and mitigate HABs.

There is also a need for a more complex, detailed understanding of ecosystems and multi-species interactions especially for fisheries managers who are often tasked with managing several interacting species. This approach would allow ecological processes and interactions to be explicitly incorporated into fisheries and HAB models as opposed to only using physical data or single species models. Such an ecosystem approach should yield numerous benefits. For example, a key benefit would be the increased ability to quantify the magnitude of ecological processes (e.g. predator-prey dynamics) relative to human (e.g. fishing mortality) and environmental effects (e.g. upwelling) in affecting the recovery of exploited stocks or in affecting the frequency and severity of HAB events.

3) What key products could help you do your job better and more efficiently?

A number of products were identified that would be beneficial (i.e. detection, prediction). Both the HAB and fishery managers need products that apply to the coastal zone, provide results in a timely manner and are cost effective, user friendly and predictive. Preferably, these products would also provide data and predictions at high temporal and spatial resolutions.

The ability to detect environmental parameters with greater detail would be a key product for resource managers. Tracking temperature, salinity, and phytoplankton remotely are powerful tools to monitor changes in the physical environment (i.e. upwelling, fronts, rings), as well as the transport of passively advected particles (e.g. larvae, algae) either directly or indirectly through a passive tracer such as sea surface temperature. Resolution issues currently limit the usefulness of satellite imagery for inshore and estuary issues and for detecting non-blooming HAB species. A spatially extensive buoy network could supplement remotely sensed methods to provide additional coverage, ground truthing and provide data for model calibration and validation. Water-masses that can affect larval survival (e.g. NAO effects, rings) can be tracked, surface conditions and concentrations monitored (e.g. nutrients, waves, current speed), along with the subsurface concentrations of various parameters.

Another key product for resource managers would be the ability to combine environmental data with model simulations to make short- and long-term predictions. Some possible areas for prediction include 1) transport of nutrients, contaminants, HABs, and larvae, 2) the timing, duration, and location of HABs and 3) the annual variation in larval/juvenile recruitment. Improved capabilities for forecasting year class strength, mortality rate, and larval transport for important fishery resources would also be beneficial. But for the model results to be of most use to managers the output needs to be displayed and accessible in a user-friendly framework to ease understanding and interpretation (i.e. more than just tables of numbers).

4) Do you see a role for models or model output in your decision-making process?

There was a consensus for the potentially important role that models can play in the environmental decision-making process. For example, models can be used to test the effects of various management scenarios (e.g. increasing the harvest amount of a particular species), forecast some parameter of a system given its current state (e.g. bloom spread), and to gain a better understanding of what controls the dynamics occurring in the ecosystem. Models have typically suffered from resolution issues and a lack of data, but increases in computer speed and more extensive monitoring networks such as the GoMOOS system in the Gulf of Maine promise to lessen this problem. The higher resolutions of the current suite of models allow for greater overlap between the scale of the model and the scale at which managers need to make decisions.

For models to reach their full potential, a number of issues have to be resolved. Models should have the key assumptions clearly identified and there should be some evidence of their reliability. Has the model been tested, does it work? For example, how well do predictions from models fit observed data, has the model been peer reviewed and are the uncertainties well described? Are there any success stories? The models should be able to provide enough insight so that managers can better understand the consequences of their actions especially in an ecosystem context. The models should also be user friendly and easy to manipulate so that they can be run at meetings for quick feedback.

Modeler: As part of the ongoing ECOHAB and GLOBEC programs in the Gulf of Maine a number of coupled physical-biological models have been developed. Four of these modeling systems were presented at the workshop followed by discussions of their potential management applications. Since each model is unique (i.e. developed for a specific purpose), it was difficult to fully summarize the talks using the focus letter format. Appendix 6 has been provided to supplement the material in the following sections while appendix 7 provides details about each of the individual models.

1) Describe the capabilities of your modeling system for a general audience.

All of the models presented at the workshop seem capable of representing the general circulation dynamics in the Gulf of Maine. Most can simulate transport processes based on weather, riverine inputs, tides and other observations. Some short-term forecasts are possible but longer forecasts are limited by the accuracy of long-term weather predictions. Climatological data analysis may allow for longer-term forecasts (e.g. annual) to be attempted under idealized scenarios. The inclusion of inshore and estuarine processes is a challenge that will require models to simulate complex physical processes (i.e. turbulence, estuarine transport, bottom shear) at high temporal and spatial resolutions.

The biological component of these physical models is still in the rudimentary stages mainly due to a lack of knowledge of life history parameters, interaction terms and behavior patterns. The overall lack of data is a major problem that affects the parameterization and validation of these models. Most models, as a result, have had to resort to simplified representations of the ecosystem under study. Simulations are possible using fully explicit biological dynamics (as opposed to representing the organisms as passive tracers) but care must be taken in interpreting the results especially without a full characterization of the errors introduced with different model formulations and parameter values.

2) What types of information can be produced by the model.

The suite of models in the Gulf of Maine can produce a wide range of information types. Physical parameters include temperature, salinity, current, density, wave, and tidal distributions. The biological components are often specific to the model but typically involve the prediction of nutrient, phytoplankton (e.g. HABs), and zooplankton (e.g. larval cod) distributions. The trajectory of these organisms can be followed through time as they interact with the physical environment and undergo biological processes such as germination, growth and predation. This information is usually simulated on a daily basis at a spatial resolution of several kilometers. Other model products are available such as; the identification of important physical features (e.g. upwelling zones, convergence zones, low/high flushing areas), conditions favorable for bloom intensification or inhibition, cohort survival and predation rates, population connectedness, the impact of parameter value assumptions and the effects of proposed management actions.

3) Over the next several years where do you see the biggest/most exciting model improvements?

It is difficult to predict where model improvements will head in the next couple of years but several trends are evident. The acceleration in computer processor power is allowing more detailed models to be constructed. This will allow more processes and state variables to be modeled, a finer grid resolution and a larger simulation domain. Users will also benefit, as many models will become more accessible because high-end computers will no longer be necessary to run the simulations. The increased resolution will enable more physical processes to be resolved (e.g. sharp fronts, turbulence effects) which should allow the models to simulate in greater detail the complex dynamics of inshore systems where many of the management decisions occur. Data availability should increase in frequency and coverage with the addition of instrumented buoys and satellite sensors providing a much-needed boost to model initialization, validation, calibration, and data assimilation efforts. With continued funding for basic research on the biology of important species and on growth and death rate processes, interactions with other species can be better quantified and used to improve model accuracy and predictive power.

4) What types of data products are needed to initialize or refine your model?

Many of the models have similar data requirements especially with respect to the modeled physical processes. Meteorological forcing variables are very important especially for accurate forecasting ability and boundary conditions. Wind, precipitation and temperature are some of the many necessary parameters. Some of this data can be obtained from satellite sensors, radar sources (e.g. CODAR, Doppler radar) and from buoy data (e.g. wind speed and direction, tidal components). There also needs to be data on the distribution of resource variables (e.g. phytoplankton, larvae) and the rates at which those resources change under various environmental conditions and interaction effects with other species (e.g. predator/prey dynamics). Data on these variables is the most lacking and difficult to obtain for many species. In addition, most data for these models needs to be at high temporal and spatial resolutions.

5) How do you think your model might be used to make environmental decisions?

Many environmental decisions could potentially be helped with the models developed for the Gulf of Maine. A yearly problem facing coastal resource managers is safeguarding the public against contaminated shellfish. Models could be useful in forecasting the transport of a bloom once it has been identified thereby allowing managers to take appropriate action. Aquaculture sites could also benefit from this information. Using climatological and climate mediated changes (e.g. sea level rise, El Nino, North Atlantic Oscillation) in the physical environment; it may be possible to conduct seasonal forecasts for harmful algal blooms and fishery resources. The testing of various management scenarios is another area where models can be very powerful. For example, the effects of increasing fishing mortality or harvest amounts could be investigated for managed fisheries. The impact of proposed nutrient additions/removal plans (e.g. a new sewer outflow pipe) is another applicable area. Models can be used to investigate the placement of reserves and aquaculture pens. By examining the transport processes coming into and out of a fixed location, areas that promote the success of the management goal can be identified.

Discussion Recommendations

From the active discussions and information in the focus letter section, a number of issues and needs were raised. These issues and needs fell into five broad categories: research, HAB management, fishery management, and joint management needs, along with, model development and model transition issues. Key points for each of the categories are described below.

Research Needs

- A greater ability to separate biological and physical effects. By determining the dominant process for a given set of conditions the appropriate model can be employed to address the question of interest. When is each process in control?
- A better understanding and simulation of near-shore hydrodynamics so that problems of interest to managers can be addressed (e.g. bloom trajectory).
- A greater understanding of biological interactions (e.g. competition, predation) so that longer-term forecasts can be implemented beyond basic trajectory models.
- A greater understanding of the long-term physical drivers so that annual and long-term forecasts can be attempted with greater accuracy.
- To determine the best way to do predictive forecasts for organisms with a patchy distribution or with high temporal variability.

HAB Management Needs

- Real-time to daily forecasts of bloom trajectories disseminated to both state agencies and aquaculture farmers to enable proactive management intervention.
- Long-term forecasting of trends to conduct long-term planning.
- Information that would help in the identification of monitoring locations and aquaculture site selection.
- More information on the loss terms of *Alexandrium* and on the controls of bloom dynamics.

Fishery Management Needs

- Longer term data for closed/open area regulations, what if scenarios, and harvest regulations.
- An understanding of what determines a strong year class and fishery recruitment.
- To quantify cohort production under different environmental conditions.
- To determine where research efforts can make a contribution and provide information to the fishery management councils.

Joint Management Needs

- Real-time information from data sources and short-term model simulations for day-to-day management decisions and for emergency response situations.

- Long-term forecasting of trends to conduct long-term planning and to understand changes due to large-scale drivers.
- Strategic and "what-if" simulations to aid management decisions relating to regulatory decisions.
- Models capable of handling large-scale physical drivers such as the North Atlantic Oscillation, freshwater input, and Gulf Stream rings.

Model Development

- **Focus future model development efforts around a core group of models:** One model cannot be expected to be applicable to all potential management issues and scenarios. There will be a need for a hierarchy of models for different forecast questions (e.g. hourly versus annual forecasts will be very different) since each will define the location, scale, and type of model that is needed. A proposed series of models are listed in appendix 8.

- **Need multiple models for the same question:** Using a suite of models will allow a comparison between model results, assumptions, and formulations. When the models agree, there will be more confidence in the result (i.e. forecast) and where they disagree, information can be gained on how the system works. A range of models will have a greater chance of catching deviations in ecosystem dynamics from typical expectations.

- **Need an honest assessment of model accuracy, sensitivity, and error:** These critical measures need to be thoroughly investigated so managers can make informed decisions fully aware of the limitations in the simulation results. There should be a suite of benchmarks (analytical, hindcasting and forecasting test cases) to compare the skill of the model to the data and to other models.

- **Model output needs to be user friendly:** The simulation results should be presented in a format that is interpretable and in a form managers can use (e.g. managers may be more interested in toxin levels than cell numbers). The raw data used to create visual maps should also be included for managers interested in conducting other types of analysis.

- **Need a way to account for uncertainty in model forecasts:** Model output should provide some indication of the uncertainty in a forecast. This could involve the use of risk analysis or probability maps to show a range of potential values for a forecast based on different parameter values or assumptions (e.g. low/high mortality, wet/dry year)

- **Need a model interface standard:** To facilitate the use of multiple models and formulations there should be a model interface standard to enable different physical and biological elements to be interchanged. For example, the same physical model could be used for both *Alexandrium* and larval transport studies by simply "plugging" in the appropriate biological model into the standardized physical model.

Model Transition

- **Need to define an acceptable level of model inaccuracy:** Different questions require different levels of accuracy for the forecasts to be useful for management purposes. The type of forecast will also affect accuracy (guidance vs. prediction forecasts). These levels of performance need to be defined to give guidance to model development efforts and to identify scenarios that are realistically possible.

- **Need to promote continuity in interactions between manager and modeler:** Managers need continuity in interactions with modelers in order to realize the full potential of a particular model. Specific questions will require active communication between the two groups and through ongoing dialog, credibility can be established and maintained.

- **Need to decide on a list of potential scenarios:** This is an important first step in any attempt to transition models to the management community. The cases that are interesting to researchers may not be of interest to managers and vice versa. There should be some consensus developed as to which cases satisfy the dual constraints of being an important management issue but also addressable with current models.

- **Need ecological forecasters to run the models and make predictions:** Simple point and click systems are most useful for educational purposes and as examples rather than forecasts. For specific applications, detailed modeling runs by knowledgeable individuals will be needed. Subsequently, the human infrastructure should be developed so that these models can be tested, updated, fine-tuned and run on a regular, sustained basis by people who have intimate knowledge of their performance and limitations.

- **Need to decide on a long-term home for the forecast models:** Forecast models need a long-term home in order to secure their continuity and funding. Government, state and non-profit organizations are all potential homes since they can help to ensure adequate funding, continuity and expertise. These organizations will also be in the best position and have the capacity to address any potential legal issues from erroneous forecasts.

- **Need to build forecasting capacity incrementally:** There will be a learning and acceptance period for these projects that has to be built up through a series of success stories which will help to increase confidence, familiarity and trust with the models. Initial efforts should probably focus on giving “guidance” rather than “forecasts” and not promise too much or release a product before it is ready and has long-term funding.

- **Need an observational system to support model development:** Models used for forecasting purposes generally have extensive data needs (e.g. calibration, verification, benchmarking, assimilation). Observational systems involving buoys (e.g. GoMOOS) are ideally suited to provide the extensive data needs for operational model forecasting, especially when combined with data from satellites, radar, and ship board measurements.

- **Need a cost-benefit analysis of proposed forecasts:** The limited resources of government and state agencies necessitate determining the value (e.g. economic, societal, ecosystem) gained from providing a particular forecast or maintaining a forecasting capability. The analysis can help prioritize efforts for those that will have the greatest benefit and identify those that can be better handled by simply expanding on existing systems (e.g. employing more monitoring sites, using satellite data).

- **Basic research needs continued funding support:** The existence of any forecasting system is only possible after extensive basic research has provided the foundation of knowledge upon which to understand the system of interest. Forecasting systems will always have a need for a greater understanding of the driving processes, life history dynamics and multispecies interactions and research funds to support these efforts should be continued.

- **Need to decide on the type of forecast to be attempted:** The type of forecast to be attempted (i.e. guidance vs. forecast) will fundamentally affect many other aspects of the model transition process. Providing an operational project is not a simple endeavor and requires a serious commitment of time, personnel and resources. Model forecasts, especially operationally based, should probably not be attempted without extensive experience with giving guidance forecasts.

Future workshops

The June 2002 workshop was not designed to be a one-time endeavor but rather to lay the foundation for more detailed discussions aimed at focusing future ECOHAB and GLOBEC model products to the specific needs of resource managers in the Gulf of Maine. Many issues will have to be addressed and hurdles overcome in order to transition some of the model products presented at the workshop. Recognizing these needs, several recommendations for future workshops were put forth by participants. The workshops could be combined or conducted in a series but for illustration purposes are not listed in any particular order. These workshops would address the following tasks:

- **Expose managers to the full range of possible model products:** Due to the time constraints of this workshop only a brief overview of each modeling platform was possible. A follow up workshop focusing only on the models, in an interactive framework, could be very beneficial to the model transition process. This workshop would expand upon the first one by allowing the managers to get a “hands on” feel for the ECOHAB and GLOBEC models, similar to a “models 101” course. Details about each of the models would be presented such as the data needs, assumptions, model accuracy and model capabilities followed by an interactive session where managers and modelers could go through various simulation experiments together. Managers would gain familiarity and an understanding of what would be involved for various model products thus gaining a greater awareness of what would be realistically possible. With this perspective, managers can then give more appropriate and focused suggestions for possible model tools, enabling future efforts to focus on these areas with greater success.

- **Identify specific problems to address**: Now that the ECOHAB and GLOBEC modelers have an idea of the management needs and the managers have an idea of the current model capabilities these groups, along with other stakeholders should define a "restricted" set of "realistic" model products that would be of interest to "both" communities. Once these products are identified, the data, research, and infrastructure needs to implement the project can be discussed and acted upon. Ideal candidate projects would be those that could be started with little development, using existing capability and provide simple forecasts that could then be built upon sequentially.

- **Identify where additional observations are needed:** Models have extensive data needs that must be addressed before management oriented forecasts can be attempted. These needs include model initialization, boundary conditions, providing realistic model parameter values, data assimilation and judging the hindcasting/ forecasting skill of simulation results. The workshop can identify these data needs and develop the appropriate sampling and monitoring network necessary to drive the various management models. Over what time frames and space scales is information needed?

- **Specify the criteria on which to judge model accuracy**: A framework needs to be developed to test the accuracy of a potential model with respect to a "benchmark model and/or dataset" and to the level of skill necessary for the particular model application. The first skill assessment would be more generic and ask questions such as "does the model get the physics and mean biomass levels right" while the second assessment might ask "how accurate is the model at predicting the location of bloom landfall". Different applications will require different levels of accuracy so identification of these levels and the appropriate tests is vital to further progress.

- **Determine the best way to present and access model output:** There are many ways in which to present and access model output (e.g. tables, graphs, maps, web). Some of these will be more useful to managers than others. The workshop can help to determine what types would be most useful to managers for their particular question.

- **Determine the most useful types of forecasting systems:** The type of system employed will usually depend on the model and desired product. Forecast systems can range from a totally automated system, where the manager just has access to the model output to one where the manager is responsible for setting up, running, and interpreting the simulations. Each of these systems will involve various levels of input and cooperation with model developers that must also be addressed.

- **Discuss long-term model transition issues:** Transitioning research models to management applications involves many complex issues. Assuming that a model product survives the difficult development, testing, and acceptance period there are still many hurdles. Who will run the model, both for idealized and novel scenarios (scientist, manager, collaboration, ocean forecaster)? Where will the model be housed (federal government, state, regional observing system, partnership)? Who will fund the model (development, day-to-day operations, improvements)? Who will assume the legal responsibility (human illness, lost revenue, overharvested stocks)?

Summary

Transitioning research models, such as those developed through the ECOHAB and GLOBEC programs, to the management community is a difficult and complex task. This is a challenge because research models are rarely directly applicable (e.g. different focus) or accessible (e.g. too complex) to the management community. Successful transition will require an active dialog, between the research and management community to ensure that developed model products are applicable to management and societal concerns. The purpose of this workshop was to identify the informational needs of HAB and fishery resource managers and to highlight the current capabilities of ECOHAB and GLOBEC models. Identified informational gaps and areas of common interest can then be used to guide future activities for those goals which are critically important to resource managers but that are also within the capabilities of the current suite of models.

All of the models presented at the workshop hold promise as a potential tool to aid resource managers. They have well-developed physical components capable of representing the general circulation and transport processes present in the Gulf of Maine. Physical transport simulations can be used to provide short-term forecasts of passively dispersed particles (e.g. oil, larvae, phytoplankton) over short time frames. The use of data assimilation techniques may help to extend these forecasts. Models have typically suffered from resolution issues and a lack of data but increases in computer speed and more extensive monitoring networks promise to increase the resolution of the current models. The simulations of inshore dynamics or frontal boundaries are now possible but there is still much work to be done to fully characterize the accuracy of these models within such a dynamic environment. These conditions create enormous data needs (e.g. model initialization, calibration and verification) which still need to be addressed if the models are to reach a stage where they can provide timely forecasts.

The long-term goal of this model transition effort is to create operational model products capable of providing ecological forecasting for the safeguarding of local economies and public health. Unfortunately, ecological based forecasting has a long way to go before reaching the funding, experience, infrastructure, and familiarity of other operational based products such as weather forecasts. Ecological forecasting also has the added hurdle of needing to incorporate complex biological dynamics on top of the already complex physical dynamics. Consider, for example, all the issues involved with forecasting the distribution of the PSP producing organism, *Alexandrium*. Factors such as seedbed distribution, endogenous clock, predation amount, and growth rate all interact with each other and the physical environment to product observed distributions. Forecasting the distribution of this single species will be difficult enough and forecasting for multispecies fisheries management is an even more daunting task. The forecast applications that will hold the greatest promise are those that are combined with other tools used by resource managers. These model products will never replace traditional tools (e.g. mouse bioassays, fishery surveys) used by managers but can provide additional vital information to complement the other data sources that are part of a larger process that has forecasting as just one of the components.

This workshop has provided the foundation upon which to guide future model transition efforts in the Gulf of Maine. Because the research and management community often do not interact getting the two groups to sit down and express their informational needs and capabilities is a good first step. Judging by the long list of research and model needs identified by the workshop participants, there are obviously many hurdles that still need to be overcome. But the task is not impossible and if this process has any chance of success it would likely be in the Gulf of Maine. The infrastructure is already in place with over 10 years of research from various projects that have produced well-developed coupled physical-biological models. An extensive management framework is in place through the Gulf of Maine council and RARGOM. There is also an extensive data and monitoring network through the GOOS regional observing system and affiliated institutions which can provide data to feed into the models and to test forecast accuracy. All the components are there for the Gulf of Maine to function as a test case to highlight the obstacles and hurdles involved in transitioning research models to a management application. Hopefully, the ideas and interactions discussed at the workshop will frame the model transition pathway to be followed in the coming years and result in model products used for societal benefit by the management community in the Gulf of Maine.

Acknowledgements

Over two years ago this workshop was conceived by Beth Turner and Kevin Sellner as a potential mechanism to facilitate the transfer of research models developed as part of the ECOHAB and GLOBEC efforts into the hands of managers for environmental decision-making. Their continued dedication to this vision enabled the workshop to proceed past the planning stage to completion. We thank Donald Anderson and Michael Fogarty for their roles as workshop organizers and would especially like to thank Judy Kleindinst for all her hard work in handling the workshop logistics. Most of all, special thanks go out to the speakers and attendees for giving up their valuable time to participate and provide input as well as grapple with the difficult but potentially rewarding task ahead.

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Appendix 2: Gulf of Maine Workshop Stakeholders

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Maine Department of Marine Resources
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Fisheries and Oceans Canada
Gulf of Maine Ocean Observing System
NOAA Northeast Fisheries Science Center
NOAA Coastal Survey Development Laboratory
NOAA Center for Sponsored Coastal Ocean Research
Woods Hole Oceanographic Institution
University of Massachusetts at Dartmouth
University of Maine

Appendix 3: Gulf of Maine Modeling Workshop Agenda

Holiday Inn by the Bay, Portland, Maine
June 17-18, 2002

Monday, June 17: - Connecticut/Rhode Island room (main level)

8:00 Continental Breakfast

9:00 Welcome and Introductions
Beth Turner, NOAA Coastal Ocean Program
Don Anderson, Woods Hole Oceanographic Institution
Michael Fogarty, Northeast Fisheries Science Center

9:15 Application of biological and finite element hydrodynamic modeling to management issues
John Quinlan, Woods Hole Oceanographic Institution

10:00 Biophysical modeling for ECOHAB in the Gulf of Maine: Commonalities with GLOBEC
Dennis McGillicuddy, Woods Hole Oceanographic Institution

10:45 Break

11:00 A new modeling approach for coastal management
Changshen Chen, University of Massachusetts at Dartmouth

11:45 Modeling for the Gulf of Maine Ocean Observing System
Huijie Xue, University of Maine

12:30 Lunch

2:00 Information needs in fishery management in Massachusetts
David Pierce, Massachusetts Division of Marine Fisheries

2:45 Information needs for coastal management in Maine
Linda Mercer, Maine Department of Marine Resources

3:30 Break

4:00 Information needs for fish farmers in the coastal Gulf of Maine
Paul Anderson, Maine Sea Grant

4:30 The Maine DMR PSP program
John Hurst/Laurie Bean/Seth Barker, Maine Department of Marine Resources

5:00 Adjourn

Tuesday, June 18:

8:00 Continental Breakfast - Connecticut/Rhode Island room (main level)

9:00 Operational modeling: what is it?
Thomas Gross, NOAA's National Ocean Service, Coast Survey Development Laboratory

9:45 GoMOOS data availability
Phil Bogden, Gulf of Maine Ocean Observing System

10:15 Break

10:30 Breakout Groups (HAB group & Fisheries group)
(Connecticut/Rhode Island room & Somerset room)
Possible topics for discussion:

- what are day-to-day information needs from managers?
- on what time frames and space scales is information needed?
- what level of detail is needed?
- what is the output of regional models?
- how is information currently presented in regional models?
- what are possibilities for running models over the long-term?
- what data will models need for continuation in operational mode?
- where would the operational models be housed?

12:00 Lunch

1:00 Resume breakout groups (mix and match if desired)

3:00 Break

3:15 Report out, recommendations for model transition

5:00 Adjourn

Appendix 4: Focus Letter

Dear (Presenter);

On behalf of the organizing committee we would like to thank you for your participation in the upcoming ECOHAB/GLOBEC Gulf of Maine Modeling workshop from June 17-18th in Portland, Maine. We are very excited about this workshop, which we hope will be the first in a series aimed at facilitating the transfer of model research products into management applications.

We will have a diverse group of attendees, drawn from both the modeling and management community, covering a wide range of backgrounds. To make this initial workshop a success, and to lay the foundation for future workshops, we are requesting that presenters try to organize their talk around the following themes:

{Modeler}

Describe the capabilities of your modeling system for a **general audience**.
What **types of information** can be produced by the model?
Over the next several years where do you see the **biggest/most exciting** model improvements?
What **types of data products** are needed to initialize or refine your model?
How do you think your model might be used to make **environmental decisions**?

{Manager}

Describe the **management decisions** that you must make.
What are the **types of information** that you need to make these decisions?
What **key products** could help you do your job better and more efficiently?
Do you see a **role for models** or model output in your decision-making process?

A critical goal of the workshop will be to highlight the potential uses and informational needs necessary for these model-based products to function as operational-forecasting tools in environmental decision-making. By focusing on the informational needs and capabilities of the parties involved (modelers and managers) hopefully areas/goals of mutual interest can be identified and agreed upon. Feel free to contact one of us or Dr. Elizabeth Turner (Elizabeth.Turner@noaa.gov) if you have additional questions.

Sincerely,

Don Anderson, WHOI
Michael Fogarty, NEFSC

Appendix 5: Management Needs List

1) Describe the management decisions that you must make

General

- Environmental monitoring (e.g. water quality, nutrients, toxins)
- Biological monitoring (e.g. age, growth, reproduction, mortality)
- Habitat characterization and assessment (e.g. SAV, EFF, toxins)
- Particle transport (e.g. HABs, toxins, larvae)

Harmful Algal Blooms

- Responsible for protecting the public health while allowing for the harvest of susceptible species of marine mollusks in areas not shown to be affected by contamination.
- Responsible for shellfish harvested, sale by wholesale shellfish dealers, and notification to receiving states when shellfish from Maine should be removed from the market.
- Shellfish toxin level monitoring for DSP and ASP (*Alexandrium, Prorocentrum, Dinophysis, Pseudonitzschia*)
- Shellfish closures
- Shellfish growing area classifications
- Identification of potential aquaculture sites (shellfish, fisheries)
- Determine how each species reacts to PSP, accumulates and depurates toxin

Fisheries

- Responsible for administering the NMFS and ASMFC management plans for Gulf of Maine fisheries (Cod, Haddock, Pollock, Dabs, White Hake, Silver Hake, Sea Herring, Mackerel, Skates, Monkfish, Red Hake, Dogfish)
- Implementation of Amendment 13 to the Multispecies Plan (reduce fishing effort and mortality)
- Implementation of Amendment 10 to the Sea Scallop Plan (rotational area management)
- Fishery controls (size limits, harvest limits, gear restrictions, seasons, spawning closures)
- Decisions regarding quotas hard and soft, closed areas, closed seasons, gear restrictions (what kind, when, when, and how much), limited entry (whose is in and out), minimum sizes, possession limits
- Allocation decisions (who gets how much and what circumstances)
- Obtaining Fishing data (landings/value, catch composition, effort, recruitment, distribution, abundance)
- Recommendations for minimizing or preventing impacts of human activities on the marine environment and fisheries
- Assessing impacts of fishing gear on fisheries habitat and minimizing that impact (gear and area restrictions)

- Determine how to minimize impact of groundfish fishing on skates which are a major component of bycatch (FMP/EIS statement)
- How to minimize bycatch and effect of fishing gear on habitat
- Impact of Sea herring abundance on groundfish recovery
- Impact of seals and marine mammals on fish populations
- Sea herring quota management
- Right Whale management
- Measures to protect marine mammals
- Identification of potential marine reserves

2) What are the types of information that you need to make these decisions

- Increased data and understanding with respect to meteorological, oceanography and life history factors to allow greater predictive modeling capability.
- Need information that fish farmers can use to make proactive decisions. For example, potential locations for sites (good flushing and food sources), type of year to expect, warning of impending bloom landfall and severity (nuisance bloom vs fish kill).
- We need environmental impact statements with every fishery management plan and information that would help in the effort to rebuild and conserve fish stocks.
- Need for a more complex, detailed understanding of ecosystems and multispecies interactions.
- Increase the used of ecosystem-based management to address more widely and systematically ecological considerations in fisheries models and management. The challenge remains to quantify the magnitude of ecological processes relative to fishing.
- Populations of seals in the Gulf of Maine appear to be steadily rising. With numbers now being assessed, what models exist or what models can be constructed to examine the impact of these predators of Gulf of Maine fish populations and elsewhere?
- The sea herring fishery is intensifying in the Gulf of Maine and on Georges Bank. What impact is this removal having on the forage base important for cod and other species? Are there any ecological considerations that can be modeled?
- For about 5 consecutive years the year-class sizes for Georges Bank cod have been below average. What environmental and/or other factors might prevent cod from rebounding? Is predation a leading factor limiting or capping a strong year-class and subsequent recruitment? Is this happening on GB and elsewhere?
- Elasmobranchs are a major component of the Gulf of Maine and Georges Bank. Dogfish and skates in the late 80s dominated the ecosystem and overwhelmed the gadids. It's been speculated that because gadid abundance was relatively low, there was a competitive release for elasmobranchs. As a consequence elasmobranchs greatly benefited. Can this elasmobrach/gadid/pelagic interaction be modeled? With managers apparently being required to rebuild every stock to B_{msy} values, under what circumstances will this be impossible due to species interactions involving competition and predation?
- El Nino is well known. The North Atlantic Oscillation is getting more attention and press. According to Canadian researchers, there is evidence that cod recruitment is strongly related to broad scale environmental factors like the Oscillation that change in magnitude

and impact. How does this Oscillation affect recruitment of Gulf of Maine and Georges Bank cod?

- Need an increased biophysical understanding of the impact of Gulf Stream rings and other environmental influences affecting phytoplankton and zooplankton and fish larval survival and growth.
- Marine or ecological reserves are now the hot topic. CLF and the World Wildlife Fund-Canada are working to assemble a Seascapes map. Managers would like to better understand the worth of reserves in the New England area in terms of sources and sinks of reproductive products for enhancing our sock rebuilding efforts.
- Baseline information is needed for models that are integral parts to stock assessments – simple yet critical information: age and growth, stock-recruitment – movements such as Gulf of Maine and Georges Bank cod back and forth, accurate catch information – good estimates of discards.

3) What key products could help you do your job better and more efficiently?

- Being able to predict the transport of nutrients, contaminants, HABs, and larvae.
- To predict the annual variation in larval/juvenile recruitment.
- To predict the timing, duration, and location of HABs.
- Improved biotoxin detection methods that are field-based, reliable and affordable.
- Improved predictive capabilities for forecasting harmful algal bloom events, severity and transport.
- Improved capabilities for forecasting year class strength, mortality rate, and larval transport for important fishery resources.
- A greater understanding of life history traits and species interaction effects.
- A greater understanding of meteorological and oceanography factors affects species survival.
- Enhanced communication with respect to data access and scientific and regulatory collaboration.
- A multi-disciplinary approach to managing and mitigating HABs.
- We need to continue to improve our understanding of the life history in hopes of developing reliable predictive capabilities.
- We need flexible regulatory approaches that encourage innovation and discovery of new methods and new strategies for HAB response.
- Data and models that can be used at the management scale-individual sites for HABs
- Models with key assumptions clearly identified.
- Models with some evidence of their predictability, have they been tested, do they work?
- Models that are user friendly; easy to manipulate and run at meetings for quick feedback
- Models with uncertainties well described.
- Models that have been peer reviewed.
- Need more than just tables of numbers. Need creative ways to display data to ease understanding and interpretation.
- Need honest assessment of how well the models work depending on number of years into any projection.

4) Do you see a role for models or model output in your decision-making process?

Harmful Algal Blooms

- Can we predict the occurrence of HABs offshore and nearshore?
- What are the effects of nutrients in the coastal zone on HABs?
- Is the frequency, duration, and spatial occurrence of HABs changing?
- What is the impact of population growth in the coastal zone? Climate change? Global warming?
- Are there threats to fisheries?
- What are the threats of DSP and ASP?

American Lobster

- Determine the lobster broodstock source for larval settlement and harvest areas and the relationship and relative contributions of the inshore and offshore broodstock.
- Study nearshore oceanography to understand impact on larval transport/settlement for lobsters.
- Are there large-scale oceanographic or climatic influences causing the reduced lobster larval settlement in the last 5 years? If so, through what mechanisms are those influences operating?

Green Sea Urchin

- Are there large-scale oceanographic or climatic influences causing the reduced settlement of larval sea urchins in the last five years? If so, through what factors or mechanisms are those influences operating?
- Understand urchin spawning, settlement survival, size/age ratio, and other biological measures in a local context to support local management.

Northern Shrimp

- What are the key factors in shrimp larval survival?
- Can environmental conditions at the time of larval release be used as a predictor of shrimp year class strength?
- What factors regulate timing of juvenile shrimp migrations, sexual transformation (male to female) and female inshore/offshore migration?
- Refine our understanding of the effects of large-scale oceanographic events such as the North Atlantic Oscillation, El Nino, and global warming on the Gulf of Maine.

Sea Scallop

- Fine scale research and current modeling to determine scallop larval dispersement patterns.
- Where is the effective broodstock for each scallop area?
- Do adult scallops or scallop larvae move inshore and/or offshore?

Appendix 6: Model Capabilities List

1) Describe the capabilities of your modeling system for a general audience.

- Approximating the general circulation dynamics in the Gulf of Maine, coastal zone, and estuaries in decreasing order of accuracy
- Simulating the transport of individual passive particles and bulk dissolved constituents over short time frames
- Simulating the life-cycle of *Alexandrium* populations with species interactions parameterized
- Simulating multi-species fishery interactions within an ecosystem context and for characterizing the errors associated with unknown or poorly known parameter values

2) What types of information can be produced by the model.

- Output on several physical parameters (temperature, salinity, current speed) and biological (chlorophyll, zooplankton, larvae) through time in 2 or 3-dimensions or at a particular location (grid cell)
- The projected transport of particles or dissolved constituents over short (1-3 days) time frames based on current and forecast environmental conditions
- Hypothesis testing for scientific and management questions or what-if experiments

3) Over the next several years where do you see the biggest/most exciting model improvements?

- Further increases in processor speed
- Advances in model design (finite-element/finite-difference hybrids) and architecture (parallel processing)
- Improvements in methods to parameterize unresolved processes (turbulence)
- Additional high resolution data sources to calibrate and validate model results against and with which to perform data assimilation
- Improvements in data assimilation and interpolation techniques
- A greater understanding of physical-biological interactions
- A finer grid resolution and a greater extent allowing larger systems to be simulated in greater detail
- Further progress in the use of nested modeling frameworks
- A greater understanding of how to parameterize behavioral processes

4) What types of data products are needed to initialize or refine your model?

- Satellite data (sea surface temperature, chlorophyll)
- Buoy data (air temperature, water temperature, salinity, phosphorescense, tides)

- Radar data (surface winds and currents, precipitation)
- Riverflow estimates
- Bathymetry
- Catch statistics
- Biological rate measurements
- Biological population distributions
- Biological interaction terms
- Estimates of turbulent effects
- Climatological data estimates for winds and other variables

5) How do you think your model might be used to make environmental decisions?

- Generate daily and short-term forecasts of oceanic properties and conditions
- Generate maps of the spatial distribution of important biological properties (phytoplankton)
- Identify potential sampling locations for shellfish toxicity testing
- Identification of locations at high risk of bloom development
- Identification of weather and oceanic condition favorable for bloom development
- Trajectory forecasting of passive particles and contaminants
- Identification of locations suitable for shellfish and aquaculture sites
- Seasonal forecasts based on large-scale climatic and oceanic events (NAO, El Nino)
- Understanding the impact of point sources of pollution (nutrients, contaminants)
- Understanding the impact of climate change (sea level rise, precipitation changes)
- Understanding the impact of fishery management regulations (harvest amounts, size limits)
- Identification of sites suitable for marine reserves
- Understanding the relationships between protected and non-protected species and reserves
- Understanding the impact of physical environmental changes (water diversion, dams)
- Investigate how physical processes affect biological distributions
- Investigate the interaction between species from an ecosystem context
- Infer processes in the life history for which data may be sparse
- Inform spatially-based management strategies
- Refine conceptual models of life history strategies
- Explore the implications of various actions/sources of variability
- Provide a fundamental part of an iterative scientific process – hypothesis generation
- Investigate lift history strategy and population spatial structure
- Investigate the effects of connectance and dispersal on fishery stocks and reserves
- Examine environmental trends and drivers of interannual variability

Appendix 7: Individual Model Statistics

Presentation title: Predictive model of *Alexandrium* in the Gulf of Maine
Presenter: Dr. Dennis McGillicuddy

Model Purpose: To simulate the mechanisms for initiation, growth, accumulation and transport of *Alexandrium* cells in Gulf of Maine with emphasis on the western Maine coastal current (WMCC), eastern Maine coastal current (EMCC) and Massachusetts Bay.

Management Applications: To allow coastal managers to better determine anthropogenic impacts on bloom frequency and extent. Results will yield specific information relevant to coping with and mitigating HAB's in the Gulf of Maine. It will also allow regulators and aquaculture farmers to make more informed decisions on sitting of new shellfish and finfish farms. The model will be available as a product that may be used to explore the impacts of future environmental decisions regarding fin and shellfish resources and nutrient loadings in the Gulf of Maine.

Where has the model been applied: Georges Bank, Gulf of Maine Basin, Gulf of Maine Coastal Region

Which variables are output by the model: Currents, salinity, temperature and *Alexandrium* vegetative cell distributions

Computer resources needed to run model: This is application dependent (i.e. it depends on how much output you want). Typical runs requesting temperature, salinity, and cell distribution at daily intervals over a 3 month period produce ~ 100 MB data files. I would suggest a typical contemporary PC or workstation (i.e. 256 MB – 1GB RAM, P3 or P4 processor) but you could run it on quite a bit less.

Length of a typical simulation (CPU time): ~ 3 months are simulated, and it could be run overnight (i.e. 6-12 hours) on a typical PC with specs above.

Access to previous simulation results: Websites are currently being updated with latest results and manuscripts are in preparation.

Background needed to run new model simulations: A considerable background in Fortran and Matlab is now needed to create and diagnose the results.

What are your recommendations on making this product operational for managers: We have a new ECOHAB project starting January 1 2003 in which one of our objectives is to develop an implementation plan for transition of the model to an operational framework. This plan will be crafted in the context of an ongoing dialogue with management personnel that will continue in a series of yearly workshops over the next three years. Thus it is premature to make specific suggestions at this time; we will update this entry as progress is made on the plan.

Physical Model

General Information

- **Model name or simulation platform:**
    - ECOM 3D
- **Model Characteristics:**
    - Sigma coordinate, Free surface, Primitive equation
    - Curvilinear orthogonal model grid (allows spatially variable mesh)
    - Mellor&Yamada level 2.5 turbulence scheme for vertical mixing (sub-model)
    - Finite-difference scheme for solving the equations
    - 3D model with 10 vertical layers
    - (1.5-3.0) Km variable cell width
    - (1-10) min time-step
    - Typical simulation covers a few months
    - Data on state variables is output each time-step
- **Model state variables:**
    - Temperature, Salinity, Pressure
    - U,V,W
- **Modeled processes:**
    - Hydrostatic coastal hydrodynamics
    - Surface heating and cooling (Large and Pond, 1982)
    - Wind forcing and parameterization (Large and Pond, 1981)
    - Mixing
- **Key published reference:**
    - Blumberg & Mellor (1987)
    - Mellor & Yamada (1982)
    - Blumberg (1991)
    - Large and Pond (1981, 1982)
- **Parent model name:**
    - Princeton's Ocean Model (POM)

Model testing and accuracy

- **What data is typically used to calibrate the model:**
    - There is no calibration of the physical model. The model is simply run forward with specified forcing.
- **What data is typically used to validate the model:**
    - Validation is carried out against salinity, temperature and current data.
- **Has an uncertainty or error analysis been performed:**
    - This model is widely used by the modeling community and has been shown to perform well in environments such as the Gulf of Maine.
- **How successful have hindcast simulations been (opinion):**
    - Recreated the general features of the large-scale circulation of the Gulf of Maine and Georges Bank.
- **How successful have forecast simulations been (opinion):**

    - No forecasts have been attempted yet.
- **Describe where the model performs the strongest (opinion):**
    - Recreating the general features of the large-scale circulation of the Gulf of Maine and Georges Bank.
- **Describe where the model performs the weakest (opinion):**
    - Representing the small-scale variability, particularly that which is below the resolution of the model grid. This is more of a limitation than a weakness, no model is going to resolve motions below grid scale.

Data and research needs

- **What are the model data needs and how are they satisfied?**
    - **Boundary conditions and initialization**
        - Temperature fields (Satellite-AVHR)
        - Baroclinic structure at depth (CTD/mooring)
    - **Forcing functions**
        - River discharge (USGS),
        - Wind (NOAA Met stations)
        - Short wave radiative flux (NOAA Met Stations)
        - Tides (NOAA tide gauges)
        - Low frequency sea surface elevation
    - **Forecasting needs**
        - Wind fields (Eta model)
- **How is data assimilated into the model (method and data types):**
    - No assimilation is being carried out at this time.
- **Top 3 physical assumptions or issues that managers should know about the model:**
    - Small scale patchiness cannot be resolved (i.e. the model may miss considerable spikes in cell numbers)
    - Coastal topography will be difficult due to grid-mesh limitations.
    - Climatology is currently being used for low frequency sea surface elevation.
- **What are your current interests for future model improvements:**
    - Future plans may consider assimilating current data to infer the low frequency sea surface elevation boundary condition.

Biological Model

General Information

- **Model name or simulation platform:**
    - *Alexandrium* population dynamics model
- **Model Characteristics:**
    - Changes in state variables are based on a fixed reference frame (Eulerian)
    - State variables are updated every time step
- **Model state variables:**
    - *Alexandrium* vegetative cell distribution

- **Modeled processes:**
    - Mortality (simplified)
    - Germination
    - Growth
- **Key published reference:**
    - Manuscript is in preparation
- **Parent model name:**
    - Original model

Model testing and accuracy

- **What data is typically used to calibrate the model:**
    - Ship transect data from cruise in 1993
- **What data is typically used to validate the model:**
    - Ship transect data from cruise in 1994
- **Has an uncertainty or error analysis been performed:**
    - Yes, the 4 most important parameters are; maximum growth rate, mortality rate, half-saturation for dissolved inorganic nitrogen, depth of sediment over which resting cysts contribute to blooms. I'd like to stress that these are the parameters that the model is most sensitive to over the range of their uncertainty.
- **How successful have hindcast simulations been (opinion):**
    - Somewhat successful. Reproduced many features from the 1993 dataset
- **How successful have forecast simulations been (opinion):**
    - We have yet to do forecasts
- **Describe where the model performs the strongest (opinion):**
    - Reproducing the general timing and magnitude of bloom development
    - Simulating trends in growth with temperature, salinity and light
    - Approximating the magnitude of germination rates as a function of temperature and light
- **Describe where the model performs the weakest (opinion):**
    - Reproducing small scale variability in space and time – which at times can be substantial

Data and research needs

- **What are the model data needs and how are they satisfied?**
    - **Boundary conditions and initialization:**
        - Cyst map for germination function (observations)
        - Approximation of cell levels at inflow boundaries (observations)
        - Initiate model before the bloom season when concentrations are near 0
    - **Forcing functions:**
        - Short wave radiative flux (observations)
        - Dissolved inorganic nitrogen field (observations)
        - T, S fields (physical model)
    - **Forecasting needs:**
        - Projected wind fields

    - Projected river outflow
    - Alexandrium cell distributions
- **How is data assimilated into the model (method and data types):**
  - No assimilation is performed at this time
- **Top 3 biological assumptions or issues that managers should know about the model:**
  - Model is heavily dependent on the input of cell inoculums for bloom initiation
  - There are no explicit species interactions currently modeled
  - Assumes no vertical Migration
- **What are your current interests for future model improvements:**
  - Better constraints on growth, mortality and the upstream boundary conditions

Presentation title: A New Unstructured Grid, Finite-Volume Gulf of Maine/Georges Bank Model (FVCOM)
Presenter: Changsheng Chen

Model Purpose: Simulate and forecast the stratification and 3-D currents as well as the lower trophic level food web and population structures in the Gulf of Maine/Georges Bank.

Management Applications: To provide managers and fishermen real-time, 3-dimensional distributions of temperature, salinity and currents. Allow managers and public to access the model for purposes of tidal forecasting and for the coastal management of marine environments and fishery resources.

Where has the model been applied: Georgia estuaries, Lake Superior, the Gulf of Maine/Georges Bank, Mount Hope Bay, the western Florida shelf, the East China Sea/Changjiang estuary.

Which variables are output by the model: Temperature, salinity, 3-D currents, turbulent kinetic energy, vertical eddy viscosity, thermal diffusion coefficient, nutrient concentration, phytoplankton biomass, DO, etc.

Computer resources needed to run model: PC with Linux with 2GB memory, and 100 GB hard disk.

Length of a typical simulation (CPU time): On a 2.4 GHz PC with Portland Fortran, it takes 1 day of computer time to run a 15-day simulation. A comparison has been made between FVCOM and ECOM-si, which shows that if the horizontal resolution is the same, the time required to run FVCOM and ECOM-si is very close.

Access to previous simulation results: The animations of the model results are posted on the following website: (http://codfish.smast.umassd.edu). The GLOBEC-IV website is being built and includes a section on Georges Bank, but is only accessible by password. The password can be obtained directly from Changsheng Chen (c1chen@umassd.edu).

Background needed to run new model simulations: A background in Fortran is needed.

What are your recommendations on making this product operational for managers: We are working toward a real-time simulation and forecast system for the Gulf of Maine/Georges Bank. A significant effort needs to be made to make the model easily accessible from the web and to make the model code compatible with a windows operating system. To achieve this will require long-term, ongoing support from managers or NOAA.

Physical Model

General Information

- **Model name or simulation platform:**
  - FVCOM
- **Model Characteristics:** The FVCOM model is configured with unstructured non-overlapping triangular grids and solved numerically with advanced finite-difference methods. It combines the best of the finite-element method (for geometric flexibility) and finite-difference methods (for computational efficiency).
  - Free surface, Primitive equations
  - Unstructured non-overlapped triangular meshes with a horizontal resolution of 1 km on Georges Bank
  - Mellor&Yamada level 2.5 turbulence scheme for vertical mixing (sub-model) with flexibility to use other turbulent parameterizations
  - Finite-difference scheme for solving the model equations with second order accuracy
  - Sigma coordinate with 51 vertical layers
  - 100 second time-step integration
- **Model state variables:**
  - U, V, W
  - Temperature, salinity, density
  - Vertical eddy viscosity
  - Thermal diffusion coefficient
  - Turbulent kinetic energy
- **Modeled processes:**
  - Tidal-driven currents
  - River discharges
  - Surface heating/cooling
  - Mixing
  - Lagrangian water and mass transport
  - Groundwater intrusion
  - Flooding/drying processes
  - Wind-driven motion
- **Key published reference:**
  - Chen, C., H. Liu, and R. C. Beardsley, 2002. An unstructured, finite-volume, three-dimensional, primitive equation ocean model: application to coastal ocean and estuaries. *Journal of Atmospheric and Oceanic Technology*, in press.
- **Parent model name:**
  - Original model

Model testing and accuracy

- **What data is typically used to calibrate the model:**

    - The model is driven with the MM5 meteorological model, which is calibrated with existing buoy data in the Gulf of Maine. The hydrographic survey and satellite-derived SST data are used to assimilate the temperature fields.
- **What data is typically used to validate the model:**
    - Compare model output with analytical solution and model-model comparisons.
- **Has an uncertainty or error analysis been performed:**
    - It is being conducted as one component of the US GLOBEC/Georges Bank Phase IV Program.
- **How successful have hindcast simulations been (opinion):**
    - FVCOM has successfully simulated the tidal structure in the Gulf of Maine/Georges Bank and the near-resonance nature of tidal waves in the Bay of Fundy. The model has also improved upon the simulation of residual currents and tidal mixing fronts.
- **How successful have forecast simulations been (opinion):**
    - It is being evaluated right now by comparing with the ECOM-si, POM, and HOP simulation models.
- **Describe where the model performs the strongest (opinion):**
    - Provides an adequate 3-D structure of circulation in the Gulf of Maine with flexible horizontal resolution. The model shows promise in resolving the water transport over the intertidal zones in complex geometric regions, tidal resonances, and residual currents over steep bottom topography. The model also does a good job at maintaining mass conservation, which is critically important in resolving the near-resonance nature of tidal motion in the Gulf of Maine.
- **Describe where the model performs the weakest (opinion):**
    - So far, we have found none.

Data and research needs

- **What are the model data needs and how are they satisfied?**
    - **Boundary conditions and initialization:**
        - Temperature (satellite SST)
        - Salinity
        - Hydrographic data
    - **Forcing functions:**
        - Winds
        - Heat flux
        - River discharges
        - Upstream inflow from the Scotian shelf
    - **Forecasting needs**:
        - Wind fields (ETA model)
        - SST (satellite)
- **How is data assimilated into the model (method and data types):**
    - Two types of data assimilations have been incorporated into the model. One is optimal interpolation and the other is the adjoint method.
- **Top 3 physical assumptions or issues that managers should know about the model**:
    - Initial conditions with climatological temperature and salinity fields.

  - Open boundary condition with connection to the North Atlantic Ocean is not included yet, which would be added later by linking with the North Atlantic Ocean basin model, but no validation could be made to see if this boundary condition is correct.
  - The upstream condition of the inflow from the Scotian Shelf is specified using the climatological averaged value.
- **What are your current interests for future model improvements:**
  - Make a version of the model for the windows operating system, which would allow managers to easily run the model for coastal management purposes without a need to have prior knowledge of the model structure.

Biological Model

General Information

- **Model name or simulation platform:**
  - Water Quality, NPZ, IBM (available)
  - NPZD (in development)
- **Model Characteristics:**
  - Turbulent closure and massive conservative advective computation, including the basic kinetic mechanisms among the foodweb system, and the key processes controlling water quality. IBM model includes the dynamics of the life stages.
- **Model state variables:**
  - Water quality model: DO, nutrients, phytoplankton, benthic flux, organic matter
  - NPZ: nutrients, phytoplankton, and zooplankton
  - NPZD: 8 component model which includes nutrients, phytoplankton, zooplankton, detritus, and bacteria
  - IBM: a 13-life stage of *Calanus finmarchicus*.
- **Modeled processes**:
  - Uptake
  - Grazing
  - Mortality
  - Advection
  - Mixing
- **Key published reference:**
  - Franks and Chen (1996, 2000)
  - Website: (http://codfish.smast.umassd.edu)
- **Parent model name:**
  - None

Model testing and accuracy

- **What data is typically used to calibrate the model:**
  - No calibration is made
- **What data is typically used to validate the model:**

    - Nutrients, Chl-a, Do, etc.
- **Has an uncertainty or error analysis been performed:**
    - Model results have captured patches, but no comparisons have been made to detailed biomass values.
- **How successful have hindcast simulations been (opinion):**
    - Reasonable simulation of nutrients and phytoplankton distributions on Georges Bank.
- **How successful have forecast simulations been (opinion):**
    - No tests have been made
- **Describe where the model performs the strongest (opinion):**
    - Simple model and mass conservation of state variables
- **Describe where the model performs the weakest (opinion):**
    - Resolving the details of the energy transformation in the biological system since there are not many data available to prove the correct pathway of such a linkage. This is a general problem for all biological models.

Data and research needs

- **What are the model data needs and how are they satisfied?**
    - **Boundary conditions and initialization**:
        - Flux of nutrients, Phytoplankton, Bacteria from rivers
        - Upstream open boundary over the Scotian Shelf
        - Open boundary connecting to the open ocean
    - **Forcing functions:**
        - Winds
        - Heat fluxes
        - River discharges
        - Benthic flux
    - **Forecasting needs**
        - Meso-scale wind fields (which is available for this model right now)
- **How is data assimilated into the model (method and data types):**
    - Optimal interpolation and adjoint method
- **Top 3 biological assumptions or issues that managers should know about the model:**
    - Climatological initial conditions for nutrients, phytoplankton and zooplankton
    - No intense comparison has been made since no biological data are available
    - Model provides a good prediction for patches but the values are sensitive to biological parameters
- **What are your current interests for future model improvements:**
    - Conducting more tests to validate the biological model and to make it accessible for managers through the web.

Presentation title: Circulation modeling for the Gulf of Maine Ocean Observing System
Presenter: Dr. Huijie Xue

Model Purpose: The GoMOOS circulation modeling focuses on developing an operational model for the Gulf of Maine region, making model results available via the web in real-time in nowcast mode, and producing forecasts by coupling the circulation model with available meteorological forecasts.

Management Applications: Potential applications include fisheries (temperature), search and rescue (currents), coastal zone management (sea level).

Where has the model been applied: Gulf of Maine, Bay of Fundy, and Georges Bank

Which variables are output by the model: Currents, salinity, temperature, and sea level.

Computer resources needed to run model: The model can be run on a broad range of platforms. Minimum requirement is a P3 or P4 desktop with 512MB RAM. Standard output includes a data file of ~90 MB for a 48-hour forecast and a restart file of ~40 MB.

Length of a typical simulation (CPU time): ~ A 48-hour forecast including pre and post processing takes 2 hours on a Dell desktop with dual P3 866MHZ processors or 20 minutes on an 8 processor SGI origin 3200.

Access to previous simulation results: Results are available at (http://gomoos.org) and (http://rocky.umeoce.maine.edu/GoMPOM).

Background needed to run new model simulations: A considerable background in Fortran is now needed to create and diagnose the results.

What are your recommendations on making this product operational for managers: We run the model and update the 48-hour forecast daily. Only the sea level and the sea surface temperature have been validated, and they will soon be adopted by the GoMOOS as operational data products. We hope to include assimilation of CODAR data in the daily operation in the near future.

Physical Model

General Information

- **Model name or simulation platform:**
    - Princeton Ocean Model
- **Model Characteristics:**
    - Sigma coordinate, Free surface, Primitive equation
    - Curvilinear orthogonal model grid (allows spatially variable mesh)
    - Mellor&Yamada level 2.5 turbulence scheme for vertical mixing (sub-model)
    - Finite-difference scheme for solving the equations
    - 3D model with 22 vertical layers
    - 3-5 Km variable cell width
    - 3.5 minute time-step
    - Typical simulation covers 48 hours
    - Data on state variables is output every 3 hours
- **Model state variables:**
    - Sea level, Temperature, Salinity, Eddy viscosity and diffusivity
    - U, V, W
- **Modeled processes:**
    - Local processes including tides, river plumes, wind driven currents, surface heating/cooling, and mixing
    - Remote processes imported through the open boundary conditions including the Scotian shelf flow, slope water inflow, and the Gulf Stream warm core rings
- **Key published reference:**
    - Xue, Chai & Pettigrew (2000)
    - Blumberg & Mellor (1987)
    - Mellor & Yamada (1982)
- **Parent model name:**
    - Princeton Ocean Model (POM)

Model testing and accuracy

- **What data is typically used to calibrate the model:**
    - There is no calibration of the physical model. The model is simply run forward with specified forcing.
- **What data is typically used to validate the model:**
    - Validation is carried out against sea level, temperature and currents.
- **Has an uncertainty or error analysis been performed:**
    - This model is widely used by the modeling community and has been shown to perform well in environments such as the Gulf of Maine.
    - Errors associated with the sea level and the SST have been analyzed routinely.
- **How successful have hindcast simulations been (opinion):**
    - Recreated the general features and seasonal changes of the large-scale circulation of the Gulf of Maine and Georges Bank.
- **How successful have forecast simulations been (opinion):**

    - Consistent forecast of the sea level
    - Consistent forecast of the sea surface temperature
- **Describe where the model performs the strongest (opinion):**
    - Recreating the general features of the large-scale circulation of the Gulf of Maine and Georges Bank.
- **Describe where the model performs the weakest (opinion):**
    - Stratification. We believe the problem stems from the bias in the open boundary condition obtained from the COFS, which is known to have higher salinity and warmer temperature on the Scotian Shelf. We are working with scientists in NOAA on this issue.

Data and research needs

- **What are the model data needs and how are they satisfied?**
    - **Boundary conditions and initialization**
        - Boundary conditions are from the larger scale operational model (COFS from NCEP/NOAA)
        - Surface temperature fields (Satellite-AVHRR)
        - River discharge (USGS)
        - Bathymetry (USGS)
    - **Meteorological Forcing functions**
        - Wind (NCEP/NOAA Eta model)
        - Heat flux (Eta)
        - Evaporation and precipitation (Eta)
    - **Forecasting needs**
        - Wind fields (Eta)
        - Heat and fresh water fluxes (Eta)
- **How is data assimilated into the model (method and data types):**
    - Assimilating SST by optimal interpolation
    - Assimilating sea surface velocity based on Kalman Filter theory
- **Top 3 physical assumptions or issues that managers should know about the model:**
    - Coastal embayments will be difficult to resolve due to grid-mesh limitations.
    - Forecast skill is limited by the quality of data input to the model, namely, wind forecast, AVHRR, and CODAR measurements.
    - COFS has known biases in salinity and temperature on the continental shelf, which affects our upstream condition. We are working with the NOAA scientists to address this problem. In addition, we are also developing a redundant forecast system using alternative open boundary conditions.
- **What are your current interests for future model improvements:**
    - Data assimilation and forecast skill assessment

Appendix 8: Model Forecasting Types

1. Empirical models: Correlating changes in ecological variables with changes in physical forcing variables to derive statistically based predictive indices

Purpose: To provide intermediate (weekly) to long-term (monthly) general forecasts (i.e. this will be a good or bad year over what one would typically expect). Also conditions that are favorable for bloom development

Management Applications

Fishery: North Atlantic Oscillation effects on fishery recruitment
HAB: Upwelling index effects on bloom likelihood and potential toxicity

Data needs

Climatology
Historical data
Forecast of future conditions
Understanding of driving process

Modeling Needs

Need to formulate predictive indices (no need for large scale numerical model). These could be for large time-scale (e.g., annual) or short time-scale predictions (e.g., using daily or weekly upwelling indices)

2. Population and Ecosystem models (1-Dimensional): Non-spatial population models focusing on species and ecosystem interactions under idealized physical forcing scenarios

Purpose: To provide an understanding of how species interactions (e.g. predator/prey relationships) and biological dynamics (e.g. growth, predation) influence observed species abundances. To understand the connections between species and the flow of energy through the ecosystem. To investigate physical and biological interactions in idealized systems. Models can focus on individual species (e.g. *Alexandrium*, Cod/Pollock dynamics) or trophic levels (i.e. NPZ, NPZD, NPSDF models)

Management Applications

Fishery: Effects of intra- and inter-species competition
HAB: Effects of predation on bloom persistence

Data needs

Temperature, salinity, nutrients, trace element effects on growth
Flushing rate

Modeling Needs

An adequate biological submodel

3. Hydrodynamic transport and particle tracking models (3-Dimensional): Spatially explicit models, which simulate realistic flow fields and are capable of following passively, advected particles (i.e. no biology included)

Purpose: To predict the trajectory, transport and dispersal of target species (i.e. particle tracking with little or no biology). To identify advective events with negative effects on recruitment of target copepod and fish species. Evaluation of site specification for Marine Protected areas for fish

Management Applications
- **Fishery:** Closed area analysis and marine protected areas
- **HAB:** Short-term predictions of HAB landfall

Data Needs (joint)
- Winds, Tides, Freshwater Inputs
- Temperature and Salinity
- Distribution (Vertical and Horizontal) of Target Species/Life Stages for Tracking
- Behavior of Target Species (where appropriate)

Data needs (habs)
- Bloom or patch observations (cruise transect, moored sensors, PSP measurement)
- Location of sensitive resources (fish farms)
- Real-time physical data to calculate trajectory

Modeling Needs (joint)
- 3-D Hydrodynamic Model
- Individual-Based Model Incorporating Behavior affecting Vertical Distribution

Model Needs (habs)
- Near shore shallow water hydrographic modeling
- Define spatial scale accuracy
- Trajectories of diffusive patches

4. Coupled hydrodynamic and population/ecosystem dynamics models: Incorporating biological dynamics within a spatially explicit physical framework using population (i.e. Alexandrium, Cod) or ecosystem models (i.e. NPZ, NPZDF).

Purpose: To predict the primary production characteristics of the Gulf of Maine. Annual forecasts, bloom landfall predictions, “what-if” scenarios. PSP prediction (over daily or weekly time frame)

Management Applications
- **Fishery:** Identify conditions affecting recruitment probability distribution of copepods and fish
- **HAB:** Identify conditions affecting the probability of HAB events

Data needs (joint)

- Nutrient Inputs
- Incident Solar Radiation
- Winds, Tides, Freshwater Inputs
- Temperature and Salinity
- Phytoplankton Species Composition, Abundance and Distribution
- Ratio of New to Recycled Production
- Zooplankton Species Composition, Abundance and Distribution
- Zooplankton Grazing Rates

Data needs (ecohab)

- Biology/Ecology of Harmful Algal Species
- Climatology, historical data, forecast of future conditions
- lots of basic biology (growth, encystment, excystment, grazing, vertical migration, nutrient uptake)
- understanding of process

Data needs (ecohab additional)

- bivalve toxin submodel
- empirical experience based conceptual model
- lots of basic biology (growth, encystment, excystment, nutrient uptake, etc.)
- initialize model

Data needs (globec)

- Fish Species Abundance and Distribution
- Fish Consumption Rates and Prey Composition
- Consumption by Higher Trophic Levels

Model Needs (joint)

- 3-D Hydrodynamic Model
- Models for Population Dynamics of Target Species
  - N-P-Z models for ECOHAB
  - N-P-Z-F models for GLOBEC

Modeling Needs (ecohab)

- better parameterization of biological processes (nutrient responses, swimming behavior, life history responses, grazing dynamics, etc)
- lots of basic biology
- large scale models for boundary conditions

Modeling needs (ecohab additional)

- shallow water hydrography and biology
- numerical techniques for thin layers
- define concentration/toxicity threshold and uncertainty
- lots of basic biology (growth, encystment, excystment, nutrient uptake, etc.)
- data assimilation