Gulf of Maine Symposium— Advancing Ecosystem Research for the Future of the Gulf: Proceedings of a Symposium held at St. Andrews, NB, October 5-9, 2009

Co-Editors: Lara L. Cooper, Robert L. Stephenson, and John H. Annala

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2010

Canadian Technical Report of Fisheries and Aquatic Sciences 2904

Fisheries and Oceans Canada | Pêches et Océans Canada

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

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GULF OF MAINE SYMPOSIUM— ADVANCING ECOSYSTEM RESEARCH FOR THE FUTURE OF THE GULF: PROCEEDINGS OF A SYMPOSIUM HELD AT ST. ANDREWS, NB, OCTOBER 5-9, 2009

by

Co-Editors
Lara L. Cooper, Robert L. Stephenson, and John H. Annala[1]

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This is the two hundred and ninety-fifth Technical Report of the Biological Station, St. Andrews, NB

Cat. No. Fs 97-6/2904E ISSN 0706-6457 (print version)
Cat. No. Fs 97-6/2904E-PDF ISSN 1488-5379 (online version)

Correct citation for this publication:

Cooper, L.L., Stephenson, R.L., and Annala, J.H. 2010. Gulf of Maine symposium— Advancing ecosystem research for the future of the Gulf: proceedings of a symposium held at St. Andrews, NB, October 5-9, 2009. Can. Tech. Rep. Fish. Aquat. Sci. 2904: xiv + 168 p.

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Cooper, L.L., Stephenson, R.L., and Annala, J.H. 2010. Gulf of Maine symposium—Advancing ecosystem research for the future of the Gulf: proceedings of a symposium held at St. Andrews, NB, October 5-9, 2009. Can. Tech. Rep. Fish. Aquat. Sci. 2904: xiv + 168 p.

The *Gulf of Maine Symposium – Advancing Ecosystem Research for the Future of the Gulf* was held October 5th through 9th, 2009 , at the Fairmont Algonquin Hotel in St. Andrews, New Brunswick. This symposium was initiated by the Regional Association for Research on the Gulf of Maine (RARGOM), an association of institutions that are actively involved in research, management and stewardship activities related to the Gulf of Maine and its watershed, and was co-convened by Fisheries and Oceans Canada St. Andrews Biological Station (DFO SABS), the Gulf of Maine Research Institute (GMRI), the Communication Partnership for Science and the Sea (COMPASS) and the Gulf of Maine Census of Marine Life (GoMA/CoML).

The symposium programme was designed to inform participants about current research and policy objectives, constraints, and future influences on the management of marine resources, to share new developments in scientific knowledge regarding the Gulf of Maine, and to identify research priorities to meet future needs from an ecosystem-based approach. The symposium objectives were 1) to examine what progress had been made over the past decade in implementing an ecosystem approach, 2) to evaluate how well positioned we are to implement an ecosystem approach in the Gulf of Maine, and 3) to propose research priorities. The Symposium involved over 200 participants, from approximately 75 institutions (mainly from Atlantic Canada and New England), and approximately 100 presentations.

RÉSUMÉ

Cooper, L.L., Stephenson, R.L., and Annala, J.H. 2010. Gulf of Maine Symposium—Advancing Ecosystem Research for the Future of the Gulf. Compte rendu d'un colloque tenu à St. Andrews, au N.-B., du 5 au 9 octobre 2009. Rapp. tech. can. sci. halieut. aquat. xiv + 168 p.

Un colloque intitulé *Gulf of Maine Symposium – Advancing Ecosystem Research for the Future of the Gulf* a eu lieu du 5 au 9 octobre 2009, à l'hôtel Fairmont Algonquin, à St. Andrews, au Nouveau-Brunswick. Ce colloque était une initiative du réseau Regional Association for Research on the Gulf of Maine (RARGOM), auquel sont associées des institutions qui participent pleinement à des activités de recherche, de gestion et de gérance associées au golfe du Maine et à son bassin hydrographique. Ce colloque a été convoqué conjointement par la Station biologique de St. Andrews du MPO (SBSA-MPO, le Gulf of Maine Research Institute (GMRI**),** le Communication Partnership for Science and the Sea (COMPASS) et le Gulf of Maine Census of Marine Life (GoMA/CoML).

Le colloque avait pour but d'informer les participants des objectifs actuels en matière de recherches et de politiques, des contraintes dont il faut tenir compte, ainsi que des incidences futures sur la gestion des ressources marines. Il visait également à favoriser l'échange des récentes percées dans le savoir scientifique concernant le golfe du Maine, et à cerner les activités de recherche qui sont prioritaires pour répondre aux besoins futurs d'une approche écosystémique. Les objectifs du colloque sont les suivants : 1) examiner les progrès réalisés au cours de la dernière décennie pour favoriser la mise en œuvre d'une approche écosystémique, 2) examiner notre positionnement face à la mise en œuvre d'une approche écosystémique, 3) proposer des activités de recherche prioritaires. Le colloque a attiré plus de 200 participants, provenant de quelque 75 institutions (surtout du Canada atlantique et de la Nouvelle-Angleterre) et on y a présenté une centaine d'exposés.

PREFACE

The last major symposium for science in the Gulf of Maine was the RARGOM scientific symposium and workshop held in St Andrews, New Brunswick in 1996. Since that date, there have been tremendous advances in our understanding of the Gulf of Maine, there have been changes in legislation (in both Canada and the USA), and federal, provincial, and state jurisdictions in Canada and the USA have moved forward with ecosystem approaches to managing marine resources. Therefore, it was timely to review and update the last decade of policy approaches and science, and make recommendations on the knowledge required to move forward with an integrated management approach/ecosystem approach to management (IM/EAM) in the Gulf of Maine.

The geographical focus of this symposium was the Gulf of Maine watershed (delineated by the eastern tip of Massachusetts in the southwest and Cape Sable at the southern tip of Nova Scotia in the northeast). Both Massachusetts Bay and the Bay of Fundy are included within the Gulf of Maine system.

Symposium goals

The overarching goal for the symposium was to synthesize and advance the ecosystem research that supports the future management of the Gulf of Maine. The symposium program was designed to inform participants about current objectives, constraints, and future influences on management of marine resources, to share new developments in the state of scientific knowledge in the Gulf of Maine, and to identify scientific requirements and directions to meet future needs from an ecosystem-based approach. In order to achieve this goal, the following questions were addressed:

1) How has the scientific basis for an ecosystem approach advanced in recent years (and especially since the previous symposium)?

- What is our current understanding of the Gulf of Maine and its ecosystems, and how does it compare to our knowledge in 1996 at the last Gulf of Maine symposium?

2) How able are we to implement an ecosystem approach in the Gulf of Maine?

- What is the state of our current scientific capacity to address management needs now and in the future? What are the knowledge requirements to implement an ecosystem approach to management?
- What is impeding us from making decisions now?

3) What are the research priorities?

- What are the future concerns and knowledge requirements?
- What are the gaps in our knowledge?
- What natural and social science research, and particular data sets and analyses, will be required over the next 5 years to meet management requirements for an ecosystem-based approach?
- What science is required to observe and predict change and respond to future uncertainty?
- What role should scientists play in ensuring research is applied to current management questions?

Symposium format

The *Gulf of Maine Symposium— Advancing Ecosystem Research for the Future of the Gulf* began on Monday October 5th at the Fairmont Algonquin Hotel in St. Andrews, with concurrent technical sessions featuring research contributions from both natural and social scientists, who sought to connect the relevance of their research to marine resource managers and policy and decision-makers. Themes for the technical sessions included:

- *Ecosystem Services in the Gulf of Maine*
- *Biodiversity in the Gulf of Maine*
- *Seafloor Mapping for Ecosystem Management in the Gulf of Maine*
- *Life Histories of Gulf of Maine Fishes and Invertebrates*
- *Assessing Linkages between Ecosystem Health and Measures to Evaluate Change*

Plenary sessions combining perspective and keynote talks, and theme presentations and discussions were held October 6th through 9th , including a poster session on October 6th. Plenary theme sessions included:

Theme 1: Tools for integrated policy and management

This theme was a synthesis of the management and policy tools and approaches that are required to implement integrated management in the Gulf of Maine:

- Development of new scientific approaches, tools, and analysis methods for EAM, including integrated ecosystem models, management strategy evaluation approaches including marine protected areas as a spatial conservation tool, etc.
- Integration of the above approaches, tools, and methods into policy and management
- Coordination of science and management scales (the scale for observation and the scale for feedback) for multiple ecosystem services and sectors— identifying

temporal and spatial mismatches between biological systems and human institutions
- Assessment and measurement of management success from a coupled social-ecological perspective

Theme 2: Structure and function of the Gulf of Maine system

This theme was a synthesis of the current ecological and oceanographic understanding of the Gulf of Maine, and the social, economic, and cultural interactions and goals within the Gulf of Maine:

- Habitats, biodiversity, and function
- Population structure and trophic ecology
- Biological, chemical, and physical oceanography
- Social, economic, and cultural attributes

Theme 3: Anthropogenic and external influences on the Gulf of Maine ecosystem

This theme was a synthesis of the major pressures being exerted on the Gulf of Maine that impact the achievement of objectives or the desired state of valued attributes (ecological, social/cultural, and economic):

- Measurement and assessment of effects of climate change on Gulf of Maine ecosystems
- Impacts of commercial fishing
- Impacts of marine invasives
- Land-based impacts, including pollution
- Impacts of alternative developments of the marine zone, including aquaculture and energy facilities, e.g. wind, tidal, LNG
- Watershed/land use/river inputs (e.g. nutrient and sediment loads)

Theme 4: Monitoring/observation, data collection, analyses, and tools required for an Ecosystem Approach to Management (EAM) of the Gulf of Maine

This theme was a synthesis of the science that is required to observe and predict changes in the Gulf of Maine ecosystem, and to evaluate the strategies used to implement an ecosystem approach to management:

- Evolution of monitoring approaches for EAM
- Ocean mapping
- Ocean observing systems
- Indicators and reference points for monitoring programs
- Socio-economic indicators

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- Fisheries and Oceans Canada, St. Andrews Biological Station (DFO SABS)
- Gulf of Maine Research Institute (GMRI)
- Communication Partnership for Science and the Sea (COMPASS)
- Census of Marine Life Gulf of Maine Area (CoML/GoMA)

Major Contributors

- United States National Oceanographic and Atmospheric Administration (US NOAA)
- United States Geological Survey (USGS)
- Regional Ocean Science Initiative (MIT Sea Grant College Program)
- New Brunswick Environmental Trust Fund (Province of New Brunswick)
- Environment Canada
- Fisheries and Oceans Canada

Symposium Supporters

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- Town of St. Andrews

ACKNOWLEDGEMENTS

The success of this symposium was very dependant on the contributions of many DFO staff members. We would like to thank Judy James, Pierre Clement, Trish Hopkins, Sheri Reid, Janelle Arsenault, Michele Saunders, Shawn Chase, Angela Vance, Steve Neil, Rodney Lord, and John Trynor. We would also like to thank Sandra Clark, Nancy Leavitt, and all of the other staff at the Huntsman Marine Science Centre for hosting a fabulous poster session. There were many others who contributed their time and expertise, and all are gratefully acknowledged.

SYMPOSIUM AGENDA

MONDAY, OCTOBER 5

Concurrent Technical Sessions

- ***9:00 am to 4:00 pm****— Technical Workshop on Ecosystem Services in the Gulf of Maine (Stephen Hale and Maxine Westhead)*
- ***8:00 am to 4:15 pm****— Technical Workshop on Biodiversity in the Gulf of Maine (Lewis Incze, Peter Lawton, and Sara Ellis)*
- ***8:30 am to 4:30 pm****— Seafloor Mapping for Ecosystem Management in the Gulf of Maine (Jonathan Grabowski, Brian Todd, Page Valentine, and Tracy Hart)*
- ***10:00 am to 4:00 pm****— Technical Workshop on Life Histories of Gulf of Maine Fishes and Invertebrates (Jake Kritzer)*
- ***2:30 pm to 5:30 pm****— Assessing Linkages between Ecosystem Health and Measures to Evaluate Change (Verna DeLauer, David Keeling)*

TUESDAY, OCTOBER 6

Symposium Plenary Opening and Perspective Talks

8:00 am to 12:00 pm —

- ***Dr. Robert Stephenson***
- ***Dr. Michael Fogarty***
- ***Ms. Sally McGee***
- ***Mr. Jean Guy D'Entremont***
- ***Dr. Bonnie McCay***
- ***Dr. Pete Jumars***

1:30 pm to 5:30 pm — Plenary Session

Theme 1 — Tools for integrated policy and management: Co-Conveners: Andy Rosenberg/Leslie-Ann McGee (US) and Arran McPherson/Tim Hall (Canada)

WEDNESDAY, OCTOBER 7, 2009

8:00 am to 12:00 pm – Plenary Session

Theme 2 — Structure and function of the Gulf of Maine system: Co-Conveners: Michael Fogarty/David Townsend (US)

1:30 pm to 5:30 pm — Plenary Session (Theme 2 continued)

THURSDAY, OCTOBER 8, 2009

8:00 am to 12:00 pm — Plenary Session

Theme 3 — Anthropogenic and External Influences on the Gulf of Maine Ecosystem: Co-Conveners: Madeleine Hall-Arber/Judy Pederson (US) and Jim Abraham/Peter Wells (Canada)

1:30 pm to 5:30 pm — Plenary Session

Theme 4 — Monitoring/Observation, Data Collection, Analyses, and Tools Required for an Ecosystem Approach to Management (EAM) of the Gulf of Maine: Co-Conveners: Jeffrey Runge (US) and Michael Sinclair/Bob O'Boyle (Canada)

FRIDAY, OCTOBER 9, 2009

8:00 am to 12:00 pm — Plenary Session (Symposium wrap-up and conclusions)

12:00 p.m. — Official Symposium Closing

SYMPOSIUM PLENARY OPENING AND PERSPECTIVE TALKS

Session Chair: John Annala (RARGOM/Gulf of Maine Research Institute)

Dr. Robert Stephenson (Fisheries and Oceans Canada, St Andrews Biological Station)

Context for advancing ecosystem research for the future of the Gulf of Maine

Underlying themes of the last RARGOM scientific symposium held in St Andrews, New Brunswick in 1996, were ecosystem modelling and recognition of the importance of transboundary linkages between terrestrial (air- and watershed) and adjacent marine ecosystems. Since that time, there have been significant advances in our understanding of the Gulf of Maine, and federal, provincial, and state jurisdictions in Canada and the US have moved forward with ecosystem approaches to management. The international context for an ecosystem based approach has evolved, and there have been legislative changes in both USA and Canada. There has also been an evolution of the public perspective with respect to the need for enhanced stewardship in the face of ecological change. There is increasing awareness of the need for development of an integrated approach to the management of multiple human activities in relation to a more diverse set of objectives that include a higher standard of ecological integrity, and diverse aspects of sustainability. It is timely to review and update the last decade of science and make recommendations on the knowledge and priorities required to move forward with an integrated management approach/ecosystem approach to management (IM/EAM) in the Gulf of Maine.

Dr. Michael Fogarty (Ecosystem Assessment Program, Northeast Fisheries Science Center, Woods Hole, Massachusetts)

Ecosystem-based fishery management for the Northeast Continental Shelf large marine ecosystem: Options for implementation

There is an emerging global consensus on the need to adopt an ecosystem approach to management of human activities in marine systems. Key elements of the approach include the recognition that humans are an integral part of the ecosystem, that management must consider inter-relationships among components of the system and the effects of environmental forcing, and that management units should be based on ecological rather than political boundaries. I will review progress toward defining an ecosystem approach to fishery management on the Northeast Continental Shelf. This approach must necessarily be complemented by related management considerations for the nearshore environment and for the cumulative effects of multiple environmental stressors. One approach under development at the Northeast Fisheries Science Center focuses on the delineation of ecological subregions of the northeast shelf, the identification and estimation of production processes and fishery production potential for

the system, the specification of sustainable ecosystem exploitation rates, and an allocation strategy to define allowable harvest levels of individual species subject to constraints designed to protect ecosystem structure and function. I will provide an overview of progress on each of these topics and outlook for the future.

Ms. Sally McGee (Policy Director, Environmental Defense Fund Oceans Program in New England)

We really can get there from here: Important steps toward ecosystem based fishery management:

Ecosystem based fisheries management has been on the to-do list for the Gulf of Maine for decades. The problem in implementation has been the need to put out fires before the big picture can be considered adequately. The good news is that with changes in the Magnuson Stevens Act requiring scientifically determined catch limits for federally managed fisheries, many of the fires should be extinguished in the coming years. As a result, on the U.S. side of the Gulf of Maine, there is renewed interest in interspecies or "integrated fishery management" especially in the past year. Currently, the term IFM is being used to mean incorporating flexibility between fishery management plans to allow and account for mixed catch (e.g. – yellowtail flounder in the sea scallop fishery). This is an evolving process in the context of the NEFMC that has the potential to move the region toward an ecosystem based approach to fishery management if developed properly and thoroughly.

If this new approach (IFM) is going to play a role in promoting EBFM, there are several key components that must be addressed: 1) adequate monitoring across all fisheries must be provided; 2) flexibility across existing management plans must encourage reporting and landing rather than discarding; 3) inter-jurisdictional coordination (within and among states and federal management bodies) must improve, and 4) the US/Canada resource sharing understandings should be expanded where appropriate. All of these elements are key to fishery management that promotes abundance, resilience, and diversity.

Mr. Jean Guy D'Entremont (President, Scotia Harvest Seafoods Inc.)

Fishermen without borders

The Gulf of Maine (GOM) may have defined borders to some, but to the Canadian fishing industry, it carries a flow of larvae, nutrients, etc… from Georges Bank, to the West Scotian Slope, to the Bay of Fundy, and all points in between. The GOM provides an economic driver to people and communities as well as supplying what may be the last natural food on the planet. The fishery has been utilizing the GOM for centuries yet it is only recently that monitoring and data gathering has been taking place. In my opinion, we can extract much more value from the fisheries than we presently do. If the fisheries resource of the GOM is not delivering its full potential, who is ultimately responsible and accountable? In the past decade, transboundary groundfish resources from Georges Bank

have been successfully managed through the Transboundary Management Guidance Committee (TMGC). We can improve decision-making even further in a greater ecosystem context recognizing that decisions have to be made with the information available. Ecosystem Approach to Fisheries (EAF) proposes a pragmatic view based on assessing the risk of not meeting agreed objectives.

Dr. Bonnie McCay (Professor, Anthropology and Ecology at Rutgers University, New Jersey)

Where are the people?

The study of ecosystems such as the Gulf of Maine and efforts to realize the objectives of ecosystem-based management are proceeding apace, but the so-called "human dimensions" need greater attention, rhetoric notwithstanding. They are mainly limited to representations of the anthropogenic effects of people and their artifacts and activities, such as overfishing, pollution, or drilling for oil. The relevant ecosystem has inputs from people but does not include them. As in standard fisheries management, the people are relegated to a single indicator, "F," fishing mortality, and perhaps, if we push it a bit, in "E" for effort, as in CPUE. Making it ecosystem-based adds small "e" to equations or elaborates on matters such as predation, competition, sea surface temperatures, but does no more for the people involved. We tend to keep people out of the "ecosystem," despite much rhetoric to the contrary. If we want to take this seriously, we need to address not only (1) the above notion of anthropogenic influences on a non-human ecosystem; but also (b) "social and economic impact" and related analyses; and (c) recent efforts at "coupled natural and human systems." Throughout, we should not lose sight of the critical roles of people as actors—in "tragedies, comedies, and other dramas of the commons—and as chroniclers and witnesses.

Dr. Pete Jumars (Director of the School of Marine Sciences, University of Maine)

Stalk-eyed views of the Gulf of Maine: Through a nepheloid layer dimly

All biological oceanographers are students of the Gulf of Maine. The notions behind compensation depths and critical depths were born here in the work of Gran, Braarud and Riley and deal with effects of light on phytoplankton. The problem that I treat herein, however, involves the benthic-pelagic coupling interaction of light with sedimentary benthic communities as reflected in habitat use by sedentary and mobile animals. Light availability clearly produces resource gradients through photosynthesis, but it also produces risk gradients. Visual predators produce nearly ubiquitous decreases in activity of benthos during daylight. Add swimming ability and dietary breadth, however, and the interaction between use of space and the diel and seasonal clock gets more interesting. I argue herein that resource and risk gradients select for onshore-offshore migration as well as for vertical migration. Light also serves a purpose in navigation via polarization, with cues most reliable near dawn and dusk.

Oceanographers typically have avoided shallow water because it is a complicated place to work, with steep gradients in all three Eulerian coordinates and rapid changes in time. Nevertheless, some resource gradients are apparent from even a cursory look. Abundance of benthic diatoms peaks in Maine coastal waters at about 10 m water depth and does so very early in the year. Climatological estimates of compensation depth at Gulf of Maine latitudes are near 30 m, so phytoplankton as well as phytobenthos are prone to bloom earlier in shallower coastal waters. Unfortunately, remote sensing resolution near shore is poor due to the abrupt optical transition for down-looking optics at the shore and due to complex mixtures of particle suspensions and land-derived solutes, but two migrations suggest the importance of a head start of the spring bloom in coastal waters. The best documented is the northern shrimp, a beneficiary of the cod cascade during the cod's demise. It predicts onset of the local bloom and releases eggs in time for its larvae to be fed by the bloom.

Less conspicuous members of the food web are the more omnivorous mysids, heavily dominated in the western North Atlantic by *Neomysis americana.* According to the NMFS survey, "*N. americana* is the most common mysid inhabiting the northeastern coastal waters of the United States and undoubtedly the most abundant mysid in the western North Atlantic Ocean." Mysids are notoriously difficult to quantify because they are too small for big nets and too fast for small nets. *N. americana* also appears to congregate where phytobenthos and phytoplankton come early in the year but show an unusual change in depth distribution with latitude, being restricted largely to the surf zone and muddy estuaries from the mid Atlantic states to Florida. Their diel and seasonal distributions are consistent with high risk of visual predation even though the residual risk remains substantial. They highlight the importance of horizontal resource and risk gradients.

PLENARY THEME SESSIONS

THEME 1: TOOLS FOR INTEGRATED POLICY AND MANAGEMENT

Session co-conveners: Leslie-Ann McGee, Arran McPherson and Tim Hall

Rapporteurs: Heather Breeze, Mark Craig, Maxine Westhead

Session Summary

Theme I, Tools for Integrated Policy and Management, explored the management and policy tools and approaches that are required to implement integrated management in the Gulf of Maine. In particular, poster authors and oral presenters addressed one or more of the following Theme I topics:

- Development of new scientific approaches, tools, and analysis methods for an ecosystem approach to management (EAM), including integrated ecosystem models, management strategy evaluation approaches including marine protected areas as a spatial conservation tool
- Integration of the above approaches, tools, and methods into policy and management
- Coordination of science and management scales (the scale for observation and the scale for feedback) for multiple ecosystem services and sectors – identifying temporal and spatial mismatches between biological systems and human institutions
- Assessment and measurement of management success from a coupled social-ecological perspective

Advances in General

There have been significant advancements in developing tools for integrated policy and management since the RARGOM Symposium of 1996. A better understanding of the history of, and changes in, fisheries and oceans management has been essential in bringing both scientists and policy makers to where we are today. Developments in management, particularly fisheries management, due in part to recent amendments to the Magnuson-Stevens Act in the USA, have resulted in the use of different controls to manage fish catches. Managers have gained a better understanding of what does and does not work in regulating fisheries.

These developments have gone hand in hand with changes in the overall legislative and policy framework. In Canada, the *Oceans Act* (proclaimed in 1997) and efforts to renew the *Fisheries Act* have led to the creation of new policies and strategies to manage our oceans, including Canada's Oceans Strategy (2002) and the Sustainable Fisheries Framework (2009). In the US, the 1996 *Sustainable Fisheries Act* amended the Magnuson-Stevens Act with a requirement to identify essential fish habitat and to make

progress towards reducing, avoiding or mitigating both fishing and non-fishing impacts to these habitats. Such examples of promoting sustainability and the ecosystem approach to management through oceans-related legislation and policies have parallels in the private sector, with efforts by business to implement ISO standards and by fisheries to achieve eco-certification.

While we now have a better understanding of the overall context of oceans management and have developed legislation and policy to help implement an ecosystem approach to management, the current operating environment does not lack challenges. Oceans management on both sides of the Canada-USA border is complex with many different jurisdictions responsible for managing fisheries and other aspects of the marine environment in the Gulf of Maine. This complexity has been compounded by the use of the court system to address fisheries management issues, particularly in the US.

A positive, yet challenging development that has occurred since the 1996 Symposium is the proliferation of organizations and networks focused on the Gulf of Maine marine environment. The number of organizations with an interest in the Gulf demonstrates the importance of the region to a wide range of stakeholders from politicians and decision-makers, students and researchers, resource users and those living in coastal communities while at the same time pose communication and governance challenges. These multitude of diverse interests brings the necessary diversity of perspective to discussions but also makes timely integration of policy, management, and science difficult. The means by which we can all work together effectively remains an outstanding issue.

Advances in Tools

Tools for integrated policy and management meet a wide range of functions and originate from a variety of fields, from the physical and biological sciences to social sciences and organizational studies. Tools presented included those used for organizing and evaluating information, such as tools to better classify ecosystem features; tools for assessing the implementation of management objectives, such as Ecosystem Approach to Management (EAM) frameworks and State of the Environment Reporting (SoER); and, tools for communication, such as adult learning models and new media technology.

There exist new scientific tools to support ecosystem approaches to management. In the US, new methods of identifying essential fish habitat (EFH) will improve management of these designated areas. It also opens the possibility of utilizing EFH designations in a broader, marine spatial planning context. The classification of inlets along the Atlantic coast of Nova Scotia has been accomplished with the aid of a geographic information system (GIS). This classification approach, and other similar analyses using GIS, could be used for such management activities as conservation planning.

Tools and approaches now exist that are employed to better organize, evaluate and share existing information with the goal of implementing ecosystem-based management. The Ecosystem Based Management (EBM) Tools Network launched an EBM Roadmap in the spring of 2009 for EBM practitioners. The Maritimes Region of Fisheries and Oceans Canada is developing an Ecosystem Approach to Management (EAM) framework that

will assist in developing specific management strategies to respond to EAM objectives. State of the Environment reporting for the Gulf of Maine is being developed through the Gulf of Maine Council on the Marine Environment. The goal is to help decision-makers better understand the main issues affecting the Gulf, and thus assist in designing appropriate management responses. The COINAtlantic initiative aims to provide one-stop access to online data for those responsible for implementing integrated management.

The application of developmental psychology and adult learning models to oceans management and the emphasis on exploring novel means of communicating are new considerations when employing an integrated management approach. In designing ecosystem-based management programs in the Gulf of Maine, we are challenged to consider the varying characteristics of those involved with integrated management, in addition to the diverse ways that they can contribute. Time spent in building capacity and understanding among those involved with ecosystem-based management may be, at the very least, as important as developing the technical tools to implement it. The potential of new technologies working together, to enable greater collaboration, communication, knowledge sharing and to permit management to be more open and transparent is acknowledged.

Future Directions

Better tools for evaluating and managing cumulative effects are still warranted. New activities, such as tidal and wind power, have been proposed for the Gulf of Maine. These new variables need to be taken into consideration; however, we are still in the process of developing methods to describe and address the impacts of existing activities. Collaborative efforts to develop tools and approaches for addressing cumulative effects will be needed in order to fully implement the ecosystem-based management approach.

While it is recognized that much progress has been made toward integrated policy and management, an overall evaluation of that progress is difficult. The application of State of the Environment Reporting, frameworks such as the Ecosystem Approach to Management, or approaches developed by the EBM Tools Network may assist in measuring and evaluating our progress towards ecosystem-based management.

Improved communication among those involved in research, education and policy in the Gulf of Maine is still required. Raising the general levels of ocean literacy is also desirable. Communicating research results should be a significant component of the research planning cycle and financial resources for this aspect should be built into all research programs. Furthermore, it is recommended that researchers developing tools or approaches for integrated policy and management aim to engage those they think will use or benefit from their research at the earliest possible stage. The integration of decision-makers, scientists and others involved in “integrated policy and management” in developing tools and approaches will aid in making them practical, pragmatic and, above all, applicable to ecosystem-based management in the Gulf of Maine.

Theme 1 – Schedule of Oral Presentations

13:30 Keynote Address — Faith Scattolon (Fisheries and Oceans Canada)
Progress towards integrated management: A self-assessment

14:00 Keynote Address — David Preble (New England Fishery Management Council)
Fishery management tools in New England: Moving towards ecosystem approaches in the last decade

14:30 McGee, Leslie-Ann
Essential Fish Habitat as an Ecosystem-Based Management Tool

14:50 DeLauer, Verna
The mental demands of marine ecosystem-based management: Are we in over our heads?

15:10 Feurt, Christine
What would Don Quixote do? Exploring new paradigms in ecosystem management

15:30 Health Break

15:50 Greenlaw, Michelle
Representative conservation planning in the nearshore: A classification of coastal inlets of mainland Nova Scotia, using geophysical information to define representative types and to assess existing protected areas

16:10 Walmsley, Jay
State-of-the-environment reporting for the Gulf of Maine

16:30 Taylor, Peter H.
A roadmap for implementing ecosystem-based management (EBM)

16:50 Boudreau, Paul R.
COINAtlantic: An initiative of the ACZISC to facilitate and promote the application of available online information to coastalshed management

17:10 Ryan, Susan
Strategic communications in the Greater Gulf of Maine: Connecting the islands of research, education and policy

Theme 1 – Abstracts of oral papers

Keynote— Progress towards integrated management: A self-assessment

Faith Scattolon, Regional Director General

Fisheries and Oceans Canada, Maritimes Region, Dartmouth, Nova Scotia

Fisheries and Oceans Canada has made substantial efforts towards implementing the principles of integrated management in its regional operations. Working in a transboundary environment presents its own unique set of challenges, but the region is committed to operationalizing the ecosystem approach to management and has made contributions in support of sustainable fisheries, protection of sensitive benthic habitat, tools to assess the effectiveness of integrated approaches as well as governance models. This presentation will review our progress in moving forward on integrated management, provide an assessment of our results to date and comment on the policy implications for the Gulf of Maine.

Keynote— Fishery management tools in New England: Moving towards ecosystem-approaches in the last decade

David Preble

New England Fishery Management Council

An important user of the Gulf of Maine is the New England groundfish fishery, which includes both commercial and recreational fishermen. Since 1996, the management of this fishery has experienced major changes. At the start of this period the open access fishery was changed into a limited access program that used effort controls to achieve mortality targets. Over time, there was a gradual introduction of output controls into portions of the fishery. These complex measures reduced fishing mortality and increased stock size of most stocks, but did not achieve mortality targets and had adverse social and community impacts. With the imminent implementation of Amendment 16 the fishery will begin a transition to output controls, but the final form of that output control system has yet to be determined. Each of these fishery management approaches has strengths and weaknesses. Significant and frequent changes in the scientific and legal framework supporting the management system complicated management efforts, forcing managers to react to rapidly shifting objectives. These fishery management experiences highlight the challenges facing implementation of a coordinated ecosystem approach in an area with multiple jurisdictions and potentially different management objectives: the policy and legal framework that managers operate within may be as dynamic as the physical processes within the ecosystem."

Essential fish habitat as an ecosystem-based management tool

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Living marine resources contribute to the food supply, economy, welfare, health, and recreational opportunities of the Nation [United States]. In 1996, the Sustainable Fisheries Act (Public Law 104-297) amended the Magnuson-Stevens Act of 1976 and included a provision to define and protect habitats associated with federally-managed fishery resources. These "essential fish habitat" provisions call for directed progress towards reducing, avoiding or mitigating both fishing and non-fishing impacts to fish habitats. Toward this end, Congress mandated the identification of habitats essential to managed species and measures to conserve and enhance this habitat.

Essential fish habitat (EFH) means those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity (Magnuson-Stevens Act, 16 U.S.C. 1801 et seq). Federal agencies must consult with the Secretary of Commerce (NOAA as designee) on all actions, or proposed actions, authorized, funded, or undertaken by the agency, that may adversely affect EFH. In return, NOAA shall provide recommendations, which may include measures to avoid, minimize, mitigate, or otherwise offset adverse effects on EFH, to conserve EFH.

This presentation will explain how EFH designations were first employed after the 1996 SFA amendments and their subsequent maturity as a tool supporting ecosystem-based management of marine resources in the Gulf of Maine. The presentation will include a review and update on the advancement of EBM through the use of EFH designations, as well as recommendations on improving policy implementation. The evolution of designation methodology since the inception of the SFA has allowed for a more spatially resolved way of capturing many ecosystem-level parameters. This provides two important benefits. First, NOAA's ability to consult on, and devise mitigation strategies for, the impacts to EFH from proposed offshore projects utilizing non-fishing marine resources will be improved. Second, future ecosystem-based management and marine spatial planning efforts in the Gulf of Maine will be better served by these more sophisticated EFH modeling tools.

The mental demands of marine ecosystem-based management: Are we in over our heads?

Verna G. DeLauer*[1]

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Ecosystem-based Management (EBM) is a relatively new and promising approach to the management of marine systems. EBM is holistic by seeking to include all stake- holders affected by marine policy. Stakeholders may include individuals from varying levels of government, academia, environmental organizations, and marine-dependent businesses and industry. This presentation lays out the substantive differences of marine EBM stakeholder engagement processes versus other, single sector processes. EBM processes are more complex than existing stakeholder engagement mechanisms, to sufficiently require a more sophisticated conceptual understanding of the process and the people involved. There are implicit cognitive, interpersonal, and intra-personal demands of EBM that are not addressed by current literature. The research being presented sought to understand the mental demands of EBM. A constructive developmental framework (from the field of developmental psychology) is used to illuminate how decision-makers reason or make sense of the ideals and values underlying EBM, the mutual relationships that must be built among management sectors, and the personal experiences and emotions that accompany change. The research considerations include useful lessons for facilitating an ecosystem-approach to policy formation by understanding the mental and emotional capacities of those responsible for change.

What would Don Quixote do? Exploring new paradigms in ecosystem management

Christine Feurt

University of New England, Wells National Estuarine Research Reserve

Natural resource managers and environmental policy makers trained in disciplines grounded in the natural sciences learn quickly that some of the biggest challenges to the practice of ecosystem management are social ones. While ecosystem theory provides a conceptual framework for integrating the ecological, socioeconomic, cultural and institutional elements of environmental problems, the *practice* of ecosystem management remains illusive. Interdisciplinary degree programs offer a new generation of resource managers theoretical and methodological grounding in practices geared to navigating the challenges of ecosystem management. However, mid career professionals frequently lack such training and can benefit from skill building and perspective altering social science techniques. A “science to management” initiative of the National Oceanic and Atmospheric Administration (NOAA) implemented within the National Estuarine Research Reserve System (NERRS) provided the context for developing innovative interdisciplinary approaches supporting ecosystem management.

This action research case study at the Wells, Maine NERR evaluated the application of social science methodologies to community based ecosystem management. Stakeholder and institutional analysis methodologies were applied to understand the context of municipal decision making about water. Results of these methodologies, combined with instructional design and collaborative learning methodologies facilitated watershed partnerships in coastal watersheds in southern Maine. Application of science and implementation of best management practices benefited from the partnership structure.

An understanding of the cultural roots of conflict, motivational forces guiding ecosystem management and perceived barriers to collaboration guided the place-based design of this national science to management initiative. The social science methodologies applied in this case study yielded surprising and valuable perspectives about the social system influencing community based ecosystem management. The conceptual framework for integrating social science into ecosystem management developed through this research suggests a need for fundamental perspective shifts in the way bio-physical science researchers approach the science to management/policy interface.

Representative conservation planning in the nearshore: A classification of coastal inlets of mainland Nova Scotia, using geophysical information to define representative types and to assess existing protected areas

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Selection of candidate sites for designation as Marine Protected Areas (MPAs) in coastal waters still involves many arbitrary choices. Analysis of candidate sites, according to a combination of geophysical and ecological criteria, can lead to the recognition of representative coastal areas, and potentially reduce the arbitrary nature of these decisions. In coastal areas, estuaries have long been classified according to their geophysical properties. Bays and coves are at least as diverse in character, yet existing classifications are dependant largely upon description of the benthic communities themselves and take little advantage of existing hydrographic and digital information. This thesis presents a classification of coastal marine inlet types designed to predict biological community patterns including specific community types and α and β-diversity patterns. The classification is based on GIS analysis of existing digital hydrographic and associated data and uses fuzzy cluster analysis to deal with uncertainty and intermediate types in the classification.
This fuzzy inlet classification method was applied to Nova Scotia's Atlantic shoreline although this method could easily be applied globally to determine which inlet types are naturally repeating in each region of interest. On Nova Scotia's Atlantic Shoreline, inlets fall into three primary categories and 17 recognizable inlet types, with intermediates quantified using a fuzzy classification.

Inlet types were analyzed in comparison to the current and proposed protected areas along the Nova Scotia Atlantic shoreline to determine the how well each inlet type is represented in the current protection scheme. Only 2% of the area of inlets on the Atlantic shoreline of Nova Scotia are currently protected, although 14% of the shoreline length is protected. The intermediate benthic estuary type was the only inlet type that was well protected (according to IUCN conservation objectives of 10%), with 58% of it's area protected under the current protection scheme. While ten of the inlets had over 10% of their shoreline protected. Proposed protected areas (DFO's EBSAs) were biased towards large bays and estuaries, presumably inlets DFO has spent the most time analyzing in the past.

State-of-the-environment reporting for the Gulf of Maine

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The Gulf of Maine Council on the Marine Environment has recognized the importance of state-of-the-environment (SOE) reporting as a management tool. Although participating members are individually taking steps to catalogue the collective understanding of the Gulf of Maine and there are many fine examples of reports that address aspects of a state-of-the-environment report (SOER), there is currently no Gulf-wide synthesis of pressures on the environment, biophysical and socio-economic status and trends, and responses to identified issues. A scoping study has been undertaken to assess the most appropriate method to report on the state of the Gulf of Maine. The study included: understanding the use of and challenges to SOE reporting; identifying the target audience for a SOER for the Gulf of Maine; identifying some of the reporting requirements for the Gulf of Maine; assessing information requirements and availability, and proposing an approach to develop a SOER for the Gulf of Maine.

The main objective of a SOER for the Gulf of Maine would be to inform decision makers on the main issues affecting the Gulf. The aim would be to provide the information in a form that is easily accessible and readable, without compromising scientific validity. SOE reporting should be guided by a conceptual framework that facilitates development of information and makes the linkages between the environment and socio-economic factors. The reporting framework recommended for SOE reporting in the Gulf of Maine is the driving forces-pressure-state-impacts-response (DPSIR) framework. This framework lends itself most easily to reporting on an issue-by-issue basis, so that the pressures, state, impacts and responses are described for each issue in turn.

The recommended SOE reporting system comprises three main components including: a modular SOER that can be readily updated as required (formal SOE document); a wiki site that allows for informal reporting on SOE by interested parties, and a SOER web portal that provides linkages to other products and initiatives. Much of the information

required for a SOER is already available in a variety of publications. The main challenges to developing a SOE reporting system for the Gulf of Maine are funding and human resource capacity; ongoing commitment of the Council and compatibility across jurisdictions.

A roadmap for implementing ecosystem-based management (EBM)

Peter H. Taylor

Waterview Consulting

Ecosystem-based management (EBM) is a comprehensive, integrated approach to managing human impacts on the ocean and coast to ensure sustainable ecosystem services. EBM is intended to overcome the shortfalls of past environmental policies and management, which have proved insufficient to address the increasing intensity and variety of human impacts on the ocean. Many people and organizations in the Gulf of Maine region and other geographies are moving EBM from concept to practice, but they have expressed a need for practical information about how to implement EBM. Waterview Consulting, COMPASS, and the EBM Tools Network created the EBM Roadmap in response to this need. The concept for the EBM Roadmap emerged from focus groups, needs assessments, interviews, and an extensive literature review. Launched in spring 2009, the EBM Roadmap is an online resource that presents Core Elements of EBM, Focus Questions, case studies, background information, and tools for implementing EBM. It is one of a growing number of communication tools designed to facilitate science-based advances in marine and coastal management. The Roadmap serves as a touchstone and common point of reference for everyone involved in EBM: scientists, managers, policy makers, and stakeholders. The Roadmap provides a framework that can be adapted and customized for specific geographies and environmental issues, and it is intended to be expanded, updated, and refined over time. The EBM Roadmap is available online at www.ebmtools.org/roadmap.html.

COINAtlantic: An initiative of the ACZISC to facilitate and promote the application of available online information to coastalshed management

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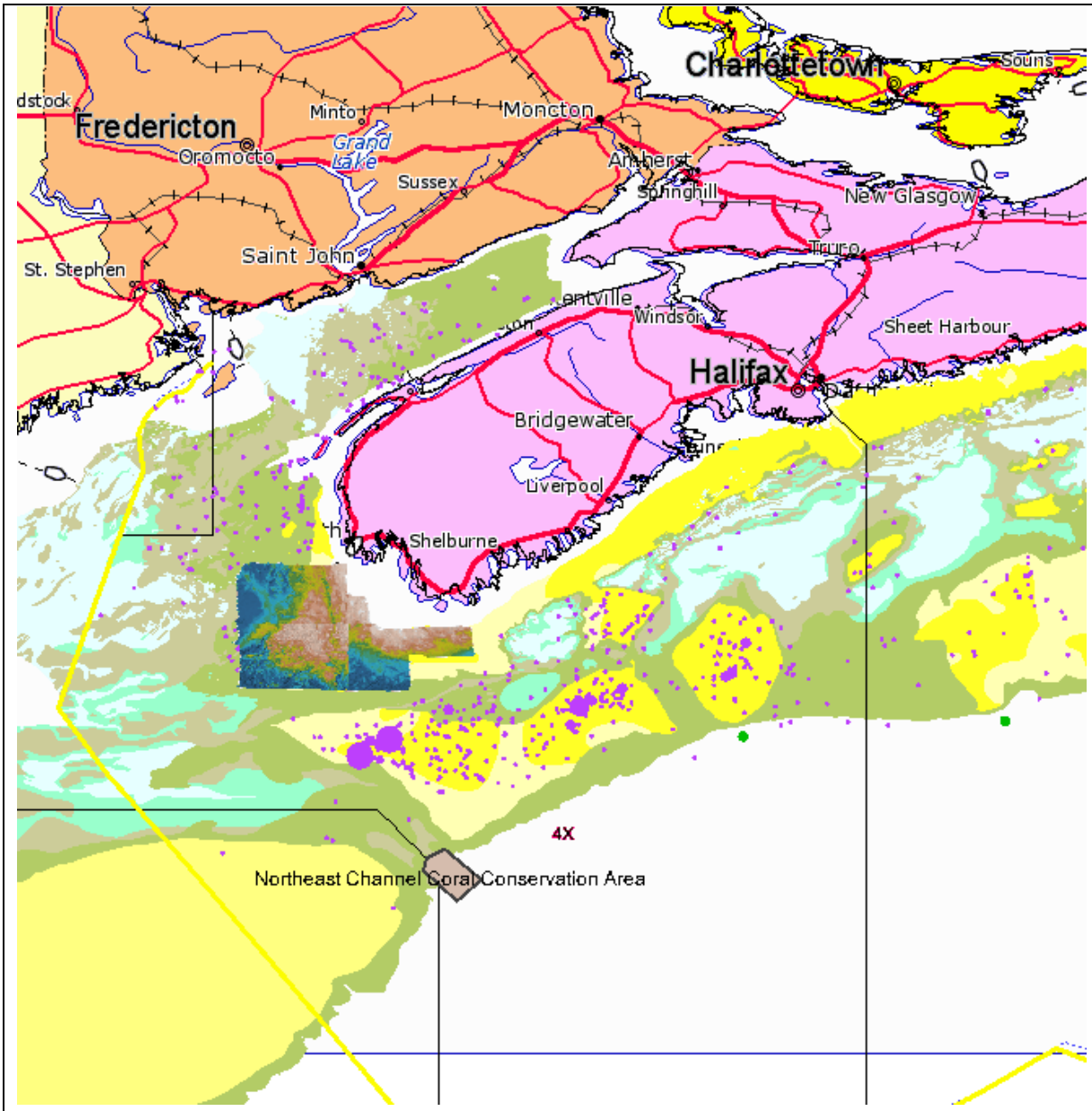
The Coastal and Ocean Information Network Atlantic (COINAtlantic), an initiative of the Atlantic Coastal Zone Information Steering Committee (ACZISC), is working to facilitate the application of available information for integrated coastal and ocean management (ICOM).

This initiative is a blend of “people, information and technology”. The people, the core of the network, are representatives of those departments, agencies and organizations which

have responsibilities for ICOM and information management and distribution in the region. They have a direct interest in accessing and applying available information to coastalshed management. The information consists of data that is commonly available online using standard internet formats. The technology, applied through COINAtlantic, brings the data providers and data users together in a simple and innovative manner using internet browsers.

To be successful, ICOM must access and use information concerning land, water and sea, the "coastalshed" defined as the geographic area made up of oceans, estuaries, inland seas, and their adjacent sub-watersheds.

The presentation will draw attention to the large variety of information that is generally required for effective ICOM. It is evident from the geography of Canada's coastalshed that the information requirements are the domain of a large number of agencies and organizations. No one agency can, or should attempt to, manage it all. Thus, COINAtlantic has worked to bring the people, the information and the technology together to access the necessary information, from many authoritative sources through common internet standards. Through the work of COINAtlantic participants, and funding from GeoConnections, an online utility has been implemented that allows users to search, find and map information from various sources on common internet browsers.



Map image generated using COINAtlantic to display information from several branches of DFO and NRCan.

Strategic communications in the Greater Gulf of Maine: Connecting the islands of research, education and policy

Ivar Babb[1], Susan Ryan*[2], Pam DiBona*[3], and Peter Taylor[4]

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The way the scientific community retains the privilege to do research using public funds is by communicating their results in a way that is meaningful to the public (Jesse Ausubel, Sloan Foundation, 2006)

The Gulf of Maine Summit will provide a significant forum for the presentation of the current state of research being conducted in the Gulf. The information shared during this week-long event has the potential to greatly advance research, policy, management, and education efforts in the region. However, fulfilling that potential requires a regional strategic communications initiative. There is widespread agreement that research results need to be communicated to various audiences, but how this can occur in the region needs to be considered as methodically as the research itself. The region incorporating the Gulf of Maine and adjacent Bays is home to multiple networks engaged in communications and education, such as the Ecosystem-Based Management Communications Work Group, bringing together diverse partners to advance EBM through communications; New England Ocean Science Education Collaborative (NEOSEC), focusing on informal and formal education and outreach initiatives; Massachusetts Ocean Partnership, engaging stakeholders, conducting public outreach, and integrating science for improved state-level ocean management; Gulf of Maine Council on the Marine Environment, sharing information among government agencies, NGOs, and the public; and numerous other informal and formal networks of professionals and academics. To achieve a goal as complex as ecosystem-based management of the Gulf of Maine, communication strategies need to be designed to serve the needs of multiple audiences, to be multi-layered (increasing in depth and complexity depending on users) and to be delivered by multiple partners over time. This presentation will examine progress to bridge the islands of research, education, and policy in the Gulf of Maine and provide recommendations for improving these bridges, based on input solicited from practitioners in the region. The session will seek input from the audience (e.g., scientists, managers) on the recommendations and ideas as to how to best serve their needs.

Theme 1 –- Poster Abstracts

US Northeast Coastal Ocean Forecast System (NECOFS): Applications to simulate multi-scale estuarine-coastal interactions in the Gulf of Maine and adjacent coastal regions

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A team of University of Massachusetts-Dartmouth and Woods Hole Oceanographic Institution researchers has developed the Northeast Coastal Ocean Forecast System (NECOFS). NECOFS is an integrated atmosphere-ocean model system in which the ocean model domain covers the northeast US coastal region (the New England Shelf, Georges Bank, the Gulf of Maine, and the Scotian Shelf) with a horizontal resolution of 10-15 km in the open ocean, 1-5 km on the shelf, and down to 20 m in estuaries, inner bays, inlets and harbors. The system includes: 1) two community atmospheric mesoscale models, WRF (Weather Research and Forecasting model) and MM5 (fifth generation NCAR/Penn State model), modified to incorporate the COARE 2.6 air-sea flux algorithm); 2) the unstructured-grid Finite-Volume Coastal Ocean Model configured for this region (FVCOM-GOM) with a nested higher resolution FVCOM configured for Massachusetts coastal waters (FVCOM-MASS); 3) an unstructured-grid surface wave model (FVCOM-SWAVE); and 4) the FVCOM-based unstructured-grid sediment model. In its present initial stage, the forecast system is built based on WRF and FVCOM-GOM/FVCOM-MASS. Both meteorological and ocean models have been tested through comparison with field data in hindcast experiments covering the period 1979 to present. The system produces 3-day forecast fields of surface weather, surface waves, 3-D ocean velocity, temperature, and salinity, with daily updating using hindcast data assimilated fields whenever field data are available. The forecast fields are then posted on the NECOFS website http://fvcom.smast.umassd.edu/research_projects/NECOFS/index.html. FVCOM-GOM and FVCOM-MASS are being upgraded with a new semi-implicit FVCOM code, which will allow regional and coastal as well as estuarine model runs with a significant reduction in computational power. The model-predicted flow, temperature and salinity fields have been validated by comparison with available hydrographic, CODAR, and current data in this region. NECOFS forecast data are currently being used by the National Weather Service Taunton WFO and the NECOFS software is being implemented for the northern Gulf of Mexico by the National Ocean Service. Some results and applications will be presented.

Use and influence of marine environmental information: Continued studies of the publications of intergovernmental groups such as the Gulf of Maine Council on the Marine Environment

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Our research addresses fundamental questions about the use and influence of scientific information produced by marine environmental governmental and intergovernmental groups. The Gulf of Maine Council on the Marine Environment (GOMC), celebrating its twentieth anniversary in 2009, has long recognized that decision makers in marine environmental management must have efficient access to data and information about the Gulf of Maine and Bay of Fundy region. Hence, production and communication of new information has been a Council priority, resulting in over 300 publications of various types, disseminated in print copy and, since the late 1990s, available in digital format on the Council's website (www.gulfofmaine.org). We are tracking this literature, mostly "grey literature," by several methods (e.g., citation analysis (via *Web of Science* and other web-based tools), content analysis, and interviews) to determine its use and influence at policy and decision making levels of state, provincial, and federal governments. The study has to date assembled an extensive, cross referenced bibliography of the GOMC publications and the literature has been analyzed bibliometrically. GOMC publications are now distributed more efficiently via the Internet than in print, and are used and cited in a number of contexts, including public policy settings. The study is proceeding with further in-depth analyses of use, especially with interviews of users around the Gulf of Maine region. This poster summarizes past work and describes our most recent results. Our research emphasizes the vital importance of linking information generation with its access and use to resolve environmental issues in the Gulf of Maine region.

Habitat models for species at risk in the Bay of Fundy

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Protection of essential habitat is an important component of marine ecosystem-based management, but is limited by habitat definition for most species. Habitat modelling via various spatial regression approaches has been successful in defining the niche hypervolume for a wide range of marine and terrestrial species. The Bay of Fundy constitutes an important sub-area of the Gulf of Maine characterized by large tidal range, steep turbidity gradients, and the presence of many species at risk. Under the Species at Risk Act, DFO has responsibility for protection and recovery of populations at risk. A joint research program between DFO and Dalhousie University seeks to determine the best approach to habitat modelling, define relevant spatially-located, ecogeographic variables (EGV), and undertake habitat definition for a variety of species. A number of challenges exist for this project, including the fact that few EGV exist, especially with spatial resolution or format suitable for GIS. Bathymetry was used to derive additional variables such as bottom slope and roughness. A circulation model was used to provide layers of residual and mean circulation. Satellite remote sensing allowed layers of temperature, turbidity, and CDOM as a tracer of salinity. In addition to EGV, various species represent challenges such as Atlantic salmon faithful to rivers, and marine mammals oriented toward upwelling zones. Examples of habitat models and their application within the Bay of Fundy are presented as a broadscale approach to management of essential habitat.

Open-water integrated multi-trophic aquaculture (IMTA): Advances, challenges and considerations for coastal zone management.

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Integrated Multi-Trophic Aquaculture (IMTA) is a modern iteration of polyculture. Intensive monocultures from different trophic levels are integrated and connected by nutrient and energy transfer through the water. An IMTA farm can accommodate at least three niches with organisms that extract 1) organic particulates, 2) settleable solids and 3) soluble inorganic nutrients. IMTA has been lauded as an improved approach to intensive marine finfish aquaculture. 'Proof of concept' has been demonstrated with a number of pilot projects world wide. There are now several commercial 'open-water' IMTA sites located in the Bay of Fundy, and over a dozen of IMTA licence applications pending with the Province of New Brunswick. Given the significant increase in this type of aquaculture practice, what considerations should be given for coastal zone management and environmental monitoring? Such considerations will be a function of system efficiencies, metrics of sustainability and the number of niches filled. Arguably one of the most important considerations is the scale at which IMTA may be practiced as this will dictate space requirements and mitigation potential. The scale will be driven by industry, not researchers. Despite much advancement in 'open-water' IMTA development, several of the aforementioned parameters remain to be adequately quantified. The state of the art,

knowledge gaps, challenges and considerations of IMTA will be discussed in the context of Ecosystem Based Management, Coastal Zone Management and Ecosystem Goods and Services.

Towards operational estimates of copepod abundance and right whale distributions

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Copepods such as *Calanus finmarchicus*, *Centropages typicus*, and *Pseudocalanus* spp. are the key link between primary productivity and populations of fish, mammals, and birds in the Gulf of Maine. Furthermore, the distribution and reproductive success of higher trophic levels is often tied to changes in the relative abundance of major copepod taxa. We have developed a model that uses satellite data (sea surface temperature and chlorophyll) to drive simulations of the reproduction and development of *C. finmarchicus, C. typicus,* and *Pseudocalanus*. By coupling this model to output from a numerical circulation model, we can produce high resolution estimates of copepod abundance in the Gulf of Maine. These estimates can be further refined by assimilating observations of copepod abundance and stage distributions. We have used the output from these models to predict the distribution of endangered northern right whales in Cape Cod Bay and habitat usage in the Great South Channel. Copepod estimates could also be used to understand changes in the distribution, abundance, and reproductive success of fish such as herring, cod, and haddock.

Solutions from the water: fishermen-led efforts to reduce North Atlantic right whale entanglements in Canada

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Conservation of North Atlantic right whales (*Eubalaena glacialis*) requires mortalities caused by entanglements in fishing gear to be significantly reduced. In the U.S., there has been much effort to reduce these mortalities by regulating fishing practices through

federal law. In Canada to date, there has been less government regulation directly involved in mitigating this threat, but the subject has not been disregarded. WWF-Canada has been working on this issue with the goal of integrating fisheries management and species conservation in order to establish sustainable fishing practices that will reduce the threat of entangling right whales. To accomplish this, WWF-Canada has engaged fishermen to take a lead role in addressing entanglements because their involvement is a crucial component for success. Canadian fishermen have indicated their commitment to do their part to reduce the threat to right whales while ensuring the sustainability of their fisheries. They agree that solutions should: 1) reduce the actual threat to whales; 2) reflect the seasonal distribution of the whales; and 3) be specific to local fishing areas. Lobster (*Homarus americanus*) fishermen from southwest Nova Scotia and New Brunswick, one of the largest fisheries in Canada, are in the process of implementing a threat reduction strategy in collaboration with WWF-Canada. The first phase of this voluntary strategy focuses on reducing the amount of rope in the water column by specifying gear dimensions (i.e. rope lengths) and operating practices. In June 2009, these standard practices were adopted by the port representatives of Lobster Fishing Areas (LFA) 33 and 34 on behalf of the 1700 fishermen in these areas. This strategy will continue to be updated as knowledge about the entanglements of right whales in fishing gear improves. A similar process is being initiated with other LFAs and other fisheries (*e.g.* groundfish gillnet and longline) in Canada that are also considered potential threats to entangle right whales.

THEME 2: STRUCTURE AND FUNCTION OF THE GULF OF MAINE SYSTEM

Session co-conveners: Michael Fogarty and David Townsend

Rapporteur: Emily Klein

Session Summary

Understanding ecosystem structure and function requires identification and enumeration of the species comprising the system, and information on the nature of the relationships among these species, patterns of energy flow and utilization, spatial characteristics and interchange among system components, and the role of external stressors on system dynamics. Theme Session 2 provided new insights into these issues in the Gulf of Maine (GoM), covering a broad spectrum of topics including advances in understanding of (1) patterns of biodiversity, (2) nutrient dynamics and biogeochemical cycling, (3) biophysical coupling (4) lower trophic level dynamics, and (5) trophic interactions and upper trophic level dynamics. Our objective was to synthesize these findings and to document progress since the 1996 Gulf of Maine Ecosystem Dynamics Symposium. These issues have assumed greater importance as the impetus to move toward an Ecosystem Approach to Management has accelerated at both national and international levels.

An important dimension to the progress since the last symposium, and very much in evidence in Theme Session 2 was the development of new sampling and analytical tools and the implementation of new research and monitoring programs in the GoM. Advances in genomics have made possible the identification of previously under-represented microbial components. The now routine use of satellite observations for estimation of chlorophyll concentration on fine spatial and temporal scales has revolutionized our ability to document critical ecosystem processes related to bloom dynamics and overall levels of productivity. Advanced in-situ sampling tools ranging from gliders to coastal observatories have provided important adjuncts to traditional sampling devices in the GoM. Isotopic signatures have been examined in investigations ranging from identifying water mass characteristics to diet composition and trophodynamics. Finally, advances in high-end computing resources have opened important avenues for the development of coupled physical-biological models with data assimilation capabilities.

Recent Advances:

Since the last Gulf of Maine symposium, our understanding of patterns of biodiversity in the Gulf has increased immeasurably with the implementation of a major research program established under the auspices of the Census of Marine Life (CoML). The Gulf of Maine is an extensively studied system with a long history of ecological research conducted by an impressive concentration of research facilities distributed along the coast. As a result, the biodiversity of mid- and upper- trophic levels in particular is well known and the ecological roles of these species has been intensively investigated. What is strikingly evident in the years since the last GoM symposium is the increase in

knowledge of other components of the system. As a result of the CoML initiative, more than 50,000 new viral and bacterial Operational Taxonomic Units have now been recognized. A species register for the Gulf of Maine is under development and will provide an invaluable reference source for overall levels of biodiversity in the Gulf. Important new insights have been also been gleaned from studies conducted on a broad spectrum of spatial and temporal scales. These include a new CoML Discovery Corridor initiative encompassing a broad swath from the intertidal, through deep ocean basins, to the edge of the continental shelf and beyond. In-depth studies documenting local biodiversity hotspots in the Gulf have also been undertaken. This work has been nicely complemented by studies of nearshore biogeographic patterns and biodiversity of benthos in relation to physical characteristics. It has also been possible to examine evidence of temporal changes in fish and macroinvertebrate biodiversity through a careful comparison of samples collected in two research programs separated by a century. Further, sustained monitoring of plankton communities in the GoM using both Continuous Plankton Recorder and standardized Bongo sampling (MARMAP-EcoMon) Programs show changes in plankton species composition and biodiversity on decadal time scales.

We have now documented multi-decadal changes in nutrient regimes and have deepened our understanding of the role of arctic and subarctic influences in Gulf of Maine nutrient dynamics and productivity. Satellite-derived estimates of the timing and magnitude of the spring phytoplankton bloom over the last decade show marked interannual variability which can be related to hydrographic characteristics and their effects on nutrient supply. These in turn have been linked to non-local effects. Evidence for this far-field forcing on nutrients and productivity has been complemented by coastal studies of more proximal events related to river discharge patterns. Both sets of observations can be linked to climate-related factors operating on different spatial-temporal scales. Broad-scale spatial patterns are evident within the Gulf with important differences in nutrient regimes and particle fluxes in the eastern and the western GoM with resulting differences in productivity patterns. The establishment of monitoring programs such as the Gulf of Maine North Atlantic Time Series (1998-present) since the last symposium has provided high resolution views of nutrients, hydrography, chlorophyll concentration and primary production along a transect in the Gulf.

State of the art numerical models of coupled physical-biological systems have now been developed and implemented to explore seasonal phytoplankton bloom dynamics in relation to changing salinity characteristics, to set the stage for development of operational forecasts of red tide blooms, and to understand the role of high frequency internal waves on patchiness of phytoplankton in the GoM. Biophysical models also hold considerable promise for understanding dispersal pathways and recruitment processes for meroplanktonic organisms. The utility of this approach for understanding interannual variation in recruitment was demonstrated for Atlantic cod where retention patterns and down-welling processes played key roles in recruitment success. Collectively, these initiatives open the way for predictive modeling capabilities for application in fisheries and environmental management.

Research on plankton communities in the GoM has a long and storied history, beginning with pioneering work of Henry Bigelow in the early decades of the last century. Bigelow's seminal study provided an important impetus to the establishment of the long term monitoring programs noted above and his identification of *Calanus finmarchicus* as a keystone species at the nexus of the food web in the GoM remains a vital research area. A five year monitoring program with high temporal resolution documented seasonal patterns in zooplankton and ichthyoplankton communities on Jeffries Ledge and highlighted the dominant role of *Calanus* in the system. An individual-based model of *Calanus* in the Gulf of Maine has been used to explore the interplay of environmental factors and food reserves in determining diapause and overwintering success of this species, with important implications for understanding potential climate effects in this system.

Embedded within each of the issues described above is the overarching theme of energy flow. This topic has been extensively studied in the Gulf and several generations of network models have been developed over the last three decades. These models also depend heavily on information on feeding interactions at upper trophic levels. It was demonstrated in the session that long term diet composition studies conducted by both the Department of Fisheries and Oceans and the National Marine Fisheries Service can be effectively combined to provide broad spatial coverage throughout the Gulf and long term trajectories of change in consumption patterns. An examination of cod feeding inside and outside the Western Gulf of Maine Fishery Closed Area has revealed interesting differences not only in prey availability and growth rates but differences in modes of feeding (pelagic *vs* benthic). Closed areas as a tactical management tool therefore seem to have implications not only for abundance and demography but trophodynamics. Detailed studies of ontogenetic shifts in diet composition for herring show a propensity to feed selectively on smaller prey items, including copepods, at larger sizes. Further linkages among *Calanus*, Atlantic herring, and bluefin tuna in the foodweb of the Gulf have been explored in the context of inter-related changes in lipid energy stores to explain changing condition factors in tuna, an extremely valuable apex predator in this system. Finally, the interplay of environmental conditions and predator distributions patterns has been framed in terms of a predation gauntlet experienced by salmon smolts as they exit river systems and enter the marine environment.

No overview of the Gulf of Maine could be complete without consideration of two iconic species, Atlantic cod and the American lobster, which have shaped the history of the region and determined the character of local fishing communities. Evidence suggests that once numerous local nearshore populations of cod have been decimated through overfishing in the Gulf by the turn of the last century and possibly exacerbated by declines in river herring populations, a principal prey resource. Lobster fishing gradually replaced groundfisheries in these coastal environments. There is some evidence of a recent resurgence of cod in these areas and studies have been undertaken to examine the possible role of recovery of river herring some Maine rivers. While cod populations in the Gulf have undergone long term declines, lobster populations and catches have increased markedly over the last several decades. A reduction in predation on lobsters by fish predators is among the hypotheses under consideration for the increase. The establishment, in 1993, of a long-term intertidal monitoring program has both

documented the increase in lobster juvenile lobster abundance and explored mechanisms allowing increased utilization of hard substrate habitats through shelter-sharing with important implications for understanding overall carrying capacity.

Emerging Generalizations and Research Needs

Contributions to Theme Session 2 nicely illustrate not only the state of the science in the Gulf of Maine but the state of the system itself. The basic theme of change emerged in presentations throughout the session and was neatly encapsulated and foreshadowed in the two keynote addresses that opened this session. The Gulf of Maine has undergone dramatic changes in fundamental aspects of its structure that can be tracked on multidecadal to centennial time scales. Changes on seasonal to interannual time scales are no less in evidence and emerging issues such as the possibility of important changes in phenology deserve urgent attention. The prospect of future climate change in the Gulf highlights the need to understand its current status and past changes that can be related to anthropogenic and natural forcing factors. In complex systems, surprise is to be expected and the possibility of rapid change to alternate stable states must be anticipated.

Research presented in Theme Session 2 solidified our understanding of key aspects of system dynamics ranging from the effects far field forcing on oceanographic properties and productivity of the GoM, basic biology of ecologically and economically important species, and aspects of community structure of nektonic, planktonic and benthic assemblages. It further identified important progress in new areas and challenges to come. The impressive gains in identifying microbial components of the system must be continued and the role of the microbial food web in system productivity fully explored. Our understanding of benthic communities in the Gulf has also greatly benefited from renewed attention and this effort must be expanded to permit a fuller understanding of issues such the role of benthic-pelagic coupling in overall system structure. The immensely complex physiographic structure of the Gulf highlights both the difficulties involved and the importance of the task.

Continued emphasis on synthesis and integration of the rich body of research in the Gulf and the development of models that can be used to predict the effects of changing environmental conditions and the implications of alternative management actions is essential. Important strides have been made, particularly in development of coupled biophysical models. Linkage of numerical hydrodynamic models to a broader array of ecological models will be necessary to place the modeling efforts in service to management. We must further develop approaches that link our hydrodynamic models to General Circulation models at the basin scale to evaluate the potential impacts of climate change on the Gulf.

Implications for Ecosystem-Based Management

It is now widely appreciated that a more holistic approach to management is needed that accounts for the full spectrum of human impacts in the marine environment and the implications for the ecosystem services these systems provide. Ecosystem-Based Management embodies several key attributes: (1) it is place-based and entails the

development of integrated management plans for defined ecological regions, (2) it considers humans as integral components of the ecosystem, and (3) it requires an understanding of the inter-relationships among the components of the system and the environment. Adoption of Ecosystem-Based Management strategies for the Gulf of Maine will require the implementation of regulatory and legislative frameworks to allow the full spectrum of management considerations that will emerge including confronting tradeoffs among and within different ocean use sectors. It will further require the development of appropriate governance structures and close cooperation between the United States and Canada.

With this backdrop, it is clear that the rich history of research in the GoM provides a strong foundation for moving towards Ecosystem-Based Management in this region. . The Gulf of Maine is a semi-enclosed continental shelf sea with distinctive characteristics relative to adjacent regions such as Georges Bank and the Scotian Shelf. Reasonable arguments can accordingly be made for the Gulf of Maine proper as a spatial unit for EBM. Results provided in Session 2 provide further insights into questions related to the appropriate spatial scales for management. Based on these investigations, it is clear that distinctive differences in physical and ecological characteristics exist in the eastern and western GoM. It is further evident that for a number of reasons, the nearshore GoM may require special consideration. The diversity of human activities on the coast and in the immediate coastal zone requires consideration of cumulative impacts of fishing, pollution, and habitat alteration/destruction. The nearshore region is also substantially affected by watershed influences which affect productivity patterns and other characteristics. Collectively, these and other consideration suggest that it is possible that nested spatial structures for management could be recognized within the Gulf to account for these differences.

With respect to understanding inter-relationships among parts of the system and with the environment, again it is clear that we have much to build on. There is important evidence of bottom-up control in the system with effects throughout the food web. Further, results presented at the session show that the system has undergone regime shifts related to climate and physical forcing affecting nutrient dynamics with attendant consequences for primary production, zooplankton community composition, and fish community structure. These considerations will necessarily play an important role in devising management strategies in an ecosystem context. In particular for Ecosystem-Based Fishery Management, understanding shifts in productivity states will be essential in devising sustainable exploitation strategies at the ecosystem level that account for shifting environmental states. We also have a rich data base on diet composition of higher trophic levels that are essential for building and refining multispecies and ecosystem models for management. In all of this, it must be remembered that the GoM was subject to important alteration long before detailed scientific studies were undertaken. These include the dramatic reduction of whale populations, the decimation of anadromous fish stocks due to obstruction of rivers, habitat loss and overfishing, and overfishing of once dominant species such as halibut. We must be aware of the implications of these changes for overall system productivity.

Finally, it must be recognized that we are still in the very early stages of understanding how best to integrate the human dimension into EBM in the Gulf. We need to understand how humans have and will impact the system and how changes in the GoM affect human communities.

Theme 2 — Schedule of Oral Presentations

8:00 Keynote Address — Ken Frank (Fisheries and Oceans Canada)
Structure and Stability of Marine Ecosystems

8:30 Keynote Address — John Hare (NOAA)
Changing Views of Lower Trophic Levels in the Gulf of Maine

9:00 Incze, Lewis
Biodiversity: Results from the Census of Marine Life. Part I.

9:15 Lawton, Peter
Biodiversity: Results from the Census of Marine Life. Part II.

9:30 Cournane, Jamie M.
Historical and recent patterns of marine biodiversity in the Gulf of Maine and Georges Bank

9:45 Trott, Tom
Location of a biological hotspot in the Gulf Of Maine

10:00 Lai, Zhigang
Impacts of high-frequency internal waves on plankton dynamics in Massachusetts Bay, Gulf of Maine

10:15 Townsend, David W.
A changing nutrient regime in the Gulf of Maine

10:30 Health Break

10:45 Balch, William M.
The Gulf of Maine North Atlantic Time Series, GNATS: A retrospective of the productivity of the Gulf of Maine

11:00 Pilskaln, Cynthia H.
Seasonal and interannual biogeochemical particle flux dynamics in the Gulf of Maine

11:15 Thomas, Andrew C.
Satellite-measured variability of the spring bloom in the Gulf of Maine and Southern Scotian Shelf

11:30 Keafer, Bruce A.
Bloom dynamics of the red tide dinoflagellate *Alexandrium fundyense* in the Gulf of Maine: a synthesis and progress towards a forecasting capability

11:45 Ji, Rubao
Variability of phytoplankton blooms in the Gulf of Maine: Observations and modeling

12:00 Lunch Break

13:30 Jones, Rebecca J.
Results of a collaborative monitoring program of coastal zooplankton and ichthyoplankton in the Western Gulf of Maine, 2003-2008.

13:45 Maps, Frederic
Population response of the planktonic copepod, *Calanus finmarchicus*, to environmental change in the Gulf of Maine: the role of diapause

14:00 Record, Nicholas R.
Ecological scales and dynamics of pelagic zooplankton biodiversity in the Gulf of Maine

14:15 Holmes, Ashley
Biodiversity of macroinvertebrate communities within deep water soft sediments of the Gulf of Maine's Jordan Basin

14:30 Hales, Stephen S.
Biogeography of nearshore benthic invertebrates in the Gulf of Maine

14:45 Cowan, Diane F.
Lobster nursery habitats: how crowded can they get?

15:00 Health Break

15:15 Golet, Walter J.
Bottoms up: Potential effects of environmental forcing on apex predators in the Gulf of Maine

15:30 Wilson, Karen A.
Diet habits of modern cod from two traditional nearshore fishing grounds

15:45 Runge, Jeffrey
Dispersal of planktonic early life stages from the late spring spawning population of Atlantic cod in Ipswich Bay: the role of downwelling winds for recruitment success

16:00 Friedland, Kevin D.
Environmental and biological factors affecting the survival of Atlantic salmon, *Salmo salar*, in Maine, USA

16:15 Sherwood, Graham D.
Monitoring the impact of closed areas on groundfish ecology in the Gulf of Maine and Georges Bank

16:30 Stockwell, Jason D.
Seasonal and ontogenetic diet shifts in Atlantic herring (*Clupea harengus*): application of diet and isotope analyses

16:45 Bundy, Alida
You are what you eat … Whenever you eat it: an integrative analysis of fish food habits across different seasons in Eastern US and Canadian waters

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Theme 2 — Abstracts of oral papers

Keynote— Structure and stability of marine ecosystems

Kenneth T. Frank, Research Scientist

Fisheries and Oceans Canada, Bedford Institute of Oceanography, Dartmouth, Nova Scotia

The need for a mechanistic understanding of the differential resiliency of ocean ecosystems to anthropogenic forcing is an urgent requirement as modern approaches to resource management and conservation increasingly involve spatially-explicit planning and legislation (e.g. MPAs, deepwater coral protection, etc.). The ability to forecast when, where and under what conditions ecosystem functioning and the resultant services they provide become degraded and non-responsive to traditional management measures is of paramount importance to the advancement of ecosystem based management strategies and restoration planning. The development and accuracy of such forecasts of threshold responses hinges on our understanding of the contextual dependency of such effects. It is now known that warm water systems are capable of sustaining fishing pressure directed at higher trophic levels two to four times higher in comparison to cold water regions, due to a higher probability of rapid, compensatory responses within functional groups of large-bodied predators and the faster recovery of target species subjected to excessive exploitation. These processes preserve the trophic structure of warmer water systems by preventing the aggregate top predator biomass from declining thereby maintaining a balanced state with their prey. A model is presented that can used to set limits for exploitation rates that preserve the functional relationships between predator–prey groups and to assess the potential for and measures required to achieve recovery of degraded fish communities. Special emphasis is given to the Gulf of Maine area.

Keynote— Changing views of lower trophic levels in the Gulf of Maine

Jonathan Hare, Research Fishery Biologist

National Oceanographic and Atmospheric Administration (NOAA), Center for Coastal Fisheries and Habitat Research

From a biological oceanography perspective, the Gulf of Maine is one of the best studied regions in the world. The rich abundance of higher-trophic levels - cod, lobster, and whales – have been known and exploited for centuries. Knowledge of the lower trophic levels - phytoplankton, microbes, zooplankton, and marine larvae – developed more recently, primarily during the 20th century. Much of the oceanographic work in the Gulf of Maine has focused on describing the system: the seasonal cycles of abundance, distributions patterns throughout the Gulf, the ecological interactions among organisms, and numerous other topics. The importance of the spring bloom to temperate marine

ecosystems originated in part from studies conducted in the Gulf of Maine. The concept of bank systems as areas of retention arose, in part, from the study of Georges Bank. The concept of bottom-up forcing from primary to secondary to fisheries production also has origins in Gulf of Maine region. Although investigations have been conducted for almost a century, the biological oceanography of the Gulf of Maine continues to yield surprising and notable findings. Phytoplankton production cycles are more complicated than a simple spring bloom and there is evidence for inter-annual and decadal scale variability in production. Zooplankton communities are not static and a large shift was documented in the early 1990's to smaller bodied species, with a shift back to larger-bodied species in the early 2000's. The meroplanktonic components of lower-trophic levels also have changed; larval Atlantic herring abundance on Georges Bank has dropped almost by an order of magnitude over the past several years. These more recent results indicate that the Gulf of Maine is not a static system. Cycles and long-term trends in environmental forcing combine with human-induced change to create a dynamic system in both time and space. The major challenge for the coming decades is designing management strategies that are robust to the complex and non-stationary nature of the Gulf of Maine ecosystem.

Biodiversity: Results from the Census of Marine Life. Part I.

Lewis S. Incze*[1], Peter Lawton[2], Sara L. Ellis[1], Michelle E. Greenlaw[2], Catherine L. Johnson[3], Noreen E. Kelley[2], Peter F. Larsen[4], Scott D. Kraus[5], William Li[3], Jeffrey A. Runge[6], Michael E. Sieracki[4], R. Kent Smedbol[2], and Nicholas H. Wolff[1]

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The Gulf of Maine Area program (GoMA) of the Census of Marine Life has endeavored since 2003 to advance the study and understanding of regional marine biodiversity, and to collaborate in efforts to incorporate biodiversity theory and information into management frameworks. Goals have included a description of the known and unknown biodiversity of the Gulf, improved access to data, new field studies, an exploration of the relationships between biodiversity and key regional ecosystem processes, and an assessment of biodiversity changes driven by anthropogenic and non-anthropogenic forcing. This talk presents an overview of progress in broad programmatic goals, and syntheses from three of our six expert group topics: microbes, zooplankton and pelagic nekton, and upper trophic level predators.

Biodiversity: Results from the Census of Marine Life. Part II.

Peter Lawton*[1], Lewis S. Incze[2], Sara L. Ellis[2], Michelle E. Greenlaw[1], Catherine L. Johnson[3], Noreen E. Kelley[1], Peter F. Larsen[4], Scott D. Kraus[5], William Li[3], Jeffrey A. Runge[6], Michael E. Sieracki[4], R. Kent Smedbol[2], and Nicholas H. Wolff[2]

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This second presentation from the Gulf of Maine Area program (GoMA) of the Census of Marine Life continues with reports from three expert groups convened to prepare syntheses of regional marine biodiversity represented within (respectively): coastal margins, benthic communities and demersal fish assemblages, and slope and seamount environments. As with any sub-division of a large marine ecosystem, our selection of boundaries was clearly arbitrary, but provided a way to focus on existing information within discrete geographical regions. Each expert group evaluated current understanding of structure and function within specific ecosystem "compartments", identified promising new lines of scientific enquiry and technologies to close the gap between known and unknown biodiversity, and suggested key attributes of biodiversity that are relevant to ecosystem approaches to management.

Historical and recent patterns of marine biodiversity in the Gulf of Maine and Georges Bank

Jamie M. Cournane* and Stefan Claesson

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Developing historical baselines for marine biodiversity conservation is problematic due to the difficulty in linking past with more recent patterns. Currently, biodiversity assessments in the Gulf of Maine and Georges Bank rely heavily on National Marine Fisheries Service (NMFS) bottom-trawl surveys that monitor commercially valuable groundfish. Ecological community metrics provide tools for comparative study to bridge

patterns of historical marine communities with more recent ones. Through a statistical analysis, NMFS bottom-trawl surveys (1963-2007) are compared to observations from 19th-century, fisheries-independent surveys by the U.S. Commission of Fish and Fisheries vessel *Fishhawk* (1880-1899). The study area includes the western portion of the Gulf of Maine and Georges Bank and the northern section of the Mid-Atlantic Bight. Genera and fish species richness, and guild composition were compared over space (coastal bight, shelf and slope) and time. *Fishhawk* trawl surveys detected more genera in the late 19th century than in the NMFS bottom-trawl surveys; however, the NMFS bottom-trawl surveys detected more fish species. The guild composition was similar for both surveys with respect to demersal species but not pelagic. These differences in richness and composition may be best explained by changes in gear technology and complexity of bottom habitat.

Location of a biological hotspot in the Gulf Of Maine

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Rock-framed, macrotidal Cobscook Bay lies nestled in Passamaquoddy Bay, near the heart of the Quoddy Region of the Gulf of Maine. The unusually high biodiversity of macroinvertebrates found in Cobscook Bay has been known since the mid-1800s through the interests of fishery biologists and zoologists. Evidence that Cobscook Bay represents a biological hotspot in the Gulf of Maine for this faunal group was gathered through meta-analysis of macroinvertebrate biodiversity documented for bays in and outside of the Gulf of Maine. Comparisons of this type are constrained by differences in size, habitat, depth, sampling method, and sampling effort to name a few limitations. Given these caveats, the remarkably high biodiversity of Cobscook Bay stands out. Cobscook Bay has the highest species richness of macroinvertebrates among major bays in the Gulf of Maine, e.g., Penobscot, Sheepscot, and Casco Bays. Species richness remains highest among locations as different as eastern seaboard Chesapeake Bay and Gulf of Mexico Perido Bay. Species richness in the Canadian sub-Arctic is lower at several locations. Boreal East Atlantic sites in the UK have approximately the same or lower species richness. Some East Atlantic comparisons show notable resemblance to Cobscook Bay. For example, the macroinvertebrate fauna of Cobscook Bay is particularly similar to northern Norway and Spitsbergen. Over 50% of the species occurring in Cobscook Bay occur somewhere on the Norwegian coast. Glaciation followed by rapid geological events with subsequent hydrographic changes that lead to species invasions is one possible scenario which could account for the origin of this similarity. The Cobscook Bay biological hotspot is likely due to factors like habitat diversity, macrotidal amplitudes, and sea water temperature. The significance of this biological hotspot in the Quoddy Region needs to be recognized in an integrated management /ecosystem approach to management (IM/EAM) in the Gulf Maine.

Impacts of high-frequency internal waves on plankton dynamics in Massachusetts Bay, Gulf of Maine

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An ecosystem model was coupled with the non-hydrostatic FVCOM (FVCOM-NH) to study the impacts of high-frequency internal waves on temporal variation and spatial distribution of phytoplankton in Mass Bay. FVCOM-NH successes in simulating the generation, propagation, and dissipation of internal waves that are generated over Stellwagen Bank. The coupled physical-biological model predicted that the formation and distribution of phytoplankton patchiness in Mass Bay is significantly influenced by the interaction of tides and high-frequency internal waves. The patches are separated as the high-frequency internal wave packet arrives in an area and at the time when tidal currents are converting from flood and ebb phase. The phytoplankton concentration in the patch zone is significantly intensified as an increase of nutrient flux due to the enhancement of local vertical displacement during the internal wave passage, rather than the transfer from the upstream area by the internal wave. This finding is supported by the modeling oriented dye experiment, which is distinct from our understanding based on previous studies at west US coast. Similar numerical experiments were also made using the hydrostatic FVCOM and results suggest that the hydrostatic approximation tends to overestimate the vertical displacement at the leading edge of the internal tidal waves and thus vertical nutrient flux from the deep water. As a result, it blurred the predicted phytoplankton patchiness.

A changing nutrient regime in the Gulf of Maine

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Recent oceanographic observations and a retrospective analysis of nutrients and hydrography over the past five decades have revealed that the principal source of nutrients to the Gulf of Maine, the deep, nutrient-rich continental slope waters that enter at depth through the Northeast Channel, may have become less important to the Gulf's nutrient load. Since the 1970s, the deeper waters in the interior Gulf of Maine (>100m) have become fresher and cooler, with lower nitrate (NO_3) but higher silicate ($Si(OH)_4$) concentrations. Prior to this decade, nitrate concentrations in the Gulf normally exceeded

silicate by 4-5 μM, but now silicate and nitrate are nearly equal. These changes only partially correspond with that expected from deep slope water fluxes correlated with the North Atlantic Oscillation, and are opposite to patterns in freshwater discharges from the major rivers in the region. We suggest that accelerated melting in the Arctic and concomitant freshening of the Labrador Sea in recent decades has likely increased the equatorward baroclinic transport of the inner limb of the Labrador Current that flows over the broad continental shelf from the Grand Banks of Newfoundland to the Gulf of Maine. That current system now brings a greater fraction of colder and fresher deep shelf waters into the Gulf than warmer and saltier offshore slope waters which were previously thought to dominate the flux of nutrients. Those deep shelf waters reflect nitrate losses from sediment denitrification and silicate accumulations from rivers and in situ regeneration, which together are altering the nutrient regime and potentially the structure of the planktonic ecosystem.

The Gulf of Maine North Atlantic Time Series, GNATS: A retrospective of the productivity of the Gulf of Maine.

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We have run the Gulf of Maine North Atlantic Time Series (GNATS) since 1998; it is a transect time series, using ships of opportunity, crossing the Gulf of Maine (GOM) between Portland, Maine and Yarmouth, Nova Scotia. Here we use this coastal time series to document the space-time variability of hydrography, nutrients, optics, phytoplankton standing stocks and carbon fixation in the GoM, in response to several years of extreme river discharge. We hypothesize that, during wet years, fresh water input capped the surface euphotic layer, impeding the upward diffusion of nutrients, thus lowering the phytoplankton biomass and carbon fixation rates. We have enumerated phytoplankton functional groups during this work and will report trends in various algal species in the Gulf as well as changes in the particle size distribution function (resulting from ecological shifts in functional groups). Regional algorithms were derived to estimate particulate organic carbon and carbon fixation. More recently, we have been sending a Slocum glider across the GNATS line. This has allowed new observations of physical and bio-optical variables with unprecedented horizontal and vertical resolution. We have extended the GNATS time series back to 1978, using other historical data sets of temperature, salinity and chlorophyll. I will end the talk with a 30-year retrospective of the Gulf of Maine based on this time series.

Seasonal and interannual biogeochemical particle flux dynamics in the Gulf of Maine

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The Gulf of Maine displays significant spatial and temporal variability in particulate nutrient export below the mixed layer, deep-water delivery of biogeochemical components, and benthic nepheloid layer resuspension activity. Offshore, moored time-series sediment trap deployments document spring and fall peaks in organic carbon, biogenic silica, and calcium carbonate fluxes that are coupled to seasonal phytoplankton blooms in the overlying surface waters. Largest annual organic carbon and diatom-silica export through the water column occurs in the western gulf, and maximum carbonate fluxes (represented primarily by planktonic foraminifera and pteropod shells) are seen in the eastern gulf. Comparisons of 1995-1997 and 2005-2006 trap data from the same deployment sites reveals a 50% lower organic matter delivery rate in 2005-2006. Interannual variability may explain the temporal difference in mass export, or it may reflect a shift in the Gulf of Maine's ecosystem regime coincident with an observed decadal decrease in fall plankton bloom intensity and large diatom abundance.

Benthic nepheloid layers (BNLs) with measured above-bottom thicknesses of 10-30 m are seen throughout the Gulf of Maine and often appear aligned along bathymetric contours. Optical and geochemical data from time-series traps indicate that the particle components of the BNLs are a mix of labile, fresh planktonic matter and older, more refractory sedimentary particle material. Additionally, trap samples collected in the near-bottom, particle-rich layers document highly variable abundances of *Alexandrium* dinoflagellate cysts and an impressive abundance of macrozooplankton, as compared to trap samples obtained in the overlying water column. Elevated, gm-scale, daily particle resuspension fluxes are observed in the deep gulf nepheloid layers and are significantly higher in the eastern vs. the western Gulf of Maine. Spring and fall peaks in the upper water column biogenic export pattern are reflected in the magnitude and composition of the near-bottom resuspension fluxes. Labile organic matter residence time in the BNL, coupled with the level of micro- and macro-organism activity within the particle-rich layers, will ultimately determine the importance of continental margin BNLs as POC and PON chemical transformation zones.

Satellite-measured variability of the spring bloom in the Gulf of Maine and Southern Scotian Shelf

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Ten years (1998-2008) of SeaWiFS chlorophyll-a data quantify variability in the time/space patterns of the spring phytoplankton bloom in the Gulf of Maine. Climatologically, the earliest bloom is over Nantucket Shoals (< day 50) and then central Georges Bank and the Scotian Shelf (day 60-70), followed by shallow (< 100m) coastal regions of the western Gulf and the Northeast Channel area (day 70-80) and deeper basins of the central Gulf (day 90), and latest in eastern Maine coastal regions and the Bay of Fundy (> day 100). In individual years, strong spatial gradients in magnitude and timing are present, especially in regions < 100m deep, making generalized statements of bloom annual timing/magnitude problematic. The climatology also hides significant interannual variability in magnitude, timing and location. Overall, the weakest blooms are in 1998 and 2005 and strongest blooms are present in 1999 (Eastern Gulf) and 2003 (Western Gulf and Scotian Shelf), although localized exceptions are evident. Variance on interannual time scales is weak in winter and strongest in spring (March, April) associated with specific bathymetric features, suggesting frontal zone control. We show that the strongest area-averaged interannual signals in bloom magnitude and timing have a poor relationship to differences in local physical forcing (heat flux, wind mixing, light availability). However, the weak blooms in 1998 and 2005 and the early bloom in 1999 are each associated with anomalous hydrographic characteristics and vertical density structure. In 1998, these physical differences are known to be accompanied by reduced macro-nutrient concentrations. These factors point to strong non-local control of regional average bloom characteristics.

Bloom dynamics of the red tide dinoflagellate *Alexandrium fundyense* in the Gulf of Maine: a synthesis and progress towards a forecasting capability

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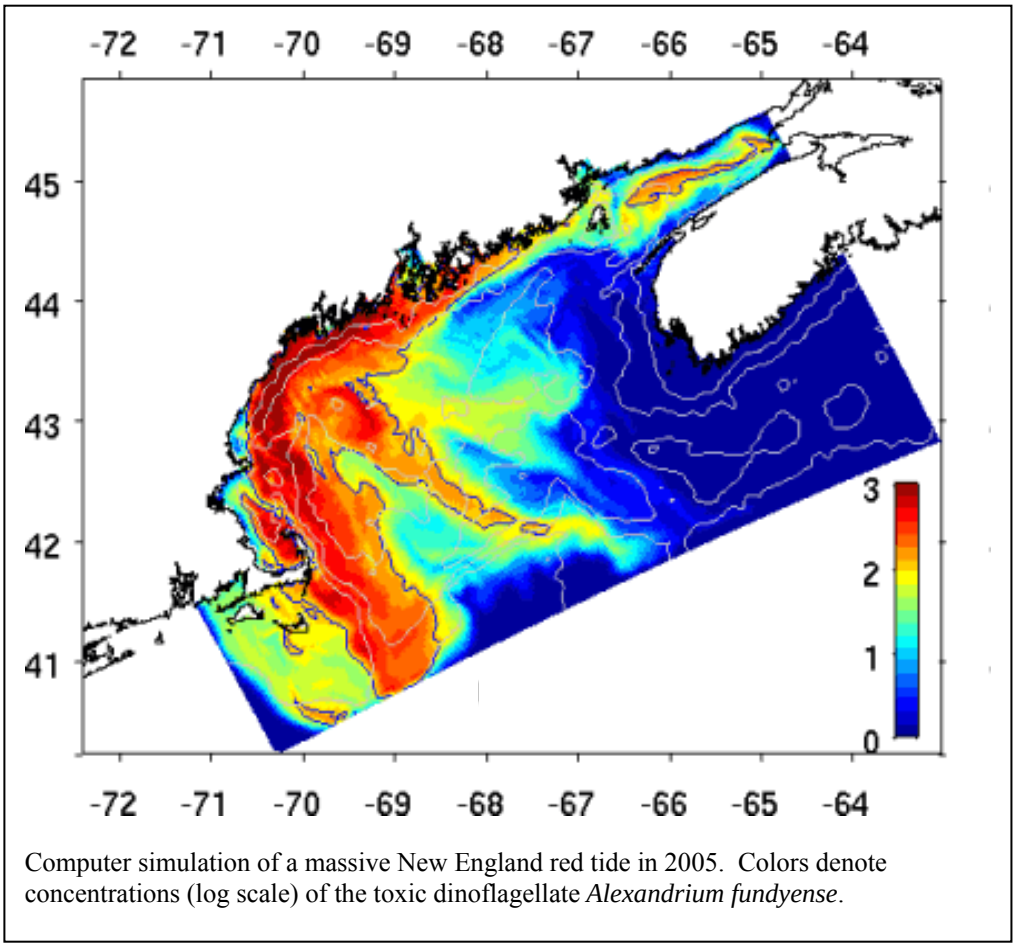
Blooms of the toxic dinoflagellate *Alexandrium fundyense*, commonly called “red tides” have been a serious problem in the Gulf of Maine since 1972. The blooms are associated with the accumulation of potent neurotoxins in shellfish and some fish species, leading to paralytic shellfish poisoning (PSP) in human consumers – a potentially fatal poisoning syndrome. This talk will summarize more than a decade of large-scale field and modeling activities in the nearshore waters of the region, leading to a conceptual model of bloom dynamics that is consistent with cruise observations and with patterns of shellfish

toxicity, and to numerical models that are being used for weekly and seasonal, forecasts. The long-term implications of the blooms and their deposition of dormant cysts will also be discussed, as there is good reason to believe that the western Gulf of Maine region will experience more frequent and more intense PSP outbreaks in the coming years, compared to the last decade. The challenges and potential for an operational red tide forecasting system in the Gulf of Maine will also be discussed. We will also describe seasonal to interannual variability in *A. fundyense* blooms on Georges Bank, which appear to be decoupled from the near-coastal blooms, at least in terms of their initiation and development.



Computer simulation of a massive New England red tide in 2005. Colors denote concentrations (log scale) of the toxic dinoflagellate *Alexandrium fundyense*.

Variability of phytoplankton blooms in the Gulf of Maine: Observations and modeling

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Phytoplankton blooms in the Gulf of Maine (GoM) are highly seasonal, and typically exhibit a major spring bloom in late winter/early spring and a smaller fall bloom. Central to these bloom phenomena are the seasonal changes in light and nutrient conditions, and therefore one would expect to see an interannual variation of phytoplankton blooms when local or remote forcing vary from year to year. Observational data from the Gulf of Maine region have revealed significant changes in surface low-salinity Scotian Shelf Water inflow and deep slope water intrusion. Analyses of SeaWiFS ocean color and hydrographic data have suggested that these changes can have significant impact on the phytoplankton dynamics in this region. We have developed coupled biological-physical numerical models to examine underlying mechanisms, especially on the impact of freshening, through a quantitative comparison of circulation pattern, water column stability, nutrient/phytoplankton concentrations, and net primary productivity between low and high freshening scenarios. Both observation and model results will be presented, and the implication of phytoplankton bloom variability on higher trophic levels will be discussed.

Results of a collaborative monitoring program of coastal zooplankton and ichthyoplankton in the Western Gulf of Maine, 2003-2008.

Rebecca J. Jones* and Jeffrey A. Runge

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In a collaborative project with a number of New England commercial fishing vessels, zooplankton was sampled 2-3 times a month between 2003-2008 at a station on Jeffreys Ledge and zooplankton and ichthyoplankton were sampled semimonthly during 2007 and 2008 at stations located off of Gloucester, MA and Ipswich Bay, NH. We report here on seasonal patterns in diversity and abundance in the zooplankton and ichthyoplankton communities. Notable is the dominance of *C. finmarchicus* on Jeffreys Ledge and the dramatic decline in summer abundance of this species between 2003-2005. Interannual differences in timing of peak abundance and in species dominance of ichthyoplankton

possibly reflect a change in environmental conditions between 2007-2008. While these time series provide valuable information about change in the coastal planktonic communities in the Gulf of Maine, currently there are no observing programs that sample coastal communities at frequency sufficient to show seasonal and interannual change.

Population response of the planktonic copepod, *Calanus finmarchicus*, to environmental change in the Gulf of Maine: the role of diapause.

Frederic Maps, Andrew Leising, Jeffrey Runge, and Andrew Pershing

We describe a 1-D individual-based *Calanus* life cycle model that incorporates the Lipid Accumulation Window hypothesis to explain observed life cycle patterns of *C. finmarchicus* in coastal waters of the south-west Gulf of Maine. According to this hypothesis, individual *Calanus* can only enter diapause if their food and temperature history allows them to accumulate sufficient lipid for overwintering, molting and early gonad development. The duration of the dormancy period is also variable, dependent on ambient temperature during dormancy and the level of lipid stores. We use the model to examine how local climate-forced variability in seasonal primary productivity and ambient overwintering temperature influences lipid reserves and diapause and whether this population, which exists at the limit of its biogeographical range, would be threatened by a small increase in the mean overwintering temperature.

Ecological scales and dynamics of pelagic zooplankton biodiversity in the Gulf of Maine

Nicholas R. Record and Andrew J. Pershing

The mechanisms that regulate biodiversity in the pelagic ecosystem operate across a range of spatial and temporal scales. The zooplankton abundance data from NOAA's continuous plankton recorder (CPR) survey contains 40 years of taxonomically detailed samples along a transect from Boston, MA to Yarmouth, NS. We examined patterns of species richness at spatial scales of 10-100s of kilometers and on seasonal and interannual time scales. There is a significant abrupt decrease in diversity across a coastal-oceanic gradient, distinguishing near-shore communities from offshore communities. A strong seasonal cycle of high summer diversity and low winter diversity was linked to the seasonal signals of productivity and temperature. Diversity increased during the 1990s, possibly due to enhanced productivity and stratification during the fall and winter.

Biodiversity of macroinvertebrate communities within deep water soft sediments of the Gulf of Maine's Jordan Basin.

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As part of the Discovery Corridor initiative of the Centre for Marine Biodiversity (http://www.marinebiodiversity.ca), this study aims at filling a gap in knowledge by investigating the benthic community structure found within the deepwater soft sediments of Jordan Basin. During the 2005 Discovery Cruise, a 0.5m^2 video grab was used to collect samples from three sites at 200-220 metres depth within the Basin, with three replicate grabs taken per site. Sediment sub-samples were also taken. The specimens collected have been identified, enumerated, and curated at the Atlantic Reference Centre, Huntsman Marine Science Centre.

The community structure is being analyzed using various univariate indices, as well as bivariate and multivariate techniques. The diversity analyses include traditional indices as well as the new average taxonomic distinctness (AvTD) and variation in average taxonomic distinctness (VarTD) measures. Funnel plots for AvTD and VarTD will determine if the biodiversity found within the Jordan Basin samples are representative of the biodiversity found within the Gulf of Maine. Possible correlations of physical and biological parameters are also being investigated. The anticipated results and significance of this portion of the study are to: characterize the benthos found in the soft bottom sediment of the deeper waters of Jordan Basin; evaluate the level of biodiversity found within these sites; contribute to the overall species list for the Gulf of Maine; and discover animal range extensions.

Rapid biodiversity assessment techniques may reduce the time and costs involved with specimen collection and taxonomic identification. This study will also investigate the use of indicator groups, such as polychaetes, molluscs and crustaceans as well as aggregated information to higher than species level (such as genus, family and class) as possible surrogates to the overall species diversity found within the Basin. The results may suggest possible indicator groups to be used as rapid assessment monitoring tools within the Gulf of Maine.

Biogeography of nearshore benthic invertebrates in the Gulf of Maine

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The biogeography of nearshore benthic invertebrates in the Gulf of Maine was studied to compare recent data with historical biogeographic studies, define physical-chemical factors affecting species distributions, and provide information needed to calibrate benthic indices of environmental condition. Cluster analysis and multidimensional scaling were done on Bray-Curtis similarity matrices of species relative abundance, using 145 stations (2000-2004) from the National Coastal Assessment. Depending on the salinity and sediment grain size class, faunal breaks of varying degrees occurred at Cape Ann, the Casco Bay area, Penobscot Bay, and possibly the high biodiversity Cobscook Bay-Passamaquoddy Bay area. A comparison of the ordinations of benthic community data and abiotic data, along with a multivariate regression tree, showed that temperature controlled broad distribution patterns; salinity and sediment grain size controlled local distributions. Warm-temperate Virginian Province species assemblages in Cape Cod Bay resembled those south of Cape Cod. In addition to providing information for studies of chemical contamination, eutrophication, and hypoxia, these results can help address broad-scale and long-term issues such as global climate change, species invasions, conservation planning, and ecosystem-based management.

Lobster nursery habitats: how crowded can they get?

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The American lobster, *Homarus americanus* is reputed to be the quintessential solitary animal and is prone to aggression and cannibalism in captivity. The great abundance of lobster in the Gulf of Maine (ASMFC 2009) begs the question: how can lobster density be so high if members of this species are solitary cannibals? Others have suggested limits to the carrying capacity of the lobster's environment based upon a demographic bottleneck at the time of settlement due to limited available habitat (Fogarty and Idoine 1986, Wahle and Steneck 1991). However, in a 16+ year monthly census (1993-present), postlarval and first-year lobsters were routinely found together under rocks at the intertidal/subtidal interface. We suggest that group living in juvenile lobsters may function as a mechanism to overcome the constraints of limited availability of rocky habitat.

Lobsters were hand-sampled monthly from 1993 – 2008 by overturning rocks in fixed square-meter quadrats placed along transects running parallel to the water's edge 0.2-0.4

m below mean low water. Three size classes were identified: (1) settlers (<6.5 mm CL), (2) first-year (6.5 to 17.4 mm CL), and (3) older juvenile lobsters (>17.4 mm CL). Shelter sharing was related to body size, but group composition was random with no preference for any particular sized lobster living with one size class rather than another. Both the occurrence of shelter sharing and the number of lobsters living together beneath a single rock was related to lobster density. We speculate that settlers and first-year lobsters gain three advantages from living in groups: (1) finding a suitable place to live, (2) gaining protection from predators and exposure, and (3) foraging on prey captured by older juveniles. Regardless of the benefits to the individual, group living in juvenile lobsters may increase the carrying capacity of the limited rocky habitat available for lobster settlement and early life.

In summary, the results of this study suggest that limits to crowding may be overcome via social behavior in the form of shelter sharing among postlarval, first-year and older juvenile lobsters. These data have important implications for Gulf of Maine management for myriad reasons and data from this study have already been used in policy making most often concerning habitat protection at a local level.

Bottoms up: Potential effects of environmental forcing on apex predators in the Gulf of Maine

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The Gulf of Maine, a highly productive shelf region in the northwest Atlantic, supports a large biomass of energetically rich prey species such as Atlantic herring, Atlantic mackerel, and the planktonic copepod, *Calanus finmarchicus*. Seabirds, marine mammals and large pelagic fish migrate seasonally to this region where consumption of this prey base yields rapid accumulation of lipid stores used for reproduction and migration. Oceanographic data indicate the Gulf of Maine has experienced a pronounced shift in salinity, primary and secondary productivity during the mid-1990's. Generalized additive models used to assess Atlantic herring and northern Atlantic bluefin tuna somatic condition suggests these oceanographic shifts may have contributed to significant changes in fish condition and lipid energy stores during the previous decade. For example, medium and giant size classes of bluefin tuna experienced a 5-25% decline in summer body weight between the early 1980's and late 1990's. Such reductions to key energy stores have the potential to severely alter migration and reproductive patterns of highly mobile species and highlight the importance of understanding and incorporating the effect of bottom up forcing in fisheries management.

Diet habits of modern cod from two traditional nearshore fishing grounds

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Univeristy of Southern Maine

The nearshore waters of the Gulf of Maine, those areas within site of land, usually less than 10 km from the nearest mainland point, were productive fishing grounds historically. Areas of 35m depth and more that would hold large fish throughout most of the year were common prior to mass commercialization of fishing in the nineteenth century. In the 1950s nearshore waters showed signs of a commercial species collapse. Most nearshore fishing grounds were abandoned by ground fishermen, and have since been taken over by lobstermen. Reports in the early 2000s of cod caught in lobster traps led us to ask whether nearshore fishing grounds are recovering. In 2007 and 2008 we chose two traditional fishing areas, the St. George River, near Port Clyde, ME, and the Damariscotta River, near East Boothbay Harbor, ME, to collect cod and other ground fish for diet analysis. Out of East Boothbay Harbor we fished from port out to the southern end of Damariscove Island; out of Cushing we fished from port to the southern end of Burnt Island. We employed hook & line as the primary fishing technique; though not as efficient as mobile gear methods, the density of lobster gear limited the methods we could employ. Cod were present in both areas, though more abundant and more evenly distributed in the western (Damariscotta) sites. In the eastern (St. George) sites, cod were caught exclusively on the southern side of Burnt Island, with a few catches on the north eastern side in 2008. Cod occupied hard bottom, particular on the slopes of underwater features that were 25 m on top and dropped to approximately 37 m where they joined the mud bottom. Splitting the study areas into river, within islands, outer islands strata, more cod were caught per hook hour from the eastern outer island strata than from any other strata. Overall, cod caught were relatively small, indicating that although cod numbers are growing in the area, recovery to commercially viable populations will take more time. Diet analysis indicated that all cod, regardless of size, were eating crustaceans. Crab were the most common food item. Fish were a sporadic diet item and made up a relatively small proportion of the diet items analyzed.

Dispersal of planktonic early life stages from the late spring spawning population of Atlantic cod in Ipswich Bay: the role of downwelling winds for recruitment success

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Present understanding indicates at least two genetically differentiated complexes of Atlantic cod in the western Gulf of Maine: a late spring-spawning inner coastal

population centered in Ipswich Bay and a population that spawns in the inshore western Gulf of Maine, some of its offshore banks and at sites in southern New England. The two populations likely diverge in trophic interactions and physiological and behavioral responses to different winter and spring environments. Here we analyze the dispersal of eggs and larvae spawned in Ipswich Bay in May-June using a particle tracking model coupled to velocity fields generated by the first generation FVCOM Gulf of Maine/Georges Bank hydrodynamic model, with high resolution in both time (1 h) and space (1 km in the coastal zone). Despite simplifications made in the first generation model, our results show that, over an 11 year period between 1995-2005, highest transport success to nursery areas in Ipswich and Massachusetts Bays occurs when average May winds are downwelling favorable (i.e., from the north). The five years of highest recruitment success of the western Gulf of Maine cod complex, as measured by the recruits/spawner ratio, also occurred during the five years when average May winds were from the north. We hypothesize that recruitment success of the western Gulf of Maine cod complex is largely tied to retention of the late spring spawned eggs in the coastal nursery areas, driven by downwelling favorable winds.

Environmental and biological factors affecting the survival of Atlantic salmon, *Salmo salar*, in Maine, USA

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The general parameters of a recruitment mechanism for North American salmon have emerged that suggests sea mortality is a punctuated event that occurs within the first two months at sea; the post-smolt population is most likely decremented by predator-mediated mortality and thus survival is independent of the growth of the post-smolts. We examined a suite of environmental and biological factors in order to test and extend the hypothesis formulated for the North American stock complex to the stocks that would utilize the Gulf of Maine as post-smolts. The marine survival of Atlantic salmon in the Gulf of Maine appears to be influenced by a complex set of physical and biological interactions. Marine survival has declined as sea surface temperature in the coastal ocean has increased, and there also appears to have been a deterioration of synchronization between smolt migration and ocean conditions for post-smolts. There has been a change in spring wind conditions in the Gulf of Maine area, which could be modifying the post-smolt migration across the Gulf of Maine and Georges Bank regions. The shift in environmental conditions have also affected the distribution in time and space of many predators that likely prey upon salmon post-smolts. Notably, hake species have increased in abundance in the areas that serve as migration corridors for post-smolts. The time series changes in environmental conditions and predator distribution is consistent with the hypothesis that Gulf of Maine salmon experience a growth-independent mortality during the first months at sea, thus forming the basis of recruitment control for these populations.

Monitoring the impact of closed areas on groundfish ecology in the Gulf of Maine and Georges Bank

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Various studies have been completed and are ongoing at GMRI to assess the potential impact of area closures on groundfish ecology in the Gulf of Maine and Georges Bank. Questions addressed in these include: How have closed areas affected the life-history (feeding, growth, movement) of Atlantic cod? Have closed areas influenced the recovery of haddock stocks? or more specifically, how are haddock actually using closed areas, particularly Closed Area I? What impact have closed areas had on monkfish biology? And finally, which habitats within closed areas do cod tend to associate with? We will review and synthesize key results from all of these studies that are largely in agreement with Murawski et al. (2005) regarding species specificity arguments. In general, closed areas tend to favor more sedentary species and life-histories.

Seasonal and ontogenetic diet shifts in Atlantic herring (*Clupea harengus*): application of diet and isotope analyses

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Diet information for Atlantic herring (*Clupea harengus*) in the Gulf of Maine is limited and is mostly aggregated to gross taxonomic categories (e.g., copepods, eggs, fish). Those studies reporting diet information tend to be seasonally limited as samples are typically collected during routine surveys. In this study, we present diet information and results from stable isotope analyses for Atlantic herring from each month between May 2008 and April 2009. Samples were collected from NMFS surveys and the U.S. commercial herring fleet. We examine seasonal and ontogenetic patterns in diets and test the hypothesis that Atlantic herring switch from larger (e.g., krill) to smaller (e.g., the calanoid copepod *Calanus finmarchicus*) prey as they grow. Consideration of species-specific prey and ontogenetic shifts has implications for how environmental variability may alter energetic dynamics of Atlantic herring, and thus the higher trophic levels that are dependent on this forage species.

You are what you eat … Whenever you eat it: an integrative analysis of fish food habits across different seasons in Eastern US and Canadian waters

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How much does fish diet change across seasons, particularly over broad scales? Few multi-seasonal trophic studies exist over large areas to address this question. We examined this question for the first time in temperate, contiguous Northwest Atlantic waters by comparing food habits data for 10 species of fish collected concurrently during the Spring and Autumn surveys in the US (Gulf of Maine proper and Georges Bank) and in the Summer survey in Canada (western Scotian Shelf/Bay of Fundy) over the past 10 years. The US and Canadian samples were collected from slightly different but largely overlapping regions; as such we treat them as representative of the broader Gulf of Maine area. For most species, there was a general concurrence among the 3 seasons: summer diets had the same dominant prey items as Spring and Autumn diets. Although a suite of multi-variate analyses did elucidate some differences in specific proportions of the diet for these species across seasons, again the main prey did not substantially change for most of these species. These results suggest that 1) these fish have a preference for specific prey items, and 2) the prey field is relatively consistent for these species in this part of the Atlantic. Many fisheries ecosystem and multi-species models are dependent upon food habits data where resolving seasonal differences in diet remains an important consideration; however, the present work implies that amalgamated estimates of diet from seasonal surveys may be a reasonable approach when no finer seasonal resolution exists.

Theme 2 –- Poster Abstracts

Assessing stakeholder perspectives on the impacts of a decade of collaborative fisheries research in the Gulf of Maine and Georges Bank

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Analysis of perceptions held by commercial fishermen, marine scientists, and other stakeholders of the Gulf of Maine and Georges Bank ecosystem, revealed that the benefits of a decade of collaborative fisheries research have been extensive, and a loss of further research opportunities would be consequential. To date, over 1,000 individuals have participated in research funded by the Northeast Consortium and the NOAA Fisheries Northeast Cooperative Research Partners Program, two initiatives dedicated to promoting collaborations between scientists and fishermen. For the impact analysis reported here, a series of eight public meetings were held in the summer of 2008 to learn from fishermen, scientists, and others how collaboration has affected them, their communities, and the management of important marine resources. Fishermen had the greatest participation (28%) followed by scientists (24%) in the study. Meeting attendees (n = 142, duplicates removed) most frequently cited an increase in the regional capacity to conduct research as the greatest benefit of collaboration. Improvements to communication, relationships, and trust between science, industry and other stakeholders were also lauded. In addition to the social impacts, economic benefits included enhanced gear efficiency, new fishery opportunities, and help to sustain fishing operations in times of more restrictive fisheries management. Most participants felt that a loss of funding in the future would seriously limit the capability for science and management to address local, immerging, or regulatory priorities. Less funding would result in fewer opportunities for stakeholders to work together, build trust, and network. We conclude that as demands for stakeholder engagement and scientific information are only increasing with the global shift towards ecosystem-based management, programs specifically designed to foster collaboration within the region and beyond are vital.

Comparative modelling of trophic interactions and fisheries in the Bay of Fundy and Western Scotian Shelf

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The Bay of Fundy and western Scotian Shelf are located within NAFO Division 4X, and are part of the greater Gulf of Maine area. For fisheries stock management purposes, they are usually treated as one ecosystem but in fact their dynamics are quite different. The western Scotian Shelf is a wide continental shelf area and is influenced by currents from Labrador and the Gulf of St. Lawrence; the defining characteristic of the Bay of Fundy is the magnitude of tides, which generate intense vertical mixing caused by bottom turbulence and generate high levels of marine productivity. We have developed ecosystem models of the two areas to explore how these different influences impact the structure and functioning of these ecosystems.

Ecosystem models can be used as a tool 1) to provide a framework to identify potential changes in complex systems that cannot be identified with single-species models, such as counterintuitive changes in abundance when species interactions outweigh the effects of fishing impact or climate change, 2) to emphasize the need to improve knowledge about specific parts of the system, 3) to "test" the compatibility of data sets and 4) to serve as a useful basis for the exploration of scientific hypothesis about system structure, dynamics and functioning. The first step in this process is the development of ecosystem models. Two trophic models of the Bay of Fundy and Western Scotian Shelf were built using the Ecopath with Ecosim (EwE) software to represent these ecosystems in the late 1990s (1995 - 2000). Here we present the data sources used and assumptions made during the parameterisation and balancing of the two models, and then compare these models using a range of ecosystem metrics. The main question to answer is "how different are these ecosystems?"

Event, seasonal and interannual variability of temperature, salinity, and water column heat content on the southern flank of Georges Bank, 1995-1999

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During GLOBEC (Global Ocean Ecosystems Dynamics) Western Atlantic/Georges Bank program, measurements of moored currents, temperature and salinity were made during 1994-1999 at a 76-m site on the southern flank of Georges Bank. The measurements were

concentrated on the biologically crucial winter and spring periods, with more limited coverage during the fall.

The semidiurnal M_2 tidal component dominated the current time series, with a substantial wind-driven component which was linked, especially during summer, to regional–scale response patterns. The monthly mean flow was southwestward throughout the year, but strongest in summer with a subsurface maximum in geostrophic balance with the cross-bank density gradient associated with a near-surface freshwater tongue wrapping around the Bank.

Temperature and salinity time series demonstrate the presence of intruding water masses which could last anywhere from a couple days up to about a month. The sources of these intrusions can be broadly classified as the Scotian Shelf (especially during winter), the western Gulf of Maine (especially during summer), and the deeper ocean south of Georges Bank (throughout the year).

On longer time scales, the temperature variability is dominated by seasonal temperature changes. During the spring and summer, these changes are balanced by local heating or cooling, but wintertime cooling involves large advective lateral transports as well. Numerical model simulations are examined to help determine the upstream source(s) of the colder water. Salinity variations have weak, if any, seasonal variability, but are dominated by interannual changes that are related to regional- or basin-scale changes.

Gulf of Maine Register of Marine Species

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The Gulf of Maine Register of Marine Species (GoMRMS) is currently the most comprehensive register available for the Gulf of Maine area. The goal is to provide an authoritative list of all species in the Gulf, with validated entries, regular updates, and links to other important sources of information such as global distributions and biological and ecological descriptions.

GoMRMS is a preliminary compilation of more than 3,300 species of plants, animals, and selected protists from the Gulf of Maine, Georges Bank, western Scotian Shelf and surrounding waters to 1000 m depth. GoMRMS was developed by the Atlantic Reference Centre (ARC) with support from the Gulf of Maine Census of Marine Life and Canada's Department of Fisheries and Oceans/Center for Marine Biodiversity. Ongoing work includes (1) updating taxonomic relationships; (2) adding to the register from newly-released data from research cruises and publications; and (3) making GoMRMS

searchable and interoperable with other taxonomic databases. We provide an introduction to the register and some of its existing tools and areas under development.

THEME 3: ANTHROPOGENIC AND EXTERNAL INFLUENCES ON THE GULF OF MAINE ECOSYSTEM

Session Co-chairs: Madeleine Hall-Arber/Judy Pederson (US) and Jim Abraham/Peter Wells (Canada)

Rapporteur: Peter Wells

Session Summary

Report prepared by Madeleine Hall-Arber, Judith Pederson, and Peter Wells

The goal of this session was to provide a synthesis of the major pressures being exerted on the Gulf of Maine, including the Bay of Fundy, that impact the achievement of objectives or the desired state of valued attributes (ecological, social/cultural, and economic).

Theme 3, Anthropogenic and External Influences on the Gulf of Maine Ecosystem, covered a broad array of topics that were examined from two perspectives. The first set of papers addressed issues related to climate change and other impacts to the ecosystem, the second set of presenters addressed resilience and adaptation. The poster presentations explored in more depth several different types of pressures on species and ecosystems, use of history in analyzing changes, and carbon flux in the ecosystem. In this summary, we review present developments in the context of the past decade (or more), evaluate our ability to manage, and provide recommendations to shape research in the future.

Historical perspective: How far have we come?

The first Gulf of Maine Conference in December 1989 focused on "Sustaining Our Common Heritage," a theme returned to with several presentations in 2009. In both the earliest conference and this one, themes included historic uses of the Gulf of Maine such as for fisheries and waste disposal, and the importance of analyzing faunal communities over time. The fate and effects of nutrients and contaminants have also been a theme in all of the past four symposia. What is perhaps the most significant change in our perspectives on the GOM is the recognition that ecosystem management is critically important but, to be effective, it must consider intertwined ecological and social factors, and be operationally feasible.

For example, historical records identify changes in species abundance over time. Indeed, four hundred-year old archeological records mark changes in fisheries and other fauna that can be resolved in near decadal chronologies. Many of these changes cannot be explained without reference to human resource use. Fisheries have been a major driver of change. In addition, anthropogenic influences and external forces are closely linked to other drivers such as climate change, chemical pollution, nutrient loading and invasive species.

From pre-European settlement times to the present, the pressures of colonization, clearing of land, building sawmills and ships, industrialization, and increased runoff from agricultural lands with consequent eutrophication, have affected the watersheds and coastal areas of the Gulf of Maine and the Bay of Fundy. Increased nutrient loading, for instance, has led to a downgrading of the St. Johns River, with the largest watershed in the region, from low impact to high impact throughout most of its length. It was not until the 1970s, with the advent of many industrial effluent regulations that efforts were made to reverse the on-going pollution of both fresh, estuarine and marine waters. The reversal of past contamination, however, is slow, particularly for persistent organic pollutants (e.g. PCBs, DDT). Gulfwatch, an 18-year old monitoring program that analyzes the levels of chemical contamination in blue mussels (*Mytilus edulis*) throughout the Gulf of Maine, reveals that some contaminants but not all are diminishing. These results show that the time required for reversing contamination and pollution may be long, even when regulations are in place and enforced.

In addition to understanding recovery times from pollution and other disturbance, fine-scale information and spatial patterns are noteworthy needs. Broad scale fisheries data on abundance and diversity over time are necessary for fisheries management, but finer-scale data may help evaluate why some areas are more productive or recover more quickly than others. Recent work, for example, suggests that the value of forage fish (e.g., herring) to groundfish such as cod in inshore habitats has been underappreciated and that fishing may have altered forage fish diets. Similarly, changes in top predators have altered species abundance, if not total biomass, but the data are incomplete to fully test the hypothesis of unequal abundance and diversity in northern and southern portions of the Gulf of Maine.

A forty-year study of marine benthic communities in the Gulf of Maine demonstrated a major shift in species and their abundance. The pressures identified as causing the observed changes included the development of a fishery in response to an overpopulation of green sea urchins (*Strongylocentrotus droebachiensis*), a major benthic omnivore, followed by overfishing of the urchins, which led to competitive advantages of non-native species that displaced other native populations. The observed ecological shift was dramatic and will have long-lasting impacts on other resources.

Although aquaculture has been a part of the Gulf of Maine and Bay of Fundy history for 30 or more years, it was only briefly addressed in past symposia. Aquaculture has the potential to supplement wild harvests thus helping to fulfill a growing societal appetite for seafood, but the culture of certain species e.g. Atlantic salmon (*Salmo salar*), can have negative ecological impacts. Eutrophication, for example, is common concern for aquaculture facilities, but the release of antibiotics and other pharmaceuticals to the waters has drawn increased attention. Many of the drugs used to combat parasites on fish may also impact lobster and crabs, and their sub-lethal effects on other organisms is largely unknown, but widely suspected. Health hazards to humans from the use of antibiotics and other drugs in the management of aquaculture remain a concern, despite regulatory controls. These issues are likely to be topics of discussion in future meetings.

Management: How well are we situated to inform management?

During the past decade, researchers have focused on biophysical and socioeconomic impacts of activities in Gulf of Maine, the utility and value of ecosystem services, and insights gained from the aforementioned hazard and risk assessment and monitoring. The session pointed to the continuing challenges to ecosystem health of climate change, pollutants, and overuse of natural resources, but also featured signs of resilience, recovery and adaptation pertinent to management strategies.

Climate change, rarely mentioned or investigated in the past decade around the Gulf, has emerged as a high priority problem today. The debate is no longer about whether climate change is occurring, but rather, whether we can slow the change and/or adapt. Communities and governments are undertaking pilot projects to evaluate adaptation options. Increasing storm surges, sea level rise, more violent storms, and changes in precipitation are likely to have a significant impacts on coastal habitats and societal infrastructure, especially in low lying areas e.g. flood plains, estuaries. Because each geographic area is unique, and tidal amplitudes especially vary enormously north to south, a variety of approaches are needed to support and sustain coastal communities. In addition to encouraging community adaptive responses, governments are interested in the potential to slow change by reducing carbon and greenhouse gases.

In Massachusetts, the state has undertaken an ocean management planning effort to assist with balancing conflicting uses of the oceans. The planning effort examined the potential of the ocean to support alternative energy generation, as well as natural resources within coastal Massachusetts waters. Although the plan is not yet implemented, the goal of the planning effort is to support environmentally compatible decisions and meet societal needs. Similarly, efforts to harness tidal energy through siting turbines in the Bay of Fundy reflect the desire to obtain energy with fewer negative environmental consequences than traditional sources. One recently funded project in the Minas Channel is examining models and impacts on fisheries, benthos, and sediments as well as the technical aspects of the effects of ice and debris on the turbines themselves. The data from these studies will inform future decisions regarding the feasibility of tidal energy extraction in macro-tidal parts of the Gulf.

Research on carbon flux from water-air interface suggests that despite the Gulf of Maine's high plankton productivity, during the winter months there is a net escape of CO_2 from vertical mixing of the waters and release of dissolved inorganic carbon. When the data from the entire northeastern seaboard are analyzed, we will have greater understanding of the role of oceans in carbon flux.

What shall we do now?

We should develop conceptual models and an operational framework for managing the Gulf of Maine and Bay of Fundy in the context of unpredictable ecosystem change. Scientific research, long-term monitoring programs, more frequent state of environment assessments, inter-disciplinary and inter-agency collaboration, and communication are crucial.

Communication and joint action among stakeholders is essential for progress in achieving the sustainability of the ecosystems of the Gulf of Maine. Sharing knowledge of the history of the region, of the booms and busts in fisheries, and of changes in habitat, between fishermen and scientists may lead to innovative approaches to fisheries management. In the past decade, steps towards successful collaboration and communication between scientists and fishermen have been taken through the cooperative research projects sponsored by the Northeast Consortium, Gulf of Maine Research Institute, NOAA Fisheries, and the Canadian Fisherman and Scientists Society. In increasing numbers of cases, conversations among fishermen and scientists involved in collaborative work has been mutually beneficial, but the challenge of quantifying qualitative data for use in models remains elusive.

Public education, outreach and communication among the other stakeholders for the Gulf of Maine, and Bay of Fundy, are also vital. In the past, environmental history was melded with fisheries history to create compelling stories useful for public education. Writers and artists, fishermen and scientists worked in concert to develop stories about or depict images of the fisheries contribution to the economic and ecological health of both countries, and the North East US and Maritime regions. Then, for a time, stories about the negative role of fisheries in marine ecosystem health was used to educate the public about the unintended consequences of over use of marine living resources. Today, new perspectives on fisheries and resource management are creating new opportunities for public education. More generally, a visioning and spatial planning process for the Gulf of Maine, with input from a diversity of interests, should be undertaken. However, a concerted effort to raise environmental literacy is essential at the same time, to ensure that the full value of the Gulf's ecosystems and resources is recognized and protected for future generations.

Theme 3 — Schedule of Oral presentations

Part 1: Climate Change and Other Impacts

8:00 Keynote Address — Danika van Proosdij (St. Mary's University)
Impacts and adaptations to climate change in the Bay of Fundy

8:30 Harris, Larry
Shifts in benthic community composition in the Gulf of Maine: increasing roles of invasive species

8:50 Redden, Anna
Tidal power developments in the Minas Passage and the research challenges in addressing associated environmental impacts

9:10 Culp, Joseph
Effluent loading, nutrient status and criteria development for the Saint John River

9:30 Burridge, Les
Chemical use in finfish aquaculture: A summary of products, potential effects and risk

9:50 Health Break

Part 2: Resilience and Adaptation

10:10 Keynote Address — Michael Chiappra (Western Michigan State University)
Usable pasts of harvested waters: The working role of American fisheries history

10:40 Jones, Steve
Can Gulfwatch serve ecosystem-based contaminant monitoring in the Gulf of Maine? Lessons learned and future needs

11:00 Willis, Theo
Pickling and winkling in the shadow of the ancients: How fisheries exploitation altered one of the great inshore marine ecosystems

11:20 Callaghan, Todd
Energy facility siting in the ocean: Can ocean planning help? Management and monitoring case studies from coastal Massachusetts

11:40 Thorne-Miller, Boyce
The culture of information and its impact on fishery ecosystems

Theme 3 — Abstracts of oral papers

Part 1: Climate Change and Other Impacts

Keynote— Impacts and adaptations to climate change in the Bay of Fundy

Danika van Proosdij, Saint Mary's University

Department of Geography, 923 Robie St., Halifax, NS B3H 3C3 Canada

The purpose of this presentation will be to examine the impacts and adaptation to climate change for coastal regions of the Bay of Fundy. Particular emphasis will be placed on the impacts of low lying regions of the Upper Bay which have been identified as being highly sensitive to sea level rise and contain vulnerable infrastructure and transportation corridors.

This Fall (2009), the Atlantic Regional Adaptation Collaborative (RAC) is expected to raise just over $10M in cash and in-kind resources to implement a three-year climate change adaptation plan in Atlantic Canada. The Atlantic RAC is a regional governing body comprised of provincial and municipal representatives from all four of the Atlantic Provinces (Prince Edward Island, Newfoundland and Labrador, New Brunswick and Nova Scotia), as well as representatives from the Insurance Bureau of Canada, the provincial engineers associations, and the Atlantic Planners Institute. The purpose of this collaborative is to reduce community vulnerability to coastal and inland water impacts of climate change and enhance infrastructure resilience in Atlantic Canada by identifying vulnerabilities and developing tools to assist managers in developing sound adaptation strategies. Opportunities and challenges for cross jurisdictional and boundary collaborations will be discussed with examples from two projects in the Cumberland and Minas Basins.

Shifts in benthic community composition in the Gulf of Maine: increasing roles of invasive species

Larry G. Harris*

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The benthic communities of the Gulf of Maine have experienced major regime shifts over the last 40 years. The sea urchin *Strongylocentrotus droebachiensis* experienced a major population explosion around 1980 that led to conversion of most hard bottom habitats from the historical kelp bed communities to sea urchin dominated barren grounds. Overfishing of sea urchins, that began in 1987, resulted in a return to algal dominated communities, but with a composition that included a number of previously rare introduced algal species and several colonial tunicate species and an encrusting bryozoan

that have produced communities significantly different in composition from the previous kelp bed community state. The previous kelp dominated canopy now includes the green alga *Codium fragile* ssp. *fragile* and the understory is now often dominated by Bonnemaisonia hamifera and Neosiphonia harveyi. The bryozoan *Membranipora membranacea* and the tunicate *Botrylloides violaceous* are conspicuous epibionts, while the tunicates *Diplosoma listerianum* and *Didemnum vexillum* compete with algal species for space within previously algal dominated upper surfaces. Fouling communities have also seen a significant shift in composition with increasing roles played by a growing number of introduced species, in which tunicates are the most obvious. A series of additional introduced algal and animal species, which tend to be most common south of Cape Cod and in a few disjunct habitats with warmer summer water temperatures appear to be increasing in abundance and distribution. Increasing water temperatures and other anthropogenic factors appear to be facilitating these transitions to new community states. Continuing monitoring of permanent stations throughout the GOM suggest that these communities are still in transition and are far from reaching a new equilibrium.

Tidal power developments in the Minas Passage and the research challenges in addressing associated environmental impacts

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In the century that has passed, more has been learned about the Bay of Fundy as a result of tidal power investigations than for any other reason, leading to a wide recognition of the global importance of this unique ecosystem. In late Oct 2009, we expect to see the first commercial-scale, tidal in-stream energy conversion (TISEC) device in place in the Minas Passage, Bay of Fundy (OpenHydro), followed by the deployment and grid connection of two other TISEC device types (Marine Current Turbine and Clean Current). These demonstration units offer an opportunity to examine the effects of the environment on a range of TISEC technologies as well as the impact of these devices on the environment. The newly established Fundy Energy Research Network (FERN) was initiated in 2008 to identify priority research needs that require long term and/or large scale, collaborative approaches that would build the knowledge base required for assessing the potential for, and risks of, commercial-scale marine renewable energy from the Bay of Fundy. Research challenges are numerous and fall into three general areas: a) technology and grid integration; b) resource assessment and modeling; and c) ecosystem responses to energy extraction. Similar issues are faced by TISEC demonstrations elsewhere in the world, but the results of those studies may not be transferred easily to the Bay of Fundy. The unique features of the upper Bay of Fundy – tidal range, extreme currents, high suspended sediment loads, sediment-laden ice, diverse and abundant migratory species, some of which are considered species at risk – are found in few other places in the world, and seldom together. In addition, technologies for monitoring environmental parameters and animal behaviour in relation to turbine infrastructure are still very much ‘works in progress’, and are not always well suited for deployment under

extreme current/tidal conditions. This presentation will address some of the work that is planned and currently underway to address potential environmental impacts of TISEC device installation and operation in the Minas Passage.

Effluent loading, nutrient status and criteria development for the Saint John River

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The Saint John River is the largest in Maine/New Brunswick (673 km in length, draining 55,000 km^2), with a history of natural resource use and nutrient effluent release to the watershed since the late 17^{th} century. The objective of this study was to obtain a basic understanding of the contemporary nutrient condition of the Saint John River in relation to historical conditions, to consider how the river is affected by point and non-point source nutrient loadings, and to determine how much of these loadings enter the Bay of Fundy. The study included review of historical provincial and federal water quality databases dating back to the 1960s. Current water quality monitoring programs have focused on nitrogen (nitrite, nitrate, ammonia, TKN), phosphorus (total, dissolved, and soluble reactive phosphorus), DIC/DOC, periphyton and phytoplankton biomass. In addition, nutrient diffusing substrate studies were conducted in several river reaches to assess nutrient limitation and enrichment. This broad range of information was interpreted using a weight of evidence approach to combine the results of the mentioned studies to establish the trophic status and nutrient criteria for various sections of the river. Finally, we will provide an historical analysis of nutrient loading from the river to the Gulf of Maine, and give an overview on the ecological state of the Saint John River Ecosystem

Chemical use in finfish aquaculture: A summary of products, potential effects and risk

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Use of chemicals and therapeutants is an integral part of salmon aquaculture activities. These compounds are used to reduce fouling of nets and to treat disease outbreaks. Each compound has specific chemical characteristics that influence its fate and persistence in the marine environment which, in turn, determines the bioavailability of the chemical. There have been significant concerns expressed regarding the potential for these

"aquaculture chemicals" to affect indigenous species, in particular the American lobster, in southwest New Brunswick. Copper–based paints are used as net treatments to limit the growth of fouling organisms on nets. The copper may accumulate in sediments under fish farms to concentrations that exceed sediment quality guidelines. Antibiotic compounds are used as in-feed additives to treat diseased fish and these compounds have also been shown to accumulate in sediments. The consequences of this accumulation could be significant including promotion of antibiotic-resistant species of bacteria. Pesticides and drugs are used to combat infestations of ecto-parasites (sea lice) on farmed fish. As these compounds are designed to kill arthropods their potential effects on lobsters are well-studied. This presentation will touch on patterns of use of anti-foulants, antibiotic and anti-parasitic compounds and their known hazards. The author will also address the more environmentally-relevant issue of risk.

Part 2: Resilience and Adaptation

Keynote— Usable pasts of harvested waters: The working role of American fisheries history

Michael J. Chiarappa, Western Michigan University

The advent of modern fisheries research during the second half of the nineteenth century was striking in its historical and ethnographic orientation, a precedent set by such pioneering work as George Perkins Marsh's, *Man and Nature,* and the collective labor of the U.S. Fish Commission and certain state fish commissions that followed its lead. This approach served to provide more than limited context or introductory remarks for scientific studies, but, with compelling clarity, took seriously the historical and cultural experiences of fishing communities in an effort to structure wide public discourse on the pressing concerns confronting the use of fisheries resources. Hoping to employ knowledge of fisheries history and occupational culture in the service of publicly engaged, progressive policy and management, these investigations reached audiences not just through government reports, but also through popular periodicals and fisheries exhibitions. Today, the work of environmental and cultural history—in conjunction with their vital interdisciplinary links to oral history, anthropology, geography, field documentation, and museology—is revitalizing this tradition and establishing important patterns in how fisheries issues are communicated and deliberated in society. Similar to earlier periods, the implications of these contemporary initiatives are important for those stakeholders wishing to participate in the public culture that frames current fisheries life. This presentation will explore these developments, along with the role and relevance they have assumed in public/applied history, anthropology, and civic engagement.

Can Gulfwatch serve ecosystem-based contaminant monitoring in the Gulf of Maine? Lessons learned and future needs

Steve Jones and Christian Krahforst

Assessing contaminant exposure and impacts on an ecosystem-wide basis in the Gulf of Maine is a significant challenge. An ecosystem-based approach requires a well conceived paradigm that includes elements of ecological, human health and quality of life issues. There is a near endless myriad of environmental matrices and levels of impact that could be the focus of a number of monitoring programs. Thus, monitoring exposure of resident organisms to contaminants can become quickly complicated and challenge the elements of monitoring design, logistics of organizing, and garnering sustained support. For toxic contaminants, the Gulf of Maine Council's Gulfwatch Program has shown the need for long-term data that are eventually of use for determining temporal trends and the impacts of management activities.

The Gulfwatch Program has maintained an annual blue mussel monitoring program at over 70 coastal sites from Cape Cod MA to Yarmouth NS since 1991. Results have been reported each year, and used by public health and environmental resource managers, in addition to scientists and the general public. The full strength of the program is beginning to be realized in trends analyses because temporal thresholds are being reached. The Program can now show where there have been significant decreases and increases in trace metals and toxic organic contaminants concentrations over the past decade and a half. While increases and decreases been observed, analyses of the data through 2008 generally show most of the monitored contaminants have not changed, despite efforts to control environment release. Annual monitoring also helps to provide a contemporary perspective of where contaminant levels occur in the Gulf of Maine and often shows clear transboundary gradients and repeated hot spots of pollution to which environmental management can be directed.

When viewed within the framework of ecosystem function and public health issues, long-term monitoring by the Gulfwatch program, while providing unique and invaluable insights into Gulf-wide contaminants trends in blue mussels, is quite narrow. For example, the Gulfwatch program recognizes the importance of emerging contaminants as threats to ecosystem health and function in the Gulf of Maine but, because of limited resources, is not able to contribute monitoring information in order to assess the extent of exposure that Gulf of Maine organisms may be experiencing. Understanding the state of contaminant exposure and communicating this to the residents of the Gulf of Maine are lofty goals that requires additional efforts and resources beyond the current Gulfwatch design. It is likely that other toxic chemical monitoring programs which include monitoring of other matrices and organisms already have complimentary data; yet little to no resources have been made available to integrate these sources of information. Modest, independent efforts in integrative analysis of data from different programs have revealed information that greatly improves our understanding of this issue. Given the difficulties involved with finding resources to expand monitoring efforts, further support of similar efforts that mine existing data and information may be one approach to bridge the gap

between current, more narrowly-focused monitoring efforts to one that is sensitive to a broader understanding of contaminant exposure at ecosystem level of the Gulf of Maine.

Pickling and winkling in the shadow of the ancients: How fisheries exploitation altered one of the great inshore marine ecosystems

Theo Willis, Karen Alexander, W. Leavenworth, and N. Hamilton

University of Southern Maine

This paper compares the current catch diversity and species sizes in Passamaquoddy Bay to historical and pre-historic catch diversity and size. Passamaquoddy Bay is an inlet of the Bay of Fundy, between Maine and New Brunswick and includes the mouth of the St. Croix River. The lower portion of the bay has a number of underwater features that, in combination with the eight meter tidal amplitude, create whirlpools and gyres which retain or attract a wide array of marine organisms. Passamaquoddy Bay is the ancestral home of the Passamaquoddy Indian Nation. The city of Eastport, the center of fish commerce in Passamaquoddy Bay for over a century, is also sited near the mouth of the Bay. The protected nature and physical and oceanographic features of Passamaquoddy Bay made it a prime location for human exploitation of marine resources.

Bone evidence from archeological digs around the Bay demonstrated that marine life played a significant role in providing sustenance. Marine mammal and fish bones were prominent features in most strata, stretching back to 2500 B.P. Settled by Europeans in 1772, incorporated in 1798, Eastport was principally established as a port and fishing station. Landings records and economic data from the 19th and 20th centuries show trade and consumption of cod, herring and pollock as drivers of Eastport's economy. However, signs of shrinking catch rates and smaller fish were apparent by the end of the historic period (circa 1950s). The diversity of sustenance species was high in the pre-historic period. The diversity of commercially fished species in the early historic period was lower, with certain recognized high-value species (e.g., cod, pollock, haddock, etc.) being most prevalent in the landings. However, as size of individual fish gradually decreased, the diversity of landed species increased. Benthic species took on a more prominent role in the catch.

A modern study, conducted from 2006-2008, collected fish by hook and line from sites between the Perry, ME shoreline (Gleason Cove) and Eastport. Catches consisted primarily of longhorn and shorthorn sculpin (*Myoxocephalus* spp.). Very few cod were caught in the three year duration of the study; cod grounds identified by older fishermen from the area produced few cod. Pollock were absent until year three of the study. The change is particularly striking when the size and composition of the modern fish community is compared to that identified over the two thousand year history of the bay.

Energy facility siting in the ocean: Can ocean planning help? Management and monitoring case studies from coastal Massachusetts

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The Gulf of Maine is increasingly under pressure from energy generation, delivery, and storage proposals. Recent interest in renewable energy generation includes arrays of wind and tidal turbines in both the nearshore and offshore waters of the Gulf. At the same time, natural gas delivery and storage facilities have been proposed and are being developed throughout the Gulf. Competition among these emerging ocean uses and traditional uses has led to heightened interest in proactive planning for the ocean as a source of, and conduit for, energy. In Massachusetts, the construction of two offshore liquefied natural gas ports and three natural gas pipelines in coastal waters resulted in the implementation of multi-year monitoring programs to better understand how the construction of natural gas infrastructure affects benthic communities. Other ocean energy conduit proposals in Massachusetts include a 1000-megawatt transmission cable to bring electricity from Wiscasset, Maine to Boston as well as the transmission cables that will be built to support proposed offshore wind turbine arrays. While data on post-construction benthic impacts and recovery exists, effects from other aspects of ocean energy generation, delivery, and storage (e.g., noise, collisions with turbine blades, migration disruption, species displacement) are still unknown. In an effort to manage multiple future uses, and address their unknown ecological effects, Massachusetts is proposing an ocean management plan and companion science plan. Here we discuss monitoring programs that produced scientific information that had useful management implications and suggest a general description of data needed to move forward with planning for and managing the impacts of ocean construction projects.

The culture of information and its impact on fishery ecosystems

Boyce Thorne-Miller

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How information is shared among scientists, fisheries managers, and fishermen and how it is applied to management decision-making has a marked affect on fisheries ecosystems and fishing communities. The intersection of science values, management structures, technology, and traditional fishing knowledge has been fraught with conflict, which has led to unsuccessful fisheries management and declining marine fishery ecosystems. The history of fisheries management in the Gulf Maine bears that out.

Since the collapse of marine fisheries became apparent in the 1980s, cultural barriers have grown to make successful fisheries management difficult. Science is too often slave to deconstruction and software. Scientists have lost their bravery. Fishermen have

difficulty trusting in ever-changing management systems. Fisheries managers are held accountable to everything except the truth. The public has lost interest. At the heart of the problem is the difficulty of sharing information across these different cultures. Recent cooperative research programs are promising signs of change, but more is needed to expand such programs and bring information from them to bear on management decisions.

A rich and well-integrated base of information should enable the framing of management plans more consistent with ecosystem scales and design and incorporating biological and cultural interrelationships. The trick is to begin a collaborative process of thinking like a fishery ecosystem. The language of discussion might finally move toward long-term interdependencies among species of the ecosystem (including fishermen), critical temporal and spatial scales, appropriate market characteristics, and design and responsiveness of both fisheries and management.

The Gulf of Maine could be an ideal place to begin this process.

Theme 3 –- Poster Abstracts

The development of the salmon aquaculture industry in southwestern New Brunswick, Bay of Fundy

B.D. Chang and F.H. Page

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The farming of Atlantic salmon (*Salmo salar*) in the southwestern New Brunswick portion of the Bay of Fundy began at one farm in 1978. The industry has grown substantially since then, and by 2007 there were 92 licensed farms, of which approximately two-thirds were operating, with a total production of 39 000 t. The concept of bay management areas was first introduced in 1995, when 10 management zones were created to assist in the management of sea lice. The Province's finfish management policy of 2000, which was developed primarily to address fish health concerns, in particular the viral disease infectious salmon anemia (ISA), included the creation of 21 Aquaculture Bay Management Areas (ABMAs) and a requirement for farms to move toward single year-class farming and a 2-yr rotation stocking system. Under this ABMA framework, ISA continued to cause large economic losses. Starting in 2006 a new framework was introduced, with fewer ABMAs, a 3-yr rotation stocking system, and mandatory fallowing between successive year-classes. Since the implementation of the new ABMA framework, there have been no outbreaks of ISA disease in SWNB.

Profiles of lobster fishery groundlines in relation to their threat to entangle North Atlantic right whales in the Bay of Fundy, Canada

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Fishing gear is a known threat to North Atlantic right whales (*Eubalaena glacialis*) and it is commonly hypothesized that the groundlines used in the lobster (*Homarus americanus*) trap fishery are an important component of this threat that may in some incidents lead to mortality. This research tested this hypothesis on Canadian lobster gear. The elevations of 17 groundlines of commercially active lobster gear in the Bay of Fundy, Canada were recorded using depth data-loggers and several factors governing rope profiles were evaluated. Mean elevation of the groundlines was 1.6 m (SD = 0.9, n = 5968, range = 0 - 7.0 m). The hypothesis that groundline elevations were ≤ 1.0 m (the predicted height of taut groundlines) was rejected (Fisher's C, $p < 0.01$) as was the hypothesis that elevations were > 3.0 m (the approximate body-height of a right whale; $p < 0.01$). The proportion of groundline elevations ≤ 1.0 m was 0.32 and < 3.0 m was 0.92. Groundline elevations

were negatively related to the velocity of the tide at the time of setting ($p < 0.001$, $r^2 = 0.33$), but once the gear was set, the effect of the tide on the elevations of the groundlines varied according to their tautness. Elevations were also lower in deep water than in shallow water ($p < 0.05$, $r^2 = 0.07$). This research is the first to continuously and accurately measure groundline elevations on commercially active lobster gear. Results suggest that the groundlines of lobster gear in the Bay of Fundy may not constitute a large part of the threat associated with the entanglement of right whales because lines were rarely above the elevation hypothesized to be a threat (3m). We also demonstrated several factors within control of fishermen (e.g. setting practices) that minimize groundline elevations without using sinking line. Predicting the risk that fishing gear poses to entangle North Atlantic right whales requires knowledge of the potential for whales to encounter fishing gear as well as knowledge of the profile of the fishing gear in the water column. This research has contributed to these needs and is currently being expanded to investigate the profiles of buoylines of fixed-gear fisheries to evaluate their contribution to the risk to entangle right whales.

Understanding long-term fishery change: Atlantic herring (*Clupea harengus*) as a case study for time series analysis

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In the Gulf of Maine, Atlantic herring (*Clupea harengus*) provide critical forage for many commercially and recreationally valuable species, while supporting a major New England fishery. Extensive research and stock assessments conducted on herring since the 1960s have focused on recent patterns of distribution, abundance, and other fishery characteristics. This work often neglects longer-term patterns or changes suggested by historical documents and the long history of anthropogenic influence and exploitation. The research here used time series analysis to explore herring fishery data and the possible influence of anthropogenic events and natural drivers from 1871 to the present.

Historical information on Atlantic herring and oceanographic features was compiled from many sources around the Gulf of Maine. Time series analysis, specifically auto-regressive-integrated-moving-average (ARIMA) models, was used to model the underlying patterns of the herring fishery and interpolate for years of missing data. Two additional time series methods compared the fishery patterns found with possible external influences. First, intervention analysis identified outliers and unexpected changes in the herring time series, which were compared to socioeconomic and industry events from the qualitative literature. Second, cross-correlation analysis explored relationships between the herring time series and sea surface temperature and salinity.

This study demonstrates the potential of time series analysis and historical data, including the qualitative literature, to better understand fisheries over the long term. Time series analysis can be a useful tool for applying historical data to study ecosystems in their

entirety, from historical fisheries to today, rather than isolated in time or context. These methods are applicable to additional species with similar historical data, and can broaden temporal perspectives and provide insight into the factors affecting the fishery over an extended time period.

Determining harbour porpoise (*Phocoena phocoena*) behaviour patterns via monitoring echolocation activity in the vicinity of aquaculture sites

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T-PODs are acoustic data loggers that record the time when echolocation clicks of harbour porpoise (*Phocoena phocoena*) are received. One (2006) or three (2007) T-PODs were deployed near an aquaculture cage site at the mouth of Back Bay, NB, during the summer and fall. Echolocation activity was lowest during the day, increased in the evening and was highest between midnight and dawn. This pattern may reflect the transition from diurnal vision to nocturnal echolocation. The diel pattern was not influenced by the presence (2006) or absence (2007) of Atlantic salmon (*Salmo salar*) in the cages during the summer. When clicks were detected, the patterns indicated that the porpoise were either in transit and passing through the area or were stationary and active, either feeding or socializing, for over an hour. By examining the fine details of the click rate intervals, it may be possible to differentiate between food capture and social interactions.

Environmental history in the Western Gulf of Maine: using archaeology to study faunal change (1620-1910)

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A well preserved archaeological record of 400 years of human activity at the historic offshore coastal fishing sites on Smuttynose Island, Isles of Shoals (ME) provides an opportunity to investigate faunal change and marine resource utilization during a period of environmental and climate change (1620 – 1910). We are studying assemblages that include marine fish, birds, mammals, and mollusks to document patterns abundance of these species over time. Systematic sampling of these fishing sites with diagnostic material remains (ceramics, pipes, nails and glass) from the historic human community on Smuttynose Island reveals a finely resolved near decadal chronology. Deep

stratigraphic deposits provide the opportunity to investigate two meters of cultural and faunal samples. Analysis of the fish and gastropod remains will provide data on species demography, seasonality of utilization of different species by human populations at these historically important island sites, and provide a check on historical written records of marine invasions. The late 17th to early 18th century fishing (English and Irish) population at Smuttynose provides a rich opportunity to develop environmental history in the Gulf of Maine.

Efficacy of using multiple acoustic systems to quantify Atlantic herring (*Clupea harengus*) aggregation metrics before and after fishing events

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The use of midwater trawls to harvest Atlantic herring (*Clupea harengus*) in the Gulf of Maine has been a controversial topic for many years. A majority of the concern revolves around the potential physical disruption of Atlantic herring aggregations and the potential impact on ecological processes and other industries (e.g., other fisheries and eco-tourism) that rely on these aggregations. Preliminary acoustic data collection in fall 2008 using a combination of 1) Simrad ES60 echosounders (38- and 120-kHz), and 2) a Simrad SP90 omni-directional sonar (20-30 kHz), showed promise for quantifying herring aggregation metrics. In this presentation, we report on a pilot study conducted in the summer of 2009 that uses these acoustic systems in a before-after-control-impact design to quantify and describe herring aggregations before and after midwater trawling with a pair of fishing vessels over multiple fishing trips. We report on the efficacy of using acoustic systems to quantify the potential impacts of fishing on herring aggregations, and discuss the next steps to fully evaluate these potential impacts at spatial and temporal scales relevant to the fishery.

Examination of interannual ocean CO2 and air-sea CO2 flux in the Western Gulf of Maine

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This study is focused on observations collected by the University of New Hampshire to evaluate and quantify air-sea CO_2 flux dynamics in a highly productive marginal sea –

the Gulf of Maine (GOM) located on the NW Atlantic shelf. While this region has been intensively studied for decades, this work will provide the first annual estimates of net CO2 flux at the air-sea interface. Our hypothesis is that the seasonally stratified GOM is a source of CO_2 to the atmosphere despite a significant net production of organic carbon. This occurs because the large vernal CO2 drawdown due to phytoplankton growth is more than offset by the fall-to-winter recharge of the surface layer dissolved inorganic carbon and enhanced wind-driven gas exchange. This net imbalance is investigated alongside other known factors controlling seasonal air-sea gas flux using a combination of field measurement and coupled 3D circulation/biochemical model data that addresses gas transfer dynamics as well as the time evolving disequilibrium between atmospheric and oceanic CO2. The research utilizes a unique East Coast coastal CO2 data set that spans from 2004-present and includes monthly shipboard spatial coverage of inner, mid, and outer shelf stations as well as a moored CO2 measurement platform with hourly time resolution. Hypotheses related to interannual controls and spatial variability in the mass flux are being addressed using the same data-model fusion approach undertaken in the overall investigation. Comparison and contrast with similar recent investigations in the Mid- and South Atlantic Bights will be used to highlight the relative importance of biology and vertical mixing processes to surface C dynamics in this marginal sea versus solubility control in those regions.

Geography of top-down forcing in the Northwest Atlantic groundfish-lobster interaction: The role of predator diversity, identity and abundance

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In the wake of widespread groundfish depletion, American lobster (*Homarus americanus*) abundance has increased dramatically since the 1980s in the Gulf of Maine, but not in coastal southern New England. We evaluated the hypothesis that the difference could be attributed to contrasting regional diversity and composition of the predator assemblage. Trawl survey data (1981-2004) indicate that despite harvesting, the collective biomass of predatory groundfish did not decline over the period in either region, whereas collective groundfish average body mass did, resulting in a statistical correlation between shrinking groundfish body mass and the increase in lobster abundance for the Gulf of Maine. Stationary video surveillance, ROV surveys and tethering experiments in shallow rocky lobster nurseries confirmed a strong southward increase in fish diversity, fish predation and lobster shelter-use. Certain groundfish species attacked tethered lobsters at rates disproportionate to their abundance, underscoring the importance of species identity, as well as abundance in assessing interaction strength. These findings, together with the recent onset of a shell disease

epizootic suggest a diversity of strong biotic interactions in southern New England not experienced by lobsters to the north.

Developing an Outreach Program for Invasive Tunicates in the Maritimes, Canada

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Five invasive tunicate species of concern to Atlantic Canada: include the solitary species *Ciona intestinalis* (vase tunicate) and *Styela clava* (clubbed tunicate) and the colonial species *Botrylloides violaceus* (violet tunicate), *Botryllus schlosseri* (golden star tunicate) and *Didemnum vexillum*. These fouling tunicates threaten our estuarine resources both ecologically and socio-economically. Atlantic Canada has been impacted by all of these species except *D. vexillum* in the past 15 years. A monitoring program was initiated by the Department of Fisheries and Oceans with various partners in the spring of 2006. Collection plates were deployed at a large number of sites along the coast of the Bay of Fundy, mainland Nova Scotia and Cape Breton.

Once a tunicate species is established in an area, it is virtually impossible to eradicate making prevention or spread of new introductions critical. Therefore, efforts to promote awareness of the risks posed by non-indigenous tunicates to the environment and efforts to promote community-based monitoring are on-going to educate the general public including community groups, universities, fishers, aquaculture lease holders, shellfish harvesters, divers and boaters. Bilingual educational materials such as posters, brochures, ID watch cards, key chains, traveling displays and other promotional materials were developed and distributed. Methods for preventing and minimizing the risks for introductions are outlined. Stewardship and outreach activities included presentations at museums, schools, shellfish festivals, conferences, workshops, BIO Open house, personalized training for deploying monitoring collectors, and etc. Further information can be obtained by contacting 1-888-435-4040 (BIO) or 506-529-5961 (SABS).

Monitoring for non-indigenous tunicates in the Maritimes, Canada

Jennifer Martin[1], Dawn Sephton[2], Benedikte Vercaemer[2] , Murielle LeGresley[1] and Joanne Keays[2]

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Five species of invasive tunicates are of concern in Atlantic Canada: the solitary species *Ciona intestinalis* (vase tunicate) and *Styela clava* (clubbed tunicate) and the colonial species *Botrylloides violaceus* (violet tunicate), *Botryllus schlosseri* (golden star tunicate) and *Didemnum vexillum*. These fouling tunicates can threaten our estuarine resources both ecologically and socio-economically. For instance, the shellfish culture industry in Atlantic Canada has been impacted by invasions of four of these fouling tunicates in the past 15 years. A monitoring program, with various partners, was initiated by the Department of Fisheries and Oceans in the spring of 2006. Collection plates were set out at a large number of sites along the coast of the Bay of Fundy, mainland Nova Scotia and in Cape Breton. Collectors deployed in May/June were retrieved either in mid August as a summer set or late October/November as a full season set. Another set was deployed in mid August and collected in late October/November as a-fall set. Physical measurements (temperature, salinity, oxygen) were collected at most deployments and retrievals. Surfaces surrounding the collectors were examined for the presence of non-indigenous tunicates. Seventy-six monitoring sites were selected based on the risk of non-native species introduction or establishment. Other factors for selection included proximity to: shellfish processing facilities, aquaculture operations, ports and marinas with international traffic, fishing harbours, and other high risk ports. Additional surveillance was carried out in high-risk areas where *Didemnum vexillum* might invade such as: Passamaquoddy Bay (Campobello Island, Deer Island), Isle Madame-Canso, Shelburne-Port La Tour, Halifax-St. Margaret's Bay and Lockeport-Digby.

Since 2006, *Ciona intestinalis* appears to have increased along the south shore of Nova Scotia, especially in 2008, and continues to be very abundant on Isle Madame. In the Bay of Fundy, *C. intestinalis* was observed at high concentrations in 2006 and 2008. *Botryllus schlosseri* was the most widespread tunicate in Nova Scotia during the sample period, whereas it became more widespread as years progressed in the Bay of Fundy. Although *B. violaceus* has not yet been observed in the Bay of Fundy it seems to be increasing and spreading on the south shore of Nova Scotia, with a new occurrence in Yarmouth in 2008. *Styela clava* and *Didemnum vexillum* were not observed in coastal New Brunswick and Nova Scotia during 2006, 2007 or 2008.

THEME 4: MONITORING/OBSERVATION, DATA COLLECTION, ANALYSES, AND TOOLS REQUIRED FOR AN ECOSYSTEM APPROACH TO MANAGEMENT (EAM) OF THE GULF OF MAINE

Session Co-chairs: Jeffrey Runge (US) and Michael Sinclair/Bob O'Boyle (Canada)

Rapporteurs: Bob O'Boyle, Catherine Johnson and J. Ru Morrison

Session Summary

The goal of this session was to provide a synthesis of the science that is required to observe and predict changes in the Gulf of Maine ecosystem, and to evaluate the strategies used to implement an ecosystem approach to management.

The afternoon session accommodated eleven presentations, and an additional 12 presentations were contributed as posters. Two keynote talks, by M. Fogarty, U.S. National Marine Fisheries Service, and S. Gavaris, Fisheries and Oceans, Canada, summarized the strategies to implement an ecosystem approach to management in the Gulf of Maine by the two respective federal governments. J. R. Morrison provided an overview of the newly formed Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS), a U.S. contribution to observing and predicting change in the Gulf of Maine. P. Smith and coauthors described results of mooring data on currents in the Northeast Channel, indicating a shift in the flow of water in and out of the Gulf of Maine sometime between 2000, when the last BIO/GLOBEC mooring was removed, and 2004, when a new mooring was installed as part of NERACOOS. This shift has potentially important implications for production in the Gulf of Maine ecosystem. C. Johnson and J. Hare reviewed the status and needs for zooplankton monitoring in the Gulf of Maine, the data from which provide evidence of change in the pelagic ecosystem linked to larger-scale forcing. N. Makris described new technological advances for observing large herring schools using acoustic remote sensing. K. Stokesbury and coworkers described an independent, cooperative video survey method, conducted annually since 2003, allowing a mosaic approach to habitat mapping and enabling estimation of abundance of sea scallops in support of management of the commercial fishery. C. Davis reviewed advances in understanding physical-biological mechanisms controlling plankton and fish recruitment dynamics in the Gulf of Maine- Georges Bank region and their relationship to local and climate-scale forcing. This understanding has been incorporated into 3-D biological-physical models that can serve as diagnostic and predictive tools for understanding effects of climate change in the context of ecosystem approaches to management. J. Fisher examined the characteristics of successful long term resource surveys to monitor marine finfish and invertebrate populations among federal, state and provincial management agencies conduct in the Gulf of Maine. He discussed how the long time series data might be used to assess upper level ecosystem change, and emphasized that new knowledge and discoveries increase exponentially with length of the time series. N. Shackell examined indicators that represent a range of processes influencing dynamics of NW Atlantic coastal ecosystems and presented multivariate and time series statistical approaches to compare the primary drivers (associated with climate

and fisheries) of change across NW Atlantic ecosystems, including the Gulf of Maine. J. Grant presented a new multivariate approach that analyzes process-oriented variables for assessment of the health of nearshore ecosystems.

A number of contributed papers in poster session presented other biological observations in the Gulf of Maine (Diamond: Arctic terns; Nye et al: coherency of trends in major fish species; Thompson et al.: phytoplankton biomass in the Damariscotta River Estuary; Poulton et al.: microbial time series in Boothbay Harbor; Branton and Bridger: Ocean Tracking Network). Several studies discussed approaches for analyzing marine biodiversity (Ellis et al.; Pohle and Van Guelpen),variability in species abundance and distribution (Cook and Bundy), and dealing with data gaps for development of ecosystem indicators (Tilburg et al.). Tilburg et al. present results from the Saco River Coastal Observing System and analyze variability in freshwater discharge and extent of the freshwater plume, important processes affecting the near coastal ecosystem. Becker and Kanwit present a survey of bycatch of haddock in the N.E. U.S. herring fishery. Bergeron et al. present a model of American lobster growth that uses temperature time series to examine effects of environmental forcing.

In the plenary session on Friday morning, the Theme 4 session was discussed with reference to the following questions: 1) Since the last Gulf of Maine Science Symposium in 1996, how far have we come in the science of observation and prediction of change in the Gulf of Maine, and in the implementation of an ecosystem approach to management? 2) how well situated is the science now to inform management? and 3) what must we do to advance EAM in the Gulf of Maine?

How far have we come?

Over the past 15 years, considerable steps have been taken to organize observation of change in the region. The Canadian Atlantic Zonal Monitoring Program began in 1998, supporting the Halifax line and a fixed station on the Scotian Shelf off Halifax and in the Bay of Fundy, providing sustained funding for observation of physical and biological variables at the upstream boundary of the Gulf. The Gulf of Maine Ocean Observing System (GoMOOS) was established in the late 1990's, resulting in the installation of a series of observational moorings along the Maine and Massachusetts coasts for weather and hydrographic measurements and limited phytoplankton sampling. In 2009, the transition from GoMOOS to NERACOOS was made after several years of planning by a multidisciplinary advisory committee of regional experts. The geographic range of NERACOOS includes not only the Gulf of Maine but also the southern New England bight and Long Island Sound. This regional infrastructure has advanced the capacity for coordinated observation of change, although the extent of sustained funding and range of variables to be observed is not yet established.

A number of time series that began earlier than 1996 have continued. Some new time series have started, while others have had to be discontinued. In addition to annual and biannual fish trawl surveys conducted by both NMFS and DFO, NMFS has sustained the Continuous Plankton Recorder line between Cape Sable and Boston, as well as the EcoMon surveys that are conducted 6 times each year. Satellite derived sea surface

chlorophyll time series began in 1997, and presently two satellites (SeaWifs and MODIS) cover the Gulf of Maine each day. The duration of these time series is beginning to yield information on interannual and interdecadal variability and trends.

New tools for integrating and analyzing observational data have been developed. Notable are great advances in coupled physical-biological modeling, supported in large part by the U.S. GLOBEC Northwest Atlantic/Georges Bank program . Trophic models of energy and material flux across the ecosystem food web and time series and multivariate statistical approaches web have also advanced significantly. These approaches have been facilitated by the tremendous increase in computer capacity over the past decade.

In terms of EAM, both Canadian and US federal agencies responsible for management of harvested resources have been working toward a strategy for integrating observations into information for management decisions. The U.S. strategy involves development of Integrated Ecosystem Assessments within a framework of evaluating drivers (eg large scale climate forcing), pressures (e.g temperature increase), ecosystem states (from observations and indicators), assessment of impacts (using ecosystem models) and determination of responses. The Canadian strategy is more incremental, building on existing fisheries management practices within a framework of defining objectives (e.g. maintain productivity, preserve biodiversity, protect habitat), determining strategies and specifying tactics to achieve objectives.

How well situated is the science to inform management?

The establishment of AZMP in Canada and NERACOOS in the U.S. combined with ongoing resource surveys by federal and state agencies and research-industry partnerships provide a foundation for providing information to management about change in the Gulf of Maine. Knowledge of past and present change is substantially improved. New developments in ecosystem modeling and multivariate statistical and time series analysis offer tools to integrate and interpret multidisciplinary data. Different scientific approaches using different types of ecosystem modelling to assess change and inform management are being developed, involving considerable thought and effort.

The science is nevertheless not realizing its potential to contribute to management. The range of ecosystem variables measured in time series and the spatial scale of time series observing in the Gulf of Maine is inadequate. An integrated scientific strategy to engage species- centric and trophic centric models to inform management about ecosystem change has not yet been achieved. The mechanisms for transfer of knowledge from science to decision making are underdeveloped.

The level of funding of Gulf of Maine science is one constraint on its capacity to produce relevant information to management. Another constraint is the infrastructure (including personnel) to transfer new observational data and methods for analysis and interpretation of results to federal/ state-provincial and community levels where this information can be used in decision making.

What must we do?

There is a need for collection of time series observations across ecosystem levels, particularly in the nearshore and coastal regions, and for the benthos. The science needs to continue along many fronts to analyze and interpret data and to develop predictive, integrative models of climate change scenarios on the Gulf of Maine ecosystem and its resource populations. Bridges to transfer new research knowledge, understanding and information support tools from science to management implementation need to be developed and maintained. The NOAA cooperative institutes (CINAR) in the Gulf of Maine is an example. Connections to coastal managers need to be fostered.

Theme 4 — Schedule of oral presentations

13:30 Keynote Address — Michael Fogarty (NOAA)
Drivers, pressures, and ecosystem states: Toward an integrated assessment of the Northeast U.S. Continental Shelf Large Marine Ecosystem

14:00 Keynote Address — Stratis Gavaris (SABS, Fisheries and Oceans Canada)
Experience with making an ecosystem approach to management operational

14:30 Morrison, J. Ru
The Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS)

14:45 Smith, Peter C.
Regime shift in the Gulf of Maine

15:00 Johnson, Catherine L.
Plankton monitoring in the Gulf of Maine: Past, present, and future

15:15 Davis, Cabell
Multi-scale biological-physical modeling of the Gulf of Maine in support of an ecosystem approach to management

15:30 Makris, Nicholas C.
Critical population density triggers rapid formation of vast herring shoals on Georges Bank

15:45 Health Break

16:00 Stokesbury, Kevin D. E.
Absolute measures enabling ecosystem-based management for fisheries: the sea scallop example.

16:15 Fisher, Jonathan
Resource monitoring programs for marine finfish and invertebrates: challenges to informing ecosystem based management

16:30 Grant, Jon
Indices of coastal ecosystem health: a new paradigm

16:45 Shackell, Nancy
Ecosystem drivers in the Northwest Atlantic: A comparison of Canadian and US indicators from several, contiguous regional ecosystems

Theme 4 — Abstracts of oral papers

Keynote— Drivers, pressures, and ecosystem states: Toward an integrated assessment of the Northeast U.S. Continental Shelf Large Marine Ecosystem

Michael J. Fogarty

Northeast Fisheries Science Center, National Oceanic and Atmospheric Administration, Woods Hole, MA 02543

The development of strategies for marine ecosystem-based management will require the identification and sustained monitoring of key indicators of system change as a key element of the overall approach. These indicators can be classified into three major categories: (1) anthropogenic and natural *drivers* of ecosystem change, (2) the *pressures* exerted on ecosystems as a result of these forcing factors, and (3) the resultant changes in *state* of the ecosystem. The consideration of drivers of ecosystem change encompass factors exerting bottom-up and top-down forcing of the system. An example of the former would be increased temperatures related to climate change (a driver) resulting in intensification of stratification and impacts on nutrient regeneration (a pressure), potentially leading to changes in primary production (ecosystem state). Top-down factors might include drivers such as increased human population size and demand for seafood (a driver) leading to increased fishing pressure, resulting in declines in biomass of living marine resource species (ecosystem state).

The large number of potential indicators falling into these categories requires the development of strategies for identifying the most informative measures. It will also require approaches for the integration and synthesis of the array of selected indicators, tracing the connections between drivers, pressures and ecosystem states. Application of this approach to the Northeast U.S. Continental Shelf Large Marine Ecosystem (encompassing the Gulf of Maine) indicates sustained directional changes in physical and human-related drivers related to changes in pressures exerted on system dynamics and leading to strong changes in ecosystem state. These changes in state include alteration of primary production processes, changes in planktonic community composition, a switch in fish community composition including a dominance of small pelagic fish and elasmobranchs, and changes toward a warmer-water fish community. Collectively, these changes have resulted in an overall decline in landings and revenue from the traditional groundfish fishery in this region.

Keynote— Experience with making an ecosystem approach to management operational

Stratis Gavaris

Fisheries and Oceans Canada, Biological Station, 531 Brandy Cove Road, St. Andrews, NB, E5B 2L9 Canada

An ecosystem approach to management requires consideration of all impacting marine activities on valued ecosystem components while recognizing the effects of environmental forces. The ecosystem approach should be incorporated throughout the entire management planning process. Fisheries and Oceans Canada is responsible for regulating fisheries but also has the mandate to oversee management planning of other marine activities in addition to fisheries. Management planning translates objectives to operational strategies. A strategy specifies what will be done about a human pressure. A reference, established from consideration of the responses by valued attributes, signals when the pressure is unacceptable. Management planning also specifies tactics, management measures used to implement strategies. Management decisions are either strategic, decisions that establish a suitable reference for the pressure, or tactical, decisions that identify levels of a management measure that keep the pressure acceptable relative to the reference. The extension of traditional management to an ecosystem approach implies consideration of additional pressures and attributes. This will require increased monitoring of a broader range of fishery and ecosystem characteristics. Also, some sort of triage will need to be employed to identify priorities for first attention. An initial list of strategies to meet the conservation objectives at both the population and ecosystem levels was developed and formed the basis of a framework for making an ecosystem approach operational. The framework identified actions that need to be taken to make progress. Experience applying this framework in pilot studies provides insight on how the process may be improved.

The Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS)

J. Ru Morrison*[1] and others

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NERACOOS is one of eleven regional associations in the United States charged with developing the coastal component of the Integrated Ocean Observing System (IOOS). NERACOOS seeks 1) to lead the development, implementation, operation, and evaluation of a sustained, regional coastal ocean observing system for the northeast United States and Canadian Maritime provinces, as part of the United States Integrated Ocean Observing System (IOOS), 2) to promote the development, assessment, and dissemination of data and data products that meet the needs of end users, and 3) to advocate through education and outreach for the regional, national, and global ocean observing system and the application of scientific assessments using environmental data to meet societal needs. Current priority areas identified in recent strategic planning efforts include Coastal and Ocean Ecosystem Health with one aim being the support of ecosystem based management. Here we will describe our current observational capacity and future plans.

Regime shift in the Gulf of Maine

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Conventional wisdom, based on observations spanning roughly two-and-a-half decades is that inflow to the Gulf of Maine occurs primarily in two locations: inshore on the Scotian Shelf off Cape Sable, NS, and on the eastern side of the Northeast Channel (NEC). In particular, the monthly mean currents in the NEC show persistent inflow at all depths and in all seasons, except for the occasional reversals near the bottom. Conversely, the flow on the western side of the NEC is normally directed out of the Gulf in the surface layers, consistent with the clockwise gyre over Georges Bank, but those currents do show relatively frequent reversals to inflow in the deeper layers, in sympathy with the flow on the eastern side.

At some point between the year 2000, when the last BIO/GLOBEC mooring was removed from the eastern NEC, and 2004, when a new mooring was placed there as part of the US ocean observing array, a transformation of this picture occurred. The recent data, collected with a profiling current meter from a location in the eastern NEC that lies clearly among the sites of the historical moorings, show a strongly seasonal current signal, marked by persistent periods of outflow in the deep layers (>100m), particularly in winter. Moreover, the outflow currents occasionally extend to the surface layers as well, most notably in the winter of 2004-'05.

This new mode of behaviour in the NEC currents could have important consequences for the Gulf's ecosystem. The deep inflow through the NEC is thought to be the primary source of nutrients to the deep waters of the Gulf, which in turn, are thought to "fertilize" the surface layers through intense vertical mixing processes. However, analyses of nutrient data over recent years (the 2000s) exhibit a change in the deep-layer nutrient concentrations that are consistent with a reduced inflow of rich slope waters between 2003 and 2005. Moreover, historical nutrient data from the intermediate layers (60-100m) of the nearby Scotian Shelf indicate a gradual, but significant, depletion of nutrients (e.g. nitrate), suggesting that these effects may be more pervasive.

In this talk, the evidence for, and possible causes of, this "regime shift" in the NEC circulation and eastern Gulf deep water nutrient fields will be explored, and implications for the Gulf ecosystem discussed. The observations will also be compared to recent results of an operational model which has been run since late 2005.

Plankton monitoring in the Gulf of Maine: Past, present, and future

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Plankton perform a critical role as primary and secondary producers in marine ecosystems, including the Gulf of Maine (GOM). They are vulnerable to climate-induced changes to the marine environment, such as changes in temperature, stratification, or circulation, but changes to their populations and communities are difficult to discern without sustained ocean monitoring. The physical, chemical, and biological environment of the GOM is strongly influenced by upstream inflow from the Scotian Shelf and through the Northeast Channel, and thus consideration of processes both in the GOM and in upstream regions is necessary to understand plankton variability and change in the GOM. Large-scale, short-term plankton sampling efforts have been performed in the GOM since Bigelow's cruises at the beginning of the twentieth century. More recent, on-going plankton monitoring efforts include Continuous Plankton Recorder (CPR) sampling in the GOM and on the Scotian Shelf, National Marine Fisheries Service's MARMAP (Marine Resources Monitoring, Assessment, and Prediction) and EcoMon programs, and Fisheries and Oceans Canada's Atlantic Zone Monitoring Program (AZMP) on the Scotian Shelf and in the GOM. This talk will discuss similarities and differences among on-going plankton monitoring programs in the US and Canada and present examples of inter-regional comparisons of plankton variability in the GOM/Scotian Shelf region. Broad-scale synthesis of ocean monitoring data is necessary to generate knowledge and tools for marine management. The continuity of marine ecosystems across international borders highlights the need for more coordination of ocean observing activities between countries at the federal level.

Multi-scale biological-physical modeling of the Gulf of Maine in support of an ecosystem approach to management

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Over the past decade, the US Global Ocean Ecosystem Dynamics (GLOBEC) NW Atlantic program has been studying the underlying physical-biological mechanisms controlling plankton and fish populations in the Gulf of Maine-Georges Bank region to better understand the combined effects of local- and climate-scale forcing. Field studies and retrospective analyses revealed changes in the ecosystem that coincide with changes in Scotian Shelf surface salinity and intrusions of Labrador Slope Water. We have developed a 3-D biological-physical model of this region to examine the underlying mechanisms impacting plankton dynamics and recruitment. This modeling approach is a useful diagnostic tool for exploring potential links between climate and plankton populations. The model also is being used to help assess ocean observing strategies and for forecasting ocean conditions over a range of scales. This approach is broadly applicable to a variety of scientific and management problems, and the potential for development of a modeling-observing system in support of ecosystem based management will be discussed.

Critical population density triggers rapid formation of vast herring shoals on Georges Bank

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General predictions about animal group behavior believed to apply in nature irrespective of animal species were confirmed by monitoring the Georges Bank marine ecosystem in the Fall of 2006 with Ocean Acoustic Waveguide Remote Sensing (OAWRS) and simultaneous conventional fish finding sonar and trawl sampling, in conjunction with the US National Marine Fisheries Services (NMFS) Annual Herring Survey of the Gulf of Maine. By quantifying the formation process of vast oceanic herring shoals during spawning, it was shown that (i) a rapid transition from disordered to highly synchronized behavior occurs as fish population density reaches a critical value; (ii) organized group migration occurs after this transition; and (iii) small sets of leaders significantly influence

the actions of much larger groups. The spawning process was found to follow a regular diurnal pattern in space and time which proved to be difficult to detect without the continuous wide-area sensing abilities of OAWRS, which instantaneously imaged areas spanning 100 km in diameter every 75 s and so enabled continuous time-space monitoring of shoaling behavior over an ecosystem scale. First, pre-existing populations of diffusely scattered herring reached a critical density at one or more discrete locations near the northern flank of Georges Bank just before sunset, apparently in response to diminishing light level. The emergence of leading clusters then triggered shoal forming convergence waves that propagated tens of kilometers in tens of minutes, speeds an order of magnitude greater than herring typically swim. Subsequent migrations were observed towards southern spawning grounds on Georges Bank, immediately after shoals formed. The evidence suggests the primary biological function of the shoals is a prelude to synchronized spawning and the shoals form in deeper water with migrations under cover of darkness to avoid predators.

Absolute measures enabling ecosystem-based management for fisheries: the sea scallop example.

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Ecosystem-based management for fisheries requires that the relationship between species and the environment are quantitatively determinable. This can only be accomplished if the numbers per unit area of each species are measurable. We developed a cooperative video survey protocol designed to estimate the absolute number of scallops in closed and open areas on Georges Bank and in the Mid-Atlantic Bight. Sea scallops, *Placopecten magellanicus*, support one of the most valuable fishing industries in the United States. Large fluctuations in landings during the 1980s and a steady decline in harvest during the early 1990s had severe effects on the fishing industry. Despite restrictions in fishing effort in the mid-1990s the sea scallop stock remained in an overfished condition. In 1994 three large areas of Georges Bank were closed to protect groundfish stocks, thereby excluding scallopers from historically important fishing grounds. At the time of closure, scallop densities in these areas were low. However, after four years of closure, scallop biomasses were believed to be high within these areas, but the quantities were unknown. Using the video survey we estimated the number of scallops and harvestable biomass in the closed areas, and found record high densities. Since our initial survey in 1999, the sea scallop resource has made a spectacular recovery attaining record landings. In 2003, the survey was expanded to the entire commercial sea scallop resource in US waters and has been conducted annually since then. In 2007, it was estimated there were 300 million lbs (130,000 mt) of harvestable scallops on the sea floor worth approximately $2 billion USD. Further because the video survey captures an image of the sea floor we have been able to expand our observations to include 50 different taxa and 15 different substrate categories, allowing a mosaic approach to habitat mapping. By creating a time series of

direct observations we are able to track changes in population abundance and habitat structure. Incorporating these observations into oceanographic models allows us to begin to approach an understanding of the ecosystem.

Resource monitoring programs for marine finfish and invertebrates: challenges to informing ecosystem based management

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Many federal, state and provincial management agencies including the Department of Fisheries and Oceans, NOAA Fisheries Service, Maine Department of Marine Resources, New Hampshire Fish and Game, the Massachusetts Division of Marine Fisheries and the Atlantic States Marine Fisheries Commission conduct resource surveys to monitor marine finfish and invertebrate populations in the Gulf of Maine. Most agencies conduct annual or biennial bottom trawl surveys to monitor marine fish and invertebrate populations and several conduct specialized bottom trawl and dredge surveys for commercially important marine invertebrates (northern shrimp, Atlantic sea scallop, ocean quahog). These surveys provide data to examine trends in resource abundance and distribution as well as key information on trophic dynamics. Furthermore, resource surveys provide important inputs to ecosystem-based assessment and management by revealing baseline states, guiding potential management targets, and by quantifying management success. Given the extraordinary data-richness in the Gulf of Maine, one focus for ecosystem based assessments has been the search for reduced dimensional indicators of change. Assessments that focus on functionally important traits of species and assemblages at the ecosystem level (e.g., body sizes, geographic distributions, trophic structure) provide model inputs and targets for management that may be more tractable and responsive than alternative metrics of biological diversity. Past trophic and size structures have been established and distribution, movement and migration patterns have been investigated for several species (e.g., Atlantic salmon, Atlantic cod, yellowtail flounder, spiny dogfish) through conventional tagging programs, archival tags and acoustic tracking programs. While surveys for demersal species are relatively well developed, sampling of pelagic resources has been more limited. Acoustic sampling programs have been conducted by both U.S. and Canadian resource agencies, but their focus has been limited in terms of both target organisms (primarily Atlantic herring) and spatial coverage. Future resource surveys and investigations will need to be synoptic in terms of integrating data collection across trophic levels, habitats, spatial/temporal scales and may involve adaptive monitoring approaches. The introduction of advanced sampling platforms including the FSV Henry B. Bigelow provide new opportunities to refine resource monitoring programs to better inform ecosystem approaches to management.

Indices of coastal ecosystem health: a new paradigm

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Interest in measures of ecosystem health has been stimulated by continued emphases on ecosystem-based management. For coastal environments, various indices most often involve benthic biodiversity, and the creation of metrics based on indicator species and/or multivariate statistics. It can be argued that these metrics are not indicators of ecosystem health, but instead direct measures of health; in essence the groundtruth data are being used as the indicator. Quantification of benthic biodiversity is cost- and time-intensive, requiring taxonomic specialists. In Canada, regulation of coastal impacts has in many cases taken a geochemical approach, e.g. using sulfides as an indicator of hypoxic conditions from organic loading. This has been applied widely in the regulation of aquaculture impacts. We extend this approach by maintaining that process-oriented variables such as tidal exchange, sedimentation rate and nutrient upwelling can be combined to provide indices of ecosystem health with (a) a priori predictive capability, (b) inclusion of model data layers (bottom stress) , (c) spatial resolution within estuaries and bays, and (d) low data requirements. For example, comparison between input terms (point source pollution), benthic respiration, and residence times provides information about accumulation and assimilative capacity. Creation of indices has in the past been largely casual, without consideration of weighting schemes or error in the index components. We employ statistical modelling to create objective and mathematically robust indices using static and flux-based variables. Although we advocate application of average conditions, it is acknowledged that there are strong gradients in the coastal zone. We therefore we have derived novel ways to spatialize the physics of our indices. Examples of these indices applied to several study sites in eastern Canada are provided, including their relationship to benthic biodiversity.

Ecosystem drivers in the Northwest Atlantic: A comparison of Canadian and US indicators from several, contiguous regional ecosystems

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There are numerous calls to take a more systemic view of how marine ecosystems function, particularly in the context of living marine resource management. To that end, here we present some indicators developed from several other projects (Indiseas, CANUSE, ERI, ESR, etc.) that indicate the status of regional marine ecosystems in the Northwest Atlantic. These ecosystems encompass the Gulf of Maine proper, the Scotian Shelf, and contiguous ecosystems. The indicators chosen describe a range of processes that influence the dynamics of these ecosystems. Indicators include the typical metrics on size, landings, biomass, trophodynamics, oceanography and diversity, but are also "packaged" in novel ways (e.g., in aggregate, for specific groups, canonical axes, etc.) to reflect a systemic perspective. Using several multivariate and time series statistics on these indicators, we explore (simultaneously) what the main drivers of ecosystem change have been across the Gulf of Maine regional ecosystems.

Theme 4 –- Poster Abstracts

An overview of biological ocean observing systems in and around the Gulf of Maine

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The Ocean Tracking Network (OTN) now being developed at Dalhousie University in Halifax Canada, in addition to simply tracking tagged marine organisms and providing a biological basis for ocean observing systems also provides government and academic researchers with innovative policies and practices with which to manage and share metadata and data. Furthermore, as OTN is a pilot project of the Global Ocean Observing System, it follows that its activities in the NW Atlantic are also a vital part of the Northeast Regional Association of Coastal and Ocean Observing Systems (NERACOOS). In this presentation we will describe OTN data policy and practice and from that give a dynamic and altogether unprecedented overview of biologically based ocean observing activity as it emerges in and around the Gulf of Maine.

The data speed bump: Finding data for use with indicators

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The Gulf of Maine Council on the Marine Environment (GOMC) is a U.S.-Canadian partnership of government and non-government organizations focused on the health, environmental quality and productivity of the Gulf of Maine. In 2006, the GOMC identified indicators to monitor ecosystem health as a priority in the Gulf of Maine, including the Bay of Fundy. The Ecosystem Indicator Partnership (ESIP) led activities in six indicator theme areas (coastal development, climate change, contaminants, eutrophication, aquatic habitats, and fisheries and aquaculture). Subcommittees were established for each theme area, and currently more than 100 volunteers from local, state and federal governments, along with academics and partners from non-government organizations participate in one or more of these subcommittees. Relying on a consensus-based process, the subcommittees selected priority indicators for each of the theme areas.

Following the thorough process of selecting priority indicators in the theme areas, intense work began on locating appropriate data for use with the indicators. This effort has become increasingly complex as ESIP tries to determine appropriate methods, time scales, geographic scales, and data quality for comparison across the Gulf of Maine. Numerous datasets have been identified for use with selected indicators. However, ESIP has encountered data gaps throughout each of the theme areas. Although this could be considered a road block to further work, ESIP has decided to reach out to other practitioners in the area for assistance locating and obtaining the required data.

Scales of change in species composition: combining data from multiple sampling methods

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Describing the variability in species' distribution and abundance across broad scales of space and time is important as we move toward ecosystem approaches to management, since it increases our understanding of ecosystem structure and dynamics. A broad spatial method is required as marine communities are often highly connected. The incorporation of temporal information is useful as marine habitats are continually disturbed by, and respond to, anthropogenic and climactic influences. In describing this variability, often the only data available with adequate coverage comes from demersal trawl surveys, which are selective for certain size classes and species. Augmenting the trawl data with food habits data, which in essence treats the fish stomachs as indirect sampling units of species and size groups not available to the trawl survey, has been effective elsewhere in providing information not otherwise available. In the current study we describe the variability in species distribution from the combined RV Survey trawl data and stomach contents data from two distinct time periods, pre-1970 (1961-1968) and post-1999 (1999-2008) across the Scotian Shelf. Further we generate species-habitat associations using the available temperature, depth and salinity data. These associations will be compared across time periods to determine what change has occurred, how it varies spatially and what the implications are for ecosystem approached to management.

Loss of North America's largest Arctic Tern colony— top-down, bottom-up, or sideswipe?

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Fifteen years of monitoring diet and demographics of seabirds on Machias Seal Island, on the border between the Gulf of Maine and the Bay of Fundy (and Canada and the U.S.), has revealed dramatic changes in the birds' diet that suggest a food-web shift of wider

ecological significance beyond this one seabird colony. Proximate factors – ecological, environmental, and economic – that led to the loss of the continent's largest colony of Arctic Terns *Sterna paradisaea*, are explored through detailed data on diet and demographics (breeding success, survival, inter-colony movement) of four species of seabird. A combination of bottom-up effects on the plankton community, mediated apparently through oceanographic changes, top-down effects of predation by gulls, and unintended "sideswiping" by unrelated policy changes, is presented to explain this unprecedented biological event.

A comparison of regional marine biodiversity studies and their application to ecosystem approaches to management

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Every study of an ecosystem is a compromise based on resources, time, urgency, interests of investigators and funding agencies, and the social, legal and economic drivers behind the study. Each study therefore has unique approaches, opportunities, findings, and interpretations, and each yields different types of useful information and recommendations. We compare the motivations, objectives, approaches, achievements and general "lessons learned" of four ecosystem-level studies of marine biodiversity: the Gulf of Maine Area Census of Marine Life, Baltic History of Marine Animal Populations, Great Barrier Reef Seabed Biodiversity Project, and Gulf of Mexico Biodiversity Project. The purpose of this comparison is to identify how information and results from biodiversity studies can be used to improve decision-making on marine and coastal issues.

Coherence in population trends of major fish species in the Gulf of Maine ecosystem: a comparison of fisheries independent survey data

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For many reasons, we delineate fish into distinct population or stock units that often reflect human institutional borders more so than ecological factors. Recent work on metapopulation dynamics and ecosystem approaches to fisheries management highlight the importance of understanding trends and coherencies at larger spatial scales. In the Northwest Atlantic, common species occur in the broader Gulf of Maine Area (GOMA), yet the area is surveyed and managed for the most part in the south by the US and in the north by Canada. We compared biomass time series of nineteen representative fish species and of total biomass from seven different surveys conducted by the US and Canada in GOMA. In over half of the species one common trend could accurately describe the population trends across all regions in the GOMA. For instance, Canadian and US populations of Atlantic cod, Atlantic herring, haddock, thorny skate and goosefish have very coherent trends within species. Conversely, some species show differing survey time series trends and asynchronous event timing like longhorn sculpin and spiny dogfish, suggesting population dynamics differ spatially in these species. Collectively our results demonstrate the value of comparing survey time-series for common species from contiguous ecosystems, with the potential to elucidate the relative importance of major factors affecting population dynamics in each species.

Bay of Fundy near-shore biodiversity: an integral component of a global biodiversity initiative

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Natural Geography In Shore Areas (NaGISA) is a world-wide collaborative effort (http://www.coml.org/projects/natural-geography-shore-areas-nagisa) aimed at inventorying and monitoring coastal biodiversity. Started in 2002, there are now regional centers in Japan, USA, Italy, Venezuela, Kenya, and since 2007 at the Huntsman Marine Science Centre (HMSC) in St. Andrews, NB (http://www.nagisa.coml.org/region/ao/atlantic).

As one of the first Census of Marine Life (CoML) field projects, NaGISA has an ambassadorial role linking CoML goals and local interests, encouraging international

cooperation and capacity building in coastal monitoring and research. Large-scale inventorying and monitoring of biodiversity are crucial tasks for identifying and clarifying activities that impact ecosystems. NaGISA provides baseline data for long-term monitoring, and information needed to answer fundamental questions concerning changes in biodiversity with latitude and longitude. Implementation is through a simple, cost efficient, low-tech sampling protocol adopted by many research groups and countries, with the intent of promoting local community involvement. Based on a series of 30m transects from the high inter-tidal zone to a depth of 10m, the target habitats are rocky shore and soft bottom sea-grass communities, chosen for their global distribution, community complexity and poor state of current knowledge. Data are being incorporated in the Census` Ocean Biogeography Information System (OBIS), an online global atlas for accessing, modeling and mapping marine biological data.

Local NaGISA activities include three partnership sites within the Bay of Fundy, with sites on both sides of the US/Canada border and data from two successive years submitted for global analyses for presentation in October 2010 as part of the CoML "Decade of Discovery" public release. A comparative and temporal analysis contrasting community structure with that of NaGISA sites on the Atlantic coast of Nova Scotia is also being undertaken.

Monitoring microbial patterns in plankton during a multiyear study in Boothbay Harbour, Maine

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The ability to identify environmental or climatic changes requires monitoring programs that measure well defined and easily obtained variables for sustained periods of time. In order to understand differences on annual to decadal scales a large number of observations are needed for statistical significance. Over the past 9 years (2001 to 2009), weekly observations at high tide of phytoplankton, bacterioplankton and eukaryotic heterotrophs were made using flow cytometry at a single location in Boothbay Harbor, Maine. Temperature, salinity and chlorophyll *a* were also determined. Flow cytometric ataxonomic groups were defined and enumerated (*Synechococcus*, cryptophytes, total phytoplankton, small eukaryotic phytoplankton (< 2µm), & large eukaryotic phytoplankton (2-20µm)). Bacterioplankton were detected and enumerated using the DNA stain PicoGreen (Invitrogen). Heterotrophic eukaryotes (microflagellates and small ciliates) were detected using the food vacuole stain Lysotracker Green (Invitrogen). The imaging-in-flow system, FlowCAM, was used to count, image and size the larger microphytoplankton (15 –300µm).

The site experiences a strong seasonal cycle in temperature, ranging from about 1 to 20°C. Distinct annual and seasonal patterns emerge in both the flow cytometric data and chlorophyll *a* that correlate with changes in temperature and the onset of both the spring

and fall phytoplankton blooms. Cryptophytes and *Synechococcus* bloom on an annual basis within a very defined period of time, usually July and September, respectively. Bacterioplankton initially increase following the spring bloom and increase again as temperature increases and remain high until the temperature and concentration of phototrophs begins to decrease. The larger microphytoplankton are imaged by the FlowCAM capturing the onset of the spring and fall blooms, the size distribution of these phytoplankton (size spectra) and taxonomic composition (often to the Genus level). The spring bloom is dominated by diatoms, typically *Thallassiosira, Chaetoceros,* and *Skeletonema*, and the fall bloom is a mix of diatoms and dinoflagellates, usually *Prorocentrum*.

The overall changes and observations in plankton here in Boothbay Harbor are the beginnings of a potentially larger data set in future years. In order to begin to address societal concerns regarding climate change, pollution impacts, and biodiversity, long-term monitoring sites are required to interpret change. Since plankton have relatively short life-spans (days to weeks) they can adapt to changes in the environment. These observations of plankton here in Boothbay Harbor will be compared to other regional and global patterns that would ultimately identify changes in the environment.

Monitoring Phytoplankton Biomass in the Damariscotta River Estuary, Maine, USA

Thompson, B.P., E. Kallin, and M.J. Perry

A sampling program was established in 2002 to monitor daily changes in phytoplankton biomass in the Damariscotta River Estuary, Maine, USA. Measurements of chlorophyll *a*, pheopigments, and temperature were made for surface water collected approximately 2-3 times per week, typically in the morning, from a dock located halfway up the estuary at The University of Maine Ira C. Darling Marine Center (DMC). To better understand environmental factors responsible for the temporal and spatial characteristics of phytoplankton abundance and production, the program was expanded in 2005. Between February and December 2005 surface water samples were collected 2-5 times per week from docks at the estuary head and mouth, in addition to the DMC dock (middle). Analysis included size-fractionated chlorophyll *a*, pheopigments, temperature, salinity, dissolved inorganic nutrients, and identification of major phytoplankton taxonomic groups. During summer, *in situ* measurements of chlorophyll *a* fluorescence, temperature, and salinity were collected with towed, profiled, and moored instruments. Photosynthetically available radiation recorded at the DMC and additional data sets were used to assess the influence of external forcing. Chlorophyll analysis of water samples, collected at the DMC dock, indicate that at least a twenty-fold variability in phytoplankton biomass can occur. An initial late winter/early spring phytoplankton bloom was observed each year, with fall blooms occurring less frequently. Throughout most of the spring and summer of 2005, especially at the head of the estuary, cells smaller than 20 micrometers were the major component of the phytoplankton biomass, as measured by chlorophyll analysis. With one exception, weekly mean chlorophyll concentrations remained above 2 micrograms per liter at the head, middle, and mouth, from early May through late September. During this period, strong spatial gradients in

chlorophyll *a,* temperature, and salinity were observed in the estuary, with the largest phytoplankton biomass occurring in the upper section, above a major constriction. Tidal oscillations were responsible for movement of the peak phytoplankton biomass up and downstream in the upper estuary, with maximal values of chlorophyll *a* occurring in the early evening and minimal values in early morning after sunrise. A drawdown of nitrate at the DMC dock began days to weeks before the initial accumulation of biomass in 2005, 2006, and 2007. In 2005, a drawdown of silicate also preceded the initial bloom, with peak concentrations occurring during periods of intense freshwater discharge. High pheopigment concentrations in the late spring and summer may indicate high rates of grazing.

Dynamics of the Saco River plume: Preliminary observations and modeling

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The Saco River is the fourth largest river in the state of Maine. Discharge rates are highly variable but can exceed 600 m^3s^{-1} during spring run-off events. During these events, the freshwater surface plume emanating from the river may extend over 100 km^2, though the location of the plume is variable. The Saco River Coastal Observing System (SaRCOS) is a suite of instruments within the Saco River and the adjoining coastal region that was deployed in spring of 2007. Here we document the preliminary observations of the Saco River plume from SaRCOS and weekly, boat-based CTD surveys as well as output from a numerical circulation model of the region to characterize the three dimensional spatial and temporal variation of the plume from the years 2007-2009. We find that the depth and areal extent of the plume is closely linked to the forcing mechanisms of winds and river discharge.

Haddock (*Melanogrammus aeglefinus)* bycatch in the Northeast United States herring (*Clupea harengus)* fishery: Results from the 2004-2006 portside bycatch survey of the Northeast United States herring fishery

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The Maine Department of Marine Resources (DMR) first secured funding in 2004 to support a portside bycatch survey of the Atlantic herring (*Clupea harengus*) fishery. This ongoing survey focuses on quantifying bycatch from herring landings sold to processing facilities throughout the northeastern United States. The herring fishery is a high volume industry that transfers catch by pumps minimizing opportunities to remove incidental catch and bycatch at-sea. The methods of this survey provide at a minimum, data on

similar sized bycatch and non-target species. This paper presents results specific to haddock-herring interactions from 169 portside bycatch samples which were executed between January 2004 and December 2006. A total of 625 kilograms (kg) of haddock (*Melanogrammus aeglefinus*) were documented as bycatch from 5,275 metric tons (t) of herring evaluated. This ongoing portside bycatch survey offers valuable data on bycatch and incidental catch in the herring fishery and represents a novel approach for collecting bycatch data in a unique and cost effective manner.

Developing regionally specific growth models for the American lobster: revealing spatial variability and environmental forcing

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The Gulf of Maine and northwest Atlantic shelf waters are characterized by dramatic regional differences in temperature and other environmental conditions that have important consequences for fishery productivity. For long-lived marine crustaceans, like the American lobster (*Homarus americanus*), that have no morphological age markers, this adds complexity to the already difficult challenge of estimating size-at-age, which can be highly variable within the species geographic range. Current growth models fail to incorporate individual growth variability and therefore are of limited use for stock assessment models. Here we present a stepwise growth model for the American lobster that offers a new approach to age determination by integrating two growth analysis methods traditionally used independently, (1) modal analysis of size-frequency distributions of early juveniles for which we have reasonable estimates of absolute age, and (2) mark-recapture studies of older juveniles and adults giving estimates of relative age and growth. We compare growth curves developed for three oceanographically distinct regions for which these data are available: the southern New England shelf, central Gulf of Maine, and the Bay of Fundy. We further incorporate bottom temperature time series from each region as growing-degree-days (GDD) to account for regional differences in growth trajectory. By broadening the size range of lobsters contributing empirical growth data as well as incorporating key environmental factors that influence growth in this way should provide more biological realism to population dynamic models.

THEME 5: SYMPOSIUM SYNTHESIS AND WRAP-UP

Session Chair: Robert (Bob) O'Boyle (Beta Scientific Consulting Inc.)

Rapporteur: Rob Stephenson

Session Summary

In introducing the Gulf of Maine Symposium synthesis discussion, R. O'Boyle reviewed the objectives of the workshop – to review recent developments towards EBA, to evaluate how we are placed to undertake/implement EBA, and to recommend/prioritise research). He pointed out that the Symposium had heard approximately 140 presentations including a diverse set of perspectives regarding the relevance and challenges of an ecosystem approach, a set of technical workshops and four theme sessions (dealing with tools, for IM, ecosystem structure & function, anthropogenic & external influences, and monitoring & observation).

O'Boyle observed that there had been some trends. There has been impressive growth of knowledge of the Gulf of Maine ecosystem and impacts (especially with respect to biophysical modelling and climate change). There has been considerable progress on habitat mapping, and a start on ecosystem-level assessment and reporting. There is, however, a considerable distance to go on EAM decision support and implementation.

Theme session and technical session co-convenors/chairs summarised the results of their sessions with respect to the Symposium objectives:

Progress and recent developments towards EBA include:

- Increased knowledge of patterns of biodiversity in the GOM (Theme 2; Tech session on biodiversity)
- Progress on coupled biophysical models and advanced models of the physical system (e.g. FVCOM) (theme 2)
- Increased knowledge of nutrient dynamics (theme 2)
- Recognition of the importance of different spatial scales (theme 2)
- Importance of climate effects (climate change and the need for adaptation) (theme 2, theme 3, and workshop on climate change)
- Understanding and modelling of circulation (although there is evidence that flows are changing) (theme 2)
- Progress in networking related to people (theme 1) and data/informatics (including ocean data partnership, data mining, rapid assessment) (tech session on biodiversity)
- Knowledge of the life histories and biology of relevant species (although the knowledge base differs widely among species) (tech session of life histories)

- Greater appreciation of aspects related to conservation objectives such as the importance of populations subunits (ecotypes), variability of growth and productivity, species richness/biodiversity (tech session on life histories)
- Increase in observation resulting in part from new technologies but resulting in new time series that will show environmental shifts (theme 4)
- Increased high resolution seafloor mapping and development of approaches to characterize habitat in mapping (tech session on seafloor mapping)
- Recognition that EAM includes ecological and social/economic considerations (theme 3) and that it demands an interdisciplinary approach (theme 1)
- Progress on understanding of pollutants (from listing to active monitoring) (theme 3)
- Research related to novel approaches to energy generation (e.g. in-stream tidal power)
- Better understanding of the lessons of past management and long-term effects of exploitation (theme 3 and theme 1)
- Legislation (in both Canada and USA) to address more holistic approaches and multiple uses (theme 3)
- Development/evolution of tools for marine spatial planning and state of the environment reporting (theme 1)
- Evolution of concepts and framework for essential habitat and for ecosystem-based approach (theme 1)

<u>How ready are we to implement EBA?</u>

- Considerable progress has been made. We now have:
    - enhanced understanding and model development (theme 2)
    - foundation for conservation planning from CoML and other initiatives
    - awareness of multiple biophysical and socioeconomic impacts and services, of climate change, of pollutants, invasives, etc (theme 3)
    - insights from hazard and risk assessment and from management
    - learned much about resilience and adaptation from fisheries and environmental histories (theme 3)
    - improved ocean planning and evolving participatory processes (theme 3)
    - information as basis for siting of projects, resolving conflicts, 'Marine spatial planning'
    - recent improvement in appreciation of growth, population complexity (technical session on life history)

- There is a range of approaches to the ecosystem approach at present…from evolutionary to revolutionary (theme 2)
- There is a challenge in implementing the ecosystem approach in the GoM because of the complexity in jurisdiction and increasingly litigious environment (theme 1)
- There remains the problem of ecosystem complexity including 'the scope of the unknown and ubiquity of the rare' (CoML session)

- There is an issue of need for enhanced monitoring and information to support evolving management landscape
- Need for institutional (governance) to support cross disciplinary and interjurisdictional considerations
- The time for action is now (theme 2)

What are the priorities with respect to EAM for the Gulf of Maine?

The discussion of priorities fell into two categories – needs of science and needs of institutions:

- Appropriate governance structures and improved institutional capacity for implementation of an ecosystem approach, including:
    - A common vision of goals and objectives
    - interdisciplinary participation,
    - legislative basis and development of appropriate governance structures
    - consistency among jurisdictions
    - participatory structures (engagement of users)
    - more comprehensive approach to ocean use planning
    - enhanced collaboration in evaluations/assessments

- Increased basic understanding related to environmental and governance change
    - Evaluation of models of climate (is GoM warming?) and flow (are flows changing?)
    - Enhanced understanding of coastal processes and life histories in relation to environmental change
    - Knowledge of benthic, and especially microbial processes
    - Strengthened science and monitoring of aspects of relevance to EAM decisions in management
    - Strong link among those with science, management, social and legal expertise
    - Institutional 'bridges' to link information and research to management
    - Requirement for greater general ocean literacy
    - Clarification of terminology, and consistency of use
    - Enhanced understanding of cumulative impacts
    - Metrics of progress and of success (how will we know when we are there?)
    - Continued mapping for marine spatial planning

It is clear that success in implementing an ecosystem approach for the Gulf of Maine requires agreement on what the ecosystem approach really is, and the integration of currently disparate elements within a framework that links management, science and users in a more holistic approach. The need for the holistic approach was described in three summaries as follows:

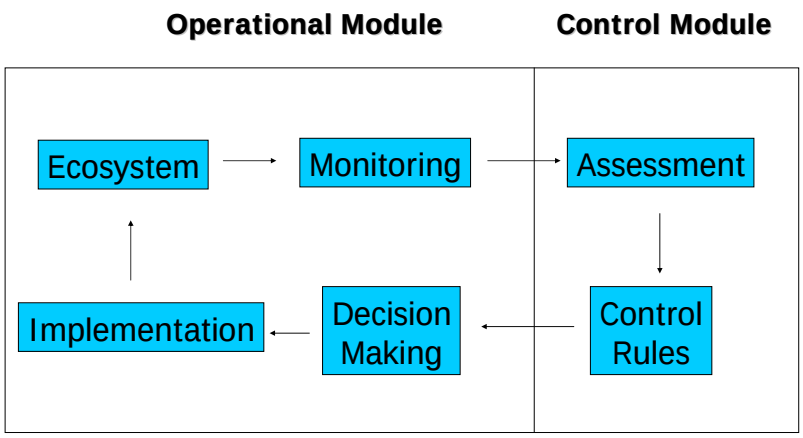
- Development of an operating framework for managing the Gulf of Maine using an ecosystem-based approach and in the face of ecosystem change

- Development of a comprehensive, interdisciplinary, approach to management and a framework for the evaluation of management (management strategy evaluation).

- Development of an organized approach to adaptation throughout the region (perhaps through GoM Council)

R. O'Boyle used the figure from McAllister (1999) to illustrate the need for a cyclical process that integrates **monitoring** in relation to the ecosystem, leading to **assessment**, development of **decision rules**, leading to **decisions,** and **implementation** with impact on the **ecosystem** (the Symposium had papers on all aspects except decision/control rules).

How Well Placed to Undertake EBM?
Elements of Management System



From McAllister et. al. 1999

He suggested that research needs fell into three groups:

- Decision Support
  - Ecosystem – level modeling that allows exploration of alternative management strategies & tradeoffs
  - Institutions of complementary US / Canada management
- Ecosystem Structure & Function
  - Productivity – habitat link
  - Biodiversity & resilience
- Assessment
  - Cumulative impacts

TECHNICAL CONCURRENT SESSIONS

A total of five technical sessions were run concurrently on Monday October 5th, 2009. The purpose of having the technical sessions was to provide a forum for scientists and managers to come together and discuss advances on specific topics of relevance to implementing EAM in the Gulf of Maine. The topics for the five technical sessions included:

- Ecosystem Services in the Gulf of Maine
- Biodiversity in the Gulf of Maine
- Seafloor Mapping for Ecosystem Management in the Gulf of Maine
- Life Histories of Gulf of Maine Fishes and Invertebrates
- Assessing Linkages between Ecosystem Health and Measures to Evaluate Change

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TECHNICAL WORKSHOP ON ECOSYSTEM SERVICES IN THE GULF OF MAINE

Session Summary

Goal: To move toward identifying, mapping, quantifying, and valuing marine ecosystem services in the Gulf of Maine.

Session organizers

Stephen Hale, Research Ecologist
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Office of Research and Development
U.S. Environmental Protection Agency
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Background

"Sustaining the long-term capacity of systems to deliver ecosystem services is the core goal of ecosystem-based management (EBM) for the oceans" (McLeod & Leslie 2009). Ecosystems and biodiversity are essential for human well-being. "Ecosystem services" are the benefits humans derive from ecosystems—the things we need and care about that we get from Nature. This approach makes the importance of a healthy environment more obvious and relevant to politicians, economists, business people, and the public. It is hoped this will motivate conservation and sustainability. Often, ecosystem services—other than goods provided that we can easily put a dollar value on—are not factored into important decisions that affect ecosystems and are not included in cost-benefit analyses.

This damages the ability of nature to provide services, making human society and the environment poorer.

The Gulf of Maine provides humans many ecosystem services. Seafood, recreation, and aesthetics are highly visible to the public but there are numerous other services that need to be recognized. The Millennium Ecosystem Assessment in 2005 identified four categories based on function: (1) Provisioning services such as food, fresh water, fuel, and timber; (2) Regulating services such as the regulation of climate, floods, disease, water and air quality; (3) Cultural services such as recreational or aesthetic enhancement; and (4) Supporting services such as upwelling, nutrient cycling, and primary production.

This workshop gathered researchers focused on evaluating ecosystem services from Canada and the United States to share methods, techniques and experiences. The workshop identified further research needed in the Gulf of Maine to transform the way we account for the type, quality, and magnitude of nature's goods and services so they can be considered in management decisions. We discussed the needs for data, methods, and models to better understand and communicate the benefits of considering ecosystem services. We gauged interest in forming a partnership to identify, map, quantify, and valuate ecosystem services in the Gulf of Maine including estuaries and coastal wetlands.

Benefits of an ecosystem services approach

1. Healthy ecosystems are the foundations of healthy economies. To develop policies and programs that ensure the viability of ecosystems while supporting sustainable development and the needs of human societies we must document the economic value of Ecosystem Goods & Services (EGS) to society.
2. Accounting for ecosystem services is essential in our pursuit of economic prosperity if we want to accumulate wealth that is sustainable.
3. Costs for replacing EGS can be unacceptably high and in some cases not possible.
4. Accounts for cross-sectoral interests and cumulative impacts of activities that affect ecosystems. Requires taking impacts into account and allows dealing with trade-offs.
5. Benefits generated for each ecosystem service give decision-makers a more complete picture of total costs and benefits so they can compare policy options.
6. Laws of our lands still do not reflect all people want such as access, beaches, etc. Ecosystem services approach will expand the variety of things we value and put all these on the playing field.
7. Gives certainty to industry by being explicit about what people value and why. Implementation requires clarification of our interests and goals.
8. Provides another tool for management decisions.
9. Provides a framework for assessing and resolving tradeoffs.

Presently

1. We have many of the scientific and technical elements to move forward with ecosystem-service approaches and ecosystem-based management now.
2. Management for multiple services is underway at a range of scales globally.
3. Models and other tools can facilitate exploration of how ecosystem services are linked, tradeoffs among them, and effective management strategies.

4. Natural and social scientists can play vital roles in research, synthesis, and translation of knowledge to advance these efforts.
5. Recognition/awareness/communication of the concept of ecosystem services.
6. Early valuation of ecosystem services and benefits.
7. Any good or service will hold a variety of values for society. Valuation helps frame trade-offs in monetary terms so they can be compared using the same unit of measurement. Some values show up as market values, and some not.
8. Environmental Valuation Reference Inventory (www.evri.org) is a valuation database that includes over 2200 studies.

Examples

1. Exploring responses of coupled social-ecological systems (artisanal fishery and sport fishery tourism) to perturbations in Baja California.
2. Management for multiple services already happening in California, Wadden Sea, Gulf of Maine, Massachusetts Ocean Plan, Taunton Bay, etc.
3. Use on non-market solutions in designation of marine protected areas in Saint Lawrence Estuary and the listing/recovery of marine mammal species at risk (harbour seal, beluga whale, blue whale).
4. Use of InVEST tool for watershed land use planning in Hawaii; upcoming application of Marine InVEST tool to west coast of Vancouver Island.
5. Applying nutrients credits to Integrated Multi-Trophic Aquaculture (IMTA) in the Bay of Fundy. Social scientists on team that look at attitudes and consumer opinion.
6. Calculating monetary value from oyster reef restoration in Chesapeake Bay and North Carolina to recover ecosystem services. Tool to help with management decisions and restoration success measurements.
7. Applying EGS framework to Canada's Northwest Territories protected areas.
8. Confronting tradeoffs between groundfish, pelagic fish, and Right whales in the Gulf of Maine.

Lessons learned

1. Important to include ecosystem services in regulatory and management framework; important to get into policy.
2. Some situations may not require hard numbers and a more theoretical/qualitative approach may be enough.
3. The value of oyster reef services provided by reef sanctuaries that persist for decades likely far surpasses the value that could be derived from destructively harvesting reefs for oysters.
4. The Total Economic Value analytical framework provides the values for a direct comparison between the present state and the impact of policy decisions on EGS.
5. The Marine InVEST tool could inform integrated management by doing ecosystem services scenario assessment that allowed different options to be weighted.
6. Big challenge is disconnect between the disciplines.
7. Easy to get mired in detail. Need to keep it simple; however, need to be specific in defining the exact ecosystem service.

8. Comes down to tradeoffs and good planning. We should be strategic and purposeful about our tradeoffs.
9. Interdisciplinary work required between science and economics, data and knowledge requirements are large, need to remain policy relevant, some methods remain unfamiliar or even controversial.
10. Markets could be used to reward sustainable behaviour and good stewardship (pay more for eco-labelled seafood).
11. Need solid framework, methods for benefits valuation, data (social, economic value, biophysical), capacity to quantify impacts of ecosystem services.
12. Recommend an adaptive management approach.
13. Regulatory and policy decisions can have massive implications for ecology and the economy – need to be made in a more rigorous manner.
14. Benefits of ecosystem goods and services need to be given full weight to balance economic considerations.
15. Need to include social scientists along with ecologists and economists.
16. How far you go into the future depends on your data and how you can realistically track things. Protection means up front costs with benefits over the long-term.

What next?

1. There are many gaps in identifying, quantifying, and valuing ecosystem services that would benefit from more research and more policy/governance work.
2. Risk and threats are the only thing considered to list an endangered species right now. Not enough – should include economic value of listing species and need population trajectory scenarios to use.
3. Specify manageable number of indicators that could fit into a Driver-Pressure-State-Impact-Response (DSPIR) model. Could quantify what the scenario outcomes would be, then work together to develop the metrics that would inform decisions.
4. Give economists physical measurements of the goods and services being provided by ecosystem functions.
5. Dollar value important but there are other ways to get points across and we can get creative. Important to understand training and perspectives between economists.
6. Should student ecologists and economists take more courses from each other's fields?
7. Strengthening analytical/data capacity**:** examine gathering of environmental statistics under EGS framework; estimation techniques; expand benefits transfer capacity; interdepartmental cooperation; learn from international milieu.
8. Could aquacultured seaweeds and invertebrates be traded for nutrient/carbon credits and coastal eutrophication reduction? What agency would fund? Should it be a regional, national, or international agencies?
9. Confront tradeoffs by specifying policy alternatives for a carefully bounded problem, defining ecosystem services against which management actions will be evaluated, and assigning scores for each policy alternative against each attribute.
10. Need decision support tools and refined metrics for trade off analysis, economic valuation, market development, monitoring, and evaluation.
11. Need governance piece to look at translation into management.

Some outstanding research questions

1. More complete understanding of *all* ecosystem services and how they can be valued.
2. How do the links within and among social-ecological systems influence the delivery of marine ecosystem services?
3. How can emerging science be more effectively connected with management and policy processes, particularly in terms of trade off analyses?
4. How do we measure success of this new approach?

To ensure success

1. Need clear vision, enabling institutions with clear mandate, EBM science infrastructure, integrative and interdisciplinary partnerships
2. Discrete project with clear goals, vision, and decision.
3. Start local/regional with multi-disciplinary partnerships.
4. Start with high-level, not a quagmire of detail. Scaled down (realistic) expectations. Would be a trap to get too far down into the weeds because systems are complex.
5. Need governance and/or structures and legislative basis for decisions.
6. Time may be right for senior support (new National Oceanic and Atmospheric Administration leadership, senior Environment Canada support) - this will be a high priority issue and new leadership could make the difference.
7. Pick a project for a pilot where a decision is needed.
8. Need to implement as soon as possible taxes/credits and governance.
9. Must have governance structures right. In US, need new structures for governance committees that can look at cross-sectoral issues (such as Canada's *Oceans Act*).

Agenda and Oral Abstracts

9:00-9:15 Stephen Hale, Research Ecologist, Atlantic Ecology Division, U.S. Environmental Protection Agency, and Maxine Westhead, Section Head, Protected Areas & Conservation Planning, Fisheries and Oceans Canada
Introduction to workshop

9:15-9:45 Heather Leslie, Assistant Professor of Environmental Studies and Biology, Center for Environmental Studies, Brown University
Managing for resilience in the Gulf of Maine: the need for an ecosystem services approach

9:45-10:15 Alejandro DeMaio-Sukic, Senior Economist, Fisheries and Oceans Canada
Thoughts on the dynamics between ecosystems and economies, and on the role of government as a steward of our society's endowment of ecosystem goods and services

10:15-10:30 Break

10:30-11:00 Katie Arkema et al., Ecologist, Natural Capital Project, Stanford University
Marine InVEST: a tool for mapping and valuing services provided by coasts and oceans

11:00-11:30 Thierry Chopin et al., Professor of Marine Biology, Centre for Coastal Studies & Aquaculture, University of New Brunswick
From Integrated Multi-Trophic Aquaculture (IMTA) to nutrient trading credits: recognizing and valuating the environmental/economic/societal services and benefits of the inorganic extractive component of IMTA

11:30-12:00 Jonathan Grabowski et al., Research Scientist, Gulf of Maine Research Institute
Restoring oyster reefs to recover ecosystem services

12:00-1:30 Lunch

1:30-2:00 Luis Leigh, Director, Environmental Policy Analysis and Valuation Division, Environment Canada
A proposed analytical framework for integrating environmental goods and services in policy decisions

2:00-2:30 Michael Fogarty, Research Fish Biologist, Northeast Fisheries Center, National Marine Fisheries Service
Confronting tradeoffs in marine ecosystem-based management

2:30-2:45 Break

2:45-3:45 Panel Discussion:

Alejandro DeMaio-Sukic, Senior Economist, Fisheries and Oceans Canada

Thierry Chopin, Professor of Marine Biology, Centre for Coastal Studies & Aquaculture, University of New Brunswick

Heather Leslie, Assistant Professor of Environmental Studies and Biology, Center for Environmental Studies, Brown University

Michael Fogarty, Research Fish Biologist, Northeast Fisheries Science Center, U.S. National Marine Fisheries Service

3:45-4:00 Westhead/Hale
Closing remarks and next steps

Managing for resilience in the Gulf of Maine: the need for an ecosystem services approach

Heather M. Leslie[1]

[1]Brown University, Center for Environmental Studies & Dept. of Ecology and Evolutionary Biology, Box 1943, Providence, RI 02912 USA

As overfishing, climate change, and other stressors continue to impact ocean ecosystems, national and international bodies have called for a shift toward more comprehensive and integrated management that recognizes the full array of benefits provided by coastal and marine ecosystems. This innovative approach is referred to as *ecosystem-based management*. Key elements of ecosystem-based management include: 1) A place-based approach that considers the entire ecosystem, including people; 2) recognition of the interactive and cumulative effects of human activities; and 3) explicit analysis of tradeoffs among different benefits – also known as ecosystem services – and human activities. Drawing on research from throughout North America, Dr. Leslie will discuss how ecosystem services can provide a framework for assessing and resolving tradeoffs among different human activities in coastal and marine areas, so as to maintain or restore healthy, resilient, and productive marine ecosystems. She will conclude with a discussion of outstanding research needs related to ecosystem services that would further implementation of ecosystem-based approaches in the Gulf of Maine.

Thoughts on the dynamics between ecosystems and economies, and on the role of government as a steward of our society's endowment of ecosystem goods and services

Alejandro DeMaio Sukic*[1] and Thida Souksanh[1]

[1]Fisheries and Oceans Canada Fisheries, Economic Analysis, 200 Kent Street, Ottawa, Ontario K1A 0E6 Canada

Accounting for ecosystem goods and services is essential in our pursuit of economic prosperity, if we want to accumulate wealth that is sustainable. Governments can play an important role in generating and disseminating knowledge that inform consumers' sustainable choices, and in setting up policies that minimize the ecological footprint of economic activities and products. Fisheries and Oceans Canada undertakes a significant amount of economic analysis and research with the goal of integrating ecosystem goods and services considerations into policy decision making. Examples include cost-benefit analysis and non-market valuation work for species at risk initiatives, and pathways of effect models. Nevertheless, the department is lacking a conceptual framework for systematically doing this. This presentation enumerates some of the lessons learned thus far from socio-economic analysis in this area, as well as explores some of the commonly used concepts in economics with relevance in the context of ecosystem goods and services. In particular, some of the limitations associated with prices and transaction costs are discussed.

Marine InVEST: a tool for mapping and valuing services provided by coasts and oceans

Arkema, K.*[1], A. Guerry[1], M. Ruckelshaus[2], J. Toft[1], C. Kim[1], M. Papenfus[1], Y. Qi[1], H. Tallis[1]

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Many important ecosystem services are provided by coastal and ocean environments. However, a growing variety and intensity of human activities, coupled with impacts of climate change, threaten the sustained delivery of these services. Moreover, the processes and ecosystems that humans rely on for food, recreation, coastal protection, and other services, are poorly understood, scarcely monitored, and often only appreciated after they are lost. The ultimate aim of marine ecosystem-based management is to sustain the full suite of services, but such a holistic approach requires knowledge about the true costs and benefits of policy decisions for humans and ecosystems. The Natural Capital Project, an innovative partnership among Stanford University, The Nature Conservancy and World Wildlife Fund, has embarked on a 2-year program to develop a suite of spatially-explicit ecosystem service models called Marine InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) and to apply them in a temperate ecosystem. Marine InVEST 1) maps and values ecosystem services under current and future management and climate change scenarios, 2) is highly flexible, for use with diverse habitats, policy issues, stakeholders, data limitations, and spatial and temporal scales, 3) includes modules for a variety of services (food from fisheries and aquaculture, recreation, and coastal protection are likely to be available first; future models will quantify and value nursery habitat, transformation and sequestration of wastes, cultural services, and energy generation), 4) includes process-based models that consist of a biophysical step where supply of the service is quantified, a use step where demand for the service is quantified, and an economic step for valuation in monetary terms. The models run in ArcGIS on input layers that describe ecosystem structure and human use. Initial application of Marine InVEST will occur in British Columbia or California in late 2009 and 2010. We have begun scoping potential sites to insure that the tool is built in concert with user needs. In the meantime, we are testing the models in Puget Sound, Washington and will show preliminary outputs from three of the models: coastal protection, food from aquaculture, and recreation. Marine InVEST will be freely available for download and application to any temperate ecosystem. This work could inform integrated management in the Gulf of Maine by serving as an example of ecosystem services scenario assessment and by producing a tool which ultimately could be applied in the region.

From Integrated Multi-Trophic Aquaculture (IMTA) to nutrients credits: recognizing and valuating the environmental/economic/societal services and benefits of the inorganic extractive component of IMTA

T. Chopin*[1], M. Sawhney[1], E. Campbell[1], R. Shea[1], E. Belyea[1], S.J. Pang[2], G.K. Reid[1,3], S.M.C. Robinson[3], K. Haya[3], L. Burridge[3], F. Page[3], N. Ridler[1], M. Szemerda[4], F. Powell[4], J. Sewuster[5], S. Boyne-Travis[6]

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To continue to grow, the aquaculture sector needs to develop more innovative, responsible, sustainable and profitable practices that optimize its efficiency, create diversification and ensure the mitigation of the consequences of its activities to maintain the health of coastal waters. One of the innovative solutions for environmental sustainability (biomitigation), economic stability (product diversification and risk reduction) and societal acceptability (better management practices) of aquaculture is integrated multi-trophic aquaculture (IMTA). IMTA combines the cultivation of fed aquaculture species (*e.g.* finfish, shrimps) with organic extractive aquaculture species (*e.g.* suspension- and deposit-feeders) and inorganic extractive aquaculture species (*e.g.* seaweeds) for a balanced ecosystem management approach.
The inorganic extractive component of several IMTA sites in the Bay of Fundy, Canada, presently includes the kelps *Saccharina latissima* and *Alaria esculenta*. New candidate species are under investigation to increase the inorganic biomitigation capacity of the system throughout the year. We continue to scale-up experimental systems towards commercial levels. Rethinking site design, dimensions, scale and logistics are crucial to optimizing open-water IMTA, not just within the conventional site boundaries but also at the bay management level.

Extractive aquaculture not only produces a multiple-use biomass, it also renders provisioning, regulating, cultural and supporting ecosystem services. The economic value of the environmental/societal services and benefits of extractive species needs to be recognized and accounted for to establish the true value of this component of IMTA. This would create even stronger incentives for aquaculturists to develop IMTA systems, in which seaweeds and invertebrates should be traded for nutrient/carbon credits and coastal eutrophication reduction, through long-term planning/zoning in the broader context of integrated coastal zone management.

The occurrence of the world's largest macroalgal green tide ever observed, in Qingdao, China, in the summer of 2008, and its recurrence in 2009, will be used to illustrate the nutrient scrubbing services of seaweeds, the lessons we can learn from such events, and how it is important to communicate the value and benefits of considering ecosystem services so that they become an integral part of common sense biomitigative solutions in our regulatory and management framework.

Restoring oyster reefs to recover ecosystem services

Jonathan H. Grabowski[*1], Charles H. Peterson[2], Michael F. Piehler[2], Robert Conrad[3], James Opaluch[4]; and Robert D. Brumbaugh[5]

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The decline of the oyster fishery in the eastern United States continues despite extensive restoration efforts. While other emergent biogenic estuarine habitats such as sea grass beds and salt marshes have received both legal and regulatory protection for performing valuable ecosystem functions (e.g., they act as nutrient sinks, stabilize sediments, and provide critical nursery grounds for fish and invertebrates), oyster reef habitat has been managed primarily as a resource to exploit. However, coastal management plans have recently recognized the need to further our understanding of the services provided by oyster reefs rather than permit continued overexploitation of oysters. In addition to producing oysters for commercial and recreational value, oyster reefs perform a wide array of ecosystem services. For instance, oyster reefs provide habitat for and augment the production of commercially and recreationally valuable fish, filter the water column and consequently enhance seagrass habitat, and stabilize shoreline erosion of salt marshes and other valuable habitats. We assessed the ecological and economic value of ecosystem services provided by oyster reefs. Our evaluation suggests that the value of oyster reef services provided by reef sanctuaries that persist for decades likely far surpasses the value that could be derived from destructively harvesting reefs for oysters.

A proposed analytical framework for Integrating environmental goods and services in policy decisions

Luis G. Leigh[1]

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The author will present a proposed analytical framework for integrating the impact of policy decisions on ecological goods and services, as a part of cost benefit analysis. The presentation will outline a framework that builds on the Millennium Ecosystem Assessment and subsequent developments for the identification of ecosystem goods and services, uses a Total Economic Value approach to their valuation, and speaks to the valuation methods that can be used. The framework demonstrates the importance of a dynamic approach that measures the change in the EG&S values due to policy decisions rather than the total stock of EG&S. The presentation will outline how the proposed framework will be applied to priority policy issues, including protected areas decisions, and sustainable management of water resources. The main objective of the speaker is to obtain feedback from conference participants in terms of the conceptual soundness, feasibility of the proposed framework, and their views in terms of the applicability of the framework in these and other policy areas.

Confronting tradeoffs in marine ecosystem-based management

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Consideration of tradeoffs among potentially conflicting objectives is a central issue in ecosystem-based management. In the Gulf of Maine, some key management and conservation concerns include the status of Atlantic cod stocks, decline in bluefin tuna condition, herring fishery development, and northern right whale recovery. Recently, important concerns have been raised about maintaining sufficiently high pelagic fish abundance to support predator populations. However, strategies to maintain high pelagic fish biomass may also have unintended consequences, including effects on cod recruitment, competition with right whales for their preferred prey, the copepod *Calanus finmarchicus*, and reduced condition factors for herring leading to reduced condition of bluefin tuna. Herring biomass has shown an order of magnitude increase in the last three decades. Abundance and survival of late stage *Calanus* is inversely related to pelagic fish biomass. Intercalf interval of Right whales is positively correlated with pelagic fish biomass. Calving success of Right whales is positively correlated with late stage *Calanus* abundance. To confront these tradeoffs, risks of alternative courses of action must be assessed and quantified. It is suggested that a formal decision analysis framework be used to provide a transparent approach to this problem. The approach specifies policy alternatives for a carefully bounded problem, defines a set of attributes against which management actions will be evaluated, assigns weights to the attributes reflecting both objectively defined characteristics and values and preferences, and assigns scores for each policy alternative against each attribute. This general decision framework can be set in the context of an explicitly adaptive management approach.

TECHNICAL SESSION ON BIODIVERSITY IN THE GULF OF MAINE

Session Organizers:

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Background

The international Census of Marine Life is a ten-year initiative (2000-2010) that set out to describe the biodiversity of life in the oceans: past, present, and future. The Census is comprised of 17 projects involving approximately 2,000 scientists in 80 countries. The Gulf of Maine Area (GoMA) program is the regional ecosystem project of the Census. GoMA's study area includes US and Canadian waters including the western Scotian Shelf, the Gulf of Maine, Georges Bank, the continental slope, and the western New England Seamounts.

GoMA's overarching goals are to increase understanding of biodiversity in the Gulf of Maine area; describe how this biodiversity supports regional ecosystem functioning; and suggest ways in which biodiversity information can be used to support decision-making regarding the marine environment. As part of its synthesis phase, GoMA has convened six expert groups organized around a combination of trophic/community types and habitats: coastal margins; benthos and demersal nekton; slope and seamount environments; microbial communities; zooplankton and pelagic nekton; and upper trophic level predators. In addition to evaluating current understanding of diversity, structure, and function within specific ecosystem "compartments", each expert group was asked to identify promising new lines of scientific enquiry and new technologies (emerging or needed), and to identify how biodiversity knowledge in each compartment can contribute to ecosystem approaches to management (EAM).

At this technical session, attended by 40 people, leaders of each expert group gave a presentation on their approaches, progress, and results to date. This provided an opportunity for feedback from the general research community and between the expert groups. This workshop was informal and included questions and discussion throughout the day. We were pleased to have a number of students attend the session. Highlights from each presentation are given below, followed by suggested cross-project connections, recurring themes, and comments on the applicability of this work to EAM.

Coastal Margins

Co-leads: P. Lawton* and P. Larsen*. *Contributors*: M. Buzeta, M. Greenlaw, A. Holmes, N. Kelly, M. Owen, R. Singh, T. Trott, M. Wong

The coastal study area has been defined by depth (intertidal down to 20 m). Data sources for this synthesis include literature, data reports, existing or compiled databases, and species registers. Recognized gaps in this project, due to unavailability of additional regional experts, are macroalgae, salt marshes and the Upper Bay of Fundy region.

Progress to date includes reviews of the nematode fauna and coastal invasive species, and several comparisons of historical species lists with the current Gulf of Maine Register of Marine Species (GoMRMS). One historical species checklist containing records dating back to the 1840s contains 1,401 coastal Maine species, as compared with a count of 1,485 in GoMRMS. Examining differences by phylum shows that the checklist sometimes has more than the register, and *vice versa*. One of the objectives of GoMA is to update the register with a provisional list of all potential additions and questions identified through searches of databases, checklists, and other sources.

A geospatial database compiled from 59 intertidal stations in Maine in the 1970s is being used to compare biodiversity between and within seven habitat types and over geographic scales; to examine relationships with physical parameters; and to identify species and diversity hotspots. Some patterns noted to date include a surprisingly rich diversity in mudflats; ubiquity of some species (*e.g.*, some oligochaetes) in all habitats; and an absence of general biodiversity hotspots for all six habitats among the sampled sites. Additional work by this expert group will focus on drivers, functional roles, and unknown biodiversity. The recognized gaps will be addressed by focused literature reviews and submission of the draft publication to regional experts for review and comment. An exception to the lack of biodiversity hotspots in the intertidal zone appears to be Cobscook Bay, which is the subject of a focused GoMA analysis, as well as a GoMA/NaGISA study and a History of the Nearshore project (see section on cross-project connections).

* asterisks indicate presenters

Benthos & Demersal Nekton

Lead: P. Lawton* *Contributors*: P. Auster, A. Cooper, J. Grabowski, A. Holmes, N. Kelly, G. Pohle, N. Shackell, D. Wildish, J. Witman

As with other expert groups, the goal is to summarize the composition and spatial and temporal patterns of known biodiversity; describe drivers of these patterns and the functional roles of biodiversity, identify the scope of unknown biodiversity, and identify ways that biodiversity information are important to EAM. This group's progress has been slow due to competing demands on most of its principals; the group may need to reduce its scope.

Several ongoing projects outside of this group are providing pertinent data compilations and specific synthesis points, including a project on seabed diversity; a new Canadian marine biodiversity program that is using ROVs to sample soft sediments in deep basins ("Discovery Corridor"); and a DFO regional ecosystem initiative in the northern GoM.

The seabed diversity project is using data from the Great Barrier Reef, Gulf of Maine, and Gulf of Mexico to determine how physical factors affect the distribution and abundance of benthic species/assemblages in each system. Data for the Gulf of Maine include a database of macro-benthic invertebrates provided by NOAA as well as multiple sets of more than 15 physical variables (*e.g.*, seabed type, sea surface temperature, chlorophyll) that are being compiled from Canadian and US sources. This project will also use data from Canadian and US fisheries trawl surveys. These valuable databases, and some of the project's analyses, will soon be available to the benthic expert group and the research community at large.

Slope, Seamounts and Other Deep-Water Environments

Lead: N. Kelly* *Contributors*: E. Shea, A. Metaxas, P. Auster, R. Haedrich, T. Sutton, M. Vecchione

This study area is defined by latitude, longitude and depth (39-43º N, 71-63º W, 200-3,500 m). It has been expanded from the original "Slope and Seamounts" to include all deep water habitats except for the deep basins inside the Gulf (*i.e.*, it includes the continental slope and canyons, adjacent areas of the abyssal plain, Bear Seamount, and the Northeast Channel).

To assess known biodiversity, the group mined multiple data sources (primary and secondary literature, contributed datasets, Web sites, and museum records) to find species records dating from 1874 to 2006. They compiled a database of species occurrences, most of which are geo-referenced and include depth associations. The database currently contains 18,810 unique records, comprised of ~2,000 unique species. The ten most numerous species records are for 7 teleost fishes, 1 cephalopod, 1 decapod crustacean, and 1 elasmobranch.

Species accumulation curves and species richness estimators suggest that the relatively well-studied regions, such as the NE Channel and Georges Bank canyons, may have fewer than 10 epibenthic species remaining to be added to the known species list, while the less-studied regions, particularly the soft-bottom continental slope regions, may have more than 120 infaunal species still to be discovered. However, both of the above numbers are underestimates of the unknown diversity in these regions, due to the limited spectrum of sampling methods and non-statistical sampling designs relative to variations in habitat.

The group conducted various analyses of taxonomic group by area, *e.g.*, gap analyses, species richness, and taxonomic distinctness. The abyssal and seamount habitats had lower than expected taxonomic distinctness, but higher than expected variation in taxonomic distinctness. GIS maps illustrated that canyons and the NE Channel have high species richness of corals, while the most important area for fish diversity was Bear Seamount.

Literature reviews are underway to assess drivers of deepwater biodiversity such as circulation, bathymetry, human impacts, inter-species associations, and climate change. Next steps will be to refine the current analyses, conduct new analyses such as comparisons to global patterns (*e.g.* diversity with depth, substrate type), and develop lists of pressing questions and technology needs.

Microbial communities

Co-leads: W. Li* and M. Sieracki* *Contributors*: R. Andersen, D. Gifford, L. Incze, J. Martin, C. Pilskaln, J. Rooney-Varga, W. Wilson

Microbes encompass a broad trophic range of organisms with a wide phylogenetic diversity. This expert group focused on free-living, planktonic microbes including viruses, heterotrophic prokaryotes (bacteria and archaea), phototrophic prokaryotes (cyanobacteria and photoheterotrophs), and eukaryotic phototrophs (phytoplankton) and heterotrophs (ciliates and microflagellates). The common definition of "species" does not apply well to the full range of microbial diversity. All units of microbial diversity including species, morphotype, phylotype, and operational taxonomic units (OTUs), have biases that may lead to under- or over- estimation of actual diversity.

Despite these difficulties, a provisional estimate of bacterial taxonomic richness was made. The total abundance of bacterioplankton in GoM area is the sum of cells in 14 physiographic regions, integrated by hypsometrically determined depth layers through the water column to the ocean bottom This yielded an estimate of 1.6×10^{25} bacterial cells in the entire Gulf of Maine area. This abundance estimate was then used in a parametric model to estimate the taxonomic richness of bacterioplankton as 4×10^{5} OTUs in the GoM area. This is 20% of the global bacterioplankton estimate of 2×10^{6} OTUs, which suggests a very diverse microbial community in the GoM area.

Other topics this group has been exploring are:

- patterns of distribution and abundance over space and time,
- functional roles (decomposition and breakdown of organic matter, cycling of materials, genetic transfer, and evolution),
- estimates of unknown microbial diversity,
- pressing questions (C, N, P, energy flow, links to how communities function; links to ecosystem modeling), and
- past and future diversity (historical records beginning in the 1920s; new species coming in from ballast water or from Arctic waters moving south; effects of climate change).

Zooplankton and pelagic nekton

Co-leads: C. Johnson* and J. Runge *Contributors*: A. Bucklin, E. Durbin, J. Hare, L. Incze, J. Link, G. Melvin, T. O'Brien, L. Van Guelpen

Quantifying zooplankton diversity using currently-available data is challenging, due to limitations in the sampling ability of nets, differences in gear and taxonomic resolution among programs, and the focus of most zooplankton sampling programs on dominant species. There has been a wide array of zooplankton monitoring programs in the GoM dating back to 1912, and four are currently ongoing. However, sampling methods are not standardized, there is only limited coastal/nearshore sampling, and there is generally inadequate sampling of the annual cycle in the Gulf of Maine.

The GoMRMS at its current stage of development lists about 420 species of holoplankton and meroplankton, of which about 190 are provisional additions identified during the present study through comparison with species lists from zooplankton monitoring programs. About 350 species of fish with pelagic stages are currently included in GoMRMS. Examination of additional databases will help develop a more accurate species count for the zooplankton.

Zooplankton diversity was also evaluated using indices such as species richness (the total number of taxa) and species evenness (the distribution of abundance among taxa). Species richness was lower at stations sampled year-round in the western Gulf of Maine than at similar stations in the northwest Bay of Fundy and Scotian Shelf, due to the greater numbers of Arctic and warm-water, offshore species present at the latter stations. Evenness was low at all of these stations, with fewer than 10 species making up more than 95% of total abundance. The highest zooplankton community gradients occurred between the neritic and offshore environments and at the shelf break. Species richness increased dramatically at the shelf break. The diversity of samples collected by the Continuous Plankton Recorder in the Gulf of Maine since 1961 was high during the 1990s, concurrent with a community shift from large to small-bodied copepods. Because large-bodied copepods such as *Calanus finmarchicus* are key prey species for many fish, marine mammal, and seabird species, this shift in diversity may be associated with changes in energy pathways to higher trophic level species.

Drivers of variability in zooplankton communities and diversity include physical habitat (*e.g.*, water depth, tidal mixing,), community interactions, water properties (*e.g.*, temperature, salinity, stratification), and advection (from Scotian Shelf, NE Channel, offshore).

Underknown groups that are likely to have important ecosystem functions include meroplankton (larvae very similar), gelatinous zooplankton (difficult to sample), euphausiids and mesopelagic fish (hard to catch).

Pressing research needs include:

- comprehensive nearshore and offshore zooplankton observing programs/systems,
- standardization of diversity and abundance indices,
- coupled physical-biological life history modeling for sensitivity to climate scenarios
- ecological modeling for sensitivity to shifts in abundance of key structural species or functional groups,
- understanding of underknown species: abundance trends and functional roles, and
- genetic structure of populations.

Upper trophic level predators

Co-leads S. Kraus* and K. Smedbol *Contributors*: J. Anderson, S. Ellis, A. Gilbert, J. Gilbert, W. Golet, L. Incze, R. Kenney, K. Lagueux, M. Lutcavage, C. Mayo, J. Neilson, A. Pershing, J. Robbins, P. Stevick, J. Stockwell, M. Weinrich, N. Wolff

This expert group has taken a different approach than others. Since the biodiversity of upper trophic level predators (UTLPs) in the Gulf of Maine is well known, the group focused more on functionality and ecological questions. Species counts of UTLPs in the Gulf of Maine area include 184 birds, 3 sea turtles, 4 pinnipeds, 1 mustelid, 27 cetaceans, and 49 elasmobranchs. This study also included 3 species of large tunas, 1 swordfish, and 1 ocean sunfish, but excluded groundfish, sturgeons, and salmonids.

The primary prey species of UTLPs in the GoM are limited to 6 species (a copepod, krill, herring, sandlance, and two species of squid), a classic "wasp waist" trophic structure, where biodiversity is lowest among high-biomass prey species. Changes in abundance of these few prey species could have cascading impacts up the food chain, leading to population collapses, range shifts, and ecosystem changes.

The two dominant zooplankton prey species are the krill, *Meganyctiphanes norvegica* and copepod, *Calanus finmarchicu*s. Despite their role in supporting a large portion of the GoM ecosystem, the present distribution, abundance, and seasonal patterns of *Meganyctiphanes* and the future abundance of *Calanus* and *Meganyctiphanes* under climate change are not well understood. Herring is another major forage species for

many large vertebrates including tunas and whales. Herring abundance has recently increased, but questions remain about the effects of herring spatial distribution on predator species (80% of GoM herring are on Georges Bank) and about the future of herring if *Calanus* and krill patterns change.

Pressing research questions include: How will climate change affect diversity, distribution, and abundance of UTLPs? Does diversity in the UTLP suite provide some flexibility in potential top-down control on trophic dynamics if the GoM system undergoes substantial change? What biological and oceanographic processes lead to aggregations of multiple species of UTLPs at feeding "hotspots"?

Recommendations to advance knowledge of UTLPs include centralization of disparate datasets, data integration, long-term periodic surveys, multi-disciplinary studies, new technologies (*e.g.*, tagging, listening devices, Doppler radar for birds), monitoring for health, stress, and condition, and more modeling to determine trends in distribution and abundance.

Cross-project connections

Discussions led to suggestions for several expert groups to connect with each other and/or with some external projects on specific topics:

- Coastal and apex predator groups should connect regarding seabirds, especially in the upper Bay of Fundy.
- Microbial and benthic groups should cooperate to address bentho-pelagic coupling.
- Coastal and benthic groups should consider using some of the measures of taxonomic distinctness employed by the slope/seamount group.
- The slope/seamount group should work with N. Wolff of GoMA to ensure inclusion of recent trawl surveys on seamounts in the deepwater database.
- The coastal group should connect with "Natural Geography in Shore Areas" (NaGISA) regarding macroalgae since this has not been addressed adequately. They should stay apprised of the progress of two other NaGISA projects (a comparison of historical diversity at Cobscook Bay, ME and Simpsons Island, NB, and a worldwide comparison of 5 sites including Cobscook Bay) to be able to point to these works in their publication.
- Several projects have conducted comparisons with GoMRMS. GoMA has conducted similar exercises to find provisional species and can help groups with searches/comparisons, to weed out synonymies, etc. All new species need to be identified for potential inclusion in GoMRMS.
- Each group should consider recent publications by Historical Marine Animal Populations (HMAP) on historical changes in the GoM ecosystem.

Recurring themes and recommendations

Several recurring themes and recommendations emerged during the workshop.

- The closer we look, the more we see. Even in areas that have received a lot of attention, new sampling is revealing new species or range extensions (*e.g.* in Jordan Basin). This means that EAM, which includes the conservation of biodiversity at functional levels, must employ approaches that are robust to the lack of specific knowledge about all species, their distributions and dynamics, or their ecosystem roles.
- Data mining is still providing new insights, including new species and range extensions. This highlights the importance of historical data that have been underutilized—often because they have not been very available. Digital databases are changing this, and making an important contribution to future management.
- The Gulf of Maine Register of Marine species remains a work in progress. Adding species to the register involves a specific set of comparisons against original taxonomic authorities, and other regional and global registers. Careful comparisons of the existing register against the databases being compiled by several expert groups will provide for some prioritization for ongoing work to make the register as comprehensive and useful as possible.
- Although the GoM is an exceptionally well-studied system (compared to many other regional ecosystems) many of the research and monitoring programs have been sporadic. There are actually few standardized and regionally-comprehensive (in time and space) monitoring programs, and only some databases are generally available to the wider research community. This demonstrates the need for strategic Gulf-wide and nested, smaller-scale biological observing programs that include plans for standardization and sharing of data.
- Although historical sampling may not be thorough, *i.e.*, we can't determine the full range of species that were present, we can get a sense of what species were historically abundant, and gain insights into shifting baselines over time.
- While each of these expert groups is examining biodiversity within a specific "compartment" there is a need for end-to-end coupling and integration of the knowledge across trophic levels as well as spatial domains. This gets to be a very large problem and will require new modeling strategies that reduce the problem to tractable levels without losing credibility.

Integrating Biodiversity Knowledge Into Management

Conserving biodiversity is one of the central goals of EAM. This is challenging because the majority of marine biodiversity is still unknown and will remain so for the foreseeable future, most species are comparatively rare, and the "importance" (function) of rare species is difficult to quantify in the present and impossible to predict for the future. The analyses, papers, and databases generated by these expert groups, and GOMA as a whole, are important steps toward an understanding of regional biodiversity.

We are still in the discovery phase for biodiversity characterization and mapping. We need to promote and recognize contributions to ocean biogeographic databases and build

a comprehensive regional ecoinformatics framework. The latter requires exchange of technical approaches, and building and publishing scientific workflows (from standardized data acquisition techniques, through analytical routines for generation of biodiversity metrics).

In addition to the suggested end-to-end modeling, it will be valuable to construct integrated views of defined "ocean spaces," such as Stellwagen Bank, or the Bay of Fundy, or a deep basin, and their interactions with neighboring ocean spaces. Such pilot studies will help to develop techniques for data integration and spatial modeling, and explore issues of scaling—all of these are essential to scientifically informing the process of EAM.

TECHNICAL WORKSHOP ON SEAFLOOR MAPPING FOR ECOSYSTEM MANAGEMENT IN THE GULF OF MAINE

Session Summary

Session organizers:

Jonathan Grabowski, Gulf of Maine Research Institute (jgrabowski@gmri.org)
Brian Todd, Natural Resources Canada (Brian.Todd@NRCan-RNCan.gc.ca)
Page Valentine, United States Geological Survey (pvalentine@usgs.gov)
Tracy Hart, Gulf of Maine Mapping Initiative (harttrac@gmail.com)

I. Introduction

Goal: To identify and explore current and potential uses of seabed information for Ecosystem Based Management in the Gulf of Maine.

Background and objectives: The Gulf of Maine ecosystem contains a diverse array of geological and biological substrates that serve as habitat for commercially and ecologically important mammals, seabirds, fish, and invertebrates. Managing this system effectively will require balancing the habitat needs of these species with ongoing and emerging human activities such as fish harvesting, offshore energy development, and shipping, among others. Seafloor mapping is a relatively new technology that already has been used as an effective tool in assessing ecosystem impacts of human activities and defining essential fish habitat of economically important species. Yet, high-resolution seabed habitat information is extremely limited, especially in the U.S. portion of the Gulf of Maine.

Over the past decade, the Gulf of Maine Mapping Initiative (GOMMI) has organized forums and coordinated efforts to advance mapping of critical seabed habitat characteristics in highly utilized regions of the Gulf of Maine. In April 2009, GOMMI and the Gulf of Maine Research Institute convened a workshop on how to integrate seabed information into fisheries management decisions more effectively. Scientists and managers at this workshop articulated that ecosystem-based management will require improved information about the habitats of economically and ecologically important species and the impacts of different human activities.

The mapping workshop at the Gulf of Maine Symposium brought together geologists, benthic ecologists, fisheries scientists and coastal managers from Canada and the United States to explore a.) How seabed information is currently being used in ecosystem management, and b.) How this information can be made more useful to those who manage fisheries, energy development, and other human activities in coastal and offshore waters of the Gulf of Maine. In particular, we examined if there is a mapping strategy (or strategies) that best fits the needs of managers and scientists.

II. Conclusions and Broader Applications to EAM

a. How is seabed information currently being used in ecosystem management?

Several of the presentations and posters highlighted how mapping information is currently being used in ecosystem management. Examples ranged in spatial scale and covered a variety of ongoing and emerging human activities. Brian Todd demonstrated how seafloor substrate information from high-resolution acoustic data is essential to the effective location of tidal energy development projects. Efforts to develop offshore energy projects will benefit heavily from proactive mapping efforts that guide these projects to choose suitable bottom and minimize impacts. For example, Joe Kelley demonstrated how seafloor mapping can be utilized to delineate coastal features such as drowned lakes that likely contain preserved cultural features of historical value. Features such as these should be considered by managers when siting future offshore energy development projects in the Gulf of Maine.

Chad Demarest revealed how the Habitat and Ecosystem Plan Development Team (PDT) of the New England Fishery Management Council has utilized existing seabed information in an assessment of the vulnerability of seafloor habitat to fishing gear impacts. This assessment is currently hindered by a lack of substrate information in the Gulf of Maine region. Existing video survey and sediment grain size sample data were used to map substrate types as a part of the assessment, but high-resolution geophysical acoustic seabed data were not used because the data have not been made readily available and do not exist region-wide at a scale that is applicable to fisheries management. Several of the other presentations demonstrated how this effort by the habitat PDT would be enhanced by continuous seafloor habitat information because point data often result in inaccurate seafloor maps.

Jessica Sameoto demonstrated how seafloor maps can be combined with fishery data to help understand species-bottom type associations and how this information can be utilized to minimize negative interactions among fisheries that overlap spatially. Integration of the management of fisheries that are linked either by natural processes or human activities is a key first step in shifting to an ecosystem approach to management.

Daniel Sampson discussed how seafloor mapping is being used in marine spatial planning efforts by the state of Massachusetts. This presentation illustrated how mapping of seabed characteristics (substrate, depth, roughness, etc.) is often a necessary initial step in managing marine ecosystems and the goods and services that they provide.

b. How could seabed information be more useful for fisheries management?

Discussions and presentations throughout the workshop revealed several thoughts on how seabed information could be more useful for fisheries management:

There is limited seabed substrate information in the Gulf of Maine, especially in the U.S. (see the Gulf of Maine Mapping Initiative's website for a map showing regional coverage: http://www.gulfofmaine.org/gommi/coverage-map.php). This paucity of

mapping information limits the ability of managers to use this parameter in ecosystem management activities that require more holistic coverage of this bioregion. For example, the lack of available substrate information in this region limits fisheries managers' ability to a) define essential fish habitat and design closures that protect EFH; b) assess habitat vulnerability from fishing and other human activities that impact the seafloor; and c) evaluate how habitat affects fish productivity and integrate seafloor parameters into the stock assessment models used to manage regional fisheries.

The field of acoustic seafloor mapping is relatively young, and data acquisition technologies and analytical approaches are evolving rapidly. For example, Yuri Rzhanov provided insights on how ongoing efforts by researchers at the University of New Hampshire's Center for Coastal and Ocean Mapping are developing more effective automatic methods for segmentation of hydro-acoustic remote sensing data acquired by multibeam echosounders in order to generate quantitative estimates of the spatial distribution of seafloor relief, bottom type and composition. The development of methods that enhance our ability to discriminate between benthic habitats will consequently improve our ability to manage the valuable resources associated with these habitats.

Participants mentioned that seabed data should be presented as interpretive maps, which requires groundtruthing to validate acoustic interpretations. Clearly defining the data sources that were used to create and groundtruth a map would also assist managers in deciding whether the map is of use for a specific management objective. Furthermore, the raw seabed data should be published when and where possible in order to make it available for future management initiatives that require seafloor information.

Participants also noted that careful thought needs to be given to choosing the appropriate spatial scale at which to collect seabed data in order to meet scientific and management objectives. Walter Barnhardt's presentation demonstrated the tradeoff between using existing fine-scale substrate information from sediment samples vs. continuous acoustic information on seafloor substrates. The geophysical data provide continuous coverage and superior resolution of seafloor geology, but are not available in most areas and the cost of acquiring this information currently limits more extensive seafloor mapping. Meanwhile, using only existing point data, which are available at no cost, results in misinterpreting much of the seafloor bottom which invariably will limit our ability to manage it effectively. This problem will become even more apparent as marine spatial planning expands from state waters to federal waters of the Gulf of Maine where mapping information is sparse. Seafloor information is often the foundation upon which marine spatial planning is based, so that attempts to manage and sustain marine resources and ecosystems will require accurate seafloor information.

Better geophysical seabed information certainly will enhance efforts to manage the Gulf of Maine ecosystem and associated resources; yet in many cases this information only provides the basis for further investigations. For example, achieving an understanding of how seafloor substrates affect fish productivity (i.e., level 4 EFH) requires coupling seabed information with additional investigations of how these substrates influence fish life history parameters such as survival, growth, and ultimately productivity. Steve

Fromm presented suitability models that produce maps which characterize habitats in terms of their "scope for growth" for important biota. The habitat types modeled from interactions of physical variables also reflect sensitivity of seabed habitats and communities to human impacts such as fishery. This approach is currently being used in Canada as well, and is a potential mechanism to begin incorporating habitat features and impacts to habitat into efforts to manage the productivity of fisheries. Mark Anderson also demonstrated how efforts to map the northwest marine ecoregion are being used to assess the ecosystem services associated with habitats in this region.

Participants of the workshop debated the utility of striving for one overarching map or relying on a mapping strategy that uses multiple complementary maps. Several of the presentations demonstrated the utility of this latter approach to achieve ecosystem management goals. For instance, Page Valentine demonstrated how seafloor substrate information in the Stellwagen Bank Marine Sanctuary could be used to identify essential fish habitat for many commercially and ecologically important species.

Several of the studies provided insights regarding the value of mapping efforts to ongoing area-based management efforts in the Gulf of Maine. Both Jonathan Grabowski and Craig Brown discussed the importance of mapping for assessing ecosystem services associated with key offshore features such as Cashes Ledge in the Gulf of Maine and Stanton Bank off the coast of Ireland. For example, seafloor habitat information is being used in these studies to develop a better understanding of how habitats influence fish life history characteristics. These studies are intended to inform managers about whether marine closures such as the Cashes Ledge Closure Area are recovering and performing important ecosystem functions (i.e., nursery habitat).

Agenda and Abstracts

8:30–9:00 Introduction to the workshop

9:00–9:15 Bay of Fundy in-stream tidal power: mapping the seafloor to provide insight into constraints to development
Brian Todd, Geological Survey of Canada

9:15–9:30 Integrating spatial information for ecosystem-based management: an example for the scallop fishery in Southwest Nova Scotia
Jessica Sameoto, Fisheries and Oceans Canada

9:30–9:45 Advances in benthic habitat mapping: The application of acoustic backscatter data for habitat discrimination
Craig Brown, Fisheries and Oceans Canada/University of Ulster

9:45–10:00 Mapping physical seabed characteristics for ecosystem management
Page Valentine, United States Geological Survey

10:00–10:30 *Coffee Break*

10:30–10:45 Developing cod habitat maps to evaluate the Cashes Ledge Closure Area
Jonathan Grabowski, Gulf of Maine Research Institute

10:45–11:00 Mapping to Management in Massachusetts
Daniel Sampson, Massachusetts Office of Coastal Zone Management

11:00–11:15 Seafloor Mapping for Ocean Management in Massachusetts, USA
Walter Barnhardt, United States Geological Survey

11:15–11:30 Preservation potential of drowned, former terrestrial habitats: implications for cultural resource management
Joe Kelley, University of Maine

11:30–1:00 *Lunch*

1:00–2:00 Poster Session

2:00–2:15 Habitat Suitability Modeling using the Habitat Template Approach as an Indicator of Distribution of Benthic Invertebrates
Steven Fromm, NOAA-Northeast Fisheries Science Center

2:15–2:30 High-resolution delineation of acoustically homogeneous areas in multibeam backscatter maps
Yuri Rzhanov, University of New Hampshire

2:30–3:00 *Coffee Break*

3:00–3:15 The Northwest Atlantic marine ecoregional assessment
Mark Anderson, The Nature Conservancy

3:15–3:30 A spatially explicit assessment of the adverse effects of fishing on benthic habitats in the Northeast U.S.: the Swept Area Seabed Impact model
Chad Demarest, NOAA-Northeast Fisheries Science Center

3:30-4:30 Wrap-up discussion

Bay of Fundy in-stream tidal power: mapping the seafloor to provide insight into constraints to development

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The Bay of Fundy has the largest tidal range in the world, reaching 17 m in places. Associated tidal current velocities exceeding 4.5 m s^{-1} will be exploited in 2009 for engineering tests of turbines placed on the seabed for in-stream tidal electrical power generation. If successful, these turbine tests may lead to future installation of a full-scale tidal power system on the seafloor of the bay. Understanding the Bay of Fundy subsurface geology and its stability is necessary for turbine engineering design and installation site selection. Understanding the regional surficial geology is necessary for predicting sediment mobility and implications of that mobility for the design of seabed infrastructure and mobile sediment mitigation. In anticipation of Bay of Fundy tidal power development, the Geological Survey of Canada, in cooperation with the Canadian Hydrographic Service and the University of New Brunswick, instituted in 2006 a broad-scale regional program to map the entire sea floor of the Bay of Fundy. To date, 12,466 km^2 of multibeam sonar coverage have been acquired, with more coverage being collected in late 2009. Geophysical transects, seafloor imagery, and sediment samples were collected in 2009 with further investigation slated for 2010. The information will be integrated to produce a series of surficial geology and benthic habitat maps at a scale of 1: 50 000. Preliminary interpretation has revealed that the Bay of Fundy is floored by widespread glacial deposits (till), 10 to 30 m thick, overlying bedrock. In some areas, deep channels have been eroded in glacial sediment, presumably through the action of tidal currents. Superimposed on the glacial sediments are modern sediments in the form of discrete sand waves and fields of sand waves up to 20 m high. The mobility of the sand bedforms will be measured in 2009–2010 through the installation of *in situ* instrumentation to measure sediment dynamics. The results of the geoscientific investigations will provide scientific interpretations necessary for informing government management decisions regarding the use of the Bay of Fundy seabed for in-stream tidal power projects and for other competing seabed uses.

Integrating spatial information for ecosystem-based management: an example for the scallop fishery in southwest Nova Scotia

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The general conservation principles of maintaining productivity, preserving biodiversity and protecting habitat for ecosystem based management are well established. However, to translate these objectives into viable measures to assess costs, benefits, and risks associated with various policy decisions requires accurate, quantitative and spatially

explicit information. Here, we discuss the use of biological, geophysical and fishery data within a Geographic Information System (GIS) environment to assist in an ecosystem approach to management in the evaluation of scallop stocks in Scallop Fishing Area (SFA) 29 off the Southern coast of Nova Scotia, Canada.

SFA 29 presents a unique case to study the use of seafloor information as a tool in an ecosystem approach to fisheries management. Access was granted to this area for scallop fishing in 2001 with the condition of a full satellite-based vessel monitoring program (VMS), observer coverage to monitor discards, and a post-season industry-funded survey. In 2002, a joint project agreement was signed between the fishing fleets, Natural Resources Canada, and the Department of Fisheries and Oceans with all parties providing funds to conduct multi-beam acoustic mapping of the seafloor. From this, a geophysical characterization of bottom type was developed in 2008.

These datasets have been used relatively independent of one another; for survey design, to determine associations between bycatch species and bottom type, and to characterize spatial fishing patterns. However, the potential of these data has yet to be fully realized. We present a case study that integrates these data to address a potential management scenario and discuss how seafloor mapping can contribute to addressing the conservation principles of ecosystem management.

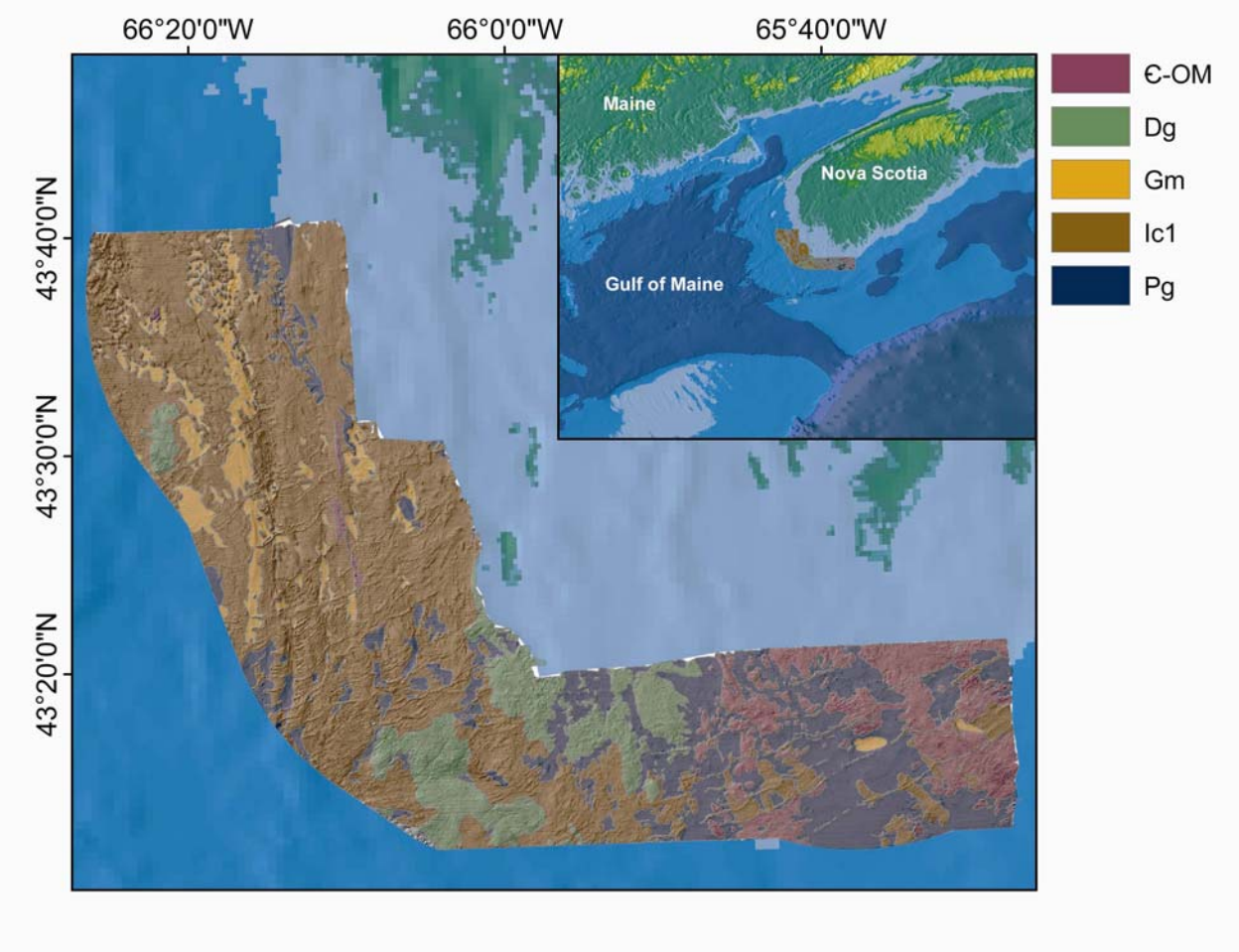

Figure 1. Geophysical substrate of Scallop Fishing Area (SFA) 29.

Advances in benthic habitat mapping: The application of acoustic backscatter data for habitat discrimination.

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Human impacts on the seafloor environment have reached unprecedented levels. To facilitate ocean management and mitigate these impacts there is a need to improve our understanding of seabed habitats. Recent developments in acoustic survey techniques, such as multibeam sonar, have revolutionised the way we are able to image, map and

understand benthic ecosystems. It is now cost effective to image large areas of the seafloor using these techniques, and the information from such surveys provides base line data from which thematic maps of the seabed environment, including maps of benthic habitats, can be derived when interpreted in conjunction with in-situ ground-truthing data. However, despite the recent developments in this field of research, no standardised methodology exists for the integration of remote acoustic data with ground-truthing data for the production of benthic habitat maps. Recent studies at the Centre for Coastal and Marine Research (CCMR), both in Ireland and the Gulf of Maine, have focussed on addressing this issue. Traditional methods for the interpretation of acoustic backscatter rely on experienced interpretation by eye of grey-scale images produced from the data. Whilst this method is effective in delineating regions of similar seabed attributes where boundaries between neighbouring substrate types are clearly defined (e.g. rocky reefs adjacent to soft sediments), it has proved less effective in areas where there are gentle sediment/biological gradients from one substrate/habitat type to the next, or where there is a high degree of small-scale sediment heterogeneity. In these difficult areas interpretation of data can be extremely subjective. Recent studies at the CCMR have explored the relationship between raw backscatter values and benthic geological and biological characteristics. Recent developments in automated classification of backscatter data have also been evaluated for assisting the production of benthic habitat maps. An overview of a number of ongoing research themes at CCMR in this field of research is presented.

Mapping physical seabed characteristics for ecosystem management

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The sea floor exhibits a suite of mappable attributes that include topography, sediment texture and mobility, seabed features (bedforms, gravel pavements, boulder ridges, living structures), seabed water temperatures, and species distributions, among others. Such information is required to define and map habitats (places) where plant and animal populations and communities live. For effective ecosystem management, maps need to show the distribution of habitats for specific species populations and communities. This can be achieved by overlaying occurrence data for a species or community onto maps that show the various physical characteristics of the seabed. For a biological unit of interest, this process will provide information that can then be used to predict the existence of suitable habitats in areas where only physical data are available.

In one area of the Stellwagen Bank region in the Gulf of Maine, physical information in the form of multibeam sonar backscatter and topographic data, sediment texture analyses, and seabed images have been compiled into a series of maps showing sea floor geology and ruggedness, sediment mobility, substrate texture, and seabed features. They document a wide range of physical settings that include rippled mobile coarse sand in shallow water (35-50 m), gravel pavements and boulder ridges, steep slopes of mixed sediment, and immobile muddy fine sand in deep water (80-180 m). These maps are

successful in highlighting for managers the physical attributes of the seabed that influence the distribution of living organisms, but their usefulness in support of ecosystem management is limited by the availability of appropriate biological data.

Developing cod habitat maps to evaluate the Cashes Ledge Closure Area

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The effectiveness of fisheries management is limited by the paucity of information on how management tools, such as marine protected areas, impact key fisheries species. In the Gulf of Maine, more information is needed to determine how marine protected areas such as the Cashes Ledge Closure Area influence fish population dynamics and subsequently the status of fishery stocks. Moreover, whether closure areas recover habitat features that increase fish survivorship, growth, and ultimately productivity remains unclear. We utilized video surveys and multibeam sonar to quantify current habitats on Cashes Ledge. We also conducted seasonal surveys in 2006 and 2007 on the kelp, barren cobble, and mud habitats in the vicinity of Cashes Ledge using video, trap, and gill net sampling to quantify how habitat influences the abundance and distribution of Atlantic cod, *Gadus morhua*. Seasonal surveys identified that cod are still abundant on Cashes Ledge, and that their spatial and temporal distribution is influenced by habitat as well as by other species on Cashes Ledge such as spiny dogfish, *Squalus acanthius*. These results are being compared with historic cod datasets that were collected prior to the inception of the closure, and predate extensive harvesting on Cashes Ledge in the early 1990's, to determine if cod populations have recovered locally. Quantifying important ecosystem functions such as the provision of nursery habitat for commercially important fish species will assist managers in selecting the most appropriate areas for management action. This study will also provide baseline information that will be of value to ongoing efforts to monitor the impact of the Cashes Ledge Closure Area on rebuilding cod populations throughout the Gulf of Maine.

Mapping to Management in Massachusetts

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The Massachusetts Oceans Act of 2008 requires the Secretary of the Executive Office of Energy and Environmental Affairs (EEA) to develop a comprehensive ocean management plan by Dec. 31, 2009. The plan is largely an exercise in four-dimensional zoning, and, as such, is highly reliant on spatial data. A key component of these spatial data are seafloor mapping data from the United States Geological Survey (USGS) who have to date mapped 35% of Commonwealth waters. The USGS data provide high resolution bathymetry, sidescan sonar mosaics, depth to bedrock measurements, and geologic interpretations and were examined for their potential use in deriving maps of sediment, habitat resources, and suitable locations for human uses, including alternative energy generating sites, infrastructure (pipelines, cables), and sand extraction for beach nourishment. Despite the presence of this rich data source, some emergent management needs called for information that could not be easily extracted from the USGS data: most prominently, a synoptic map of seafloor sediment. As work on the management plan has evolved, our understanding of data and information needs has commensurately evolved to reveal the need for additional data products. Amongst these are statewide merged bathymetry, modeled tidal currents, and perhaps most importantly, a seafloor/water column geophysical "habitat" map. Such a habitat map would allow managers and scientists to begin habitat suitability modeling for species of interest, diversity, and patch metrics to better identify areas of unique conditions (representing particular habitat) that should be exempted from some or all potential ocean/seafloor uses. The draft ocean management plan contains a proposed Science Framework identifying prioritized scientific/data acquisition needs in the next five years, which includes development of such data products.

Seafloor Mapping for Ocean Management in Massachusetts, USA

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The Commonwealth of Massachusetts recently approved an ambitious plan to manage development in the State's ocean waters that extend up to 3 miles (4.8 km) from the coast. The *Massachusetts Oceans Act of 2008* requires that all decisions and permits conform to a single, science-based management plan, instead of being considered on a case by case basis. Before the plan can take effect, however, areas must be identified that are suitable for development or protection.

The Massachusetts coastal ocean encompasses more than 6530 km^2 of diverse seafloor environments, including submerged rock ledges, mobile sand deposits, rugged boulder fields, and deep muddy basins. Effective management of ocean resources in this complex region requires detailed knowledge of the type and distribution of benthic marine habitats, which are strongly controlled by seafloor geology. The geologic factors that primarily determine habitat suitability for benthic organisms are bathymetry (i.e., seafloor topography) and substrate type (i.e., rock, gravel, sand, mud). This presentation gives examples of how geologic information can support management decisions and compares different approaches to creating seafloor maps. Choosing a particular mapping approach is based primarily on the objectives (habitat research, regional sediment management, etc.), time frame for results, and availability of funds. Water depths in the planning area will determine the appropriate technologies to use.

A cooperative program involving the U.S. Geological Survey and the Massachusetts Office of Coastal Zone Management has employed high-resolution sonars, bottom photography, and sediment sampling to fully characterize seafloor geology in water depths greater than about 10 m. Overlapping swaths of bathymetric and backscatter data, combined with closely spaced subbottom profiles, provide a comprehensive, three-dimensional view of the physical structure of the seafloor. Mapping began in 2003 and, to date, has covered 2200 km^2 of seafloor, approximately 35% of the total area. Although the long-term goal is to produce detailed maps covering all of the State's waters, management decisions typically cannot wait and must depend on the best information available at a given time.

In areas where comprehensive knowledge about the seafloor is currently lacking, resource managers are limited to existing information such as usSEABED (http://walrus.wr.usgs.gov/usseabed/). This large compilation contains sediment data at many point locations that can be spatially interpolated to create crude maps of surficial sediment distribution. However, care must be taken to evaluate the validity of data in usSEABED or any other database, especially with regard to the horizontal accuracy of older samples.

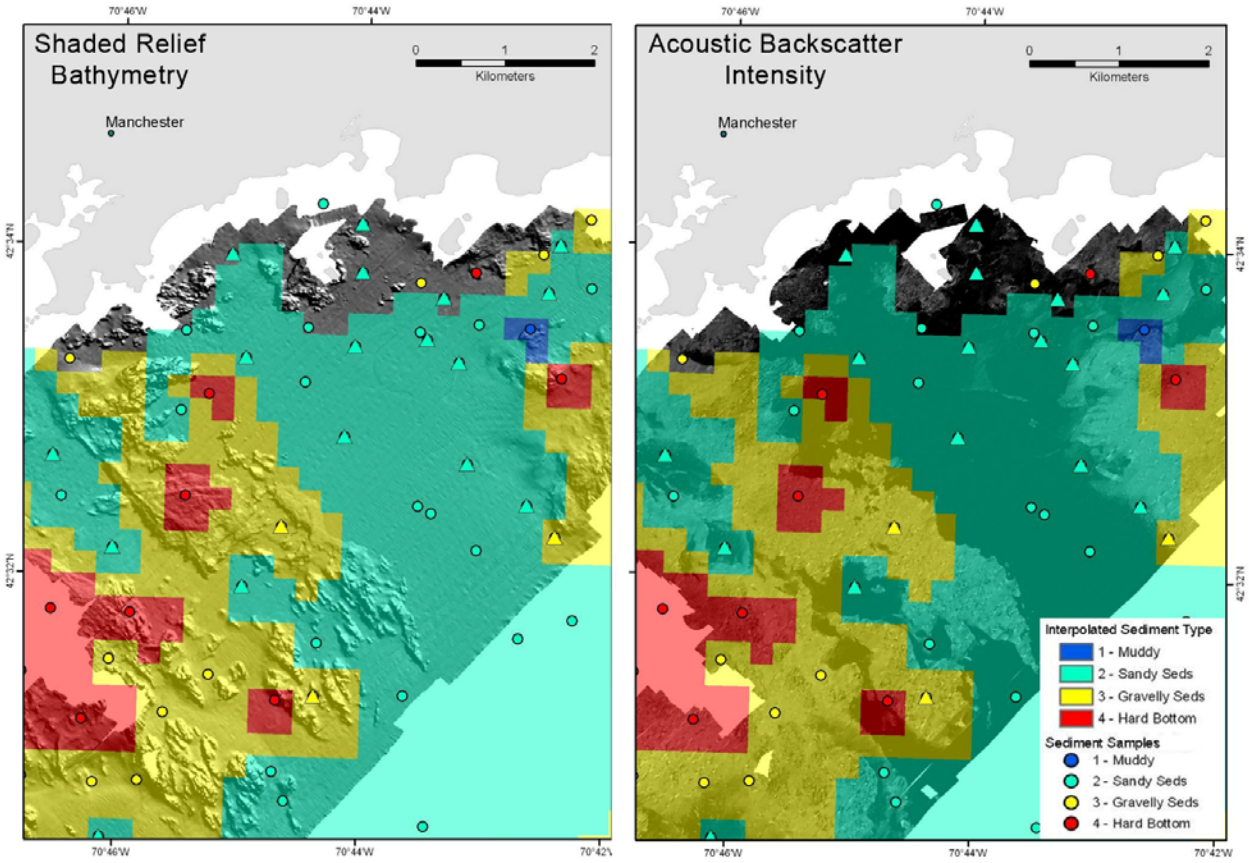

Figure 1. Maps of the Massachusetts inner continental shelf showing gridded interpolation of point data overlain on shaded relief bathymetry (left) and acoustic backscatter intensity (right). The geophysical data provide continuous coverage and superior resolution of seafloor geology, but are not available in most areas. Point data are from usSEABED (triangles) and Barnhardt et al., 2007 (circles). Bathymetry and backscatter data are from Barnhardt et al., 2007.

Preservation potential of drowned, former terrestrial habitats: implications for cultural resource management

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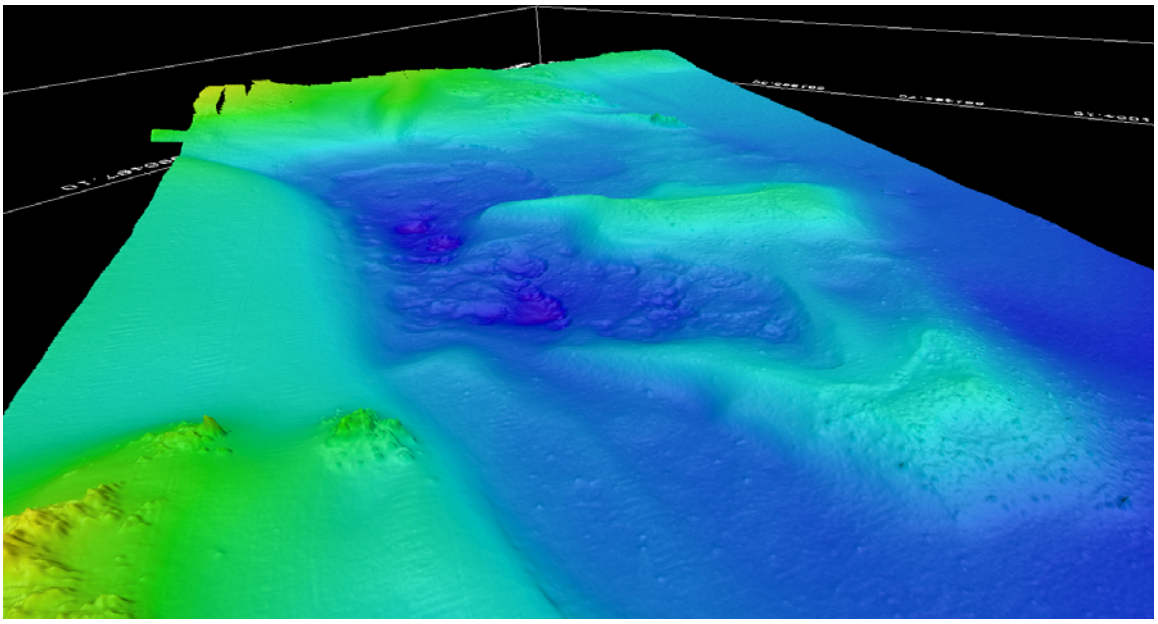
Sea level dropped to at least 60 m depth in the Western Gulf of Maine following deglaciation and isostatic adjustment. The depth and timing of the lowest position of the sea varies across the Gulf of Maine, but significant areas of seafloor were once terrestrial environments and potentially inhabited. The degree of erosion of past landscapes was controlled by the rate of sea-level rise and rate of erosion of various materials. For

example, glacial till deposits erode slowly compared to glacial-marine mud deposits and so stand a better chance for preservation. Neither of these materials is likely to harbor cultural resources in place, however, because the formerly inhabited surface layer is typically removed as the land surface passes through the surf zone and drowns. Periods of slow sea-level rise resulted in enhanced erosion of glacial materials (because there was more time with the plane of sea-level at one elevation), but at the same time, are associated with landforms like beaches that formed from the eroded material. As on the modern coast, beaches formed from eroding till and glacial moraines (linear mounds of till) often are spits that enclose embayments. Moraines often impeded terrestrial drainage and sheltered lake and estuarine environments before they were drowned. Along the Maine coast, conditions for preservation of cultural materials in the context of a lake or estuarine shoreline are, thus, best met during the period of very slow sea-level rise between about 11,500 and 7,500 calendar years ago. The best example of a preserved terrestrial environment in association with archeological materials was recently found off Mt. Desert Island, ME (Figure 1). Here scallop draggers recovered mid-Archaic artifacts from what we interpret as a drowned lake/bay shoreline. Cores penetrated beach and tidal flat deposits with freshwater wetland peat as well as articulated shellfish and submerged aquatic vegetation all dating between 7,700 and 9,200 years before present. Drowned sites such as these are probably common and need consideration as wind and tidal energy sites are examined. The best model for where to look for such drowned sites is guided by the local sea-level curve.



Habitat Suitability Modeling using the Habitat Template Approach as an Indicator of Distribution of Benthic Invertebrates

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The characterization and suitability of benthic marine habitats for biota are largely determined by hydrography and surficial geology which can be expressed in terms of "disturbance" and "scope for growth". This relationship made possible the development of a broad-scale modeling approach primarily using hydrographic data. The model produces maps, which characterize habitats in terms of their "scope for growth" for biota as well as mechanical "disturbance". This approach is based on theoretical work by Southwood (1977, 1988) which had been implemented in spatial modeling and successfully applied to benthic habitat mapping (Kostylev 2005, Kostylev and Hannah 2007).

The habitat types modeled from interactions of physical variables reflect sensitivity of seabed habitats and communities to human impacts such as fishery. It is suggested that this approach may be a reasonable and cost-effective tool for fisheries managers seeking to identify important habitats and determine necessary action. Using data collected by the NOAA Northeast Fisheries Science Center and other sources we produced a broad-scale benthic habitat map of the Gulf of Maine. This habitat template is compared to the distributions of select groups of benthic invertebrates. The array of benthic organisms displays distinctive geographical variation in the Gulf of Maine, reflecting differences in sediment composition, depth, temperature, food availability and hydrography. The species distributions of some taxonomic groups appear to be reasonably associated with the defined habitat types.

High-resolution delineation of acoustically homogeneous areas in multibeam backscatter maps

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A complete description of essential seafloor habitats requires the analysis of multiple properties acquired from the seafloor, the water column, and the surface properties. Nevertheless, one essential step in this analysis is the characterization of the seafloor substrates. There were attempts to accomplish this task through optical techniques, which offer the ability to provide very high-resolution (mm-scale) images of the seafloor, but the limited propagation of light in seawater severely restricts the seafloor area that can be

covered. A more viable option are acoustic techniques, mainly multibeam echosounders (MBES) , which offer the ability to cover broad areas with high spatial resolution and thus the ability to provide detailed maps of morphology and rugosity. Calibrated acoustic backscatter acquired by multibeam sonars can be used to provide estimates of the grain size and impedance (the product of sound speed and density) of the sea floor through the inversion of acoustic backscatter model that takes into account the angular dependence of backscatter (ARA – Fonseca and Mayer, 2007). The use of angular dependence for seafloor characterization is normally limited to "patches" of the seafloor that have dimensions on the order of the swath width of the sonar, thus constraining the spatial resolution of the characterization process. In order to surpass this limitation a "thematic" approach was developed to analyze seafloor backscatter data – however the thematic approach requires an *a priori* delineation of areas of the seafloor with common acoustic response. We present a new automatic approach for delineation of areas representing different acoustic facies. The technique is not directly dependent on the mosaic, the appearance of which is affected by the particular method of its construction (the mosaic is essentially an example of many-to-one mapping), and utilizes all the backscatter data available for the survey. Automatically determined boundaries derived using this approach correlate well with those obtained by manual procedures and available groundtruth data yet have much higher resolution. Thus, the new approach provides a rapid, unbiased and objective process for the high-resolution delineation of regions of the seafloor of common acoustic response which can then be input into an appropriate inversion model for seafloor characterization.

In recent years, many attempts have been made to develop automatic methods for segmentation of hydro-acoustic remote sensing data acquired by multibeam echosounders in order to generate quantitative estimates of the spatial distribution of seafloor relief, bottom type and composition. The majority of the segmentation methods presented so far have been based on image processing techniques, which assume implicitly that the backscatter mosaic reflects all the available backscatter data. This limits their ability to unambiguously discriminate seafloor properties, as the primary observation of an MBES is not backscatter imagery or mosaics, but rather backscatter angular response. Mosaics are only projections of the original observations, with resulting loss of information. The method we are developing is fully automatic and attempts to segment the acoustic remote sensing data simultaneously in the image-textural space and in the angular-response space. The output of this automatic procedure is a thematic map, where the individual themes have boundaries defined at the mosaic image resolution, but still have sufficient angular coverage to allow for seafloor characterization. Angular Range Analysis (ARA) inversion is then applied to the average angular response of individual themes, generating estimates of the acoustic impedance, acoustic roughness, and mean grain size of the seafloor within each theme. The technique described above is applied to a Simrad EM1002 95kHz MBES dataset acquired from a study area covering an offshore reef at Stanton Banks, UK. The results are compared to still photo images, grab samples and previous habitat maps existent in the area, to asses the ability of the acoustic theme segmentation to discriminate benthic habitats.

A spatially explicit assessment of the adverse effects of fishing on benthic habitats in the Northeast U.S.: the Swept Area Seabed Impact model

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To assist fishery managers in meeting the requirement of the U. S. Magnuson-Stevens Fishery Conservation and Management Act to minimize to the extent practicable the adverse effects of fishing on fish habitats, a team of regional scientists has created a spatially explicit model that estimates bottom-tending gear impacts on the seabed, as conditioned by the vulnerability of benthic habitats likely to be encountered during fishing. The model combines fishing effort data with substrate data and sub-surface water flow velocity estimates in a geo-referenced, GIS-compatible environment. Fishing effort is scaled according to gear- and habitat component-specific susceptibility values, and decays over time according to a habitat component-specific recovery parameter. The result is a relative estimate of the magnitude of potential and/or actualized fishing effects on benthic habitats.

Poster Abstracts

Shallow natural gas as a potential seafloor geo-hazard for infrastructure development: The case for subsurface mapping in the Gulf of Maine

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With the push for clean and secure energy, and a growing appreciation of the Gulf of Maine's potential for wind and tidal power generation, the Gulf of Maine is poised to become a major site for coastal and offshore energy production. Although not found in economical quantities, natural gas, or methane, occurs throughout Maine's muddy coastal embayments and in the Gulf's deep basins, and represents a risk to offshore development. Along the Gulf of Maine coast, large seafloor craters, or pockmarks, proliferate. These features were formed within the past 12,000 years and are associated with catastrophic seafloor fluid (gas and water) escape events. The frequency and magnitude of these fluid escape events is uncertain, and evidence suggests they may be ongoing. Natural gas in the Gulf of Maine's seafloor, thus, puts at risk offshore development that occurs in

ignorance of this potential hazard. Although some indicators of past fluid escape are recognizable in bathymetric studies (pockmarks), present day shallow natural gas deposits require subsurface data for identification. Seismic reflection data collected in tandem with bathymetric data offers a cost-effective, first-order method for identifying: a) areas where the potential hazards of seafloor gas, pockmarks, and other features may exist; b) benthic habitat critical to fisheries; and c) sediment types useful in siting offshore infrastructure.

Map Once, Use Many Times: An Interagency Effort to Improve the Efficiency of Ocean and Coastal Mapping

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Many organizations in government, academia, and the private sector are engaged in mapping ocean and coastal regions. Because data sharing and coordination of effort can reduce costs, the U.S. Interagency Working Group on Ocean & Coastal Mapping (IWG-OCM) is developing a registry of planned, ongoing, and completed field activities and a clearinghouse for geospatial data within Geospatial One-Stop (GOS, http://geodata.gov). IWG-OCM is working with the GOS project team to improve the usefulness of these services for the ocean and coastal mapping community. This poster requests your advice.

Program managers are faced with many sound proposals for data-acquisition projects, and limited budgets. Managers need to know whether other organizations have already acquired any of the relevant data, or are planning to acquire them soon. Geographical and topical queries against the metadata holdings of GOS can provide this information. IWG-OCM needs to know what search criteria and interface would make this task easier and what type of report would best document the need for data acquisition.

Data collections and data servers are only useful if organizations know they exist. Publishing metadata to GOS increases data visibility. GOS offers a variety of methods for publishing metadata, including automatic harvesting protocols. IWG-OCM needs to know which metadata publishing methods or processes would be helpful and what kinds of reports on published metadata would be useful.

Often research projects have time and budget constraints that rule out data-acquisition activities and must depend on data that have already been acquired. Geographical and topical queries for data registered with GOS provide this information. IWG-OCM needs to know what search criteria and interface would make this task easier and what information would provide quick indicators of data suitability.

Data-acquisition partnerships strengthen a project proposal while reducing the cost to each organization. A project manager needs to know which organizations have expressed interest in acquiring data of the same type and location. The Marketplace section of GOS provides this information. IWG-OCM needs to know what search criteria and interface would make this task easier and what information would provide quick indicators of data suitability.

Evaluation of image-based multibeam sonar backscatter classification for benthic habitat discrimination and mapping at Stanton Banks, UK,

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In recent years, efforts have increased to develop quantitative, computer-directed methods for segmentation of multibeam (mbes) backscatter data. This study analyses mbes backscatter data collected at Stanton Banks (UK) through the *QTC-Multiview* software environment to evaluate its ability to perform unsupervised classification. Statistical comparison with ground truth data (grab, stills and video) enabled cross validation of acoustic segmentation and biological assemblages observed at the site. Using established algorithms, 132 unspecified variables were extracted from user-specified rectangular patches of the backscatter image, reduced to three vectors by PCA, then clustered and classified in 3-D vector space. Multivariate analyses of ground truth data were conducted on 75 stills images and 51 grab samples. Video footage coincident with the 29.3% of the stills was divided into 30s segments and coded by dominant substrate and species. Crosstabulation determined the inter relationship between software classification, multivariate analysis of the biological assemblages and coded video segments. *Multiview* optimally identified 19 classes using the automated clustering engine. These were revised to 6 habitats, which broadly correspond to major physiographic provinces. Multivariate statistical analysis reveals low levels of assemblage similarity (<35%) for samples occurring within *Multiview* classes, irrespective of the mode of acquisition. Coded video data is more spatially appropriate than the other methods of ground truthing investigated, although it is less well suited to the extraction of truly quantitative data. Multivariate analysis indicates assemblages within physiographically distinct *Multiview* classes have a low degree of biological similarity, supporting the notion that abiotic proxies may be contraindicative of benthic assemblage variations. *QTC*-30 *Multiview* performs well as a mechanism for computer-assisted segmentation of mbes backscatter imagery into acoustic provinces, however a degree of caution is required prior to ascribing ecological significance to these classifications.

Putting the "H" in EFH: Mapping Essential Fish Habitat in the Northeast U.S.

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Essential fish habitat (EFH) was identified and mapped for federally-managed marine fish species in the Northeast region of the U.S. (North Carolina to Maine) in 1998. As required by the Magnuson-Stevens Fishery Management and Conservation Act, EFH designations for 24 species managed by the New England Fishery Management Council (NEFMC) are currently being revised as a first step in a process that will re-examine how best to minimize the adverse impacts of fishing on EFH. Maps of the original designations relied heavily on spatially-defined relative abundance information (average numbers of fish caught per tow in ten minute squares of latitude and longitude) compiled from 35 years of continental shelf trawl surveys performed by NOAA's National Marine Fisheries Service (NMFS), without any habitat-related information. The proposed new EFH maps are based on a longer time series of NMFS survey data, inshore state trawl surveys, correlations of survey catch rates with depth, bottom temperature, and sediment type, and geo-referenced information on the regional distribution of these three habitat features. Habitat-related data sources included NOAA National Geophysical Data Center Coastal Relief Model 3 arc-second raster bathymetry data, the US Geological Survey usSEABED substrate database, and seasonal bottom temperatures collected during a variety of NMFS surveys on the continental shelf. Substrate and temperature data were compiled by ten minute square. Revised EFH maps will also include areas beyond the edge of the shelf that are utilized by species managed by the NEFMC. New EFH designations are expected to be implemented in 2011.

Evaluating Local Lobster Population Dynamics with Geo-referenced Trap Arrays, Mark-recapture Methods & Seabed Mapping

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Combining habitat mapping, spatially referenced trap arrays and mark recapture modeling can be a powerful approach to characterize population dynamics of lobsters and crabs on geographic scales of 1-100 square km. A proof-of-concept study is described that develops and tests the approach to evaluate the dynamics of lobster populations on four 1-km-scale study areas in coastal Maine. Mark-recapture-based abundance estimates from these trap arrays were validated by concurrent diver visual surveys in the study

areas. Impact assessments are prime application of the method. An impact study is described of sediment disposal on spatial and temporal trends of lobster and crab abundance and movement during the weeks immediately following one such perturbation in Penobscot Bay, Maine.

TECHNICAL WORKSHOP ON LIFE HISTORIES OF GULF OF MAINE FISHES AND INVERTEBRATES

Session Summary

Session Organizers
Jake Kritzer, Environmental Defense Fund (jkritzer@edf.org)
Jamie Cournane, University of New Hampshire & Environmental Defense Fund (jleff@unh.edu)

I. Introduction

Goals:

1) Examine species for which life history information is lacking or uncertain, and discuss methods for overcoming these obstacles.
2) Describe and explain spatial and temporal patterns in life history traits as determined by natural and anthropogenic factors.
3) Explore the implications of life history patterns for species distributions, stock productivity and management strategies.

Background: Basic life history traits, including growth, mortality, migration, maturation, fecundity, spawning and recruitment, are the drivers of population dynamics. These traits determine how many individuals exist in a population, how large they become, where they are located in the ocean, when they beginning spawning, how frequently they spawn, how many offspring they produce, and even the survivorship of their offspring. As such, these traits are key inputs into stock assessment models, and therefore play a pivotal role in our understanding of the status of a stock and the management strategies we develop. Yet, our estimates of these traits often receive less scrutiny than, for example, the accuracy of landings and discard data, despite the pronounced effects they can have. Many estimates are uncertain due to limited research on the species in question, aspects of the species' biology that make estimation difficult, or both. Furthermore, many of these traits vary naturally in space and time, or have changed due to effects of fishing, altered food web structure, changes in temperature, lower water quality, or other factors. Not only are life history traits responsive to the surrounding ecosystem, but these traits can in turn affect the ecosystem through the species' role as predator, prey or other functions. Understanding the nature of changes in and effects of life history traits is essential for effective management in either a single species or ecosystem-based context because failure to do so can lead to management strategies that exacerbate the changes induced if the stressors are not corrected. Fisheries stock assessments have become increasingly sophisticated and complex as analytical tools have developed and data sources have grown, and will become even more so as we continue to move toward EAM. Understanding the underlying demographic processes that shape fish stocks and their role in the ecosystem will be as, if not more, important in this new paradigm. This session provided a synopsis of the status of this important area of research.

II. Conclusions and Broader Applications to EAM

The eight presentations in this session and panel discussion following those presentations, bolstered by valuable audience questions and comments, explored three key themes outlined below:

a. Attention to basic biology cannot be lost.
The session began with two presentations that did not address ecosystem science or management, but rather addressed fundamental challenges in deriving estimates of life history traits of harvested species. Beth Wetterhahn focused on the Atlantic herring, a species that is increasingly becoming the focus of ecosystem-based studies given its role as a forage fish. Despite growing prominence of the species in an ecosystem framework, Beth noted concerns with existing age estimates for herring, and described her work to improve those estimates by incorporating otolith weight as a covariate in the analysis. Fiona Hogan discussed her work on the Gulf of Maine skate complex, a group of species for which we generally lack any age estimates with which to derive life history traits. At present, skates are managed collectively as a stock complex, but Fiona's work suggests that life history differences challenge the wisdom of that approach. During the closing panel discussion, Bob O'Boyle highlighted the importance of work such as that being done by Beth and Fiona to strengthen contemporary single-species management, and ensure that we understand individual species basic biology as best we can before moving into an ecosystem context.

b. Ecosystem attributes and processes have clear but complex effects on life histories.
The next three presentations demonstrated how physical, chemical and biological characteristics can induce variation in life history traits that have important implications for both population and ecosystem dynamics. Marie-Jose Abgrall showed how recruitment of softshell clams, one of the first major life history events a species experiences, is not random in space, but rather driven strongly by organic matter and other aspects of sediment geochemistry. Charlene Bergeron examined patterns of lobster growth across a large spatial scale, spanning the Gulf of Maine and into southern New England, and found differences in growth rates and trajectories that are in part temperature-driven. Her work indicates how changes in ocean temperature that emerge due to climate change might alter stock dynamics and ecosystem function of lobster. Shelly Tallack also examined growth patterns across the Gulf of Maine using an extensive tagging study of Atlantic cod. She also documented clear spatial patterns, reinforcing the growing body of information on the complex spatial structure of cod stocks.

During the panel discussion, Bob O'Boyle called attention to the clear message of spatial patterns, and suggested that both single species and ecosystem modeling work will need to increase spatial resolution. Jon Grabowski highlighted the important links between habitat attributes and life history traits in addition to the physical and chemical parameters discussed by the presenters, but also noted the limited quantitative information on these effects. Jon and others endorsed research on the relationship between habitat metrics and stock productivity as key priority in an EAM context. Bob, Jon and Ed Trippel all commented on the need to build better avenues for getting these

types of studies in the stock assessment and management processes to ensure that they are used most effectively. Panelist Karen Wilson noted that river herring and other diadromous species spawn and use nurseries in freshwater and estuarine areas for which we have fairly good habitat and water quality information, but spend the majority of their lives in the open ocean that is largely a "black box" in their life cycle. Finally, panelist Jeffrey Runge pointed out that temporal patterns can be just as or perhaps even more important than the better studied spatial patterns. He called attention to the science of phenology, or the study of timing in life histories, and how phenological changes can have ripple effects across ecosystems.

c. Life history patterns determine species' impacts on ecosystems.

The final trio of presentations examined emergent properties of life history patterns, wherein attributes at the organismal level scale up through individuals to drive evolutionary, population and ecosystem dynamics. Following Shelly Tallack's talk on spatial variation in cod growth, her GMRI colleague, Graham Sherwood, discussed sympatric differences in life histories evident in both Newfoundland and in the Gulf of Maine that are driven by different feeding, spawning and migratory strategies. Graham noted that spatial management strategies, which are often incorporated as part of EAM, could have the unintended consequence of increasing effort on more migratory genotypes that move beyond protected area boundaries. Ed Trippel discussed the work of NAFO's Working Group on Reproductive Potential, which is moving beyond simple gross biomass metrics to more complex demographic factors (e.g., age and size structure) in understanding stock productivity. The Working Group's efforts align closely with EAM because the ecosystem function of a stock is determined not only by overall abundance or biomass, but also by its composition. Jenn Dijkstra provided a poignant reminder that not all ecosystem-based science and management issues of concern to the Gulf of Maine fall within the typical bounds of fisheries science. She described her work uncovering the physiological and life history determinants of invasion success in non-native ascidians. Although invasive species ecology is often separate from fisheries science, these invaders overgrow and outcompete native benthic organisms that may be fishery targets, or may create habitat or serve other ecosystem functions.

Complementing Jenn's call for attention beyond solely fishery targets, Theo Willis issued a call during the panel discussion for much greater attention to the needs, motivations, behaviors, and other complexities of the human component of the ecosystem. At present, human needs and behaviors are often incorporated simply as fishing mortality rates applied and revenue earned. However, we are a species at least as complex as those for which we are uncovering variation and change in life histories, and our complexities need to be considered as well. Audience member and fishing industry representative Jean Guy d'Entremont seconded Theo's call, conveying that the industry wants to develop effective science and management systems that are workable for all stakeholders and the resources.

Agenda and Oral Abstracts

10:00 – 10:20	Introduction to the workshop **Jake Kritzer**
10:20 – 10:40	Can otolith weight improve age estimation techniques for Atlantic herring (*Clupea harengus*)? **Elizabeth Wetterhahn*, Jason Stockwell, and Blanche Jackson**
10:40 – 11:00	Validating the age of little and winter skate in a captive rearing experiment **Fiona Hogan*, Steve Cadrin, and Ken Oliveira**
11:00 – 11:20	Break
11:20 – 11:40	What makes a clam happy? Importance of substrate geochemistry in the settlement and recruitment of the softshell clam *Mya arenaria* **Marie-Josee Abgrall, H. Hunt, and G. Miron**
11:40 – 12:00	Developing regionally specific growth models for the American lobster: revealing spatial variability and environmental forcing **Charlene Bergeron, Richard Wahle, and Yong Chen**
12:00 – 1:30	Lunch
1:30 – 1:50	Regional growth estimates of Atlantic cod, *Gadus morhua*: applications of the maximum likelihood GROTAG model to tagging data in the Gulf of Maine (USA/Canada) region **Shelly M.L. Tallack***
1:50 – 2:10	Potential ecotypes in cod: Implications for management and recovery **Graham D. Sherwood*, Jonathan H. Grabowski, Mathew Windle, and George A. Rose**
2:10 – 2:30	Activities of the NAFO Scientific Council Working Group on reproductive potential **Edward A. Trippel***
2:30 – 2:50	Break
2:50 – 3:10	Linking life-history characteristics, biogeography and success of non-natives in subtidal communities in the Gulf of Maine

Jennifer A. Dijkstra*, Erica L. Westerman, Cameron Brooks and Larry G. Harris

3:10 – 3:50 Panel discussion on key scientific issues regarding life histories
Panelists: Jonathon Grabowski, Gulf of Maine Research Institute; Robert O'Boyle, Beta Scientific; Jeffrey Runge, Gulf of Maine Research Institute; Theo Willis, University of Southern Maine; Karen Wilson, University of Southern Maine

3:50 – 4:00 Wrap-up and adjourn

Can otolith weight improve age estimation techniques for Atlantic herring (*Clupea harengus*)?

Elizabeth Wetterhahn*[1], Jason Stockwell[1], and Blanche Jackson[2]

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Methods for age estimation of fish have largely relied on counting the annual growth rings of otoliths and scales. However, relying on these techniques when age-validation studies or other independent methods are not available to evaluate results can be problematic. Inaccurate age estimates can have potentially significant impacts on stock assessments and subsequent management strategies. Development of age-length keys is a critical step for determining the age-structure of fish populations. Length measurements and age estimates of a subset of individuals from a sample or population are used to estimate the proportion of each age class within a series of length strata. These proportions, or age-length keys, can then be applied to a larger subset of length-frequency data for which ages are not known, which can then be expanded to represent the age-composition of the population in question. In this study, we examined if using otolith weight as a variable could improve age-length keys of Atlantic herring (*Clupea haengus*) collected from the Gulf of Maine between May 2008 and April 2009. Lengths of individual fish ($n \approx 1{,}200$) were recorded and otoliths were extracted, weighed to the nearest 0.001 mg, and mounted for age estimation. We then developed age-length keys with and without otolith weight as a predictor variable. We applied the two keys to population assessment data to compare estimates of age composition. Our expectation is that otolith weight will improve age-length keys, particularly for older age-classes.

Validating the age of little and winter skate in a captive rearing experiment

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The northeast US skate complex is composed of seven skate species. The skate complex has been designated as a data poor stock, with inadequate information on life history characteristics. An age validation study has been initiated in order to provide reliable age data on little and winter skates. Adult little (*Leucoraja erinacea*) and winter (*Leucoraja* ocellata) skates were given an intraperitoneal injection of tetracycline and maintained in a seawater laboratory facility for a minimum of one year. To reduce stress on the captive individuals, seasonal temperature experienced in the natural environment were identified for both species and recreated in a temperature-controlled recirculating seawater system as closely as possible. Tetracycline was successfully incorporated into the vertebrae of injected adults. As part of an exploratory study to validate the formation of the birthmark, egg cases of little and winter skates were injected with tetracycline. Two trials of injections were conducted: (a) tetracycline directly injected into the yolk-sac; and (b) tetracycline injected into the cavity of the egg case. Neither trial indicated tetracycline was incorporated into the vertebrae of the developing embryos. Tetracycline validation will improve the age estimates used in the management of these species. In addition, it will aid in the fulfillment of the recommendations from the Northeast Data Poor Stocks Working Group.

What makes a clam happy? Importance of substrate geochemistry in the settlement and recruitment of the softshell clam *Mya arenaria*

Abgrall*1 M.-J., Hunt1 H., and Miron2 G.

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The softshell clam Mya arenaria is one of the most ecologically important bivalve species found in soft sediments along the coastal waters of the Maritimes and New England, influencing primary production and nutrient cycling. This species also has a long history of exploitation and is considered commercially important. However, important declines in landings have been observed due to closures of clam flats. In some areas, these closures are a result of increasing H2S contamination, usually correlated with an accumulation of organic matter. In addition to H2S formation, the bacterial breakdown of organic matter can lead to increases in sediment's acidity and depletion of O2, rendering the sediment unsuitable for early stages of softshell clams. To provide a better

understanding of how sediment geochemistry (organic matter and H2S) may affect settlement and recruitment of M. arenaria and to determine whether high organic matter and high H2S concentrations have detrimental effects on clams, field measurements of sediment geochemisty, bedload transport, larval settlement and abundance of postlarvae were conducted at Kouchibouguac National Park, NB. In the Park, declines in the previously healthy clam populations have been partially linked to rapid changes in sediment geochemistry and increasing H2S contamination, a situation also observed in salt marshes around the Gulf of Maine. Preliminary data suggest that softshell clam larvae may actively settle in relation to sediment geochemistry. Resuspension rates of post-larvae transplanted into sediment with various concentrations of organic matter tended to be higher when exposed to high concentrations of organic matter and high concentration of H2S. Burrowing depth appeared to be shallower and burrowing rate tended to be slower at higher concentrations of organic matter. Abundance of early age classes was, in general, very low in sediment with a high concentration of organic matter, suggesting poor recruitment in organically rich habitats or important post-settlement losses caused by resuspension. This study suggests that the sensitivity of a clam population to anoxia and H2S may depend on which life stages have been exposed. Therefore, it is essential to look at the sediment geochemistry which is likely to influence the most sensitive life-stages of Mya arenaria in order to adequately predict the fate of its populations.

Developing regionally specific growth models for the American lobster: revealing spatial variability and environmental forcing

Charlene Bergeron[1,2], Richard Wahle[1], Yong Chen[2]

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The Gulf of Maine and northwest Atlantic shelf waters are characterized by dramatic regional differences in temperature and other environmental conditions that have important consequences for fishery productivity. For long-lived marine crustaceans, like the American lobster (*Homarus americanus*), that have no morphological age markers, this adds complexity to the already difficult challenge of estimating size-at-age, which can be highly variable within the species geographic range. Current growth models fail to incorporate individual growth variability and therefore are of limited use for stock assessment models. Here we present a stepwise growth model for the American lobster that offers a new approach to age determination by integrating two growth analysis methods traditionally used independently, (1) modal analysis of size-frequency distributions of early juveniles for which we have reasonable estimates of absolute age, and (2) mark-recapture studies of older juveniles and adults giving estimates of relative age and growth. We compare growth curves developed for three oceanographically distinct regions for which these data are available: the southern New England shelf, central Gulf of Maine, and the Bay of Fundy. We further incorporate bottom temperature time series from each region as growing-degree-days (GDD) to account for regional differences in growth trajectory. By broadening the size range of lobsters contributing

empirical growth data as well as incorporating key environmental factors that influence growth in this way should provide more biological realism to population dynamic models.

Regional growth estimates of Atlantic cod, *Gadus morhua*: applications of the maximum likelihood GROTAG model to tagging data in the Gulf of Maine (USA/Canada) region

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The maximum likelihood GROTAG model was applied to mark-recapture data collected by the region wide, collaborative 'Northeast Regional Cod Tagging Program' to provide new, supplementary growth estimates for Atlantic cod, *Gadus morhua*, in the Gulf of Maine (USA/Canada) region. The dataset (114,467 releases and 6334 recaptures) were filtered for quality, resulting in 3675 growth records which were categorized into stock management areas (5Y, 5Z and 4X) and fine-scale general areas (Inshore Gulf of Maine, Georges Bank, Cape Cod and the Bay of Fundy). Growth seasonality was detected and region-wide, growth peaked during July. The overall regional von Bertalanffy estimate for cod was $L\infty$ = 135.3cm and K = 0.17, however statistically significant variation was found between management areas and between general areas throughout the study region. The fastest growth (K = 0.31) and smallest asymptotic size ($L\infty$ = 105.7) were found for 5Z cod, while cod in 5Y showed slower growth (K = 0.13) but a larger asymptotic size ($L\infty$ = 151.3); estimates for the Canadian management area 4X ($L\infty$ = 117.5, K = 0.22) were most similar to the 5Z estimates. Least squares analysis of length-at-age data yielded comparable results. The Inshore Gulf of Maine estimate ($L\infty$ = 154.5, K = 0.13) was highly consistent with that for management area 5Y; similarly, the Georges Bank estimate ($L\infty$ =104.1, K = 0.26) supported the 5Z estimate. However, more variability was seen in estimates for the Bay of Fundy ($L\infty$ = 134.2, K = 0.16) and Cape Cod ($L\infty$ = 173.5, K = 0.13). The differing growth rates between regions are thought to be influenced by cod movement patterns, GROTAG methodology and the number and size–structure of fish sampled in each region.

Potential ecotypes in cod: Implications for management and recovery

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Previous tagging studies in cod have focused on describing contemporary stock structure and/or average movement behavior of individuals within putative stocks or populations.

Within-population variations in movement have been largely ignored due likely to the absence of ancillary information (e.g., diet, growth, body morphology, color, genetics) that could put tagging results into an evolutionary and ecological framework. At the same time, the existence of life-history variants (movement and feeding ecotypes/morphotypes) is being demonstrated in a large number of other fish species (primarily freshwater and diadromous) where the migrant form is usually the most productive. In this presentation, we will present early results from Newfoundland and the Gulf of Maine that suggest cod may also be adopting alternative life-history strategies. Specifically, in one spawning population from Newfoundland, the existence of nearshore, benthic residents versus offshore, pelagic migrants was established using acoustic telemetry and stable isotope (diet) analyses. In the Gulf of Maine, an ongoing study is showing that red coloration in cod is correlated to life-history traits consistent with a sedentary life style. Red cod may be an extreme expression of residency, but this is not to say that all resident cod should be red. Future cod tagging studies should consider within-population (fine-scale) variation in movement behavior, and if ecotypes do indeed exist, management should consider the possibility that poor recovery may be related to a change in the relative frequency of ecotypes with the fishery being dominated by the less productive (resident) form.

Activities of the NAFO Scientific Council Working Group on reproductive potential

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The objectives of the NAFO Working Group on Reproductive Potential are to provide an international forum to develop protocols for the assessment of reproductive attributes of marine fish populations and to apply this knowledge to improve scientific advice for fisheries management. The Working Group has been in existence for a decade and is comprised of 21 members representing nine countries. The 3rd Terms of References (ToRs) specifically sets out to (1) explore and conduct evaluation of underlying assumptions of protocols used to estimate total realized egg production (2) investigate the potential effects of changes in water temperature and food supply on reproductive success, and (3) undertake an appraisal of methods to improve fish stock assessments and fishery management advice that incorporate new biological data for highly exploited and closed fisheries. Recently, it is has integrated some of its activities with the EU COST Research Network Action Fish Reproduction and Fisheries (FRESH). Mutual benefits of having the two groups meet together were achieved as both have complimentary science and management advice objectives. ToRs will be explored for stocks in the NAFO area where possible (e.g. 3LNO American plaice 3NO cod, 3M cod, Georges Bank cod, and others) but stocks from the northeast Atlantic will be included as additional sources of information (e.g., Baltic cod, North Sea plaice and others). A Workshop is scheduled in 2011 to help facilitate the transfer of techniques developed by WG members to stock assessment personnel that routinely conduct stock assessments.

Linking life-history characteristics, biogeography and success of non-natives in subtidal communities in the Gulf of Maine

Jennifer A. Dijkstra[*1], Erica L. Westerman[2], Cameron Brooks[3] and Larry G. Harris[3]

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Physiology has been used to establish the biogeographic distribution of multiple ectothermic species (e.g., mussel, tunicate, crab). However, the connection between predicted distribution of species, their dominance and impacts on local communities is not well understood. Here, we link the physiology of non-native Botryllid ascidians to temperature, growth, and biodiversity using a combination of field and laboratory experiments. Adult colonies of each *B. schlosseri* and *B. violaceus* were exposed to abrupt temperature fluctuations (4 °C, 10 °C, 15 °C, and 20 °C) in the laboratory. Heart rates, physiological system that reflects stress in marine invertebrates, were used to assess the condition of individual colonies and monitored approximately every other day for two weeks. Growth rates of species were also calculated over this same period. Spatial dominance of colonial ascidians and diversity in the field were documented using 100cm^2 Plexiglas panels deployed in June 2006 and photographed after three months at four sites in the Gulf of Maine (Salem, MA, Portsmouth Harbor, NH, Damariscotta Estuary, MA and Eastport, ME). The location of each of the four sites represents a gradation in temperature. In the coastal Gulf of Maine sites, temperature ranges from -1 °C to 25 °C. Results revealed that heart rates and growth rates of both *B. schlosseri* and *B. violaceus* increased with rising temperatures. However, *B. schlosseri* experienced greater growth than *B. violaceus* at lower temperatures while *B. violaceus* experienced greater growth at higher temperatures. Understanding the mechanistic basis of regional biogeography and biodiversity patterns is critical to predict the potential effects of global warming on ecosystem function.

NORTHEAST REGIONAL OCEAN COUNCIL (NROC) ECOSYSTEM HEALTH WORKSHOP— ASSESSING LINKAGES BETWEEN ECOSYSTEM HEALTH AND MEASURES TO EVALUATE CHANGE

Session Summary

Session Organizers:
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Background: The Gulf of Maine Council and the Northeast Regional Ocean Council (NROC) are in a unique position to promote the use of coastal and ocean ecosystem health reporting and indicator initiatives within New England by state legislators, agency decision-makers, members of Congress and the region's Governors.

NROC, COMPASS, and other partners have formed a USA/CA steering committee to convene an ecosystem health workshop this winter to discuss avenues for more effective coordination and collaboration among the various governmental entities to, among other things, better communicate the results and importance of their work to policymakers, managers, and the media. New linkages among regional efforts could be created to be mutually-supportive and connected.

Goals: This Technical Session at the Gulf of Maine Science Symposium will be used to:

- Comment on the draft straw man definition of ecosystem health and discuss how it can be implemented in the Maritimes & the northeast (e.g., legal standards for implementing an ecosystem-approach to management, etc.); and
- Review an inventory of the region's ongoing ecological and socio-economic indicator initiatives and identify ways to promote more collaboration amongst these efforts.

Structure: Facilitators will lead participants through two 1.5 hr. sessions, each dedicated to obtaining feedback on the goals above.

Context & Objectives

There are numerous emerging and existing indicator efforts within (and outside of) the Gulf of Maine region. While each effort has its specific objectives, funding, geographic scale, and scope, they are all driven by the same overarching goal of providing metrics to inform coastal ocean resource management and to communicate conditions to an array of stakeholders. Emerging efforts should be communicating to ensure appropriate deployment of financial resources, utilization of people's time, consistent messaging, and proper coverage of regional needs. New initiatives should also build on the foundation of existing and past indicator efforts.

The objectives of this session were to gain input on the efficacy of a regional definition of ecosystem health while responding to a compilation of definitions from around the world and; to understand whether there is a need for more communication among those involved in indicator efforts in the region. The session was split in two with an hour and a half devoted to each objective. The input and conclusions will guide the development of an ecosystem health workshop to be held Spring 2010.

Conclusions

Participants believed there was value in organizing and convening a workshop for those engaged in current or emerging indicator initiatives to:

- offer a few straw man definitions of ecosystem health for use with different audiences with an understanding that health means different things to different people and a recognition that definitions will change as stakeholder' values evolve;
- discuss the region's ongoing ecological and socio-economic indicator initiatives, relevant national indicator initiatives, and identify ways to better integrate and strengthen these efforts with the specific purpose of more consistent messaging and communication to policymakers and users; and,
- if useful insights were gained from the above, create recommendations for Massachusetts as they create their own suite of indicators for use with the MA Oceans Plan.

Future Goal: Engage legal experts with a goal of spending some time thinking about developing legal standards for EAM for inclusion in existing and new State statutes throughout the region.

Considerations for EAM

We are particularly interested in convening those working on various aspects of this issue to ensure the following:

- Shared Communications – With the adoption of straw-man definitions of ecosystem health, we could begin to develop similar messages about the goals and

objectives of the various indicator efforts particularly in relation to protecting/conserving key ecosystem services. The efforts within the region, while unique from one another, share remarkably similar audiences. This workshop could be an opportunity to brainstorm how to present these metrics in ways useful to primary audiences.

- Data Sources – It will be critical to leverage those initiatives that have already gone to data providers to avoid "data fatigue".

- Shared Understanding – As we review the indicator work together, we can potentially set up some ongoing mechanism to continue to share, consult and advise on using indicators to enable EAM.

APPENDIX 1— INDEX OF CONTRIBUTING AUTHORS

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