The Gulf of Maine Program
of the Census of Marine Life

BIODIVERSITY IN SUPPORT OF INTEGRATED OCEANS MANAGEMENT

THE IMPLEMENTATION PHASE

A proposal submitted for consideration
by the Alfred P. Sloan Foundation
October 2002

University of Southern Maine
96 Falmouth Street
Portland, Maine 04101-9300
(207) 774-9844 fax (207) 773-8672

Evan D. Richert
Principal Investigator

Lewis S. Incze, Ph.D.
Co-Principal Investigator

Amount Requested
January 1, 2003 – $ 576,365
January 1, 2004 – $ 567,218
January 1, 2005 – $ 500,939

_____ _____
Evan D. Richert Date
Associate Research Professor

_____ _____
Larry Waxler Date
Director, Office of Sponsored Programs

EXECUTIVE SUMMARY

This proposal will be the first stage of implementing the goal articulated in the Gulf of Maine Program's Science Plan:

To gain enough knowledge to enable ecosystem-based management in a large marine environment within ten years. The Program will advance knowledge of both biodiversity and ecological processes over a range of trophic levels (from plankton to whales) and habitats.

The principal outputs will be:

- An upgraded and expanded Gulf of Maine Biogeographic Information System (GMBIS), spatially and temporally reconciled, and attached to the Internet using GIS software.

- A 3-part field program involving:

    - at least six research projects aimed at understanding the biodiversity of life in the benthos, the biodiversity of the slope sea and seamounts bordering the Gulf of Maine, and the role of predation by large fish and mammals in the dynamics of the ecosystem;.

    - additional field studies to be developed by working groups under the Scientific Steering Committee, as guided by the needs specified in the Program's statement of Program Directions (the initial Science Plan); and

    - Bringing ongoing studies and monitoring programs relevant to the Census into its orbit.

- Development of a technology section of the Program's web site to elucidate the modern tools available to a systematic program of observation and sampling of a spectrum of organisms in a large marine ecoystem.

- Pathways for funding of new field research.

The principal products and outcomes will be:

- An electronic **Dynamic Atlas** with unprecedented access to marine databases for research and, for resource managers and industry, the ability to visualize patterns in the ecosystem;

- A preliminary **"state-of the-ecosystem report,"** available as of the end of the 3-year period, which will be both a building block of the worldwide Census of Marine Life, representing the Gulf of Maine's contribution to date; and a reference work available to support the preparation of a Fisheries (or Ocean

Management Area) Ecosystem Plan likely to be called for in a reauthorized Magnuson-Stevens Act.

- Advanced understanding, both from field studies and the Program's web site, of the **technologies** needed and appropriate to assess the abundance, diversity, and distribution of life in large marine ecosystems.

- Established **partnerships** with agencies and organizations upon which the long-term maintenance of GMBIS (and the Dynamic Atlas) and the monitoring of abundance, distribution, and diversity of marine life will depend.

It is intended that both the products and the process undertaken to produce them will serve as templates for other field programs of the Census of Marine Life involving large marine ecosystems.

CONTENTS

I. BACKGROUND

A. The Census of Marine Life

The Census of Marine Life program began with a meeting in La Jolla, California, in March 1997 (Ausubel 1999) focused on the objective of assessing what is known and unknown about the diversity of marine fishes (Neirenberg 1999). The program has since expanded to conceptually include all life in the sea (Alldredge et al. 1999). Specifically, it seeks to assess and explain changes in diversity, distribution and abundance of life in the oceans. By adopting this broad theme of biodiversity, the program emphasizes that many important features of systems have been largely unsampled or ignored by monitoring and process-oriented studies of the past. The program's goal is to focus attention on these gaps in order to better define ecosystems and manage human activities within them.

A U.S National Research Council workshop urged the structuring of the census program around three questions: **What did live in the oceans? What does live in the oceans? What will live in the oceans?** The first question requires retrospective analysis and new methods for understanding past populations. The second question requires mining existing data bases and new scientific investigations. The last question, what *will* live in the oceans, requires that we understand processes well enough to make predictions.

B. The Gulf of Maine Area

The international Census of Marine Life Program has identified six organized regional projects with a variety of objectives, including technology development and testing, exploration of regions where the biota are not well known, and capacity building in

countries with historically small marine science efforts. The Gulf of Maine area was selected for the first ecosystem-level project.

The Gulf of Maine area is defined for this program as all of the Gulf of Maine, including Georges Bank, Browns Bank, the Bay of Fundy and the bordering continental slope and overlying sea. It thus extends from the upper inter-tidal through all depths to the open Northwest Atlantic Ocean. The program also includes the New England Sea Mounts south of Georges Bank.

II. GOAL OF THE GULF OF MAINE PROGRAM

The initial Science Plan for the Gulf of Maine pilot (titled "Program Directions" and available for review and comment at **www.whoi.edu/gomcensus**) calls for connecting its census of marine life to an overarching societal goal of enabling ecosystem-based management in the Gulf of Maine.

The need for ecosystem-based management in the Gulf of Maine is upon us, and policy mandating it is gathering momentum. In the U.S., it is likely that the reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act will require Fisheries Ecosystem Plans as a supplement to fisheries management plans for individual species or groups of species. In Canada, the Oceans Act of 1997 explicitly recognizes the "fundamental importance" of an ecosystem approach. It requires the application of ecosystem-based principles and tools, for example through the use of precautionary approaches and marine protected areas.

The Science Plan thus states the overarching goal as follows:

> **The goal of the Gulf of Maine Program of the Census of Marine Life is to gain enough knowledge to enable ecosystem-based management in a large marine environment within ten years. The Program will advance knowledge of both biodiversity and ecological processes over a range of trophic levels (from plankton to whales) and habitats.**

In stating this goal and its ambitious timeframe, emphasis is on "enough" knowledge. Some portion of what is unknown about the Gulf of Maine's ecosystem will be converted to the known during the horizon of the Gulf of Maine Program. The Science Plan has identified key areas in which knowledge must increase.

However, a central feature of ecosystems is uncertainty. This derives not merely from not having yet converted all that we might know to the known. Rather, uncertainty is in the very nature of ecosystems. They are dynamic, nonlinear, and driven by the collective behaviour of many smaller-scale units. These ensembles of units do not obey any single "chain of command." Each also is subject to external perturbations and indirect influences. (Walters, 1997) Consequently, much about ecosystems and their futures is unknowable. In turn, it probably is not possible to truly "manage" an ecosystem. (Sissenwine and Mace, 2001) **With adequate knowledge, however, it is possible to manage what human beings do within the system; to predict the directionality of the impacts of human and other perturbations; and, with that knowledge, to apply principles and techniques of ecosystem-based management that will help sustain the biodiversity and abundance of life in the oceans**.

III. PROGRESS TO DATE

Since planning for the Gulf of Maine Program began in 2000, progress has been made on four fronts. This progress has brought the Program to the stage of implementation. The four fronts include organization, science, information systems, and outreach/funding.

A. Organization

A program that aspires to examine components of an entire ecosystem requires a level of organization that goes beyond the normal Principal Investigator team typical of discrete research projects. It must have an overarching goal that links multiple disciplines and interests to a common purpose. Many affected parties must be involved early and intimately. The goal must appeal to scientists, policy makers, participants in industry, and ultimately to funding organizations, with the potential both for new basic understanding and for application to pressing needs. The organizational framework must be "flat" to respect the *modus operandi* of scientific endeavour, but with sufficient gravity and enticements (in terms of access to funds, tools for assistance, control over some products, intellectual reward, etc.) to engage scientists in and direct them toward the Program's mission over a long term.

Progress toward such an organization includes:

- A secretariat (program director and chief scientist) with management experience related to the Gulf of Maine and knowledge of both the Gulf of Maine and systems of scientific support. This secretariat joined the program in July 2002 and is in full operations.
- A Policy Advisory Committee that can present a unified voice for the Gulf of Maine census. The Committee consists of the leadership of federal and state

marine resources and coastal agencies, respected representatives of the fishing industry and conservation interests, and leadership of key academic institutions.

- A Scientific Steering Committee, whose first members have been brought on board.

- Strategic partnerships with organizations, agencies, and individuals whose participation will provide access to important data bases, outreach to industry, and contact with related international endeavours.

- A cooperative relationship with the national Census of Marine Life secretariat to secure U.S. federal funding earmarked for the Census.

B. Science

B-1. Initial Science Plan

The Initial Science Plan has been completed and is the framework within which the Gulf of Maine Program will be carried out. It identifies major gaps in knowledge that must be narrowed to reach the Program's goal. The gaps were identified during a series of workshops with scientists from around the region. The list is not exclusive, but highlights areas with glaring deficiencies of data:

- the diversity and distribution of life on the seafloor (intertidal, near shore, and off shore);

- a large number of under-sampled or virtually unknown species, including certain nekton and the least understood small plankton: viruses, bacteria, and flagellates;

- quantification of the role of predation by large fish and mammals in the dynamics of this large marine ecosystem;

- life in the relatively unexplored slope sea and on the seamounts just beyond the Gulf, and

- the roles of natural vs. human-induced change.

The identification of these gaps in knowledge led to the development of more than a dozen research proposals (see below). However, we believe the definition and

prioritization of the “knowable” within these areas need refinement to increase the rate of success of proposals and to bear down on the overarching goal of the Gulf of Maine Program. Furthermore, the proposals developed to date do not cover the breadth of program needs. These represent immediate tasks for working groups under the Scientific Steering Committee.

.

B-2. Funded Studies

In summer 2002, two studies were funded from NOAA’s Ocean Exploration Program that will advance the Gulf of Maine census, and work has begun. These were funded under the CoML umbrella and became the first new studies of the Gulf of Maine Program. They are:

1. “Biodiversity of Bear Seamount and Vicinity Explorations.” While the geology of the New England Seamounts and their effects on the Gulf Stream have been extensively studied, the biota has been almost completely ignored. This expedition will consist of exploratory trawling of the most inshore seamount of the New England chain to discover the distribution patterns of new and poorly-known species. It will also examine whether and to what extent fauna around this seamount differ from those of the nearby continental slope.

2. “Biodiversity on the Continental Slope off Georges Bank: Resource Potential and Vulnerability to Disturbance.” This integrated survey will use hydroacoustics, video, and trawling to characterize the slope water system in both the pelagic and demersal realms of the continental shelf off Georges Bank. Key objectives include mapping megafaunal

species in relation to habitat type, characterization of the biodiversity of the region, and assessment of potentially vulnerable species or habitats.

More than a dozen other proposals to carry out research in the areas called for by the Initial Science Plan are in various stages of development or have been submitted and/or are being revised. **The Science Plan and its cogent goal will help focus the revisions, bring already funded projects into its orbit, and stimulate the development of new proposals**. Some of these proposals will likely be for basic exploration, some for process studies, and some for pilot or modified monitoring strategies or technology development.

It should be noted that numerous ongoing studies developed and funded independently of the Gulf of Maine Program's Science Plan can nonetheless contribute data and ideas that are closely aligned with CoML's objectives. Excellent and relevant research is taking place, and federal agencies are already preparing for some of the mandates of ecosystem-based management and the conservation of biodiversity. The Gulf of Maine Program is embracing this work, acting as a catalyst and organizer to add to it where gaps in knowledge remain large, and helping to advance the scientific understanding needed for implementation.

C. Biogeographical Information System

A foundation for the Gulf of Maine census has been laid with the successful completion of a proof-of-concept project to create the Gulf of Maine Biogeographic Information System (GMBIS). This joint effort among System Science Applications, Inc., the University of Southern California (Dr. Dale Kiefer), and the Bedford Institute of

Oceanography in DFO-Canada explored how geographical information system (GIS) and Internet technologies can be used to access data bases and address specific questions about the biogeography and status of marine populations within the Gulf of Maine. This proof-of-concept was undertaken using data sets from DFO-Canada's groundfish research trawl surveys and selected other Canadian data bases. It was successfully concluded in 2002.

GMBIS is a part of the developing worldwide Ocean Biogeographic Information System (OBIS). Progress on GMBIS includes understandings that all GMBIS data bases will be OBIS-enabled.

The success of the project paves the way for one of the cornerstone products of the Gulf of Maine census, the Dynamic Atlas of the Gulf of Maine. A three-step strategy that both produces useful interim products and achieves a full Dynamic Atlas within three years has been mapped. (see V. Program Elements).

D. Outreach/Funding

Three important outreach tools are now available to the Gulf of Maine Program. First, the pilot GMBIS and its visualization tool, EASy, will allow interested parties to explore and visualize, with maps they themselves create, the biodiversity of the Gulf, using the data bases from DFO that now populate the system. Second, the Gulf of Maine Census's web site contains extensive educational information, and we plan to develop this aggressively. Third, a 6-panel, illustrated brochure explains the goals and potential of the program, and the technologies and techniques that will be used to carry it out. This will

be a primary tool for fundraising. In addition, over the last two years extensive contacts have been made with the fishing and seafood industries, with the help of Thor Lassen of Oceans Trust.

Over the last quarter of 2002, a systematic outreach program to potential funding agencies has been launched. This includes contact with selected foundations, which has resulted in formal letters of inquiry to (1) assist with creation of a seed research fund that would be used to leverage federal dollars and (2) help fund discrete products of the census.

IV. ANTICIPATED PRODUCTS AND OUTCOMES

IV-A. Products:

Within the 3-year term of this grant, the following will be produced:

- Expansion and institutionalization of the Program's **relational geographic data base, GMBIS,** built from existing as well as new data, for the ongoing use of scientists, industry, and managers. **Outcome**: dramatically improved access to existing data bases to allow assessment of biodiversity and distribution of surveyed life in the Gulf of Maine.
- An electronic **Dynamic Atlas** accessible via the Web to educators, scientists, and the public (dynamic both because it will track biodiversity over time, and because users will be able to interact with it). **Outcomes**: an ability to assess and explain the biogeography of the Gulf of Maine that can arise only from connecting (statistically and visually) marine life to the physical environment; a prototype for linking data

bases with GIS and Internet technologies that can be adapted in other Census of Marine Life projects around the world.

- A synthesized compendium of findings**,** including a **preliminary "state-of the-ecosystem report,"** available as of the end of the 3-year period. **Outcomes**: a building block of the worldwide Census of Marine Life, representing the Gulf of Maine's contribution to date; and a reference work available to support the preparation of a Fisheries (or Ocean Management Area) Ecosystem Plan likely to be called for in a reauthorized Magnuson-Stevens Act.
- A **technologies web page** explaining and providing links to technologies for the observation and censusing of life in marine waters. **Outcome**: enhanced ability of other CoML field programs to evaluate and choose among technologies needed to assess the abundance, diversity, and distribution of life in large marine ecosystems.

IV-B. Summary of Measurable Progress as of the End of 2005

All of these products can be expected to evolve after the 3-year term of this grant, since field studies and other inputs necessary to create the knowledge sufficient to enable ecosystem-based management will extend beyond this timeframe. However, as of the end of 2005 it is anticipated that the following measurable progress will be made:

- Whereas today there is no generally shared or integrated data base on the Gulf of Maine, access by scientists and resource managers to such a data base via GMBIS and the Dynamic Atlas will be routine.
- At least six field programs will be in the water or completed, addressing diversity of life in the benthos, the seamounts and slope sea, and the role of predator-prey

dynamics; and commitments or pathways to funding of a credible fraction of the $25 million projected to be needed for Census field studies will have been established.

- An initial assessment of the state of the Gulf of Maine ecosystem will be available to resource managers and industry.
- Investigators both in the Gulf of Maine and elsewhere who need information on the modern technologies and platforms available to conduct observations of a spectrum of organisms in a large marine ecosystem will have a central source via the Program's web site.

IV-C. Early Visibility

Given the distributed nature of the Census, it will be important to establish recognition and the "branding" of the Census fairly early. Therefore, the secretariat will try to foster and bring visibility to one or more newsworthy events during the first year of implementation. Possibilities include:

- Findings of funded projects that have gone to sea (one went to the Bear Seamount in late summer 2002, and at least one voyage is planned in the slope sea for 2003);
- Release of a set of maps (*e.g.*, the biophysical maps that will be the first-stage product of the Dynamic Atlas project) that tell a story about the ecosystem of the Gulf of Maine;
- The securing of funds for a major element of the pilot Census.

V. PROGRAM ELEMENTS

A. Extracting Knowledge from Existing Data

A-1. Dynamic Atlas of the Gulf of Maine

The Dynamic Atlas will be a core product of the Gulf of Maine Program. Its focus over the term of the proposed grant will be on capturing and disseminating for wide use the rich sets of existing data held by federal, provincial, and state marine agencies, the region's research institutions, and the real-time data of the Gulf of Maine Ocean Observing System (GoMOOS). In future years, as field work produces new data sets, and as new data are added to the established data bases, they will be incorporated into the Atlas.

The Dynamic Atlas will develop in three steps, each resulting in a product for a variety of users.

A-1-a. First Stage Product: Prototype Biophysical Maps of the Gulf of Maine

This first stage product will be a set of approximately 25 finished images developed from *existing data bases* relating to the Gulf of Maine. Their common theme will be to demonstrate the explanatory power of visually linking the biology of the Gulf of Maine with the physical environment. The maps individually or in groups will tell "stories" about these links: how a given species relates to different environmental conditions over different life stages; how distribution of a species may have changed over time; how abundance of one species might compare to abundance of another; how phytoplankton blooms vary with temperature of the water, and so forth. These prototypical maps will not be intended to be comprehensive, but rather suggestive and illustrative.

The maps will represent layers of biological and physical and geographic information. They will be built from such existing data sets as the groundfish trawl surveys by the federal marine agencies of the U.S. and Canada; the bathymetric data bases available for the Gulf; the East Coast of North America Strategic Assessment Groundfish Atlas Project (NOAA-DFO); data sets captured by cooperating nonprofit organizations such as Island Institute and the Gulf of Maine Ocean Observing System, among others. A primary source will be the initial output of GMBIS's proof-of-concept project with DFO.

Partners: The Prototype Biophysical Maps will be prepared in partnership with the National Marine Fisheries Service (NMFS), Dept. of Fisheries and Oceans (DFO), Woods Hole Oceanographic Institution, System Science Application, Inc. (developers of the EASy software that is the visualization tool for GMBIS), the Island Institute, and Bigelow Laboratory of Ocean Science. The Island Institute, which has produced other scientific education products for the Gulf of Maine, will coordinate production. See Appendix for the complete proposal.

Users: The maps will be available both electronically and in hard copy. Resource managers will use them to spot patterns in the ecosystem. Scientists will use them to refine hypotheses and prepare proposals. Educators will have a provocative tool for marine and environmental education. They also will be an important product to promote awareness of the Gulf of Maine Program of the Census of Marine Life and, by testing "storylines" (*i.e.,* the relevant themes) related to physical-biological links, will serve as a necessary stepping stone to the Program's Dynamic Atlas.

A-1-b. Second Stage Product: Dynamic Fisheries Atlas

The Second Stage product will expand and replicate in the U.S. waters of the Gulf of Maine GMBIS's proof-of-concept work done with the Canadian data bases. It will incorporate selected fisheries data sets maintained by NMFS's Northeast Fisheries Science Center and Woods Hole Oceanographic Institution along with data on physical oceanography. They will be integrated into GMBIS to produce, along with the Canadian data already in the data base, a Dynamic Fisheries Atlas that links fish to the physical environment across the Gulf of Maine, over time. EASy software will enable the integration and visualization of layers of data that pertain to the distribution of marine populations in relation to environmental variability (different temperatures, salinities, depths, water density differentials, etc.) and over decades of time in the Gulf of Maine. The full data bases incorporated into GMBIS will be downloadable by interested parties.

Partners: the Northeast Fisheries Science Center, BIO, WHOI, and Dr. Dale Kiefer of the University of Southern California and System Science Applications, Inc. Included in the Appendix is NFSC's letter of endorsement and pledge to provide access to its data bases.

Users: The Dynamic Fisheries Atlas will:

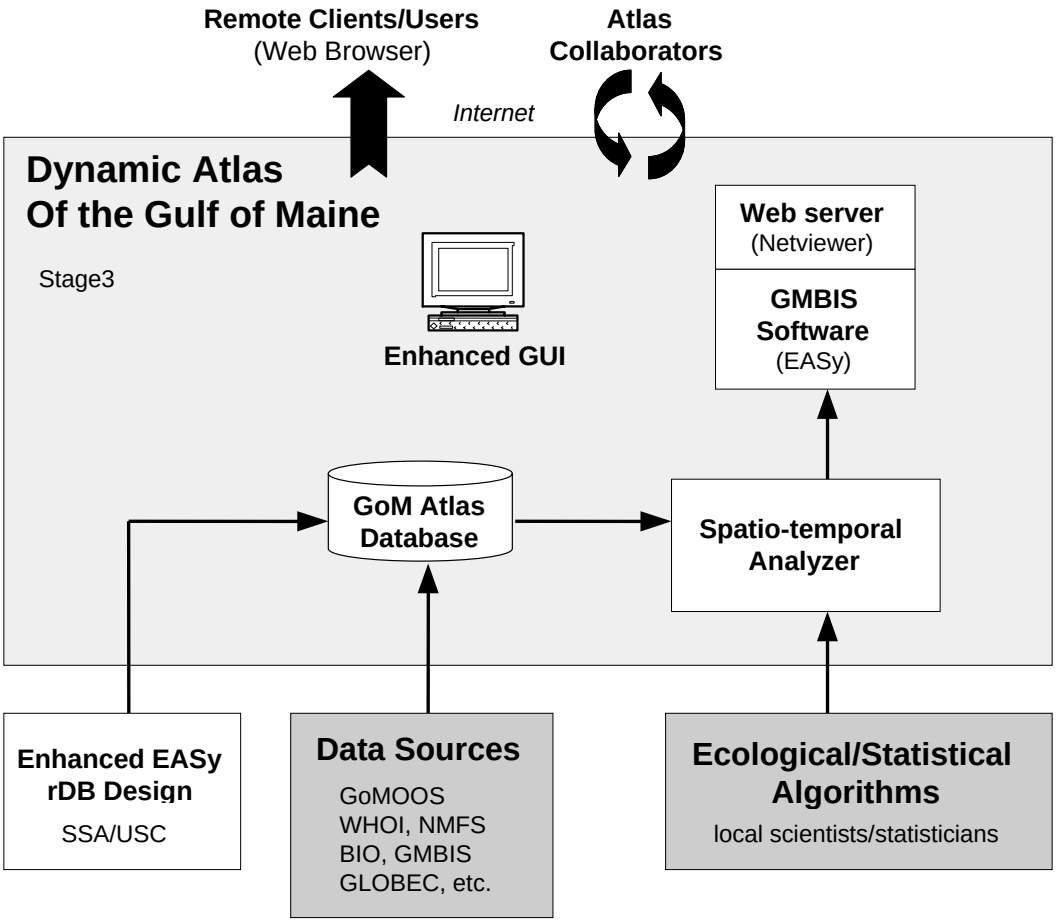
- allow resource managers and decision-makers, private and public, to obtain an unprecedented picture of the abundance and distribution of fish life over time.
- greatly improve access to data sets needed to energize investigation of the Gulf of Maine ecosystem;

- enable scientists to develop metrics and hypotheses about the processes that drive the Gulf of Maine's ecosystem.

A-1-c. Final Stage Product: Final Dynamic Atlas of the Gulf of Maine

If there were no additional design of the Dynamic Atlas and no additional work with the data bases that populate it (other than to keep the atlas up-to-date), the biophysical maps and Dynamic Fisheries Atlas would serve a long and useful purpose. But with additional design and additional work with the data bases, the Atlas's functionality can be significantly upgraded. Indeed, this work will be required if the Gulf of Maine census is to reach its goal of enabling ecosystem-based management. The graphic below illustrates the proposed general architecture for the final Dynamic Atlas.

The final Atlas will incorporate statistical and modeling routines that allow "intelligent contouring" (extrapolation of known biological conditions to analogous habitats). In addition to partners previously mentioned, it is anticipated that the University of New Hampshire will play a central role in developing needed ecological and statistical algorithms that will allow reconciliation of disparate data bases. See Appendix for a full description of the 3-stage process for developing the Dynamic Atlas of the Gulf of Maine and the components of the Atlas.



A-2. Registry of Data Bases

While as many data bases as possible will be incorporated into GMBIS, many data sets held by institutions or individual investigators will not be able to be incorporated for a variety of logistical and other reasons. However, the Program will create a registry of known data sets, with contact information, so that scientists and others will know of their existence and how to get to them.

B. Reconstructing Knowledge: Promoting HMAP in the Gulf of Maine

As recognized by the Census of Marine Life, what lives in the ocean can be truly understood only in the context of what lived in the ocean, at least during the so-called "historical" and "proto-statistical" periods of commercial exploitation (Holm, et al, 2001). The University of New Hampshire is one of three academic centers attempting to reconstruct the history of marine animal populations. One of UNH's foci is the Gulf of Maine. The Gulf of Maine Program wishes to support this effort in two ways. First, it is important to maintain momentum for the archival work needed to extract and interpret historic information in the Gulf of Maine. Second, the project needs to determine the statistical methodology that can relate the historic data to contemporary data, so that conclusions might be drawn about change in abundance and distribution of marine animals since at least the mid-19th century.

C. Gaining Knowledge from New Field Studies

C-1. Preamble

Most of the historical surveys in the Gulf of Maine over the past 30 years have focused on commercial fish and shellfish species, with varying degrees of detail used to describe other taxa captured by the sampling gear. This is one of the most extensive such data sets available anywhere in the world, but it provides only a partial description of the fisheries ecosystem. The other long time-series collected by NOAA focuses on the zooplankton (the Continuous Plankton Recorder and the MARMAP data sets; see a description at www.bigelow.org/PI/~incze). The whales and other marine mammals also have been studied and their populations estimated. Little of the mid-sized pelagic fauna that

occupies the water column and the trophic levels between these various groups has been assessed in a comprehensive way.

Scientific studies typically focus on the biology or ecology of organisms in order to understand life history or important rate processes, such as growth, reproduction, feeding or mortality. There is a wealth of such knowledge for a limited number of taxa. More recent studies have begun to explore the genetics of a few important organisms. A limited number of scientific cruises have been funded to survey the benthos which, in addition to the pelagic microbes, contains the greatest number of unknown species. Funding for this type of work has generally been difficult to obtain, however, because the organisms are not of obvious commercial value, and science has favored the funding of hypothesis-driven research over exploration.

The Gulf of Maine Program must accomplish three goals with new field programs. It must **promote and enable basic exploration** of the unknown in order to add to our knowledge of the biodiversity of the ecosystem; it must **fill some of the prominent gaps in knowledge and assessment of important trophic levels** that have not been adequately sampled in the past; and it must **engage process-oriented studies** in the themes of explaining patterns of biodiversity and understanding the factors that bring change. The framework for connecting these various types of work and establishing the partnerships that will do the work will come from expert working groups under the Scientific Steering Committee.

C-2. Proposed Field Studies for CoML Involvement

Germane topics. With so much to do, there must be a strategy that will allow the Gulf of Maine Program to connect numerous interests and opportunities without severely over-committing itself. The following areas are germane to CoML objectives. The Gulf of Maine Program is helping to organize, promote, and assist field studies that do the following:

(1) Increase knowledge of the structure, diversity and extent of benthic habitats in the Gulf of Maine

(2) Identify unique habitats and species assemblages

(3) Define species-habitat relationships

(4) Define patterns and levels of genetic diversity

(5) Explore benthic and microbial communities (the most poorly known but taxonomically rich communities), particularly in ways that help estimate over-all diversity

(6) Conduct population estimates of trophically important links in the food web that have been chronically under-sampled and given high priority by previous planning groups (e.g., euphausiids, mysids, squids, small mid-water fish)

(7) Conduct process studies that can be used to help predict population responses to changing environmental conditions, including biological and physical interactions. This knowledge is useful in predicting and interpreting spatial patterns of distribution as well as changes over time, both past and future. Directionality of change in abundance and diversity, rather than predicted abundance, is a reasonable and functional goal.

Field Program: a 3-part strategy. (1) During the pilot period of the Program, the secretariat is committed to embracing or catalyzing a minimum of six field studies that either are, or soon can be made to be, ripe for funding and implementation. Further, during the pilot period the secretariat is committed to stimulating an additional series of

proposals to help narrow the gaps in knowledge identified in the Science Plan through the efforts of the Scientific Steering Committee and their working groups.

Of the first six targeted proposals, two have been funded by the Ocean Exploration Program and are or will be in the field. (See Section B-2). Two failed upon first submission to the National Science Foundation but will be resubmitted early in 2003 based on encouraging reviews. These are already competitive proposals with an intended funding agency. The Program will provide programmatic linkages (a wider audience, new perspectives, statistical modelling, data display and outreach) that will allow them to get more out of their work and assist in getting the proposals funded. The final two proposals are under development. Their authors have asked the Program to help tune the proposals to focus on CoML objectives and improve chances for funding. We will work with the proposers with the goal of submitting proposals during the winter of 2002/2003 and beginning field work in 2004. Each of the six projects will contribute to the Gulf of Maine Census through exploration of biodiversity, testing ecological relationships, and/or demonstrating techniques or technologies for conducting a census in a marine ecosystem. By topical area identified in the initial Science Plan, the six are:

Benthos:

- The diversity and abundance of small benthic organisms in offshore waters of the Gulf of Maine, using landscape ecological approaches. (Status: resubmission to NSF early in 2003)

- The community diversity of intertidal and shallow subtidal benthos: comparison of two well-know bay systems, Penobscot and Cobscook Bay, using remote sensing methods. (Status: proposal is under development, with objective to submit in winter 2002/2003.)

Role of Predation by Large Fish and Mammals in Dynamics of Ecosystem

- Biophysical relationships and ecosystem (prey) dynamics of marine birds and mammals in the Gulf of Maine. (Status: proposal is under development, with objective to submit in winter 2002/2003.)

Biodiversity of the Slope Sea and Seamounts

- Biodiversity of Bear Seamount and vicinity explorations. (Status: funded and began field work in summer 2002.)

- Biodiversity on the Continental Slope off Georges Bank: resource potential and vulnerability to disturbance. (Status: funded and field work will begin in May 2003.)

- Bathypelagic organisms of the slope sea. (Status: resubmission to NSF early in 2003.)

Field studies typically require substantial lead time to propose, receive funding, schedule ships (if needed) and conduct the sampling.

(2) During the first phase of implementation (this three-year proposal), we will stimulate development, through working groups with specific charges, of new proposals consistent with the Science Plan. In stimulating new proposals, the Program will provide the technical assistance of a spatial statistician and guidance on appropriate technologies. The proposals will fall into the subdivision of functional groups organisms identified in the Science Plan, namely: deep benthos, shallow benthos, plankton, fish and squid, and marine mammals and birds.

(3) We also will focus on (a) bringing ongoing studies and results into the CoML orbit; (b) adding, when feasible, to cruises or field work that is already planned; and (c) stimulating additions or modifications to work being revised for resubmission. As a pilot for ecosystem-level work, the Gulf of Maine Program must develop and demonstrate

ways by which these add-on approaches can yield significant results. Indeed, the list of topics germane to the Program's objectives is large and could not be accomplished by a single program. It is possible to consider such a list only because so much is already going on in the Gulf of Maine. There is not always much communication and coordination among these areas of research, however, and the goals of individual scientists and missions are not always "biodiversity-oriented." Further, a number of agencies, authorities and groups conduct routine sampling or monitoring of marine life. These activities are ongoing but often are narrowly focused due to missions and budgets. Through a cooperative review of sampling methods and priorities, the Program will seek to foster broader ecosystem linkages among these programs and to achieve more from their efforts. **The Gulf of Maine Program will act as a catalyst to stimulate new thinking, avoid lost opportunities in the short term, add value through coordination of efforts, and establish a course for continuing and expanding efforts in the future**. The expert working groups will be a major mechanism for engaging the academic and agency communities toward implementation, and the Secretariat will be responsible for follow-through.

D. Managing and Communicating Knowledge

D-1. Contribution to Census of Marine Life

The Gulf of Maine pilot is a demonstration of how to assess and explain the abundance, diversity, and distribution of life in a large marine ecosystem. The following results will be transferable to the worldwide effort:

- the organizational format required to conduct a census that calls upon multiple disciplines, multiple approaches (from taxonomic to process studies), multiple investigators, and multiple sources of funding over a significant period of time;
- the scientific strategies for (1) the *systematic sampling* to provide adequate spatial coverage to estimate abundance and distribution of a spectrum of marine life, especially those that are at present severely under-sampled; and (2) the *synoptic sampling* sufficient to identify linkages among species and between species and habitat;
- the technologies appropriate to the collection and organizing of biogeographical data, communicated through a special technologies web page;
- a data management and visualization system (the Dynamic Atlas) that demonstrates how to advance the assessment and explanation of the diversity, distribution, and abundance of an ecosystem based on existing large data bases; that facilitates the analysis of the health of ecosystems; and that is accessible to policy makers and producers as well as scientists; and
- the data itself that will be part of the overall Census of Marine Life.

D-2. GoMOOS Products

One of the advantages of a pilot in the Gulf of Maine is the presence of the Gulf of Maine Ocean Observing System, one of the few operational regional coastal ocean systems in the U.S. During 2003 GoMOOS intends to target, among other users, resource managers with a suite of informational products delivered through its web site (www.gomoos.org). Its observations are extensive and continuous, but emphasize physical oceanography. Biological data are limited to observations derived from optics that measure chlorophyll,

phytoplankton and plant production at selected sites, and from satellite images. Resource managers are in search of more extensive biological information and linkages to physical oceanography, such as currents, water temperature, and salinity. GoMOOS believes that by connecting to GMBIS, it can add biological value to the suites of information products it will be delivering. To this end, a cooperative relationship will be developed with GoMOOS around a shared mission of getting information to managers, who will be primarily responsible for deciding upon ecosystem-based approaches.

D-3. Long-term Management of GMBIS

A cooperative relationship with GoMOOS may be especially important, because, if the results of the Gulf of Maine pilot are to be enduring, there must be a long-term home for GMBIS. In effect, GMBIS must be institutionalized in a setting where the interest is Gulf-wide and international, where data base development and management is an integral part of operations and capacity for it thus exists, and where data are available on an open basis. GoMOOS may be the logical long-term host. Through the development of GMBIS-based products and through participation in the evolution of the GMBIS data base and the related Dynamic Atlas, the Gulf of Maine Program and GoMOOS will jointly explore the feasibility and desirability of migrating GMBIS to GoMOOS at the end of the grant period for long-term management.

D-4. Technology Web Page

A section within the Gulf of Maine Program's CoML web site will be developed devoted to the recent and emerging technologies and techniques that make a census in a complex marine ecosystem possible. The order of priority will be that of (1) operational tools, (2)

research tools in use by the inventing or responsible research group, and (3) research tools under development. An attempt will be made to establish a unified bibliography of printed and electronic documents. For each generic tool, the operating principle will be described, particular realizations will be exemplified, with characteristic data or results, and references will be given. The references will be collected in Endnote, a commercial database. This section of the web site will be developed by Dr. Kenneth Foote of Woods Hole Oceanographic Institution. See Appendix for the complete statement of work.

E. Synthesizing Knowledge

A census of marine life covering a complex, 36,000 square mile water body will not be complete in three years. Nor will all the information needed to narrow gaps in knowledge and enable ecosystem-based management be achieved in such a short time: a 10-year goal is itself ambitious.

However, as (1) existing data bases are mined and patterns of biodiversity and distribution are observed, and (2) incremental advances in new knowledge are made, it is important that these be synthesized in a systematic way, with products that will be useful to all who may benefit from the integrated information. To this end, two approaches will be incorporated:

- Annual syntheses of findings to date, sponsored by the Secretariat with the assistance of the Scientific Steering Committee, leading to a 3-year compendium of knowledge gained as of that time. The annual syntheses and the 3-year compendium will be constructed in a “known, knowable, unknowable” context.

They will be essential progress reports for presentation to the Program's Policy Advisory Committee and constituencies of the Program.

- In the third year of the Program, upon the expansion and upgrading of GMBIS into a final Dynamic Atlas, a broad assessment will be made of patterns of and trends in abundance, diversity, and distribution of selected marine life, detectable from the multiple, integrated data bases, and of the state of the ecosystem. This will require selecting and examining the metrics that best represent key processes in the ecosystem and employing the appropriate multivariate statistical models. It is expected that the availability of GMBIS to the wide community of scientists and industry will independently stimulate a good deal of such examination and analysis. The intent of the proposed task is to pioneer the assessment based on the rich sets of existing data and, with this first-ever synthesis in hand, to offer insights to industry and resource managers; and be better able to elucidate the Program's agenda for the subsequent five years, to 2010.

VI. PATHWAYS TO FUNDS

The Gulf of Maine Program's secretariat is not itself the research team that will be carrying out the field research studies. Rather, one of the secretariat's main jobs is to find and, indeed, to build pathways to funds that can be made available for the competitive research studies needed to fulfil the Program's goal. A preliminary estimate of funds required for new field research is in the range of $25 million. This is being attacked in three ways, some of which have been pursued during the planning and design period, and each of which has been launched anew by the Program's secretariat during the third and fourth quarters of 2002 as part of implementation:

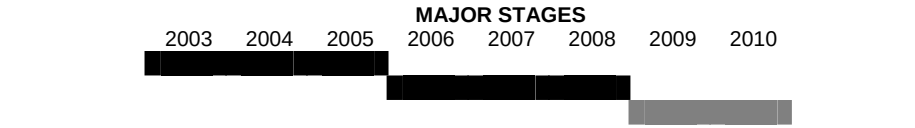
(1) **Identifying existing governmental (primarily federal) programs** within agencies that (a) provide internal funding to agency scientists for purposes consistent with the Gulf of Maine pilot census and/or (b) provide external funding for competitive projects; and encouraging each of these to formally recognize the Census of Marine Life as a worthy umbrella under which to fund census-related research. Among the most important of these agencies and programs are NOAA's Office of Ocean Exploration and National Sea Grant; the fisheries and science and technology programs of NMFS and DFO-Canada; the Coast Survey program of NOAA; the Office of Naval Research; the National Ocean Partnership Program; and several divisions within the National Science Foundation.

(2) **Creating an authorization for and appropriation of funds** for the Census of Marine Life through congressional action. The Gulf of Maine pilot is working with the national secretariat at CORE on authorization legislation for submission early in 2003.

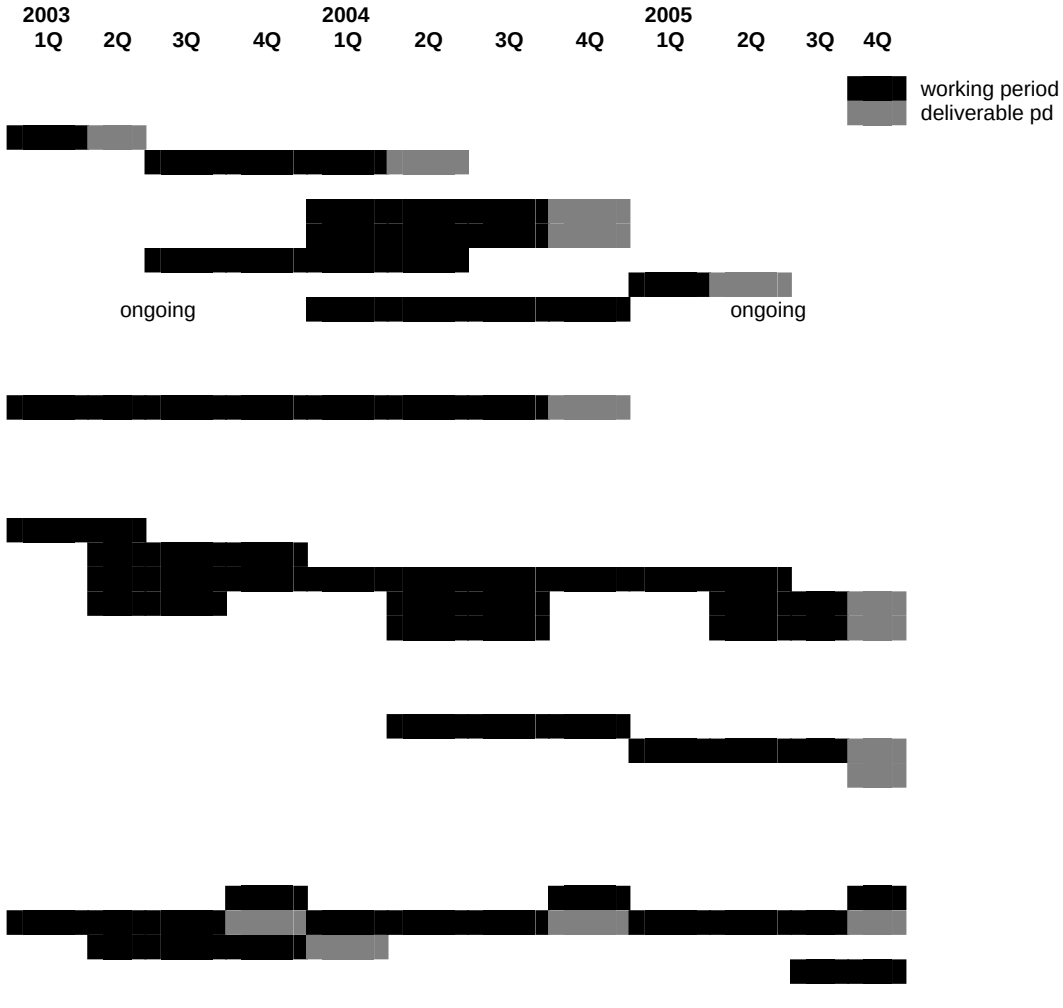
(3) **Approaching private sources** – philanthropic foundations and industries – with missions and interests in the marine environment, biodiversity, and managing of ecosystems. These sources are being approached at two levels: (a) to fund discrete products, especially those relating to the Dynamic Atlas, and (b) to determine feasibility of building a Gulf of Maine Ecological Research Seed Fund, which would be available to investigators (both scientists and collaborators in the fishing industry) for proof-of-concepts leading to Gulf of Maine census projects and to leverage federal funds.

VII. TIMELINE

TIMELINE: GULF OF MAINE PROGRAM OF CENSUS OF MARINE LIFE



PILOT/INITIAL IMPLEMENTATION: 3-YEAR TIMELINE OF DELIVERABLES



VIII. BUDGET

A. Budget

The period January 1, 2003, through December 31, 2005, is the Gulf of Maine Program's initial implementation phase and is concurrent with the pilot status of the program. The budget for this 3-year period is attached.

B. Justification

B-1. Personnel

Personnel costs cover 60% of the time of the Program Director, Evan Richert, and one-half time of an Administrative Assistant, who will be housed at the secretariat's office in Portland, Maine.

B-2. Subcontracts

Partnerships have been developed with investigators at several institutions to carry out the work in the proposal.

Chief Scientist

- The Gulf of Maine Program's chief scientist, Dr. Lewis Incze, is based at the Bigelow Laboratory for Ocean Sciences. Dr. Incze will devote 40% of his time to the Program. The services also include limited time of a research assistant and environmental educator. The budget includes all travel costs.

General Consultation

- Woods Hole Oceanographic Institution: Dr. Andy Solow will serve a consulting role, advising investigators across the program, and especially those developing proposals for new field studies, on the spatial statistics required for a unified census. Dr. Kenneth Foote will be responsible for developing a technologies page for the Program's web site, with Gulf of Maine scientists and other CoML field programs the targeted audiences.

Dynamic Atlas

The 3-step progression to the Dynamic Atlas of the Gulf of Maine is estimated to cost a total of $783,300. By stage, the costs are estimated to be:

- Stage One, Prototype Biophysical Maps $ 51,032
- Stage Two, Dynamic Fisheries Atlas $162,473
- Final Stage, Dynamic Atlas of the Gulf of Maine $569,795

Of these totals, the proposed budget of this grant seeks $272,422 over the 3-year period ($119,477 in Year 1, $122,945 in Year 2, and $30,000 in Year 3;). The requests are intended to pay for activities prerequisite to creating the Atlas (e.g., personnel required to capture data from extant data bases), and to either match or leverage funds that will be sought from private sources. Applications are being submitted during October 2002 to two such possible sources (National Fish and Wildlife Foundation and the Davis Conservation Foundation).

Subcontractors include:

- The Island Institute: Chris Brehme and Benjamin Neal, GIS and environmental education specialists, will coordinate the production of the Stage One product of the Dyamic Atlas, the prototype biophysical maps.

- The University of Southern California: Dr. Dale Kiefer and Dr. Vardis Tsontos, developers of GMBIS and its visualization software, EASy, will participate in the Stage One prototype biophysical maps. They will lead the development of the Stage Two product, the Dynamic Fisheries Atlas and the Final Stage Dynamic Atlas of the Gulf of Maine.

- The University of New Hampshire and WHOI: It is anticipated that Dr. Andy Rosenberg and Dr. Kenneth Foote will have primary responsibility for developing the ecological and statistical algorithms needed to feed into the Dynamic Atlas's program for the reconciliation of data bases.

- In addition, it is expected that the Program will contract a preliminary assessment of the ecosystem, based on the availability of the full Dynamic Atlas, during the final year of the Program.

Other Subcontracts

The Program wishes to support HMAP as it applies to the Gulf of Maine, including archival work and the statistical work to relate historical data to the diversity and abundance of marine life known to exist in the late Twentieth Century.

Finally, the Program has the opportunity to leverage census products through a partnership with the Gulf of Maine Ocean Observing System, which will match specified dollars in the proposed grant on a 3:1 basis.

C. Other Direct Costs

The majority (71%) of these costs are for travel, meetings, and scientists' stipends. In turn, the largest share will support the travel, meeting, and stipends of the Policy Advisory Committee, the Scientific Steering Committee, and the SSC's working groups, which will be responsible for guiding development of the field research. Stipends are for the seven members of the Scientific Steering Committee, each of whom will chair one of the seven working groups specified in the Science Plan. The remaining other direct costs support the operations of the secretariat.

IX. REFERENCES

Alldredge, AL, DL Bradley, D Butterworth and JH Steele, 1999: "Assessing the Global Distribution and Abundance of Marine Life," *Oceanography*, Vol. 12, No. 3

Ausubel, JH., 1999: "Toward a Census of Marine Life," *Oceanography*, Vol. 12, No. 3

Holm, P, TD Smith and DJ Starkey, eds., 2001: *The Exploited Seas: New Directions for Marine Environmental History*, International Maritime Economic History Association/Census of Marine Life (St. John's, Newfoundland)

Neirenberg, WA, 1999: "The Diversity of Fishes: The Known and Unknown," *Oceanography*, Vol. 12, No. 3

Sissenwine, MP and PM Mace, 2001: *Governance for Responsible Fisheries: An Ecosystem Approach*, Reykjavik Conference on Responsible Fisheries in the Marine Ecosystem (Post-Conference Paper #21)

Walters, C, 1997: *Challenges in adaptive management of riparian and coastal ecosystems*, The Resilience Alliance (www.consecol.org/vol1/iss2/art1)

APPENDICES

Resumes of Evan D. Richert and Lewis S. Incze

Letter of support and cooperation in providing data bases to GMBIS, from John Boreman, PhD, Acting Science and Research Director, Northeast Fisheries Science Center (hard copy only)

Island Institute's Proposal for Prototype Biophysical Maps (Stage One of Dynamic Atlas)

University of Southern California's Proposal for Development of a Dynamic Atlas for the Gulf of Maine

Woods Hole Oceanographic Institution's Proposal for Expanding the Technology Section of the Project Website

Curriculum Vitae (July 2002)

EVAN D. RICHERT, AICP

Address: Muskie School of Public Service, University of Southern Maine, PO Box 9300 – 49 Exeter St., Portland, ME 04104-9300; Tel. (207) 774-9844; e-mail: *erichert@usm.maine.edu*

Positions Held:

Associate Research Professor: Muskie School of Public Service, University of Southern Maine, Portland, Maine, 2002 to present

Director: Maine State Planning Office, Augusta, Maine, 1995 to 2002. Appointed by Governor Angus S. King, Jr., in January 1995. The Director is an *ex officio* member of the Cabinet. Related appointments by the Governor included:

Chair, Land and Water Resources Council (1995 to 2002)
Chair, Land for Maine's Future Board (1995 to 2002)
Commission on Performance Budgeting (1996 to 2002)
Maine Indian Tribal-State Commission (1996 to present)

President: Market Decisions, Inc., South Portland, Maine, 1981 to 1995
Planning Director: City of South Portland, Maine, 1977 to 1981
Planner: Greater Portland Council of Governments, Portland, Maine, 1975 to 1977
Assistant to Executive Director: Legislative Commission on the Water Supply Needs of Southeastern New York State, Syracuse, New York, 1973 to 1975

Formal Education

Syracuse University, Master of Regional Planning, 1974
Syracuse University, Bachelor of Arts, Journalism and Political Science (dual degree), 1969

Academic Appointments

Adjunct Professor in the Graduate Program for Community Planning and Development, Muskie School of Public Service, University of Southern Maine, 1997 to 2002
Visiting Lecturer in environmental affairs, Bowdoin College, Brunswick, Maine, 1990 to 1994

Related Certifications and Activities

American Institute of Certified Planners
Founding President, Gulf of Maine Ocean Observing System, 1999 to present
Member, U.S. Coastal Global Ocean Observing System Steering Committee, 2001 to present
Member of Growing Smart Directorate, American Planning Association, 1995 to 2001
Member, Board of Directors, Maine Development Foundation, 1997 to 2001
Founding President, Clean Casco Bay, Inc., 1992 to 1995

Awards

Environmental Merit Award, EPA New England, 2002
Environmental Award, Maine Audubon Society, 2000
Planner of the Year, No. New England Chapter of the American Planners Association, 2000
Planner of the Year, Maine Association of Planners, 1993 and 2000
Outstanding Contribution to the Public Planning Process, Maine Association of Planners, 1981
Phi Beta Kappa, Syracuse University, 1969

Publications

Richert, E. 1988. *The People of Maine: A Study of Values.* Commission on Maine's Future, Augusta, Maine.

Richert, E. 1990. "Maine's Changing Population and Values," in *Changing Maine*, Richard Barringer, ed. University of Southern Maine, Portland, Maine.

Richert, E., and Nash, B. 1991. "The Maine Reasons for Recycling." *American Demographics*, Vol. 13, No. 2.

Richert, E. 1992. *Comprehensive Planning: A Manual for Maine's Communities.* Maine Department of Economic and Community Development, Augusta, Maine.

Richert, E. 1993. *A Time of Change: Portland Transportation Plan.* City of Portland, Maine.

Richert, E., and Dorta-Fernandez, O. 1996. "Made to Measure." *Planning*, Vol. 62, No. 6.

Richert, E. 1996. "Service-Center Communities: An Urban Policy for Maine?" *Maine Business Indicators*, Vol. XLI, No. 4. University of Southern Maine, Portland, Maine.

Richert, E. 1996. "Electrical Industry Restructuring: From Policy to Implementation." *Maine Policy Review*, Vol. 5, No. 3. Margaret Chase Smith Center for Public Policy, Orono, Maine.

Richert, E. 1997. "Tax Revenue Targeting as the Anchor for Tax Reform." *Maine Policy Review*, Vol. 6, No. 2. Margaret Chase Smith Center for Public Policy, Orono, Maine.

Richert, E., and Lapping, M. 1998. "Ebenezer Howard and the Garden City." *Journal of the American Planning Association*, Vol. 64, No. 2. 1998 Best Feature Honorable Mention.

Richert, E. 1999. *Markets for Traditional Neighborhoods.* Maine State Planning Office, Augusta, Maine.

Sage, L., Levi, C., and Richert, E. 2001. "Beaming Discoveries of Ocean Frontiers to a Technological Audience." *Marine Technology Society Journal*, Vol. 35, No. 1.

Richert, E. 2001. 30 and 1000: How to Increase Maine's Incomes to the National Average by 2010. Maine State Planning Office, Augusta, Maine.

Abridged Curriculum Vitae (May 2002)

LEWIS S. INCZE

Address: Bigelow Laboratory for Ocean Sciences, West Boothbay Harbor, ME 04575
Tel. 207-633-9600, e-mail: *lincze@bigelow.org*

Positions Held

Research Oceanographer: Joint Appointment with University of Washington School of Fisheries, Pacific Marine Environmental Laboratory (NOAA/OAR) and Northwest and Alaska Fisheries Science Center (NOAA/NMFS), Seattle, 1983-1988.

Research Scientist/Principal Investigator, Bigelow Laboratory for Ocean Sciences, 1988-present; Laboratory Director and CEO, 1991-1995.

Personal: b. 9 January 1953, U.S. Citizen, SS# 005-46-7491; married with two children

Formal Education: B.S., Cornell University, 1976 (Biology, discipline in Ecology and Systematics); M.S., Univ. of Maine 1979 (Oceanography); Ph.D., Univ. Washington 1983 (Fisheries)

Research Interests: Physical-biological coupling in the oceans; plankton ecology and physiology, with emphasis on meroplankton; population dynamics and recruitment, with emphasis on fisheries

Regional and National Committees:

Regional Association for Research on the Gulf of Maine: Founding Chairman in 1991; Chairman 1995-1997; Board Member 1991-present.

National Science Foundation Committees: Arctic System Science (1989-90); Northwest Atlantic Global Ecosystem Dynamics, Initial Science Plan (1991-1992)

National Science Foundation Panels: Program in Biological Oceanography (1987, 1989, 1991, 1997, 2001); Program in Polar Biology and Medicine (1999)

National Research Council: Committee on Atlantic Salmon in Maine (2001-present)

Professional Memberships: American Association for the Advancement of Science, American Geophysical Union, American Society of Limnology and Oceanography, The Oceanography Society.

Ten Publications Related to this Proposal:

Incze, L.S. and N. Wolff. 2002 (Accepted). Can scientific observations of early life stages be extrapolated to the level of a fished population? J. Fish. Res.

Incze, L.S., D. Hebert, N. Wolff, N. Oakey and D. Dye. 2001. Changes in copepod distributions associated with increased turbulence from wind stress. Mar. Ecol. Progr. Ser. 213: 229-240.

Vitae: L. Incze, p.2

Incze, L.S. and C.E. Naimie. 2000. Modeling the transport of lobster (*Homarus americanus*) larvae and postlarvae in the Gulf of Maine. Fish. Oceanogr. 9: 99-113.
Incze, L.S., R.A. Wahle and A.T. Palma. 2000. Advection and settlement rates in a benthic invertebrate: Recruitment to first benthic stage in *Homarus americanus*. ICES J. Mar. Sci. 57: 430-437.
Ice, L.S. and K.M. Bailey. 1998. Oceanography and localized fishery stocks: Possible mechanisms. Pp. 31-37 In: The Implications of Localized Fishery Stocks (H. von Herbing, I. Kornfield, M. Tupper and J. Wilson, eds.). Natural Resources, Agriculture and Engineering Service, Cornell University, Ithaca, NY, 200 p.
Incze, L.S., R.A. Wahle and S.J. Cobb. 1997. Quantitative relationships between postlarval production and benthic recruitment in lobsters, *Homarus americanus*. J. Freshwater Mar. Sci. 48: 729-743.
Wahle, R.A. and L.S. Incze. 1997. Pre- and post-settlement processes in recruitment of the American lobster, *Homarus americanus*. J. Exp. Mar. Biol. Ecol. 217: 179-207
Incze, L.S., D.W. Siefert and J.M. Napp. 1997. Mesozooplankton of the Alaska Coastal Current: Abundance and community composition. Cont. Shelf Res. 17: 287-305.
Napp, J.M., L.S. Incze, P.B. Ortner, D.L. Siefert and L. Britt. 1996. The plankton of Shelikof Strait, Alaska: Standing stock, production, mesoscale variability and their relevance to larval fish survival. Fish. Oceanogr. 5: 19-38.
Incze, L.S., P. Aas and T. Ainaire. 1996. Distributions of copepod nauplii and turbulence on the southern flank of Georges Bank: Implications for feeding by larval cod (*Gadus morhua*). Deep-Sea Res. II, 43: 1855-1873.

Collaborators, past 48 months, other than Bigelow Lab (alphabetical order):
K.M. Bailey (NOAA/NWAFSC, Seattle); K. Beard-Jackson (Univ. Maine); D. Brooks (TAMU); J.L. Buckley and E. Calderone (NOAA/NMFS, Narragansett, RI); Yong Chen (Univ. Maine); J.S. Cobb (URI); M. Fogarty (NOAA/NEFC, Woods Hole); D. Greenberg (BIO); D. Hebert (GSO, URI); R.Houghton (L-DGO, Columbia University); J. Irish (WHOI); P. Lawton (DFO, Biol. Laboratory, St. Andrews, NB); (J. Manning (NOAA/NEFSC, Woods Hole); C. Naimie (Dartmouth College); N. Oakey (BIO); F. Page (DFO, Biol. Laboratory, St. Andrews, NB); N. Pettigrew (Univ. Maine); J. Runge (UNH); R. Steneck, A. Thomas, D. Townsend (Univ. Maine); F. Werner (UNC Chapel Hill); C. Wilson (Maine Dept. Marine Resources); H. Xue (Univ. Maine).

Ph. D. Advisor: D. A. Armstrong (Univ. Washington)

Proposal to: The Census of Marine Life,
Gulf of Maine Pilot Study
From: The Island Institute, Rockland, Maine

Stage One of Dynamic Atlas:
Prototype Biophysical Maps of the Gulf of Maine

Project Summary:

The Island Institute will create a series of approximately 25 finished images visually linking the biology of the Gulf of Maine with the physical environment, for the purpose of producing a text and image document that will be a prototypical example of future Census of Marine Life work, illustrative of the complexity of the gulf of Maine and suggestive of the scope of future study. These images will be developed from existing data bases and sources, with specific topics to be developed by a working group convened by the Island Institute. This group will convene a second time to review the draft images, which will also be posted on a web site for review. 500 copies of the color document will be produced and delivered to the Census of Marine Life.

I. Scope of work proposed and approach

A. Image Topic Identification

1. Identify and invite participants
Island Institute staff will identify contributors from the marine fields to meet and discuss thematic content, presentation of images. 10-20 contributors will be invited to form the working group, to include participants from the National Marine Fisheries Service (NMFS), Canadian Dept. of Fisheries and Oceans (DFO), Woods Hole Oceanographic Institution, System Science, Application, Inc. (developers of the EASy software that is the visualization tool for GMBIS), the Island Institute, and Bigelow Laboratory of Ocean Science.

2. Convene and conduct initial meeting
Island Institute staff will organize, host, and direct first meeting to discuss map themes. Island Institute staff will attend meetings to define map themes and discuss data availability. We will work with participants to develop list of possible "stories" and their data requirements.

B. Map Development (3 steps)

1. Data Development and Management
We will import and review data for maps, convert data to GIS format, and check for attribute consistency. As appropriate, we will standardize, modify data to support symbology and map themes. We will add or standardize fields and codes as required to support map design

2. Map Design
We will develop overall design for Prototype Biophysical Maps of the Gulf of Maine that includes the following:
-layout location of map frame, logos, acknowledgements, scale bars and other marginalia
-symbology for standard base map "background" layers--bathymetry, coastline, lat/long grids, placename labels and other layers.
-symbology to effectively display biophysical data for each story

3. Map Initial Distribution
We will create hardcopy and digital maps for review by printing prototype maps on Inkjet printer and/or adding to a website for review.

C. Follow-up content meeting

The original working group will reconvene to discuss effectiveness of the products, any changes in content, and the next steps for outreach. Based on this final review we will create final digital "print-ready" and web-ready maps in appropriate format for four-color printing and in digital format (jpeg, pdf) for distribution via the Internet. Island Institute staff will provide logistical, content, and facilitation for this meeting.

D. Document production

1. Text explanations, to be provided from the Census of Marine Life, will be added to the image document.

2. 500 copies of the document will be printed in color, bound as needed, and delivered to the Census of Marine life.

II. <u>Timeline for completion.</u>

- January 2003, Convene first working group meeting.
- February-March 2003, produce images, post for review.
- April 2003, conduct follow-up working group meeting.
- May 2003, alter images as needed, prepare document for printing.
- June 2003, document delivery.

Development of a Dynamic Atlas for the Gulf of Maine

Dale A. Kiefer

Vardis M. Tsontos

Department of Biological Sciences
University of Southern California
3616 Trousdale Pkwy, AHF342
Los Angeles, CA 90089-0371

Tel: 213-7405814
kiefer@usc.edu

Overview

The Gulf of Maine Atlas (GoMA) project is conceived of as a three-year activity organized in series of overlapping stages and producing a range of complementary products that provide a synthetic picture of the physical and biological structure of the Gulf of Maine relative to current understanding of ecosystem function. The first of these is a catalog of selected existing, fixed imagery data products available in both hardcopy and electronic forms that will provide a synoptic view of the GoM in the near term. The second stage entails development of a dynamic, Web-based atlas integrating fish population data from NMFS and DFO for the region together with relevant oceanographic information. The final stage aims to extend the number and types of source databases included in the dynamic atlas such that a more comprehensive depiction of biogeographic patterns in the GoM is provided. This dynamic GoM Census Atlas in turn will ultimately serve as the hub for data products generated by the Gulf of Maine Pilot Census field program (GoMAP).

GoMA will capitalize on the availability of both long-term oceanographic/ecological databases and associated derived data products but also new physical data provided by operational observing systems. It will also draw upon the established expertise of researchers, scientific programs and institutions in the region, including the Woods Hole Oceanographic Institution (WHOI), Northeast Fisheries Science Center (NEFSC, NMFS), Bedford Institute of Oceanography (BIO, DFO), and the GLOBEC Georges Bank and GoMOOS (Gulf of Maine Ocean Observing System, University of Maine) programs. GoMA will build upon the data and software tools assembled during the Gulf of Maine Biogeographic Information System (GMBIS) project, but also extend the capabilities of the toolset with methods that address the problem of reconciling data collected on varying spatial and temporal scales.

The discussion that follows reviews in more detail the specific stages and products of GoMA, its source databases, and tools. Also described are the work components of the Gulf of Maine atlas activity to be undertaken by partners at the University of Southern California and System Science Application (SSA) together with associated budget information.

Stages & Products

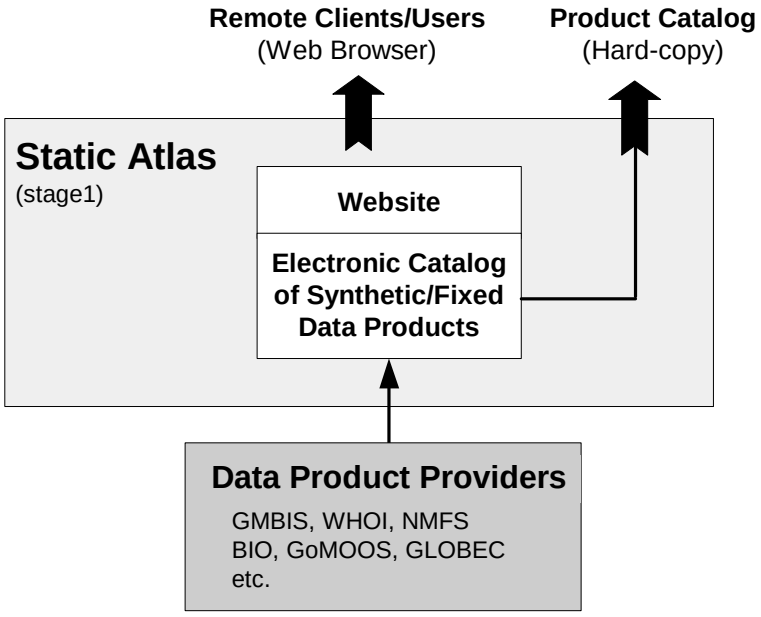
The GoMA activity consists of three partly co-occurring phases, each generating a discrete yet complementary set of Atlas products.

Static Atlas

The Static Atlas (figure 1) is an electronic catalog comprised of a finite number of (roughly 30) prefabricated graphical data products that illustrate key biogeographical patterns for the GoM. Structured along thematic lines as a series of inter-related scientific storylines, these products will show how species distribution and diversity in space and time within the GoM relate to one another and to aspects of the physical and chemical environment. Sources for these readily available data products will include GMBIS, NEFSC and WHOI amongst others. Resulting synthetic data products will be assembled in an electronic archive that users will be able to view and download as fixed imagery from the project Website via the Internet. Additionally, the contents of this repository will be compiled into a printed catalog that will be made available to parties interested in the Gulf of Maine Pilot Census (GoMAP) program and its Atlas component. The expected timescale for completion of this work is six months.

The contribution of USC/SSA in this activity will be to assist in defining the set of data products to be included in the static atlas catalog in support of chosen scientific storylines, and provide selected outputs from GMBIS. If desirable, we also undertake to contribute towards the development/implementation of the electronic catalog of products that will be available online via the project website.

Figure 1. Structure and contents of the GoM Static Atlas



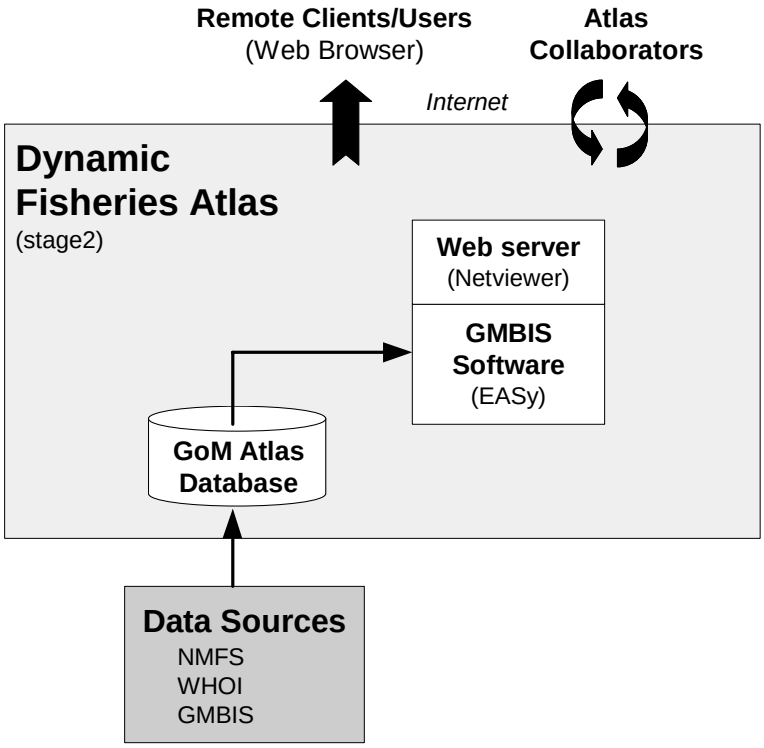
Dynamic Fisheries Atlas

The dynamic fisheries atlas developed during stage 2 of the GoMA activity is a simple extension of the GMBIS system to include relevant selected fisheries oceanography datasets from US sources, specifically NMFS and WHOI, which focus on the Gulf of Maine. This data will augment and thus provide comprehensive views of the physical and biological structure of the region currently available via GMBIS and originating principally from Canadian sources (DFO BIO and ARC). The system aims to expose and display available biogeographic datasets in a manner that maintains the fidelity of the fundamental data and displays them "as is", without recourse to any processing methods aiming to reconcile differences in the spatial sampling schemes employed in different survey programs (such utility is, however, integral to the comprehensive Census atlas to be developed in stage 3 – section 2.3 below). Also, unlike GMBIS which developed capability and software tools to tap diverse, remote distributed databases real-time, the Dynamic Fisheries atlas (and indeed also the Dynamic Census atlas) access only a central local database of fisheries oceanographic data products for the Gulf of Maine.

The structure and contents of the Dynamic Fisheries atlas for the GoM is shown in figure 2. At the lowest level are the providers of selected data products, namely NEFSC WHOI, and GMBIS, that support an interwoven set of scientific storylines such as those developed during the GMBIS project. These data products will be ingested and maintained within a local database residing on the Atlas project Web-server computer. Existing database connectivity tools within the EASy GIS software will be used to access this fisheries oceanographic archive, and integrate and dynamically display interactively defined mapped outputs from this multivariate database. The EASy Netviewer component permits deployment and running of EASy GIS applications across the Internet by remote users (clients) operating only their browser software. For the Atlas, Netviewer will be the tool by which widespread, interactive access to the dynamic fisheries atlas will be achieved and the method by which atlas data products will be disseminated via the Internet. Atlas GIS application development will be achieved by project collaborators operating EASy software locally.

The timescale for development of the Dynamic Fisheries atlas is estimated at one year. This stage 2 activity should begin upon completion of the static atlas, 6 months after GoMA initiation, but could potentially occur concurrently with the stage 1 work as may be necessary. No software development work is required for either of these stages, and the role of USC/SSA is solely to ensure assembly and implementation of the dynamic fisheries atlas using available GMBIS technology and given a selected range of datasets from identified data providers.

Figure 2. **Structure and contents of the GoM Dynamic Fisheries Atlas**



Census Dynamic Atlas

The GoM Census Dynamic Atlas builds directly upon the information system product assembled during stage two of the GoMA activity, by providing dynamic, electronic access to further data products from an expanded number of data providers. This comprehensive online atlas for the GoM additionally provides an enhanced toolset for the better integration and visualization of data in support of the GoM Atlas activity and the future Census field program for region. Implemented within the GMBIS software that is a central component of the dynamic atlases, the improved functionality includes: 1) a relational database facility for the better handling of metadata, data object hierarchies, and other specific data structures for the handling of categorical-frequency data (enhanced EASy rDB); 2) implementation of quantitative methods for the analysis of spatial data and reconciliation of Census data collected on disparate spatio-temporal scales (Analyzer); and 3) a custom graphical user interface and enhanced plotting capability (enhanced GUI) to accommodate the full range of display types demanded by the Census.

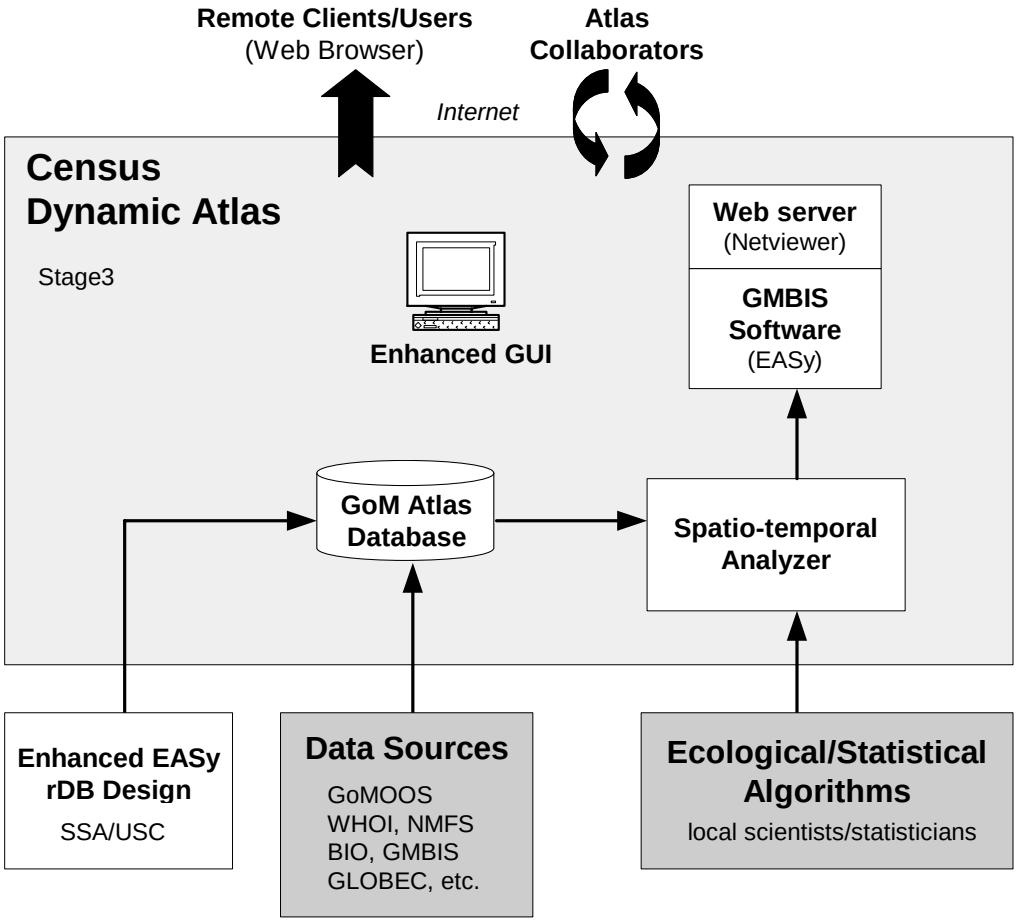
The information system design and components of the Dynamic Census Atlas are illustrated in figure 3. The four boxes at the bottom of the figure are activities and products that occur outside of the system but which are required for development of the system. They consist from left to right of work to improve relational database

functionality required for development of the atlas database, the source datasets to be provided by all key holders of ecosystem data for the GoM (eg. WHOI, NEFSC, BIO, GoMOOS, GMBIS, GLOBEC Georges Bank etc), and the ecological and statistical algorithms that must be developed to reconcile spatial and temporal gaps in the data, thereby providing a coherent and comprehensive description of biogeographical distributions.

The dynamic atlas, (larger, light gray area) is in fact an application of the EASy geographic information system, whose components reside on the Census server computer. These components consist of the Gulf of Maine Atlas database, a spatial-temporal data analyzer, GIS tools that are currently found in the GMBIS application (described in section 3.1 below.), and a new graphical user interface specifically designed for operation of the atlas over the Internet. The database will be a comprehensive electronic archive of all relevant oceanographic and biogeographic information provided by all key holders of ecosystem data for the GoM (eg. WHOI, NEFSC, BIO, GoMOOS, GMBIS, GLOBEC Georges Bank etc). Included will be diverse types of raster, vector, point data obtained on varying spatial and temporal scales. The spatial-temporal data analyzer is custom computer code to integrate the diverse types of data and synthesize it into realistic and comprehensive descriptions of patterns in environmental and biogeographic distributions. This process of synthesis will be achieved via application of statistical and scientific algorithms that will be developed to characterize the habitat of species and then applying this information to an “intelligent” contouring of species distribution. The spatial-temporal analyzer will require considerable effort to develop, and is integral only to the Dynamic Census Atlas (not the Fishery Atlas, stage 2). Interactive, remote access to the dynamic atlas application will be achieved via EASy Netviewer. Project collaborators will additionally be provided with the EASy software to facilitate development of the atlas GIS application and associated modeling tools.

It is expected that the stage 3 activity and the Dynamic Census Atlas can be completed within two years, and should begin one year into the GoMA project. Specific system component development work to be undertaken by USC/SSA is depicted in white in the figure below.

Figure 3. Structure and contents of the GoM Census Dynamic Atlas



Description of Atlas Components

GMBIS Software Tools

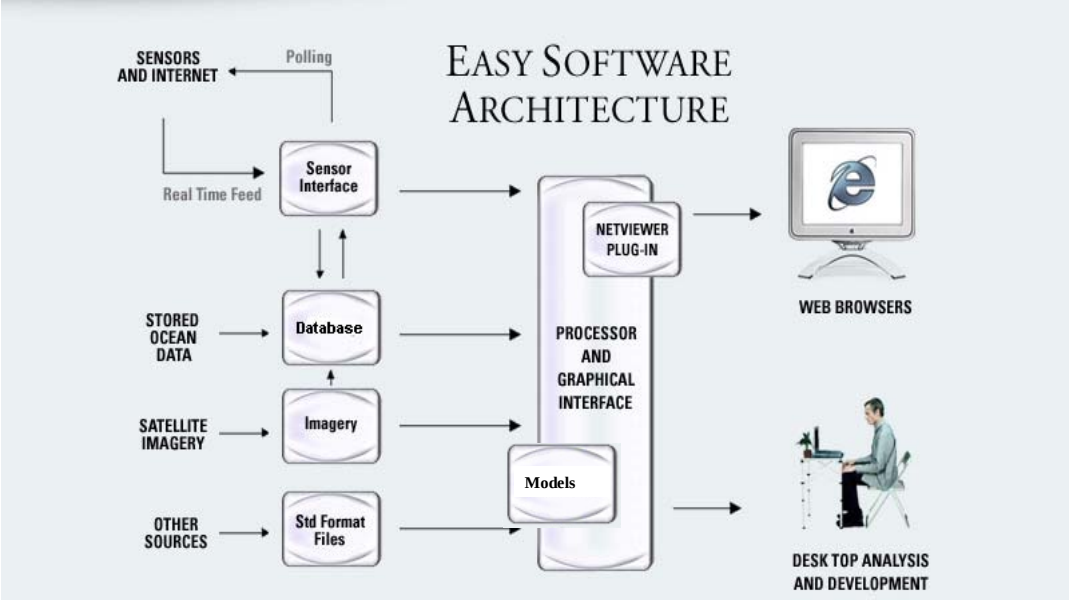
Both the Gulf of Maine Biogeographic Information System and the proposed Gulf of Maine Dynamic Atlases are applications of EASy (Environmental Analysis System), a geographic information system that is specifically designed for marine and coastal applications (www.systemscienceapp.com and www.runeasy.com). It runs under Windows operating systems upon PC desktops and upon PC servers. The power of the software is based upon the GIS's capacity to integrate diverse types of environmental information and models within a 4 dimensional context of space and time. In addition the software includes interfaces to automate the process of updating information on a server.

The desktop mode of operation (see figure 4) is used to build projects by importing diverse formats of data including that from relational databases, raster imagery and photographs, vector formats, as well as multimedia and links to the Internet. Project development may also include the incorporation of models, statistical algorithms, and connections to real time data streams.

The software proves a graphical interface to import diverse types of information from relational databases, Excel spreadsheets, and ASCII files. It can also handle many of the diverse formats of raster imagery and photographs, as well as vector objects such as Shape files and DXF files. Project model and algorithm modules are incorporated into the GIS as dynamic link libraries. These range from widely used statistical functions and spatial interpolation methods to custom algorithms and models that have been coded in a range of languages such as FORTRAN, C++, VISUAL BASIC, and MATLAB (under development). Time series information produced from simulation models or temporal queries of the database can be stored as a binary file and played back. This capability will prove extremely useful in analyzing and running environmental simulations and models. Selected data and analyzed products can be exported as raster images, ASCII text, or as a relational database.

The GIS employs commercial relational databases (most commonly MS ACCESS) as the basis for data management rather than developing a new and unfamiliar management system of its own. It simply links dynamically to the associated project database via standard SQL calls when querying for subsets of data. Emphasis on such protocols ensures scaling of the database and associated software according to need and growth of the project data archive. Use of SQL and ODBC protocols permits porting of the project database to larger and more costly relational database software, such as ORACLE without necessitating changes in the specific project application. Imagery is provided upon demand from a file server and vector objects are stored in their standard formats.

Figure 4. Components of the geographical information system. The figure also shows the 2 modes of operation, the "Netviewer" for serving information interactively over the Internet and the desktop for project development.



The "Netviewer" plug-in supports interactive access to data, visualization products and analytical tools over the Internet. The "Netviewer" mode of operation is initiated by simply activating a plug-in to the GIS that is residing on the server. Although it runs under the Windows operating system, the Java/ActiveX-based plug-in to the software allows a remote client to operate the GIS over the World Wide Web. The "Netviewer" allows complete viewing of all spatially and temporally referenced information (images, stations, shapefiles, selected plots, Internet links, and multimedia) remotely over the Internet. This information can then be interactively analyzed, selected, and downloaded onto the client's PC.

GMBIS components are already being used to support other existing CoML projects. In addition to GMBIS itself, EASy/Netviewer GIS is currently being employed as a data integration, visualization and dissemination tool in the Stanford TOPP (Tagging of Pacific Pelagics) project and the Duke SEAMAP (Spatial Ecological Analysis of Megavertebrate) information system project focusing on marine mammal, bird and turtle data archives. The SEAMAP project focuses on the birds, mammals, and large fish, and will have also a Gulf of Maine focus. SEAMAP will thus be a source of additional data and products on higher trophic groups for the Atlases. Finally, plans are currently underway to employ EASy/Netviewer to expose the extensive ecosystem database for the Chesapeake Bay LMER developed by the TIES (Trophic Interactions in Estuarine Ecosystems) project.

The graphical user interface of the EASy "Netviewer" software is fairly well designed, but it will need to be improved to provide a friendly interface for viewing, analyzing and downloading data from the Atlases. In addition changes will be made to allow better access to metadata. Likewise the GMBIS database has proved adequate, but several improvements in its basic structure will be required in order for it to meet the specifications of the Atlas database. This includes the capacity to store size frequency data, allow interactive binning of spatial and temporal data, and allow categorization of parent-child relationships in order to handle the large number of species that will be found in the atlas. These enhancements to the GMBIS software are among the tasks listed below.

GoM Ecosystem Databases

The GoM is a well-studied marine ecosystem, and one for which extensive multivariate scientific data on environmental conditions, species biomass distributions and resource exploitation exist. Motivated largely by the study of and management of trans-boundary fish stocks within the Northern Atlantic, databases resulting from long-term monitoring and research activities within an area representing a major biographic discontinuity between north and south temperate species (Mahon et al., 1998), document not only natural processes affecting species distribution patterns within the GoM but also the effects of large-scale ecosystem perturbation due to harvesting (Fogarty & Murawski, 1998). These datasets provide the foundation for an improved understanding of biogeographical and ecosystem processes operative within the GoM and the empirical

basis for the management and restoration of fisheries resources within this ecologically sensitive area.

Source data for the GoM Atlas project will be derived from selected key ecosystem databases that are maintained by several research institutes and agencies active in the region. Data will include time series of satellite imagery products, spatially referenced larval and fish survey data, *in situ* physical oceanographic observations, nutrient measurements, quantitative phytoplankon, zooplankton, benthic survey data and specimen collections data. They will also include results from circulation models combined with new, high resolution and frequency surface current data from CODAR now available operationally for this area. Principal holders of these data include: DFO Bedford Institute of Oceanography (BIO), the Atlantic Reference Centre (ARC, Huntsman Marine Science Centre), the NMFS Northeast Fisheries Science Centre (NEFSC), the GLOBEC Georges Bank program, and the Gulf of Maine Ocean Observing System (GoMOOS) amongst others. Detailed data holdings maintained by some of the collaborating institutes are listed in the appendix.

Analyser and Algorithms

As stated above the spatial/temporal analyzer is computer code implemented during stage 3 of GoMA and available to the Gulf Census Atlas. It is designed to provide improved interpolation and contouring of the geographic distributions of species given disparate source observations made at varying spatio-temporal scales. Inevitably field surveys of a species distribution will contain spatial and temporal gaps; the analyzer will attempt to fill these gaps using a combination of statistical and modeling methods. The details of the statistical and scientific algorithms to produce such a "scientific" description of biogeographic patterns has not yet been determined, and the development of such algorithms is a major task in creating the Gulf Census Atlas. As indicated in figure 3, the algorithms implemented and found in the analyzer will be developed by local marine scientists and statisticians who have established research interests in the Gulf of Maine. These algorithms will then be directly linked to the analyzer via a COM interface or the algorithms will be recoded and inserted as dynamic link libraries into the Atlas.

For many if not most (rare) species current ecological and biogeographic information will be insufficient to characterize their habitat. However, for common species or those that are sampled comprehensively because of their commercial value, that analyzer will likely provide much-improved descriptions of distributions.

The analyzer will contain at least 3 types of logic:

- routines for characterizing the habitat of a species from its observed spatial temporal distribution and from other sources of information on the physiological and ecological characteristics of the species. Characterization of the habitat will may be limited to physical and chemical parameters such as temperature, salinity, depth, light intensity, bottom type, and current velocity, but it may be possible for selected species to include data on biological factors such as the local size of the species' prey and predator populations.

- multivariate contouring routines and the information on a species habitat to provide a scientific. It will also contain routines for characterizing the habitat of a species from its observed distribution Knowledge of a species habitat will then be applied to the process of contouring.
- routines for reconciling the disparities in the spatial and temporal scales of sampling for physical, chemical, and biological measurements

The scientific and statistical algorithms that will be incorporated into the analyzer will likely be adaptations of existing computer code. Identification of habitat of a species is a frequent requirement in terrestrial conservation (often a key activity in the protection of endangered or threatened species), and a number of computational methods have been developed. These or related methods have been applied marine species in attempts to define "essential habitat" for improved management as well as the establishment of protected areas for both commercial species as well as endangered and threatened species. areas applications of these methods Similar methods have also be applied to the identification of essential fish habitat/species range. Such methods include GAMs (General Additive Model), GARP (Genetic Algorithm for Rule Set Production, Stockwell & Peters, 1999), and GIS-based methods (Eastwood, Meaden, 2001) amongst others. Spatial-and-Geostatistical approaches may also be included in the analyzer to identify patterning properties such as anisotropy, positional location of spatial structures, autocorrelation, dominant scales of patterning variability, and variance scaling relationships (Renshaw & Ford, 1983; Legendre, 1993; Hastings & Sugihara, 1993; Tsontos, 1997 & 1998). Various spatial statistical techniques are available for the quantification of these attributes in data series including autocorrelation analysis, correlogram and variogram analysis, 2D-spectral analysis, wavelet analysis, and fractal measures. Spatial cross-correlation methods (e.g. coherence spectra) are used to identify and quantify interdependencies between coincident data series. Methods may differ in terms of their data requirements and result outputs, but an appropriate set of complementary spatial statistical approaches will be used in the proposed work. Relationships between available overlapping data series will also be explored by more traditional statistical approaches such as multiple regression and multivariate analysis.

System Science Applications has created a prototype analyzer for the monitoring of water quality in the ocean and in water reservoirs. It has used its GIS to create for NOAA/NESDIS an automated means of providing over the web-based maps of the predicted distribution of sea nettles from environmental data and knowledge of the preferred temperature and salinity ranges of the medusae. The prototype analyzer includes a nonlinear search routine for automatic tuning of multivariate models to spatial/temporal datasets, a scheme for creating a common data model for reconciling disparate datasets, and a routine for calculating principal components. The prototype analyzer provides a foundation to develop multivariate, scientific contouring of species distributions. Finally, USC is currently involved in a NOAA/NESDIS funded project with NEFSC exploring the use of GIS and spatial statistical methods for the analysis of coherence between environmental data from satellite imagery and series of cod and haddock distributional data for the GoM.

Gulf of Maine Program of the Census of Marine Life:
Expanding the technology section of the project website

Kenneth G. Foote
Woods Hole Oceanographic Institution
Woods Hole, MA 02543

15 October 2002

SUMMARY

The technology section of the website belonging to the Gulf of Maine Program of the Census of Marine Life [Internet address: http://www.whoi.edu/gomcensus/] will be expanded over a two-year period. In particular, generic tools for observing and sampling marine organisms, as well as platforms used in such operations, will be elaborated by explaining their principles of operation, and by exemplifying and illustrating these with characteristic data or results derived from the same. Source references consisting of both printed and electronic publications will be organized in a central database by means of a standard commercial software system. The proposed WHOI subcontract to the University of Southern Maine consists of a brief review of background, work statement, schedule, summary statement of deliverables, budget, and budget justification, which are presented below.

BACKGROUND

The Gulf of Maine Program of the Census of Marine Life is a research initiative that endeavors to answer the question of what lives in the Gulf of Maine. It aims to do this by applying modern tools of technology in a systematic program of observation and sampling of a spectrum of organisms. These are coarsely divided into five functional groups: offshore subtidal benthos, intertidal and nearshore subtidal benthos, plankton, fish and squid, and large marine animals and seabirds. Significantly, organisms within each of these groups can be observed or sampled by the same or similar tools.

During the period 1999-2002, the interests of the regional research community in this program were identified. To provide information to researchers, as well as to the larger, interested public, a project website was established, with Internet addresses given above. Basic reference material is served at this website.

The goal of the present proposal is to expand the technology section of the website, as elaborated below. In addition to serving the particular needs of the Gulf of Maine Program, an expanded technology section will serve as a common resource for researchers participating in other efforts sponsored or inspired by the global Census of Marine Life program [Internet address: http://www.coml.org/].

WORK STATEMENT

Woods Hole Oceanographic Institution will develop the technology section of the project website in order to elaborate and exemplify each of the generic tools, including platforms, listed below. In each case, the principle of operation will be explained, particular realizations in devices or gear will be described, and references will be given.

Sampling tools for physical capture
- Water bottle
- Pump
- Gauze recorder
- Plankton net
- Bottom trawl
- Pelagic, or midwater, trawl
- Seine
- Gillnet
- Weir
- Longline
- Trap
- Box corer
- Dredge

Observational tools for remote sensing
- Optical particle counter
- Video microscope
- Imaging flow cytometer
- Other video systems
- Camera
- Bathyphotometer
- Acoustics: scientific echo sounder
  - Short-range ultrasonic narrowband
  - Long-range ultrasonic narrowband
  - Composite narrowband and broadband
  - Broadband
- Acoustics: sonar
  - Electronic sector scanning
  - Multibeam
- Sighting, both shipboard and aerial
- Tagging
- Laser line scan
- Spectrometer
- Lidar

Platforms
- Research vessel
- **Fishing vessel**
- **Towed vehicle**
- **Remotely operated vehicle**
- **Autonomous underwater vehicle**
- **Buoy (drifting, moored)**
- **Ocean bottom system**
- **Airplane**
- Satellite

The order of priority will be that of (1) operational tools, and (2) research tools in use by the inventing or responsible research group. Given the rapidity of developments in instrumentation, and the diverse forms of publication of materials, spanning the range from journal publications to conference proceedings to institution report series to websites, an attempt will be made to establish a unified bibliography of both printed and electronic documents. This will be updated on a regular basis.

The basic tasks are listed. These are to be executed for each generic tool, including platforms, on the above list, and the results are to be published directly in the technology section of the website.

Task 1. Describe the operating principle for the particular tool of observation or sampling.

Task 2. Exemplify the tool by particular realizations, also presenting characteristic data or results derived with the tool.

Task 3. Give references both to the tool and illustrative uses.

Task 4. Prepare a bibliography of source documents, if feasible employing Endnote, a commercial software system used by librarians.

SCHEDULE

The series of tasks will be conducted for each generic tool listed above. The primary activity during the first year will be completion of the tasks for those tools that are operational. During the second year, the principal activity will be completion of the tasks for research tools that are only being used by the inventing or responsible research group.

DELIVERABLES

The primary deliverables will be additions to the technology section of the website. Attention will be called to the latest additions through the What's New field on the website homepage. Summary reports of progress will be prepared on a semi-annual basis.