The Future of Marine Animal Populations (FMAP)

Data synthesis and prediction of future marine populations and communities for the Census of Marine Life

On Behalf of the FMAP Network: Ransom A. Myers, Killam Chair of Ocean Studies
Department of Biology, Dalhousie University
Halifax, Nova Scotia, Canada B3H 4J1

Summary

The Future of Marine Animal Populations (FMAP) is a new modeling component of the Census of Marine Life. It is a network of statisticians and mathematical modelers that will ultimately address the third question of CoML, "What will live in the oceans?" However, the network will contribute to CoML in several key ways besides prediction, including exploration of the limits of knowledge in the past, present, and future. During the next two years, FMAP will add to existing CoML expertise to create a network of top ecological modelers, balanced internationally and in terms of schools of thought. This network adds three FMAP Centers, in Iceland, Tokyo, and Nova Scotia. The Nova Scotia Center has overall managerial responsibility for FMAP. During 2003, FMAP will provide feedback on the design of present Census field projects to help refine and coordinate them. During 2004, it will help identify gaps in the overall CoML field plans to influence design and selection of added observational efforts. Members of the network will begin to use existing and new datasets arising from the Census, publishing methods and maps to be made available through OBIS before the end of 2004. FMAP is planning activities for 2005-2010, including identification of a core team to contribute to global integration of results.

1 March 2003

Contents

1. Introduction: Modeling as an Integral Part of CoML

The Census of Marine Life (CoML) initiative is an international research program aimed at assessing and explaining the diversity, distribution and abundance of marine organisms throughout the world's oceans. This ambitious overall goal is to be reached by stimulating well-coordinated, dedicated, regional research efforts based on initial projects that demonstrate efficient methods to census ocean habitats. Together these will provide significant new information on patterns and processes of marine life on a global scale. Modeling is crucial for the cost effective collection of data, formulation of testable hypotheses, synthesis of data, and prediction of the future. It is important that modeling and analysis be integrated into research from the beginning so that the initial sampling is done in an optimal manner and so that design can be modified as field work continues, based upon modeling that is simultaneous with data collection. Modeling cannot wait until fieldwork is finished.

Three questions encapsulate the CoML: What did live in the oceans? What does live in the oceans? What will live in the oceans? The Future of Marine Animal Populations (FMAP) adds to the critical modeling and analysis components of all three aspects of CoML - past, present, and future. Models are needed to interpret and design sub-sampling of historical data. Statistical design provides for optimal and cost effective data collection and interpretation. Synthetic, meta-analytic models are needed to combine and understand the data collected. Finally, models effective for synthesis have potential for prediction. The best test of a model's ability to predict the future is its ability to predict the past. Thus, early and extensive efforts to develop collaborations with the existing CoML elements are essential to FMAP's success. New HMAP information about historical oceans is a critical link between current field censuses and future prediction. Moreover, modeling can help define the limits of knowledge: what is known and how firmly, what may be unknown but knowable, and what is likely to remain unknowable. Thus, FMAP will make major contributions to the culminating report of the CoML in 2010.

FMAP grew out of a workshop held in Halifax, Nova Scotia (Canada) in June 2002. Representatives of all the major elements of the Census - its program on the History of Marine Animal Populations (HMAP), its initial field projects, and its data assimilation framework (the Ocean Biogeographic Information System, OBIS) participated there and subsequently. The current vision will continue to evolve as the members of the network reach out to the existing CoML elements.

2. Themes

FMAP focuses on 5 themes: Design, Data Exchange and Model Interface, Model Development, Data Synthesis, and Prediction.

a) Statistical Design for the CoML. Efficiency of scientific surveys can be greatly enhanced by careful statistical design. FMAP's modeling efforts will test survey and experimental designs in initial field projects and improve those in future expansion projects through at least three means: (1) a statistical advisory team, (2) data quality control models for CoML, and (3) standard programs for extrapolation of sample data.

b) Data Exchange and Model Interface. Model applications can be broadened by data format and access standards. Initial FMAP projects will focus on (1) enhancement of standard data exchange formats easing model use, (2) quickly increasing the volume of fisheries data in OBIS in forms suitable for the types of modeling CoML requires, and (3) improving archiving of non-fisheries data for compatibility.

c) Model Development and Sharing. It is crucial that a diversity of modeling approaches be considered within CoML and that data from different habitats be compatible. FMAP will provide a central clearing house for sharing important advances in analysis in present and future CoML projects. Early FMAP projects focused on analysis will evaluate available models for CoML use and consider ways to enhance them. Areas of particular interest are: (1) standard interpolation and overlap models, (2) standard mapping models to optimally use environmental and location data, (3) models of pelagic fish biodiversity, (4) animal movement models to infer the distributions of marine animals from state-of-the-art tracking devices, and (5) spatial multi-species models. In each case, FMAP will explicitly consider the limits of knowledge and why the limits now are where they are.

d) Data Synthesis. Recent meta-analytic methods have revolutionized interpretation of medical and scientific research, showing that in some cases much more is "known" than is apparent. FMAP will adapt and bring to CoML the latest of such techniques. These efforts will be focused on the meta-analysis of interactions.

e) Prediction. FMAP will work toward predicting the future of marine life. Heretofore, attempts have consisted of imposing large changes on a poorly understood baseline. CoML field projects and HMAP, combined with other data assembled in OBIS, will provide a much better baseline and time series. FMAP will focus on two major aspects: the effects of trends in fishing and of possible climate change. Both will profoundly change the nature of marine ecosystems, and what will live in the ocean in the future. Among the initial prediction projects being considered are: (1) global fishing effort and its consequences, (2) effects of climate change on marine biodiversity, and (3) possible marine extinctions. Future fishing effort, depending on social choice, is fundamentally unknowable. Climate change may also be unknowable at the level of detail important for many species, but the use of plausible scenarios allows useful advances. .

Theme Projects and Approaches

A. Statistical Design for CoML

The CoML Initial Field Projects (IFPs) need to develop statistical rigor in their sampling programs, to place their data in convenient and compatible database formats and to maximize the utility of the data for a variety of analyses and modeling processes. Although each project has its own well thought out scientific goals and analyses, the concept of OBIS is that the data assembled can be analysed online in ways that the original samplers never anticipated. The FMAP network will explore various ways of analyzing and modeling, providing feedback to projects on possible improvements. This will improve the utility of the data in OBIS and the potential for synergy among IFPs and HMAP to improve descriptions and understanding of biodiversity on a global scale. Early FMAP experience will help shape Expansion Field Projects based on IFPs. FMAP will benefit from this role of supporting the IFPs because it serves its own goals of creating descriptive and predictive models capable of working on large scales. Each IFP has designated a liaison to FMAP and network members will participate in IFP and HMAP meetings as necessary.

CoML will collect an enormous amount of data. For the data to be maximally useful, it must be evaluated and scrutinized by models to detect errors and extrapolate estimates on an appropriate spatial and temporal scale. FMAP will adapt and extend models from other disciplines, particularly epidemiology, which can be used with spatially-temporally misaligned data, i.e. when variables (typically counts or rates) are aggregated and sampled over differing regional and temporal boundaries (Zhu and Carlin 2000).

Just as CoML has begun to use the members of the SCOR Working Group on New Technologies for Observation of Marine Life as a kind of review and oversight group for technologies throughout the Census, FMAP will develop a small group of statisticians available to assist existing and expansion CoML projects. This will facilitate new groups of researchers adopting CoML approaches in new places and lower the barriers to obtaining new funding.

B. Data Exchange and Model Interface

FMAP will follow OBIS' lead in extending the highly successful approach used by physical oceanographers in the Distributed Oceanographic Data System (DODS) (Sgouros 2001) to handle formats for marine life data and model outputs. Early achievements can be in the area of fished species. Although FMAP does not have the resources to compile all the world's fisheries data, it will have the capacity to serve as a catalyst for additional data to be made accessible to and through OBIS. Fisheries scientists have a long history of international cooperation, and are in general willing to share most data. FMAP will expand the network of international fisheries biologists currently working with OBIS to agree on common data formats. (Note that existing FAO databases report landings, not abundance.) See http:fish.dal.ca/~myers/welcome.html for an ongoing project to compile the world's fisheries data. Boris Worm will serve on the OBIS International Committee as liaison between FMAP and OBIS.

C. Develop Modeling Frameworks for CoML: Some examples of early modeling work

Models for mapping distribution and abundance. We have hardly begun the investigation of biodiversity in the ocean; even the large scale patterns are only vaguely known. Neither have the patterns of the large, well known species been studied on a global scale. As an example, Fig. 1 shows the pattern of species diversity of tunas and billfish recently calculated on a global scale. The detection of such large-scale patterns of biodiversity is an early step in understanding the underlying causes of patterns of biodiversity.

This is a domain in which candor about present limits of knowledge matters greatly. Visualizations of the oceans can also be very misleading about what is known -- a few data points may turn into an area on a map covering tens of thousand of square kilometers. A crucial task for CoML is to provide the tools needed to map ecological data on species abundance and distribution. Much recent research exists in this area (Scott et al. 2002), primarily for terrestrial species, but unfortunately, relatively little has statistical rigor.

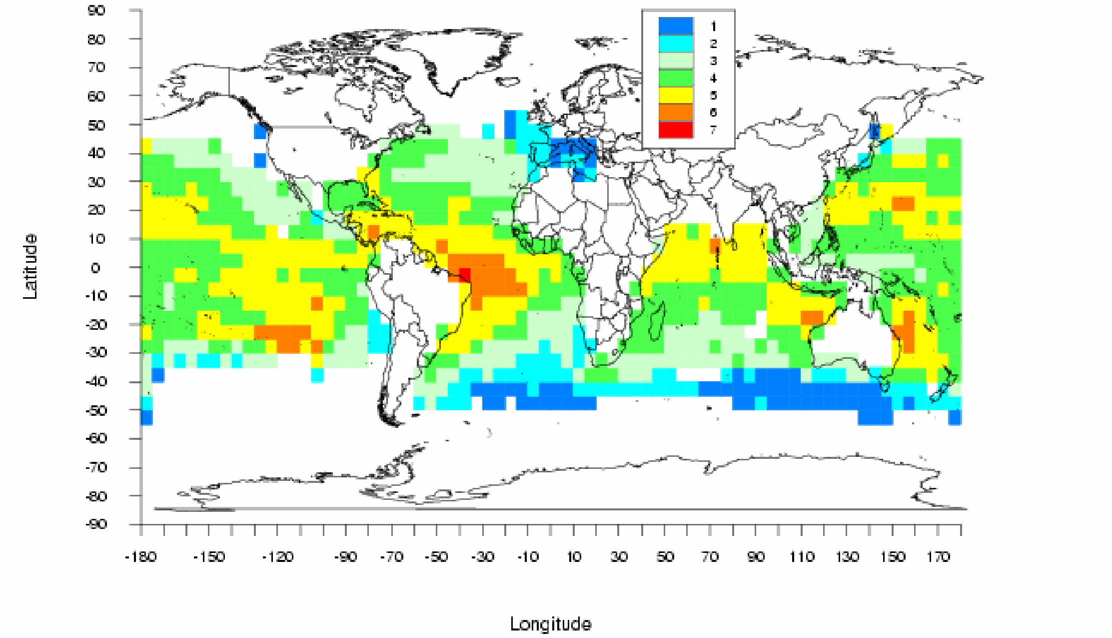

Fig. 1. The expected species richness per 40 individuals for large commercial pelagic species (tunas and billfish) observed in Japanese longline operations between 1962 and 1980 calculated by the rarefaction method.

While existing methods work for well-studied species sampled throughout their range, this is a tiny proportion of marine life. Here FMAP will identify needs and opportunities for research. In spite of massive effort that has gone into mapping ecological data, relatively few useful tools are readily available for mapping species where the data are poor and only a small part of the distribution is sampled, e.g. the type of data available for most marine animals.

A simple example illustrates this point on a group of the best known of all marine species: the hammerhead shark[1]. The rapid decline of this species group went unnoticed until recently (Baum et al. 2002), partly because of the inability of available models to adequately model the data, and even to map it. We have mapped these data in terms of the number of times the species was reported on commercial longline operations per 10,000 hooks in Fig. 2. This map is unusual in that it shows where there was effort, but no animals seen. It also shows that hammerheads occur well east of the Grand Banks, in disagreement with standard range maps. The tools to display this type of data are essential for the success of CoML, and FMAP will support OBIS in identifying, testing, and providing these tools on line. It is remarkable that the

[1] In this plot three species of hammerheads are included: *Sphyrna mokarran, S. lewini, S. zygaena* however, most of the observations are from the scalloped hammerhead, *Sphyrna lewini.*

distribution and abundance of a species as conspicuous as the hammerhead shark is only approximately known today. Such tools could contribute very effectively to the survival of this and other species in rapid decline.

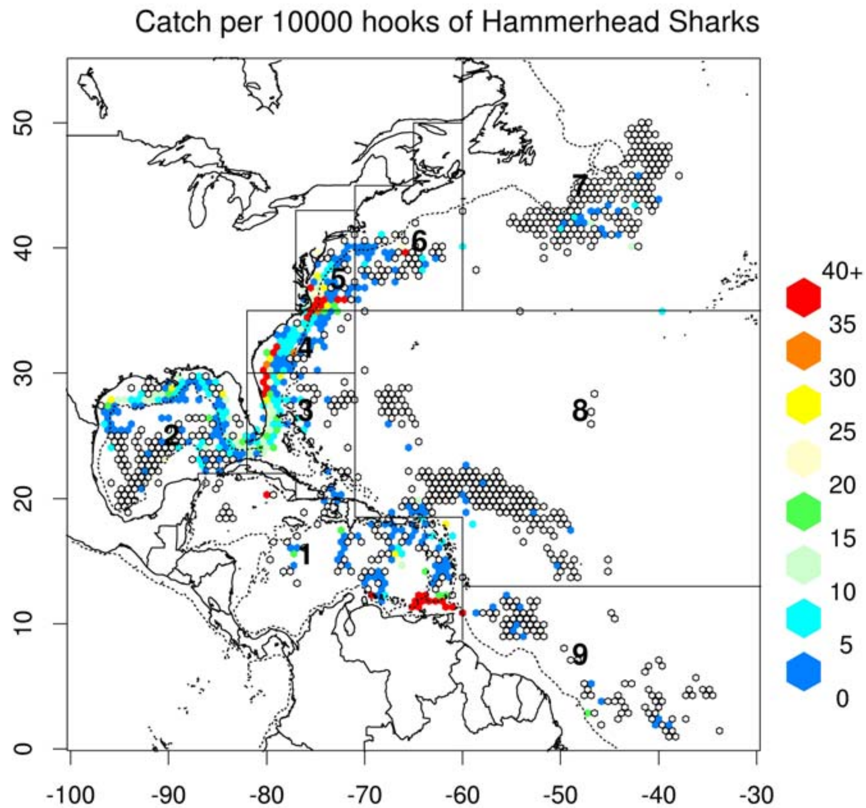

Fig. 2. The number of hammerhead sharks reported per 10,000 hooks in the US longline fishery. Empty hexagons represent areas with effort, but no animals taken.

Deliverables should include a suite of standard tools to help map the world's marine biodiversity. These tools should address the following issues: (1) Honest confidence regions should be provided for distributional maps. This is a hard problem for poorly sampled regions where predictions will be based upon extrapolations not interpolations. In this case, true standard errors are hard to estimate. (2) Methods should predict abundance, not just presence, if the data exist. (3) Museum data should be optimally used. Data are placed in museum collections for a variety of purposes, and the utility of the data could be greatly enhanced by identifying the data type using statistical classification methods, to allow correct inference. For example, if samples of range extensions are preferentially collected, then this will affect how inferences are made on distribution. (4) Spatial auto-correlation should be explicitly modeled. (5) Different models need to be available for the 4 data types commonly available (presence only, presence/absence, abundance, and abundance with zeros that cannot be trusted). The methods should explicitly take into account the type of error distribution in each case, i.e. least squares methods should not be used. Details of the mapping portion of FMAP can be found on http://fish.dal.ca/fmap.html.

Tools to Predict Where CoML Should Sample. CoML has begun with sampling in areas that have clearly been under-sampled, such as mid-ocean ridges (MAR-ECO), or areas such as the near-shore where a standard protocol repeated over very large areas (NaGISA) would surely yield big benefits. However, to complete CoML systematically, we need methods to identify where new sampling should take place. These methods are extensions of mapping tools, but must consider many species at a time. These tools will be integrated with the information in OBIS, and will be a key tool to influence design of the field programs. Unfortunately, such analytical tools do not exist today, and FMAP must initiate their development. This will be done in conjunction with terrestrial researchers, where such tools are also needed, and with the wider statistical community. These deliverables will be key to the cost effective sampling during fieldwork in CoML.

Inferring animal movement and distribution from state-of-the-art tracking devices. The study of the movement and behavior of marine animals is being revolutionized by technology that allows tracking of movements of individual animals using a variety of satellite and acoustic devices. The ability to model and analyze such data, however, has lagged behind the collection methods. FMAP's proposed research will focus on the development of nonlinear state-space models that can be used to: (1) improve location estimates from field data collected with state-of-the-art tracking devices, (2) statistically test alternative behavioral models, (3) combine key movement parameters across individual animals to allow integration with predictive population or community dynamics models, and (4) optimal estimation of distribution by integration with other data. An initial implementation of this approach is available (http://fish.dal.ca/fmap.html).

D. Synthetic Models for OBIS

Ultimately, CoML data will be used to synthesize the dynamics of marine populations and communities to understand and deal with the human impacts (overfishing, species invasions, climate change) currently occurring. At present, the scattered nature of the information makes it almost impossible for an individual researcher to collate enough of the data to come to broad, scientifically valid conclusions. Coupled with the paucity of historical data, it is almost impossible to model and understand changes at a population level, much less a community level (Dayton et al. 1995). The historical information is of particular importance in determining the true productivity that marine systems may be able to sustain, and the loss of historical data results in the "shifting baseline syndrome" (Pauly 1995).

Here, FMAP will encourage proposals to develop approaches for the synthesis and prediction of data on the world's marine animal populations. It aims to design structures that will lead to the compilation and synthesis of much of the global population dynamics data, for example, on exploited fish and aquatic invertebrate species. We will use the observational data to test patterns of species richness, develop plans that will allow the usefulness of various ecosystem models to be compared, and describe how methods that can include new tracking methods can be incorporated into models.

The goal of this theme, however, goes beyond the simple compilation of data; we must standardize data so that they can be analyzed in a systematic fashion. For example, the simple question of how maximum population growth rate or carrying capacity varies for well known species, e.g. cod, could not be addressed without a meta-analytic approach to the problem.

Although the need for a synthetic approach to the study of marine animal population dynamics has long been recognized, for several reasons a synthesis is only possible now. First, modern assessment methods have allowed detailed analysis of more stocks to be completed. Second, the more widespread use of research surveys improves the accuracy of assessments. Most important, new statistical and analytical methods allow analyses and computations not possible a few years ago.

Meta-analysis is the term used to describe quantitative methods for combining evidence across studies. In FMAP work, results will be combined across populations instead of experiments. One treats the time-series of each population as a realization of a natural experiment, and combines results across populations. The use of meta-analysis is motivated by the lack of long term data for any one population. We may never have reliable data on over 100 generations for a natural fish population, and yet this is what we need to make reliable statistical inferences. Here again we encounter interesting and challenging limits to knowledge. Combining estimates for many populations may allow reliable conclusions from much shorter time series.

Subtle pitfalls occur if multiple studies are combined in a naive fashion. For example, when studies are being reviewed, it is of interest to determine how often a given hypothesis is statistically significant. This procedure is known as vote-counting, and has been shown to have serious flaws. The proportion of studies with significant results reflects the average power of the studies to an ecological process, but may only be examining the power of the tests used to detect it. Furthermore, this bias is not reduced as the number of studies increases. This is a severe problem in fisheries research because many studies have very low statistical power.

New approaches, based upon meta-analysis (Myers and Mertz 1998), variance components models (Myers et al. 1999), and Bayesian analysis (Punt and Hilborn 1997; Hilborn and Liermann 1998) are becoming the standard approaches to understanding population dynamics. The use of meta-analytic approaches provides some hope, by allowing estimates of critical biological parameters to be included in models of community dynamics.

The formulation of the fundamental questions in the CoML framework will maximize use of the data for the field programs, as well as allowing more efficient use of the data in OBIS. A key deliverable for FMAP is the formulation, testing, and implementation of these statistical and analytical tools to obtain maximum utility for OBIS.

E. Develop Predictive Methods for Changes in Biodiversity: Some novel approaches

Ecological consequences of global fishing. Targeted and by-catch fishing mortality is a dominant force driving the dynamics of many marine populations (Jackson et al. 2001). Therefore, it seems likely that fishing affects biodiversity to an equal degree through direct removals, and trophic and habitat changes. Despite the obvious importance, most management or population projection analyses ignore how effort might change in response to (1) population abundance and distribution; (2) regulation; and (3) changes in economic climate. In this theme, FMAP will make assumptions about changes in the fishing effort globally, and examine consequences for the abundance, distribution, and diversity of fish populations.

Climate change and marine biodiversity. Climate scientists predict changes in the ocean based upon a variety of scenarios for greenhouse gas input and assumptions about the parameters and nature of climate models. Employing these predictions, and the results from habitat mapping models, it is possible to make scenarios of the future distribution, abundance, and diversity of marine animal life in the ocean. Some examples available thru OBIS are on LoiczView.

Possible marine extinctions. Although a number of marine bird and mammal species have disappeared in modern times, marine species are often considered "extinction-proof" because they are assumed to have large geographic ranges, huge population sizes, and long-distance dispersal. Yet vast numbers of marine species have disappeared in the past, before humankind became dominant in the biosphere. A number of species in taxa considered extinction-proof have disappeared in modern times or are now approaching extinction. Extinction in the ocean is the endpoint of a process of sequential elimination of many local populations by overexploitation and habitat degradation. Marine species may be vulnerable to extinction because of subsidies that encourage overexploitation, long age to maturity, and the adaptation to an environment with little disturbance. The purpose of this theme is to predict patterns of extinction in the ocean, and to test these predictions with existing data and data to be collected in CoML.

3. Organization and Collaboration: the Management Strategy

The management structure will address the following tasks: (1) creation and maintenance of a network of FMAP researchers that is balanced in its methodological approaches, geography, and span of concerns of marine life; (2) identification of crucial research tasks, and publicizing of needs and opportunities; (3) obtaining and allocating seed funds to stimulate key research; (4) stimulation of proposals to obtain the funds to carry out the full vision of FMAP; (5) integration of FMAP with the other components of CoML; and (6) ensuring progress is made on deliverables by the FMAP network. These tasks can to some extent be separated. For example, the review process for seed funds within FMAP can be done by an independent group of scientists not competing for funds.

The FMAP Steering Group will oversee the identification of critical problems and the control of money. Founding members of this Committee include: Ransom A. Myers (Canada), Gunnar Stefansson (Iceland), Hiroyuki Matsuda (Japan, liason to NaGISA), Jeremy Collie (USA, liason to GoM), and Andrew Rosenberg (USA, liaison to HMAP). The review of proposals will tentatively be carried out by a separate group, the FMAP Scientific Review Committee, whose job it will be to conduct fair and impartial reviews of proposals and ensure a diversity of approaches.

FMAP will be anchored at three Centers: Dalhousie University with Ransom Myers, University of Iceland with Gunnar Stefansson, and University of Tokyo with Hiroyuki Matsuda.

Each of these researchers has a great deal of experience organizing large, complex, long-term research projects and programs[2]. Day-to-day management of FMAP will be at Dalhousie, where a Network Manager will (1) take care of the finances and disperse funds, (2) coordinate, e.g. manage the FMAP Website, and communicate with OBIS, HMAP, and CoML field projects, (3) ensure communication among FMAP projects. This would be a half time position. It is expected that a meeting of the network members will take place about every 18 months. We hesitate to offer much detail at this point, as our intention is, as it has been for the six months since the first FMAP meeting, for network members, and the new Centers, to come forward with initiatives.

Communication with Field Projects, OBIS, and HMAP. As indicated, communication between FMAP and the other parts of CoML will be maintained by network members who serve as liaisons with each major component of CoML. The CoML's International Scientific Steering Committee (Grassle Committee) will designate one of its members as liaison to FMAP. FMAP members will work together with other CoML components for the major 23-25 October 2003 Washington DC meeting that will present CoML's Baseline Report. Responsibility for the execution and delivery of FMAP lies with Steering Group and ultimately with Ransom Myers. CoML senior scientist Ron O'Dor, who helped plan and participated in the June meeting, has assisted in the preparation of this proposal and will continue to work for cohesion.

Reporting Process. FMAP is structured as an interrelated series of themes, whose whole would be much greater than the sum of the parts, but whose parts can succeed on their own. The latter is crucial for fund-raising. Still, each subproject is related to several others, and each is part of a larger plan. FMAP is identifying primarily young, excellent researchers who have recently completed their PhDs to carry out most of the work. At this critical stage in their careers, they should require little encouragement to carry out their work and have strong incentives to raise funds and build their reputations. Nevertheless, the timely completion of deliverables requires the leverage and leadership of the Steering Group and some core funding. Below several short term (2 year) benchmarks are identified under each theme.

[2] See web sites fish.dal.ca and www.hafro.is/dst2/

4. Outreach to the Public and Research Community

Like all parts of the Census, FMAP has huge potential for education and outreach. We will work closely with the group led by Sara Hickox at the U. of Rhode Island now charged to encourage education and outreach throughout the Census. FMAP will designate a network member (or perhaps the Network Manager) to participate in CoML E&O network.

For the public, FMAP will attempt to show how models can be used to understand present data, guide the understanding of future data, and to predict the future of marine life. In several areas, FMAP work lends itself to outreach. These include: (1) the use of models to understand the migration and distribution of tagged tuna, turtles, and seabirds, (2) the use of models to predict the consequences of overfishing, and (3) the use of models to explore chances of extinction. To reach the public, FMAP will emphasize informal science education (learning that is voluntary, self-directed, and motivated by intrinsic interests and curiosity) and linking its work to issues of critical public interest. While the FMAP website will be an obvious means for outreach as well as building an identity and community, public outreach will go beyond the use of the internet. At Dalhousie, five journalism students will be employed as interns for varying durations. The PI has extensive contacts with the media and also with popular magazines such as Discovery. FMAP has specific plans to make the modeling of movement and distribution usable to those in secondary education.

5. Synergy with OBIS

FMAP is designed to greatly and visibly increase the value of OBIS. OBIS must be used in many scientific publications for it to receive long-term support from funders such as the US National Science Foundation. FMAP will generate the kind of papers that are accepted in *Science* and *Nature*. Moreover, each of the Center leaders has extensive experience with large databases, which will ensure easy communication with OBIS. Each model that is developed, if it proves to be of general use, will be directly linked to OBIS, and will result in large added value to OBIS. As mentioned, Boris Worm will serve as liaison between OBIS and FMAP.

6. Plans for Integration with the Initial Field Projects

Following are suggested linkages to existing field projects. These are not the only linkages, but ones that appear important at the outset.

Census of Marine Life in the Gulf of Maine (GoM) One of the first goals of GoM will be to synthesize the existing data in the region. Here, the project on Standard Programs for Extrapolation of Sample Data, headed by Rosenberg, will be focused on collaboration with GoM. Furthermore, the spatial multi-species models and meta-analysis of interactions subprojects will use data from this region.

Patterns and Processes of Ecosystems in the Northern Mid Atlantic (MAR-ECO) Planning and collaborations to deal with design and estimation problems inherent in the vast and sparsely sampled MAR-ECO project will be an early priority.

Pacific Ocean Salmon Tracking (POST) The Movement Models subproject is focused directly on this project and TOPP.

Tagging of Pacific Pelagics (TOPP) The extinction modeling theme will analyze the data collected on endangered species in this project.

Biogeography of Chemosynthetic Ecosystems (ChEss) Inferring the distribution of chemosynthetic ecosystems is one of the most difficult of any attempt to map ecological data. The Standard Mapping Modeling theme will identify and provide mapping tools for ChEss. The meta-analysis subproject will help synthesize the existing data on these ecosystems. FMAP will need to work interactively with the specialized community integrating information about deep sea currents and geological patterns that influence these ecosystems.

Natural Geography in Shore Areas (NaGISA) The theme on archiving of non-fisheries data will provide data access for this project. The meta-analysis project will help with synthesis.

Census of Diversity of Abyssal Marine Life (CeDAMar) Sampling effort in the abyssal regions is so limited that large scale modeling will be difficult until the project progresses, but modeling efforts for other projects should help develop sampling strategies. Developing liaisons with this newly affiliated group will help to integrate them into the CoML.

7. Proposed Budget and Matching Funds

We request that the Sloan Foundation provide about 30% of the start up costs of FMAP. Since the June workshop, network PIs have successfully secured matching funds for several of the FMAP themes, and more proposals are in preparation. Each project will develop a detailed individual budget, including the direct FMAP subvention. Here we summarize totals. Each project is conceived as a two-year effort. However, the Steering Group will reallocate funds during the second year if a project fails to meet its first year goals, fails to obtain long-term funding to ensure the viability of FMAP over the lifetime of CoML, or diminishes in priority. Each PI has an excellent record of obtaining and administering large grants. We have in hand more than half the required match, and will seek funds to maintain FMAP in the long term.

	Sloan	**Matching**	**PI**
Statistical Design and Consulting			
Statistical Advisory Team			Centers
Standard Programs for Extrapolation			Rosenberg
Data Exchange - Model Interface			
Standard Data Exchange Formats			Centers
Fisheries Data into OBIS			Centers
Archiving of Non-Fisheries Data			Worm
Model Development			
CoML Standard Mapping Modeling			Center and Open Competition
Movement Models			Sibert, Flemming, Myers
Pelagic Fish Biodiversity			Worm
Spatial Multispecies Models			Stefansson
Data Synthesis			
Meta-Analysis of interactions			Myers-Collie
Prediction			
Global predictions of fishing			Cox
Models for dynamics of biodiversity			Open Competition
Extinction models and analysis			Open Competition
Organization			
Center and Organizational			Myers, Stefansson Matsuda
Total			

8. Deliverables

As exemplified below, each of projects has deliverables within the two year time-line, plus long-term goals to 2010. Here we list the general deliverables for each research theme. During the next year, the Steering Group and Network members will work out a much more detailed picture for the evolution of FMAP 2005-2010.

First Year	Second Year	Long-Term
Statistical Design and Consulting **(1)** Statistical Advisory team formed **(2)** Meetings held with each field project **(3)** Extrapolation methods developed, implemented, and tested	**(1)** Statistical advisors established for each field project **(2)** Extrapolation methods incorporated in OBIS	**(1)** Statistical advisor an integral part of field projects
Data Exchange -Model Interface **(1)** Standard data exchange formats proposed and field tested with users	**(1)** Standards implemented into OBIS	**(1)** Ongoing development of standards **(2)** Fisheries data entry into OBIS semi-automatic
Model Development **(1)** Mapping models needs identified **(2)** Meta-analytic state-space movement models implemented **(3)** Pelagic fish biodiversity mapped **(4)** Implement initial spatial multispecies models	**(1)** Mapping models implemented in OBIS	**(1)** Analytic tools continually improved for OBIS
Synthesis **(1)** Meta-analytic methods identified	**(1)** Implemented in OBIS	**(1)** Models used to synthesize CoML results
Prediction **(1)** Models for predictions of fishing, habitat dependent biodiversity, and extinction developed	**(1)** Implemented in OBIS	**(1)** CoML results predicted in short and medium time frame

Additional details about the proposal and methods can be found on the website

http:fish.dal.ca/fmap.html.

9. Justification, Scientific and Societal Benefits

Besides intellectual interest, FMAP, the modeling component of the CoML, will be key to improved conservation of the natural resources of the ocean. The results from mapping the present diversity, distribution, and abundance in the ocean will improve conservation and sustainable use of ocean life. The meta-analysis of communities will improve our understanding of species interactions and help to predict how the diversity of marine life will change with natural and anthropogenic impacts. The extinction models will enable protection of endangered life. FMAP will surprise us with how much we can know and it will shock us with how much we might never know. In short, FMAP brings to the CoML the statistical and analytical tools needed for its success, for maximum impact for the conservation and understanding of life in the ocean.

10. Bibliography

Baum, J. K. 2002. Determining the effects of exploitation on shark populations using fishery-dependent data. MSc, Dalhousie University, Halifax, Nova Scotia.

Baum, J. K., Myers, R. A., Kehler, D., Worm, B., Harley, S., and Doherty, P. 2002. Collapse and conservation of sharks in the Northwest Atlantic. Science in press.

Beverton, R. J. H., and Holt, S. J. 1959. A review of the lifespans and mortality rates of fish in nature, and their relation to growth and other physiological characteristics. In CIBA Foundation Colloquia on Ageing 5. Edited by G. E. W. Wolstenholme and M. O'Connor. CIBA Foundation, London, pp. 142-174.

Brander, K. 1994. Patterns of distribution, spawning, and growth in North Atlantic cod: The utility of inter-regional comparisons. ICES Mar. Sci. Symp. 198: 406-413.

Cohen, A. N., and Carlton, J. T. 1998. Accelerating invasion rate in a highly invaded estuary. Science 279: 555-557.

Cooper, H., and Hedges, L. V. 1994. The Handbook of Research Synthesis. Russell Sage Foundation, New York.

Cushing, D. H. 1971. The dependence of recruitment on parent stock in different groups of fishes. J. Cons. Int. Explor. Mer 33: 340-362.

Dayton, P. K., Thrush, S. F., Agardy, M. T., and Hofman, R. J. 1995. Environmental effects of marine fishing. Aquat. Conserv. Mar. Freshwater Ecol. 5: 205-232.

Fujiwara, M., and Caswell, H. 2001. Demography of the endangered north atlantic right whale. Nature 414: 537-541.

Goldberg, E. D. 1995. Emerging problems in the coastal zone for the twenty-first century. Marine Pollution Bulletin 31: 152-158.

Hedges, L. V., and Olkin, I. 1985. Statistical Methods for Meta-analysis. Academic Press, San Diego.

Hilborn, R., and Liermann, M. 1998. Standing on the shoulders of giants: learning from experience in fisheries. Rev. Fish Biol. Fisheries 8: 1-11.

Jackson, J. B. C., Kirby, M. X., Berger, W. H., Bjorndal, K. A., Botsford, L. W., Bourque, B. J., Bradbury, R. H., Cooke, R., Erlandson, J., Estes, J. A., Hughes, T. P., Kidwell, S., Lange, C. B., and Warner, R. R. 2001. Historical overfishing and

the recent collapse of coastal ecosystems. Science 293: 629-638.
Myers, R. A., Bowen, K. G., and Barrowman, N. J. 1999. The maximum reproductive rate of fish at low population sizes. Can. J. Fish. Aquat. Sci. 56: 2404-2419.
Myers, R. A., and Mertz, G. 1998. The limits of exploitation: a precautionary approach. Ecol. Appl. 8, Supplement 1: S165-S169.
Myers, R. A., Mertz, G., and Fowlow, P. S. 1997. Maximum population growth rates and recovery times for Atlantic cod, Gadus morhua. Fish. Bull. 95: 762-772.
Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. J. Cons. Int. Explor. Mer 39: 175-193.
Pauly, D. 1995. Anecdotes and the shifting baseline syndrome of fisheries. Trends. Ecol. Evol. 10: 430.
Peterson, A. T., Ortega-Heuerta, M. A., Bartley, J., Sanchez-Cordero, V., Soberon, J., Buddemeier, R. H., and Stockwell, D. 2002. Future projections for mexican faunas under global climate change senarios. Nature 416: 626-629.
Punt, A., and Hilborn, R. 1997. Fisheries stock assessment and decision analysis: The Bayesian approach. Rev. Fish Biol. Fisheries 7: 35-65.
Ricker, W. E. 1954. Stock and recruitment. J. Fish. Res. Bd. Can. 11: 559-623. Ruiz, G. M., Carlton, J. T., Grosholz, E. D., and Hines, A. H. 1997. Global invasions of marine and estuarine habitats by non-indigenous species: Mechanisms, extent, and consequences. American Zoologist 37: 621-632.
Scott, J. M., Heglund, P. J., Morrison, M. L., Raphael, M. G., Wall, W. A., and Samson, F. B. 2002. Predicting Species Occurrences: Issues of Accuracy and Scale. Island Press, Covelo, CA.
Sgouros, T. 2001. Distributed Oceanographic Data System ([DODS]) User Guide (1.10 ed.). University of Rhode Island.
Zhu, L and B P Carlin. 2000. Comparing hierarchical models for spatio-temporally misaligned data using the deviance information criterion. Statistics in Medicine 19: 2265-2278.

Appedix 1. CV's of Representative Project Researchers

The CV's of several of the key network members and leaders follow.