Comparative Analysis of Marine Ecosystem Organization (CAMEO):

Advancing Fundamental Understanding of Marine Ecosystem Processes as a Foundation for Living Resource and Habitat Management

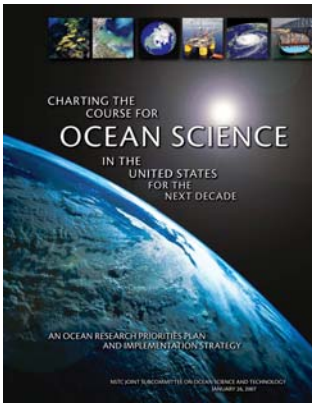
February 2008
(This document set the stage for the initial funding opportunity and serves only as a reference until the CAMEO Science Plan is released in 2010)

A Prospectus

Introduction

The report of the US Commission on Ocean Policy stressed the importance of investments in ocean research to meet the ocean related challenges facing the Nation. In response, **Charting the Course for Ocean Science in the United States for the Next Decade: An Ocean Research Priorities Plan and Implementation Strategy** (26 January 2007) (referred to as the Ocean Research Priorities Plan or ORPP) was prepared by the Joint Subcommittee on Ocean Science and Technology of the National Science and Technology Council of the White House Office of Science and Technology Policy.

The ORPP identified "Comparative Analysis of Marine Ecosystem Organization" (CAMEO) as a near term priority (to be undertaken in the next 2-5 years) to address two of its societal themes: (1) Improving Ecosystem Health and (2) Stewardship of Natural and Cultural Ocean Resources. Specifically, "*management of marine ecosystems can be improved by*



elucidating the underlying dynamics of these systems at a variety of scales. This effort will provide a greater basic understanding of ecosystem processes and practical tools for evaluating the effectiveness of local and regional adaptive ecosystem-based management efforts." The ORPP also offered ideas for effective approaches to living resources management which include

understanding complex dynamics controlling productivity, behavior, population connectivity, climate variability and anthropogenic pressures. It envisaged the use of a diverse array of ecosystem models, comparative analyses of managed and unmanaged areas, ecosystem-scale mapping in support of research, forecasting and management decision support. This prospectus outlines a coordinated and integrated response to the call for ocean research investments and sets the stage for inter-agency funding of scientific research aimed at supporting multiple agency missions and societal needs. Partnerships among the academic community, government laboratories, private industry and stakeholder organizations, as appropriate, will be strengthened and forged so that the Nation's scientific research assets are applied effectively and efficiently.

This prospectus was developed with the advice of a committee of experts from academia, government, and NGOs assembled by NOAA and NSF. The committee has met twice and has reviewed and commented on evolving drafts via email inter-sessionally. The prospectus attempts to describe the range of scientific challenges to be addressed by CAMEO, and is intended to stimulate the ocean science community to explore innovative ways of applying comparative analyses and other approaches to fulfill societal needs.

In framing issues to be addressed by CAMEO, this prospectus uses some important ecosystem concepts, such as "resilience", "regime shifts" and "connectivity" without rigorously defining or thoroughly discussing them. These are evolving concepts, and this prospectus aims to facilitate discussions between scientists and managers through a series of community meetings/workshops over the next 1-2 years in order to refine optimal research strategies. NOAA and NSF will solicit proposals to initiate CAMEO research, with future funding depending on Congressional budget appropriations for FY 2009 and beyond. A detailed program plan will emerge to focus research at later stages of CAMEO.

Scientific Challenges and Research Opportunities for Comparative Analysis of Marine Ecosystem Organization

Comparative studies of ecosystems have a long history in marine ecology. Many of these studies have been theoretical, using mathematical models with limited or no data, and narrow in scope in terms of the properties of ecosystems and the drivers of change considered. Others have compared and contrasted large amounts of observational data to draw general inferences. CAMEO's goal, and challenge, is to carefully design approaches by which similarities and divergences among observed ecosystems (comparative ecosystem analyses) are effectively interpreted in a manner that can yield management

insights. The spatial scale of comparative analyses can range from ocean basins to local oceanic (e.g., seamounts, shelves) and coastal (e.g., bays and estuaries) features. The scale should be appropriate to the ecosystem properties being considered. In some cases, a hierarchy of nested scales may be appropriate. Obvious components of this comparative approach involve the use of experiments, models, and observational data, ultimately leading to sophisticated integrations of all three. Spatial contrasts offered by comparing ecosystem function and structure within and outside marine protected areas are one form of comparative analysis that may offer insights into how ecosystems respond to human activities. An important and ancillary challenge will be to identify recent and emerging technologies (e.g. molecular techniques and instrumentation) that may be applied toward the significant challenges of CAMEO.

Experimental Approach

Model-required parameters such as environmental tolerances and reproductive, growth, survival, and trophic transfer rates are often generated through field, mesocosm, and laboratory experiments. Experiments also shed light on the mechanisms (e.g. habitat selection, competition, predation, facilitation) driving large-scale patterns and processes. In addition, adaptive management is a form of experimentation conducted at larger spatial scales that can illuminate factors structuring ecosystems. A substantial challenge is how to integrate across spatial and temporal scales -- from local, short-term manipulations to regional, decadal processes -- to produce information applicable to stocks of managed resources, ecosystems, and management decisions.

Observational Approaches

Environmental sampling and observation, historically dependent on ship-based and often infrequent snapshots, has advanced rapidly with the availability of new technologies. Various forms of remote sensors provide valuable data, and increasingly, arrays of *in situ* sensors are being deployed, particularly in coastal regions. New deployments will proliferate with the implementation of IOOS (Integrated Ocean Observing System) and NSF's OOI (Ocean Observing Initiative). With the advent of sensors communicating real-time data to shore stations and receiving relatively unlimited operating power, long-term deployment of modern analytical equipment is now possible. In waters beyond the reach of cable, buoys with onboard power and telemetering capability can be deployed. Additionally, free-ranging autonomous underwater vehicles (AUVs) can collect and download data. For even broader coverage, fleets of gliders with on-board sensors can range widely and transmit their data to shore or ships.

CAMEO will not duplicate or compete with existing or planned observing systems. For the most part CAMEO will utilize existing observing systems, and will use data from new sensors and technology, by developing research programs that integrate these data with experimental, comparative, and modeling approaches.

Human Dimensions

A goal of CAMEO is to provide science-based information for policy makers and managers. Therefore, the results of CAMEO research shall be geared towards practical policy and management applications. In the longer term, CAMEO may address two-way interactions between the services provided by natural ecosystems and the human dimension.

Modeling Approach

Studies of marine ecosystems have employed a diversity of models to help shape our ideas about population and community dynamics, trophic transfer of energy, individual foraging behaviors and habitat use, and the impact of human disturbance therein. CAMEO is interested in furthering models that can provide robust predictions on the impacts of physical, biological, and anthropogenic drivers on marine ecosystems. New ways of applying existing models may be found, and new classes of models may emerge. Moreover, modeling approaches will help identify which observational and experimental data are most critical to collect. CAMEO will ultimately rely on models to test the generality and operational use of concepts such as "resilience" or "regime shift."

Integration of Approaches

Integration of information from the approaches above is key to CAMEO. Emergent properties of ecosystems such as connectivity and resilience can only be addressed through such integration. CAMEO researchers will need to utilize appropriate observing systems in comparative ecosystem analyses, combining results of studies conducted over different spatial and temporal scales, and assimilating observing system and experimental data into models to produce forecasts useful to managing the systems under consideration. They will also need to use observational capacities and models to guide the design of experiments and sampling programs.

The Way Forward

A conceptual framework for comparative analysis of marine ecosystems involves selecting appropriate ecosystem types that are comparable in terms of structure and function, drivers of change, and characterization of socially relevant properties of ecosystems.

Key aspects of ecosystem structure and function include:

- Diversity in terms of species, genetics and stock structure, trophic structure, and habitats;
- Ecological interactions between species, such as predation, competition, facilitation, and other interactions (e.g., parasites and diseases); and
- Spatial distributions and connectivity of biota and habitat (including hydrography, circulation, and other fundamental oceanographic processes).

Key drivers of ecosystem variability and change include:

- Extraction of living resources, such as fishing;
- Introduction of exotic predators, parasites, diseases and competitors;
- Alteration and loss of living and non-living habitat; and
- Environmental change including natural variability, climate change, eutrophication and pollution of coastal ecosystems and ocean acidification.

Socially relevant properties of marine ecosystems can be expressed as ecosystem goods and services, such as food production, regulation of water quality, and aesthetic values. These goods and services can be characterized in terms of:

- Magnitude, such as biological productivity;
- Temporal and spatial variability; and
- Resilience (e.g., ability to adapt or rebound from ecosystem shifts to different regimes or multiple stresses and/or irreversible or slowly reversible changes).

Many socio-economic factors, such as culture, governance structures, and access to alternative livelihoods, make humans an important component of marine ecosystems, and need to be taken into consideration in comparative analyses. These include:

- Demand for ecosystem goods and services;
- How services are valued (in both the short and long term);
- Feasibility of management alternatives;
- Attitudes about risks of undesirable changes in ecosystems; and
- Responses to management applications (e.g., redeployment of fishing effort displaced by a marine protected area).

The scientific challenge for CAMEO is to use comparative analysis of marine ecosystems in innovative ways in concert with experimental, modeling and data assimilation approaches to elucidate:

- How the provision of goods and services by ecosystems with different characteristics responds to natural and anthropogenic pressures and drivers of change;
- Limits to ecosystem resilience, and thresholds that, when crossed, lead to phase or regime shifts, and the nature of reversibility of such shifts;
- Relative performance of different management "treatments" (such as marine protected areas) by comparing similar ecosystems or sub-ecosystems subjected to different treatments;
- Relationships between the human dimension of ecosystems, drivers of change, and the willingness and ability to apply management alternatives; and
- Ways of translating scientific knowledge into scientifically based decision support tools that policy makers and managers need and will use.

Decision support tools must be more than a compilation of knowledge about the complexity of marine ecosystems, the nature of ecosystem goods and services and/or a general appreciation of the limits to resilience. Such knowledge,

without offering management alternatives, presents decision makers with open-ended challenges that confuse and bewilder, and may fail to lead to advances in policy and management.

Effective decision support tools may take many forms, such as:

- Identification of indicators of changes in ecosystem structure and function (e.g., reduction in mean trophic level, mean size of organisms) that may be indicators of thresholds and regime shifts;
- Models that predict changes over annual or multi-decadal time scales;
- Approaches to compare and combine types of change drivers (i.e., express them in a "common currency"); and
- Tools to evaluate alternative management methods, and aid in the design of site-specific applications (e.g., design and placement of marine protected areas and other forms of spatial management).

Ultimately CAMEO should enable the development of guidelines to avoid resiliency limits and thresholds resulting from anthropogenic pressures, including ways to engage decision makers and stakeholders in translating high level (i.e., general) goals to operational objectives and implementation of ecosystem-based management.

Next Steps

The Ocean Research Priorities Plan recognized the value of comparative marine ecosystem analysis by highlighting CAMEO as one of its most immediate priorities. It is important that the ocean science community responds quickly to this opportunity with tangible results while at the same time fostering comparative and integrative analyses of marine ecosystems in the long-term. Requests for research proposals will be forthcoming from the federal agencies (in 2008, up to $2M for 5-10 projects). It is envisioned that the initial response might consist of the following:

- Development of strategies and methodologies for comparative analyses, including modeling frameworks that can be applied consistently across ecosystems, and that facilitate design of decision support tools. This might be accomplished through individual research projects and/or workshops.
- Modeling studies focused on specific concepts, such as connectivity, resilience or thresholds. The intent of such studies should be to unify comparative analyses and to generalize some of the key scientific questions to be addressed by comparative analyses.
- Retrospective studies that analyze or re-analyze or synthesize existing information (historic, time-series, ongoing programs, etc.) using a comparative approach.
- Short-term empirical studies based around existing or proposed observation systems designed to "demonstrate" how such a system could be leveraged towards ongoing comparisons. Such studies might utilize marine protected areas which are contained within coastal observation systems.
- Short-term (a year or less) pilot projects to allow groups of investigators to organize and design larger programs. These pilot efforts can be evaluated for their potential to scale up into larger programs with further design, and organization. It is

expected that results will be publishable in peer-reviewed literature.

The foregoing activities should have a clearly articulated strategy to produce scientifically based decision support tools.

Potential Agency Actions

The CAMEO program will develop mechanisms to advance its goals as well as provide oversight, evaluation and support, including:

- Workshops to further develop aspects of human dimensions in comparative analyses, harmonizing social science and natural science approaches and concepts, and to foster formation of interdisciplinary research teams;
- Establishment of a CAMEO program office and scientific steering committee to oversee the program, guide preparation of a "grand strategy" for comparative analyses, and synthesize program results across projects.

Since CAMEO is intended to be a multi-year program envisioned at $10M per year, following these initial steps it is envisioned that CAMEO will ultimately support several large-scale multi-investigator (academia, government and private sector) projects. The results of CAMEO will provide critical advances towards improving ecosystem health and stewardship of natural resources, as envisioned in the ORPP.

The lead federal agencies (NSF, NOAA) will shortly be publishing a combined RFP and Federal Funding Opportunity soliciting proposals from the community of researchers interested in comparative ecosystem studies, based on the concepts in this prospectus. Questions or comments regarding CAMEO activities can be directed to:

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NOAA/NMFS: Mike Ford (Michael.Ford@noaa.gov) or Lora Clarke (Lora.Clarke@noaa.gov)

Visit the CAMEO web site at: http://cameo.noaa.gov