A Social Scientist's Perspective on the Census of Marine Life

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Abstract

Over 300 natural scientists in 53 nations are taking part in the Census of Marine Life (CoML) to investigate what lived, what lives, and what will live in the oceans. The CoML is a scientific experiment that is exploring the limits of ocean science. The paper discusses the potential applications of CoML research and the mechanisms by which the potential benefits can be measured and preserved. I recommend developing and integrating policy advisory committees with the natural science activities to both maximize the benefits of the research and to avoid unintended consequences.

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James N. Sanchirico*

I. Introduction

The U.S. National Oceanic and Atmospheric Administration (2000) estimates that 95% of the world's ocean area is unexplored. Many believe that there are also over 5,000 more marine fish species, a million species of nematodes, and thousands of types of shellfish to be discovered (O'Dor 2003). Partially to address these knowledge gaps, the Census of Marine Life (CoML) project was launched in 2000. The ten-year project funded by both public and private sources includes approximately 300 scientists from 53 countries.

A typical census would strive to count every living thing, but the CoML is hardly typical. It is a scientific experiment with a potentially large upside. The goal is to explore the limits of science to determine what is unknown but knowable and what will remain unknown for the foreseeable future. Such an endeavor requires developing baselines of what lived in the oceans in the past, documenting and understanding what is there now, and where it is found. Potential scenarios of the future biological state of the oceans will be developed using sophisticated numerical models.

Advocates argue that an advantage of the CoML, over the status quo in ocean research, is that the scope and scale of this coordinated endeavor could lead to greater scientific returns than the sum of the individual research projects (Ausubel 2001, O'Dor 2003). For example, CoML efforts could potentially increase funding levels for open ocean research. Current levels are most likely lower than society would prefer, because the high seas are held in common. Within each of the project areas, scale economies in

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technology are possible. Researchers could coordinate the development and purchasing of scientific instruments, resulting in incentives to spur technological advances and lower prices. Across the projects, researchers could also discover areas of intersection of scientific inquiry that might otherwise have gone unnoticed or taken longer to discover. As Ausubel (2001) notes, whether these gains are realized, however, depends on the researchers involved.

CoML comes at a dynamic time in ocean science and management. Assumptions that marine populations are uniformly distributed across a homogenous environment are being contested with notions of patchy systems supporting local populations possibly connected by dispersal of larvae, juveniles, and adults (Cowen et. al 2000). Because historical management has been characterized by systems of relative uniformity of regulatory actions over space, this shift has important management implications. Societies also appear to be moving away from managing the marine environment solely for extractive uses—even as the number of economic activities is growing—toward a more holistic approach that includes marine conservation. The recent excitement about the need to create networks of marine reserves—areas closed to all extractive uses—symbolizes both of these changes.[1]

The research that comprises the CoML is intertwined and fundamental in fostering both of these shifts. Because of this it has potential to be used for more than “guidebooks that will make information-hungry marine biologists weep with joy” (Malakoff 2003). For example, the documentation of species ranges and habitat preferences will improve our understanding of fundamental spatial ecological processes. This information will help inform the design of management policies at scales that will ensure the economic and biological sustainable use of marine resources. In addition, effective integration and communication of the results will increase the public’s awareness of the past, current, and likely future state of the marine environment—a process that will further advance a marine conservation ethic.

The goal of this paper is to highlight potential applications of CoML research with particular attention to how it can contribute to ocean management over the next

[1] See, for example, the Scientific Consensus Statement (2001), Pauly et al. (2002), and the Pew Ocean Commission Report (2003).

century.[2] The discussion is organized around marine stewardship and management, and marine technology and data development. In each theme, I also address whether the economies of scale and scope are likely to be significant and whether the mechanisms and institutions are in place to ensure that the benefits of the CoML research are realized and preserved.[3]

While the CoML is an international endeavor, most of the examples and discussions in the paper are focused around the United States. Of course, similar issues and discussion will occur in other countries, but the particulars will differ based on their governance and institutional settings. The scope of the discussion is also limited to four pilot projects that comprise only a portion of the CoML. The projects were chosen because each has sociopolitical and economic elements that fall across the highlighted themes. The fact that each of these projects is less than halfway completed, as is the CoML, forces a heuristic rather than quantitative approach.

One conclusion reached from this analysis is that the extent of societal benefits of CoML is not predetermined.[4] The value of scientific research is difficult to measure, but we know that it depends on the services and outputs that it generates. Because the regulatory environment is highly charged with many competing uses all of which are vying for limited resources where rights are not well defined, any value-added from CoML research is likely to be dissipated, as free-for-alls are likely to lead to a tragedy of intellectual and ocean commons. This is true for pelagic species, deep-sea marine resources, and inhabitants in the coastal environs. To address this, I recommend that CoML scientists and leaders expand the current involvement of social scientists, stakeholders, and managers. With only about a half dozen now participating, there is plenty of room to integrate other disciplines into the natural science work currently under way. Such an effort will undoubtedly increase its value.

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[2] See Ausubel (2001), Decker and O'Dor (2002), and O'Dor (2003) for an overview of the CoML project.

[3] Similar questions and analysis has been done on the economic benefits of sustained ocean observing systems, such as Integrated System of Ocean Observing System (ISOOS) and Global Ocean Observing System (GOOS). ISOOS is a large ongoing research project with the goals of developing an integrated set of research projects both across space and time and a clearinghouse on oceanographic data. See, for example, Stel and Mannix (1996), Sassone and Weiher (1999), Adams et al. (2000), Kite-Powell and Colgan (2001), and Kite-Powell, Colgan, and Weiher (2003).

[4] To be clear, the paper is focusing on the potential applications of the science and not making any statements about the value of basic scientific research.

Along with improving the use of CoML science in ocean policy, this integration will help to address the “concerns of environmentalists that governments might be unable to prevent a rush to exploit any new populations uncovered by the census” (Malakoff 2000b). The current crisis in the Patagonia toothfish fishery, which began after commercially viable stocks off of Antarctica were discovered in the early-1990s, is a good example of what can happen, if international agreements or institutions are not prepared for discovery of new taxa in international waters.

The paper is organized as follows. In Section 2, I provide a short background on the components of the CoML and the four pilot projects I focus on. Section 3 highlights the roles that the CoML can play in marine conservation, capture fisheries management, coastal zone management, marine life biotechnology, marine science technology, and research and data sharing. Section 5 discusses an approach to quantifying the benefits of CoML research and the potential issues and questions that arise during such an exercise. Section 6 concludes with a strong recommendation to increase the integration of the science with rigorous policy analysis to help reduce the likelihood of unintended consequences.

II. Census of Marine Life

The Census of Marine Life consists of five main components.[5] First, it sets out to develop baselines of what lived in the oceans in the past using archival information from ship logs, catch records, and historical accounts of fish abundances. The History of Marine Animal Populations (HMAP) research group located in Denmark is coordinating this research (Holm 2002). Second, scientists will be documenting what currently lives, and where it is found in the oceans. Third, the baseline data along with current species maps and abundance measures will be combined with oceanographic data in mathematical models to predict potential scenarios for the future state of the oceans—this research falls under auspices of the Future of Marine Animal Populations (FMAP)

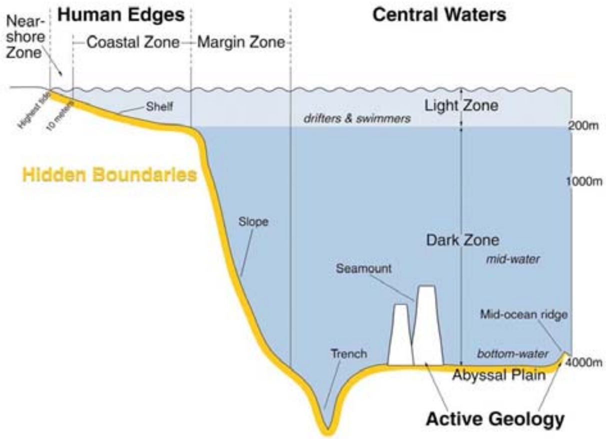
[5] The CoML is different from other integrated ocean research programs, such as what is being proposed for ocean observing systems (e.g., ISOOS[5] and GOOS), because it is a flexible project that has directly incorporated into its design the importance of experimentation and learning.

research group.[6] Fourth, the CoML is working with the Ocean Biogeographical Information System (OBIS) to have all of the information and data included in the ongoing effort to develop a central clearinghouse for marine biodiversity information. Finally, outreach and education are significant components, because without effective communication of the results to the public, some of the most important benefits of this project might not be realized.

The four projects that I focus on are migration patterns of large pelagic species (TOPP), coastal biodiversity survey of the Western and Eastern Pacific (NaGISA), exploration of ecosystems of the Northern Mid-Atlantic (MAR-ECO), and the Gulf of Maine research project (GOM). Each of these targets different horizontal and vertical scales that span multiple zones of the ocean environment. Figure 1—which is a modified version of what appears in O'Dor (2003)—illustrates the zones investigated in CoML projects. MAR-ECO will concentrate sampling efforts along the Mid-Atlantic Ridge (MAR), which is a geological structure along the Abyssal Plain (mid-ocean ridge in the figure). NaGISA is focused on the near-shore zone or the "front yard" of coastal nations and falls under the coastal nation's sovereignty. TOPP's environment is endogenous and determined by the characteristics of the tagged species, but because of the nature of satellite tags the species occupy the light zone periodically. Finally, the Gulf of Maine project is focused in a geographical region that spans from the "front yard" out to the margin.

[6] An interesting statistical question is if the set of research projects that will embody the CoML are a representative sample of the ocean environment. If this is the case, then the project results can be used to predict the likelihood of distributions of species both in numbers and taxonomic composition in areas of the ocean that are not yet explored and are not likely to be explored in the near term.

Figure 1: Horizontal and Vertical Scales of Ocean Research



(Source: O'Dor 2003)

The four studies were selected for a number of reasons all of which are highly correlated with their zones.[7] First, each project has a different set of direct beneficiaries and outputs. Second, marine resources that are known to exist in these study areas are managed with goals ranging from commercial fishery production to non-consumptive use activities. Understanding the services and context of the research is critical for defining the scope and scale of the potential benefits. Third, the biological resources exist across a range of institutional and management settings from those that are well defined, such as in developed country waters, to settings with little or no management institutions in place, such as in the open ocean or in some developing countries that do not have the resources necessary for management and enforcement.[8] This sociopolitical and economic context is essential for understanding whether the research will yield a substantial rate of return or will be dissipated by the absence of property rights. Finally, I choose these projects because of their contribution to the policy and research changes under way in ocean management.

In what follows, I briefly describe the four projects.

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[7] The CoML is larger than these four projects and each of the other projects also have important policy implications (visit www.CoML.org for the latest information).

[8] Additionally, in each project, the discovery of new taxa could either create additional pressures on the existing set of institutions or lead to the call for the development of new institutions.

Tagging of Pacific Pelagics (TOPP)

Do tuna, leatherback turtles, salmon sharks, humpback whales, and albatross share common "watering" holes in the ocean? Does a "Serengeti of the Sea" exist in the Pacific for pelagics? Researchers don't yet know, but the team of scientists in TOPP plans to find out by developing and deploying state of the art microprocessor-based satellite tagging technologies (Block et al. 2003). The TOPP research program includes the tagging of air-breathing vertebrates and of fish, shark, and squid. The collection of species listed in Table 1 includes both charismatic mega fauna some of which are endangered, such as leatherback turtles, and others that are important commercial species, such as bluefin and albacore tuna. According to Block et al. (2003), species choices balanced the requirements that the species could be successfully tagged and the desire to capture the imagination of the public by focusing on animals that are "organismal ambassadors."

Table 1: Species included in the TOPP program (Block et al. 2003)

Air-breathing vertebrates	*Fish, shark and squid*
Leatherback and Loggerhead turtles	Bluefin, Yellowfin, and Albacore tuna
Blue, fin, and humpback whales	White, Mako, Salmon, Blue, and Common thresher sharks
Elephant seals	Squid (*Dosidicus gigas)*
California sea lions	Ocean sunfish *(Mola mola)*
Sperm whales	
Pink and sooty shearwaters (seabirds)	
Black footed and Laysan albatross	

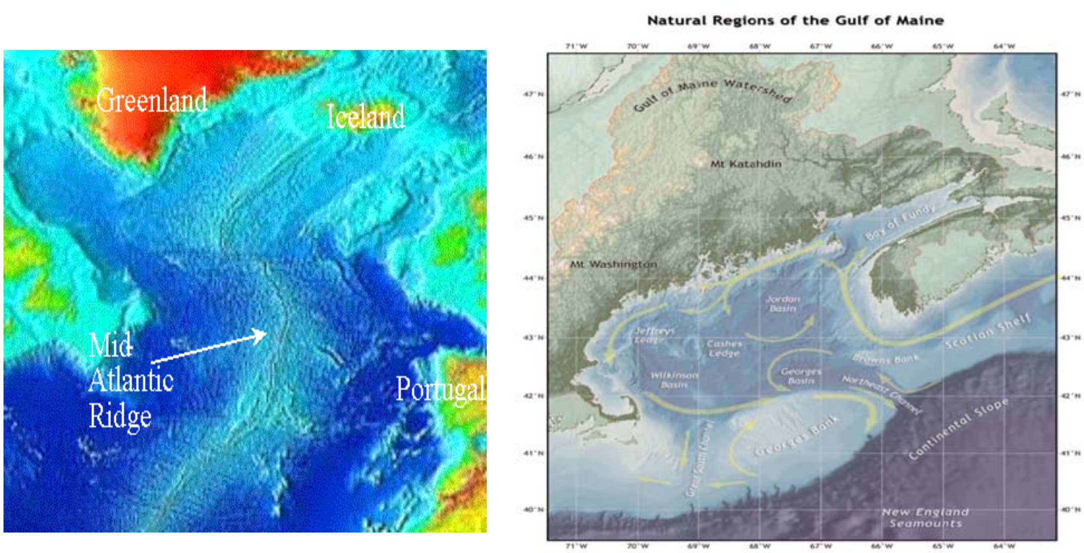
Mid-Atlantic Ridge Ecosystem (MAR-ECO)

The Mid-Atlantic Ridge (MAR) is a volcanic mountain range created by the spreading of the Eurasian and American continental plates and spanning most of the northern and southern Atlantic Ocean. The MAR-ECO project consists of approximately 90 researchers whose goal is "[T]o describe and understand the patterns of distribution, abundance, and trophic relationships of the organisms inhabiting the mid-oceanic North Atlantic, and identify and model the ecological processes that cause variability in these patterns" (Bergstad and Godo 2002). Sampling is occurring along the seabed at depths greater than 3500m, at the same time information on pelagic species, squids, and jellyfish residing above the ridge are also recorded. Researchers will also investigate the abundance of marine life surrounding seamounts and hydrothermal vents.

Natural Geography of Inshore Areas (NaGISA)

NaGISA researchers are measuring the abundance and diversity of marine life in the nearshore zone, less than 20m in depth. Researchers in a dozen countries are currently involved in this global assessment of the marine biodiversity that is found in each country's "front yard".[9] A unique aspect of this project is the combination of the

Figure 2: Mid-Atlantic Ridge and Gulf of Maine



(Source: NOAA National Geophysical Data Center) (Source: Rickert and Incze 2003)

Note: The right panel includes representations of the large-scale oceanographic flows within the Gulf of Maine.

worldwide scale of the sampling that follows both a longitudinal and latitudinal transect of the globe and the fine scale of sampling that are being conducted at each site. More importantly, the researchers have developed a protocol that will allow the samples to be

[9] As of March of 2004, the countries participating in NaGISA are Japan, Malaysia, Thailand, United States (Alaska), Philippines, Taiwan, Korea, China, Australia, New Zealand, Vietnam, and Russia.

compared across the sites enabling cross-country studies and analysis of distribution patterns on a global scale. Within the nearshore environment, the sampling effort is being focused on algal communities, seagrass and soft-bottom communities.

Gulf of Maine (GOM)

Can there really be anything scientists don't know about the Gulf of Maine? New England and the Gulf have been a hub of economic activity for centuries. The collapse of the cod stocks in the mid-1990s is enough evidence to conclude yes—there is a lot we don't understand about the feedback between the physical, ecological, and social systems. A large focus of this pilot project is to assimilate the research that has been done (Rickert and Incze 2003). The vehicle to compile and analyze the data is the Gulf of Maine Biogeographic Data, which is a part of the OBIS data archives (Tsontos and Kiefer 2002).

Not all, of course, has been explored and scoured, especially the slope and seamounts. Both areas are being targeted with the goal of not only finding new taxa but also in understanding how these unique habitats contribute to the functioning of the Gulf of Maine ecosystem. Research on the continental slope will undoubtedly increase our understanding of how ocean processes affect species distributions in the Gulf of Maine. While NaGISA or MAR-ECO focus on a particular ocean-depth environment, GOM will range from cataloguing microbial diversity to tracking movements of whale populations.

III. Potential Applications of CoML Research

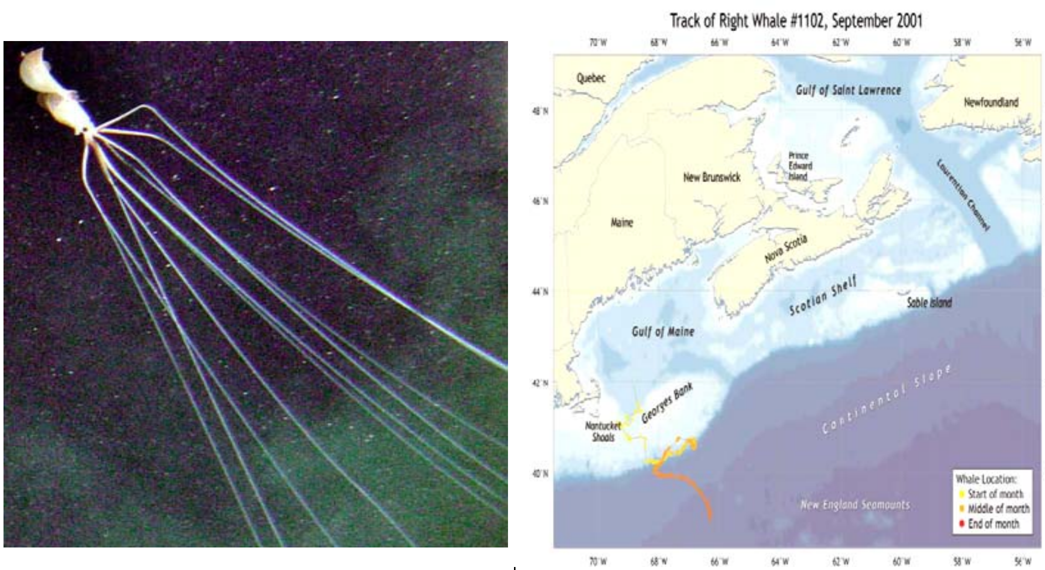
The discussion of the potential applications of the CoML research is organized around topics related to ocean stewardship (marine conservation, marine capture fishery management, and coastal zone management) and marine technology and data development (marine life biotechnologies, marine science technology, and data sharing). Each topic is considered in turn.

Marine Conservation

Momentum to shift the goals of ocean management from maximizing extractive activities to balancing marine conservation and extraction is evident in the recent Pew Oceans Commission report. The constituent base for marine resources must get more knowledgeable, more vocal, and gain better representation at the table, however, before conservation will be a “legitimate” goal in the political economy of marine policy. As it stands, according to a survey by The Ocean Project[10], “[The American Public possesses] only superficial knowledge of the oceans, their functions, and their connection to human well-being” (Belden et al. 1999).

CoML researchers hope to foster a growing conservation ethic for the marine environment by inspiring new scientists and students at all levels to the wonders of the ocean. Discoveries of new deep-sea species will provide the vehicles for such outreach along with films and classroom materials that are being developed in MAR-ECO. So too will the romanticism surrounding the exploration of unknown environments (e.g., deep-sea hydrothermal vents, seamounts).

Figure 3: Wonders of the Deep-sea and Track of a Right Whale in Northeast Atlantic



(Source: M. Vecchione) | (Source: Rickert and Incze 2003)

Note: The left photo is by M. Vecchione (NOAA, USA) of a deep-sea squid—only known from photographs—photographed at the Charlie Gibbs Fracture Zone along the MAR. The right panel illustrates the track of a right whale over a month period (Sept) in 2001. The right whale population is endangered with less than 300 individuals estimated in the northern Atlantic.

Without the potential romanticism of exploration in the deep-sea or the fuzziness

[10] For information on, The Ocean Project see www.theoceanproject.org (accessed March 2004).

of “organismal ambassadors” the ability of NaGISA to progress the conservation ethic appears limited. NaGISA researchers argue that by operating in the “front yard” of coastal villages, towns, and cities will bring home the importance and uniqueness of the marine habitat in a way that the other studies could not. For this to happen, the scale of the effort in the local environment would need to be much larger than simply a few scientists scouring over transects in the tidal zone. NaGISA efforts to teach local scientists and educators how to follow the low-cost sampling protocol such that sampling could continue after NaGISA researchers depart will help in this regard.

While the increasing awareness of the public will generate support for the necessary and often controversial decisions on conservation of marine species, very little action will occur without the best available scientific information. CoML researchers hope to provide that also. For example, researchers from TOPP are investigating whether there are north-south, east-west migration corridors keyed to oceanographic or topographical features that a certain species or group of pelagics frequent on their way to spawning sites or foraging locations.

Information on the spatial and temporal distribution of endangered marine animals, such as the leatherback turtles—listed on World Conservation Union’s (IUCN) critically endangered list in 2002—is vital for persistence of these populations. Such information could be used to refine fishery management and maritime activities to reduce the likelihood of bycatch and vessel strikes. Understanding also the differences, for example, between the leatherback turtles that nest in Mexico and those that nest on western Pacific beaches is also be important for directing conservation efforts to ensure a successful recovery of the populations (Eckert 2002). GOM research will also help in the conservation of right whale populations by progressing our understanding of their migratory behavior. A track of a right whale is illustrated in Figure 3.

Discovering patterns and potential oceanic hotspots could also be used in the design of marine reserves—areas of the ocean set-aside from all extractive uses. Marine reserves are typically thought of as being fixed in location and set-aside for perpetuity. However, the boundaries and locations of hotspots might turn out to be dynamic, shifting with changes in the physical environment. If this is the case, management agencies could use real time oceanographic information to protect the species during aggregation periods. Dynamic area closures are used in the management of right whale populations off of the east coast of the United States (see Figure 3).[11] This type of coordinated management based on real-time monitoring of oceanographic conditions is possible with information technology. Whether it is feasible or likely to occur when it requires coordination across multiple countries is less clear.

Marine Capture Fishery Management

Fishery management has traditionally been designed one species at a time with fishing regulations set over vast areas of the ocean. Many believe this approach, scientific uncertainty, and tendencies to favor higher catch totals for sociopolitical purposes account for the current state of affairs in ocean management (Botsford et al. 1997). The last of these, however, is only a symptom of the common pool nature of ocean resources—the implications of which I discuss in the quantifying the benefits section. In this section, we highlight how TOPP, MAR-ECO and GOM research can address scientific uncertainty and can be used as a scientific basis for the development of zonal ecosystem plans.

Additional research on species abundances, distribution, trophic interactions, and life-cycle characteristics will help to quantify the costs, benefits, and risks associated with different fishery management regulations. For example, the research of Block et al. (2001) on Atlantic bluefin tuna foraging, breeding, and migratory behavior is being incorporated into the International Commission for the Conservation of Atlantic Tunas (ICCAT) quota setting for western and eastern Atlantic tuna fisheries.[12]

Better scientific information will help reduce uncertainty and whether that leads to increases or decreases in catches will depend on current management. For fisheries

[11] For example, "on March 4, 2004, NOAA Fisheries Aerial Survey Team reported a sighting of three right whales in the proximity of 42° 45.5' N lat. and 68° 55.5' W long" (NOAA Fisheries www.nmfs.noaa.gov). This information led to a dynamic area management closure zone that required modifications to all lobster traps/pots and anchored gillnet gear in the zone for 15 days to reduce the risk of entanglement of right whales (NOAA Fisheries).

[12] Another CoML pilot project is tagging salmon to test whether the Smolt Highway Hypothesis holds. This hypothesis suggests that all West Coast salmon make their way to the Pacific, head north along the coast past the Aleutian islands and out to sea, allowing some to enter Alaska waters either on the way in or out. This information has management implications for salmon catches, watershed management, and the siting of aquaculture operations off of the Pacific coast (Welch 2003).

with conservatively set catch quotas, as uncertainty about the species is reduced catch limits could increase. On the other hand, regulators could discover that the current estimates of, for example, natural and fishing mortality rates have been too optimistic and therefore catch limits should be reduced. This reduction will create short-run losses, but if a fishery collapse is averted or fish populations recover fast enough, then some of these losses could be mitigated with future benefits. Some of the unanticipated variations in catches might also be explained, improving the ability of related industries, such as fish processors, to plan their production schedules.

Given that the MAR is part of the 95% of the ocean that is yet to be explored, there is very little research on ecosystem processes and biological information for policymakers to undertake rigorous science-based policy analysis. Current thinking is that deep-sea fisheries are overexploited in other regions of the world, such as in the Southern Pacific Ocean (Battle 2003). Overexploitation is likely caused by a combination of slow-growing species aggregating in many instances over seamounts out in the high seas where there is very little oversight on fishing practices.[13]

Being able to develop baselines in the Northern Atlantic before the potential development of deep-sea fisheries is a necessary and important step in crafting sustainable management plans and building the international coalitions to support such plans. For example, expeditions might discover areas rich in demersal and benthic habitats, such as deep-sea corals, that provide important cover for juvenile fish stocks that could be destroyed by mobile-bottom fishing gear. In this case, a potential policy tool is to create a zone where mobile-bottom gear is prohibited.

Recent proposed legislation in the 107th and 108th U.S. Congresses emphasized the need to design ecosystem-based management plans. The potential findings of the Gulf of Maine project can be used as a basis for developing ecosystem plans for the Gulf. While there is agreement about the need to develop ecosystem plans and to understand species-habitat linkages, many of the hard policy questions remain on the table, such as what a “true” ecosystem management plan entails. In addition, it is not clear *ex ante* what the ecological and economic trade-offs inherent in an ecosystem plan would be.

[13] Everything else being equal, slow-growing stocks are more vulnerable to recruitment overfishing and the fact that they aggregate around seamounts implies that the costs of fishing are lower due to less searching costs. Finally, the open-access nature of high seas fisheries results in overexploitation of fish stocks.

For example, will ecosystem plans entail overharvesting some species to remove predation pressures so that others might prosper? What happens when one sector of the economy is dependent on the species whose population abundances are to be reduced? What is the appropriate scale of an ecosystem plan? These are difficult questions, but with the research and analysis coming out of the GOM, researchers will begin to address some of them.

GOM research will also provide detailed information to design spatially explicit policies that are tailored to the patchy distributions of population abundance and biodiversity (Tsontos and Kiefer 2002). Policies designed to limit certain types of commercial fishing operations in zones or all extractive uses in marine reserves. The baseline information along with system dynamics will help to quantify the ecological and economic impacts from off-wind farm developments, oil and gas explorations, offshore and inshore aquaculture operations, and maritime activities.

Coastal Zone Management

Developing a baseline of what exists and where it lives is critical for coastal zone management, as resources are coming under increasing stress, as more people move to the coast. For example, between 1986 and 1997, the United States experienced a net loss of 10,400 acres of estuarine and marine wetlands (Dahl 2000). Coastal development—including road construction, and marina and port development—and dredging accounted for most of this loss. Furthermore, runoff from urban streets, lawns, and agricultural areas delivers nutrients and chemicals to coastal estuaries and wetlands can cause fish kills and even stimulate algae blooms, which rob the water of oxygen and leave behind dead zones, such as in the Gulf of Mexico. Without a baseline, it is impossible to quantify the losses associated with such trends in terms of the marine biodiversity making coastal zone management decisions even more difficult.

CoML outputs will provide important information for environmental impact assessments on coastal development projects, inshore aquaculture operations, oil and gas explorations, seabed mining operations, telecommunication cables, and offshore wind farms. Presently, there is little information on the potential ecological and economic costs associated with these operations. For example, in the United States, Section 404 permit applications[14] for coastal development often include detailed economic analysis on the gains from the development, but agencies, such as NOAA Fisheries that are called in to consult often lack the information to develop estimates of the ecological and economic costs of such actions. Often this imbalance leads to development projects getting approved—some of which might have had a benefit-cost ratio greater than one even with good estimates of the ecological costs, others perhaps not.

The ecological and economic damages of invasive alien species (IAS) are also gaining increasing attention in the scientific, conservation and policy arenas both domestically and internationally. This attention is not surprising given the recent back-of-the-envelope estimates that the U.S. spends $138 billion per year to prevent or mitigate IAS damages (Pimentel et al. 2000) and the pronouncements that IAS are likely the second-largest cause of biodiversity loss worldwide (Holmes 1998). International treaties, such as The Convention of Biological Diversity require the signatories "to prevent the introduction of, control, or eradicate those alien species which threaten ecosystems, habitats or species."[15] The 1999 U.S. Presidential Executive Order 13112 established the National Invasive Species Council to provide leadership and vision on how to integrate the actions and goals of the many federal agencies involved.

In addressing the problem of invasive alien species (IAS), decisionmakers have a variety of policy options, each targeting different aspects of the problem as it evolves over time and space. For example, the likelihood of entry of invasive species into a particular area can be reduced by inspections, quarantines, and reducing the volume of trade in goods across areas that may be infested. Efforts could also be targeted at the likelihood of the long-term establishment and spread of invasive species through preventive measures, such as better coastal management practices.

The approach that is followed will depend on the particular context, but in some instances there is very little information on what is being lost. CoML research can be used to quantify the potential damages from a marine invasion and help target international efforts and funds to reduce the likelihood of such an invasion. For example,

[14] Section 404 of the U.S. Clean Water Act governs wetland impacts above a certain size and requires mitigation for wetland losses caused by development and other activities (33 U.S.C. § 1344 (1994)).

[15] This requirement is included in article 8(h) of the Treaty. See Perrings et al (2000) for more information on the treaty and international efforts currently underway to address the global spread of IAS.

the work under way in NaGISA is investigating the global patterns of coastal biodiversity in addition to coming up with inventories on what exists where—information that can be used to quantify potential damages. The researchers are looking for patterns or pockets of marine biodiversity hotspots. These areas could then receive priority for funding to minimize the possibility of a marine invasion.

Marine Life Biotechnology

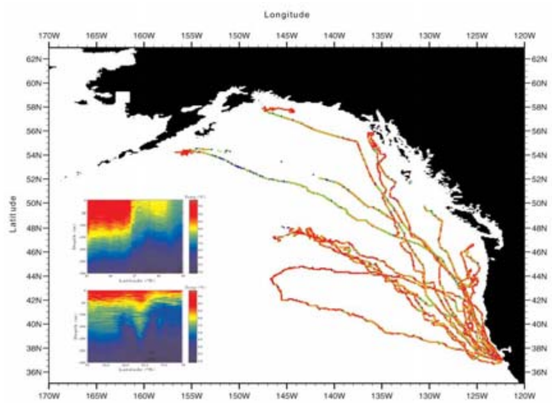
Society can directly benefit by discoveries of marine-sourced material from the CoML projects, such as pharmaceuticals, enzymes, fine chemicals, and agrichemicals (Newman, Cragg, and Snader 2003). In the 1980s, the U.S. National Cancer Institute (NCI) initiated a considerable collection effort of marine invertebrates in the nearshore environment, with 10% of their samples determined as "active" (Green 2003). Costs from sampling to drug development are considerable, however, and the early research efforts in the deep-sea environment proved too costly and were suspended. Other efforts have continued, and sponges have yielded promising compounds, for example, chemicals extracted from *Tethya crypta* are used in antiviral medicines that have over $50 million in annual sales.

Scientists can often also improve the performance of existing technologies by studying the biological characteristics (natural technologies) of marine species. A recent example are the fibers of a sea-sponge the construction of which is shedding light on how to make better fiber-optic cables, used in modern telecommunications (Aizenberg et al. 2001). The combination of strength and malleability of the sea-sponge's fibers surpasses man-made fibers that when contorted often break.

With nanoscience and technology the next frontier, many researchers are focusing on the marine environment for inspiration because the microorganisms that inhabit it are living nanotechnologies. Crookes et al. (2004) focus on the proteins of squid reflective tissues, which have potential applications in spectroscopic and optical applications. Overall, the materials discovered in the oceans are not always ready for industrial applications; however, there are often lessons to be learned (Gross 2003).

Many believe that ocean biodiversity is still an untapped profitable resource, especially since only a small number of marine organisms have yielded more than 12,000 novel chemicals (Faulkner 1998). This view stems, in part, from the megadiversity and high number of endemics found in the chemosynthetic ecosystems of hydrothermal vents and seamounts. Because the enthusiasm for bioprospecting has not materialized (Macilwain 1998), it is not clear that bioprospecting returns should be as prominent in discussion surrounding the CoML.[16] If this application of CoML research was so promising, you would expect private companies to be already engaging in such activities.

Figure 4: Elephant seals are oceanographers, explorers, and foragers in residence.



(Source: Boehlert et al. 2003) **(Source: O'Dor 2003)**

Note: The right panel is a picture of an adult female elephant seal with two types of electronic tags (Boehlert et al. 2003). Argos is a satellite tracking device (records location) that is placed on the head to ensure that it remains above the water during surfacing, and Mk 7 TTDR records the temperature profile of the water and based on the behavior of the elephant seals remains under the water. The left panel is plot of migratory routes of 9 elephant seals tagged along the central coast of California over a 12-month period. The inset illustrates the temperature information that is recorded with the tags. (Boehlert et al. 2001, Block et al. 2003).

Marine Science Technology

One of the major goals of the CoML is exploring the limits of technology, which will inevitably lead to benefits from research and technological spillovers.[17] This

[16] With respect to terrestrial biodiversity, Simpson, Sedjo and Reid (1996) illustrated that at the margin, the value of another (hectare) area in returns to bioprospecting is low. Put simply, the more areas there are to investigate the lower the value of an additional unit. Of course, areas with endemic species are more valuable, everything else being equal, but the general conclusion remains valid along with the corollary that bioprospecting is not the financial means to preserve biodiversity.

[17] Although somewhat outdated, a special issue of *Oceanography* (vol. 6 #3, 1993) focuses on technology spillovers in oceanography research. However, the analysis of the economics of technology transfers by Hoagland and Kite-Powell (1993) is applicable to the CoML.

emphasis runs counter to many large projects where technological advances are auxiliary aspects and not a primary focus of the research effort. For example, lasers located on airplanes are being used to locate and identify pelagic species (O'Dor 2003). Other advances with optic and acoustic sensors, sampling techniques on remote operated vehicles (ROVs), data storage, management, and analysis will also play critical roles in accomplishing the goals of the CoML.

Advantages of the large-scale effort under way in TOPP and the resulting economies of scale is the development of new tags (Block et al. 2003)—such as archival tags with GPS technology—and the potential to leverage the buying power of the group to lower the costs of the tags. Historically, tagging studies have focused on single species and are often limited in the number of animals due to the costs of the tags, capturing and tagging the animals, information retrieval, data analysis, and so on. For example, Boustany et al. (2002) tag six white sharks and record their depth and position between October 2000 and April 2001 throughout the Pacific. Along with developments leading to smaller tags and therefore more potential species to include in a tagging program, the researchers are experimenting to determine the appropriate tags for different species.

In addition to providing ecological information, TOPP scientists are collecting oceanographic information—time-temperature-depth measurements. Using data from tagging nine adult elephant seals over one year (see Figure 4), Boehlert et al. (2001) discuss how environmental data retrieved from tagged animals, if properly calibrated, could be used to augment traditional oceanographic sampling. According to Boehlert et al. (2001) estimates, temperature profiles from the northern elephant seals are cost-effective relative to profiles from the eXpendable BathyThermograph (XBT)—which is itself a cost-effective method of collecting profiles because it uses ships of opportunity rather than research vessels. Boehlert et al. (2001) illustrate the necessary steps to standardize this information with NOAA's World Ocean Database, thereby increasing how this information will be used and its potential value.

Deep-sea environments create many difficulties that will challenge the researchers to devise and test new sampling techniques. Technologies targeted for refinement and development are remote-sensing tools that can be deployed on ROVs and AUVs. Currently, private and public partnerships across both the maritime and fishing industries are providing the resources for these developments. For example, in Norway alone, there are 10 informal and formal partnerships providing support for technological developments (Bergstad, personal. comm.). Researchers are also employing biochemical analysis (such as DNA) and new capturing techniques to improve the analysis of stomach contents that will help decipher the trophic interactions in the deep-sea environments.[18]

NaGISA sampling does not have the same technological problems as in the deep-sea environment. However, as Nierenberg (1999) notes there is a shortage of taxonomists to record and confirm the discovery of new species, especially nematodes and microbials. This shortage, along with recent advances in DNA analysis, has spurred researchers in NaGISA and other projects of the CoML to scope out the possibility of using DNA bar coding as a means to identify new species. In fact, CoML scientists are setting up protocols to ensure that DNA sampling is uniform and meets a minimum set of scientific standards (O'Dor 2003).

Environmental genomics represents a revolution in taxonomy and has far-reaching implications for both marine and terrestrial biodiversity research and conservation. For example, DNA analysis can quickly and at very low cost screen large samples of microbials for new species (Vinter et al. 2004). Taxonomists could then focus their efforts just on the new species—given the shortage of taxonomists this could greatly increase their efficiency and help the CoML reach its goal by 2010.

Research and Data Sharing

Traditionally, ocean research has taken place at a scattering of research laboratories and academic settings around the world. The research was often disseminated in the form of reports and peer-reviewed journal articles, but primary data remained at the institutions. There is nothing unique about ocean scientific research and research in other environs in this regard. The Ocean Biogeographic Information System (OBIS) is, however, an attempt to change all that (Ausubel 1999). The OBIS portal—located on researchers desktops—will provide access to data on species characteristics, geospatial survey data, and comprehensive ocean environmental data (Zhang and Grassle 2002).

To accomplish this vision, researchers will need to convert existing data that is in many different forms and programs into a consistent web-based format and to begin to

[18] Deep-sea species will typically regurgitate their stomach contents because of the changes in pressure between the surface and the depths where they were caught.

adopt the OBIS reporting standards. Such an exercise is bound to have significant costs in researcher time and money and in the development of programs to convert existing data into a standardized format. Another significant issue is the assurance that intellectual property rights are upheld.

Even with the caveats, OBIS does have the potential to be one of the most important aspects of the CoML. If it plays the central organizing role that it can, then OBIS will be the vehicle to bring together otherwise disparate research. Such a vehicle is vital for CoML research to yield potential economies of scale over the status quo in ocean research. The Gulf of Maine project will provide an early signal on its potential value as it is scheduled to be the earliest full implementation of the OBIS system.

IV. Quanitifying the Benefits

CoML advocates argue that the total contribution to society will be larger than the sum of the parts.[19] That very well might be true, but at this point in the project, it is not assured and might not even be the appropriate measure of success. Another metric would be the maximum contribution the research could make to society by improving the health of marine ecosystems and our quality of life. Both metrics will be difficult, if not, impossible to measure at the scale of the CoML. For practical reasons and because of the interests of the researchers involved, a likely metric of the success will be the number of new species identified and the existence of guidebooks that include species ranges and distributions. While this is interesting and useful information, it is not necessarily positively correlated with the other measures. These more tangible measures also do not highlight what is attributable to the CoML versus what would have occurred under the status quo.

Even though it is difficult to quantify the benefits of the CoML, I discuss briefly a value of information approach. The discussion on how one might attempt to measure the benefits is a useful exercise, because it illustrates factors that will affect the value to

[19] This section focuses on the potential uses of the science for management, but it is important to recognize the value associated with identifying, understanding, and monitoring marine biodiversity. Biodiversity also has an important functional role in ecosystems and understanding this role, which most likely differs across habitats and environmental conditions, may help policymakers develop policies to preserve ecosystem functions and services.

society from the CoML, regardless of whether a formal analysis is carried out. The two issues I highlight are the common pool nature of ocean resources and distributional or fairness issues that will inevitably arise in the application of CoML science.[20]

A value of information (VOI) analysis is an often-used method to measure the net benefits of research and learning, where VOI is simply the change in a metric, such as welfare or profits, with and without the information.[21] In many industries, rates of return from investments in information (research and development) are measurable, because the outputs are typically traded in the marketplace—revealing the willingness to pay of consumers for the product that embodies the information and the net returns to the producers taking into account the R&D costs. Most of the CoML outputs, however, will not be traded in a marketplace, but rather are inputs into policy discussions. In some cases, the information generated by the CoML will not even be a sole input but be one component of a much larger analysis.[22] Aside from the development of a new chemical compound stemming from a discovery of a species, quantifying the expected value of information is difficult because of the nature of the outputs, even if all of the research outputs could be known (they could not). This does not imply that the VOI is low, but the fact that many ecosystem functions and services, including biodiversity, are public goods does hinder the ability to measure the value.

Whatever metric one employs to measure the VOI, the magnitude depends on the services or outputs that the research or information generates. For example, proponents of the ISOOS—integrated, sustained ocean observing system—measure the benefits in terms of the economic services provided by the data, such as reducing costs in weather-related industries. In particular, Adams et al. (2000) report benefits from improved ocean

[20] Another more technical issue is that the magnitude of VOI—information that by its very nature will reduce some uncertainty about a future event—is affected by underlying risk preferences and the availability of risk-sharing arrangements in the society. See, for example, Eeckhoudt and Godfroid (2000) and Eckwert and Zilcha (2003) for a discussion of the "Blackwell" and "Hirschleifer" effects.

[21] Broad, Pfaff, and Glantz (2002) illustrate in the context of ENSO forecasts that determining the criterion or whose welfare counts is not as straightforward as I just implied. The choice of this metric, of course, has important implications for measuring the net value of information.

[22] For example, a major source of uncertainty in marine systems is due to climate variability, climatic changes, and regime shifts. Rigorous policy design will, therefore, require information discerned from the CoML, ocean observing systems, and traditional stock assessments. While integration of the information is critical for marine management, disentangling the benefits attributable to each one is difficult.

monitoring including $300 million per year for U.S. agriculture, tens of millions of dollars for recreational fishing and boating, and in excess of $100 million per year in search and rescue operations.[23] The lion's share of the benefits takes the form of damages that are avoided because of the new information, for example, rescue missions at sea that no longer need to be made.

A VOI framework can be applied to estimate the value of reducing the uncertainty around a parameter within a model. For example, using the PRICE model on the economics of global climate change, Nordhaus and Popp (1997) estimate the value of early information about the level of economic and geophysical parameters at between $1 and $2 billion per year. Simulating the VOI for reduced uncertainty around many parameters enabled them to conclude that information on abatement costs and damages due to climate change comprise over 75% of the value of information in their model.[24] Such an analysis could be done, for example, for fishery management where the VOI of reducing uncertainty on natural mortality rates due to CoML research is calculated.

Underlying this discussion is the fundamental assumption that the institutions exist to ensure that these gains can be appropriated and sustained. Unfortunately, this is not the case with ocean research and the probability decreases the farther offshore the resources are found. Even research that will be used directly in fishery management within a country's territorial waters is not guaranteed to yield the greatest benefits. It will depend on how the particular fishery is managed. Research benefits on the presence of endemic species and bioprospecting are also affected by the rules regarding intellectual property rights stemming from naturally occurring organisms.

How do fishery management institutions, for example, affect the value of CoML research? If the fisheries are regulated open-access fisheries where all returns, even from new information on stock sizes, are dissipated by excess investments in capital and labor, in the long run, the value added to commercial fishers is small or even zero. However,

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[23] Sassone and Weiher (1999) estimate the rate of return from the investment in research on ENSO forecasts on the U.S. agricultural industry to be between 13-26 percent. Costello et al. (1998) calculated for the Pacific Salmon Fishery the net present value of benefits of El Nino forecasts, where "perfect" forecasts resulted in an increase in 1% of the value of the fishery per year ($1 million).

[24] For their particular model and simulations, Nordhaus and Popp (1997) also conclude that "uncertainties involving natural sciences comprise about 15 percent of the potential value of improved knowledge, while those involving behavioral and social sciences account for about 85 percent."

there still is value created to society from managing the resource in a more sustainable fashion, especially if this results in improvements in health of the marine ecosystem. On the other hand, if the fishery was under rights-based management, such as individual fishing quotas[25], then the value of information will be capitalized in the fish quota prices. Research that results in greater or more stable fish population abundances would lead to increases in value of the fishing quota, everything else being equal.

The importance of institutional factors is more pronounced in CoML projects, because many of the species spend time in the high seas. Sustainable management of highly migratory pelagic species, for example, requires coordination among multiple countries. A recent agreement on highly migratory species under the auspices of the UN Convention of the Law of the Sea addresses this coordination by providing rules for the development of international regional management commissions (Delone 1998).[26] However, it is not clear if these regional fishery management organizations are flexible enough to handle management instruments, such as dynamic area management closures. Species are also "covered" by the Convention of Biological Diversity, where signatories are responsible for enforcement of fishing vessels and other marine expeditions (e.g., seabed mining operation) operating under their flag.

MAR-ECO research faces the same difficulties because these resources, for the most part, fall completely outside any coastal nation's territorial seas. Intergovernmental organizations, such as OSPAR, NEAFC, NAFO and the UN are currently responsible for

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[25] Under individual transferable quotas (ITQ) management, the total allowable catch (TAC) is capped and the privilege of harvesting the catch is allocated to individual fishermen through quota shares that are secure and transferable with the objective of maximizing net economic returns (NRC 1999). Other possible rights-based approaches are cooperatives (e.g., Alaskan pollock) and community development quota (e.g., select Alaskan communities).

[26] See, for example, the 1995 Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 Relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (S. Treaty Doc. No. 104-24, at 1 (1996), 34. I.L.M. 1542. The Agreement develops the membership and functions of regional fishery management organizations and authorizes the use of the precautionary approach, and the mandate to conserve fish stocks (deLone 1998)

the management of the living and nonliving marine resources in the North Atlantic.[27] The coordination of the international agencies, treaties, and coalitions are, therefore, critical to preserving the benefits of the research. Such safeguards are needed to avoid a "tragedy of the commons," for example, with discoveries of commercial viable deep-sea fisheries or potential biodiversity hotspots that could lead to uncontrolled bioprospecting operations.[28]

Even though GOM research falls mainly within U.S. and Canadian waters, it is not clear that the difficulties at preserving the value of the research are any less. For the simple reasons that rights over the resources are not well defined and the U.S. New England Fishery Management Council is notorious for avoiding change (Eagle, Newkirk, and Thompson 2003).

The lack of well-defined rights and established institutions contributes to many of the distributional issues and conflicts arising among users of the ocean environment. These conflicts will affect how the research is utilized and valued. Distributional issues are often not acknowledged when advocates for more scientific research argue that the benefits of such efforts outweigh the costs (e.g., see Malakoff 2000). New information and the methods and effectiveness of dissemination strategies can, however, create winners and losers. Whether the net value is positive will, therefore, depend on the relative weights placed on the groups affected.

Pfaff, Broad, and Glantz (1999) illustrate how ENSO forecasts and their incorporation into decisions did affect groups differently based on how the information was disseminated and their abilities to understand technical information. In their

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[27] OSPAR (Oslo and Paris Commissions) Convention signed by 14 countries and the European Union outlines objectives for the management and protection of the marine environment in the North-East Atlantic. Annex V of the Convention contains provisions with regard to the protection and conservation of the ecosystems and biodiversity (www.ospar.org/eng/html/content.html). The North East Atlantic Fisheries Commission (NEAFC) was formed to recommend measures to maintain the rational exploitation of fish stocks in the Atlantic and Arctic Oceans (http://www.neafc.org/). Northwest Atlantic Fisheries Organization (NAFO) is a regional fisheries body that incorporates scientific advice and management. Sixteen countries plus the EU signed the NAFO Convention that applies to most fishery resources of the Northwest Atlantic (www.nafo.ca).

[28] Access and use of genetic resources beyond national jurisdiction are currently unregulated, except where states regulate the activities of own nationals per the Convention of Biodiversity and other international laws (Green 2003; Leary 2003).

example, the Peruvian industrial fishing sector was able to use the information given the dissemination of the forecasts, often at the cost of the small-scale fishing fleet. Distributional issues regarding how competing users would use the CoML data were singled out in early focus groups with the fishing industry (Lassen 1999).

Distributional effects are not limited to contemporaneous users of the information. Improved information on the life cycle of commercially harvested fish species that results in reductions of the total allowable catches will benefit future fishers, as the fish stock recovers and lowers the costs of fishing. The current set of fishers, however, face a cost in lost revenue from harvesting that might affect their operations, for example their ability to repay bank loans for fishing gear and equipment.

Finally, even if the institutions were in place to sustain the returns from CoML research, its value is dependent on other aspects of the market economy. For example, Glasby (2000) argues that the original claims of abundant supply of metals (e.g., Mn, Co, Ni, and Cu) in the marine environment in the 1960s led to both private and public investments in deep-sea mining technologies. However, because the world prices of these minerals continued to decline, the feasibility of extracting these large beds of deep-sea mineral deposits proved uneconomical. In the end, approximately US$650 million ($1.5 billion in 2004) from the 1960s to mid-1980s was spent on R&D with very little return (Glasby 2000).

V. Discussion

Driven by advances in scientific knowledge over the past 25 years and a growing marine conservation ethic, ocean management is moving away from the traditional production focus towards a multi-objective ecosystem approach. However, many basic questions remain to be explored, such as which areas are to be restricted and for what uses. Creating guidebooks on species' ranges will help in this endeavor, as will research on the causal factors that effect oceanic systems, trophic interactions, and variations across space in population abundances

While such a system is on the horizon, more pressing issues for CoML researchers are to avoid potential unintended consequences that worry many environmentalists. For example, a biodiversity hotspot might occur in an area with insufficient marine management and enforcement to ensure protection. Fishermen or others with economic interests could act on this information faster than governments. It is also easy to imagine that as scientists learn more about the diversity of species and local abundances that commercial fishermen will also learn about them, especially if efforts are made to disseminate the research broadly. Broad, Pfaff, and Glantz (2002) studied the use of El Nino information in Peruvian fisheries management and found a range of unintended consequences, including increased efficiency in exploitation by some groups given the advanced notice of likely shifts in population abundance.

The research will also stretch the limits of our current regulatory system along with potentially developing further disgruntlement from the regulated. This could occur if the protection of an endangered marine mammal or a "watering" hole requires the use of real-time data and coordination of maritime activities across a number of countries. A new discovery or the prediction that new taxa exist in heavily exploited areas can result in further restrictions and/or new regulations that will draw the ire of the current users, who already feel that they are overburdened with regulations.

Unintended negative consequences and ill-equipped institutional frameworks need not be a foregone conclusion. Under the current model, however, they are likely to come about. Investing in rigorous policy analysis alongside the natural science research will mitigate the degree to which they occur. Successfully navigating the research through the political economy of ocean management might not achieve the maximum returns possible from the CoML, but it will ensure that the gains are greater than under the status quo.

One possible model for this "social science" effort is that within each project, a policy advisory committee is created or at the very least, each project should adopt a handful of social scientists. While a policy committee does exist in the Gulf of Maine project, the set of participants could be expanded. A committee that includes social scientists, lawyers, natural scientists, government representatives, industry (those using and affected by the information), and nongovernmental organizations seems required. Overall, this effort needn't be at the same scale or scope of the natural science component.

Given that the CoML is less than halfway complete, it is hard (and foolish) to predict what the value will be, and may never be accurately accounted for, but it is clear that actions can be taken now to increase its value to society. Public outreach and education are key components in this effort and will help build constituencies for ocean science and biodiversity conservation, but a narrow focus on these groups is only a sufficient condition.

The team of natural scientists behind the Census of Marine Life is striving to create a flexible and adaptive research program on a scale not seen before in oceanic research. Such an undertaking will transform ocean science in the questions asked, methodologies employed, and the allocation of research funds. If the team does not reach out now to include other disciplines when questions and projects are still being decided, an opportunity to make the best transformation possible will be squandered.

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