Biodiversity and Ecosystem Management
Approaches for Researching the Roles of Marine and Coastal Biodiversity in Maintaining Ecosystem Services

A Workshop Sponsored by the U.S. National Committee of the Census of Marine Life
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About the Census of Marine Life
The United States Census of Marine Life (U.S. CoML) was established in 2002 in consultation with the National Academies of Sciences, the National Research Council, the National Oceanic and Atmospheric Administration (NOAA) and the international Scientific Steering Committee (SSC) of the Census of Marine Life (CoML). The U.S. component, led by a National Committee (USNC), seeks to build broad U.S. community support to establish CoML as a sustained national research and monitoring program for marine and coastal biodiversity in support of its mission.

The U.S. CoML's mission is to serve as an unbiased source of sound scientific information to support the needs of the nation by assessing and explaining the changing diversity, distribution and abundance of marine species, as well as the functional role of marine biodiversity in the U.S. and its territories and commonwealths in the past, present and future.

About CORE
The Consortium for Oceanographic Research and Education (CORE) is a Washington, DC-based non-profit association representing leading ocean research and education institutions. Since 1994, CORE has established a leadership role on oceanographic issues and the development of marine science policy. CORE is respected as the voice of the ocean community and is dedicated to promoting awareness and appreciation of the oceans among government agencies, non-governmental organizations and the general public.

Executive Summary

Biological diversity is an intrinsic component of healthy, vibrant ocean ecosystems. The Convention on Biological Diversity defines the term – also called biodiversity – as the variability of living organisms residing in terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part. This includes diversity within species, between species and of ecosystems.[1] Biodiversity provides many benefits for ocean ecosystems, including bolstering ecosystem function, resiliency and adaptability. Conversely, loss of biodiversity can lead to lower resiliency, vulnerability and the inability of ecosystems to recover from or even survive stressors. It is a vital component of ecosystem-based management, which is the "integrated approach to management that considers the entire ecosystem, including humans…[with the goal] to maintain an ecosystem in a healthy, productive and resilient condition so that it can provide the services humans want and need."[2]

Biodiversity is so integral to healthy ecosystems that the U.S. Commission on Ocean Policy proclaimed in its 2004 report, "One of the central goals for ecosystem-based management should be the explicit consideration of biodiversity on species, genetic and ecosystem levels…[A]n ecosystem's survival may well be linked to the survival of all the species that inhabit it." Yet despite its importance, there is still a substantial gap in the understanding of the roles biodiversity plays in maintaining ocean ecosystem functions and its value to humans.

In an effort to improve the understanding of how marine and coastal biodiversity affects ecosystems and to apply this knowledge to efforts aimed at sustainable and adaptive ecosystem-based management of resources, the Consortium for Oceanographic Research and Education (CORE) – under the auspices of the U.S. National Committee of the Census of Marine Life (CoML) – sponsored a biodiversity workshop in Washington, DC from September 11 to 13, 2006. The workshop, titled "Approaches for Researching the Roles of Marine and Coastal Biodiversity in Maintaining Ecosystem Services," brought together experts from a wide variety of scientific disciplines, academia and management agencies to address three central questions:

- How does biodiversity at genetic, species and community levels contribute to ecosystem function, resilience or adaptability and what are likely consequences of loss of biodiversity in marine systems?
- How might increased knowledge of biodiversity at all levels be used to improve management of marine systems over the next decade? That is, what can we conclude, infer or reasonably anticipate about the functional roles and values of

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[1] Convention on Biological Diversity, "Article 2: Use of Terms," n.d. <http://www.biodiv.org/convention/articles.shtml?a=cbd-02> (15 March 2007)

[2] Compass Consensus Statement, "Scientific Consensus Statement on Marine Ecosystem-Based Management," n.d. <http://www.compassonline.org/pdf_files/EBM_Consensus_Statement_v12.pdf> (15 March 2007)

biodiversity, and what do we know, what do we not know and what do we need to know in order to inform robust ecosystem-based management approaches to marine resources?
- What pragmatic but revealing metrics of biodiversity and/or ecosystem function should be considered for inclusion in ocean observing and assessment systems to provide continuing information flow for enhanced ecosystem-based management approaches?

Several plenary sessions helped establish the context for these questions. These sessions covered an array of biodiversity topics, including terrestrial and aquatic biodiversity, roles of biodiversity in marine ecosystem function, potential impacts of biodiversity on management practices and measures of biodiversity for ocean observing. Overall, these presentations illustrated that biodiversity has shown positive effects – and that loss of diversity can have negative effects – on a variety of ecosystems. Consequently, maintaining and restoring an ecosystem's biological integrity should be an important goal of ecosystem-based management. During plenary discussions, participants noted the paucity of supporting data on a large scale and in the marine environment, but concluded that there was sufficient information to support the idea of biodiversity as a foundation for ecosystem services (which include the provision of food and clean water, oxygen production, nutrient cycling and waste assimilation). Workshop participants also used the plenary findings to support and enrich the workshop's central question discussions. *(A brief summary of the various plenary sessions' key points can be found on page xx.)*

Throughout the workshop, participants expressed support for maintaining natural biodiversity and greater emphasis on ecosystem-based management. They cited benefits of biodiversity, including ecosystem resiliency, productivity and recovery. However, participants noted that scientific support alone for these concepts is not enough to make changes in management practice. They acknowledged that resource managers are also a vital component of success. They offered several proposals to aid managers in the pursuit of managing for natural biodiversity conservation, including:

- Endorsing the need to support frequent meetings between scientists and managers to facilitate joint communication, commitment and strategies and to assure that ecosystem management is instituted in different types of ecosystems in the near future;
- Supporting the creation of clear mandates – most likely through new legislation or amendments to existing laws – that would establish parallel management goals across different ecosystems and foster coordination among agencies; and
- Encouraging policymakers to adopt the U.S. Commission on Ocean Policy's recommendations to create a comprehensive and integrated ocean management structure.

Participants recognized that the public could also be a valuable ally in gaining support for ecosystem-based management and conservation of natural biodiversity. As a result, participants emphasized the need to educate the public on the consequences of biodiversity loss, especially as it relates to tangible effects, such as beach closures or fishery stock collapse. The group anticipated that an educated public would be able to influence and convince policymakers to include consideration of diversity in ecosystem management.

The group also identified several challenges to conserving natural biodiversity and encouraging ecosystem-based management, including:

- Creating a single, simple definition of biodiversity suitable for a broad audience;
- Overcoming gaps in knowledge (by understanding the basic biology, natural history, baseline biodiversity estimates, etc. of each ecosystem) that hinder scientists' ability to understand the consequences of reduced biodiversity;
- Providing enough scientific information to aid managers and educate decision-makers on the importance of biodiversity;
- Developing biodiversity indicators to help managers improve ecosystem-based management;
- Overcoming the lack of an administrative and legislative framework for comprehensive U.S. ocean management;
- Including multiple uses – such as fishing, water quality, waste management and recreation – when considering ocean management issues; and
- Encouraging more federal funding for taxonomic work and encouraging more individuals to become taxonomists.

During the workshop, participants acknowledged that scientists, managers and other stakeholders face several daunting tasks to conserve and restore biodiversity. However, participants who were optimistic that these challenges were not insurmountable offered solutions to potentially resolve some of these issues, including:

- Performing additional scientific research on ecosystems to determine where and how diversity plays a pivotal role in ecosystem functions;
- Creating visual aids, such as dynamic maps, to summarize and demonstrate the impacts and effects of biodiversity;
- Increasing monitoring and data collection across ecosystems, to include a variety of biodiversity measures and impacts of biodiversity loss;
- Collaborating with businesses to market sustainably-produced food and other products; and
- Supporting the establishment of integrated ocean legislation that mandates consistent management across agencies for natural biodiversity conservation.

By the workshop's conclusion, three signal findings had emerged from the discussions:

1. The weight of evidence shows that biodiversity is integral to robust ocean ecosystems, and loss of biodiversity is a clear threat to marine ecosystem functions and sustainable use.
2. Using conservation of natural biodiversity as a common, primary management target could substantially improve the way people approach and implement ecosystem-based management.

3. While scientists and ecosystem managers do not currently know all they need to know about biodiversity and its relevant measures, there is enough information to allow scientists and managers to move forward with biodiversity as a management target.

The workshop results will be provided to sponsoring entities (see Appendix), the Joint Subcommittee on Ocean Science and Technology (JSOST), the Subcommittee on Integrated Management of Ocean Resources (SIMOR) and federal and state agencies to advance the research priorities and potential applications identified by participants.

Introduction

"One of the greatest scientific challenges facing society today is understanding, protecting, managing and restoring biodiversity in our oceans."

—Nancy Knowlton,
Sant Chair for Marine Science,
National Museum of Natural History

Biodiversity – defined as the diversity within species, between species and of ecosystems in terrestrial, aquatic and marine environments – provides many benefits for ocean ecosystems, including bolstering ecosystem function, resiliency and adaptability. Conversely, loss of biodiversity can lead to lower resiliency, vulnerability and the inability of ecosystems to recover from or even survive stressors. Biodiversity is so integral to healthy ecosystems, the U.S. Commission on Ocean Policy proclaimed in its 2004 report that agencies "incorporate preservation of marine biodiversity in their management programs and support further study of biodiversity."

However, much is still unknown about the benefits of biodiversity. According to the Commission, "Despite the importance of biodiversity to ecosystem functions and values, very little is known about how biodiversity arises, is maintained and is affected by outside forces including climate variability and direct human impacts."

In an attempt to better understand biodiversity and apply this knowledge to support sustainable and adaptive ecosystem-based management of resources, the Consortium for Oceanographic Research and Education (CORE) – under direction of the Census of Marine Life (CoML) – sponsored a biodiversity workshop in Washington, DC from September 11 to 13, 2006. Participants represented an array of scientific disciplines, academia and management agencies (*a list of workshop steering committee members, speakers, participants and support staff is found on page xx*). During the workshop, participants examined several issues, including:

- How does biodiversity at genetic, species and community levels contribute to ecosystem function, resilience or adaptability and what are likely consequences of loss of biodiversity in marine systems?
- How might increased knowledge of biodiversity at all levels be used to improve management of marine systems over the next decade? That is, what can we conclude, infer or reasonably anticipate about the functional roles and values of biodiversity, and what do we know, what do we not know and what do we need to know in order to inform robust ecosystem-based management approaches to marine resources?
- What pragmatic but revealing metrics of biodiversity and/or ecosystem function should be considered for inclusion in ocean observing and assessment systems to provide continuing information flow for enhanced ecosystem-based management approaches?

Several plenary sessions helped establish the context for these questions. Overall, the presentations illustrated that biodiversity has shown positive effects – and that loss of diversity can have negative effects – on maintenance of ecosystem integrity, resilience and a variety of ecosystem services across wide ranges of spatial and temporal scales. Thus, maintaining or restoring an ecosystem's biological integrity should be an important goal of ecosystem-based management. The following is a brief summary of the plenary sessions' key points:

The Terrestrial Experience: Species Diversity and Ecosystem Functioning
Dr. Diana Wall, Colorado State University

- Human activities, including land-use change, climate change, nitrogen deposition and biotic exchange, are the main threats to terrestrial biodiversity.
- Biodiversity above and below surface provides ecosystem services critical to human survival.
- Empirical evidence indicates that increased grassland plant biodiversity is often associated with enhanced ecosystem functioning, e.g. primary production.
- However, it is less clear if changes in the diversity of animals, microbes or other plants influence ecosystem function, due to the limited number of studies.
- Moreover, species composition and traits likely have a greater influence on ecosystem function than species richness per se.
- The role of biodiversity in regulating the stability of ecosystem functions and their response to disturbance is currently unclear.

Biodiversity and Ecosystem Services: The Freshwater Experience
Dr. David Allan, University of Michigan

- A positive relationship between biodiversity and ecosystem function has been demonstrated in a number of cases.
- Species identity in ecosystems matters a great deal.
- Results from small-scale, low-diversity studies indicate "that the effects of changes in biodiversity…are highly variable over space and time and frequently depend on specific biological traits or functional roles of individual species" (Covich AC et al., *BioScience* 54:767-775, 2004).
- Freshwater ecosystems may provide excellent opportunities for further research on biodiversity.

The Roles of Biodiversity in Marine Ecosystem Function, Resilience and Adaptability
Dr. John Stachowicz, University of California, Davis

- Marine ecologists have long studied the effects of ecosystem processes on the maintenance of biodiversity but have been slower to assess reciprocal links of species diversity affecting ecosystem processes.
- Loss of genetic variation within populations is another aspect of diversity change.
- Many sessile marine species show effects on biodiversity similar to those found in terrestrial studies, with high biodiversity enhancing function.
- Genetic diversity within key species reduces community susceptibility to disturbance, providing "biological insurance."

- Diversity commonly buffers communities against perturbation, having an overall stabilizing effect on ecosystem functioning.

Potential Impacts of Biodiversity Information on Management Practice
Dr. Elliot Norse, Marine Conservation Biology Institute

- Several alarming indicators point to the oceans' declining health, including collapsing fisheries, disappearing megafauna, vanishing habitat-formers and proliferating noxious species.
- Ecosystem-based management: protects species composition structure and functioning; is place-based, focusing on activities affecting species and ecosystems; acknowledges interconnectedness among systems (e.g., air, land and sea); and integrates ecological, social, economic and institutional perspectives.
- There are multiple threats to marine biodiversity. Proximal threats include overexploitation, habitat alteration, marine pollution, alien species and climate change. Ultimate threats include human overpopulation and excessive consumption.
- Ecosystem managers should consider the following guidelines: maintain ecosystem integrity and resilience; retain all of an ecosystem's parts; realize that more is not always better; and understand that there is no single approach for ecosystem management.
- Taxonomists are an endangered species and need to be protected and recovered.

Essential Measures of Biodiversity for Ocean Observing
Dr. Michael Beck, The Nature Conservancy, Marine Initiative

- Ecosystem-based management is not possible without information on the distribution of ecosystems such as salt marshes, seagrass meadows, kelp forests, oyster reefs, sponge beds, and coral reefs. An Atlas on Marine Ecosystems of the United States should be central to management and conservation.
- The huge losses in coastal habitats through the United States have been accompanied by declines in top marine predators and fisheries, declines in coastal condition, loss of ecosystem services, calls for regionally informed conservation and marine ecosystem management and the need for data to inform priorities.
- Regional assessments of biodiversity should inform management. The aims for biodiversity assessments should include representation, resilience and redundancy (see www.marineebm.org).
- Representation of ecosystems in assessments will ensure representation of most species within them.
- Fundamental and pragmatic metrics of biodiversity include mapping of ecosystems and identification of communities.

Approaches for Researching the Roles of Marine and Coastal Biodiversity in Maintaining Ecosystem Services
Dr. Stephen Palumbi, Stanford University

- Documentation of species requires new tools that accelerate discovery, including morphological pattern recognition software, genetic ID automation and remote or robot sensing.
- DNA bar coding still requires a species name be matched to a DNA string. Matching requires the collaboration of genetic and systematic expertise.
- Diversity is beneficial to marine ecosystems: experimentally increasing diversity increases production and resilience.
- Ecosystems with high biodiversity are resistant to fishery collapse.
- From small experiments to large ecosystems, marine species diversity is positively associated with ecosystem function and services such as fisheries yield. However, the relationship between diversity and services must be determined in detail for more exemplars.
- Marine reserves increase diversity, productivity, recovery and tourism.

During plenary discussions, participants noted the paucity of supporting data on a large scale, especially in the marine environment, but concluded that there was sufficient information to support the idea of biodiversity as a foundation for ecosystem services. Workshop participants also used the plenary findings to support and enrich the discussion of the workshop’s central questions.

Workshop Results

Question 1 Discussion Summary: How does biodiversity at genetic, species and community levels contribute to ecosystem function, resilience or adaptability and what are the likely consequences of loss of biodiversity in marine systems?

Contributions to Ecosystem Function, Resilience and Adaptability

All workshop participants strongly agreed that there is enough scientific evidence to state that biodiversity contributes to ocean ecosystem resilience and function. As an example, the group cited the role complementarity between species plays in diverse systems. In many ecosystems, certain functions can be carried out by a variety of species. In a diverse ecosystem, having an overlap of similar species can help the ecosystem retain its functions if one species disappears. This overlap was cited as one reason why diverse ecosystems recover better from perturbations than do impoverished ones.

However, participants also acknowledged that much remains unknown about the benefits of biodiversity. While highly diverse systems are more resilient, the group wondered if biodiversity alone can signal an improvement in an ecosystem's stability, productivity, resiliency, recovery and other aspects. And while higher levels of natural biodiversity may make it easier for a degraded ecosystem to recover from damage, participants noted that in certain cases, if a system has experienced too much change, it might not be able to return to its natural state, even with restored biodiversity.

Consequences of Loss of Diversity

The group acknowledged that, while the consequences of biodiversity loss are not fully understood, systems in which natural biodiversity – regardless of whether high, medium or low – is maintained are typically more resilient and less vulnerable than ecosystems in which natural biodiversity has been degraded or lost. Nonetheless, the number of empirical examples that support this position is quite limited. The group suggested that policymakers would likely require "glaring examples" of the impacts of biodiversity loss to be convinced to use biodiversity as a metric in ecosystem-based management.

Workshop participants also admitted that gaps in knowledge hinder scientists' ability to fully understand the consequences of reduced biodiversity. To accurately observe changes to ecosystems, scientists need a baseline. For many ecosystems, like coral reefs, scientists do not know a great deal about the systems' basic biology, which makes determining baselines – and subsequent changes – difficult.

The group noted that scientists are typically much better at recording the demise of systems, which is usually triggered by the decline of a foundation species (e.g., mangroves, oysters), than predicting them. While scientists may have trouble anticipating these declines, they are fairly certain that losing one of these foundation species would impact the overall diversity of the ecosystem.

Defining Biodiversity

The definition of biodiversity was a recurring topic. The Convention on Biological Diversity defines biodiversity as the diversity within species, between species and of ecosystems in terrestrial, aquatic and marine environments. However, participants noted that biodiversity could be measured in many ways, making it difficult for people to reach solutions when they are managing for different standards.

Currently, scientists typically refer to numerical diversity (raw number of species) or functional diversity (species connectivity) as the metric of biodiversity. Focusing on the number of species in an ecosystem – diversity for diversity's sake – ignores the relationships between and among species that are vital to understanding an ecosystem. As an example, one participant described a hypothetical ecosystem with 15 species. Over time, these species are replaced by 15 invasive species. On the surface, the numerical diversity is the same – the ecosystem still has 15 species – but the biodiversity is quite different. In contrast, functional diversity focuses on interspecies relationships – the ecosystem functions to which different species and species guilds contribute – and on ecosystems being diverse enough to support all of their functions. The group supported the functional diversity model, agreeing that biodiversity is not defined solely by the number of species, but also by the structure of the ecosystem. Participants also agreed that it is important to deliver the well-documented message that biodiversity plays major roles in ecosystem functioning, stability and resilience.

Further Discussion

At the end of the session, several unresolved questions remained about how biodiversity (and its loss) can impact ecosystems. Participants discussed these issues and provided the following potential courses of action.

- There is a need to better understand how biodiversity affects ecosystem function and, conversely, how ecosystem function (processes) helps maintain biodiversity. A suggestion was made that scientists should select biological communities for study, define and measure the processes and interrelationships taking place in those communities (including those that are externally forced) and identify how biodiversity influences community stability (the feedback on biodiversity) and functioning in the face of internal and external forcing factors. Through this research, scientists could further determine where diversity plays a pivotal role in ecosystem functions.

- To keep biodiversity and ecosystem functions intact, it is vital to determine how much of an ecosystem needs to be protected and at what levels: that is, what happens to both biodiversity and ecosystem functions when elements of ecosystems are lost or degraded. Such understanding will help management determine how much damage or disturbance a system can endure and still maintain its functions. Since an ecosystem consists of many types of habitats, participants suggested detailed scientific investigations of disturbance effects in various habitats.

Question 2 Discussion Summary: How might increased knowledge of biodiversity at all levels be used to improve management of marine systems over the next decade? That is, what can we conclude, infer or reasonably anticipate about the functional roles and values of biodiversity, and what do we know, what do we not know and what do we need to know in order to inform robust ecosystem-based management approaches to marine resources?

During this session, most dialogue revolved around two subjects: what is known and what needs to be known to inform ecosystem-based management approaches.

What is Known to Inform Ecosystem-Based Management

Historically, the oceans have been managed species-by-species, which focuses on the needs of a particular species or function without taking into account the ecosystem's interrelated services and health. The result is an emergence of conflicting objectives between long-term conservation plans and short-term economic and social goals (e.g., fisheries production, recreation). Recently, the model of single-species or single-issue management has been supplanted with that of ecosystem-based management, which focuses on how species in an ecosystem interact with and depend upon each other. But, as there is no single administrative or legislative framework that oversees integrated ocean management in the United States, participants expressed concern that ecosystem-based management is susceptible to the same problems of conflicting objectives as under the single-species/issue model.

Participants discussed the need for a shift in management approaches that would focus on the goal of conserving natural biodiversity and move away from either species-by-species or service-by-service management. They noted that establishing integrated ocean legislation, which would mandate consistent management across agencies for natural biodiversity, would better ensure ecosystem function than having multiple agencies focus on a single species or service at a time. The group also agreed that managing for conservation of natural biodiversity could actually make managers' jobs easier because it would establish a single over-arching management goal.

During the discussion, participants noted that fisheries are not the only component of ocean management. They argued that the management debate should be expanded to include interactions among a variety of uses, such as fisheries, water quality, waste management and recreation.

What Needs to be Known to Inform Ecosystem-Based Management

The group agreed that scientists and managers need a fundamental description of baseline information about an ecosystem's natural history in order to incorporate biodiversity into management plans. Systematics and taxonomy were mentioned as very important components to implement this management model. The group also agreed that dynamic, frequently updated maps are a good way to summarize and demonstrate the impacts, effects of, and changes to biodiversity. Maps can readily illustrate biological effects, helping managers pinpoint important bioregions.

Each management plan will have its own objectives. Therefore, the group noted that it is unlikely that there will be a single set of universal goals for ecosystem-based management, beyond the generic idea of maintaining sustainable ecosystem services. While acknowledging differences in specifics, the group supported the creation of clear mandates – most likely in the form of new legislation or amendments to existing laws – that would establish parallel management goals across ecosystems. This would foster automatic coordination between agencies, as they would be managing for similar outcomes that would specifically include the conservation of natural biodiversity.

Participants deliberated not only about what needs to be known about biodiversity, but – perhaps more importantly – *who* needs to know. Participants mentioned resource managers and the general public as two important audiences that should be educated on biodiversity and its role in providing ecosystem services.

The group agreed that managers face several obstacles to successfully manage diversity in ocean ecosystems. One challenge is the difficulty of gaining access to existing information, coupled with a lack of concrete guideline indicators. This creates some confusion as to what, exactly, managers are trying to manage for in terms of biodiversity. Suggestions to help alleviate this problem include communicating effectively with managers on the issues of biodiversity before they begin strategizing about what their particular region might need. Additionally, scientists must work with managers to define the questions and issues to be addressed. The group noted that scientists have not supplied managers with all of the necessary information to best carry out the task: it is the scientific community's responsibility to educate decision-makers on the importance of biodiversity and how to use risk analysis to evaluate likely impacts of management actions.

The group also mentioned the management complications that arise through political boundaries. Participants explained that it could be difficult for regional managers to consider issues on an ecosystem level if a part of that system falls outside his or her purview. The group endorsed the need to support frequent meetings between scientists and managers to facilitate joint communication, commitment and strategies and to assure that ecosystem management is instituted in different types of ecosystems in the near future. Participants expressed hope that increased communication might help managers and policymakers identify and prioritize key issues and ecological services over large, regional ecosystems. They also mentioned that policymakers should adopt the U.S. Commission on Ocean Policy's recommendations regarding creation of a comprehensive and integrated ocean management structure, which would provide guiding principles for all those involved.

Participants noted that a well-educated public could influence policy makers with regard to biodiversity and its important roles in ecosystems. They argued that the scientific community should make efforts to educate the general public on these issues. The group acknowledged that, in many cases, the public does not appreciate the consequences of biodiversity loss unless it is related to something tangible, such as beach closures or loss or contamination of seafood. Participants suggested that when scientists explain the role of biodiversity in providing ecosystem services, wherever possible they should associate an economic value with ecosystem activities or changes because the public and policymakers often better understand and relate to such information than to pure science.

Question 3 Discussion Summary: What pragmatic but revealing metrics of biodiversity and/or ecosystem function should be considered for inclusion in ocean observing and assessment systems to provide continuing information flow for enhanced ecosystem-based management approaches (e.g., keystone species, proxies, indices, genetic barcode analysis)?

Improved Measures of Biodiversity

Workshop participants strongly agreed that managers need help defining ecosystems, assistance on how to best maintain and monitor them and aid in developing new methods of measuring biodiversity. Participants mentioned that a significant challenge is how scientists can help delineate ecosystems in ways useful to management.

Participants suggested that scientists should think creatively when measuring diversity components, emphasizing what is both practical and important. Management could be improved if managers were provided with useful measures of diversity, such as dynamic maps of key habitat types and their biodiversity characteristics, richness at the population, species and ecosystem levels and relative abundance and status of foundation species.

Taxonomists are key players in the expansion of biodiversity knowledge and people's capacity to assess change. Participants expressing concern about the declining number of taxonomists and lack of federal research support for taxonomy made several recommendations:

- Train and employ more taxonomists. Participants noted that scientists cannot complete biodiversity studies if they cannot identify species. Emphasizing that there is no substitute for well-trained taxonomists, they urged more funding for training and employment in taxonomy.
- Encourage training and employment of parataxonomists. Just as medical residents learn their craft while working under experienced doctors, participants stated that parataxonomists would benefit from training under established and respected taxonomists and could be employed for routine identifications.
- Marry traditional science with new techniques. Participants acknowledged that molecular approaches are providing exciting new technologies for species identification and should be used to the greatest extent possible. However, they cautioned that these techniques cannot replace an experienced taxonomist's contributions. Taxonomists are still needed because they play a central role in identifying new species and their relationships to other organisms, adjudicating difficult identifications, establishing species-molecular relationships, etc.

One participant stated that it would be very helpful to give managers a matrix that identifies the species in their ecosystem and the functions they fulfill so the managers can track changes as they occur. Participants suggested monitoring keystone and habitat-forming species (foundation species) because they play key functional roles in maintaining biodiversity and sustaining ecosystem services. Scientists should also address genetic variability, as a decrease in variability can lead to reduced species ranges and adaptability and loss of biodiversity and biological integrity.

Developing Indicators to Improve Ecosystem-Based Management

Participants stressed the need to identify indicators that managers could use to make assessments and track changes at each level of an ecosystem (e.g., within a habitat type, a community or overall). The group developed the following lists of indicators and types of information that managers could use to better measure and manage for biodiversity in ecosystem-based management approaches. While incomplete, the lists illustrate a suite of factors that could or should be used. In the "Can Have" list, the biodiversity condition indicator information or tools are generally available, although all are not fully developed or implemented. The "Cannot Have Now" list provides examples of tools and information within the scientific community's technical capability to deliver, but that will likely require considerably more investment before being ready for wide application by managers.

What Managers Need and Can Have:

- **Species richness –** Good estimates of numbers of species – at least of certain major taxa – are available for many marine habitats and ecosystems.

- **Habitat maps –** Recent and ongoing work by agencies, researchers and non-governmental organizations are producing excellent maps of some critical habitats (e.g., coral reefs, sea grass beds, salt marshes, mangroves) and some include detail on associated biodiversity characteristics.

- **Geomorphology maps –** Numerous maps are available or under development, particularly for coastal and near-shore areas, and could be combined with habitat maps to provide more information on habitat/ecosystem extent and condition.

- **Species abundance –** Lists are available for many coastal and near-shore to shelf-edge areas, particularly for species captured by fisheries or routinely sampled in benthic surveys.

- **Movement and migration –** Much information is available from both long-term and recent tagging programs – mostly of organisms of fishery concern – that could be incorporated into dynamic maps to show likely distributions, migrations, etc.

- **Mean trophic level and food web connections –** Changes in the mean trophic level of species represented in fishery or survey catches have been catalogued in many areas of the world using diet composition data and changes in catch composition. Declines in mean trophic level in major ocean regions have been attributed to selective removal of top predators and the development of new fisheries targeting lower trophic level organisms. The relative importance of these factors differs among systems.

- **Environmental quality indicators** – Many physical-chemical and related environmental data have been and are currently being collected (e.g., temperature, salinity, oxygen, nutrients, major contaminants). These can be combined in GIS format with habitat information to rapidly assess the likely status of and threats to habitats and their associated biodiversity (e.g., see the Environmental Protection Agency's National Coastal Condition Report, available at http://www.epa.gov/owow/oceans/nccr/).

- **Metapopulation structure –** It is increasingly recognized that spatially differentiated sub-populations connected by dispersal pathways represent important metapopulation units. Maintaining the ecological diversity of this type of population structure confers resilience in the face of natural and anthropogenic change.

- **Genetic diversity –** Advanced tools for measuring genetic structure and diversity are widely available and applied to marine organisms. Applications include defining population and subpopulation structures for management purposes.

What Managers Need But Cannot Have Now:

- **Food web connections –** Although considerable information on mean trophic levels and other aspects of fishery-related food webs is available, much remains to be determined about the broad range of trophic interactions among exploited and non-targeted species. Understanding such interactions will be essential for determining how harvesting certain species may affect the ecosystem.

- **Disease/parasitism –** Understanding natural levels of disease and parasitism and the population-level consequences thereof will be important to evaluate changes related to human-induced or natural ecosystem change.

- **Biodiversity census data –** Increasing the number and kinds of taxa that can be and are regularly censused, using both traditional taxonomic methods and new technologies (such as genetic bar-coding and microarrays, biological sensors, optical plankton recorders and numerous others) will provide managers with more direct biodiversity information that can be used in decision making.

- **Behavioral variability and local adaptation –** Increased knowledge of the range of behavioral variability of various species, along with the degree of local adaptations to differing environmental conditions, will help managers predict likely effects of management strategies on key species.

Workshop participants agreed that it would be unreasonable to expect to monitor everything in an ecosystem, but emphasized that researchers need to monitor more of the ecosystem than they do now. New measurements need to provide for an integrated assessment of how well an ecosystem was performing (e.g., in terms of biodiversity and functioning). Participants suggested that a matrix of information criteria and related measurements would be helpful, noting that increased monitoring would generate a tremendous amount of data. Several individuals expressed concern about overburdening managers with too much information and requiring them to break it down to use it. One proposed solution is to have data collection and analysis funded as part of a scientific activity, with the goal of refining a package of measurements and analyses that would be workable for long-term monitoring and management.

Educating the Public and Policymakers

In addition to influencing managers, participants mentioned the necessity of educating the public and policymakers about the role of biodiversity in providing ecosystem services and the role ecosystem-based management can play in sustaining biodiversity. One suggestion proffered marketing as an effective tool to influence policymakers and politicians. Participants suggested that scientists should find ways to collaborate with businesses to market sustainably-produced food and other products. The group also mentioned the use of visual aids, such as maps, to convey issues about biodiversity and to market scientific research. Mapping projects were also cited as important tools in ecosystem assessments and natural history surveys.

Conclusions

By the workshop’s conclusion, three signal findings had emerged from the discussions.

The first finding was that the weight of evidence from marine, freshwater and terrestrial systems – considered together – shows that biodiversity matters a great deal. Evidence from other systems strengthens the conclusion, based on a smaller set of marine data, that biodiversity is integral to robust ocean ecosystems, and that the loss of biodiversity is a clear threat to marine ecosystem functions and sustainable use. Participants noted that the public probably does not recognize the extent to which biodiversity is essential for sustaining human life on Earth.

The second finding was that using conservation of natural biodiversity as a common, primary management target could substantially improve the way people approach and implement ecosystem-based management. Participants acknowledged that scientists, managers and other stakeholders face some daunting tasks to conserve and restore natural diversity. However, participants were optimistic that these challenges were not insurmountable and offered several solutions. Decision-makers should be urged to recognize that the oceans have multiple uses and associated stakeholders. To ensure the best policies, all user groups should be included when considering ocean management issues. Having a common focus on conservation of biodiversity should help both stakeholders and managers.

The third finding was that although scientists and resource managers do not currently know all they need to know about biodiversity and its relevant measures, there is enough information to allow scientists and managers to move forward with the conservation of biodiversity as a management target. Participants suggested that learning more about systems biology and natural history will enable scientists to better understand the consequences of reduced biodiversity. Combining traditional science with newer technologies will help fill some of the existing information gaps. New findings must be shared with resource managers as they emerge, so that an evolving and adaptive approach to ecosystem-based management can be implemented at early stages.

In addition to the above findings, participants strongly urged the public be educated on biodiversity issues, because an informed and impassioned public can influence and convince policymakers to retain biodiversity in ecosystem management. As the group noted on the workshop’s final day, by managing for biodiversity, people are in effect managing for sustainable ecosystems and ecosystem services. And the end result will be healthy, vibrant and diverse ocean ecosystems for everyone.

Participant List

Steering Committee
Daphne Fautin, University of Kansas
Mike Fogarty, National Oceanic and Atmospheric Administration
Ben Halpern, University of California, Santa Barbara
Lew Incze, University of Southern Maine
Jo-Ann Leong, University of Hawai'i
Stephen Palumbi, Stanford University
Paul Sandifer, National Oceanic and Atmospheric Administration

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Daphne Fautin, University of Kansas
Elliott Norse, Marine Conservation Biology Institute
Jay Stachowicz, University of California, Davis
Diana Wall, Colorado State University

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The **National Oceanic and Atmospheric Administration (NOAA) National Ocean Service** is one of five NOAA Line Offices. The National Ocean Service (NOS) works to observe, understand, and manage our nation's coastal and marine resources. NOS measures and predicts coastal and ocean phenomena, protects large areas of the oceans, works to ensure safe navigation and provides tools and information to protect and restore coastal and marine resources.

NOAA's Office of Ocean Exploration is NOAA's center for new activities to explore and better understand our oceans. This office supports expeditions, exploration projects and a number of related field campaigns for the purpose of discovery and documentation of ocean voyages.

The **U.S. Department of Energy's** overarching mission is to advance the national, economic and energy security of the United States, to promote scientific and technological innovation in support of that mission and to ensure the environmental cleanup of the national nuclear weapons complex. The Department's strategic goals to achieve the mission are designed to deliver results along five strategic themes: energy security; nuclear security; scientific discovery and innovation; environmental responsibility; and management excellence.

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Approaches for Researching the Roles of Marine and Coastal Biodiversity in Maintaining Ecosystem Services

The Latham Hotel
3000 M Street, NW, Washington, DC 20007
September 11-13, 2006

AGENDA

Monday, September 11

Welcome
Dr. Lewis Incze, Bioscience Research Institute, University of Southern Maine
Dr. Jo-Ann Leong, Hawai'i Institute of Marine Biology, University of Hawai'i
Dr. Paul Sandifer, Coastal Ecology, National Oceanic and Atmospheric Administration/National Ocean Service

The Terrestrial Experience
Dr. Diana Wall, Colorado State University

The Freshwater Experience
Dr. David Allan, University of Michigan

The Roles of Biodiversity in Marine Ecosystem Function, Resilience and Adaptability
Dr. John Stachowicz, University of California, Davis

Breakout Session
Central Question 1: *How does biodiversity at genetic, species and community levels contribute to ecosystem function, resilience or adaptability and what are the likely consequences of loss of biodiversity in marine systems?*

Dinner/Reception
Jack Dunnigan, Assistant Administrator, National Oceanic and Atmospheric Administration/ National Ocean Service

Tuesday, September 12

Potential Impacts of Biodiversity Information on Management Practice
Dr. Elliott Norse, Marine Conservation Biology Institute

Breakout Session
Central Question 2: *How might increased knowledge of biodiversity at all levels be used to improve management of marine systems over the next decade? That is, what can we conclude, infer or reasonably anticipate about the functional roles and values of biodiversity, and what do we know, what do we not know and what do we need to know in order to inform robust ecosystem-based management approaches to marine resources?*

Plenary Speaker: Essential Measures of Biodiversity for Ocean Observing
Dr. Michael Beck, The Nature Conservancy, Marine Initiative

Breakout Session
Central Question 3: *What pragmatic but revealing metrics of biodiversity and/or ecosystem function should be considered for inclusion in ocean observing and assessment systems to provide continuing information flow for enhanced ecosystem-based management approaches (e.g., keystone species, proxies, indices, genetic barcode analysis)?*

Wednesday, September 13

Plenary Summary of Central Questions 2 & 3

Plenary Speaker: State of Biodiversity Research Agenda
Dr. Stephen Palumbi, Stanford University

Moderated Discussion:
Recommendations for 2006-2010 Biodiversity Research Agenda
Dr. Daphne Fautin, University of Kansas

Plenary Summary
Dr. Paul Sandifer, Coastal Ecology, NOAA/NOS