Census of Marine Life

The Census of Marine Life (CoML) is a global research initiative to assess and explain the diversity, distribution and abundance of life in the oceans in the past, present, and future. Identifying important species in marine ecosystems over spatial and temporal scales will greatly improve human understanding of the biology of the oceans. However, CoML is more than an inventory of organisms; integral to its mission is improving the understanding of the role of biodiversity in marine ecosystem function. This initiative is helping to define and explain large-scale patterns of the distribution of marine species and their influence on the ocean environment by supporting and promoting studies and new technologies that advance knowledge and capabilities to:

> Detect and monitor ecological changes related to species abundance and distribution
> Explore new habitats and discover new marine plants, animals, and microorganisms
> Understand the components of marine ecosystems and their interrelationships
> Identify determinants of species abundance, distribution, and diversity
> Assess and predict human impacts on marine life
> Support and enhance the development of taxonomic expertise


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The Congressionally mandated US Commission on Ocean Policy recently concluded that:

“An effective national ocean policy should be based on unbiased, credible, and up-to-date scientific information. Yet, the ocean remains one of the least explored and most poorly understood environments on the planet . . .”

“Improved research and data collection activities are needed to better understand coral reef ecosystems and the impact of human activities on these ecosystems.”

United States Census of Marine Life Program

The United States National Committee (USNC) of CoML was established in 2002 to expand US participation in the global initiative and to guide the development of a national program for CoML, taking into account national priorities. The mission of the US CoML is to assess and explain the changing diversity, distribution, and abundance of marine species, as well as the functional role of marine biodiversity, in the US and its territories and commonwealths, in the past, present, and future to serve as an unbiased source of sound scientific information to support the needs of the nation. At this time, the USNC has identified the following primary goals for the US CoML:

I. Research and Assessment
   Goal: Establish effective research programs, technologies, and collaborations that provide genetic, species, and community-level information to support ecosystem-based management.

II. Predictive Capacity for Projecting Ecosystem Change
   Goal: Improve capacity for ecosystem-based management and predicting ecosystem change through retrospective analyses, the development of improved tools, and the establishment of a data management system of marine biodiversity information.

III. Education and Outreach
   Goal: Establish within the US, effective long-term mechanisms for the dissemination of information about marine biodiversity and public engagement in ocean issues.
Coral Reefs represent one of the most species-diverse ecosystems on Earth. However, many reef organisms remain unknown. Simultaneously natural and human induced stresses have caused marked decline to some reef systems with a presumed loss of some yet-to-be discovered species.

With this understanding, the United States National Committee (USNC) of the Census of Marine Life (CoML) convened a workshop of US coral reef experts in Kane‘ohe Bay, Oahu, Hawai‘i, August 16-18, 2004, in order to identify priority research activities that could complement existing US and global coral reef initiatives and serve as a basis for future CoML activities. Participants included representatives from academia, US federal agencies, non-governmental organizations (NGOs), and the CoML Secretariat.

Participants identified the following potential goals for CoML coral reef activities:

> Establish species inventory of coral reef communities for groups other than corals, fishes, and mollusks
> Assess socio-economic values for coral reef ecosystems
> Characterize coral reef ecosystems and improve monitoring protocols
> Synthesize existing data and develop tools for predictive modeling of distribution and abundance
> Provide broad-scale comparative analysis across studies
> Identify ecosystem interactions that should be examined more closely and formulate hypotheses that have potential management applications

Participants identified the following major components of future CoML project proposals:

> Taxa or functional groups to be inventoried
> Ecological factors to be assessed
> Sites
> Data management
> Education and outreach

Participants discussed the types of information useful to various stakeholders and how those data could better reveal the diversity, abundance, distribution, and functional role of diversity within coral reef ecosystems. Data considered important to future research activities included:

> Presence/absence (both locally and globally)
> Abundance
> Distribution and demography
> Foodweb structure
> Dispersal and human resource use

Participants were of the view that US CoML activities should be consistent with the overall vision of the CoML, as well as with the mission and goals of the US CoML. Approaches to accomplishing both could include the incorporation of US sites into a global CoML project, or the independent development of US research that could be applied globally, such as regional studies that support ecosystem-based management. Specifically, participants discussed the importance of establishing baseline assessments of coral reef species diversity, abundance, and distribution at key locations within the US, as well as exploring the relative importance of diversity to reef system function.

The outcomes from this workshop were provided to the Chair of the Coral Reef Project Planning Committee under the CoML to contribute to the development of a CoML project proposal on coral reef biodiversity. It was the hope of participants that the outcomes could additionally contribute to future activities of the US coral reef community.
Coral reefs represent one of the most species-diverse ecosystems on Earth. However, knowledge regarding the identification, abundance, and distribution of its species is extremely limited, as is knowledge regarding species’ functional importance to the ecosystem. A workshop organized by the United States National Committee (USNC) of the Census of Marine Life (CoML) to solicit community input identified the need for a focused research program on the biodiversity of coral reef ecosystems, noting that many reef organisms are unknown and that natural and man-made stresses have caused a marked decline to some reef systems with a presumed loss of some yet-to-be discovered species.

Shallow-water coral reefs occupy an estimated 7,607 sq. mi. within the United States and its territories. These ecosystems occur along the continental shelf of the northern Gulf of Mexico and the Western Atlantic, and around Caribbean and Pacific islands. The US Coral Reef Task Force, comprising 11 federal agencies and state and territory representatives, concluded in 2002 that little is known about coral reef function, structure, and condition. The strategy the task force outlined to fill gaps in knowledge relies heavily on coordinating research among agencies, academia, industry, and NGOs. One of the three primary objectives of this nationally coordinated research program is to “conduct a long-term regional and ecosystem-based research program to improve our understanding of processes that govern the structure, function and health of coral reef ecosystems.”

The USNC recognized in 2002 that regional studies are essential for assessing the status of marine ecosystems and the effects of human activities, and for developing an ecosystem-based management approach. It identified regional studies as an integral component of the nascent US CoML program. As presented to workshop participants in the pre-meeting document in Annex 1, one region of particular significance to the US is the Northwestern Hawaiian Islands (NWHI), which, by some estimates, contains two-thirds of coral reef area under US jurisdiction. Coral reef habitats in the NWHI have been minimally affected by humans, thus representing what may be the only intact large coral reef ecosystem in the world. The NWHI therefore offers a unique opportunity to examine the structure and function of an undisturbed coral reef ecosystem that can provide a sound scientific basis for long-term ecosystem-based management decisions.

In consideration of these factors, the USNC convened a workshop of US coral reef experts in Kane‘ohe Bay, Oahu, Hawai‘i, August 16-18, 2004, to develop objectives and research priorities for US CoML activities on coral reef ecosystems. Participants included representatives from academia, US federal agencies, NGOs, and the CoML Secretariat. Workshop participants are listed in Annex 2 to this report. Participants were asked to create a framework of needed research priorities that complement activities of other US initiatives on coral reef ecosystems, and that could contribute to a broader global CoML coral reef initiative.
Organization of the Workshop

**DAY 1:**

- Presentations by workshop organizers, the USNC, the CoML coral reef project planning committee, and the Hawai‘i Institute of Marine Biology (HIMB), regarding the US CoML program and the context for US CoML coral reef activities
- Presentation by the CoML coral reef project planning committee regarding the international context for a CoML coral reef initiative
- Presentations by invited US government participants regarding their interests in the workshop and in the development of US CoML activities
- Presentation by Congressional staff regarding the importance of project outcomes to the US
- Plenary discussion regarding research outcomes, data types and their utility to various users

**DAY 2:**

- Plenary discussion regarding research project components—taxonomic groups, sites, techniques, and education/outreach
- Breakout groups for detailed discussions of research project components

**DAY 3:**

- Presentation of breakout group summaries
- Plenary discussion regarding steps in developing a proposal for a global CoML project
Outcomes of the Workshop

Participants discussed in detail how a CoML project on coral reefs could complement existing US activities and global initiatives, attempting to identify (a) gaps in key information needed by stakeholders, and (b) opportunities to improve synergies among existing initiatives. Participants concluded that data from new activities would begin to become available within five years. The group identified the following research goals:

> Establish species inventory of coral reef communities for groups other than corals, fishes, and mollusks
  ○ Data should include abundance, distribution, and functional interactions
  ○ Mining existing data would help to identify taxonomic gaps in knowledge
> Assess socio-economic values for coral reef ecosystems
> Characterize coral reef ecosystems and improve monitoring protocols
> Synthesize existing data and develop tools for predictive modeling of distribution and abundance
> Provide broad-scale comparative analysis across studies. In particular, compare rapid assessments versus in-depth surveys of coral reef biodiversity
> Identify ecosystem interactions that should be examined more closely and formulate hypotheses that have potential management applications

Participants discussed the current state of knowledge of coral reef ecosystems—what is known, unknown, and unknowable. The group framed a series of questions that CoML activities concerning coral reef ecosystems could address:

> What relevance does biodiversity (including diseases) have to coral reef ecosystem functioning and the system’s ability to provide services to humans, especially in context of human disturbance?
Outcomes of the Workshop

> How can coral reef systems be managed to sustain resilience/resistance?
> What are the common metrics that could be used for assessing the state of coral reef ecosystems (e.g., species numbers, functional groups)?
> What is the biogeographic structure of biodiversity of coral reef ecosystems, including patterns of co-distribution, abundance, and species ranges?
> What are the functional groups (i.e., roles) in coral reef ecosystems and the level and importance of ecological redundancy?
> What are the limits to taxonomic knowledge of coral reef systems?
> At what level of ecological knowledge can predictions be made about coral reef systems?
> How can resource managers plan for future human use of coral reefs based on present data? That is, how can a comprehensive global plan for human-reef interactions be achieved in the face of perturbations such as overfishing and climate change?
> What is the relationship between coral reef systems and biogeochemical cycles, especially that of carbon, taking into consideration land-sea coupling?
> Are coral reefs locally adapted?
> What are the source-sink dynamics for coral reef species?
> What spatial and temporal scales are important for coral reef ecosystem monitoring and assessment?
> What are the thresholds for sustaining coral reef species and for system change, so that use can be sustained and risks can be assessed?
> What level of species extinction and biodiversity loss from human impact is occurring without human knowledge?
> What capacity for predicting change in coral reef ecosystems at global and local scales currently exists?

Several participants made presentations of information on reefs, with a view to identifying potential CoML research priorities and techniques useful to potential CoML activities. These discussions included information on taxonomic authority databases, geographic areas of particular interest to participants (NWHI, Pacific Islands), issues of particular interest to workshop participants (e.g., coral disease assessment and microbial diversity), and sampling techniques. In addition, participants discussed education and outreach, reaffirming the importance of this as a component of any CoML project.

The major components of project proposals were considered to be:
> Taxa or functional groups to be inventoried
> Ecological factors to be assessed
> Sites
> Data management
> Education and outreach

Participants discussed the types of information useful to different stakeholders and how those data could better reveal the diversity, abundance, distribution, and functional relationships within coral reef ecosystems. Data to be considered included:
> Presence/absence (both locally and globally)
> Abundance
> Distribution and demography
> Foodweb structure
> Dispersal
> Human resource use

Participants allocated the work of developing each of five major components for future coral reef projects to breakout groups. In addition, a breakout group was formed to focus on identifying research opportunities and priorities for implementation of CoML activities within the US. Summaries of these breakout group sessions appear below, as does the draft timeline for the development of a CoML project proposal to the Alfred P. Sloan Foundation.
Breakout Group Report

Aims for inventories:

> Record diversity before it is lost
> Establish baselines for future comparison
> Ask functional questions about biodiversity

Where (e.g., how to select the sites):

> Both major (intensive) and minor (comparative) sites
> All-inclusive surveys and reef-associated habitats

Which groups:

> Focus on groups in which a large fraction of the diversity is expected (e.g. macroalgae, macroinvertebrates)
> Focus on groups for which more knowledge is most desired
> Focus on a subset of taxa and include for which intensive analysis is done to test for the existence of cryptic biodiversity

Methods:

> Use a variety of field techniques
> The first site becomes a test site for the methods; the methodological/protocol guide for biodiversity sampling elsewhere is based on experience at this site
> Employ molecular techniques to the maximum extent practicable for documenting biodiversity, including creating a baseline inventory of gene sequences for coral reef species
> Sampling must include vouchered species that will be photographed and on which genetic research will be done (“building the Rosetta Stone”)
> On-site processing will be done in addition to processing at the ultimate archival repositories. Long-term commitments must be obtained from these repositories. Training opportunities exist at both: in the field, training can be done on sorting and treatment of samples; at the latter, curatorial and taxonomic training can be conducted.

Products:

> Vouchered specimens, including barcodes and images
> Interactive keys and species pages for as many taxa as possible
> Electronic resources, including existing and new databases and interactive connections among them
> Trained students and parataxonomists
Breakout Group Report

Participants recognized that CoML projects could serve to establish baseline assessments of the species diversity, distribution, and abundance of specific coral reef systems. In addition, there was agreement that there exists a need for greater clarity of the functional role that species diversity serves to coral reef ecosystem function.

A conceptual framework is necessary for studies to integrate information and test empirical and theoretical relationships among coral reef species across various gradients (e.g., disturbance, human impact, latitude/longitude). The type of data to be collected, for each site and across sites, would be driven by the conceptual framework. The group proposed synthesizing existing information to assist in revealing the metrics to develop a conceptual model. The role of functional groups in the ecosystem and the resilience of the system could then be tested. There is great within-taxon functional diversity and thus considerable care will be required when building the framework and developing parameters for any modeling that will derive from it (although it is also true that relatively few coral species dominate most reefs and functional groups). Participants recognized that it would be important to involve modelers in this process.

DNA technology is one approach to a community census, particularly one that includes microbes. It was identified as a potentially powerful approach to automating and expanding the collection of taxonomic data, enumerating community composition, and providing useful information on the comparative diversity of marine habitats. Associating a DNA sequence with a voucher specimen provides a link between molecular data and taxonomy. After a sequence has been associated with an identified specimen, additional specimens can be identified through DNA sequences, greatly accelerating the accumulation of data useful to a census, particularly for species that are difficult to identify morphologically. DNA sequences not in the database can also be a signal that a new species has appeared in the survey, leading to further taxonomic research.

In addition to sequences from individual specimens, DNA data can be derived from PCR-amplified mixtures from many species. Such samples from a single place can provide a rapid accumulation of data on the presence of a particular species in the community, and such samples from various places and times can provide important distributional information. Quantitative PCR allows the rapid measurement of relative proportions of major taxonomic groups in community samples without extensive sequencing. DNA chips might be created to assay the relative abundance of thousands of species simultaneously from community-genetic samples. Samples for Rapid Automated Species Enumeration (RASE) of microbial taxa should be collected across spatial and environmental gradients, including water, sediment, and surfaces of corals and other substrates.

For intensively surveyed sites, Artificial Reef Matrix (ARM) substrates, including Settlement Scrubbies, should be deployed on reefs and sampled after one year. These represent replicated collections that will allow broad geographic comparisons if repeated at all international census sites. Diversity can be enumerated by morphospecies, genospecies, and community-genetic approaches to reveal how much of the existing diversity the various approaches can capture. For comparison, diversity in reef environments next to each ARM should be measured by morphospecies and RASE approaches. Also, near-reef water samples should be analyzed to discover whether overlying water contains DNA from a significant number of resident benthic taxa.
**Breakout Group Report**

At least four to five sites would be necessary to cover a range of characteristics (not all would be present at all sites). The following were considered important criteria for site selection:

1. Latitudinal gradients/biological regions
2. Potential biological diversity (all sites need not be equally rich)
3. Previous information base available
4. Variety of physical environments
5. Variety of habitats (high/low islands reefs)
6. Access/cost
7. Infrastructure and support available
8. Integration with existing programs (foundation for growth)
9. US or US territory (US project component only)
10. Range of human impacts or natural disturbances
11. Suite of funding opportunities

These criteria led to identifying as potential sites:

- **Palau:**
  - *Pro:* member of US Coral Reef Task Force, two coral reef centers, historical knowledge baseline, highest species and habitat diversity and most typical system of considered sites, accessible, protected status
  - *Con:* non-US, potential problems with sample export

- **American Samoa:**
  - *Pro:* diverse coral reef environment, historical knowledge baseline, substantial human impacts *(also could be a Con)*
  - *Con:* local and cultural sensitivities, potentially restrictive regulations

- **Kane’ohe Bay, Oahu:**
  - *Pro:* highly cost-effective, accessible year round, variety of habitats, comparison to American Samoa and Palau, laboratory facilities, comparison to remote NWHI
  - *Con:* very well studied *(also could be a Pro)*

- **Pearl and Hermes Atoll:**
  - *Pro:* highest predator abundance and endemism, most pristine of NWHI, highly representative of reefs in area, NOAA logistical support, history of disturbances, baseline for physical oceanography, largest protected area in world, extreme temperature gradients *(also could be a Con)*
  - *Con:* logistically challenging, limited biodiversity

- **Guam:**
  - *Pro:* infrastructure and lab facilities, high biodiversity, high habitat variety, best information baseline for general invertebrates in the world.
  - *Con:* highly disturbed physical environment, local participation uncertain.

**Additional sites of interest identified:**

- Moorea
- Palmyra
- French Frigate Shoals (NWHI)
- Johnston Atoll
- Dry Tortugas
- Puerto Rico
- British Virgin Islands
- Belize
Breakout Group Report/Data Management

Assumptions:
> Data will be served through OBIS (the Ocean Biogeographic Information System)
> Organization will be as a distributed data system, with many partners
> Existing standards for data will be used wherever possible
> Sequence data will be deposited in GenBank

Data Recommendations:
> Taxonomic:
  ○ Minimally genus, species, author, date
  ○ Determiner/identifier of specimen or observation (e.g., name of person who applied the name, and date it was applied)
  ○ Source of name (reference or other means used to determine the name)
> Latitude, longitude, depth, time
> Dual access to data (i.e., open access to non-sensitive data; sensitive data either controlled in access or openly accessible with reduced taxonomic and/or locality precision)

Data Tools:
> Geospatial (mapping)
  ○ At multiple scales (power of 10 zoom)
  ○ Web crawling
  ○ Lexicon (thesaurus/semantic tools)—standardized grammar
  ○ Desktop tools for data capture—user-friendly interface with data
> Robust feedback system on databases to allow corrections and data enhancements from users

Issues for consideration:
> Context and associations
  ○ Microenvironmental variables
  ○ Station associations (links between sites)
  ○ Bio-community associations (interactions between organisms)
> Quantitative data
  ○ Abundance and biomass
  ○ Demographics
> Project-specific information of limited value to other projects

Breakout Group Report/Education and Outreach

Participants reaffirmed that an overriding objective is responsible stewardship of coral reef systems. Participants identified several key considerations for any potential project proposal.

Message for education and outreach
> What is biodiversity and why is it important?
  Abundance, distribution (genetic, species, community, and ecosystem levels)
  Functional role

K-12 Education
> Curriculum development
> Traveling exhibit (social component and outreach to general public)

College and Graduate Education
> Build marine modules for a web portal

Managers and Scientists
> Taxonomy workshops/training

General Public
> “Citizen science” (e.g., LA County Museum spider survey)
> Aquarium exhibits
Breakout Group Report

Any US CoML activities should be consistent with the overall vision of the CoML, as well as with the mission and goals of the US CoML. Approaches to accomplishing both could include the incorporation of US sites into a global CoML project as a US component, or the independent development of US research that could be applied globally such as regional studies that support ecosystem-based management. Specifically, participants discussed the importance of establishing baseline assessments of coral reef species diversity, abundance, and distribution at key locations in the US, as well as exploring the relative importance of marine diversity to ecosystem function (particularly in the presence of human-induced change).

Participants identified ecosystem modeling and improved predictive capacity as an important overarching goal for project development. A project should be organized to explore coral reef diversity through an analysis of functional relationships among reef systems across gradients of disturbance (human and natural, including ocean-land interactions), latitude, substrate (e.g., age, and coral versus basalt), and protection status.

A project could include one site in the Pacific and one in the Caribbean, study a broad biogeographical area, and have smaller intensive study sites nested within the broader area. Potential study sites, with a view to applying the selection criteria developed during the workshop, were identified in priority order (given that the Flower Gardens in the Gulf of Mexico is already being studied by a US CoML-affiliated project):

- Hawai’ian Islands (Northwestern and main)
- Marianas Archipelago
- Florida Keys to Puerto Rico gradient, including Navassa
- Samoan Archipelago

In the face of limited resources, the Hawai’ian Islands would offer gradients that could be explored, including endemism, human impact, and latitude. The following sites were identified as priorities for intensive study:

1. One site on main islands (possibly on Oahu)
2. Pearl and Hermes Atoll
3. Midway (former impact)
4. French Frigate Shoals (middle of archipelago—much already known)

Outcomes of this workshop should include a CoML project proposal on coral reef biodiversity, which identifies as one component priority US sites for initial implementation of the workshop research priorities.
## Draft Development Time Framework

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<tr>
<th>Date (2004)</th>
<th>Activity</th>
<th>Comments</th>
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| 16-18 Aug  | CoML US Coral Reef Workshop | > Organizer: CoML USNC  
> Contacts: Daphne Fautin & Nancy Knowlton  
> Host: Hawai’i Institute Marine Biology |
| 18 Aug     | Draft 1 of the CoML Coral Reefs Proposal | > This will include the person who will draft the proposal  
> This group will be responsible for putting the proposal into a form ready to circulate for comment |
| 1 Sept     | Circulate for comment Draft 2 of the CoML Coral Reefs Proposal (US perspective) | > Identify those who will be asked to comment, aside from workshop participants |
| 15 Sept    | Identify the six international developers for the CoML Coral Reefs Project (building on suggestions in Draft 2) | > Identify the group leader/coordinator  
> Agree on work program including the date of the Washington, DC meeting |
| End Oct    | DC drafting meeting |  |
|            | Draft 3 of the CoML Coral Reefs Proposal (international perspective) | > Circulate draft 3 for comment to coral reefs community (those involved in the development of the proposal), others (selected by working group), relevant members (of the CoML scientific steering committee) and relevant (national and regional implementation committees)  
> Finalize proposed principle investigators (2-3)  
> Finalize international steering committee (8-10) |
| Mid Nov    | Comments on Draft 3 |  |
| End Nov    | Draft 4 to CoML scientific steering committee | > Includes principle investigators and international steering committee |
| Mid Dec    | Comments from CoML scientific steering committee |  |
| 15 Jan     | Proposal to Sloan Foundation | > Endorsed by the CoML scientific steering committee and relevant national and regional implementation committees of CoML |

**Legend**

AIMS – Australian Institute of Marine Science  
JCU – James Cook University  
MTQ – Museum of Tropical Queensland  
UQ – University of Queensland  
GBRMPA – Great Barrier Reef Marine Park Authority
US Census of Marine Life Coral Reef Field Project
Coral Reef Ecosystem Functions and Processes (meeting document)

Kristan Blackhart

Introduction
The impacts of human activities are causing rapid declines in biodiversity in both terrestrial and marine habitats. This loss of biodiversity is especially disconcerting in the marine environment, where scientists have sampled less than 0.1 percent of the volume of the oceans and many species remain unknown (CoML Research Plan, 2003). In order to effectively manage and conserve the marine environment, an understanding of what lives there and how it is affected by human activities must be reached. The CoML was created as a global research program to begin to assess and explain the diversity, distribution, and abundance of marine life throughout the world’s oceans. The US CoML program is made up of elements tied to the main CoML themes; a key element will be the US CoML Coral Reef Field Project that will explore zooxanthellate coral reef ecosystems.

Coral reefs represent some of the most biologically diverse and valuable ecosystems on earth. While their area is less than 1 percent of Earth’s surface, they are home to about 25 percent of all marine species (Buddemeier et al., 2004; NOAA, 2002). Annually, coral reef ecosystems provide $375 billion in direct and indirect economic value to humans, and approximately 500 million people rely on reefs for their livelihoods (Wilkinson, 2002). Although coral reef ecosystems are important to humans economically, culturally, and socially, they are under a large amount of stress from a number of anthropogenic factors, including overfishing, land-use and runoff, and global climate change. The nature and extent of these threats place coral reefs among the most threatened marine habitats on the planet. This is evidenced by the fact that 27 percent of the world’s coral reefs have already been destroyed or severely degraded, and 58 percent of remaining reefs face medium or high risk of degradation from human activities (Wilkinson, 2002; Bryant et al., 1998).

A wide range of coral reef habitats are represented in US waters. All US reef systems have been affected to some degree by human and natural stresses, but all areas still have some healthy reefs. The level of degradation and threats differ by region. In many areas of the US, quantitative measures of most indicators of reef health are lacking, making comparisons of temporal trends impossible. However, even with a general lack of quantitative measurements, some conclusions can be drawn. Florida and the US Caribbean are considered to be in the worst condition, while reefs in the Pacific Islands are the most poorly known (NOAA, 2002). One area of particular significance is the Northwestern Hawai’ian Islands (NWHI), which constitutes 69 percent of coral reef area under US jurisdiction (Maragos and Gulk, 2002). Coral reef habitats in the NWHI have been minimally impacted by humans, and represent the only intact large coral reef ecosystem in the world. The NWHI are important because they offer the chance to examine the structure and functions of a “natural” coral reef ecosystem. Although still relatively pristine, the coral reefs of the NWHI are currently threatened by a number of human factors. Thus they give scientists and managers a special opportunity to investigate how coral reefs can be most effectively preserved, and what could occur if effective marine protected areas (MPAs) were implemented in the main Hawai’ian Islands and elsewhere in the nation and the world.

To better understand the complexity and diversity of coral reef ecosystems, it is proposed that the US CoML Coral Reef Field Project focus on four main themes: Systematics; Biogeography; Database Management and Accessibility; and Ecosystem Function and Processes. Within the broad theme of Ecosystem Function and Processes, several sub-themes are suggested:

- Compare impacted and pristine reef habitats by investigating food webs, ecosystem functions, and vulnerability to stress
- Explore the role of microbes in reef health
- Examine the impacts of global climate change on coral reefs
Background: *What is known about coral reef ecosystems?*

**Impacted vs. Pristine Environments**

Although coral reefs are “disturbance adapted” ecosystems, the rate and nature of recent environmental changes are frequently exceeding the adaptive capacity of coral reef organisms and communities. In general, corals are able either to recover from acute stress or withstand chronic stress; however, multiple stresses may interact synergistically and cause magnified and unpredictable results. Because of this variable interaction, chronic human stresses may make corals more susceptible to acute natural stresses such as tropical storms. This can cause coral reefs to collapse quickly and unexpectedly. Of particular concern are the effects of overfishing and runoff, which have drastically altered the food web of some coral reef ecosystems. Both of these factors favor the overgrowth of algae through herbivore removal and eutrophication. Coral-based communities may be replaced with an algae-dominated system. Because mature algae are less palatable to herbivores than immature ones, and can prevent coral larval settlement, this change is difficult to reverse.

**Role of Microbes in Reef Health**

Bacteria, Archaea, and unicellular Eukaryotes are vital components of all marine ecosystems. However, it is not well understood what importance microbes have in coral reef ecosystems. Although we know little about the role of microbes in maintaining reef health, coral diseases are being reported increasingly often and represent a chronic and frequently catastrophic problem facing coral reefs. Microbes associated with corals are energy-limited, and the addition of fixed carbon from direct inputs or increased dissolved organic carbon can allow bacteria to overgrow and kill corals. Additionally, natural and anthropogenic stresses may weaken corals, leaving them more susceptible to disease.

**Impacts of Climate Change**

Climate change poses several threats to coral reefs: increased water temperature can be responsible for coral bleaching; increased concentrations of CO2 and associated changes in water chemistry may cause reduced calcification and growth rates of corals; rise in sea level may cause increased sedimentation due to shoreline erosion or eliminate some of the deeper reefs due to lack of sunlight; and increased frequency and intensity of tropical storms will cause more regular and severe damage to reef structure. Although all corals are likely to be affected by global climate change to some degree, these threats are expected to vary between reef types and regions. The effects of global warming have already destroyed or severely degraded 16 percent of the world’s coral reefs and are expected to become more serious in the future (Wilkinson, 2002). Recent estimates suggest that an increase in mean sea surface temperature of only 2°F (1°C) could cause the global destruction of coral reef ecosystems (Hoegh-Guldberg, 1999). It is also likely that the effects of climate change will combine with local and regional stresses to cause further degradation to coral reefs.

**Critical Information Needs: What Is Still Not Known about Coral Reef Ecosystems?**

Although a large amount of data has been collected and progress has been made in advancing our knowledge of ecosystem functions and processes on coral reefs, much work remains to be done before we understand these complex systems well enough to effectively manage and conserve them. Priorities must be set in order to maximize limited funding and increase cooperation among agencies. The following questions identify the priority information needs that are necessary to better understand and successfully manage these important and fragile ecosystems:

- **Impacted vs. Pristine Environments**
  - How do healthy and degraded reefs differ in ecosystem structure and function?
  - What are the adaptation and recovery mechanisms of coral reefs?
  - How do different stresses to coral systems interact synergistically?
  - How effective are MPAs at conserving coral reefs, and what is the best reserve design to reduce the adverse impacts of human activities and protect coral health?

- **Role of Microbes in Reef Health**
  - What influence do microbes have on the health of coral reefs?
> What are the distributions and causes of diseases of corals reef species?

> What role do anthropogenic factors play in determining susceptibility to disease, and how can reefs be best protected from disease?

Impacts of Climate Change

> How quickly will recovery occur after major bleaching episodes like the 1997-1998 bleaching?

> What if similar bleaching events continue to occur?

> What will the possible effects of further climate change be, when considered in combination with other natural and anthropogenic stresses?

> Can the establishment of MPAs enable coral reefs to better adapt to the effects of global climate change?

Potential Actions: Priorities of the US CoML Coral Reef Field Project

The overall goal of the US CoML Coral Reef Field Project should be to identify projects that will distinguish CoML, and complement, rather than duplicate, the many other research efforts on coral reefs. CoML should focus its research efforts in the areas of the US where coral reefs are most poorly understood, such as the Pacific Islands. An expected outcome of this workshop is the development of a strategic plan for the US CoML Coral Reef Field Project that includes benchmarks and expected products. Some initial steps that should be taken toward formulating a strategic plan are to decide to what extent field research is essential and how much can be learned from assembling existing data; identify the different types of coral reefs and select the prototype reefs for assessment; and decide how many and which sites are to be studied. Potential funding sources and agencies that should be approached for new funding must also be identified.

Impacted vs. Pristine Environments

To describe the relationships between reef organisms that constitute a healthy, self-sustaining coral reef ecosystem, CoML should examine the ecosystem properties of reefs and health of corals inside and outside MPAs and across gradients of human disturbance. CoML should also look for species groups that can serve as indicators of environmental stressors or trophic interactions for an ecosystem-based approach to conservation. Additionally, the Coral Reef field project should compile and interpret historical information and incorporate traditional knowledge and use this information to support assessments of causality for observed changes, extrapolation of future impacts, and evaluations of approaches for reducing or reversing impacts.

Role of Microbes in Reef Health

The Coral Reef field project should work with the microbial initiative of CoML to have a coral reef component. This component should measure basic microbial parameters such as growth rates, numbers, type, and carbon loads. The ecology of coral diseases should also be investigated.

Impacts of Climate Change

To examine the impacts of climate change, CoML should search for methods to better predict the effects of global warming and coral bleaching on coral reef biological communities.

Database Management and Accessibility

Key to all these efforts is interactivity among data of various sorts. They must include mobilization, including, as necessary, digitization of past records for the sites selected for study. With the environment changing rapidly, the baseline is continually shifting, so the historical record, however imperfect, is essential to providing a context for field studies. Parallel and cross-cutting efforts must be integrated: now, as never before, electronic tools potentially allow interactivity among data sorts that can highlight patterns. Finally, data gathered as part of the CoML effort must be made publicly and immediately available in a format that makes them accessible to scientists, managers, users of reefs, general public, and educators. Time and effort necessary to planning this component of the project is essential if the goals of CoML are to be met.
Literature Cited


Participant List

Chairs

Fautin, Daphne G. – University of Kansas (CoML USNC)
Knowlton, Nancy – Scripps Institution of Oceanography (CoML USNC)
Leong, Jo-Ann – Hawai‘i Institute of Marine Biology

Academia

Birkeland, Charles E. – University of Hawai‘i
Brumbaugh, Daniel R. – American Museum of Natural History
Buddemeier, Robert W. – Kansas Geological Survey
Coffroth, Mary Alice – SUNY Buffalo
Coles, Stephen L. – Bishop Museum
Colin, Patrick – Coral Reef Research Institute, Palau
Dodge, Richard E. – Nova Southeastern University
Eldredge, L. D. – Bishop Museum/Pacific Science Association
Fredericq, Suzanne L. – University of Louisiana
Gates, Ruth – Hawai‘i Institute of Marine Biology
Harvell, C. Drew – Cornell University
Hunter, Cindy – University of Hawai‘i
Jokiel, Paul L. – University of Hawai‘i
Karlson, Ronald K. – University of Delaware
Kinzie, Robert A. III – University of Hawai‘i
Kleypas, Joan – National Center for Atmospheric Research (NCAR)
Martin, Joel W. – Natural History Museum of Los Angeles County
Medina, Monica J. – Joint Genomics Institute (Walnut Creek)
Ogden, John C. – Florida Institute of Oceanography,
University of South Florida
Palumbi, Steve – Stanford University
Paul, Valerie – Smithsonian Institution Harbor Branch Laboratory
Paulay, Gustav – University of Florida/Florida History Museum
Pyle, Rich – Bishop Museum
Reaka-Kudla, Marjorie – University of Maryland
Richmond, Robert – University of Hawai‘i
Rohwer, Forrest – San Diego State University
Weil, Ernesto – University of Puerto Rico
Wulff, Janie – Florida State University

US Government Agencies

Lydeard, Charles – National Science Foundation
Brainard, Rusty – NOAA Fisheries – Pacific Region
Brown, Stephen – NOAA Fisheries – Office of Science and Technology
Fornwall, Mark – PBI/US Geological Survey
Kosaki, Randy – NOAA Ocean Service
Rodgers, Caroline – US Geological Survey
Woodley, Cheryl – NOAA Ocean Service

Non-governmental Organizations

Lindeman, Ken – Environmental Defense
Renaud, Phil – Khaled bin Sultan Living Oceans Foundation

Census of Marine Life

Poiner, Ian – CoML International Scientific Steering Committee
Caley, Julian – Guest, CoML Scientific Steering Committee
Yarincik, Kristen – CoML US Program Office/International Secretariat
Workshop Organizers

United States National Committee for the Census of Marine Life
Daphne G. Fautin, Chair, US National Committee
Nancy Knowlton, Chair, Coral Reef Field Project Planning Committee

Hawai‘i Institute of Marine Biology
Jo-Ann Leong, Director, Hawai‘i Institute of Marine Biology

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Khaled bin Sultan Living Oceans Foundation is dedicated to conservation and restoration of living oceans and pledges to champion their preservation through research, education, and a commitment to Science Without Borders.®

National Biological Information Infrastructure (NBII) of the United States Geological Survey is a broad, collaborative initiative of government agencies, academic institutions, non-government organizations, and private industry to provide increased access to data and information on the nation’s biological resources by linking diverse, high-quality biological databases, information products, and analytical tools.

The Coral Reef Conservation Program (CRCP) of the National Oceanographic and Atmospheric Administration is a multi-disciplinary program supporting effective management methods and sound science to preserve, sustain and restore valuable coral reef ecosystems.

Hawai‘i Institute of Marine Biology (HIMB) is a world-renowned research institute situated on Coconut Island in Kane‘ohe Bay that provides research facilities for its faculty and students. HIMB served as host for the workshop.

Bishop Museum is a public institution whose mission is to record, preserve, and tell the stories of Hawai‘i and the Pacific through the use of collections, research, information, educational programs, and publications in collaboration with expertise available in the community.