center for microbial oceanography: research and education
C·MORE linking genomes to biomes

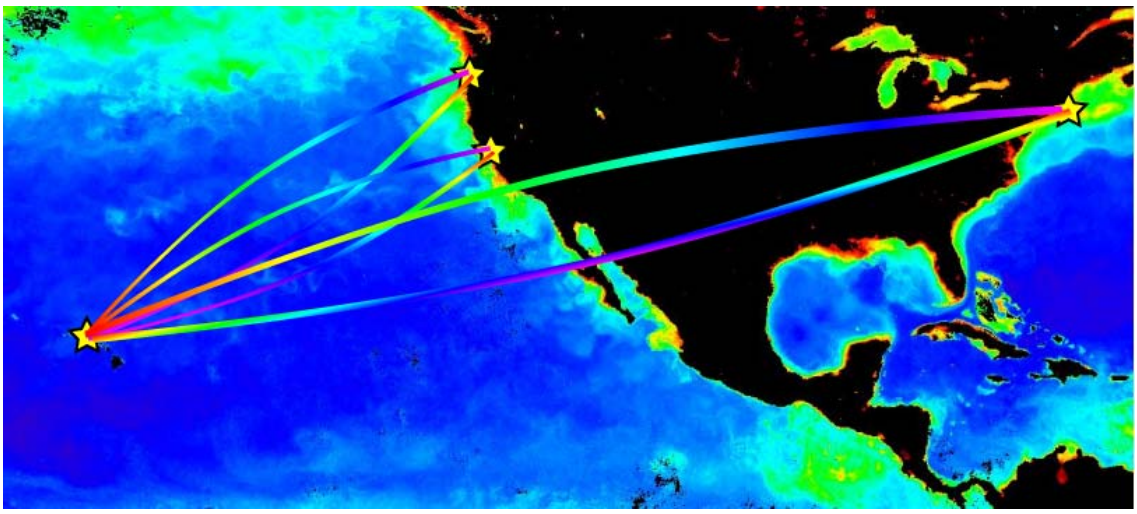
Strategic and Implementation Plan

Center for Microbial Oceanography: Research and Education (C-MORE)

2008–2009

Lead Institution University of Hawaii

Partner Institutions
Monterey Bay Aquarium Research Institute
Massachusetts Institute of Technology
Oregon State University
University of California – Santa Cruz
Woods Hole Oceanographic Institution



UC Santa Cruz · Massachusetts Institute of Technology · Woods Hole Oceanographic Institution 1930 · OSU Oregon State University · MBARI · University of Hawai'i Mānoa

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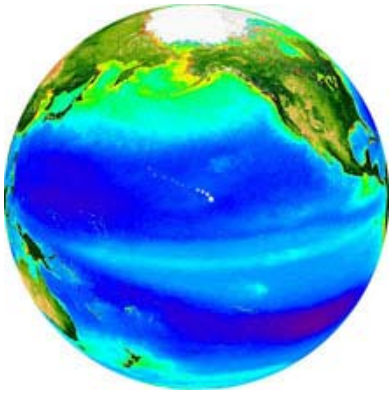
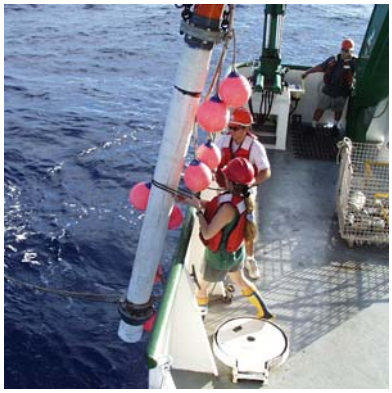



1. Executive Summary

Life on Earth most likely originated as microbes in the sea. Over the past 3.5–4 billion years, microorganisms have shaped and defined Earth's biosphere, and created conditions that allowed the evolution of macroorganisms and complex biological communities. Today microbes inhabit and sustain all of Earth's biotopes, including those found in marine environments; they are truly the "unseen majority". They catalyze key biogeochemical transformations of nutrients and trace elements that maintain productivity of the oceans, produce and consume greenhouse gases, and are a critical component of the food web linking dissolved organic matter to higher trophic levels. Until recently, very little was known about the biology of the microorganisms *in situ*, their metabolic and genomic properties, or their temporal and spatial dynamics. Recent advances have highlighted the vast unknown genetic information contained in marine microbes. Now there is an opportunity, using recent advances in molecular ecology, genomics, microbial cultivation, remote and in situ sensing, and ecological modeling, to make great strides in the understanding of the biological, ecological, and biogeochemical roles of the unseen majority in the world's largest biome: the global ocean. The Center for Microbial Oceanography: Research and Education (C-MORE), is a physical and intellectual space where a synergy among these otherwise separate disciplines will be fostered in the study of marine microbial ecology. Our primary goals are to increase our understanding of how biological diversity at the genomic level expresses itself at the ecosystem functional level in the biogeochemistry of the oceans, and to transfer this knowledge to policymakers and to the public at large.

C-MORE will facilitate broadly based research on marine microorganisms across geographical, disciplinary, and cultural boundaries. The Center will: establish, monitor, and manage research; broker partnerships; increase diversity of human resources in this and related fields; implement novel education and outreach programs; and obtain and utilize comprehensive information about microbial life in the sea. The Center will bring together teams of scientists, educators, and community members who otherwise do not have the opportunity to communicate, collaborate, and design creative solutions to long-term ecosystem scale problems, and whose collective expertise will advance microbial oceanography in new and exciting ways. The Center will conduct a range of activities, from genomic surveys to instrument/sensor development for remote and continuous sensing, mesocosm experimentation, and ecosystem modeling. Although a single marine ecosystem – Station ALOHA of the Hawaii Ocean Time-series (HOT) – will serve as the primary focal point for the integration of diverse activities, many of the fundamental results of the Center research are relevant to other systems, and comparisons with other systems are valuable tools to generalize the results of C-MORE research.

This Strategic and Implementation Plan (SIP) for C-MORE outlines the vision, mission, and planned implementation of various research, education, and outreach activities for the Center. The original document grew out of discussions at a C-MORE planning workshop that was held at the University of Hawaii in May 2006. This event brought together, for the first time, the National Science Foundation's (NSF) C-MORE management team (led by Drs. Matt Kane and Margaret Tolbert), NSF's consultants Dr. Walter Collier and Robert Mortis of C&A Technologies, Inc., and most of the C-MORE Team.

This revised document presents our prospectus for the third year of C-MORE operations: 2008–2009. It will be updated at least annually to reflect our progress towards the stated goals, as well as the incorporation of new and exciting opportunities that will undoubtedly arise.

1.1. Center Management

The Center's lead institution is the University of Hawai`i at Manoa, where the Center is positioned within the School of Ocean and Earth Science and Technology (SOEST). In his role as C-MORE Director, David Karl reports to

SOEST Dean Brian Taylor. In turn, Dean Taylor reports to the Vice Chancellor for Research and Graduate Education, Gary Ostrander, who reports to Chancellor Virginia Hinshaw.

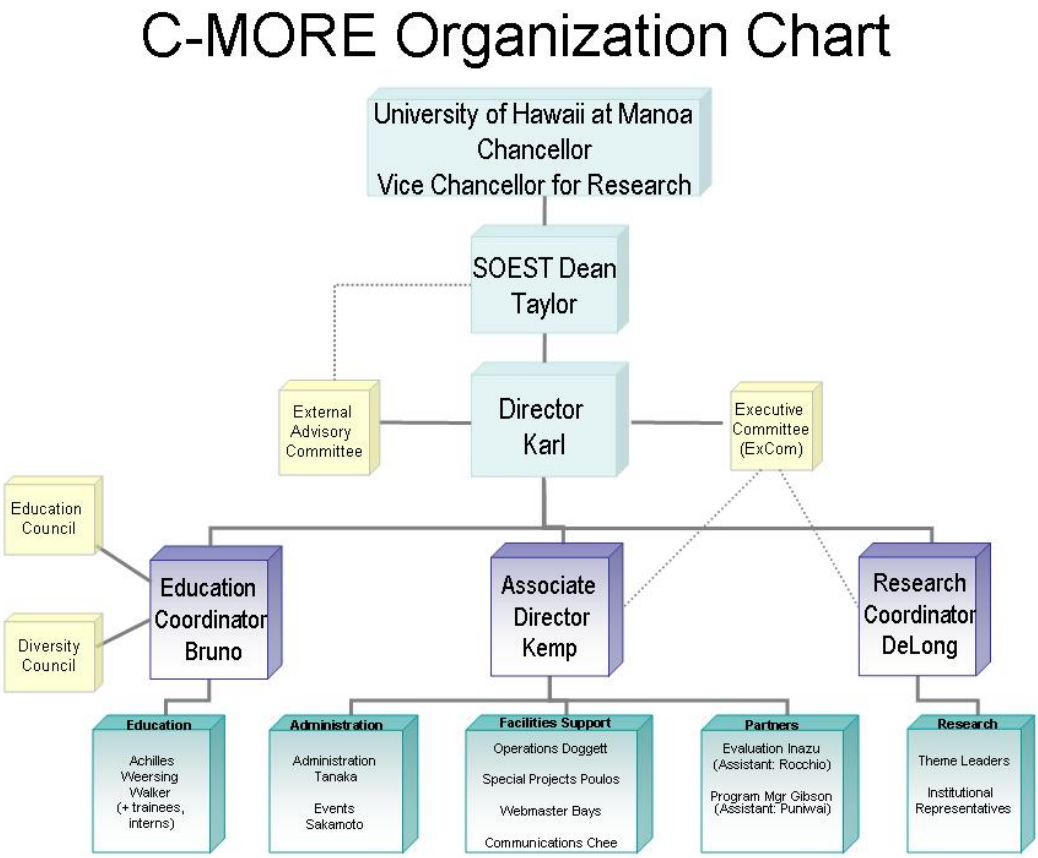
The management structure of the Center is designed for maximum efficiency and minimal administrative burden for the C-MORE team members. The Center's Associate Director (Paul Kemp) oversees and directs the administrative staff and is responsible for day-to-day Center operations including Center-wide service and support functions.

The Executive Committee (ExCom) acts as an advisory body to the Director and has regularly scheduled monthly meetings by teleconference. Minutes of each meeting are circulated to the entire C-MORE Team.

The ExCom membership consists of the C-MORE co-PIs, Director and co-Director, Associate Director, Education and Research Coordinators, and Research Theme Leaders. Two additional positions are one-year, non-renewable rotations selected by the remainder of the ExCom from the C-MORE Team as a whole. This provides an opportunity for other junior and senior members of C-MORE to participate in Center management. At its most recent meeting, the ExCom decided to encourage greater participation from students and post-docs through their representation on the ExCom. The C-MORE Associate Director serves as Chair of the ExCom.

The current membership of the ExCom is: D. Karl (Center Director), P. Kemp (Associate Director and Chair), B. Bruno (Education Coordinator), E. Delong (Research Coordinator, co-Director and co-PI), J. Zehr (co-PI and Theme II Leader), S. Chisholm (co-PI), M. Rappé (Theme I Leader), C. Scholin (Theme III Leader), S. Doney (Theme IV Leader), S. Dyhrman, D. Repeta. A. Hynes and S. Wilson serve as the student and post-doc representatives, respectively.

The organization chart for the Center is shown below.



An External Advisory Committee provides additional guidance to the Director, and is comprised of distinguished leaders in research, educators, diversity and public outreach efforts. Its membership presently includes:

Peter Betzer, Dean and Professor of Marine Sciences, University of South Florida;

Susan Cook, Director of Education at the Consortium for Oceanographic Research and Education (CORE) and PI for the Central Coordinating Office of the Centers for Ocean Sciences Education Excellence (COSEE);

Claire Fraser-Liggett, Director of newly created Institute of Genome Sciences and Professor of Medicine, University of Maryland in Baltimore;

James Kauahikaua, head of the U.S. Geological Survey's Hawaiian Volcano Observatory;

Raymond Mariella, Jr., Senior scientist and Director of the Center for Microtechnology and Nanotechnology, Lawrence Livermore National Laboratory;

James J. McCarthy, Alexander Agassiz Professor of Biological Oceanography, Harvard University;

Norman Pace, Professor of Molecular, Cellular and Development Biology, University of Colorado at Boulder;

David Kekaulike Sing, Director and Founder of Na Pua No'eau, a state-wide organization aimed at raising the educational achievements of Native Hawaiian children, University of Hawaii at Hilo; and

James Tiedje (**Chair**), University Distinguished Professor and Director of the Center for Microbial Ecology, Michigan State University.

1.2. Succession Plan and Performance Evaluations

As stipulated in the Cooperative Agreement under which the Center operates, the performance of the Director is evaluated annually by the ExCom excepting the Associate Director and Education Coordinator (who report directly to the Director), and the student/post-doctoral members. The evaluation will be managed by the co-Director. If the Center Director resigns, becomes incapacitated, or is unable to provide effective leadership as judged by the annual performance evaluation, s/he will be replaced. The Center's co-Director (presently E. Delong) then will immediately assume the role of Director until a permanent replacement can be made. The new Center Director will be recruited by the Dean of SOEST with advice and consent of the ExCom. The co-Director, Associate Director and senior members of the C-MORE team would all be eligible to serve as the new permanent Director. Should the co-Director resign or become incapacitated or have a performance deemed unacceptable to the Director, the Director will appoint a replacement subject to the approval of the ExCom.

Administrative, education, and operations staff will be assigned clear responsibilities and a clear supervisory and reporting structure will be in place at all times. The performance of all administrative and operations staff will be evaluated by their immediate supervisors at least annually.

1.3. Evaluation Plan

C-MORE has contracted with Dr. Judith Inazu, Director of the UH-Manoa Office for Evaluation and Needs Assessment Services. Dr. Inazu also evaluates Hawaii EPSCoR, one of the NSF Advanced Technological Education (ATE) grants, and the NIH-funded Hawaii Idea Network of Biomedical Research Excellence (INBRE). Initial efforts have been focused on developing appropriate goals, objectives, and metrics for the Education Office and for C-MORE's activities directed toward increasing diversity in the workforce. Discussions have begun to determine where else we can benefit most from evaluation services. Some performance metrics are straightforward and can be assessed by the Associate Director; for example, the number of publications and presentations by C-MORE investigators. Other metrics are more difficult to assess; for example, the impact of C-MORE research on microbial oceanography as a whole, or the operational efficiency of the C-MORE organization. The evaluation plan that emerges from our ongoing discussions will lead to a more effective organization and a better understanding of the productivity and impact of various C-MORE activities.

2. Research

2.1. Vision Statement

C-MORE will be a transdisciplinary, global research information center for comprehensive, integrative understanding of the living ocean, with a special emphasis on microbial plankton diversity and dynamics. The connectivity between different hierarchical levels of biological complexity (including gene and organism diversity, physiological function and regulation, and community structure and function), and biogeochemical and physical dynamics will be measured and modeled. These data, and the predictive, biologically informed ecosystem models they enable, will be essential in predicting the effects of global change in the marine environment, and managing marine biomes in the face of ongoing global environmental perturbations.

2.2. Mission Statement

The mission of the Center is to support interdisciplinary research that is operationally organized around four interconnected themes, and to integrate these studies at multiple time and space scales. Research themes are I) microbial diversity; II) microbial metabolism and biogeochemistry; III) remote and continuous sensing of microbial processes and their links to climate variability; and IV) ecosystem modeling, computer simulation and prediction.

2.3. Situational Analysis

Strengths and Opportunities

A An intellectual and human-resource base of talented, enthusiastic leaders in microbial oceanographic education and research; and an established base of oceanographic and microbiological experience, with its associated infrastructure.

B Access to the sea, with direct access to one of the largest marine biomes on Earth, the North Pacific Ocean.

C A primary focus on a single habitat, targeted microorganisms and their associated biogeochemical cycles, lending itself to collaborative research.

D The synergistic interaction of four complementary areas of research, leading to new intellectual opportunities and insights.

Challenges

A Establishing priorities for an ambitious and comprehensive research program.

B Integrating the diverse themes across multiple time and space scales.

C Integrating research activities with education, diversity, and knowledge transfer activities.

D Conducting highly collaborative and complementary research rather than individual, independent programs.

E Communicating effectively among geographically dispersed collaborators and institutions.

F Ensuring that development, testing, and application of novel tools and sensors is in service to the research needs of the scientists who will use them.

2.4. Goals and Objectives

Goals

A To understand how the information encoded in marine microbial genomes manifests itself at the ecosystem level through provision of critical and definitive ecosystem functions.

B To understand the interdependent roles of microorganisms in energy capture and transfer, and in carbon, nutrient, and trace metal cycling.

C To develop models for the prediction of microbial distributions, dynamics (growth and mortality), and response to environmental changes in the sea.

Objectives

A Characterize, interpret, and understand genomic diversity as the genetic basis of ma-

rine microbial biogeochemistry and its emergent ecological properties (Goals A–B).

B Cultivate model microorganisms representative of the key biogeochemical cycles and key microbial populations, and understand their "cellular machinery" (Goals A–B).

C Determine the links between energy source and energy flux within and between biogeochemical cycles (Goal B).

D Determine how nitrogen (N), phosphorus (P) and trace metal and organic micronutrient (e.g., vitamins) cycles regulate carbon and nitrogen fixation in the oligotrophic gyres (Goal B).

E Examine the sources and fates of dissolved organic matter, and how dissolved organic matter interacts with trace elements (Goal B).

F Develop biological sensors for detecting major microbial components (organisms or genes), and biophysical sensors for continuous *in situ* measurements of critical microbial processes (Goals A–C).

G Examine biological and other processes that affect the diversity and composition of microbial populations, and consequently their ecosystem-level functions (e.g., phage/host interactions, competition, dispersal and transport, mortality) (Goals A–C).

H Examine the role of meso- and large scale physical forcing on marine microbial diversity (Goal C).

I Build more credible, mechanism-based models for predicting current and potential future dynamics of ocean microbes and their role in marine ecosystems (Goal C).

2.5. Strategies

A Create highly collaborative, transdisciplinary research and engineering groups, and facilitate numerous and practical opportunities for their interaction (Objectives A–I).

B Emphasize high throughput and other novel approaches to obtain pure cultures and enrichments of key microbial representatives for use in model genomic and physiological studies (Objectives A–B).

C Employ multiple genomic approaches to identify metabolic properties of microbial populations (e.g., whole genome sequencing of model organisms, single cell genome sequencing, large insert libraries, shotgun cloning, microarrays, transcriptome and proteome approaches) (Objectives A–B).

D Develop biological sensors based on the Environmental Sample Processor (ESP) design for detecting key microorganisms and genes, using Station Aloha and alternate test sites as needed (e.g., Monterey Bay and contiguous waters) (Objectives B, C, F, G).

E Integrate data products of C-MORE process studies, manipulation experiments, and environmental time-series studies into the development and evaluation of marine ecological-biogeochemical models (Objective I).

F Combine *in situ* observations with spatial and temporal analyses of satellite-based remote sensed observations to assess physical forcing on marine microbial diversity (Objective H).

G Design, build, test, and deploy large mesocosms for use in open ocean nutrient perturbation experiments to test specific C-MORE hypotheses (Objectives A–I).

2.6. Implementation Plan

Objective	Goals	Actions Required	Responsible Person(s)	Primary Location(s)
All objectives	A–C	• Create transdisciplinary, collaborative working groups (Years 1–5)	PIs and Kemp	All
		• Identify new opportunities for productive partnerships and proactively encourage new collaborations among investigators (Years 2–5)	PIs and Kemp	All
A. Characterize, interpret and understand genomic diversity as the genetic basis of marine microbial biogeochemistry and its emergent ecological properties	A–B	• HOT-site specific analyses of pre-existing metagenomic datasets (Years 1–2)	Chisholm, DeLong, Dyhrman, Rappé, Zehr	MIT, UCSC, UH, WHOI
		• Create and expand new metagenomic data, and link to oceanographic data and metadata (Years 1–3)	Chisholm, DeLong, Dyhrman, Rappé, Zehr	MIT, UCSC, UH, WHOI
		• Develop and implement new molecular probes and quantitative techniques to track microbes and microbial processes (Years 1–5)	Chisholm, DeLong, Dyhrman, Kemp, Rappé, Saito, Steward, Zehr	MIT, UCSC, UH, WHOI

Objective	Goals	Actions Required	Responsible Person(s)	Primary Location(s)
B. Cultivate model microorganisms representative of the key biogeochemical cycles and key microbial populations, and understand their "cellular machinery"	A–B	• Employ traditional and dilution culture techniques with high-throughput screening targeting selected prokaryote groups (Years 1–3)	Bidigare, Chisholm, DeLong, Rappé	MIT, UH, WHOI
		• Characterize the major reservoirs of dissolved organic nitrogen and phosphorous in model microorganisms (Years 2–4)	Chisholm, DeLong, Karl, Rappé, Repeta	MIT, UH
		• Isolate and characterize new key players in biogeochemical cycles (nitrifying Archaea, photoheterotrophs, other uncultured microbes) (Years 1–3)	Church, DeLong, Rappé, Waterbury	MIT, UH, WHOI
		• Characterize hosts, phages, and basic properties of the phage-host system (Years 1–3)	Chisholm, Steward	MIT, UH
C. Determine the links between energy source and energy flux within and between biogeochemical cycles	B	• Identify biophysical markers for photosynthetic and respiratory electron fluxes and investigate photoadaptive strategies of microbes (Years 1–5)	Church, DeLong, Dyhrman, Karl, Kolber	MBARI, MIT, UH, WHOI
D. Determine how N, P and trace metal and organic micronutrient cycles regulate carbon and nitrogen fixation in the oligotrophic gyres	B	• Measure the trace metal and organic micronutrient cell quotas for key microorganisms in laboratory cultures; compare the chemical diversity and forms of bioavailable trace metals and micronutrients in laboratory and field (Years 1–3)	Boyle, Chisholm, Dyhrman, Repeta, Saito, Zehr	MIT, OSU, UCSC, WHOI
E. Examine the sources and fates of dissolved organic matter, and how dissolved organic matter interacts with trace elements	B	• Engineer and deploy new systems for the isolation of dissolved organic matter (Years 2–4)	Church, Karl, Repeta, Steward	UH, WHOI
		• Characterize the diversity and metabolic capacity of dissolved organic matter degrading microbial consortia in laboratory cultures (Years 2–4)	Church, Repeta, Waterbury	UH, WHOI

Objective	Goals	Actions Required	Responsible Person(s)	Primary Location(s)
F. Develop biological sensors for detecting major microbial components (organisms or genes), and biophysical sensors for continuous *in situ* measurements of critical microbial processes	B–C	• Document functional requirements and conduct instrumentation design reviews for new sensors and samplers (Years 1–2)	Karl, Kemp, Kolber, Scholin, Steward, Taylor	MBARI, UH, WHOI
		• Development, testing, refinement, and operation of biological and biophysical sensor instruments within C-MORE program and beyond (Years 1–5)	Kemp, Kolber, Scholin, Taylor	UH, MBARI, WHOI
		• Deploy autonomous SeaGliders for remote surveillance of open ocean blooms (Years 1–5)	Karl	UH
G. Examine biological and other processes that affect the diversity and composition of microbial populations, and consequently their ecosystem-level functions (e.g., phage/host interactions, competition, dispersal and transport, mortality)	A–C	• Characterize phage-host interactions (Years 1–3) (see also Objective B)	Chisholm, Steward	MIT, UH
		• Examine ecological interactions affecting microbial diversity (Years 1–5)	Bidigare	UH
		• Examine transport and dispersal processes affecting microbial distributions and composition (Years 1–5)	Karl, Kemp	UH
H. Examine the role of meso- and large scale physical forcing on marine microbial diversity	C	• Generate remote sensing databases for the regions studied (Years 1–2)	Doney, Letelier	OSU, WHOI
		• Develop and implement spatial and temporal statistical analyses (Years 2–3)	Bidigare, Doney, Karl, Letelier	UH, OSU, WHOI
		• Combine remote sensing analyses with *in situ* data and model development (Years 2–5)	Bidigare, Doney, Karl, Letelier	UH, OSU, WHOI

Objective	Goals	Actions Required	Responsible Person(s)	Primary Location(s)
I. Build more credible, mechanism-based models for predicting current and potential future dynamics of ocean microbes and their roles in marine ecosystems	C	• Build ecosystem models for North Pacific Subtropical Gyre for synthesis/interpretation of laboratory, field, remote sensing, and mesocosm data (Years 1–2)	Doney, Karl, Laws, Letelier	OSU, UH, WHOI
		• Expand traditional ecosystem model capabilities to incorporate microbial genetic, evolutionary, and metabolic characteristics (Years 2–3)	Doney, Karl, Laws, Letelier	OSU, UH, WHOI
		• Use models as test beds for exploring hypotheses, processes, and dynamics (Years 3–5)	Bidigare, Doney, Karl, Laws, Letelier	OSU, UH, WHOI
		• Incorporate model advances into regional and/or global 3-D ocean simulations for use in climate projections (Years 3–5)	Doney, Karl, Letelier	OSU, UH, WHOI
All Objectives	A–C	• Design, build, test, and deploy large mesocosms for use in open ocean nutrient perturbation experiments to test specific C-MORE hypotheses, including: o Design and construct test model mesocosm (Year 2) o Field test (Year 3; additional ship days will be required) o Deploy for specific hypothesis-testing activities (Years 3–5)	DeLong, Karl, Zehr	MIT, UH, UCSC
		• Organize and conduct research cruises (years 2–5)	ExCom	All
		• Take advantage of opportunities to conduct research at sea through outside partnerships. (years 1-5)	All	All

2.7. Metrics

Data will be collected to assess research productivity and to evaluate the long-term impact of the C-MORE research program. Many of these are documented through publications rather than being tracked as numerical data; e.g. "discoveries" and "emergent properties" are not simple numerical statistics. In the following, "productivity metrics" refer to measures of the productivity of C-MORE-sponsored researchers. "Outcome metrics" refer to measures of the influence of C-MORE research outside of its own investigator team.

2.7.1 Productivity Metrics

A Libraries constructed, progress in bioinformatics analysis, including: database development and findings; discoveries of new metabolic pathways; and emergent properties of oceanic microbial communities (Objective A).

B Attempts, failures, and successes of cultivation efforts. New techniques developed or in development. Habitats where cultivation efforts have been attempted (Objective B).

C Methods developed, experiments performed, and findings regarding biophysical markers of energy sources and fluxes (Objective C).

D Trace metal and organic micronutrient cell quotas obtained for key microorganisms in laboratory cultures. Comparisons made regarding bioavailable trace metals and micronutrients in laboratory and field (Objectives B, D).

E Data obtained to characterize dissolved organic matter, interactions of dissolved organic matter with trace elements, and sources and fates of dissolved organic matter components (Objective E).

F Developments in biological and biophysical sensors, including description of instrumentation and data from field deployments (Objective F).

G Progress in identifying key biological interactions, dispersal and transport processes affecting microbial distributions, diversity, composition, and function (Objective G).

H Steps taken to develop remote sensing approaches and data analysis (Objective H).

I Development of models including scales, approaches, and characteristics captured (Objective I).

J Steps completed in the design, construction, and testing of experimental field mesocosms (Objectives A–I).

K Publications and presentations of C-MORE research.

2.7.2 Outcome Metrics

L Citations of C-MORE publications.

M Invited presentations of C-MORE-sponsored research.

N Awards and honors to C-MORE participants.

O Reviews referring to C-MORE research.

P Collaborations of C-MORE investigators with others operating on non-C-MORE funding.

Q Other evidence of awareness of C-MORE research; e.g. news announcements and reports, interviews, participation in panels.

2.8. Financial Resources

C-MORE receives $19M in NSF funding through its cooperative agreement, matched by institutional contributions from C-MORE partners totaling 30% of the NSF award. In addition, C-MORE benefits from synergistic programs financed by NSF and other sponsors. These include research programs of the PIs (supported by the NSF, DOE and others), as well as institutional support (UH). Four PIs are supported by Gordon and Betty Moore Foundation Marine Investigator Awards. The Moore Foundation also supports a facility for visiting scientists at UCSC (called MEGAMER), and the development of instrumentation at MBARI (MEGA). MBARI also receives support for the development of instrumentation from the Packard Foundation, NSF, and NASA. Additional external support is being sought for ancillary projects complementary to C-MORE interests. As one example, C-MORE is sponsoring an NSF-funded symposium titled Ecological Dissertations in the Aquatic Sciences (Eco-DAS).

Resource Allocation

Research and education are closely related in C-MORE. For example, graduate students and post-docs receive education and training while performing research. The projected allocation of NSF resources to research is shown below; for the sake of this calculation, graduate students and post-docs are included with Educa-

tion spending in a later section. The specific allocation to individual projects will change as needed over time.

	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Research	1,857,000	2,887,000	2,740,000	2,740,000	2,747,000	12,971,000

2.9. Management Plan

A visual summary of the management structure for the Center as a whole is provided in Section 1.1. Research management is implemented through the ExCom.

As Research Coordinator, Edward DeLong (MIT) serves on the ExCom and has primary responsibility for oversight of research activities, working with the Director and Associate Director on all aspects of the research mission. The Research Coordinator coordinates research progress by close interaction and communication with the designated Theme Leaders, each of whom takes a leadership role for a specific research theme.

The central purpose of the Research Themes is to provide a tool to facilitate communication and organization around integral, highly related CMORE research interests. A second major function of the Themes is to identify, communicate and facilitate interactions between diverse research activities *between* the different Theme groups. Most CMORE research participants enjoy membership in more than one Theme group, which facilitates integrative communications and activities. It is critical that these Themes not be viewed as disciplinary 'stovepipes', but rather as useful organizational and communications tools supporting an integrated, interdisciplinary research agenda.

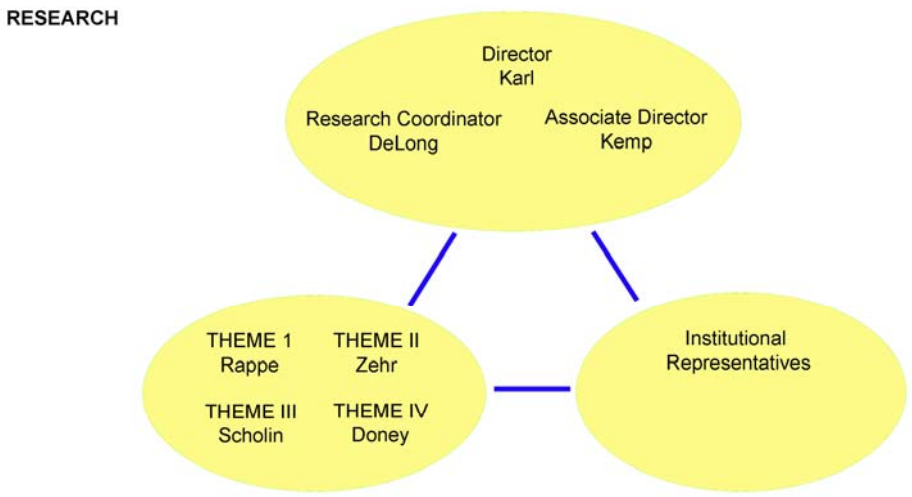
Through interactions with the Theme Leaders, the Research Coordinator ensures that good communications and other tools are operating to support CMORE's integrated, interdisciplinary research agenda. Theme metrics are tracked primarily via the annual summary of research accomplishments provided by each participating CMORE Institution, to ensure that work in progress is accurate, reflects the ongoing work of all C-MORE researchers, and that C-MORE participants are kept informed of Center research activities.

Finally, the Research Coordinator is responsible for soliciting ideas and bringing novel research projects to the attention of the Director and Associate Director for consideration as potential recipients of incubator awards. The Research Coordinator together with the Director and Associate Director will review incubator proposals and may solicit advice from the ExCom as needed.

C-MORE research activities will be coordinated via multiple communication channels, including monthly ExCom teleconferences, annual meetings of all participants, cruises that provide opportunities for intense interaction, and targeted meetings to develop and plan specific subsets of the research effort. Web-enabled technologies are being developed and implemented to facilitate reporting, exchange, and archiving of data and data products, and to facilitate collaborative interactions. The Associate Director has the primary responsibility for implementing these multiple communication channels.

Institutional representatives are the designated points of contact for communicating information between the Research Management team, to and from each partner institution.

The conceptual plan for research interactions is shown graphically below.



3. Education

3.1. Vision Statement

C-MORE will lead efforts in increasing understanding and appreciation of microbial oceanography. In doing so, we will promote increasing knowledge and awareness of ocean microbes, their key roles in ocean processes, and their essential roles in the habitability and sustainability of life on earth.

3.2. Mission Statement

Educate and train a diverse population of students, educators, researchers, and community members in microbial oceanography.

3.3. Situational Analysis

Strengths and Opportunities

A Junior and senior faculty and post-docs who are committed to participating in C-MORE's education program.

B Local and nationwide educational programs are already established at partner institutions, including internship programs, MBARI's teacher-training workshops, MIT's Open CourseWare, and OSU's SMILE (Science and Mathematics Investigative Learning Experience).

C Distance-learning instructional technology is already available at C-MORE partner institutions, providing enhanced learning opportunities for all, including persons with disabilities.

D Availability of cruise berths (e.g., on the HOT and C-MORE cruises) enables at-sea training and experience for educators and students.

E Private funding has been obtained for a Microbial Oceanography training course at UH, team taught by C-MORE PI's and other internationally renowned experts.

F Hawaii State Department of Education (HIDOE) is committed to developing state marine science standards and encouraging teacher training. Hawaii is the only state with a statewide public school system, providing unique opportunities for education and outreach.

G Active, ongoing partnership with UH's College of Education, which includes joint proposal writing and co-organization of the Ocean Literacy Alliance – Hawaii (established November 2007 to bring together federally funded groups in marine science education).

H C-MORE team members are well positioned within their home institutions to influence curriculum content in microbial oceanography and ocean biogeochemistry.

Challenges

A Given the structure and breadth of an ideal education plan, full implementation and coordination across all partner institutions will require additional funding and prioritization of immediate goals.

B Distinct differences in cultures between education and research require that mutual respect and understanding be developed.

C Allocation of resources (e.g., scientists' time, funds, ship berths) to K–16 education can pose conflicts with research activities.

3.4. Goals and Objectives

Goals

A Increase scientific literacy in microbial oceanography.

B Produce leaders in the next generation of microbial oceanographers (undergrads through post-docs) by providing state-of-the-art training.

Objectives

A Identify the fundamental concepts that constitute scientific literacy in microbial oceanography, and disseminate to public (Goal A).

B Improve, update, and disseminate K–12 activities and other instructional resources in microbial oceanography (Goal A).

C Encourage and support teachers to incorporate microbial oceanography into their disciplines (Goal A).

D Provide enhanced educational and research opportunities in microbial oceanography for undergraduate students (Goal B).

E Enhance existing graduate courses at partner institutions with microbial oceanography content (Goal B). NOTE: this objective is under evaluation regarding whether it is an effective use of time and effort.

F Provide enhanced research and education training experiences to graduate students and postdocs (Goal B).

3.5. Strategies

A Establish an Education Advisory Council to get critical input on the education program (all Objectives).

B Use the expertise of C-MORE students and scientists to identify key concepts in microbial oceanography (Objective A).

C Assess and select effective mechanisms for disseminating key concepts to the public including indirect (e.g., web-accessible educational materials) and direct methods (e.g., public workshops and lectures) (Objective A).

D Develop, evaluate, revise, and disseminate new and updated pre-college educational resources for microbial oceanography (Objective B).

E Provide a suite of opportunities to encourage educators to incorporate microbial oceanography into their teaching (Objective C).

F Engage undergraduate and graduate students in microbial oceanography through hands-on (e.g., shipboard and laboratory) experiences and internship programs (Objective D).

G Facilitate the exchange of students and researchers across C-MORE partner institutions (Objective D).

H Develop, update, and implement course content in microbial oceanography (Objectives D–E).

I Provide opportunities and resources for C-MORE participants to develop new education programs and activities (Objectives A-F).

3.6. Implementation Plan

Objectives	Goals	Action Required	Responsible Person(s)	Primary Location (s)
All objectives	A–B	• Establish an Education Advisory Group composed of stakeholders (year 2)	Karl, Kemp, Bruno	UH
A. Identify the fundamental concepts that constitute scientific literacy in microbial oceanography, and disseminate to public	A	• Review existing literature for key concepts in microbial oceanography and related fields (e.g., microbiology and oceanography); solicit input from C-MORE scientists; and develop a List of Key Concepts in clear, jargon-free language (year 2)	Primarily students and post-docs, led by Education Team	UH, All partners
		• Identify possible communication channels for disseminating key concepts, including: website, video kiosk, posters, Open House events, field trips, workshops, permanent and temporary exhibits (e.g., at museums, aquaria, discovery centers), public lectures (years 2–4)	Education Team, All participants	UH, All partners
		• Implement selected communication channels (years 3–5)	Education Team, All participants	UH, All partners
		• Seek additional funding as required	Education Team with partners	UH, All partners

Objectives	Goals	Action Required	Responsible Person(s)	Primary Location (s)
B. Improve, update and disseminate K–12 activities and other instructional resources in microbial oceanography	A	• Obtain and review existing K–12 instructional resources (e.g., textbooks, activities, programs) for accuracy and gaps (years 2–3)	Education Team	Primarily UH
		• Adapt and develop appropriate microbial oceanography instructional content (e.g., revised textbook chapter) and activities (e.g., fieldtrips or labs) based on List of Key Concepts for suggested inclusion in (or update to) existing instructional resources (years 2–4).	Education Team, All participants	UH, All partners
		• Field-test, evaluate, and revise microbial oceanography educational resources as appropriate (years 3–5)	Education Team, All participants	UH, All partners
		• Develop outlets to disseminate materials, including national meetings, website, publications, and Teacher Professional Development workshops (see below) (Year 5)	Education Team	Primarily UH
C. Encourage/support teachers to incorporate microbial oceanography into their disciplines	A	• Provide Professional Development workshop or short-course for in-service and pre-service pre-college educators: develop and implement (years 2–3); evaluate and refine (years 3–4); disseminate (year 5)	Education Team	Primarily UH
		• Provide programs for teachers to obtain equipment and supplies (e.g., equipment loan program, offer grants to purchase equipment/supplies): develop and implement (years 2–3); evaluate and refine (years 3–4); disseminate (year 5).	Education Team	Primarily UH
		• Provide shipboard experiences to teachers: develop and implement program (years 2–3); evaluate and refine (years 3–4); disseminate (year 5).	Education Team	Primarily UH
		• Seek additional funding as required	Education Team with partners	UH, All partners

Objectives	Goals	Action Required	Responsible Person(s)	Primary Location (s)
D. Provide enhanced educational and research opportunities in microbial oceanography for undergraduates	B	• Provide internships and other research experiences to undergraduates: identify existing programs (year 2); partner with existing programs (years 2–3); develop new programs as needed (years 3–5)	Education Team, All participants	UH, All partners
		• Create and provide microbial oceanography course content (e.g., course or unit, guest lectures): develop content (year 3); develop outlets to disseminate content (e.g., online course, seminar course, inclusion into existing courses) (years 4–5)	Education Team, All participants	UH, All partners
		• Seek additional funding as required	Education Team with partners	UH, All partners
E. Enhance existing graduate courses at partner institutions with microbial oceanography content	B	• Identify microbial oceanography courses currently being taught at C-MORE partner institutions (year 3)	Kemp	UH, All partners
		• Enrich courses through C-MORE resources (guest-lectures, laboratory/ field experiences) (years 4–5)	Education Team, All participants	UH, All partners

Objectives	Goals	Action Required	Responsible Person(s)	Primary Location (s)
F. Provide enhanced research and education training experiences to graduate students and post-docs	B	• Solicit feedback from Center graduate students and post-docs regarding desirable opportunities for professional advancement; e.g., participation in conferences and workshops, cross-training at C-MORE partner institutions (Year 2)	All participants led by Education Team	UH, All partners
		• Based on feedback, create research training opportunities at partner institutions. Examples: Student exchanges among partner institutions to do research (years 3–5); professional workshops (years 3–5); RA-ships (years 1–5); transdisciplinary training (e.g., cruises) (years 1–5)	All participants led by Education Team	UH, All partners
		• Based on feedback, create education training opportunities at partner institutions. Examples: Student exchanges among partner institutions to take courses (years 3–5); encourage participation in education activities (e.g., public outreach) (years 1–5); TA-ships (years 2–5)	All participants led by Education Team	UH, All partners

3.7. Metrics

For C-MORE's education component, data will be collected to assess productivity and to evaluate the impact of the program on C-MORE's education goals.

3.7.1 Productivity Metrics

A Establishment and annual meetings of an Education Advisory Council (All Objectives).

B Number of C-MORE graduate students, staff and scientists who participate in K–16 educational endeavors (All Objectives).

C Number and types of conferences and meetings attended, and types of materials distributed or presented (All Objectives).

D Number and types of educational activities at C-MORE partner institutions other than Hawaii (All Objectives).

E Number and types of outreach materials produced, and where distributed (Objective A).

F Number and types of outreach activities conducted, and number of participants reached (Objective A).

G Number and types of hands-on experiences, including labs and field-trips, for K–16 students, and numbers of participants (Objectives B & D).

H Numbers and types of K–16 instructional resources, activities and programs reviewed, updated or developed (Objectives B & D).

I Numbers and types of experiences and programs provided to educators, and number of participating educators (Objective C).

J Number and types of post-secondary courses enriched through C-MORE resources, and number of post-secondary students impacted (Objectives D–E).

K Number and types of training experiences provided to graduate students and young scientists, and number of participants (Objective F).

3.7.2 Outcome Metrics

L Increase in knowledge and positive attitudes regarding microbial oceanography among K–12 students who have participated in C-MORE workshops, fieldtrips, and in-school lessons (Objective B).

M Increase in microbial content in courses taught by K–12 teachers who have participated in C-MORE workshops and fieldtrips (Objective C).

N Increase in knowledge and positive attitudes regarding microbial oceanography among undergraduate students, graduate students, and post-docs who have participated in C-MORE internships, field experiences, and other activities (Objectives D–F).

O Increase in website visitors' knowledge, understanding, and appreciation of microbial oceanography (Objective A).

3.8. Financial Resources

Resource Allocation

The projected allocation of NSF resources to education and training is shown below. This includes training of students and post-docs who conduct research. The specific allocation to individual projects will change as needed over time.

	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Education	378,000	932,000	1,062,000	1,053,000	1,001,000	4,426,000

3.9. Management Plan

The C-MORE Education activities are managed by a full-time Education Coordinator (Barbara Bruno) assisted by two full-time marine science educators. The Education team presently includes a Postdoctoral Associate who holds a Ph.D. in oceanography, a Marine Science Educator with an M.S. in oceanography, a half-time teacher, and part-time undergraduate interns who receive training in education and outreach. The Education Coordinator is responsible for oversight and leadership of all education activities of the Center including the tracking of progress in all areas. An Education Advisory Council has been formed through consultation among the Director, Associate Director and Education Coordinator and is comprised of national leaders in science education and evaluation. Its members are:

Lisa Hunter (chair), Associate Director for Education & Human Resources, Center for Adaptive Optics;

George Matsumoto, Senior Education and Research Specialist, Monterey Bay Aquarium Research Institute;

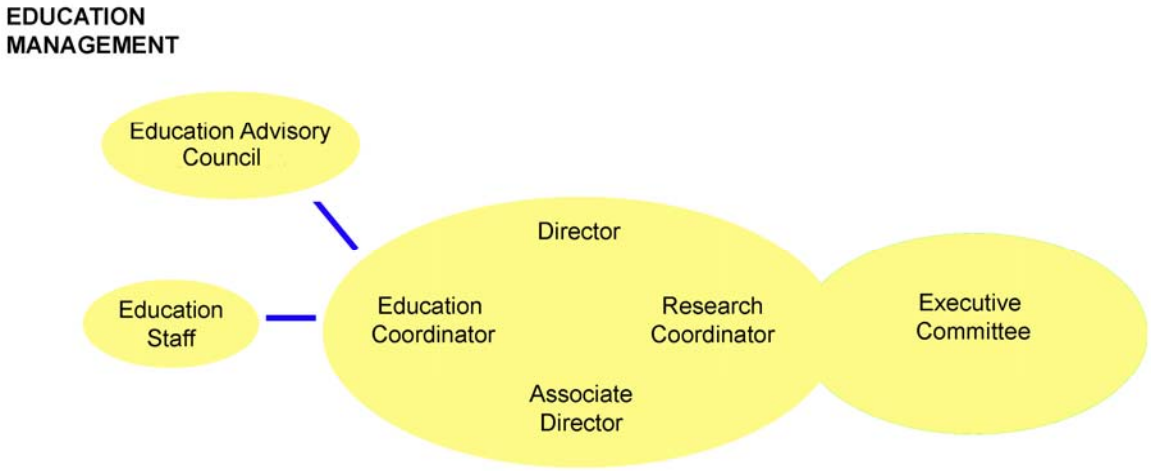
Marco Molinaro, Education director, Center for Biophotonics Science & Technology; and

Vivian Williamson-Whitney, Grants Research Specialist, and Director, Institute for Environmental Sciences Education and Research, East Central University. She is also MSPHD'S Professional Development Program evaluator.

A member of the External Advisory Committee will be invited to attend Education Advisory Council meetings. If no External Advisory Committee is able to attend, the Education Advisory Council will provide a written report on the activities of this advisory group to the External Advisory Committee. The Education Coordinator is responsible for reporting on the activities of this advisory group to the ExCom. The Education Coordinator also is responsible for preparing a succinct annual report on accomplishments and work in progress with respect to

the educational program goals, with input from all C-MORE participants as required. The Education Coordinator serves as a member of the C-MORE ExCom and works closely with the Director and Associate Director. It is their joint responsibility to ensure that educational programs are enhanced by research efforts, and the converse.

The conceptual plan for interactions with the Education Office is shown below.



4. Diversity

4.1. Vision Statement

C-MORE will become a leader in increasing diversity among scientists, the technical workforce, and educators engaged in the study and teaching of microbial oceanography.

4.2. Mission Statement

Increase the number of students, staff, and faculty among Native Hawaiians, Pacific Islanders (NHPI) and other underrepresented groups in microbial oceanography and related science disciplines. Ensure diversity in all aspects of the Center.

4.3. Situational Analysis

Strengths and Opportunities

A All C-MORE research partners (UH, MIT, UCSC, WHOI, MBARI, OSU) are committed to efforts to increase diversity among students, faculty, researchers, and staff.

B Several partner institutions participate in programs to prepare underrepresented and/or low-income K–12 students for college such as GEAR-UP (MIT, UH), SMILE (OSU), Upward Bound and Running Start (UH community colleges).

C The lead institution (UH) and several partner institutions serve diverse populations and communities. The UH community includes NHPI students and educators.

D A rigorous A.S. degree program was recently established at one of the Hawaii community colleges through a TCUP grant, and articulates with several UH Bachelor degrees relevant to microbial oceanography.

E Numerous opportunities exist for marine science outreach within Hawaii, which has an enduring legacy with the sea, and numerous partnerships already exist with marine education centers.

F Close, working partnerships exist with several NHPI-serving organizations, including Ka `Imi `Ike, Na Pua No`eau and Pacific Internship Programs for Exploring Science, all of which engage NHPI in hands-on science. Further opportunities exist to partner with the Hawai`i Academy of Science's Pacific Symposium for Science and Sustainability, a

program involving NHPI students in professional conference experiences.

G Existing partnerships between the Education Coordinator, UH's Center on Disability Studies (CDS), ALU LIKE (a Native Hawaiian-serving organization) and several minority-serving high schools to develop culturally responsive, career-oriented science curricula. (http://www.scihi.hawaii.edu).

H We may be able to develop a pathway for NHPI toward careers and graduate school through the Global Environmental Science undergraduate degree program, by establishing recruitment and retention mechanisms. This possibility is being actively explored as of the time of this writing.

Challenges

A Limited participation of underrepresented groups, especially Native Hawaiians and Pacific Islanders, in marine microbial education and research programs, and STEM in general.

B Obtaining sufficient resources to support involvement of teachers and K–16 students in field, laboratory, and ship-based programs.

C High rates of teacher turnover and student dropout in minority-serving K–12 schools.

D Social, academic, and financial challenges in recruiting and transitioning members of underrepresented groups into undergraduate and graduate programs at Center institutions.

E With few projected faculty openings associated with C-MORE, the Center has limited opportunity to achieve greater diversity in the national workforce through direct hiring.

4.4. Goal and Objectives

Goals

A Increase the number of underrepresented minorities, particularly Native Hawaiians and Pacific Islanders (NHPI), in all levels of Center research and education programs.

B Increase the number of underrepresented minorities, particularly Native Hawaiians and Pacific Islanders, pursuing careers in the ocean and earth sciences, and related disciplines.

Objectives

A Seek and develop opportunities to increase diversity among faculty, staff, and advisory personnel within the Center (Goal A).

B Develop and implement specific recruitment and retention mechanisms to increase the representation of NHPI and other underrepresented groups among students and trainees within the Center (Goals A–B).

C Develop and implement specific recruitment and retention mechanisms to increase the representation of NHPI and other underrepresented groups within the ocean and earth sciences, and related disciplines (Goal B).

4.5. Strategies

A Review the current status and identify specific opportunities and mechanisms to increase Center diversity at all levels (students, trainees, faculty, staff, and advisory) (Objectives A–C).

B Encourage professional advancement among junior and underrepresented faculty and staff members (Objective A-C).

C Identify current status and efforts to increase NHPI in careers in the ocean and earth sciences, and related disciplines, and identify appropriate models in other disciplines or among other underrepresented groups (Objectives B–C).

D Develop and implement specific recruitment and retention mechanisms for NHPI students into courses and majors in the ocean and earth sciences, and related disciplines (Objective C).

4.6. Implementation Plan

Objective	Goals	Actions Required	Responsible Person(s)	Primary Location(s)
A. Seek and develop opportunities to increase the representation of NHPI and other underrepresented groups among faculty, staff and advisory personnel	A	• Take advantage of infrequent hiring opportunities to increase representation of underrepresented groups within the Center (Years 1-5) • Invite leaders from NHPI and other underrepresented groups to serve on advisory councils (Year 2) • Provide opportunities for professional development such as representing the Center at national meetings, participation in Center management, participation in science planning within and outside Center (Years 2–5)	Center Management Bruno, Center Management ExCom	All partners UH All partners
B. Develop and implement specific recruitment and retention mechanisms to increase the representation of NHPI and other underrepresented groups among students and trainees within the Center	A–B	• Identify current status and efforts to increase Center diversity among students and trainees from NHPI and other underrepresented groups (Year 2) • Identify specific opportunities and mechanisms to increase Center diversity among students and trainees from NHPI and other underrepresented groups (Years 2–4) • *Additional actions are listed below under "Objectives C & D")*	Center Management Center Management	Primarily UH Primarily UH
C. Develop and implement specific recruitment and retention mechanisms to increase the representation of NHPI and other underrepresented groups within the ocean and earth sciences, and related disciplines	B	• Identify current status and efforts to increase NHPI and other underrepresented groups in careers in the ocean and earth sciences, and related disciplines, including recruitment into SOEST courses and majors (Year 2) • Identify appropriate models in other disciplines or among other underrepresented groups (e.g., LSAMP, M.S.-Ph.D.) (Years 2–3) • Based on above, identify specific opportunities and mechanisms to increase NHPI and other underrepresented groups in careers in the ocean and earth sciences, and related disciplines, including recruitment into SOEST courses and majors (Years 2–4) .	Bruno, Karl, Kemp Bruno, Karl, Kemp Center Management, ExCom	Primarily UH Primarily UH All partners

Objective	Goals	Actions Required	Responsible Person(s)	Primary Location(s)
Objectives B & C (stated above)	A–B	*Additional Joint Actions that apply to both Objectives B & C:* • Develop and employ recruiting tools that express diversity. Examples: website, videos and posters, esp. regarding careers. Venues: Open House events, field trips, conferences and meetings (Years 2–5) • Develop partnerships with "feeder" organizations, including NHPI-serving high schools, community colleges, and community groups (Years 2–5) • Create "A Sense of Place" for NHPI students, by providing a physical space for students to meet, share and study; providing each student with a peer mentor; and encouraging family participation (Year 3–5) • Provide scholarships, paid undergraduate research opportunities (traineeships, internships), and graduate assistantships (Years 2–5) • Establish clear pathways and pipelines toward graduation and jobs, by developing partnerships with industry and other potential employers, and fostering interaction between potential employers and students (e.g., career fairs) (Years 2–5)	Center Management for all actions	Primarily UH, with all partners

4.7. Metrics

Metrics for diversity are linked to those of education, especially in the recruitment of students at all levels. Data will be collected to assess productivity and to evaluate the impact of the program on C-MORE's diversity goals.

4.7.1 Productivity Metrics

A Establishment and semi-annual or quarterly meetings of a Diversity Advisory Council (All Objectives).

B Number and types of professional development and mentoring opportunities offered to junior and underrepresented faculty (Objective A).

C Establishment of "A Sense of Place" for all C-MORE students, including NHPI students (Objectives B–C).

D Number and types of outreach efforts that express diversity and numbers of participants reached (Objectives B–C).

E Number and types of K–16 educational activities targeted at NHPI and other underrepresented minorities, and numbers of participants (Objectives B–C).

F Number of scholarships, undergraduate research opportunities (traineeships, internships), and graduate assistantships offered to NHPI and other minorities (Objectives B–C).

G Numbers and kinds of partnerships developed with NHPI-serving and other minority-serving organizations (Objectives B–C).

H Numbers and kinds of partnerships developed with industry and the private sector (Objectives B–C).

I Number and types of recruiting efforts aimed at bringing NHPI and other underrepresented minorities into careers in the ocean and earth sciences, and related STEM disciplines (Objectives B–C).

J Number and types of recruiting efforts aimed at bringing NHPI and other underrepresented minorities into C-MORE research and education programs (All Objectives).

K Number and types of conferences and meetings attended, and types of material distributed or presented relating to diversity (All Objectives).

4.7.2 Outcome Metrics

L An increase in the number of Center faculty, staff, and advisory personnel from NHPI and other underrepresented groups (Objective A).

M An increase in the number of Center students and interns from NHPI and other underrepresented groups (Objective B).

N An increase in the number of NHPI and other minorities majoring, minoring, completing certificate programs, and graduating with degrees in SOEST and related disciplines (e.g., marine biology degree, Marine Options Program certificate) (Objective C).

4.8. Financial Resources

Diversity is an integral part of all Center activities, so resources for diversity have not been separated from those for education, research, and knowledge transfer. Because of the importance of these goals, we are considering bringing in an expert in diversity issues as a C-MORE partner, as a means of focusing attention on diversity issues as well as to provide additional opportunities for increasing diversity at all levels. Funds would be earmarked specifically for this effort.

4.9. Management Plan

The management of the Center's Diversity plan will be the responsibility of every senior member of the C-MORE Team at both the host and partner institutions. Issues related to the enhancement of Diversity will be integral to the Center's function and success. The Associate Director will coordinate and track the Center's progress toward the implementation of the Strategic Plan for Diversity, in part by developing reporting systems for routine use by C-MORE participants. All participants will be expected to provide information routinely regarding their efforts toward achieving diversity goals.

A Hawaii Diversity Advisory Council has been formed for a one-year period through consultation among the Director, Associate Director and Education Coordinator. After one year, the Council may dissolve or reform, depending on needs. The present member organizations are as follows.

Global Environmental Science, the undergraduate degree at UH Manoa that articulates with the Oceanography graduate program. Representatives: Jane Schoonmaker and Frank Sansone.

Hanauma Bay Marine Sanctuary on Southeast Oahu operates a community education program to educate the public about Hawaii's marine environment. Representative: Elizabeth Kumabe.

Ka Hana 'Imi Na'auao, a project of the UH Center on Disability Studies, creates culturally responsive, inclusive, career-oriented science curricula. Representatives: Kelly Roberts and Lisa Galloway.

Ka`Imi`Ike, an NSF-funded, career-focused program aimed at recruiting and retaining NHPI undergraduates into the earth and ocean sciences. Representatives: Barbara Gibson and Noelani Puniwai.

Kapiolani Community College STEM (KapCCSTEM) is a recently established, rigorous A.S. degree program in natural science. Representatives: John Rand and Keolani Noa.

Louis Stokes Alliance for Minority Participation (LSAMP) is based at UH Manoa and targeted at NHPI undergraduates in science, math and engineering. Representative: Josh Kaakua.

Na Pua No'eau, the Center for Gifted and Talented Native Hawaiian Children, aims at increasing educational enrichment opportunities for Hawaiian children in grades K–12. Representative: David Sing.

Pacific Internship Programs for Exploring Science (PIPES) offers internships to local students interested in the natural resources of Hawaii and the Pacific region. Representatives: Sharon Ziegler-Chong and Carmen Perez-Frayne.

Representatives of the NHPI community are invited to attend meetings as guests.

One representative (David Sing) is also a member of the External Advisory Committee.

5. Knowledge Transfer

5.1. Vision Statement

C-MORE will lead the way in the creation of microbial oceanographic data, theory, and synthesis, including tangible products and tools, and will be the international leader in transferring this knowledge to others.

5.2. Mission Statement

Engage in two-way knowledge transfer that benefits the Center, government and policy makers, industry, the public, and the academic community.

5.3. Situational Analysis

Strengths and Opportunities

A Extensive PI experience with the development and use of comprehensive biogeochemical and molecular/genomic databases, data transfer, visualization systems, and web-based information systems.

B Multiple C-MORE partner institutions and their external associations provide numerous opportunities for knowledge transfer at the national and international levels.

C C-MORE partners have experience with commercialization of intellectual properties.

D C-MORE partners are highly productive and highly visible leaders in microbial oceanography research, with a history of strongly collaborative work.

Challenges

A Making the invisible microbial world tangible and visible to the public.

B Identifying potential industrial users of C-MORE intellectual products, and developing industrial partnerships.

C Need to integrate and provide ready access to exceptionally large and heterogeneous datasets, to C-MORE partners and potential external users.

5.4. Goals and Objectives

Goals

Transfer the intellectual products of C-MORE activities, and a greater understanding of microbial oceanography, to external stakeholders including academic researchers, policy makers, industry, and the general public.

Objectives

A Disseminate scientific and technical knowledge to peers.

B Enhance public awareness of marine microbial oceanography and its importance, including educating policymakers.

C Promote economic development through commercialization and entrepreneurial use of C-MORE products ranging from basic knowledge to biotechnology and remote sensing tools and technologies.

5.5. Strategies

A Disseminate synthesized data and technical information via data centers, publications, and presentations (Goal A).

B Conduct formal and informal public seminars on topics related to microbial oceanography (e.g. global climate change)(Goals A–B).

C Develop an extensive website to facilitate dissemination of information to the public and to aquatic science professionals (Goals A–B).

D Engage and inform policy makers by interacting with congressional staff, and with national and international science planning committees and organizations (Goal B).

E Seek external partners to realize opportunities for commercial implementation of C-MORE's intellectual products (Goal C).

F Establish professional development programs for educators and students to gain a greater understanding of microbial oceanography.

5.6. Implementation Plan

Objective	Actions Required	Responsible person(s)	Primary Location(s)
A. Disseminate scientific and technical knowledge to peers	• Present results of C-MORE research at workshops and conferences (years 1–5)	All participants	All partners
	• Publish formal research papers (Years 1–5)	All participants	All partners
	• Seek out opportunities for focused discussion of microbial oceanography at national and international meetings, including developing new targeted workshops and conferences (Years 2–5)	Karl, Kemp, DeLong, All participants	All partners
	• Employ web-enabled mechanisms for data sharing and distribution (Years 2–5)	Kemp, Facilities Support Team	UH
	• Contribute annotated data, data summaries, data interpretations, and verified data sets to other data centers as appropriate (Years 1–5)	All participants	All partners
B. Enhance public awareness of marine microbial oceanography and its importance, including educating policymakers	• Use web-enabled methods directed toward informing and educating the public (Years 2–5)	Kemp, Facilities Support	UH
	• Develop multimedia presentations to communicate key concepts in microbial oceanography (Years 2–5)	Bruno, Kemp, Dyhrman	All partners
	• Present public lectures as opportunities arise (Years 1–5)	All participants	All partners
	• Provide briefing sessions for policymakers and their staff (Years 2–5)	All participants	All partners
C. Promote economic development through commercialization and entrepreneurial use of C-MORE products ranging from basic knowledge to biotechnology and remote sensing tools and technologies	• Conduct Center-sponsored workshops and seminars on C-MORE products, e.g., instrumentation, analyses, biotechnology tools (Years 1–5)	Scholin, DeLong, All participants	MBARI, MIT, All partners
	• Provide short courses, visitor training or other training opportunities for academia and industry (Years 2–5)	All participants	All partners
	• Seek out specific industrial partners for possible commercialization of tangible products (Years 2–5)	All participants as appropriate	All partners

5.7. Metrics

At present, we are tracking productivity of C-MORE participants with respect to knowledge transfer, but it is premature to assess the long-term outcome of knowledge transfer activities. Thus, only productivity metrics are listed below.

A Number of presentations by C-MORE participants, including presentations in non-academic public venues (Objectives A–B).

B Number and citations of peer-reviewed publications by C-MORE participants (Objective A; this is also evidence of recognition and therefore of long-term impact).

C Number and types of data sets made available to the scientific community (Objective A).

D Implementation of data access, data sharing and collaboration tools (Objective A).

E Number of media articles and press releases provided, and number of articles resulting (Objective B).

F Web download statistics (Objective B).

G Contacts with and briefings provided to policymakers and their staff (Objective B).

H Patent disclosures and awards (Objective C).

I Courses, workshops, conference sessions, and their attendance (Objective C).

J Information products developed and disseminated (Objective C).

K Presentations, visits and other interactions with possible industrial partners (Objective C).

L Advisory committee memberships and similar professional contributions related to C-MORE (Objective C).

5.8. Financial Resources

Resource Allocation

	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Knowledge Transfer	500,984	454,991	513,968	523,159	520,506	2,513,608

5.9. Management Plan

The Knowledge Transfer implementation plan will be managed by a small team consisting of the Director (Karl), co-Director / Research Coordinator (DeLong), Associate Director (Kemp) and Education Coordinator (Bruno). The Associate Director will coordinate with lead investigators at partner institutions to track and facilitate progress and troubleshoot any problem areas, and will be responsible for the annual summary of all Center knowledge transfer-related activities. Regularly scheduled meetings and periodic reports will be used as a management tool. Web-enabled technologies will be employed to collect information regarding knowledge transfer activities, facilitating tracking and reporting such activities.

Appendix A. Data Policy and Management

Biogeochemical and oceanographic data management and distribution plan

We will take advantage of the the data model developed by the HOT program to facilitate distribution and management of biogeochemical and oceanographic data sets. Time series data from the HOT program are freely distributed using the web-based Hawaii Ocean Time series Data and Graphical System (HOT-DOGS). HOT-DOGS was developed by members of the HOT program based on the recognition that the oceanographic community required more efficient and user friendly means of accessing data. By providing access to continuous and discrete oceanographic and biogeochemical data, HOT-DOGS allows anyone with access to the internet to download individual or grouped data (as text files), and provides a user-friendly graphical interface to display time and space dependent changes ocean ecosystem properties. Thus, our use of the HOT-DOGS data distribution model relies on proven and previously successful technologies.

We also recognize that the HOT-DOGS database does not cover all data types. We will employ and provide links to other data repositories as needed, and will develop a user-friendly data portal to all data repositories used by C-MORE personnel. All C-MORE participants are strongly encouraged to provide their data to publically available repositories as soon as the data are validated. We recognize that a brief embargo period may be appropriate in some cases (e.g. data used in a PhD dissertation under preparation).

Genomic and metagenomic data management plan

The development of metagenomic data collection, analyses, metadata tagging, and data transfer methods and standards is a large community challenge, but one that is critical to and relevant for the successful completion of goals and vision of C-MORE. Several sequencing and informatics Centers, notably the DOE Joint Genome Institute (JGI) and the California Institute for Telecommunications and Information Technology (CalIT2) at UCSD, are beginning to address this problem. Notably, a new Community Cyberinfrastructure for Advanced Marine Microbial Ecology Research and Analysis (CAMERA), has recently been established at UCSD to deal solely with this issue. While C-MORE alone will not solve all community issues related to metagenomic data analyses, handling and transfer, we plan to work in partnership, and lead by example, working other specialty institutes working on the problem. There will be yearly meetings with representatives of these groups and C-MORE personnel. DeLong is a Scientific Advisory Board member for CAMERA and will lead the coordination of these efforts.

In a rapidly evolving field of metagenomics where standards have yet to be developed, C-MORE will become an early adopter and beta tester of developing metagenomic databases, data analysis and data transfer systems. At the same time, we will manage data internally to avoid becoming reliant on systems that may not succeed or become universally adopted by the community. The general plan for this implementation follows.

Metagenomic data analyses and transfer – CMORE internal users

Internally, metagenomic datasets and databases will be managed at mirrored sites, including UH, MIT, and possibly UCSC. DeLong at MIT maintains a 15 node, 30 processor cluster backed up by a RAID array for data storage and analyses. The data and analytical packages (blast, blat, TreePuzzle, Paup, Mr Bayes, fastDNAml, EMBL package, etc) will be made available via a webserver to C-MORE users. These same systems can be used as blastservers for guest users, making data available to the wider community. We are considering establishing a mirrored site at UH-Manoa to serve as a commons for metagenomic data storage and serving. The separate sites will also provide redundant data backup facilities ensuring data security.

Data release – standard implementation

This aspect of the data management effort needs to be well coordinated with ongoing informatics efforts and developing standards. Currently, there are no firmly established guidelines for release of metagenomic data. At most major

sequencing centers (Broad Institute, JGI for instance), trace files of raw sequence data go directly from sequencing machines to the National Center for Biotechnology Information (NCBI) tracefile archive. “Finished” metagenomic datasets that are ready for analyses typically have been deposited in either the NCBI environmental database (env_nt, env_nr) or the Genome Sequence Survey database (GSS), either 6 months after sequence completion (see current examples of genomic data release policies, below), or upon publication.

We will follow these standard data release policies with metagenomic sequence data produced by C-MORE. Much of the sequence data that C-MORE will use is not generated by C-MORE but rather is obtained from leveraged projects funded by non-NSF funds (e.g., GBMF and DOE sequencing efforts). In these cases, data release will generally be handled and administered by the specific Sequencing Center that has produced the data. In this context, C-MORE is a sequence user, but importantly, also a metadata provider. As an example dataset, we have already deposited HOT sequence data into the NCBI Genome Sequence Survey database. These data are tagged with relevant metadata on physical and chemical sample parameters, and represent the first such dataset now deposited in GenBank. We anticipate that reciprocal links between sequence metadata fields and C-MORE-collected oceanographic data will be developed and implemented as C-MORE standard practice. These developments will depend on parties and programs outside C-MORE and the time frame is not clear at present.

Currently implemented data release policies

(Note : These apply mainly to individual genome sequences rather than to metagenomic datasets, which are fundamentally different.)

NIH www.genome.gov/10506537

DOE www.sc.doe.gov/ober/EPR/data.html

JGI www.jgi.doe.gov/sequencing/collaborators/datarelease.html

Appendix B. Intellectual Property Agreement

Research Institutions:	University of Hawaii (UH) Monterey Bay Aquarium Research Institute (MBARI) Massachusetts Institute of Technology (MIT) Oregon State University (OSU) University of California at Santa Cruz (UCSC) Woods Hole Oceanographic Institution (WHOI)
Research Project Title:	Center for Microbial Oceanography: Research and Education (C-MORE)
Research Funding Agency(s):	National Science Foundation
Reference Award Number:	CCF-0424599
Research Time Period:	9/1/2006 - 08/31/2011

This Intellectual Property Agreement (this "Agreement") is entered into between the Research Institutions set forth above (hereinafter collectively referred to as the "Parties," and each singularly as a "Party"), in relation to the research project set forth above (the "Project"). This Agreement sets forth the mutually agreed terms and conditions of their relationship under the Project.

RECITALS

WHEREAS, the Parties agree to abide by the regulations of the National Science Foundation (NSF) and to collaborate in developing the standards, requirements, and procedures of the Center for Microbial Oceanography: Research and Education (C-MORE); and

WHEREAS, the Parties will be collaborating on the Project, which is being funded by the National Science Foundation ("NSF") as part of its Science and Technology Centers Program; and

WHEREAS, the Parties in the course of such collaborations may be using each other's facilities including laboratory space and research vessels; and

WHEREAS, each of the Parties is also separately governed by a Subaward Agreement which defines the scope of work to be carried out by each Party in fulfillment of the goals and objectives of C-MORE; and

WHEREAS, the Parties agree that any patentable intellectual property (IP) that is conceived or reduced to practice in the performance of the Subaward Agreement, shall be owned by the institution that invented the IP and governed by the provisions of the Cooperative Agreement and Cooperative Agreement Financial and Administrative Terms and Conditions (CA-FATC); and any inventions conceived or reduced to practice in the performance of the Subaward Agreement, shall be specifically governed by Bayh-Dole 37 CFR 401; and

WHEREAS, the Parties wish to provide for the allocation of certain rights as among themselves relating to the identification, disclosure and commercialization of IP resulting from their cooperative and collaborative activities under the Project;

NOW, THEREFORE, in consideration of the promises and conditions contained in this Agreement, the Parties mutually agree as follows:

1. The Parties hereby agree that, in the event patentable inventions are conceived and first reduced to practice during the performance of the research conducted under the Project

("Inventions"), the inventorship, and the ownership of such Invention shall be as follows:

a. Ownership shall be determined by inventorship unless the inventions and discoveries of one Party are made using the facilities of another, in which event written facilities use policies or relevant state law shall also be used to determine ownership of such inventions and discoveries.

b. Inventorship shall be determined in accordance with U.S. Patent Laws.

c. For the proper determination of inventorship, the Parties shall fully and promptly disclose, in confidence, any and all Inventions in writing to the other Parties.

d. Sole Inventions: Inventions made solely by employees of one Party shall be the sole property of that Party, and shall be disposed of in accordance to the internal policy of that Party.

e. Joint Inventions: Inventions made by employees of more than one Party shall be deemed to be joint property of such Parties, each such Party having an undivided equal interest in the same.

f. The Parties agree to consult with one another prior to taking any action to obtain patent protection of Joint Inventions and shall agree upon the patent filing and prosecution strategy of said Invention.

g. Each Party's ownership of and/or interest in the Inventions shall be disposed of in accordance with the internal policy of that Party.

h. Each Party agrees not to assert patent rights in subject Inventions against any other Party for that Party's research and educational purposes.

i. Subject to the terms of the funding support from NSF, the Parties agree to cooperate to utilize and exploit any Joint Invention.

j. Each Party will undertake actions to ensure that any subject Inventions obtain the benefit of the Cooperative Research and Technology Enhancement Act of 2004.

2. Nothing contained in this Agreement shall be deemed to grant any Party directly or by implication, estoppel, or otherwise any license under any patents, patent applications, copyrights, trademarks, mask works, trade secrets or other intellectual property owned or developed before or independent of this Agreement by the other Party.

3. It is understood that it may be necessary for one or more Parties to disclose information to the other which is considered confidential in order to accomplish the work under the Project. Each Party agrees to take all reasonable precautions to prevent disclosure to third parties of such confidential or proprietary information in the absence of any written consent by the other Party of such disclosure. The receiving Party shall consider as "Confidential Information" such information, data or material which:

   a. is disclosed by the another Party in written or other tangible form during the period of performance of the Project;

   b. is conspicuously marked confidential or proprietary; and

   c. is not available in the public domain.

   It is agreed that the Parties shall disclose only information necessary to the work to be carried out under the Project. The disclosing Party shall send such information only to the Project Manager or Principal Investigator of the receiving Party. If disclosed orally, the disclosing Party shall subsequently provide a written summary of the information within thirty days of the oral disclosure. The Parties agree that, to the extent permitted by law, such Confidential Information shall remain the property of the disclosing Party and, for a period of five (5) years from the end of the Project, such Confidential Information shall not be disclosed to others by the receiving Party without the disclosing Party's prior written approval, provided, however, that the foregoing obligation of non-disclosure shall

not apply to any portion of the Confidential Information which:

a. is or shall have been known to the receiving Party before receipt thereof;

b. is disclosed to the receiving Party by a third party having no obligation of confidentiality to the disclosing Party;

c. is or shall have become known to the public through no fault of the receiving Party,

d. is independently developed by one or more of the Parties, or

e. the receiving Party is obligated to produce pursuant to an order of a court of competent jurisdiction or valid administrative or congressional subpoena, provided that receiving Party promptly notifies the disclosing Party.

4. This Agreement constitutes the entire and only agreement between the Parties regarding the disposition of intellectual property developed as part of the Project and all other prior negotiations, representations, agreements, and understandings are superseded hereby. No agreements altering or supplementing the terms hereof may be made except by a written document signed by all Parties.

5. Notices and other communications required by the terms and conditions of this Agreement shall be made by first-class mail or private courier, postage prepaid, confirmation by facsimile to the cognizant administrator at each partner institution.

6. This Agreement shall terminate with the expiration of the last to expire patent developed under the Project, or on abandonment of all patent applications developed under the Project, provided such abandonment is by mutual consent.

7. If any disagreements arise, the Parties will use their best efforts to negotiate to resolve all differences. The collaboration of the Parties is paramount.

8. Waiver by any Party of any breach or failure to comply with any provision of this Agreement by the other Party shall not be construed as, or constitute a continuing waiver of such provision or a waiver of any other breach of or failure to comply with any other provision of this Agreement.

9. The invalidity, illegality or unenforceability of any provision contained in this Agreement shall not affect or render invalid, illegal or unenforceable the remainder of this Agreement.

10. This Agreement shall be effective as of the date of the last signature below. This Agreement may be executed in one or more counterparts, which collectively constitute one agreement.

IN WITNESS WHEREOF, the parties have caused this Agreement to be executed as of the year and date below described as set forth by their duly authorized representatives.

For UH	For MBARI	For MIT
Richard Cox *Director, Office of Technology Transfer and Economic Development*	*C. Michael Pinto* *Chief Financial Officer*	*Lita Nelson* *Director, Technology Licensing Office*
For OSU	**For UCSC**	**For WHOI**
Craig Sheward *Director, Office of Technology Transfer*	*Gerald Barnett* *Director, Office for Management of Intellectual Property*	*William McKeown* *Director, Shore Operations and Technology Transfer*

Appendix C. Code of Ethics and Human Studies

All research, education and scholarship that is undertaken by the Center staff will be pursued in an environment in which high ethical standards are the norm. Academic institutions exist and operate on trust and this demands a responsibility for the integrity of the process involved in collecting, analyzing and publishing data collected through activities sponsored by the Center. At all C-MORE institutions, there are formal documents in place that articulate Ethical Standards in Research and Scholarly Activities (at UH it is entitled, Executive Policy E5.211). For example, the UH Ethics Committee is charged with investigating allegations of scientific misconduct which includes falsification of data, plagiarism, abuse of confidentiality, dishonesty in publication, deliberate violation of regulations, and failure to report fraud. This committee is appointed by, and reports to, the UH Vice Chancellor for Research. David Karl, the Director of C-MORE, was a member of this committee from 1993–1995 and served as Ethics Committee Chair from 1995–1998. A program of ethics training based on these and related documents, such as those published in 1996 by J. Woodward and D. Goodstein in *American Scientist* ("Conduct, misconduct and the structure of science," vol. 84: 479–490) and in G. Taube's 1993 special news report in *Science* ("Misconduct: Views from the trenches," vol. 261: 1108–1111), will be developed by the Center for all staff including faculty, visiting faculty, industrial fellows, post-doctoral fellows, graduate and undergraduate students, and technical assistants. In addition, UH offers a program for graduate student orientation on responsible conduct of research including: ethical violations, plagiarism, principles of authorship, conflicts of interest, and violation of relevant research policies and government regulations. There is additional training on working with human subjects, the matter of informed consent, and working with animals. This basic training program is modified to address target audiences and is expanded to address discipline-specific issues.

All research within the Center will be conducted using accepted procedures and policies as they relate to environmental health and safety, the use of radioisotopes and recombinant DNA. At all C-MORE institutions, there are well-established policies and procedures in place for oversight of Federal Regulations regarding the protection and management of risks to human participants involved in research. The UH Institutional Review Board (IRB) serves as an objective third party to enforce UH policies and procedures (http://www.hawaii.edu.irb). Requests made to this Board for C-MORE related research will be evaluated on a case-by-case basis.