SUMMARY[1] OF AAAS 2012 EVALUATION OF THE GORDON AND BETTY MOORE FOUNDATION'S MARINE MICROBIOLOGY INITIATIVE, PHASE 1 (2004–2010)

BACKGROUND

Oceans account for ~70% of Earth's surface. Primary productivity, many chemical cycles, and food webs depend on the ocean's microorganisms, which also convert carbon, nitrogen, sulfur, and trace minerals like iron from inorganic to biologically usable forms. We know that these important marine systems and processes have been experiencing unprecedented stress due to increased nutrient run-off, overfishing, and pervasive and significant changes in ocean chemistry and temperature driven by increased emissions of greenhouse gases, yet our specific knowledge is limited. Despite the fact that research in this field began more than 75 years ago, as recently as the early 2000s, even the most basic ecological questions—Which organisms are present? What do they do? How do they interact?—remained unanswered due primarily to major obstacles such as:

Box 1. Marine microbial ecology defined

Marine microbial ecology is the study of the single-celled organisms (bacteria, archaea, and eukaryotes) and viruses that live in the ocean and their interactions with each other and the environment around them. These microorganisms and viruses are the ocean's smallest and most abundant creatures, and they drive many of the chemical reactions that comprise the Earth's marine biogeochemical cycles.

- An inability to grow most microbes in culture in tandem with limited morphological characteristics capable of differentiating species, creating a major taxonomic impediment resulting in treatment of broad groups of microbes as "black boxes" with little knowledge of the role of each species.
- Limited ability to observe the distribution of most marine microbe, beyond pigmented microbes (*e.g.*, phytoplankton) living close to the ocean's surface that could be captured via satellite imaging.
- Limited capacity for ocean observation at scales relevant to marine microbes, particularly given that many of the critical processes involving microbes occur at scales of microns, while effects magnified by the microbial community may be regional and even global.

Fortunately, technological advances in the 1990s created new opportunities to begin to overcome these challenges. Most notably, new tools enabled genome sequencing that afforded, for the first time, unambiguous microbial identification, but applications of these tools to microbial ecology were few. Genome sequences were complete for only a few species, taxonomic inventory of heterotrophic microbes had hardly begun, and genetics-based taxonomy was lacking for most microbial groups. The 1990s also marked the widespread recognition of a need for better ocean observation. The development of cabled observatories and fleets of autonomous vehicles fitted with new *in situ* sensors, joined important time-series observations to offer new opportunities for observation beyond cruise-based research that typically provided "snapshot" views of dynamic oceans and their microbial life.

Against this backdrop, the Gordon and Betty Moore Foundation (GBMF) launched the Marine Microbiology Initiative (MMI) in 2004 to significantly increase resources and effort to use the new tools—

[1] Editor's Note: This document is a summary of the much longer final report submitted to GBMF by AAAS in 2012. While GBMF believes that AAAS' findings and recommendations are fully and accurately represented herein, AAAS is unable to review the document or approve its contents.

and to develop others—to delve into the "who," "how," and "where" of major marine microbial processes. Initially authorized for 10 years (2004–2013) and $145M, MMI defined as its ten-year objective: "*Marine microbiology is transformed into an integrated field of marine microbial ecology by applying novel molecular technologies and instruments with the goal of monitoring, modeling and generating new fundamental knowledge about representative microbial ecosystems in the ocean*" (See Appendix A for the full set of MMI's Phase I time-phased outcomes). To achieve this objective, during the period 2004–2010 MMI granted approximately 70 awards supporting individual researchers, development of methods, and formation of community resources.

Prior to embarking on an approved second phase of MMI (2011–2019) and building on an external evaluation of the first three years of the program conducted in 2007, GBMF commissioned the American Association for the Advancement of Science (AAAS) to conduct an evaluation of the strategic focus and design, deployment, and results of the initiative's first phase. AAAS also was asked to weigh in on the forward direction of Phase II, both in light of learning and recommendations stemming from Phase I, and based upon broader knowledge of the field. The methodology, findings, and recommendations of the evaluation are presented herein, preceded by a brief overview of the first phase of MMI and followed by an overview of MMI's second phase, incorporating GBMF's response to the evaluation.

OVERVIEW OF THE FIRST PHASE OF MMI

GBMF sought to transform the field of marine microbiology via three interwoven grantmaking strategies:

- **GBMF Investigators in Marine Microbiology** *(awards to individual PIs)***: 12 awards, $55M.** Twelve investigators—five "junior" (not tenured at the time of the award) and seven "senior" (tenured)—were supported to tackle a range of essential topics and leading questions in marine microbial ecology, with an emphasis on the contribution of specific marine microorganisms to surface ocean and coastal oceanographic processes. Several investigators also led the field in methods development and applying these methods in novel ways.
- **"Multidisciplinary Expansion"** *(research at interdisciplinary interfaces)***: 11 awards, $21M.** These grants supported multidisciplinary collaborative projects in new research areas with potential for high scientific returns, with a particular sub-portfolio of evidence-based computational ecosystem models in which modelers and experimental scientists worked closely together. Many of the multiyear grants in this sub-portfolio were launched in 2008–2010 and thus have not yet reached fruition, including modeling efforts of coastal oxygen minimum zones, the Amazon River and its marine plume, and the mineral-laden emissions that rise from the seafloor in association with deep-sea hydrothermal vents.
- **"High Impact Research"** *(projects of direct utility to the entire community)***: 41 awards, $69M.** Grants made under this strategy have supported community resource projects (data generation, methods development, training; $57M) and instrumentation and technology development ($12M). Community resources include major genome and metagenome sequencing efforts (several with opportunities for the international community to nominate organisms for sequencing), bioinformatics methods development, computational infrastructure to hold sequence data and enable researchers to analyze the data in sophisticated ways, and interdisciplinary training activities for the next generation of scientists. The instrumentation and technology bucket provided top scientists with newly available leading technologies to enable them to test how the new platforms could be used to advance the field of marine microbial ecology. For example, the latest DNA sequencing equipment was furnished to several senior investigators so that they could examine important marine microbial ecology research questions in new ways. This R&D tactic benefits the entire microbial ecology research community when the publications are released. Other technology support included geochemistry analyzers; "gliders" that

swim through the ocean collecting data, and microscopes; developing microbial sensor technologies for use in the ocean; and developing and applying advanced microscopy and cell sorting techniques.

EVALUATION APPROACH

AAAS conducted a comprehensive review over the course of one year commencing in September 2011, led by an AAAS External Advisory Committee (EAC; Box 2). The review approach had four components. First, assessment of the scientific outcomes of 70 MMI Phase I grants and their contributions to the field of marine microbiology were carried out by three independent review panels, organized around the following themes (see Appendix B for lists of projects reviewed by each Panel):

- Panel I: MMI investigators, summer courses and workshops
- Panel II: Microbial diversity, ecology, and biogeochemistry
- Panel III: Sequencing, genomics, and bioinformatics

Box 2. EAC members:

- Gary Borisy, President and Director of the Marine Biological Laboratory
- Claire Fraser-Liggett, Director of the Institute for Genome Sciences; Professor of Medicine, University of Maryland School of Medicine, Baltimore
- Robert Gagosian (Chair, EAC), President/CEO of the Consortium for Ocean Leadership
- Margaret Leinen, Associate Provost of Marine and Environmental Initiatives and Executive Director of the Harbor Branch Oceanographic Institute, Florida Atlantic University
- Paul Snelgrove, Canada Research Chair in Boreal and Cold Ocean Systems; Professor, Ocean Sciences Centre and Biology Department, Memorial University

These three panels addressed the following common evaluation questions:

- What were the major scientific accomplishments?
- What were the broader impacts?
- To what degree were the MMI processes aligned with the goals of the program?

A fourth panel was charged with conducting a detailed assessment of the Community Cyberinfrastructure for Advanced Microbial Ecology Research and Analysis (CAMERA) program. A total of 18 experts participated in the four panels, with each chaired by an EAC member to provide continuity.

Second, in order to understand the processes used by MMI to select and evaluate research that aligned with MMI goals, AAAS staff and the EAC Chair interviewed current and former MMI staff and GBMF scientific advisory board members. A survey of MMI grantees was also conducted to understand these processes and the impacts of MMI from the grantee point of view.

Third, through a subcontract to Science Metrix, Corp, a bibliometric and social network assessment was carried out on the MMI grantees and the field of marine microbiology. Finally, all of these data were reviewed by the EAC and synthesized to develop their findings and overarching recommendations, These were provided to GBMF in the form of a detailed report and, for ease of reading and sharing more broadly, are synthesized below.

PRIMARY EVALUATION FINDINGS

MMI Phase I Impacts on the Field

Consistent with its stated long-term goal—"*marine microbiology is transformed into an integrated field of marine microbial ecology*…"—and by enabling high-risk and interdisciplinary research, the AAAS panels and survey respondents generally agreed that MMI successfully transformed significant aspects of the field (Box 3, Figure 1), including, most notably:

- Made the use of "omics" (genomics, metagenomics, metatranscriptomics)—previously thought to be risky and unlikely tools for the field of marine microbial ecology—routine and a part of the canon in this field, resulting in major breakthroughs.
- Advanced the capacity to identify and observe microbes in their ocean environment, including in remote, subsurface locations.
- Enabled major insights into the role of microbial communities in cycling of major nutrients, including nitrogen, sulfur, and carbon.
- Supported the development of new tools and strategies to understand gene expression in marine microbes and how that expression influences major ocean processes related to biogeochemical cycles and ocean productivity.
- In general, brought recognition and prestige to the field of marine microbiology.
- Funded individual and collaborative efforts of major players in the study of marine microbiology, leading to a range of publications that have contributed to the field.

Box 3. Anecdotal insights from MMI survey respondents regarding the impact of the initiative.

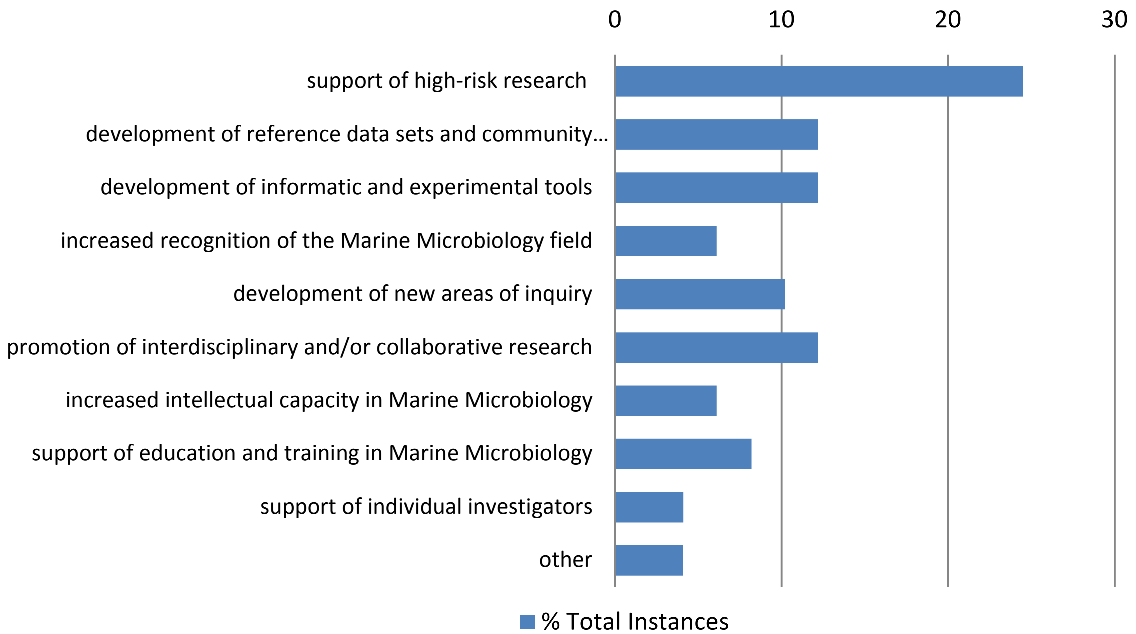
- "MMI has pushed the field of marine microbiology to entirely new levels, particularly in terms of the types of cutting-edge genomic approaches being applied to understanding diversity and functioning of marine microbial communities."
- "MMI provided funding for] discovery-based research programs that would be difficult or impossible to obtain funding for through normal federal agencies."
- "It gave us the infrastructure…and the funding necessary to run a laboratory that can take risks and go in new directions. It also gave me the freedom to take a long view of my research goals."
- "Provided resources and funding to support large-scale research programs in marine science during a time when federal sources for marine microbial ecology were shrinking."

These notable successes together represent a rapid expansion in knowledge of this critical component of marine life and how to study it, providing key insights that are attracting additional interest and investment. The significance of the advances made also validate GBMF's insightful decision in 2003 to make extensive investments in basic marine microbiology research, including enabling and ensuring the use of modern molecular biology techniques for the research.

A critical contributing factor to this success was MMI's strategy to create the MMI Investigators program, which provided remarkably generous funding to a small and highly select group of established and emerging leaders in marine microbial ecology. The established leaders were selected from several major institutions with strength and commitment in microbial ecology, and although the groups did not include all of the major players in the U.S. marine microbial research community, it included a large proportion of them. The Senior Investigators, who were established stars in 2003, continued (and continue) to lead key aspects of the marine microbial field with their MMI-supported research.

Although there is not a way to determine whether the advances they achieved through MMI might have occurred without MMI funding (leaders by definition, lead, and all of these investigators could claim multiple successes before MMI even began), there is little doubt that the program significantly accelerated the rate of progress on some of the major questions they addressed. Moreover, the established leaders all clearly performed very well. In a sense, the choice of established leaders effectively guaranteed success given that all had well-equipped labs with established personnel and workflows, and international reputations that ensured their work would attract top-notch students and postdocs, the interest of outside investigators, and complementary funding from other organizations.

Figure 1. AAAS survey results representing the view of MMI grantees (*n*= 45). The top responses to the question "To date, what has been the most important impact of the MMI on the field of marine microbiology?"



MMI Phase I Outcomes

Beyond the above overarching impacts of the first phase of MMI, the program realized a range of outcomes in the areas of research; acquisition of critical equipment and infrastructure, including establishment of several large facilities, development and acquisition of important tools, and building of major data sets; training of investigators, students, and staff working in MMI-supported labs; and education and training of more than 250 other students via workshops.

Research. Investment in the MMI Investigators program has been substantial and catalyzed major research activities in 12 core PI laboratories and in many associated laboratories supported by MMI funds (Box 4). The pioneering work of MMI grantees has transformed methodologies and approaches deemed high-risk prior to MMI's launch in 2003 to relatively tractable and appropriate tools for projects with similar scope and resources, resulting in major contributions to the field at the ecosystem, organismal, and molecular biology/biochemistry scales.

Equipment & Infrastructure. MMI invested heavily in equipment infrastructure to ensure that scientists could work with high quality and cutting-edge facilities. That strategy worked quite well, with some investments showing significant early returns and others showing great promise (Box 5). The ability of MMI to respond quickly to technology changes and take higher risks than traditional funding agencies in providing new technology significantly helped to bring advanced, diverse technologies to the marine microbial world and to the scientific community. Some of these technologies, such as high-throughput sequencing, have far broader application and will help to catalyze related disciplines. The broader impact of this infrastructure will likely emerge over time as MMI grantees and additional researchers take advantage of the instrumentation available, and others engage in the use of the novel applications to address new questions in marine microbial ecology and beyond.

Training. Within the 12 core MMI-supported labs, an impressive number of postdoctoral investigators, a relatively low number of graduate students, as well as a range of undergraduate students, lab personnel managers and technicians received training. As would be expected, training activity tended to be greater in more established labs than those of new investigators. Due to limitations of reporting, the overall impact of MMI training could not be assessed, however.

Summer Courses & Workshops. Modest support went to summer courses and workshops, with the former training over 250 students over three years primarily in molecular laboratory techniques, providing significant hands-on training with high-end instrumentation. Regarding workshops, MMI Investigators are brought together once a year to exchange ideas and network, with workshops to date covering topics such as ocean acidification and new directions in marine microbial ecology. This strategy was thought to be excellent and should be continued.

CAMERA. The vision for MMI-supported CAMERA was to create a central data repository together with bioinformatics tools to serve the needs of the marine microbiology community and other users. The program was established in 2004, with the first release of the Web portal in 2007, and a total rebuild and re-launch of the site in response to user feedback in 2010. As part of its evaluation of MMI, AAAS conducted a detailed assessment of CAMERA and found that although it has offered a range of unique and valuable services over the years; it also faces several important challenges with regard to future scale-up and continued service to its targeted community (Table 1).

Although CAMERA valuably serves the needs of a relatively small number of loyal users, MMI's original vision that CAMERA would become the genomics database of choice for the marine microbiology community has not

Box 4. MMI Phase I Research Highlights from EAC

Ecosystem Scale

- Increased understanding of abundance and function of N-fixing bacteria (Zehr).
- A novel process of aerobic methane production (Karl).
- Study of the potential role of phosphites/phosphonates (Karl).
- New mechanisms for anaerobic methane oxidation (Orphan).
- Orphan used Magneto-Fluorescent In Situ Hybridization to establish simplified consortia from deep-sea sediments
- Development of an iron-limitation index based on diatom work (Armbrust).
- Study of the influence of microbial populations on elemental stoichiometry and nutrient flow (C and N, respectively) (Karl and Zehr).

Organism Scale

- Demonstration of the complexity of the *Prochlorococcus* group and the implications of this diversity for specific environments (Chisholm).
- New insights into roles of, and how to study, the most abundant marine microbe, *Pelagibacter,* (Giovanni) and the coastal system keystone, *Roseobactor,* (Moran)
- Use of a marine flagellate as a model to study the evolution of a potential animal progenitor (King).
- The use of functional genomics was gained insight into diatom stress responses (Armburst), cyanobacteria diel cycle gene expression (Zehr), and S cycling (Moran).
- Study of interactions between Sulfate Reducing Bacteria and methanogens during anaerobic methane oxidation (Orphan) and on predator-prey relationships between microbe and virus (*e.g.*, Chisholm, Hughes-Martiny).
- Use of genomic data to investigate potential impacts on the S cycle (Moran), cellular energy conservation (DeLong, Giovannoni), C fixation (Armburst), CH_4 generation (Karl).

Molecular Biology/Biochemistry Scale

- Demonstration of the proton-pumping capacity of proteorhodopsin in one γ-proteobacterial clade (DeLong), and observation of proteorhodopsin in a SAR11 isolate (*Pelagibacter ubique*) (Giovanni).
- Exploration of novel P metabolism genes (Chisholm).
- Exploration of viral metagenomes (Rohwer).
- Demonstration of the capabilities and value of metagenomic approaches to studying marine microbes—thought unlikely previously, now a part of the canon of marine microbiology.
- Increased understanding of the use of metatranscriptomics (Armbrust, Moran, Zehr), a difficult and risky technique.
- Efforts to study the metagenomics of viruses (Rohwer), and of eukaryotes (Worden), both very challenging.

been realized. This is likely driven by the fact that consumers of genomics information often use multiple database resources to complete data analysis as rapidly and easily as possible and once a user finds a data analysis solution, their loyalty becomes difficult to change. Beyond addressing this issue, going forward, a business model is needed that would ensure CAMERA's sustainability. The increasing throughput and decreasing costs associated with generating DNA sequence data have outstripped Moore's law to the point that genome/metagenome analysis has become a standard assay in many environmental studies. And as data sets get larger and more disparate, the cost to store and integrate these data continues to increase. It should be noted that this particularly vexing problem cuts across all scientific communities, threatens to impede scientific progress, and is being discussed by all federal agencies that fund "-omics" research. Finally, the advent of next-generation DNA sequencers has democratized sequencing and moved this activity away from large genome centers and into the laboratories of individual investigators. While this has created greater flexibility in addressing priority research questions as they emerge, it also implies that careful thought is needed regarding CAMERA's future relevance and complementarity to data analysis at local levels.

Box 5. MMI Phase I Equipment & Infrastructure Highlights

Large Facilities. MMI Phase I supported community infrastructure centers such as MEGAMER and CAMERA (only the first is discussed herein, as CAMERA is addressed in detail later). MEGAMER is now well established and used by multiple MMI-funded grantees, including those engaged in MMI experiments as well as those developing instrumentation, and thus helps to bring MMI grantees together. MEGAMER is also intended to serve members of the greater oceanographic community through the opportunity to reserve lab space at the facilities; however, the evaluators were not able to determine in their analysis how many non-MMI researchers have utilized this facility. In addition, MEGAMER is intended as a training center for next-generation marine microbial scientists, and the potential for training looks very encouraging.

Tools. New tools developed under MMI may well represent one of the most significant and enduring legacies of the program. Multiple examples of new innovations (*e.g.*, ESP) and major advances in others (*e.g.*, *in situ* flow cytometer) could truly transform observation and understanding of marine microbes. Specifically, MMI scientists demonstrated the potential to monitor ecologically important (as well as harmful species), and to monitor gene expression within these species. Because these tools offer remote, long-term, and even real-time potential, they are likely to become major tools for understanding the complex dynamics of marine microbial communities. Some of the newly integrated laboratory equipment (*e.g.*, FISH-SIMS) provides never-before possible measurements that will greatly enhance microbial studies. Although, the MMI has necessarily focused on some very specific questions, the potential of "tool" development for future application to many other important problems is immense.

Off-the-shelf purchases include standard and novel applications of proven technologies. Through MMI, a variety of labs across the United States (and in one instance in Chile) were equipped with high-quality equipment necessary for field and/or laboratory experiments and measurements. All of these decisions appeared very sound, and will undoubtedly improve and accelerate marine microbial research at those locations. In some cases, PIs found new applications for existing technologies to provide new ways of "seeing" microbes (both literally and figuratively), and some of these applications show great promise.

Data sets. The MMI data sets represent an important aspect of infrastructure with many potential future applications. The CAMERA database, which is clearly the largest investment (discussed in the next section), illustrates that multiple users can benefit from shared data. The utility of MMI data beyond CAMERA and Genbank are unclear in terms of ongoing data sharing, ease of access, and future potential, though different projects report multiple examples of online data pipelines (*e.g.*, *nifH* and *Prochlorococcus* genomic and gene expression data). There is also mention of protocol development (*e.g.*, ESP, primer design) that will be invaluable although the mode of access and linkage to other protocols remains unclear. Data and standardized methodologies could be major legacies of the program but will require planning and effort to maximize utility.

Table 1. Findings from the AAAS CAMERA Review Panel Report (March, 2012)

Strengths: Unique services	Challenges: Scaling Up
• exceptionally well-curated metagenomics data sets are a resource for comparative studies by the research community • offering BLAST searches (unavailable elsewhere due to excessive computational intensity) • Web portal allows users to customize their own workflows and make sophisticated data queries • Personal, one-to-one collaboration provided by CAMERA staff to help researchers • ~50 power users that use CAMERA for research and publications	• capacity of system will not match data-intensive science of MMI Phase II • workflows are costly and current portal technology must be upgraded • balance between maintaining infrastructure on the cutting edge, and serving the needs of both high-end and naïve users • consulting capability cannot scale much beyond its current level without many additional staff • availability of other databases and bioinformatics tools to the marine microbiology community

MMI Management: Design and Implementation

Goal Definition. Originally, the MMI program defined as its goal the transformation of the entire discipline of marine microbial ecology which, while laudable, exceeds the capacity of any single agency operating over a decadal time scale. More specific goals framed with detailed milestones would have enabled more rigorous measurement of progress and impact than has been possible to date.

Strategic Approach. The primarily two-pronged approach of MMI Phase I—choosing established PIs with a proven track record for its three strategies (GBMF Investigator Awards, Multidisciplinary Expansion Awards, and High Impact Research Awards) combined with focusing on "omics" as an integrating technology across a wide range of scientific questions—clearly generated strong positive results. The only caveat is that the emphasis on "omics" altered the perception of the importance of other, more traditional molecular biology approaches, which also will be needed to achieve MMI's long-term goals.

Grantmaking. Although the process for selecting the MMI grantees was not transparent to either the research community or the independent review panels, senior researchers selected produced strong outcomes and most or all of the emerging investigators will likely produce solid and, in some cases, important research. The latter group faced important challenges that in some cases resulted in lower than expected results, including : 1) large grants with high expectations being awarded to new and largely unproven young faculty and 2) the need for some junior investigators to first establish necessary physical space and staff before actual work could commence.

Grants Management. With several changes in program management staff, reporting on grants by principal investigators was neither reliable nor uniform, making it difficult to assess the impact of MMI funding beyond publications. As a key consequence, the GBMF (and this review) may be underestimating the full impact of the MMI investment.

EVALUATION RECOMMENDATIONS FROM MMI PHASE I AND LOOKING FORWARD TO PHASE II (2011–2019)

Overview of MMI Phase II

In its second phase, MMI's Outcome is to uncover the underlying principles that:

- Govern the interactions among microbes (who interacts with whom, how, when, where, and the consequences thereof); and

- Influence microbially mediated nutrient flow in the marine environment (who consumes and excretes what, when, where, how much, and the consequences thereof).

These two science focus areas are often synergistically inter-related with new knowledge in one providing a deeper understanding of the other. The strategies to realize the desired Outcome include:

- MMI seeks to overcome interdisciplinary, technological, and methodological barriers that currently hinder scientists from identifying and quantifying nutrients in the ocean, from deciphering the genetic and biochemical bases of microbial metabolism, and from understanding how microbes interact with one another and the consequences of these interactions.
- MMI supports research that addresses gaps in the development of experimental model systems, a powerful way to investigate the interactions between organisms but few exist for marine microbes.
- MMI supports the development of key technologies, methods, computational modeling techniques, and theory needed to advance our understanding of microbial interactions and their mediation of biogeochemical cycles.

These strategies are achieved using four grantmaking approaches, similar to those used successfully in the first phase:

- Single Investigator awards that support individual current and emerging leaders in the field.
- Multi-disciplinary Research Projects that support collaborations to address interdisciplinary challenges.
- Community Resource Projects that fund development of tools and infrastructure, and fosters collaborations across the broader community.
- Instrumentation and Technology Development grants that advance the community's capabilities through development of novel technology or new applications of proven technology.

Summary of Evaluation Recommendations

Goal Definition. The EAC panel felt that MMI made significant progress in identifying appropriate stretch goals for the second phase of the program. The revised goals are logical, more realistic and attainable over the remaining lifetime of MMI.

Strategic Approach.

Research Focus. Though MMI cannot encompass all aspects of marine ecology, the EAC suggests that MMI consider the following opportunities and pursue those deemed to have greatest potential to contribute MMI Phase II goals:

- Addressing coastal environments, deeper waters, and sediments more explicitly—all of these environments contribute to microbial regulation of nutrient cycling and trophic structure in the world's oceans. Arguably, some of the most important processes occur in coastal waters and in sediments, particularly from a human perspective (fisheries yields, hypoxia, and eutrophication, *etc.*). And, of course, deeper waters encompass some 90% or more of Earth's biosphere.
- Pursuing a more inclusive and comprehensive examination of how key microbial groups interact with other microbes, grazers, and other organisms up through the food web, knowledge important to better understanding of microbial population dynamics as well as the microbial role in nutrient cycling.
- Extending MMI Phase I's noteworthy consideration of viruses to consider viral impacts on microbial (and thus nutrient) dynamics, which some studies suggest could be quite considerable.

- Building from the positively reviewed DARWIN modeling work, expanding the use of models and adding additional measurements (*e.g.*, field mortality through viral and grazing loss, *etc.*) to support, in part, increased understanding of microbial and nutrient dynamics in multiple systems.
- Promoting stronger interaction between field- and lab-based studies and modelers to define data needs and potential ecological/environmental drivers of ecological and even physiological change.
- Supporting study of changing oceans and the relative impacts of human and natural perturbations, one of the greatest environmental issues of our time, with microbes sitting at the core of ecological change.

Equipment & Infrastructure. In order to maintain research at the forefront of the field for Phase II, MMI must prioritize the maintenance of the cutting-edge equipment supported, along with upgrades as technologies develop, and planning for the long-term sustainability of the large facilities.

Summer Courses and Workshops.

- Seek to standardize course evaluations and tracking of students and to prioritize course locations with greater potential to leverage additional funding.
- Because the networking between projects varied greatly, bring together PIs from all MMI projects as well as postdocs and graduate students with the GBMF Investigators.
- Use workshops more extensively to promote cross-fertilization within this geographically dispersed program to facilitate greater synthesis and value added for individual projects.

CAMERA. The EAC does not recommend continuing CAMERA in its present form. If MMI chooses to discontinue CAMERA, it will likely need to develop a transition plan that minimally disrupts current users. One possibility for serious consideration is to evolve CAMERA into a Data Coordination Center to assist scientists in (a) submitting data for long-term storage in accordance with the expectation of the MMI, (b) finding and linking all types of data related to marine microbiology, and (c) ensuring data quality and reliability. The Data Coordination Center could also collaborate with other federal and foundation-funded projects in database development and management. This strategy would deliver an extremely valuable contribution to the field as the size and types of data sets continue to increase.

Grantmaking. The perception by the marine microbiology community of MMI is a very important consequence of the GBMF funding a large percentage of the marine microbiology field. For MMI to be seen as a thoughtful contribution, the broader marine microbiology community needs to understand the decision-making processes utilized for award selection, and how these decisions track with the program's long-term, targeted time-phased outcomes. To launch MMI Phase II, an open call for proposals was issued followed by targeted invitations. This is believed to be a step in the right direction that will help to strengthen the relationship between MMI and the broader marine microbiology community, whose buy-in will be critical to the goal of transforming marine microbiology as a whole. Even with a broader call for participation, if the selection process is perceived to be uninformed by broad expertise in the field of marine microbiology, the perception problems will be exacerbated. The EAC therefore also recommends that the GBMF find ways to bring the broader marine microbial research community into their advisory process. One approach would be to create an MMI Science Advisory Committee that would report to MMI staff to help think through long-term issues and strategies for success; facilitate interactions with the marine microbiology community as a whole; serve as ambassadors to the broader scientific community; potentially provide input into the next program review and thinking regarding MMI's future beyond the next five years. In addition, for the MMI to reach its 2015 and 2019 time-phased outcomes (targeting understanding microbial interactions and nutrient flow), the program must engage researchers from other areas such as biogeochemistry and nutrient dynamics.

Grants Management. To ensure effective, timely, and consistent capture of intellectual output and other scientific contributions and efficient progress toward research outcomes, MMI should insist on streamlined but uniform templates for both financial and science reporting clearly defining budget/work, including defining and carefully tracking milestones. MMI should coordinate and enforce this policy across the entire program and identify a party responsible for this oversight. An enforcement strategy (*e.g.*, 10% funding holdback) may be necessary to achieve full compliance.

Ensuring MMI's Legacy. Despite some clear wins, the scope of the MMI program and its legacy could be significantly enhanced via careful planning around synthesizing and sharing results, improving data availability, and ensuring succession and sustainability.

- **Develop and Implement a Synthesis Plan.** Although the basic research outputs and associated publications have created an impressive foundation on which to build, the "transformative" impact of the program could be significantly enhanced via a carefully considered, well-resourced synthesis plan with audiences prioritized, outreach targets set, and MMI scientists identified who will play a leadership role in the implementation of that plan. Given the full range of audiences that must be aware of the transformation (*e.g.*, the marine microbial research community beyond MMI plus, potentially, marine ecologists more generally, educators, ocean policy and conservation specialists), a range of outreach tactics will be needed, such special journal volumes, synthesis papers, reviews, textbooks, participation in meetings like AAAS, special sessions at Ocean Sciences ASM or ESA meetings during the last few years of the project that include talks that unify the program's discoveries and conclusions. Implementing the synthesis plan will require several years of committed effort, and must begin well in advance of the program end.
- **Improve data availability.** CAMERA is examined elsewhere in this report, but improved and cohesive availability of all data forms would help expand the impact. Realistically, a single database may prove impractical at this late stage, but even a central Web page of data links could help. Similarly, an MMI Web page with appeal beyond MMI applicants could include the following elements: data linkages, project personnel (including PIs, students, technicians, and postdocs) and their expertise, and perhaps most importantly a searchable bibliography of all MMI published papers. All of these tools would increase MMI visibility within and beyond the marine microbial community, and help to integrate MMI scientists and their findings with the non-MMI community by making the program more transparent and outward looking.
- **Develop a Succession Plan.** If successful, MMI will have sponsored research that clearly shows the importance of marine microbes in the trophic structure, disease, biodiversity, and nutrient cycling of the ocean and, through these impacts, in other larger concerns such as food resources and climate. MMI will have been the dominant source of funding for a field that is now considered essential. Therefore, if there is hope for succession through other funding entities, a specific succession plan should be developed before MMI funding is completed and participating scientists retreat to their respective geographic locations. This plan should identify research leaders willing to spearhead any follow-on initiatives, as well as detailed plans for how such a program might be funded. The proposed MMI Scientific Advisory Committee (SAC) could play a key role in synthesis and in maximizing impact by helping to create a vision plan that MMI scientists can then execute.

APPENDIX A. MMI Time-Phased Outcomes

MMI Phase 1

Problem Statement: Seventy percent of the surface of the planet is ocean and ocean microbes constitute 50% or more of the planet's biodiversity, yet a comprehensive understanding of the diversity of ocean microbial populations and their strategies for nutrient utilization is largely unknown. The ocean's microbial communities are responsible for the vast majority of the geochemical cycles in the ocean and the microbial ecosystem forms the basis of ocean productivity and ocean health.

Ultimate Outcome (Unconstrained): A comprehensive understanding of marine microbial communities including genetic diversity, composition, function, and ecological role of microbial communities in the oceans and how they contribute to ocean health and productivity.

Initiative Outcome (Constrained to Phase 1): Marine microbiology is transformed into an integrated field of marine microbial ecology by applying novel molecular technologies and instruments with the goal of monitoring, modeling, and generating new fundamental knowledge about representative microbial ecosystems in the ocean.

Baseline (2003)

Baseline

- No reliable estimate of the number or diversity of microbes in the ocean
- No existing models of the role of microbes in geochemical processes in the ocean
- Only two metagenomics studies of the marine environment
- Descriptions for roughly one out of every thousand organisms in the ocean
- Investigators dependent on traditional bacterial culturing techniques, thus detailed study was limited to those organisms in culture
- All microbial genome data are placed in GenBank* and do not contain any metadata regarding environmental conditions of isolation or relationship to other organisms

**GenBank = an annotated collection of all publicly available DNA sequences*

Progress-to-Date (2008)

Initiative Outcomes to Date

- MMI Investigators formed interdisciplinary teams, are featured speakers at international meetings, earned prestigious awards, and published over 190 research papers
- Funds to MMI Investigators have supported ~ 200 graduate students, post-docs and undergraduates
- New discoveries were made in microbial sulfur metabolism, nitrogen fixation and methane production
- MMI-funded instrumentation to detect marine microbes in situ was replicated, and deployed for new uses by researchers in addition to those who invented the instruments

Behavior Outcomes

- Marine microbiologists have begun collaborations with engineers and scientists outside the field of marine microbiology on high-risk projects.

Outputs to Date

- 164 new marine microbial genomes have been sequenced and annotated
- 107 metagenomic datasets have been deposited in CAMERA, and 9281Mb of environmental metagenomes have been sequenced with MMI funds
- CAMERA has 2525 users from 76 countries

Mid-Term Targets (2009)

Mid-Term Initiative Outcomes

- MMI Investigators will establish new experimental approaches, principles and unexplored areas of scientific inquiry
- At least one integrated large-scale microbial ecosystem model is developed based on microbial evolution and physical oceanography
- 155 microbial genome sequences will be completed; ~100 viral genome sequences will be completed

Mid-Term Behavior Outcomes

- Additional multidisciplinary collaborations will develop, and monitoring of microbial activity by genome enabled sensors will become more widespread
- Additional young investigators are trained in the new interdisciplinary molecular approach to marine microbial ecology
- MMI-funded researchers will routinely publicly release "unpublished" data to DNA databases

Mid-Term Outputs

- The semantically-aware database CAMERA# 2.0 will become the key community data resource for all metagenomic fields, not strictly marine microbial ecology

 # CAMERA = Community Cyberinfrastructure for Advanced Marine Microbial Ecology Research and Analysis
Genbank = an annotated collection of all publicly available DNA sequences

Long-Term (2013)

Initiative Outcomes

- Comprehensive open source models of marine microbial ecosystems are well developed
- Ten years of genomic and physiological studies will provide a basis for understanding how microbial systems form, function and evolve
- Environmentally-induced changes in marine microbial ecosystems can be detected, validated and ascribed to specific cause
- Perturbations of marine microbial ecosystems can be used to predict changes of other oceanic ecosystems and food web dynamics

Behavior Outcomes

- A new ocean science has emerged that integrates physical, biochemical, genetic and biological factors
- Microbial ecosystem monitoring is recognized for predictive value i
- Integrated multidisciplinary teams of scientists replace "single scientist" model

Outputs

- A federal granting agency has assumed responsibility for supporting CAMERA, which has become a key international community resource in all areas of metagenomics
- Microbial monitoring is a regular component of the ocean observatories.

MMI Phase 2

Problem Statement: Seventy percent of the surface of the planet is ocean and ocean microbes constitute 50% or more of the planet's biodiversity, yet a comprehensive understanding of the diversity of ocean microbial populations and their strategies for nutrient utilization is largely unknown. The ocean's microbial communities are responsible for the vast majority of the geochemical cycles in the ocean and the microbial ecosystem forms the basis of ocean productivity and ocean health.

Ultimate Outcome (Unconstrained): A comprehensive understanding of marine microbial communities including genetic diversity, composition, function, and ecological role of microbial communities in the oceans and how they contribute to ocean health and productivity.

Initiative Outcome (Constrained): The underlying principles that govern inter- and intra-domain microbial interactions and that influence the flow of nutrients in representative marine microbial ecosystems are uncovered.

Baseline (2011)

State of the Field

The gene content of over 1000 marine microbes is available in public databases (by 2012).

Patterns of marine microbial community diversity are well understood.

A limited number of computational biogeochemistry and food web models incorporate rudimentary microbial functions.

The genomes and physiologies of a few of the most abundant microorganisms in the sea are well understood.

Public bioinformatics resources exist and are continuing to improve.

New microscopy and elemental analysis tools have begun to be used to "see" marine microbial communities in new ways.

Protocols for analyzing single cells are becoming more robust.

Prototype microbial sensors have been deployed.

Mid-Term Targets (2015)

Microbial Interactions

Tools exist to measure a basic suite of microbial interactions.

Strategic plans are developed and experiments initiated to investigate 2–3 experimental model systems.

At least one computational ecosystem model includes virus–host interactions and microbe–microbe signaling.

Nutrient Flow

Incorporation of specific nutrients into single cells can be measured.

Advanced microchip devices enable observing microbial activities.

New ideas exist for testing in the field multiple microscale phenomena.

Nitrogen cycle transformations (as an example) can be predicted from expression levels of certain genes.

Long-Term Targets (2019)

Microbial Interactions

At least one type of microbial interaction routinely measured in laboratory and field experiments.

Experimental model systems for probing microbe–microbe interactions enable generation of new hypotheses for ocean investigation.

Studies of several experimental microbial interaction systems reveal conserved patterns, suggesting an evolutionary basis.

Computational models of ecosystems include microbe–microbe interactions.

Nutrient Flow

Tools exist to decipher—at the single-cell level—who eats and secretes what, where and when.

Proxies are developed for remote sensing of microbially driven ocean processes.

A conceptual framework exists to infer ecosystem-scale processes from microscale observations.

Rates of processes can be inferred from microbial community expression data.

+ Synergies between focus areas.

APPENDIX B. MMI-funded Projects Reviewed by Each Panel

Req #	Synopsis	Principal Investigator	Organization	Start Date	End Date
PANEL I	**MMI Investigators, summer courses, and workshops (**				
2090	The Plymouth Marine Laboratory will use these funds to convene a workshop of preeminent scientific experts to discuss the effect of ocean acidification on the global services provided by marine microbes. The primary objective of the workshop is to develop	Dr. Ian Joint	Plymouth Marine Laboratory	1/19/2009	6/30/2009
2613	In support of a series of community retreats to identify transformative directions for the field of marine microbiology. Funding will be used to plan and execute a series of retreats in 2010 and 2011 and to synthesize the information gathered into a freel	Ms. Julie Farver	Consortium for Ocean Leadership	7/26/2010	9/15/2012
1601	This grant to the Marine Biological Laboratory (MBL) is intended to expand the pool of new international scholars specializing in microbial diversity and ecology through the support of the MBL Microbial Diversity Course. These researchers will be trained	Dr. Lenny Dawidowicz	Marine Biological Laboratory	9/17/2007	11/1/2010
2564	To create a dedicated "next generation" DNA sequencing pipeline for five microbial diversity summer courses supported by MMI. Students in those courses will learn to generate and interpret sequence data from advanced sequencing technologies.	Dr. Stephan Schuster	Pennsylvania State University Department of Biochemistry and Molecular Biology	5/31/2010	9/30/2012
493	This grant to UC Santa Cruz supports the work of Dr. Zehr in the development of remote-sensing probes and sampling procedures for the study of nitrogen-fixing marine microbes. Outcomes for this grant include deployment of remote microbe samplers construc	Dr. Jonathan Zehr	UC Santa Cruz Dept of Ocean Sci, School of Earth & Marine Sci	7/21/2004	8/31/2008
607	This grant to the Oregon State University supports research conducted in the laboratory of Dr. Giovannoni, a recognized expert on the cultivation of marine microbes from the natural ocean environment. Dr. Giovannoni and his team successfully cultured SAR	Dr. Stephen J Giovannoni	Oregon State Univ, Dept. of Microbiology	11/4/2004	11/4/2009
691	This grant supports research in the Caltech laboratory of Dr. Orphan. Her interests include microbial community structure and function in deep subsurface habitats marine sediments oil and gas seeps and early Earth analog environments. Outcomes for this	Dr. Victoria Orphan	Cal Tech, Division of Geology and Planetary Sciences	4/4/2005	9/30/2009
492	This grant to the Massachusetts Institute of Technology supports the research of Dr. Delong into the genetic diversity of planktonic marine bacteria and archaea. Outcomes for this grant include characterization of the genomes and genomic variability of do	Dr. Edward DeLong	MIT Office of Sponsored Programs	7/21/2004	1/31/2009
581	This grant to UC Berkeley supports the research of Dr. King into the evolution of multi-cellular animals from their unicellular ancestors. A key question under investigation at the laboratory is how and when the genetic "toolkit" that led to the origin of	Dr. Nicole King	UC Berkeley Dept of Molecular and Cell Biology	9/13/2004	9/1/2008
618	This grant to San Diego State University supports research in the laboratory of Dr. Rohwer into the genomics and evolutionary relationships of viruses. The work includes the sequencing of viral metagenomes from environmental samples. Outcomes for this gra	Dr. Forest Rohwer	San Diego State Univ Research Foundation (linked with CAMERA)	11/17/2004	11/17/2007

Req #	Synopsis	Principal Investigator	Organization	Start Date	End Date
480	This grant to the University of Hawaii's Department of Oceanography supports the research of Dr. Karl into the genetic diversity and physiological capacity of microbes in the ocean. Outcomes for this grant include construction of rDNA tools to track dynam	Dr. David M. Karl	Univ of Hawaii Foundation	5/11/2004	5/11/2009
689	This grant to Brown University supports research in the laboratory of Dr. Hughes. Her lab uses a combination of approaches from genetic surveys of natural communities to field experiments and microcosm studies. Outcomes for this grant include developmen	Dr. Jennifer Hughes Martiny	Brown Univ, Dept of Ecology & Evolutionary Biology	4/18/2005	1/18/2007
495	This grant to the Massachusetts Institute of Technology supports the work of Dr. Chisholm into the ecology and evolution of the marine cyanobacterium Prochlorococcus. Commonly called blue-green algae cyanobacteria are among the largest and most important	Dr. Sallie (Penny) Chisholm	MIT Office of Sponsored Programs	7/21/2004	1/31/2009
537	This grant to the University of Washington supports the research of Dr. Armbrust into the genomics and physiology of diatoms. Diatoms play a major role in marine ecology and in facilitating the flow of nitrogen carbon and energy in the oceans. Outcomes	Dr. E. Virginia (Ginger) Armbrust	Univ of Washington, School of Oceanography	9/22/2004	7/15/2009
582	This grant to the University of Miami supports research in the laboratory of Dr. Worden into marine microbial population dynamics and carbon cycling in marine ecosystems. Researchers will explore biochemical and molecular mechanisms of microbe-algae inter	Dr. Alexandra Worden	Univ of Miami, Rosenstiel School of Marien & Atmospheric Sciences	9/13/2004	9/13/2007
538	This grant to the University of Georgia Foundation supports the research of Dr. Moran a leading expert on oceanic sulfur cycles. Outcomes for this grant include deepened understanding of the global sulfur cycle and exploration of the taxonomic and functi	Dr. Mary Ann Moran	Univ of Georgia Foundation	9/22/2004	9/22/2009
2493	In support of the Microbial Diversity Summer Course one of five coupled grants intended to train the next generation of microbial ecologists in non-traditional immersive academic environments that emphasize cross-disciplinary collaboration and cutting-e	Dr. Daniel H. Buckley	Marine Biological Laboratory	4/26/2010	9/1/2013
2551	For the Hawai'i Microbial Oceanography Summer Course one of five coupled grants that will train the next generation of microbial ecologists in non-traditional immersive academic environments that emphasize cross-disciplinary collaboration and cutting-ed	Dr. Matthew J. Church	University of Hawaii Foundation	4/26/2010	9/1/2013
2552	In support of the Hopkins Microbiology Summer Course one of five coupled grants that will train the next generation of microbial ecologists in non-traditional immersive academic environments that emphasize cross-disciplinary collaboration and cutting-ed	Dr. Chris Francis	Stanford University Department of Civil and Environmental Engineering	4/26/2010	9/1/2013
2553	In support of the Bermuda Institute of Ocean Sciences Summer Course one of five coupled grants that will train the next generation of microbial ecologists in non-traditional immersive academic environments that emphasize cross-disciplinary collaboration	Dr. Craig A. Carlson	University of California Santa Barbara Department of Ecology Evolution and Marine Biology	4/26/2010	9/1/2013
2554	For the Geobiology Summer Course one of five coupled grants that will train the next generation of microbial ecologists in non-traditional immersive academic environments that emphasize cross-disciplinary collaboration and cutting-edge analytical techni	Dr. Will Berelson	University of Southern California Department of Earth Sciences	40294	41518

Req #	Synopsis	Principal Investigator	Organization	Start Date	End Date
PANEL II	**Microbial diversity, ecology, and biogeochemistry**				
620	Yellowstone Park Foundation is using this grant to study the subalpine habitats of Yellowstone Lake. Researchers are sampling and assessing the lake's sediments vents and spires using well-established methods and equipment as well as cutting-edge propri	John Varley	Yellowstone Park Foundation	11/8/2004	11/8/2005
713	UC Santa Cruz received this grant to establish the Microbial Genomics Experimentation and Remote Sensing Facility (MGERSF). MGERSF supports and provides a collaborative environment for UC Santa Cruz scientists visiting scientists postdoctoral researcher	Dr. Gary Griggs	University of California-Santa Cruz	6/6/2005	1/31/2009
731	To develop remote instrumentation capabilities for the study of marine microbial diversity by creating a collaborative environment for MBARI and visiting scientists to develop and implement remote instruments for *in situ* studies of marine microorganisms.	Dr. Chris Scholin	Monterey Bay Aquarium Research Institute	12/5/2005	3/31/2011
732	This grant to the University of Washington School of Oceanography supports a flow cytometry collaboration. Outcomes for this grant include increased sensitivity of flow cytometry equipment specifically for marine microbiology research.	Dr. Russell McDuff	University of Washington, School of Oceanography	2/13/2006	10/1/2010
733	Pennsylvania State University is using this grant to develop enhanced instrument capabilities at UCLA's Ion Microprobe Laboratory for the study of uncultured marine microorganisms and their geochemical roles in the environment. Dr. House from Pennsylvan	Mr. Christopher House	Pennsylvania State University, Department of Earth and Mineral Sciences	10/3/2005	1/4/2010
734	Scripps Institution is using this grant for two related marine microbe projects. Outcomes for this grant include performance of field and lab studies on the microbial ecology of coral mucus layers and application of imaging to determine the sources compo	Dr. Farooq Azam	Scripps Institute of Oceanography	11/15/2005	12/2/2009
934	To develop *in situ* sorting and observational technologies of individual phytoplankton cells. Outputs include time-series deployments of the FlowCytobot and Imaging FlowCytobot instruments and enhancements to the technologies that automate their ability to	Dr. Heidi Sosik	Woods Hold Oceanographic Institution	10/30/2006	12/31/2011
1140	This grant to the Massachusetts Institute of Technology Department of Earth Atmospheric and Planetary Sciences supports further development of the open source microbial ecosystem model Darwin. Darwin computational modeling enables studies of virtual eco	Dr. Michael (Mick) Follows	Massachusetts Institute of Technology, Department of Earth, Atmospheric and Planetary Sciences	11/20/2006	1/15/2011
1213	The focus of this grant is the provisioning of a novel and relatively accessible technology, namely unmanned underwater vehicles, as a tool for observing and understanding open ocean phenomena.	Dr. David Karl	University of Hawaii Foundation	2006	2007
1214	A New Center for Ultrahigh Resolution Mass Spectrometry	Dr. Elizabeth Kujawinski	Woods Hole		3/16/2009
1410	This grant to Harvard University Department of Organismic and Evolutionary Biology will fund the expansion of OsmoSampler technology to produce BioOsmoSamplers (BOSS) capable of acquiring samples from Ocean Drilling Project ("ODP") boreholes for a suite	Dr. Peter Girguis	Harvard University, Department of Organismic and Evolutionary Biology	4/2/2007	4/30/2008
1622	The acquisition of laboratory equipment and computer hardware to support the marine science research program in a new facility built by the University of Hawaii, Manoa.	Dr. David Karl	University of Hawaii Foundation	2007	2008

Req #	Synopsis	Principal Investigator	Organization	Start Date	End Date
1661	To support characterization of the microbial responses to two distinct seasonal oxygen minimum zone environments and to establish the geological history of oxygenation at each site. The proposed effort aims to describe the chemical and physical nature of	Dr. Ricardo Letelier	Oregon State University, College of Oceanic and Atmospheric Sciences	10/6/2008	10/6/2011
1711	In support of identifying dissolved organic compounds produced by one group of marine microbes (photoautotrophs) and consumed by other groups of marine microbes (heterotrophs) to better understand the links between marine microbial diversity metabolism	Dr. Dan Repeta	Woods Hole Oceanographic Institution	6/2/2008	7/2/2011
1761	In support of identifying relevant probes and testing biological sensors to deploy on remote *in situ* ocean observing platforms. The data generated from these studies will be used to inform models developed to evaluate the effects of microorganisms on the	Dr. Jonathan Zehr	University of California, Santa Cruz Department of Ocean Sciences, Institute of Marine Science	4/7/2008	5/7/2013
2293	In support of developing a systems-level understanding of microbially mediated elemental cycles along the lower reach of the Amazon River and its marine plume. This integrative program will collect microbial community structure and function data along the	Dr. Patricia L. Yager	University of Georgia Research Foundation	1/25/2010	3/31/2013
2295	To develop open-source evidence-based predictive ecosystem models of the physical and biological factors that contribute to the intensity scale and duration of seasonal oxygen minimum zones. These predictive models will also explore how seasonal low-o	Dr. Curtis Deutsch	University of California, Los Angeles	8/31/2009	4/15/2013
2609	To investigate and model the dynamics of whole microbial communities that inhabit distinct geochemical provinces in the deep sea associated with seafloor volcanic activity. The research aims to improve understanding of how these microbial communities regu	Dr. Gregory Dick	University of Michigan Department of Geological Sciences	10/19/2010	12/15/2013
2631	In support of developing and applying novel virus ecology approaches that enable deeper investigations of the structure and activities of natural marine virus communities and the linkages between viruses and their microbial hosts.	Dr. Matthew Sullivan	University of Arizona Sponsored Projects Services	8/6/2010	2/28/2014
2723	To procure scientific laboratory and field equipment to replace a subset of the equipment damaged during the 8.8 magnitude earthquake that struck Chile on February 27 2010.	Dr. Osvaldo Ulloa	Universidad de ConcepciÃ³n Departamento de OceanografÃa	10/4/2010	10/4/2011
2724	To enable a greater understanding of trace metals and metalloenzymes in oceanic biogeochemical cycles. By combining cutting-edge proteomic tools with trace metal analysis techniques this project aims to advance the understanding of biogeochemical cycles	Dr. Mak Saito	Woods Hole Oceanographic Institution	11/22/2010	12/31/2013
2728	Microfluidic chip technologies to enhance environmental monitoring	Dr. Chris Scholin	Monterey Bay Aquarium	2010	
2761	Equipment for Imaging Microbial Interactions	Dr. Farooq Azam	University of California, San Diego Scripps Institution of Oceanography	2010	
2764	Engineering of sampling system for mineral particles and cells	Dr. John Breier	Woods Hole	2010	

Req #	Synopsis	Principal Investigator	Organization	Start Date	End Date
PANEL III	**Sequencing, genomics, and bioinformatics**				
448	This grant to JCVI will generate 3-4 million DNA sequences in seven ocean samples from the North Atlantic Ocean. Several hundreds of thousands of new genes and thousands of new species of microorganisms are anticipated to be identified as a result of this	Dr. J. Craig Venter	J. Craig Venter Institute	2/2/2004	11/30/2004
521	With this grant the J. Craig Venter Institute is collaborating with the larger community of marine microbiology researchers to sequence the genomes of at least 155 marine microbes. The goal of this project is to greatly increase the number of whole gene	Dr. Robert M. Friedman	J. Craig Venter Institute	9/22/2004	7/31/2010
553	This grant to Rutgers Institute of Marine and Coastal Sciences supports the work of Dr. Falkowski and his team who are seeking to gain new knowledge regarding the evolutionary history of microbes. Outcomes for this grant include identification of the	Mr. Michael Breton	Rutgers University Foundation	9/27/2004	3/15/2007
932	With this grant the Massachusetts Institute of Technology Broad Institute is developing methods for sequencing marine viruses. Outcomes for this grant include development optimization and validation of a specialized methodology for amplifying marine b	Dr. Matthew Henn	Massachusetts Institute of Technology Broad Institute	2/13/2006	8/13/2006
1107	This grant to Pennsylvania State University supports a metagenomics comparative study. Outcomes for this grant include preparation of small and large insert libraries and DNA sequence via chain termination and GS20 methods and analysis of the data and co	Dr. Stephan Schuster	Pennsylvania State University Department of Biochemistry and Molecular Biology	6/5/2006	6/5/2007
1108	This grant to the Massachusetts Institute of Technology Department of Civil and Environmental Engineering funds the sequencing of 19 related marine *Vibrio* (bacterial) genomes and will be used to answer important questions pertaining to microevolution of	Dr. Martin Polz	Massachusetts Institute of Technology, Civil and Environmental Engineering	11/20/2006	8/15/2011
1109	The Broad Institute will use this grant for the sequencing and automated assembly of 150 fosmids and 75 bacterial artificial chromosomes (outputs) to complement the Marine Microbiology Initiative€™s metagenomics efforts. Several collaborators from the re	Dr. Matthew Henn	Massachusetts Institute of Technology Broad Institute	5/29/2006	10/23/2009
1112	The University of Southern California will use this grant to conduct a global survey of the diversity of single-celled microbial eukaryotes (protists) a vastly understudied aspect of marine microbial diversity. Outputs include the generation of 1000 full	Dr. David A. Caron	University of Southern California Department of Biological Sciences	6/19/2006	2/28/2009
1142	The J. Craig Venter Institute will use this grant to perform metagenomic surveys of biofilm microbial communities and associated planktonic populations in Botany Bay Australia. Grant outputs include the generation and annotation of over 1.2 million seque	Dr. Robert M. Friedman	J. Craig Venter Institute	10/23/2006	6/30/2010
1287	The Moore Foundation Darwin Project Computing Infrastructure support covers (a) installation of a linux cluster compute and data storage facility, (b) installation of a visualization wall and kiosk, (c) connection to the National Lambda Rail, (d) upgrades for the DeLong lab bioinformatics compute facility.	Dr. Matthew Gardner	Massachusetts Institute of Technology, Earth System	12/2006	12/2007

Req #	Synopsis	Principal Investigator	Organization	Start Date	End Date
1259	This grant was an infrastructure development project with the goal of helping to establish a Center that co-localizes within the University of Washington Research and Technology (R&T) Building (renamed the Hall Building), technologists and scientists dedicated to the development of: 1) new ways of combining environmental data with the ever-increasing amounts of genomic data; 2) new ways of understanding the behavior of single cells that can then be extrapolated to population structure; 3) new ways of visualizing environmental and genomic data to extract patterns; and, 4) new ways of understanding genetic diversity and structure in microbial ecosystems.	Dr. E. Virginia (Ginger) Armbrust	University of Washington	07/2007	03/2009
1554	The sequences produced through this grant will give insight into new genes and proteins novel life forms and how life is possible under unique environmental conditions. The data will be released into the public domain as part of the Community Cyberinfr	Dr. Robert M. Friedman	J. Craig Venter Institute	8/20/2007	6/30/2010
1555	This project will attempt to correlate functional gene diversity with environmental parameters through comparative analyses of microbial communities of distinct sites in Yellowstone Lake with chemical and geological data from those environments. In addit	Ms. Nina Jaeger	Yellowstone Park Foundation	9/17/2007	3/31/2011
1634	This grant to the San Diego State University adds two new metagenomic datasets to CAMERA and establishes procedures to integrate externally-developed analytical methods of broad utility to the marine microbiology community into CAMERA LABS an open acces	Dr. Forest Rohwer	San Diego State University Research Foundation	10/29/2007	2/16/2010
1654	This grant to the Earth Systems Initiative at the Massachusetts Institute of Technology will provide support for the acquisition of a DNA sequencer to support the determination of gene expression patterns (transcriptomics) of organisms identified from environmental metagenomic sampling.	Dr. Penny Chisholm/ Dr. Ed DeLong	Massachusetts Institute of Technology, Earth System	11/2007	10/2008
1660	In support of the University of California Davis Genome Center to analyze metagenomic datasets through the development of tools and illustrative use-case scenarios from Community Cyberinfrastructure for Advanced Marine Microbial Ecology Research and Anal	Dr. Jonathan Eisen	University of California Davis Genome Center	11/1/2007	10/1/2010
1668	The Monterey Bay Aquarium Research Institute will use this grant to support a collaborative team of researchers to address gaps in diversity and ecology of the eukaryotic microorganisms in the sea. Outputs include collection of three size classes of marin	Dr. Alexandra Worden	Monterey Bay Aquarium Research Institute (worked with CAMERA)	11/26/2007	3/31/2012
1669	In support of evaluating the need for and defining the operational structure of a DNA sequencing resource to serve the marine microbiology research community. The effort will determine whether a financially independent and dedicated DNA sequencing resourc	Dr. Mary Lidstrom	University of Washington Office of the Provost	11/26/2007	9/26/2008
1671	The University of Washington will use this grant to purchase cutting-edge deep-coverage DNA sequencing technology test the capabilities of this new technology for the marine microbiology research community by performing diatom environmental genomics and	Dr. E. Virginia (Ginger) Armbrust	University of Washington Office of the Provost	11/30/2007	6/7/2010

Req #	Synopsis	Principal Investigator	Organization	Start Date	End Date
1672	This grant to Pennsylvania State University will be used to increase publicly-available marine microbial DNA sequence information through the creation of a dedicated "next generation" marine microbiology DNA sequencing resource. A pyrosequencing instrume	Dr. Stephan Schuster	Pennsylvania State University Department of Biochemistry and Molecular Biology (deposit data into CAMERA)	11/1/2007	2/5/2010
1799	This grant will provide support to the Broad Institute to sequence and perform basic characterizations of marine phage and virus genomes and the genomic content of environmental marine virus assemblages. The marine phage and virus ecology research communi	Dr. Matthew Henn	Massachusetts Institute of Technology Broad Institute	11/17/2008	7/1/2009
2540	For the acquisition of a next generation DNA sequencing platform to enable important advances in the field of marine microbial ecology. This grant is part of a multi-grant strategy to expand the diversity and capacity of DNA sequencing technologies availa	Dr. Sallie (Penny) Chisholm	Massachusetts Institute of Technology Office of Sponsored Programs	4/26/2010	4/30/2011
2637	To support the sequencing and performing basic characterizations of the gene content of numerous marine microbial eukaryotes. Funding will be used to analyze the expressed genes in approximately 750 samples collected from a wide diversity of organisms. Th	Dr. Callum Bell	National Center for Genome Resources	9/30/2010	6/30/2012
2732	In support of integrating a novel suite of bioinformatic tools for analyzing viral metagenomic datasets into a major public DNA sequence analysis platform. The funding will be used to improve the Viral Informatics Resource for Metagenome Exploration and t	Dr. Eric Wommack	University of Delaware Department of Plant and Soil Sciences (with CAMERA)	9/30/2010	12/31/2012