VISION 2010: A TEN-YEAR PLAN FOR RESEARCH AT MBARI

INTRODUCTION

During its first decade, MBARI took on the very challenging tasks of designing and building an advanced class of remotely operated vehicle (ROV) for deep sea exploration, and of proving the worth of this technology for oceanographic research. In the course of meeting this challenge, MBARI demonstrated that ROVs are not only valuable tools for making observations, but that they can also perform complex experiments and manipulations in the deep sea, in effect serving as extensions of the scientists hands and eyes *in situ*. In the coming decade, MBARI plans to continue to exploit the science potential of its substantial investment in ROVs, while at the same time we take on the even more ambitious challenge of designing and building ocean observatories. ROV-serviced and installed observatories hold the promise of multiplying by many fold our ability to make observations in the ocean with unattended instruments and autonomous platforms that can be commanded from shore and that transmit data back to the laboratory in real time.

The purpose of this plan is to review MBARI's current position and the rationale for the scientific research and technology development directions we are choosing to pursue in the coming decade. We next outline a 10-year plan for how MBARI will build the requisite scientific and technical expertise in observatory-relevant fields in order to help lead the nation in the move to ocean observing systems. Finally, we end with a discussion of potential mechanisms for funding this initiative.

Box 1. Ventana

Ventana has completed more than 1700 dives since its career began in 1988, which makes it the most successful and productive scientific ROV in the world. In the last dozen years *Ventana* has been continually improved and upgraded to meet the evolving needs of MBARI scientists. The requirement to work deeper entailed the design and fabrication of a tether management system to replace the process of hand-coiling the tether on deck. Increasing the depth range to 1200 meters allowed the detection and investigation of cold-seep communities along the flanks of the Monterey Canyon, the initiation of the first time-series measurements of a mesopelagic community, and the discovery of dozens of new life forms. Converting the video recording mode to digital and the camera to high definition have significantly increased the resolution of our imaging systems and thus the precision with which we can make observations at depth. Mechanical upgrades increased payload and power, and allowed for the incorporation of new tool sleds specifically configured to meet the needs of ongoing research projects. Addition of a high-precision arm has greatly improved our ability to conduct manipulative tasks and experimental work on the seafloor.

RECENT SUCCESSES AT MBARI

David Packard founded MBARI with the vision that an institution based on a close collaboration between scientists and engineers could have a significant impact on our understanding of the ocean. The past 12 years have seen MBARI grow from a fertile idea to a robust enterprise poised at the forefront of research and development in marine science and engineering. One of MBARI's major accomplishments is the acquisition of an integrated scientific dataset that covers diverse aspects of

Box 2. Ecosystem Structure

The El Niño/La Niña climate oscillations induce some of the largest ecosystem changes seen in the ocean. Scientist Francisco Chavez and Engineer Robert Herlien teamed to develop a novel mooring and sensor system for ecosystem observations in one of the earliest projects of the institution. Measurements obtained with this system have identified an enormous phytoplankton bloom in the Equatorial Pacific that occurred as the ecosystem recovered from the 1998 El Niño. This work was published in the December 10, 1999 issue of *Science* and was featured on the cover.

Closer to home, Scientist Chris Scholin used DNA probes for toxic phytoplankton to monitor a hazardous algal bloom in Monterey Bay. These observations were reported in the January 6, 2000 issue of *Nature*. They demonstrated that the toxic phytoplankton, which caused a mortality of 400 sea lions, were not found in blue mussels. These mussels are the traditional, sentinel species for toxic plankton. Engineer Gene Massion and Scholin are developing a moored sensor for toxic plankton based on this technology.

the Monterey Bay oceanographic system. The development and operation of state of the art observational resources envisioned by Packard has produced an unprecedented description and understanding of the region from the ocean surface, to the benthos, and its underlying geology. This enables MBARI scientists and others to place new observations in a proper temporal and spatial perspective. Monterey Bay has become a model system for studying geological, chemical, and biological processes. Although MBARI is only 13 years old, it has become the predominant source of time-series data along the Pacific margin.

MBARI's geographic setting and the enabling technology developed at the Institute have provided an ideal laboratory for understanding ocean processes in significant new ways. In the past year alone, MBARI scientists have published six articles (four as lead authors, two as co-authors) in the most visible scientific journals, *Science* and *Nature*. Additional articles are in press or in review at these journals. This work represents a significant advance in our understanding of the oceans, their ecosystems and their potential response to a changing climate. This is a feat that would be difficult to match in comparably sized departments in our nation's most prestigious universities. It is only a sampling of some of the outstanding work (see Boxes 1-6) that is underway at this institution, and which utilizes the close interaction of scientists and engineers.

Clearly, prior investments in the development of state-of-the-art technology for oceanographic research and in the scientific and engineering personnel capable of exploiting this frontier have paid off. National and international attention is focused on the work of this institute. *David Packard's vision has become a reality.*

PROVING THE WORTH OF PRIOR INVESTMENTS

Many advances in ocean science will continue to depend upon an experimental approach to hypotheses concerning the function of ocean systems. MBARI's two ROV systems, *Ventana* and *Tiburon*, are poised to profit fully from their decade of development. As the discovery phase of ocean science is extended through advanced ROV technology, particularly in the deep sea, these vehicles will be essential to progress in understanding the functional aspects of deep-sea systems. ROVs remain central to MBARI's future as platforms for detailed *in situ* observations, manipulations, and experiments, as well as in support of the autonomous observing systems planned for the next decade.

Tiburon is still at a very early stage in its career, yet it is proving to be a unique and highly versatile platform for research. It has already enabled important studies on the formation of chemical hydrates at depth, geological and biological studies of nearby seamounts, and the discovery of some remarkable new bathypelagic animals. As has been the case for MBARI's first ROV, *Ventana*, we expect that *Tiburon*'s evolution will be shaped by what we learn as we gain experience working it deeper in the water column and on the deep seafloor. That experience includes the scientific discoveries that lead investigators in new directions, as well as practical knowledge of what the vehicle can do. *Tiburon* has opened up the deepest 2/3 of the canyon and its water column to us and our investigations have just begun. Already underway are technological initiatives to bring HDTV (high-definition television) to *Tiburon*, to develop "offload" instrument packages, and to deploy elevators to transport samples to the surface without recovering the vehicle.

Box 3. The Western Flyer

The *Western Flyer* has demonstrated the unique value of its special design. After its first quarter of oceanographic work the *Flyer* has proven to be very well suited for its primary role as an ROV support ship. True to its SWATH design the normal pitching and rolling of a ship its size has been minimized. Because ROV operations originate from the pivot point at the center of the ship, there is little jerking of the ROV tether. The complex operation of recovering an ROV in heavy sea states has been enhanced by the development of an ascent line system, which allows the ROV to lock onto a weighted cable as it clears the turbulent interface. The *Western Flyer*'s dynamic positioning system can maintain the ship on station to within 4 meters in 40-knot winds and 15 to 20 foot seas. For a small ship, the *Western Flyer* is uniquely capable as an ROV support platform.

In 1997 an extensive internal study projected the need for full use of both ships and ROVs by MBARI scientists for the foreseeable future. The *Western Flyer* and *Tiburon* will allow us to extend the reach of our technologies throughout the eastern North Pacific. MBARI scientists are actively planning expeditions to Hawaii, the Gulf of California, and the Juan de Fuca Ridge during the next three years. Research expeditions such as these allow us to investigate critical oceanographic processes that cannot be studied locally, present opportunities to build ocean-scale data bases, and provide us with comparative data to better understand the oceanic processes being investigated in detail within the Monterey region.

Point Lobos and *Ventana* will continue to be the local workhorse. Over the coming decade, they will conduct time-series studies in Monterey Bay, work the upper 1500 meters of the water column and the flanks and upper reaches of the canyon, and support shorter-range expeditions along the California coast. They will also serve as a test platform for ROV/AUV tools and instruments, install and service seafloor observatories, and continue to collect biological specimens for MBA (Monterey Bay Aquarium) and MBARI scientists.

Thus MBARI's ROVs will continue to play a major role in our future. In the latter half of the 10-year period encompassed by this report, we expect that it will no longer become cost effective to maintain and upgrade *Ventana* in its current configuration. At that point in time, if the current demand for two ROVs is sustained, we would likely propose to replace *Ventana* with a more portable version that can be launched from a ship of opportunity. While the *Point Lobos* would continue to be the ROV tender while working in Monterey Bay, the new design would allow researchers to use the vehicle in geographic regions beyond the current range of the *Western Flyer*.

SCIENCE QUESTIONS MOTIVATING USE OF OCEAN OBSERVATORIES

The solution to many outstanding problems in the ocean sciences depends on a future capability to acquire long time series at many locations at an affordable cost, a function for which ROVs are poorly suited. This necessity of acquiring continuous, synoptic measurements of the physics, biology, chemistry, and geology of the oceans is driving national and international initiatives to establish ocean observatories. In March 1999, MBARI held a workshop to articulate those particular science drivers that are relevant for MBARI. The workshop results centered around two themes:

- Theme A: The Biology and Chemistry of the Oceans in Relation to the Solid Earth Cycle
- Theme B: The Biology and Chemistry of the Oceans in Relation to Global Change

The goal of research under Theme A is to develop quantitative, unifying principles that govern subsurface fluid transport and venting, its control by tectonic or magmatic processes, and its influence over the habitat and ecology of benthic communities. Included under this theme are both the longest-standing unsolved problem in marine geology: the origin of submarine canyons, and the newest: population explosions of unusual life forms in the deep biosphere trigged by geologic events. MBARI's location at the head of one of the world's greatest submarine canyons and proximity to the ridges, transforms, and subduction zones offshore Oregon and Washington mean that it is ideally positioned to address these questions with the new observatory-style technology it will be developing. The episodic or even catastrophic nature of seafloor events that give rise to canyon excavation, volcanic eruptions, earthquakes, and microbial blooms is obscured by the temporal limitation of experi-

Box 4. Seismicity and Fluid Flow

In an experiment that included many technical and scientific firsts, a team headed by Associate Scientist Debra Stakes succeeded in installing a unique combination of seismic instruments on the seafloor over a period of many months. The Monterey Bay Ocean Bottom International Seismic Experiment (MOISE) was the first-ever deployment of instruments of this size and type by a remotely operated vehicle (ROV). The MOISE and the MBARI Margin Seismology programs have accomplished important steps in evaluating technology and methods for setting up seafloor observatories around the world to continuously monitor events such as earthquakes and landslides. The initial results are described in *Geophysical Research Letters* [*Stakes et al*., 25, 2745-2748, 1998].

The MBARI seismology effort clearly demonstrates the collaboration of scientists, engineers and operations specialists to create new and exciting methodologies that make a significant contribution in the seafloor observatory effort.

Box 5. Gas Hydrates and Climate Change

Carbon dioxide and methane form ice-like hydrates in the ocean that may play important roles in climate change processes. It has been suggested that fossil fuel carbon dioxide from power plants may be sequestered in the deep-sea as carbon dioxide hydrates. Scientist Peter Brewer conceived and led a series of experiments to examine the stability and fate of these hydrates *in situ*. This work was performed on the first science dives of the ROV *Tiburon*, which was designed and developed by MBARI engineers to succeed the ROV *Ventana*. The vastly greater depth ratings of *Tiburon* provided access to the depths needed to conduct the experiments. This work was described in the May 7, 1999 issue of *Science. U.S. News & World Report* recently named Brewer as one of the "bold innovators" of the 21st century.

ments that are dependent upon expeditionary science. Underlying linkages between the geophysical, geochemical, and biological processes are unconstrained by existing experimental designs. These issues would be addressed by studies of 1) the relationships between ground motion, mass wasting, and fluid flow in tectonically and/or volcanically active environments, 2) the modification of fluids by biological processes and the relationship between specific target populations and the local vent/seep environment, and 3) the quantification of major biogeochemical budgets such as greenhouse gases and hydrothermal effluent. The potential rewards from this sort of research range from the obvious (e.g., quantification of the dangerous positive reinforcement between global warming and the dissolution of methane hydrates) to the very practical (e.g., improved predictions of the stability of platforms and cables in the marine environment) to the more exotic (e.g., isolation of extremophiles that can biologically remediate toxic substances).

The overarching goal of research in Theme B is to understand the structure of ecosystems in the upper ocean and the impact of ecosystem structure on marine biogeochemistry. Processes occurring in the upper ocean are responsible for most of the planetary oxygen and protein for human consumption. They regulate our climate and cycle the greenhouse gases. There is arguably no system more important to life on Earth than the photic region of the ocean. We must understand this system better if we are to nurture and protect it, as opposed to pollute and unsustainably exploit it. MBARI's location on the shores of a high-productivity continental margin is ideally suited for making the necessary observations and performing the key experiments that will constrain models of the biogeochemistry of the upper ocean. Scientific studies highlighted in this area include: 1) an assessment of the role of the regional circulation in the redistribution of macro and micronutrients to the euphotic zone; 2) the identification of the impact of a variable nutrient supply on the community structure throughout the water column (including *in situ* bacterial processes); 3) distinguishing patterns in community structure and/or succession that derive from episodic events on time scales ranging from days to decades. Practical rewards from this sort of research include understanding what natural and human-induced environmental changes lead to harmful algal blooms and how global warming will change ocean productivity. The holy grail for this sort of research is to understand the chemical and energy cycling though the entire food web, from the picoplankton up through the top level predators, so that we can be knowledgeable stewards of Earth's most precious resource.

As MBARI's 10-year plan is implemented, these science themes will form a nexus between the scientific and engineering expertise of the MBARI staff. The requirements for long-term observations demand new tools and methods for oceanographic research. Both aforementioned science themes share the need for a suite of oceanographic instruments on a variety of platforms. These instruments must be capable of characterizing environmental parameters that are subject to both long-term change and episodic events. The data sets generated by this system must be sufficient to test specific hypotheses concerning cause and effect relationships occurring within the ocean. Importantly, the observatories developed should include highly mobile elements to enable their deployment in different regions of interest as the science demands. Finally, it was recognized that many of the components necessary for such a system are not yet generally available. MBARI has the opportunity to provide the venture capital to make observatories a reality.

Box 6. Tiburon

Tiburon is MBARI's flagship vehicle: a 4000 meter rated, state-of-the-art ROV designed and built by MBARI engineering to meet the demands of MBARI science through the coming decade. Complex and varied operational requirements led to a wide range of innovations on *Tiburon,* from acoustically quiet power systems, to interchangeable tool sleds, to a realtime microwave link to shore. Some innovations were inherited from modifications to MBARI's original operational ROV, *Ventana*, while newer ones were retrofitted to *Ventana*. Together, *Ventana* and *Tiburon* have firmly established the utility of unmanned vehicles for deep sea observations and sampling. For example, MBARI scientist Bruce Robison has been able to observe unusual behavior patterns in fragile, gelatinous midwater animals from the ROVs and determine their environmental triggers. These vehicles have been instrumental as well in returning healthy, live samples of deep-sea organisms for exhibits at the Monterey Bay Aquarium. Success at sea has led a range of institutions, both industry and academic, to initiate efforts with MBARI to acquire *Tiburon* technology.

MBARI's STRATEGIC POSITION

In 1989, David Packard, in an address to the Oceanography Society, identified three technological areas motivating the formation of MBARI: unmanned remotely operated vehicles, instrumentation for chemical analyses, and computer science and data communication. More than ten years later, these three areas remain at the heart of MBARI Engineering's efforts, and provide the foundation for building future ocean observatories. While the focus has been enlarged in some areas, and narrowed in others, the central themes of David Packard's original vision holds strong.

MBARI's emphasis on finding technological solutions to the tremendous challenges facing oceanographic science makes it unique among oceanographic institutions. While most of the great advances in understanding the ocean in the last 50 years have been enabled by technological advances, typically oceanographic institutions assign little priority to development of oceanographic technology. MBARI's mission, by contrast, is centered on exploiting the dependence of oceanographic science on technology. By explicitly recognizing the importance of this linkage, we position ourselves to have an impact on the community disproportionate to our size.

Creation of ocean observatories comprises one of the most challenging technical projects ever undertaken by the oceanographic community. MBARI is well positioned to play a leading role (Box 7). Our effort is clearly timely–a rising tide of support for observatories as new paradigm for ocean observation is widespread. National observatory efforts are being considered today by the oceanographic community at large, and the level of support has been surprisingly high. However the larger community is poorly positioned to create such observatories– the necessary systems engineering and project management skills are not cultivated in traditional oceanographic institutions. In contrast, MBARI does value these skills, and has built a group of engineers specifically honed for such a challenge. While our strong core engineering capabilities provide a strategic advantage for the present, this will not persist forever. If we are to maintain a leadership role we must cultivate scientific and technical areas of expertise in MBARI that allow us to excel at the creation and exploitation of this new method of doing oceanography.

The MBARI Ocean Observing System (MOOS) will integrate many of our science and engineering disciplines into research teams that build upon the assets and unique capabilities of each group. These teams can focus a critical mass of scientists, sensors, and sampling platforms on important oceanographic questions and avoid the temporal and spatial undersampling that typifies most other academic studies of episodic events. We now realize that episodic events dominate ocean processes ranging from carbon cycling and toxic algal blooms to the formation of submarine canyons. These focused, high quality programs will also encourage collaboration from exceptional scientists at outside institutions, gaining the best use of our assets. Plans for the first field trials of MOOS, the Monterey Upper-Water-Column Science Experiment (MUSE) have already caused the national Autonomous Ocean Sampling Network (AOSN) and Integrated Coastal Observing Network (ICON) groups to reschedule their 2000 field efforts to coincide with the MUSE program.

MBARI has now gained the momentum to build on our recent achievements and fully utilize the

Box 7. The MBARI Ocean Observing System

The MBARI Ocean Observatory System will provide a new and powerful system for conducting scientific experiments at sea. It is motivated by two fundamental and related desires: the need to observe episodic events, and the need to conduct perturbation experiments. These in turn motivate the creation of a multiscale observational capability that provides an affordable, extended**,** interactive presence in the ocean.

Episodic Event. Episodic processes provide the key to understanding a highly dynamic ocean whose changing character can destroy fisheries or even bring on a new ice age. The view of the ocean as an environment in which episodic processes are local perturbations to the steady state provided a convenient framework for combining measurements widely separated in time and space. However, our growing understanding of the importance of localized, episodic events in determining biohabitability of both the ocean, and the Earth as a whole, requires we move beyond this simple framework.

Perturbation Experiments: Establishing cause and effect is a highly demanding task for scientists unable to manipulate a natural system of study. The desire to establish quantitative laws governing the state of a system drives one to create circumstances isolating specific processes, effectively reducing the numbers of degrees of freedom available to the system. While many oceanographic processes are clearly beyond our ability to influence, our realization of the importance of small-scale processes and our growing sophistication in asking biological and chemical questions opens the door to creating structured experiments in the ocean. The great promise of such experiments is that we will be able to determine how the various oceanographic processes and biological communities interact in a much more direct and certain fashion. The challenge is to have the observational capability, which will allow us to measure and understand the results of such experiments.

substantial investments of the David and Lucile Packard Foundation. The success of the basic paradigm on which this Institute is based—synergism between scientists and engineers—has been demonstrated. Our funding structure and current assets create outstanding opportunities for research and development that would be difficult or impossible to support at other oceanographic or academic institutions. The capacity to conduct long term, multidisciplinary studies using Monterey Bay as a model system has led to the establishment of the MOOS. This institutional initiative can place MBARI at the forefront of ocean sciences.

BUILDING ON OUR STRENGTHS

Major programmatic themes of MBARI research and development are illustrated in Figure 1 and outlined in more detail in Attachment I. These themes exist within the framework of creative engineering efforts (autonomous underwater vehicles, remotely operated vehicles, moorings, cabled arrays, chemical and biological sensors, etc.) that allow MBARI scientists to respond in original and efficient ways to marine and environmental problems. Our primary efforts reside in three overlapping areas of research: (1) studies of global climate change; (2) assessing biodiversity and environmental impacts on Monterey Bay and the surrounding ocean; and (3) studying the solid Earth cycle of tectonic and volcanic events. Chemists, biologists, and geologists interact with engineers in each of these programmatic areas. Some of our most creative research efforts exist at the interfaces between these areas. For example, studies of greenhouse gasses occur at the interface of global climate change and the solid Earth cycle. Studies of toxic algal blooms occur at the interface of global climate change and biodiversity studies. Studies of deep-sea seep organisms and subsurface microbial life span the disciplines of solid Earth and biodiversity studies.

To build on these major themes and strengthen their overlap will greatly enhance the potential for success of the MOOS program. Critical new hires at these interfaces will have a greater impact on the growth of excellence at MBARI than expansion into isolated areas.

The observatory science effort can be augmented in many areas by interacting with other institutions within the Monterey Bay region. The timing has never been better to build robust connections to our sister institutions in the region (the Monterey Bay Aquarium, Stanford University and the Hopkins Marine Station, the Naval Postgraduate School, the University of California-Santa Cruz, Moss Landing Marine Laboratories, California State University-Monterey Bay, the Monterey Bay National Marine Sanctuary, the National Marine

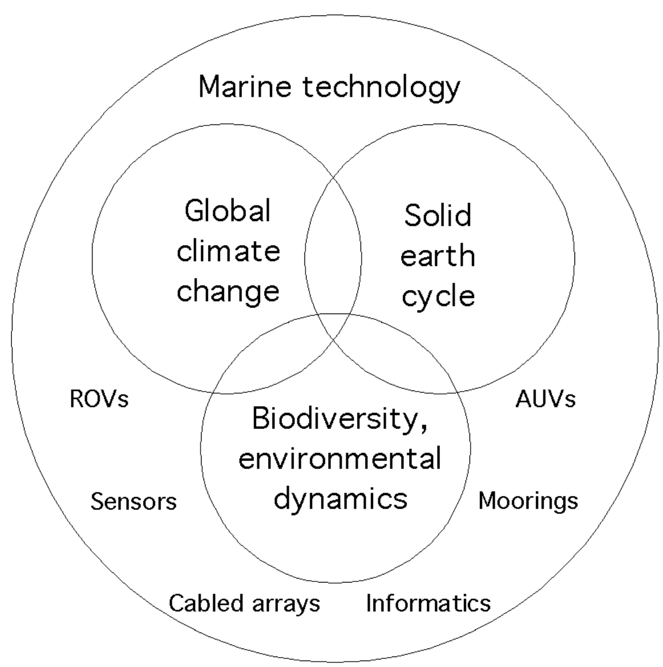


Figure 1. MBARI Science and Engineering Strengths

Future Scenario 1

The year is 2002. In an unprecedented display of public/private partnership, NSF and the Gates Foundation announce the joint funding of a fiber-optic ocean observatory, NEPTUNE, that encompasses the entire Juan de Fuca plate. The NEPTUNE proponents understand quite well the logistical challenges they face in trying to design, install, and debug an undertaking of this magnitude within the narrow weather window of the Pacific Northwest. They make the very wise decision that Node 1 of NEPTUNE will not be installed offshore Washington State, but rather in Monterey Bay, to take advantage of the considerable operations and engineering expertise and ROV assets of MBARI. Researchers designing instruments, vehicles, and other systems for use on NEPTUNE quickly learn the mantra: "It doesn't go on NEPTUNE until it has been demonstrated in Monterey Bay."

Fisheries Service, etc.). These interactions with our neighbors can provide very important components of a research program and access to major scientific instrumentation facilities. These ties will be a particularly important means to augment the MOOS program on a temporary basis. However, they may not be the best means for building long term efforts that are central to the observatory effort. Among these research institutions, only MBARI has the unique structure and funding to attract scientists, engineers, and marine operations personnel to high-risk projects with longer term payoffs, rather than the short-term benefits rewarded in more traditional academic environments.

RESEARCH SCIENCE PLAN

If MBARI is to take a prominent lead in the design and use of ocean observatories, we must be sure that we have the in-house expertise to

- set meaningful science requirements for the observing system;
- develop the sensors, assays, and experiments required to more completely characterize important ocean processes;
- select sites and deployment strategies of the functional MOOS systems; and
- exploit the data, as they become available.

Below, we provide targeted areas of inquiry that will be relevant to MBARI's ocean observing effort. The list was compiled to achieve institutional objectives, as well as to fill critical in-house science gaps. New positions considered will optimally contribute to designing, building, and exploiting a fully functional and integrated ocean observing system. The order in which the different science positions are hired is not as important as the opportunity to attract the best talent to our program, and match their expertise to evolving MBARI technical capabilities. This approach will allow us to best leverage off of current science foci and strengths, and developing initiatives. Additional science positions might be filled internally later if funds are available. Alternatively, some needs might be best met with ongoing strategic alliances with our neighbors.

Science Positions

Ecosystem dynamics and ecological conservation. A scientist who focuses on natural and anthropogenic change in key species or resources could bolster the significance and impact of current Institution initiatives. This Science position could also fill a leadership role in Monterey

Future Scenario 2
Denitrified waters from the eastern tropical Pacific sweep up the west coast of North America in the California Undercurrent. Suddenly an increase in the flow rate of the undercurrent, associated with either the El Niño Southern Oscillation cycle or the Pacific Decadal Oscillation or, even more dramatically, both, initiates a cascade of ecosystem changes from the surface to the sea floor. Although hypothesized for years, scientists lacked the technology to determine how shifts in circulation lead to dramatic ecosystem changes in the California Current. An observing system (moorings, AUVs, gliders) populated with MBARI-developed systems and instruments (chemical sensors, bio-optics, respiration chambers, imaging systems) documents for the first time how the physical and biological processes are linked. Along the coast an increase in the abundance of centric diatoms fuels an anchovy-dominated pelagic ecosystem, while the subtropical gyres far downstream are impoverished. The climate-driven signal propagates through the upper ocean to midwater and benthic ecosystems. In midwater the elevated flux of organic material favors fish, squid and crustaceans, which begin to outnumber gelatinous animals. Near and on the sea floor, the accumulation of organic material leads to a rarely observed flurry of biological activity, spanning the explosive productivity of microbial assemblages to the enhanced growth and reproduction of top benthic consumers.

Bay ecosystem studies by creating critical bridges to regional conservation efforts undertaken by the Monterey Bay Aquarium, Monterey Bay National Marine Sanctuary, Moss Landing Marine Labs, Hopkins Marine Station, and the National Marine Fisheries labs. MBARI already has strong expertise in the genetics of threatened and endangered fish and invertebrate populations. This program can only flourish however, within the context of comprehensive studies of natural habitats, and an understanding of the population and community ecology of constituent organisms. Biological observations can only be understood within the context of physical, chemical, and geological variability, natural or anthropogenic. The Monterey Bay observatory effort will provide the operational framework for the proposed new science hire to interpret complex environmental data with conservation genetics. We would seek a scientist who could integrate ecosystem studies and conservation efforts, by using the technological expertise and assets of MBARI. This individual would be encouraged to develop and implement new ways to monitor, model, and conserve threatened resources.

We expect this new scientist to develop strong collaborations internally with MBARI scientists and engineers. The candidate should bring to MBARI the ability to combine monitoring efforts, technology development, and ecosystem modeling, with key issues in conservation ecology and genetics. Currently, how the complex interplay of biotic and abiotic variables, both natural and anthropogenic, affect key resources and species is rarely known. The successful candidate will be expected to use MOOS data to more clearly focus and define conservation problems, and to suggest and test potential roads to their mitigation. This hire should forge and foster ties between colleagues and Institutions around the Monterey Bay, as well as further afield. Strong collaboration with the Monterey Bay Aquarium on conservation issues will also be nurtured by this candidate's collaborative efforts.

Zooplankton biologist. The biological expertise at MBARI spans the range from bacteria, archaea, protists and algae, to macroinvertebrates and fish. We lack, however, a biologist with expertise in zooplankton, a critical component of the marine food web that directly impacts abundance of the fish we eat and marine mammals we enjoy. Efforts to assess the health of zooplankton currently rely on brute force sampling and counting by numerous technicians. MBARI can make a significant impact in this field by developing better physical and biological sensors to automate this effort. Acoustic imaging devices deployed on ships or AUVs are one way to proceed. Automated biosensors and samplers could swim through the water column counting plankton optically or acoustically and sampling them. On shore, evolving DNA microarray technologies might be exploited to identify a complex array of species, and elucidate subtle changes in their populations at the molecular level. MBARI is particularly well poised, with in-house talent and strategic alliances, to invest the long-term efforts required to develop such daring technologies. These efforts would dovetail well with ongoing efforts of current MBARI scientists developing methods for chemical sensors, as well as methods for characterization of phytoplankton and microbes.

This scientist would provide a critical missing component of biological observations for MOOS efforts in the upper water column. The successful candidate would lead in technological developments and field observations, and interpret variability in physics, chemistry, and primary production in the context of higher trophic levels in the food chain. The top-down influence of zooplankton and the significance of their biodiverisity and variability would be interpreted in the context of other MOOS observational data. This hire would contribute significantly to modeling efforts for interpreting the influence of environmental variability on the entire food web.

Benthic biogeochemist. Virtually all of the major seafloor observatory efforts under consideration

Future Scenario3

After a mild summer and fall, a strong El Niño storm surges through the central California coast. Heavy rains and huge ocean swells pound the coast. The torrent destabilizes loosely consolidated sediment at the head of Monterey Canyon, triggering a massive turbidity flow, nearly undetectable at the surface, but accelerating rapidly down the canyon, scouring canyon walls, sweeping with it accumulated organic detritus, kelp, and other material. As it reaches 500 m depth, current sensors on MBARI's first canyon observing node measure its speed, turbidity, and organic content at various heights above the bottom. Merging with another turbidity flow originating in Soquel Canyon, it crashes through a second canyon observing station at 1500 m. Because of its anomalous size, instructions are relayed immediately to distant nodes downstream to cycle sampling devices in preparation for the event's arrival, and email notification is forwarded to MBARI investigators - even the severe storm at the surface doesn't sever satellite communications within the chain of MBARI observing stations. Hours later the tempest has carried debris over 125 miles down the canyon to the abyssal plain, where one of MBARI's benthic crawlers initiates a series of measurements documenting the physical and chemical qualities of the deposit, and its influence on the benthic ecosystem. AUVs search the water column above the canyon for evidence of nutrient injection into the euphotic zone arising from the event. The event is witnessed by thousands in the new "Live from Monterey Canyon" display at Monterey Bay Aquarium, where real-time data and images are on display along with three-dimensional, canyon-scale renderings of the storm surging through the canyon below.

at MBARI, or within the larger oceanographic community, involve studies of biologically mediated transformations of organic carbon as it enters the benthos. In the coastal zone, this benthic-pelagic coupling is the primary mechanism providing energy to the benthic community. Temporal variability in carbon input must be a major factor that shapes community structure in the deep sea. However, little is known about the mechanisms of these processes. The potential impacts of structural variations in the upper ocean ecosystem driven by climate change are a scientific unknown. Coastal observatories with both upper water column and benthic sensor suites would be well situated to make pioneering studies of these processes. Such science would greatly complement efforts at the MBA and the MBNMS. Further, the skills of a technologically inclined biogeochemist could well complement those of other MBARI scientists involved in mid-ocean ridge observatory efforts, canyon process studies, and cold-seep research. The plan to import MEMS (micro-electro-mechanical) technology into a research engineering position, as well as the current strong program in chemical sensors, would be greatly enhanced by the efforts of a benthic biogeochemist actively involved in sensor development.

Specific science deliverables from this key science hire would include the development and implementation of new *in situ* approaches for characterizing benthic biogeochemical processes., ideally deployable from benthic hubs developed in conjunction with MOOS. This hire would strengthen interdisciplinary ties with ongoing MBARI field efforts in geology, microbiology, and chemistry. This key hire could also, in collaboration with the chemical sensor group and a MEMS-oriented research engineering group, catalyze the maturation and implementation of *in situ* benthic biogeochemical sensors. New insights on the dynamics of sediment pore water chemistry, fluid flow, and its pervasive influence on biota and biogechemical cycles would develop from the research efforts of this individual. Collaborations at high-temperature hydrothermal vent environments would also naturally arise from the efforts of this individual.

Larval Biology. The structure of marine communities is largely shaped by factors that affect the recruitment of new individuals. However, the complex life histories of most marine organisms greatly complicate efforts to quantify or predict recruitment. Many marine fish and most invertebrates have a larval phase that feeds in the planktonic zone, disperses actively or passively with ocean currents, and then metamorphoses into an adult that settles on the bottom or feeds in the water column to complete its life cycle. Unfortunately, little is known about factors influencing larval life histories and dispersal (e.g., fertilization success, larval development rates and survival, transport in the water column, metamorphosis, and survival to juvenile and adult stages). The biological diversity of Monterey Bay coupled with MBARI's unique ability to regularly sample organisms from an extraordinary range of depths create research opportunities for a larval biologist that are unmatched elsewhere. We seek an experimental biologist who can apply creative new technologies to studies of development, dispersal, and recruitment of marine animals. MBARI's development of novel sampling devices, molecular markers, biosensors, and *in situ* experiments can best advance a field of study that has been plagued with difficulties in sampling and larval identification. MBARI can invent better ways to automate a census of key fish and invertebrate larvae which are needed to generate sufficient data for existing recruitment models, and to develop models to the next stage where they can appropriately integrate information on ocean currents and climate change.

Submarine Hydrology/Geodesy. The coupling between tectonic movements, fluid flow, and biogeochemical processes, is a major theme of seafloor observatory science. Progress depends on our ability to quantify the flow rates of fluid within the ocean crust and overlying based on measurements of physical parameters, including ground motion. Constraining the porosity, permeability, thermal gradient, chemistry, and rates of fluid flow is the realm of the hydrologist. Seafloor geodesy is only beginning to develop techniques to constrain the movement of slumps or faults by monitoring tilt, strain or changes in absolute depth. We would aspire to add a new scientist who would lead a multidisciplinary effort based on the approaches from both of these disciplines complemented by the adaptation or development of new marine sensors, especially sensors for geodetic measurements. This individual would play a major role in the development of seafloor observatories and would provide an important complement to our existing programs in seismology, tectonics, benthic microbiology, and proposed additions in microfluidics and benthic geochemistry. This type of scientist would benefit from a stronger in-house engineering program in acoustics (the basis of submarine geodesy) or the development of benthic sensors for porosity, permeability, and fluid flux

Physical oceanography. MBARI's multidisciplinary interests would be greatly served by a scientist with expertise in physical oceanography, particularly the relationship between physical processes and their biological and chemical consequences. The relationships between upper ocean circulation and nutrient supply, primary production, onset and redistribution of harmful algal blooms, resuspension and transport of sediments, etc., are still poorly understood. These problems are well suited for an individual with bold new ideas of how to use fixed and mobile observing systems to understand issues related to physical-biological coupling. Such an individual could also draw upon expertise available at the Naval Postgraduate School. Whether and when this type of position is filled would depend on what sort of needs remain unmet after the modeling position advocated by engineering is filled.

ENGINEERING PLAN

In a disciplinary sense, MBARI engineering efforts can be roughly grouped into three areas of expertise: (1) platforms, (2) sensors and instrumentation, and (3) software infrastructure and data management. While the larger part of engineering specializes in platform related areas, a core of engineers primarily interested in sensors and instrumentation is developing. The software infrastructure and data management area is comparatively undeveloped within Engineering at present, although this area will be increasingly important at the MOOS effort reaches maturity.

Platforms

The ocean retains its mysteries in large part through the simple expedient of being highly impenetrable to our most powerful observational tools. As a consequence, most methods for characterizing the interior of the ocean rely on the use of a variety of platforms that carry instruments to characterize their immediate surroundings. Because this is very expensive, the ocean remains largely unobserved. Advances in areas such as moorings and marine robotics promise to dramatically improve our ability to characterize the ocean. Over the past decade, MBARI has developed a strong core of engineering skills for developing advance oceanographic platforms, and these will be particularly important in the early development of MOOS.

Early efforts to develop MBARI ROVs culminated in the creation of *Tiburon*. The engineering capability established in the process has since enlarged its focus to include moorings and AUVs. These systems are highly complementary in nature: ROVs provide a high-bandwidth communications, power, and manipulative capability, although with limited mobility and relatively high cost. Moorings provide the ability to monitor a particular location for an extended period. AUVs dramatically drop the cost of access to the ocean, as well as providing a means to probe the horizontal variability of the ocean, but are not useful for complex or high-power missions.

At present, engineering is strongest in platform development, with both *Tiburon* and mooring development having strongly shaped the division. With the growth of AUV and mooring activity within Engineering, the development of platforms is broadening. This shift in emphasis is also accompanied by a shift in the technological focus underlying platform development. Specialties such as low-power electronics, navigation, mission-level control, and hydrodynamics increase in importance as efforts to develop increasing sophisticated autonomous systems mature. Given the healthy staffing levels within the platforms group within MBARI, the overall size of this effort is unlikely to increase substantially, although the emphasis of work will continue to shift to autonomous and long deployment systems.

<u>Sensors and Instrumentation</u>

The ocean is a complex soup of chemicals and biological organisms. While the development of autonomous platforms promises to provide ever more cost-effective access to the ocean, these platforms will only be as useful as the sensing systems they carry. At present, our ability to characterize the ocean is limited primarily to physical characteristics such as temperature, salinity, and current. This provides a necessary foundation enabling the study circulation and mixing processes in the ocean, however it only sets the stage for studying the ocean as an ecosystem and for understanding the role of the ocean in regulating the thermal and chemical balances of the planet. Thus, there is a critical need for sensors capable of quantifying the chemical composition of the ocean, and for detecting and identifying organisms of all types.

MBARI is already positioned in a leadership role in three important classes of sensors: in situ chemistry, in situ DNA typing, and chemical process characterization. Driven in large part by active efforts on the part of several MBARI scientists, MBARI engineers are now involved in instrumentation projects developing a range of chemical and biological sensors. Motivation for increasing activity is partly driven by tremendous opportunities in the combining in situ sensors of emerging autonomous platforms, and partly driven by the recent availability of enabling technologies such as ‘gene chips’.

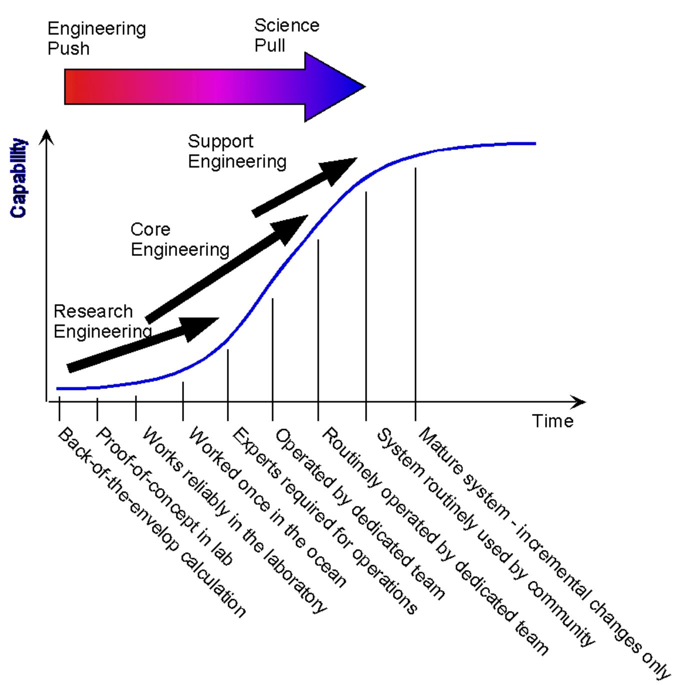
With the increasing importance of sensors and instrumentation within MBARI, a corresponding growth in engineering staffing levels is anticipated. At present, MBARI engineering contributions to sensor development are largely focused on providing the expertise to automate, package, and integrate sensors for operation on existing platforms. However, there is a clear need for more specialized engineering expertise to assist with sensor development at the 'front end.' Consequently, sensors and instrumentation will provide the primary focus for augmenting the Engineering side of R&D.

Software Infrastructure and Data Management

As the number and type of sensing platforms proliferates, and their sensing systems increase in complexity and number, the need for more powerful data management tools is rapidly becoming an important challenge for engineering ocean observation systems. Early in MBARI's history, David Packard recognized the central nature of data management. Consequently, important steps have already been taken for managing the large amount of video and digital data obtained by the ROVs. However, ocean observing systems promise challenges beyond those posed by the current generation of instruments and platforms.

A successful MOOS program will create the proverbial fire hose of data, from which MBARI scientists will drink with great difficulty. Not only will it be necessary to merge data acquired by multiple platforms into a single coherent picture, but it will be necessary to do this in near real-time so that scientists and engineers can take advantage of the reactive capability of MOOS assets. It may even be necessary for the entire MOOS system to be capable of autonomously coordinating its many platforms to optimize observation of some process or event. Certainly, the effectiveness of the entire system will be in large part determined by our ability to work quickly and effectively with observations made by various elements of MOOS.

While the software engineering group at MBARI is extremely strong, the portion of its efforts focused on software infrastructure and data management makes this the least developed of the three focus areas. Expertise in data management is also heavily vested with IAG, within the Science Division. While offering an exciting area for future research and development, the present plan is to address MOOS data management without expanding staffing in this area. As MOOS matures, priorities may change, and this area of engineering activity may become a candidate for increased attention within Engineering.



STRUCTURING ENGINEERING FOR SUCCESS

The scope of MBARI Engineering's mission is broad, ranging from developing new oceanographic technology, to developing large systems, to supporting ongoing science and operations. This breadth creates a tension between the conflicting demands of supporting ongoing science and developing new technology. Recent restructuring of the Engineering group has sought to institutionalize a balance by loosely compartmentalizing engineering functions within different branches of the division. Very roughly: Research Engineering focuses on technology creation, Core Engineering designs and builds new oceanographic systems, and Support Engineering works with science and operations to ensure success in the use of existing assets.

Research Engineering

The 1998 MBARI External Review Committee strongly advocated enhancing MBARI’s research engineering group. MBARI’s Management and Board embraced this recommendation. These positions will fill a void by providing an opportunity for researchers engaged in technology creation to join MBARI in positions equivalent to the scientist positions of the Science Division. The Engineering Department’s highest priority is to establish a strong Research Engineering activity focused on developing in situ chemical and biological sensors. Ultimately we anticipate a core of five Research Engineers as being the minimum necessary for critical mass.

The Engineering Department is currently planning to hire researchers to augment growing MBARI chemical and biological sensor development. Critical expertise in these areas will significantly enhance the MOOS program in several ways. An expert in microfluidics will allow us to move rapidly forward in developing bio- and chemical sensors that can be applied to all three thematic areas. For example, new biosensors can efficiently monitor toxic algae, identify the buildup of potentially harmful microorganisms, and monitor larval densities of finfish, shellfish, and introduced pest species. New chemical sensors can increase the efficiency of detecting the chemical signatures of environmental pollutants and greenhouse gasses and characterize the habitat and abundance of microorganisms hosted within hydrothermal environments.

An additional Research Engineer hire in the platforms area is also considered highly attractive. A researcher with experience in low power mobile or drifting platforms would provide important expertise in a field that is rapidly growing in importance. Such a person would help assist the transition of MBARI platforms focus from high-power, high-bandwidth systems to the long-duration systems which are emerging in importance for future ocean observatory efforts. Field experience and a background in physical oceanography would be highly attractive for such an addition to Engineering.

Core and Support Engineering

MBARI Core Engineering is comprised mostly of experienced engineers recruited from industrial backgrounds. Accustomed to working in teams on complex technical projects, they provide a base of cutting edge engineering talent and project management capabilities that is unmatched in the oceanographic field. The creation of *Tiburon* built an appreciation for the unique aspects of MBARI engineering in the oceanographic community, and that valuable knowledge is the foundation that makes the MBARI Ocean Observing System possible. At present, the composition of core engineering can be characterized in a broad disciplinary sense as five mechanical engineers, six electrical engineers, and eight software engineers. Within those groupings are engineers with a range of specific skills, ranging from radio communications, to finite element analysis, to high level control of autonomous systems, to power systems, and more. Core engineers are also encourage to develop project management skills, enabling MBARI to carry out more complex, higher risk projects than would otherwise be possible.

Support Engineering is a component of Core Engineering, and exists primarily to ensure that MBARI's operational assets are used to maximum effect. Thus, Support Engineering is the front-line for the Engineering Division. This group works directly with scientists and engineers to enable and insure the success of field experiments, and directly with operations to keep operational assets fully functional. The support group is new in 2000, and thus the experience base for projecting the size of this group does not exist. However, the number of Support Engineers is clearly a function of the number and complexity of operational systems maintained by MBARI, and the tempo of field experiments.

At present, the efforts of core engineering are nearly evenly split between working with scientists on focused projects and working as members of engineering teams on institutional initiatives. Long term partnering of engineers with MBARI scientists, while not widespread, has been instrumental in fostering success in a number of programs. Promoting these efforts has had the positive effect of allowing engineers to develop expertise in more narrowly focused fields, enabling science specific experiments such as the NMR experiments. These partnering relations will continue to be encouraged within the Division.

Major institutional initiatives such as MOOS are primarily executed by the staff of core engineering. The number of engineers required depends greatly on the scope of the effort, however even the less ambitious implementations of MOOS will exceed the resource requirements of Tiburon, the previous large institutional initiative. Tiburon started with eight engineers and grew to a staff of 18 engineers and technicians over the six-year development life of the project. MOOS is projected to be complete in five years, and carries the additional resource demand of a number of operational deployments of elements of the system, beginning in the first year. MOOS will occupy ten engineers in 2000, a number which could easily double by the end of the project.

Core Engineering growth is limited to a slight expansion in the sensors and instrumentation area, and perhaps more important, hires of engineering technicians. Candidate specialties for augmenting the sensors focus included optical electronics and image recognition. However, selection of these engineers will be heavily influenced by the Research Engineering hires in the sensor area. In contrast, technicians are a very high priority for near-term augmentation of the Division. At present, there are no technicians within the Engineering Division. Consequently, addition of technicians to the engineering staff to work closely with the existing engineering staff is of great importance for productivity and morale.

SUPPORTING POSITIONS

The new research positions described above are motivated by our desire to capitalize on the move to ocean observatories. We recognize, however, that a number of supporting positions will be required if the total number of researchers at MBARI is augmented.

R&D

Research technicians. We anticipate that 1 or 2 new research technicians will be needed to support each new scientist, depending on the seniority of the appointments.

Information Applications Group. At least one new position will be required in this group to create the tools to manage the large amount of data from the MOOS system. There may be opportunities to reprogram some existing efforts in IAG towards MOOS objectives as well.

Information and Technology Dissemination

Video Laboratory. We anticipate the current annotation project will result in increased shipboard annotation of video by science users so that the current 4 FTE video lab staff can provide for general support, video productions, and annotation. This estimate is based on current number of ROV dives (~150 per ship); however, if the quantity of dives increases, video staffing needs will increase proportionally (1 FTE per ~70 dives).

Communications. External requests for public information and media support already exceed what can be handled by the current communications staff, and the number of requests will only increase as new researchers and programs enhance MBARI's public profile. We would propose to generate revenue from external parties that purchase MBARI images as additional communications support.

Publications. Any additional publication support for MBARI projects would be arranged by ITD using contractual graphical and editorial assistance, when necessary, charged to the specific project requiring that support.

Documentation. While the need for technical documentation will increase with addition of technical projects and staff, support engineering will take a primary role in writing documentation and providing labeled drawings and files. ITD will provide document templates, review and edit documentation for readability and provide access to those documents and drawings. With this division of responsibilities, no additional staffing would be required.

Sample Archiving. At least half-time staffing is anticipated to update and maintain the sample archives and database system to support access to samples and accurate ancillary data for new science hires. Current sample archiving support is only quarter time.

Intellectual Property, Web Support, Special Events, Reception, Education, Image Archive, Library. No additional support would be required.

Technical Services Division

Information Systems. The largest impact to the Technical Services Division is likely to be in the area of computers. The new observatories and their associated AUVs will each become new nodes on the MBARI network. In addition, the types of researchers we advocate hiring will be heavy users of high-end workstations.

Facilities. The addition of more buildings to MBARI's facility, as the expansion of Building B is completed, will require adding one additional person to the facilities group.

Machine Shop.

Marine Operations

Although MBARI is proposing to add more scientists, internal ship needs may not subsequently increase for two reasons. First of all, we have just added the *Western Flyer* to MBARI's ship assets. Second, all MBARI scientists will be increasingly working on team projects that could conceivably reduce the number of ship days per PI for the same data return. This was in fact the experience of UNOLS during the field portions of major programs such as WOCE and JGOFS: ship demand dropped as PIs collaborated on the same expeditions.

We do anticipate increased outside demand for use of MBARI ship time, especially if NEPTUNE or any other west-coast observatory efforts are funded. MBARI's budget for calendar year 2000 already shows an income of $209,380 from sea days sold to NURP. Initial discussions with NURP have projected an increase to $286,190 in 2001. If we impose a limit of 30 days a year sold to outside users we can expect to level out at a sustainable $390,000 a year. Building MOOS moorings for outside use and ROV servicing of external observatory systems (i.e. NEPTUNE) could double the $390 K a year projected income. Thus additional ship /ROV and Observatory Group positions advocated below could be self-funded. We would need to find a funding source for the proposed AUV and Operations Tech positions.

Ships and ROVs: The *Western Flyer* and *Tiburon* currently are allocated crew positions sufficient to cover 24-hour operations plus one position. Several of the ROV crew are cross-trained as ships crew so that the loss of 2-3 (sick, training, otherwise unavailable) can be covered but limit operations to 12 hours. In order to increase operations to achieve 190 to 200 operational days per year, as might be anticipated as outside demand for use of the *Flyer* increases, an additional five Ship/ROV positions will be necessary over the next five years.

AUV Operations: AUVs currently have no authorized positions in DMO. With the transition of development AUVs to operational AUVs, an additional four positions are anticipated working in partnership between Operations and Engineering.

Mooring Support: Given an anticipated load of three MOOS moorings funded internally the Observatory Group will require one additional position.

Operations Technicians: Currently two operations technicians support 170 *Pt. Lobos* day trips a year. A gradual increase to 370 operational days (both ships) a year will require two more Operations Technicians.

<u>Management</u>

Accounting. Accounts Payable/Purchasing – one additional person. Shipping/Receiving – 0.5 to 1.0 person, depending on final staff numbers.

SPACE REQUIREMENTS

Office and Laboratory. With the completion of the Building B expansion, we should have sufficient laboratory space to implement at least the next 5 years of this plan. Depending on the types of scientists hired, modest additions to office and laboratory space may be required towards the end of this plan period.

Other. Additional climate-controlled tape storage facilities are anticipated (at least twice current space). Video lab work space for MBARI staff, collaborators and external users is at maximum capacity now, and will eventually need to be expanded.

OTHER INFRASTRUCTURE NEEDS

BUDGET IMPLICATIONS

Budget projections.

POSSIBLE REVENUE SOURCES

MBARI has enjoyed unprecedented freedom in its ability to pursue new opportunities thanks to the generous support of the Packard Foundation. However, as we evolve from a small, isolated oceanographic laboratory meeting the needs of a handful of adventuresome researchers to become a major force in the national and international observatory effort, our ambitions may outgrow the desire of the Packard Foundation to carry all costs. In putting together this 10-year plan, we have thought broadly of how we might cultivate other revenue sources without changing the following premises upon which MBARI is built:

- MBARI must continue to set its own direction internally, rather than respond to any and all external funding opportunities;
- MBARI must be able to enact an institutional agenda that is not merely the sum of the individual funded programs of its staff;
- The science/engineering peer culture must be protected and encouraged;
- MBARI must retain its core engineering expertise;
- MBARI must continue to control its own ship schedule, so that it can respond to unexpected opportunities;
- MBARI should continue to fill its role as the "venture capital" for oceanography by undertaking long-lead-time, high-risk research and development programs;
- Our special partnership with the Aquarium must be protected.

We describe below some possible revenue sources and discuss how MBARI might take advantage of them without violating the principles stated above.

<u>Passing on Costs to External Users</u>

In the discussions above we already allude to the fact that some revenue is received by MBARI in exchange for NURP use of ship time. This is an excellent example of how MBARI can pass on the costs of using its assets to outside entities. The great advantage of the NURP program is that it allows MBARI to retain full control of the ship schedule, which would not be the case if our ships were formally a part of UNOLS. Furthermore, this practice furthers a goal in MBARI's Strategic Plan by aiding in technology transfer. Currently, those NURP funds are turned around to purchase ship time on UNOLS vessels in cases when they provide our researchers with the required capabilities at a lower cost. Nevertheless, the NURP dollars are indeed an external subsidy of approximately 10% of our marine operations. We expect that external demand for use of MBARI ships will increase as observatories are installed along the West Coast. Thus external support of MBARI Marine Ops could perhaps be increased to as much as 20%, depending on internal needs for ship time.

Another area where costs could be passed on to consumers is the use of MBARI video products. Currently, a large amount of staff time is spent filling outside requests for MBARI footage. In the future, we might institute some recharge system that would retain the current system for the Aquarium, pass on direct costs to other non-profits, and recover both direct and indirect costs from for-profit entities. This mechanism could probably pay for one additional person in ITD Communications.

Federal Grants and Contracts to Individual PIs

Over the past two years, MBARI researchers have been increasingly more successful in raising external funds through competitive, federal grants. These grants have had several positive impacts on MBARI. They have:

- expanded the number of field programs using MBARI technology, particularly in remote regions of the globe;
- brought in additional temporary staff in the form of post docs and grad students who add to the creative energy at MBARI;
- called attention to MBARI's research and validated its quality through the scrutiny of peer review;
- funded external collaborators, thus reducing the demand on internal funds for that purpose; and
- increased the productivity of our scientists.

However, these proposals have their drawbacks as well, in that they

- dilute PI effort away from high-priority internal projects;'
- pre-empt internal resources when they are submitted out of synch with internal proposals;
- create a two-class system of soft- and hard-money supported research staff; and
- produce book-keeping nightmares on account of the fact that MBARI does not direct-charge projects for items like photocopying, phone, office supplies, secretarial support, etc.

We have worked on ways to mitigate the negative impacts. For example, the MBARI President signs off on all external grant proposals to ensure that the research is in line with high-priority institutional objectives. All division directors sign off to verify that the proposal requests sufficient resources to cover its incremental costs, at least, and thus will not be a burden on internal projects. Each external proposal is also required to have a companion internal proposal that formally requests whatever MBARI cost/space/manpower resources are assumed in the external proposal.

For all of the positive reasons cited above, we will continue to encourage limited external fund raising by MBARI PIs. However, it is unlikely that this mechanism will ever actually release internal funds to do new things, such as hire additional scientists. At best, these funds temporarily augment the size of existing research groups to allow them to do more. The funds are too ephemeral and unfocused to relieve the internal financial burden of MBARI's core activities.

Institute Proposals

We believe that a more viable approach is to submit annually just a few large proposals on behalf of the institution based on management's view of what internal activities have the highest prospects of being expanded to meet our goals through external fund raising. One can imagine that major components of MOOS might be supported that way, through proposals to NOPP, NOAA, NASA, NSF-Instrumentation and Facilities, etc. The funds generated could be used to support additional engineers and operations people as MOOS is designed and built, and becomes operational. The great advantage of this approach is that our scientists remain focused, because they are funded internally and thus respond to internal priorities. If the scientists are focused, the engineering will remain focused, regardless of whether the funds are internal or external. In addition, such large projects offer high national visibility for MBARI, enhance opportunities for technology transfer, and are a viable mechanism for attacking large problems.

Note that currently MBARI is still planning to adhere to our Board's guideline that no more than 20% of the institute's budget should be raised externally. However, if this mechanism of fund raising is successful, we may return to our Board to ask that this limit be raised. The limit was imposed to ensure that MBARI continues to set its own priorities apart from that of the peer review committees. We believe that proposals submitted on behalf of the institute could continue to protect MBARI's autonomy based on the arguments given above of what preserves our institutional focus.

Packard Foundation Support

Finally, we hope that the Packard Foundation will consider the possibility that MBARI might become more than a "$30M" line item, as is the current thinking. The quality and societal relevance of MBARI research has never been higher. The outside community is beginning to realize what a national resource they have in this small laboratory. The MBARI staff is completely energized to accomplish great things by working together as a team. We hope, that as the Boards of MBARI and the Packard Foundation consider the plan we put forth here in light of all possible uses of their precious science dollars, they will see a potential return for their investment at MBARI that is unique, important, and unlikely to be equaled in impact through investments elsewhere.

Attachment I.

Science - Thematic areas

Global Climate Change

UW column Biogeochemistry/ENSO	Chavez/Johnson/
Fe regulation of primary productivity	Johnson/Chavez
Greenhouse gases – natural and anthropogenic	Brewer/Chavez/Johnson
Methane clathrates	Paull/Brewer/Greene

Biodiversity and Ecosystem Dynamics

UW column Biogeochemistry	Chavez/Johnson/Scholin
Benthic pelagic coupling	Barry/Robison/Vrijenhoek/Johnson
Cold seep biogeochemistry	Barry/Vrijenhoek/Stakes
Continental margin dynamics	Paull/Greene/Barry/Stakes
Midwater biotic diversity and dynamics	Robison/Chavez/DeLong
Picoplankton diversity and dynamics	DeLong/Chavez/Scholin
Dynamics of harmful algal blooms	Scholin/Chavez/Johnson

Solid Earth Cycle

Ridge processes –	Stakes/Clague/Johnson/Vrijenhoek
Submarine volcanism -	Clague/Stakes/Vriejenhoek
Vent microbiology	DeLong/Vrijenhoek/Johnson/Stakes
Vent macrobiology	Barry/Vrijenhoek/Johnson
Methane clathrates	Paull/Brewer/Greene

Crosscutting Technologies

Platforms

ROVs	available
AUVs	MOOS Efforts
Moorings	MOOS Efforts
Cabled arrays	MOOS Efforts

Sensors and Samplers

Chemical – Chemical Sensors	Johnson & RE microfluidics person
Biological- Biosensors	Scholin/DeLong
Geophysical – Seismic	Stakes

Core Engineering - Thematic areas

Platforms

Systems Engineering	Kirkwood/ Chaffey/ Edgington/ Massion
Mechanical Design	Massion/ Griese/ Brown/ Ericson/ Shane
Electronics Design	Chaffey/ Mellinger/ McGill/ Thrumond/ Jensen
Power Design	Mellinger
Software Architecture Design	Edgington/ O'Reilly/ Radochonski/ Henthorn
Navigation	McEwen
Controls	McEwen

Instrumentation (sensors)

Video & imaging systems	Chaffey/ Davis/ McGill/ Au/ Thomas/ Cline
Samplers (Midwater, Benthic, & Geo)	Shane/ Ericson/ Au/ McGill
Embedded Devices	Edgington/ Radochonski/ Au/ Meese/ Cline
Advanced Instrumentation Techniques	Malby

Data Management and Modeling

Instrument Infrastructure	Edgington/ O'Reilly/ Radochonski/ Au/ Henthorn
Data Manager	Edgington/ Au/ Herlien

Institutional Infrastructure

Microwave	Thurmond/ Malby