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The Value of Maine's Marine Research Enterprise:

An Initial Characterization

April 2000

Maine Coastal Program
State Planning Office
38 State House Station
Augusta, Maine 04333

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An Initial Characterization

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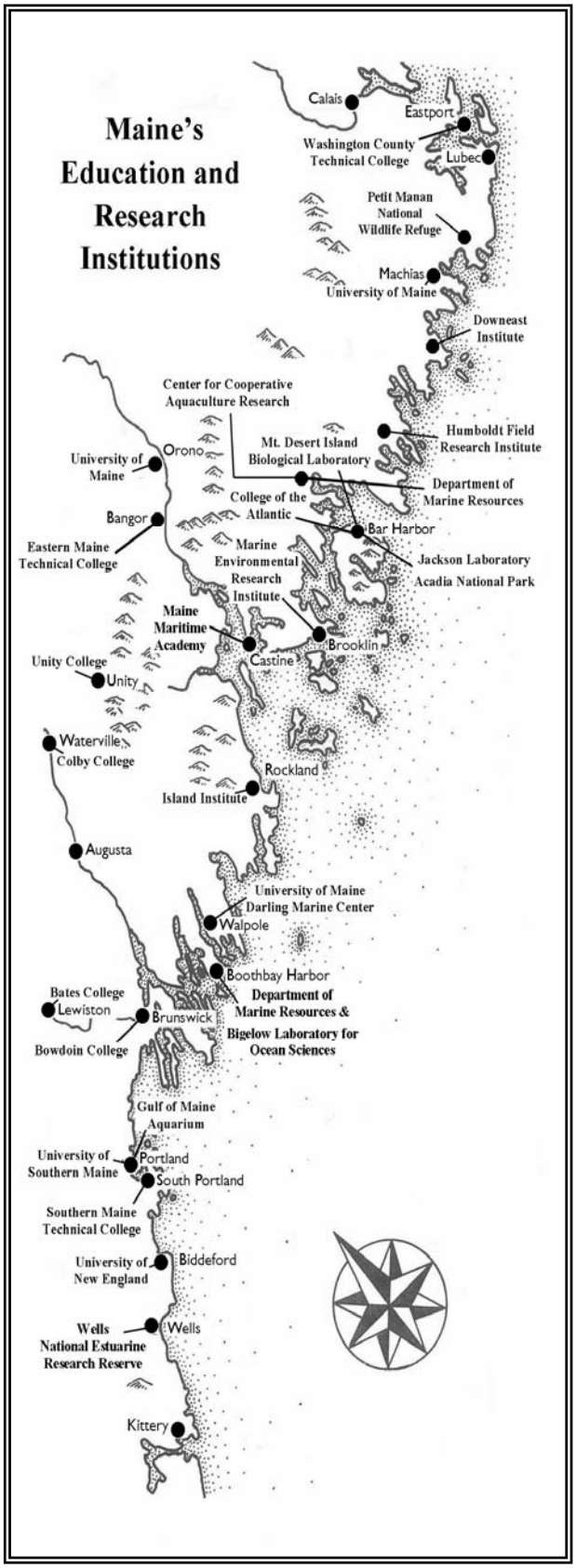
The report was produced as part of the King Administration's *Jobs from the Sea Initiative*. It provides an initial characterization of the economic and substantive value of marine research conducted by Maine's public and nonprofit organizations.



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EXECUTIVE SUMMARY

This project is a descriptive analysis designed to assess the various niches of marine research institutions in Maine, examine the funding they receive from public investments and describe the outcomes of those investments. The landscape of marine research institutions in Maine includes a comprehensive field of organizations that collectively focus on scientific research, education, economic development and outreach. This report provides information on a subset of these organizations.

On the purely scientific front, we find one of the world's premier research institutions, Mount Desert Island Biological Laboratory (MDIBL), which utilizes its proximity to cold-water to study species like the dogfish to establish powerful models for studying how cell membrane transport works in living organisms. This model has already led to greater understanding of cellular function of the liver, the kidney, the heart, the eye, and other organs. Other work done by researchers affiliated with MDIBL has led to discoveries of new antibiotics, better treatment of glaucoma, and a host of other applications.

Students of marine science in Maine benefit from a broad range of educational resources that include the University of Maine School of Marine Sciences, the University of New England's Master of Marine Science and Enterprise and collaboration with Bigelow Laboratory for Ocean Science, Bowdoin College's Ocean Studies Center, and the Maine Maritime Academy's Corning School of Ocean Studies. Since 1995, these institutions have all expanded their educational and research capabilities with additions in facilities, faculty, and increased enrollments for marine science majors. Students of marine science may choose from a comprehensive list of research concentrations that include remote global sensing, biotechnology, forecasting ecological information, aquaculture, and economic development. Although these institutions are, in many ways unique, they collectively educate students and contribute to further scientific advancements.

Some institutions in Maine converge scientific research with outreach. Through its programs, the Island Institute has forged connections with island schools, economic development efforts, health and social services agencies, and individuals engaged in the sustainable management of marine and terrestrial resources. The Department of marine Resources combined its fisheries research programs with public outreach through its public aquarium. The Gulf of Maine Aquarium's outstanding public education programs are now being integrated with new research initiatives. And the list of Maine organizations goes on.

Understanding the outcomes of research for marine science in Maine is a complicated task. Its benefits are many fold. In one light, the benefits of investing in research are seen in high levels of federal and state funds that research projects attract. These funds help to build the critical mass necessary to establish institutions of regional and national prominence. For others, the benefits of public investments are demonstrable in the increasing succession of graduating students that possess an in depth academic background of research skills and applied experiences necessary for success in today's competitive marketplace. Finally, the value of marine research lies in its ability to provide answers to pressing marine resource management issues.

Introduction

Over the past five years, the State of Maine and its 21 public and nonprofit marine research institutions have invested its land, labor and capital in research and development for the marine sciences. This investment underscores a commitment on behalf of the State to provide a critical mass necessary for the inception of innovative research and establishing institutions of regional and national prominence. Marine science is a comprehensive field that is reflected in the incredible scope of the ocean itself. It encompasses the smallest individual microscopic units of life in the sea; the myriad, interacting populations of marine species; our own Gulf of Maine ecosystem and its vast watershed; the larger dynamics of ocean chemistry, biology, and physics; and the massive ecological processes of the global oceans that reveal themselves to us through microscopes and satellites. Congruent to this diverse field of study are the many types of institutions that collectively comprise the marine science community in Maine. Although these institutions have similar goals, to advance the critical mass for marine sciences, their focus and approach to research and subsequent impacts are quite varied. Assessing the roles and specific niches of these institutions provides the Legislators and decision-makers with the necessary background and baseline for supporting the scientific value and economic benefits from public investment in marine science in Maine.

Purpose

The purpose of this project is to characterize the economic and scientific impact of the State's investment in research and development for marine sciences in Maine. This project is a descriptive analysis designed to address a plethora of informational needs. First and foremost, it answers the question, "what is going on?" by providing a baseline for understanding the landscape of marine research institutions in Maine. In addition, it assesses a broad range of institutions and highlights the specific niches they fill and what the interest of the State of Maine is on those institutions that receive significant public investment. Eight of Maine's marine research institutions, listed in the box at right, are discussed in this project. The skills and assets of our other marine research institutions will be disclosed in a subsequent report.

Bowdoin College
Bigelow Laboratory for Ocean Sciences
Island Institute
Maine Department of Marine Resources
Maine Maritime Academy
Mount Desert Island Biological Lab
University of Maine System
University of New England

Methods

This document utilized annual reports provided by individual institutions as a primary means for gathering quantitative information. In addition, semi-structured interviews were conducted with respective executive directors, academic deans, and the Office of Sponsored Programs at the University of Maine System to gather more specific information. A literature review of relevant institutional documents was also conducted to render insight on the development of specific programs.

University of New England -- Marine Science Center

The University of New England (UNE) is an independent, co-educational university with two distinctive campuses in southern Maine: the University Campus located in Biddeford, and the Westbrook College Campus located in suburban Portland. Degree programs focus on the health and life sciences, human services, education, and management. UNE includes Maine's only medical school, the *College of Osteopathic Medicine*, which was founded and merged with St. Francis to form the present university.

Located on the coast at the mouth of the Saco River, UNE offers an ideal location for studying many marine, estuary, and freshwater habitats. The wide variety of accessible habitats within ten miles include the Saco River.

The University of New England, in collaboration with *Bigelow Laboratory for Ocean Sciences*, offers a *Master of Science in Marine Science and Enterprise*. This two year innovative program focuses on a core marine science curriculum including studies in biological, chemical, geological and physical oceanography. In addition, this program of study provides breadth in the interdisciplinary fields of marine policy and law, marine technology, communications, education, and business management and entrepreneurship. UNE stresses an interdisciplinary focus as a unique characteristic of their graduate program.

The program in Marine Science and Enterprise is specifically designed to include working with the Department of Life Science in the area of marine biology, the Department of Management in the area of business management skills and marketing, the Department of Education in the area of teaching methodologies, and the College of Osteopathic Medicine (collaboration with faculty in common research areas). Development of a program in Marine Science and Enterprise also is consistent with recommendations in the UNE strategic plan, which indicates a stronger emphasis of marine science-based educational programs that could take full advantage of their coastal location and proximity to the Wells National Estuarine Research Reserve.

UNE's Marine Science Center will further strengthen the collaborative partnership with Bigelow Laboratory. Educational benefits for the school's undergraduates from the affiliation are significant and demonstrable. Undergraduate enrollment in the marine sciences has increased steadily since the affiliation in 1994 by almost 300 percent, making it the fastest growing major totaling 97 in 1999. Adjunct Faculty, Principal Investigators from Bigelow Laboratory, teach undergraduate level courses in oceanography at UNE and offer a "*Gulf of Maine*" seminar, which introduces students to research being done at Bigelow. Public investment at UNE has, thus far, been relatively minimal ($150,000 FY97-98) (Gasko, 1998). Although the University receives some spillover benefits from their alliance with Bigelow, these benefits have not supported construction of the *Marine Science and Research Center*. UNE currently employs nine professors for marine related studies (an additional three are expected to be added contingent on completion of a new facility) (Carter, 2000).

Bigelow Laboratory for Ocean Sciences

The mission of Bigelow Laboratory for Ocean Sciences is to undertake basic research on the biological, chemical and physical processes that determine the productivity of the oceans and to contribute to studies of the ocean-atmosphere system in relation to global climate and environmental changes. Special emphasis is given to work in the Gulf of Maine in order to provide the information needed for better management of the living resources of coastal seas.

A Shared Spirit for Discovery

Bigelow Laboratory contains three research facilities that host scientists from all over the world*: The Provasoli-Guillard National Center for Culture of Marine Phytoplankton*, the *J.J. MacIsaac Facility for Individual Particle Analysis*, and the *Center for Remote Sensing*. In addition to hosting international researchers, the Laboratory regularly contributes to educational programs and resources management efforts in the northeastern United States.

A shared spirit of exploration is at the core of the scientific philosophy at Bigelow Laboratory. Scientists have the freedom and flexibility to pursue collaborative research with other institutions in the context of a creative and interactive community made up of over fifty researchers and support staff on site. Bigelow scientists are involved in international research projects with scientists and research institutions around the world — working in the Arabian Sea, the polar regions, the Gulf of Alaska, the North Sea, and of course the Gulf of Maine.

Sharing the Knowledge with Public Education

One of Bigelow Laboratory's best-known projects in the New England region, *Gaia Crossroads*, brings the power of remote sensing to students in classrooms from kindergarten through high school. Through satellite imagery, students and teachers begin to see the world from space, and learn about natural resources on the global scale. The program builds a multi-disciplinary perspective in a progressive curriculum that grows along with its students from early elementary grades through high school. Over 32,000 students and 134 teachers have participated in the project since 1989. Student participation is expected to expand dramatically with nationwide distribution of the program's teacher guide. (Bigelow, 2000)

The Gaia Project gives teachers and students the ability to manipulate satellite images on computer screens to explore landforms and land use patterns in their local communities. Students use their individual creativity to explore the process of scientific inquiry and the technological tools used in that process (Bigelow, 2000).

What Research at Bigelow Means to Maine

Health and safety, economics, and the environment all benefit from the research at Bigelow. The laboratory is known for its research programs all over the world. What is less known is how that research directly affects our lives. For example, areas of high marine productivity have the potential to be sustainable sources of food. Through satellite imagery, Bigelow is expanding their ability to monitor and manage key ocean ecosystems worldwide.

Closer to home, Bigelow scientists are using new information about lobster ecology to develop an index to predict commercial lobster harvests six years in advance, enabling better management decisions and a more reliable supply of lobsters. Bigelow Laboratory has a longstanding history of providing cultures of marketable seafood species for many start-up aquaculture businesses in Maine. Bigelow also supplies cultures for scientists in biotechnology who are discovering new uses for marine organic compounds in products including sunscreens and cosmetics.

Potential Economic Impact from Marine Research at Bigelow

Scientists at Bigelow examine the biology and physics of the oceans to determine how natural processes affect distribution and interactions among marine organisms. In the Gulf of Maine, much of the focus of this research has been on the lobster, the region's most popular commercial species and largest economic resource among Maine's fisheries. The 100% increase in lobster landings that occurred over the past decade has caused widespread concern about long-term stability of Maine's lobster population. Using a combination of sophisticated tools including satellite imagery, computer modeling, and field sampling, Bigelow researchers are working to determine where lobster larvae come from and where they "recruit" (drift and settle) to adulthood on the sea floor. This research will help us to develop a critically important tool for the region's resource managers, the ability to predict trends in the lobster populations six or more years into the future, when lobsters first reach marketable size (Bigelow, 2000).

National Oceanic and Atmospheric Administration (NOAA) fisheries reported that the commercial fishing industry in Maine landed 271.3 million pounds of fish, shellfish, and other marine creatures in 1997, a catch valued at over $273 million. Of this total, 46.3 million pounds were lobsters, worth $136 million, nearly fifty percent of the total industry revenue for the year (NOAA, 2000).

Researchers Lew Incze and Rick Wahle have developed sampling protocols and data time series for studying lobsters during early life in the plankton and in shallow subtidal cobble habitats. New sampling equipment is being adapted for use on a manned submersible in the Gulf of Maine for sampling deeper and farther offshore. Adaptations include a suction probe with manipulator claws that can pick up rocks and samples in spaces between rocks in bottom habitats at depths beyond the safe limits of Scuba divers.

In 1998, support from NOAA's *National Undersea Research Program* made it possible to offer summer internships to several students from the United States and United Kingdom. These students investigated the role of shallow and deep-water cobble habitats in the Gulf of Maine's lobster population. The submersible project team, which included interns from UNE and the University of Maine (UM), was able to collect and study samples of juvenile lobsters from various bottom habitats and return them unharmed to the sample sites. Interns worked directly with principal scientists, diving in shallow waters to conduct cobble community population surveys followed by corresponding deep-water submersible dives.

These data, combined with computed modeling of larval and postlarval growth and drift in coastal currents and habitat types, are being used to develop an index that can predict future

commercial lobster harvests. This information will facilitate better fisheries management decisions by increasing our understanding of natural and fisheries processes. An additional benefit of underwater lobster research has been the opportunity to make a computer link between the submersible and the Gulf of Maine Aquarium's web site bringing direct contact with researchers and real-time digital photographs to student and teachers in schools.

Funding Patterns

Funding for marine research at Bigelow Laboratory is a comprehensive process that includes a historic public investment from the state, matching and additional funding from federal agencies and foundations, labor resources from educational institutions, and resources from collaborative projects with other laboratories.

Bigelow Laboratory received a historic public investment from the State of Maine in 1974. At that time, Governor Curtis purchased the land and current site of the Bigelow facility from the U.S. Bureau of Fisheries. Bigelow received an annual commitment for the maintenance of the land until 1992. Although Bigelow does receive funding from the Maine Department of Marine Resources, there have been no direct investments from the State since 1992. (Bigelow, 2000)

Sources of additional funding include the federal agencies NOAA, National Science Foundation (NSF), Department of Naval Research (DNR), National Aeronautics and Space Administration (NASA), Sea Grant and the Environmental Protection Agency (EPA). A descriptive analysis of agency funding underscores major contributions from NOAA, NSF, DNR, and NASA. Although these agencies have remained major sources for funding since 1992, the composition of their individual contributions has changed. In 1992, over half of the funding from federal agencies was received from the NSF. By 1998, contributions from federal agencies highlighted a more equitable distribution. Although the NSF was the leading contributor at a level of 35%, NASA came in a close second with 20%, followed by the ONR at 14% and NOAA at 12% respectively. (Bigelow, 1998)

Figure 1 illustrates funding patterns for research and development at Bigelow. The values within these objects represent percentages of the total research budget. Although these figures do not provide detail units for analysis, they do help to highlight federal agencies that invest in marine science at the Lab.

In 1994, Bigelow Laboratory entered into a collaborative partnership with UNE to establish a dynamic and distinguished marine science program. With Bigelow's world-renowned reputation, UNE students work as interns in field locations throughout the world. They participate in research at Bigelow using some of the most sophisticated technologies. Although this contribution is difficult to quantify, its impact may be seen as a symbiotic investment of labor or a variable for establishing a necessary critical mass to conduct research.

Bigelow Laboratory Research Income by Agency
1992 - 1998

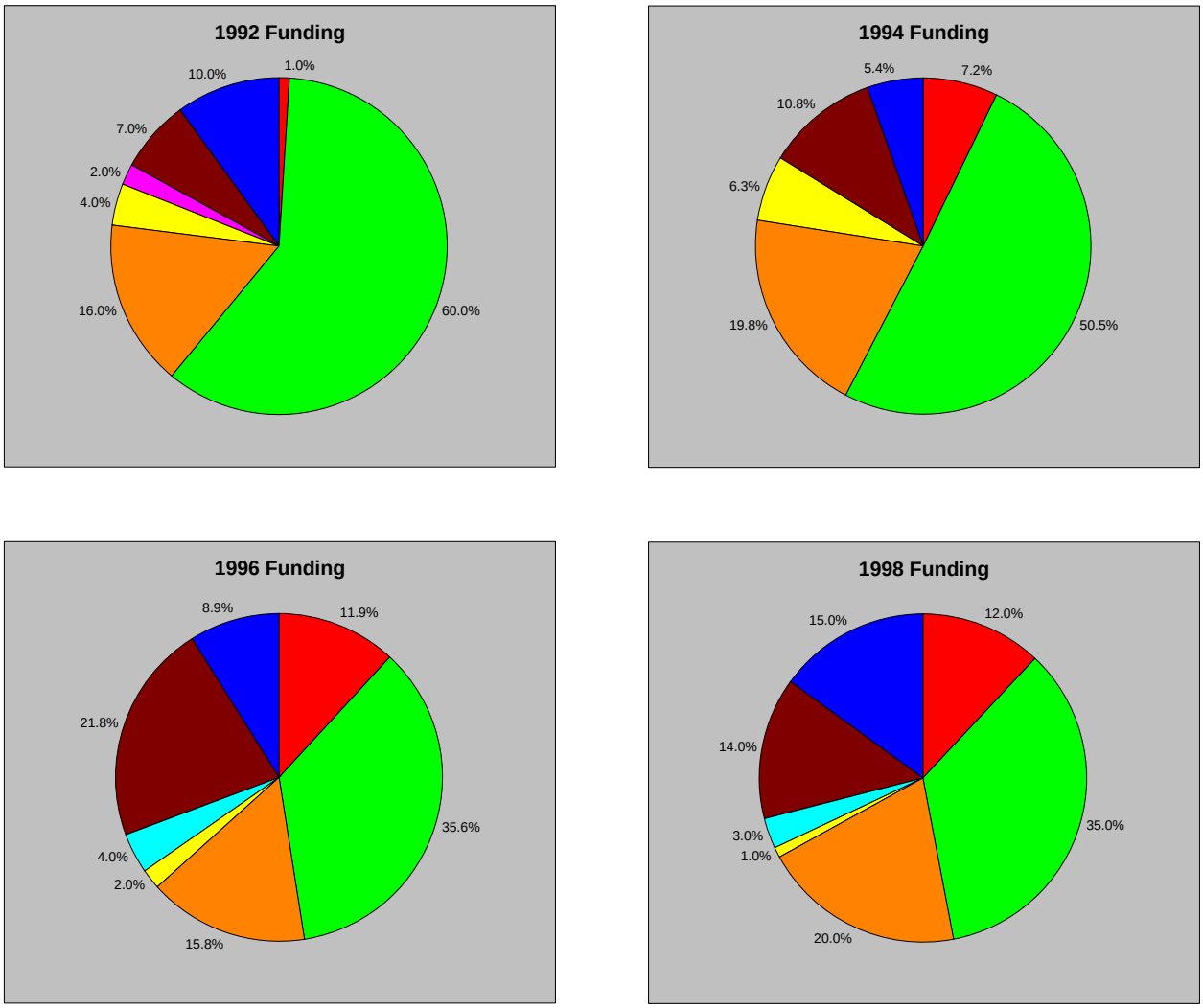

Figure 1

University of Maine -- School of Marine Sciences

The School of Marine Sciences (UMSMS) is the University of Maine's center of excellence for all aspects of marine-related research, education and public service. The School of Marine Sciences offers undergraduate degrees in Aquaculture and Marine Science (with the option of specializing in marine biology or physical science), as well as opportunities for graduate research in Oceanography, Marine Biology, Aquaculture and Marine Policy. The University of Maine is a modern research university with excellent facilities for research, including a satellite receiving station for remote sensing of the ocean, stable isotope facility, electron microscope laboratory and a DNA sequencing laboratory. *The Darling Center*, a marine laboratory, provides outstanding opportunities for teaching and research, with facilities ranging from a fleet of boats, flowing seawater and controlled environment culture laboratories, dive locker and field staging area and well equipped classrooms, visiting laboratories, residential cabins and dormitories. However, its greatest asset is undoubtedly a large and diverse faculty. With over 45 faculty members, the School of Marine Sciences represents the largest year-round concentration of marine expertise in the State of Maine, and one of the strongest programs in the northeast. The faculty has expertise in almost all areas of marine science ranging from molecular biology and biotechnology to fisheries economics and anthropology, and from marine geology and coastal engineering to aquaculture, ecology and oceanology. The faculty of the School of Marine Sciences is an outstanding resource for the state, the New England region, and the nation, and provide a wealth of expertise for undergraduate and graduate education, applied and basic research and public service. (UM, 2000)

Enrollment

Enrollment in the University of Maine's School of Marine Sciences has grown steadily since its inception in 1996. The University has enrolled an average of 48 graduate students during the past four years. Figures for enrollment in the school's undergraduate department in marine sciences have tripled since the school's inaugural year. (UMOSP, 2000)

Graduate Enrollment	
FY97	27
FY98	55
FY99	64

Darling Marine Center

Ira Darling, a retired Chicago insurance executive, founded the Center in 1965 with the donation of a 127-acre farm with the purpose of establishing a marine laboratory. Today, the Center occupies 170 acres of largely wooded property bordering 2 km of pristine water frontage on the Damariscotta River estuary.

The Darling Marine Center is actively developing its facilities to accommodate the needs of its faculty and visiting marine scientists, students, and small colleges. Over the last five years, 467 different visiting scientists from 32 states and 22 foreign countries came to the Center for short or extended stays, and nearly 1,100 undergraduates from out-of-state colleges have participated in educational and research programs. (UM, 2000)

Notable Achievements

Research and development in the marine sciences is as comprehensive as the ocean itself. When policymakers and Legislators seek to understand the value of marine research, they must employ a holistic view of the field, consider both the immediate return on investments seen as the sum of matching funds from federal agencies and larger collective impact that new technologies and discoveries render. Understanding the landscape of research and development for the marine sciences is similar to understanding the interactions between the micro and macro-levels of the ocean's vast ecosystem. While thousands, perhaps millions of microorganisms interact with each other in their respective niche environments, the sum of these activities comprise the larger macro-ecosystems we know as the ocean.

Tracking Funding for Research and Development at UMSMS

This report examines public funding for marine science research at the UMSMS over the past five years. Analysis of these time series answers two important questions: which federal and state agencies are investing in marine science at the University, and the extent of federal funding the University has leveraged to compliment state investments.

Analysis of longitudinal data highlights four federal and state agencies as top contributors to grant funded research at UM. More specifically, they are the National Oceanic and Atmospheric Administration, the National Science Foundation, the Maine Department of Marine Resources, and the U.S. Department of Defense (USDOD). Although the composition of respective contributions has changed over the past five years, these agencies represent the driving forces for funding of marine research. With the exception of FY97 ($7.3 million), funding from these agencies has remained between $2.9 and $4.3 million. (UMOSP, 2000)

The composition of funding from respective agencies has changed over the past five years (see figure 2). Historically, NOAA has been a major source of agency funding for UM. 1995 marked the largest amount of funding from NOAA for UM. NOAA's award of $3,117,824 represented 73% of the school's federal funding. In 1996, NOAA's investment fell dramatically to $358,851 or 13% of the school's federal funding. Data from 1997 highlights an increase of awards to $1,931,357, roughly 27% of the school's federal funding. Records from 1998 and 1999 underscore substantial yet smaller awards of $1,066,364 and $678,003, 26% and 21% respectively. (UMOSP, 2000).

The NSF has a longstanding commitment to funding marine research at UM. In 1995, NSF invested $907,396, roughly 21% of the school's federal funding. In 1996, NSF became the single largest contributor of agency awards with an investment of $1,095,922, roughly 39% of the school's federal funding. Since then, NSF has maintained its position as leading contributor with appropriations of $2,105,847 in 1997 (roughly 30% of the school's federal funding), $1,546,852 in 1998 (39% of the school's federal funding), and $893,082 in 1999 (27% of the school's federal funding). (UMOSP, 2000)

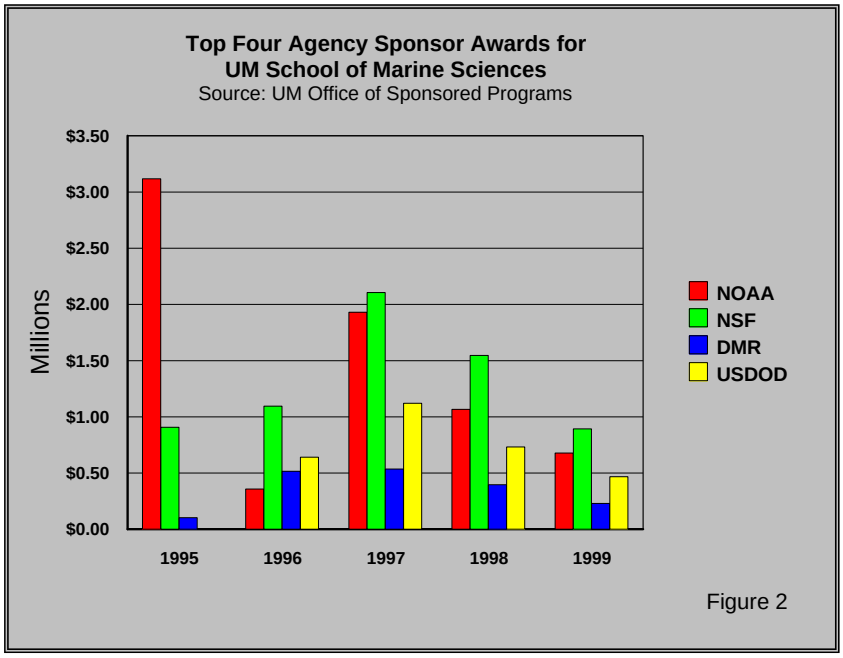

Figure 2

Since 1996, Maine DMR has also played a major role in public investments for marine research at UM. Its award in that year of $516,784 (19% of the school's state matching funds) began a four-year trend as a significant funding agent. Since then, DMR continued its commitment of funding with appropriations of $537,707 in 1997 (7% of the school's matching funds), $396,446 in 1998 (10% of school's matching state funds), and for $229,895 in 1999 (7% of the school's matching state funds). Although these investments are considerably smaller in dollar amounts then its federal counterparts, investments from the Maine DMR rank the organization as one of four top contributors over the past five years. (UMOSP, 2000)

Public investments from the USDOD are also smaller in dollar amounts then its federal counterparts from NOAA and NSF. Nevertheless, the agency ranks as one of the top four contributors to marine research in Maine. The USDOD made appropriations of $641,949 in 1996 (roughly 23% of the school's federal funding), $1,120,481 in 1997 (24% of the school's federal funding), $733,306 in 1998 (roughly 18% of the school's funding), and $469,261 in 1999 (roughly 14% of the school's funding). (UMOSP, 2000)

Understanding which federal and state agencies are funding marine research in Maine helps to highlight important short-term impacts of leverage. During the past five years, state investments from UM of $6,528,690 saw additional funding from federal and state agencies of $21,808712. Although this report cannot establish a true causal relationship between these two variables, it does underscore the commitment of federal agencies to contribute financial resources for marine research in Maine. Rough calculations estimate a ratio for additional

funding at 3:1. More simply put, for every dollar the University invested, it saw an additional three dollars. (UMOSP, 2000)

Figure 3 is a graphic representation of funding patterns for the School of Marine Sciences. The variable marked "*UM Award*" highlights the level of funding granted by the University. The variable marked "*Sponsor*" is the amount of funding the University received from federal and state institutions. The variable marked "*Total*" is the combined sum of both awards and therefore represents the total budget for granted research *(minus expenses for University faculty and facilities).*

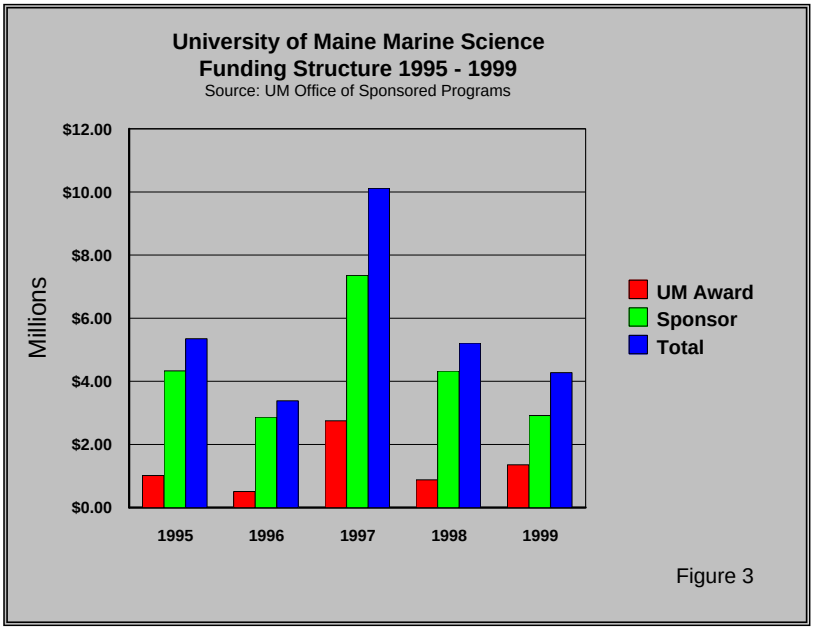

Figure 3

According to Professor Jim Wilson of the UM School of Marine Sciences, the impact or outcome of public investment in marine research may be seen in terms of "*small picture*" and "*big picture*" payoffs. Immediate impacts, or "*small picture*" payoffs, may be measured as the sum of matching federal funding. These impacts may be measured with simple descriptive statistics that underscore return on investment ratios. However, the more important "*big picture*" impacts are the collective outcomes these individual investments bring to bear by building a critical mass necessary for advancing innovation and technology in Maine.

In the early nineteen eighties, the State of Maine provided a grant to explore potential economic development activity on the Portland waterfront. As a result a coalition of fishing vessel owners, fish and seafood processors, and the City of Portland Economic Development Authority established the Portland Fish Exchange as a nonprofit all display fresh fish auction.

The success of the Portland Fish Exchange is two fold. On one hand, Portland utilized a new concept for an all display auction where a buyer can purchase all or some of a boat's catch upon satisfactory inspection. This innovation was unlike other fish exchanges in Boston and Gloucester, Massachusetts where fish was purchased unseen and in smaller units. In Portland, fish could be bought upon inspection in units as small or large as a buyer desired. These factors lead to increases in the price of fish thus enabling a more competitive market for seafood from Maine. The Exchange realizes annual revenue returns of roughly $100 million. (Wilson, 2000)

Another important factor for the success of the Exchange was the collaborative nature of its design and present management. The collaborative relationship between the fishing industry

and university academics was a critical ingredient for promoting an inclusive process with which a broad spectrum of view and interests were incorporated to design and run an efficient organization. The Portland Fish Exchange is an outstanding example of the benefit public investments in marine sciences can have in Maine. Funding for exploratory research established a critical mass for innovation and changed how business was being done. Today, we see a vibrant waterfront with competitive prices for landings between 20 to 30 million pounds of fish and seafood products per year. (Wilson, 2000)

Bowdoin College Coastal Studies Center

The Coastal Studies Center (CSC) offers facilities and resources that support student and faculty research, and courses, focused on coastal settings and issues. The scope of studies supported by the CSC is inter- and multi-disciplinary including humanities; arts; social, natural, and behavioral sciences; and mathematics. All viewpoints, separately and in combination, provide insight and understanding to the multiple facets of coastal studies. (Bowdoin, 2000)

Construction of the Coastal Studies Center at Bowdoin College was made possible with gifts from the private sector. Over $2.5 million was raised to build the marine laboratories, terrestrial lab, and art studio, to renovate the farmhouse as well as to establish an operating endowment. William and Irma Thalheimer donated the 118 acres of land associated with the CSC. (Ellars, 2000)

The CSC presently employs one half-time *"Field Manager,"* and half-time director *(faculty);* and plans to employ a postdoctoral researcher in marine biology at the CSC during the next two years.

There are 21 courses at Bowdoin that use the CSC to teach undergraduates in topics spanning the curriculum and including courses from the following departments: Art, Biology, Environmental Studies, and Geology. (Bowdoin, 2000)

Each year approximately 25 research projects are undertaken at the CSC by undergraduates doing independent research under the supervision of Bowdoin faculty. Ten of those research projects are funded by a grant from the NCUR/Lancy Foundation and four of them are funded by the Doherty Endowment at the CSC. Every year approximately 8 to 15 of the undergraduate researchers are likely to be on marine topics; and undergraduate research at Bowdoin often results in peer-reviewed publications. (Ellars, 2000)

Funded research at the CSC includes two grants from the National Science Foundation that support development of computer-based systems for dissemination of information aimed at improving teaching and the availability of real-time environmental monitoring data. Marine and terrestrial environmental sensors are either being presently installed and real-time data is expected to be available via the world wide web through Bowdoin's *"Virtual Coastal Studies*

Center" sometime during the next 6 months. Such data will be made available to students and faculty at Bowdoin as well as other institutions, and indeed anyone who logs onto the web. (Ellars, 2000)

Faculty research projects at Bowdoin currently include research on growth mechanisms in sea urchins and sea cucumbers; the ecological impacts of the red-tide alga Alexandrium on marine food webs; the mechanical and neural control of feeding in crabs; and interactions of rainfall and groundwater in a terrestrial, coastal watershed among others. These projects are supported by grants from the National Science Foundation and the Whitehall Foundation.

According to Olaf Ellars, Director of the Coastal Studies Center, the center is in its formative years and expects the number and scope of marine research to increase over the next few years.

Maine Maritime Academy - Corning School of Ocean Studies

The Corning School of Marine Studies offers a four year, Bachelor of Science degree program in general marine science. Students in the program learn scientific principles and practices in an ocean setting. In addition to course work in communication, computing, mathematics, humanities, and social sciences, faculty provide an interdisciplinary marine science program of basic and advanced courses in biology, chemistry, and geology. Ocean Studies students benefit from a strong "practical" education. Students at Maine Maritime Academy (MMA) experience the applications of classroom ideas aboard research vessels using state-of-the-art oceanographic instruments and in excellent laboratory and computing facilities. Because their education and training is general, Ocean Studies graduates are employable in a wide range of jobs. Graduates of the Ocean Studies program are or have been employed by federal and state agencies, environmental and engineering consulting firms, private analytical laboratories, biotechnical firms, and others. Ocean Studies graduates have pursued graduate studies in environmental affairs, law, and education. Figures for current enrollment at MMA indicate that the school has approximately 75 undergraduate students enrolled as marine science majors. The school has seen annual increases of roughly 32 students each year since the inception of the Corning School. (MMA, 2000)

Mount Desert Island Biological Laboratory

The mission statement of Mount Desert Island Biological Laboratory is*: "To promote research and education in the biology of marine organisms; to foster understanding and preservation of the environment; and to advance human health".*

History and Organization

MDIBL was founded in 1898 at South Harpswell, Maine by J.S. Kingsley of Tufts University. The Wild Gardens of Acadia donated its present site at Salsbury Cove and relocation

was completed in 1921. The Wild Gardens of Acadia, a land-holding group headed by George B. Dorr and John D. Rockefeller, Jr., was instrumental in the founding of Acadia National Park.

The Laboratory was incorporated in 1914 under laws of the State of Maine as a nonprofit scientific and educational institution. Founded as a teaching laboratory, MDIBL is now a center for marine research and education that attracts investigators and students from across the U. S. and around the world. Since the pioneering work of H.W. Smith, E.K. Marshall and Roy P. Forster on various aspects of renal and osmoregulatory physiology of local fauna, the Laboratory has become known worldwide as a center for investigations in electrolyte and transportphysiology, developmental biology and electrophysiology. (MDIBL, 2000)

MDIBL is owned and operated by a Board of Trustees and Members of the Corporation; at present, there are 429 members. MDIBL is an independent non-profit biological station located on the north shore of Mount Desert Island, overlooking the mouth of the Bay of Fundy. The island, well known for Acadia National Park, provides a variety of habitats including shallow and deep saltwater, a broad intertidal zone, saltwater and freshwater marshes, freshwater lakes and streams, forests and meadows. (MDIBL, 2000).

The Lab is the one of the largest cold-water research facility in the Eastern United States, and its unique site provides an outstanding environment for studying the physiology of marine and freshwater flora and fauna. During 1996, the scientific seasonal personnel included 54 principal investigators and 93 associates, representing 48 institutions in 23 states and 5 European countries. Statistics from a 1998 annual report indicate similar figures. New information concerning the administrative costs at MDIBL indicates administrative salaries for 1999 and 2000 as $157,000 and $139,000 respectively. (MDIBL, 2000)

The 100th year was a defining moment for MDIBL as it paused to celebrate its history and a century of accomplishments. Now it is poised to move ahead again, to continue its evolution as a center of scientific excellence. As it begins a second century, all agree that seasonal scientific activity is the principal contribution of MDIBL, although its new goal is to surround its seasonal efforts with a permanent scientific staff that will use the state of the art facility on a year-round basis. MDIBL will become a year-round marine laboratory for research and education, retaining its distinctive summer programs.

NIEHS Toxicology Center

In 1985, with support of the National Institute of Environmental Health Sciences (NIEHS), MDIBL established a center dedicated to the study of toxic effects of heavy metals and other environmental pollutants that pose an increasing health risk to humans and threat to the marine environment. The focus of the Center for Membrane Toxicity Studies (CMTS) is the use of marine animals, like the shark, flounder and skate, to define sites of action for metals such as mercury and cadmium that enter the environment due to improper disposal of industrial waste and as a component of some pesticides. The effects of these pollutants are wide-spread in the human body, with affected organs including the brain, kidney, liver, and gast. With incremental investments, MDIBL should develop a year-round research resource center dedicated to developing systems for functional genomics in cold water marine species. (MDIBL, 2000)

Funding Information

Funding of research projects at MDIBL is different than other marine science institutions in Maine, in that a majority of its resources are "brokered" from seasonal researchers. The Laboratory receives $250,000 (plus 62% overhead) from NIEHS, $50,000 from the NSF, and $28,000 from the American Heart Association. However, roughly an additional $8,000,000 in grants is received from seasonal principal investigators each summer. (Bowers, 2000)

Currently, MDIBL does not have control over intellectual property, since it does not pay the salary of the researchers. The scientists' home institutions own all intellectual property. However, MDIBL provides space and facilities for rent and is expanding its conference centers and converting three buildings for winter operations. (Gasko, 1997)

Island Institute

The Island Institute was founded in 1983 as a program of the Hurricane Island Outward Bound School. Its original mission was to provide ecological information directed at how islands could be used by different interests without compromising island environments. In 1986, the Island Institute gained its own tax-exempt status and became an independent organization. At that time, it took on additional roles of advocating wise development of coastal resources and providing support services to the year-round island communities. In 1993, it amended the original mission statement to include the waters of the Gulf of Maine and established the Marine Resources Program.

The Island Institute is a membership-based community development organization focusing on the Gulf of Maine; particularly the 14 year-round island communities off the Maine coast. Through its programs, the Island Institute has forged connections with island schools, economic development efforts, health and social service agencies, and individuals engaged in the sustainable management of marine and terrestrial resources. On request, they assist island communities and landowners in their dealing with state regulatory bodies, the Maine Legislature, and federal agencies. The Institute publishes a newspaper and a magazine, and is participating in a massive research project in Maine's Penobscot Bay.

The Penobscot Bay project has developed expertise in geographic information systems and the use of satellite imagery — technology of great significance to researchers and private citizens who depend on natural resources for their livelihood. The project highlights sea surface temperature in the bay, lobster life cycles, and simulation of lobster transport. It also provides current weather reports from Rockland and Matinicus Rock, Maine.

Research Initiatives and Funding Sources at the Island Institute

The Island Institute conducts a limited number of research projects with a variety of State and federal agencies. The largest of these projects is the Penobscot Bay Marine Resource Collaborative, a regional initiative that involves the Maine State Planning Office, Department of Marine Resources, Maine Geographical Information System Office (GIS), the University of Maine School of Marine Sciences, Bigelow Laboratory and the Lobster Institute.

Penobscot Bay Marine Resources Collaborative

The Penobscot Bay Marine Resources Collaborative project represents a multidisciplinary approach to ecosystem management research, and involves a collaborative of state and federal agencies, non-government organizations, and public and private research institutions. Its broad goal is the further understanding of Penobscot Bay, which is an area of more than a thousand square miles and is the second largest embayment on the U.S. Atlantic Coast. Penobscot Bay is located midway along Maine's coast about 150 miles northeast of Boston, Massachusetts.

The total research budget for the Island Institute is roughly $750,000. (McBride, 2000) However, it is important to note that approximately half of that figure is contracted out in research grants to the University of Maine School of Marine Sciences, Bigelow Laboratory and the National Oceanic and Atmospheric Administration. (McBride, 2000) The remaining $490,000 falls under the "general marine resources" account that funds additional GIS research and support for other island programs and services which the Institute provides. (McBride, 2000) Additional information indicates that research for the marine sciences at the Island Institute employs roughly seven research-oriented positions (non-FTE). (McBride, 2000)

Maine Department of Marine Resources

Facilities

The DMR's main research facility is located in West Boothbay Harbor. The Lab consists of an 8,328 sq.ft. waterfront office building and conference room, linked to a 25,156 sq.ft. laboratory building including a public aquarium. There is a wet lab and three labs for fishery research, microbiology lab, biotoxin lab, pathology lab, image analysis, and a lab designed for High Pressure Liquid Chromatography. The DMR has a small microbiology lab and satellite office for the Public Health Division in Lamoine. There is a Stock Enhancement Division office in Hallowell, which houses the anadromous fisheries research program.

Employees

The DMR employs a staff of approximately 56 full-time associates that are related directly to marine research. In addition to this staff, the agency also maintains a number of seasonal conservation aide positions.

The DMR has no full-time students or graduate assistants from any Maine schools. Generally, the DMR has 1-2 Boothbay Region High School students who will work with the agency part-time during the academic school year. In addition to these students, DMR hires college students for summer internships.

Budget Information and Economic Impact of Scientific Research

The total budget for 1999-2000 for the Bureau of Resource Management is $5,970,843 (this figure includes funding for administration, facility operations, personnel costs for support as well as scientific staff and research and monitoring programs).

The focus of research at DMR's scientific labs largely supports the seafood industry in Maine. More specifically, operations at these labs support stock assessment, gear research, the processing of whole fish and harvests of shellfish. Collectively, these industries have an annual impact on the state economy of between $650-700 million. (Mercer, 2000) Direct employment in the industry is in the range of 8000 jobs, direct and indirect employment combines to over 30,000 jobs. (Mercer, 2000) According to DMR Industry Relations Specialist Sue Inches, "without the work done by these labs, we would have no shellfish industry (because we would be unable to test for toxins) and we would be unable to manage other resources including lobsters, herring, urchins, shrimp, etc."

Outcomes from scientific research at the DMR labs highlight a number of valuable benefits. In laboratories, findings from research projects help to monitor shellfish for toxins, support stock assessment, and provide scientists with the critical data needed for complex forecasting models. Research projects at the DMR labs also render important information for decisionmakers as they continue to seek innovative methods for managing vital and finite saltwater resources. The role of the DMR is multifaceted, it is important not only to Maine's economy, but to the stewardship of our natural resources and the advancement of marine science.

Conclusion

Over the past five years, the State of Maine has made significant investments for research and development in the marine sciences. This investment underscored a commitment to provide the foundation for a critical mass necessary for the inception of innovative research and establishing institutions of regional and national prominence. Marine science is a comprehensive field and there are many research institutions that collectively comprise the scientific community in Maine. Assessing the roles and specific niches of these institutions provides Legislators and decisionmakers with the necessary background and baseline for understanding the scientific value and economic benefits from public investment in marine sciences.

This project is a descriptive analysis designed to examine the various niches of research institutions in Maine, examine the funding they receive from public investments, and what the outcome of those investments were. In one case, it is a large state run university that commands a majority of public funding. Some institutions are independent private laboratories that receive a significant portion of funding from visiting investigators and foundations. The remaining lot of

undergraduate programs has expanded a critical mass with the addition of new facilities and staff to house them.

Despite the comprehensive landscape these institutions represent, they have all made contributions of value to marine science and the State of Maine. Measuring that value is a difficult and complex task. The inputs of this equation are easily identifiable as funding for land, labor and capital utilized for facilities and research projects. The outputs of these investments are often seen as the published findings of specific studies and start-up businesses new innovations render. The outcome of public investments for marine science in Maine is more difficult to assess.

Assessing the outcome of public funding for marine science may be seen as both tangible and intangible resultants. Tangible results of public investment may be measured in terms of economic impacts. Outcomes such as the number of new businesses and jobs created are typical diagnostic measurements policymakers utilize to evaluate economic impact.

The intangible outcomes of public investment for marine science may be seen as the number of students institutions graduate with Bachelor and Master's degrees in marine and life sciences. Although these accomplishments are extremely difficult to quantify, their value must be seen as a critical component for establishing the foundation for an educated workforce. In order to achieve the goals of "big picture" impacts, as Professor Jim Wilson described, Maine must provide a sustainable means for providing educated students for a growing and ever competitive workplace. Public investment in marine science ensures the State's ability to provide an educated workforce and maintain a competitive advantage in research and development.

Recommendations

Assessing the role of public investments for marine science in Maine is critical to the state's ability to plan strategically. This project is a continuum of such efforts, as is its subsequent recommendation, to continue assessment of these investments. Understanding the landscape of research institutions, formulas for funding, and the outcomes they produce provides Legislators and decision-makers with important background information to plan strategically. Annual assessment of marine science can only strengthen and expand our understanding for an ever-changing field.

Research in the marine sciences is often a collaborative effort between institutions and universities. Subsequently, assessment of funding for collaborative projects is often difficult in a project of limited scope and requires a more lengthy and comprehensive analysis. Principal investigators often conduct research with colleagues in one or more institutions. the collaborative nature of this partnership also maintains disjointed and incremental funding for the respective projects. Limited records have made assessment of these projects impossible. However, their contribution to the funding structure should not be underestimated (e.g. Mt. Desert Island Biological Laboratories received a majority of its funding from visiting and collaborative principal investigators).

The benefits from continued assessment of public investments renders a long list of information resources. It provides decision-makers with information on trends in biotechnical and marine science research from understanding where federal and state agencies are investing their resources. Ongoing assessment offers additional insight to the business of research for marine science and highlights areas for potential collaborations between universities, private laboratories and the private sector. The success of the Portland Fish Exchange is one example of such efforts.

Assessment of research for marine science has exponential educational benefits as well. Funding for the State's university system and private colleges increases the critical mass of facilities, faculty and equipment that is necessary for generating innovative results and findings from research. These increases in critical mass enable the State's institutions to offer competitive educational programs and provide a skilled workforce for today's competitive market.

Understanding the landscape of public investment in marine science institutions is critical to the State's ability to plan strategically and allocate its resources efficiently. The State of Maine is already home to many scientific institutions of regional and national prominence. The more we understand about these institutions, the better we can allocate resources to maintain that advantage. A process of ongoing assessment will only increase our knowledge about an ever-changing field and prepare today's decision makers with information for tomorrow's challenges.

Landscape of Marine Research Institutions 1998-2000

Organization	Total Research Budget	Number of Research Related Employees (faculty)	Number of Students	Notable Achievements
University of Maine, School of Marine Sciences	$4,278,846	45 ****	65 ***	3:1 ratio for additional funding from Federal and State agencies; Undergraduate enrollment tripled since inception of School of Marine Sciences
University of New England	N/A	9 Professors	97	Planned construction of Marine Science and Research Center; Master of Science in Marine Science and Enterprise
Bigelow Laboratory for Ocean Sciences	$3,636,251 *	N/A **	N/A **	Developed model to predict commercial lobster harvests six years in advance; provide species cultures to aquaculture industry
Bowdoin College	N/A Current research funding from NSF and Whitehall Foundation	½ time Field Manager ½ time Faculty	25 Undergraduate; Focused marine related topics	"Virtual Coastal Studies Program" Marine Environmental Sensors installed in real-time data
Maine Maritime Academy	N/A	N/A	84-70 Undergraduate; Annual increases of 32 students	Training in Combined Cycle Power Plant; established model for spatial and temporal patterns of soft-shell clam; provided State with information on effective ferry service
Mt. Desert Island Biological Laboratory	$8,000,000 *****	54 Principal Investigators 93 Associates	N/A	Cellular Membrane Transport; breakthrough in understanding the cellular functions in the liver, eye, kidney, heart; new antibiotics for Glaucoma
Island Institute	$750,000 ******	7	N/A	Penobscot Bay Marine Resources Collaborative involving six federal and state agencies

* 1998 Figures from Annual Report - does not include collaborative projects with Universities & Private Institutions
** Bigelow works on many collaborative projects that includes Faculty from other Institutions
*** Figures for Graduate Students - Darling Center has had 1,100 visiting Undergraduates
**** Over past five years UMSMS has had over 467 visiting Scientists
***** MDIBL grant funding from visiting PI's, $250,000 NIEHS, $50,000 NSF, $28,000 AHA
***** Island Institute contracts out roughly half of its budget to State Agencies

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