PROJECT SUMMARY

Research Vision and Description: The vision driving this NSF EPSCOR RII proposal is that Rhode Island will be a leader in understanding and predicting the response of marine organisms to climate change. This target area of investigation was selected because it is regionally relevant, nationally significant, takes advantages of unique Rhode Island resources, and aligns with the state Science and Technology (S&T) plan. Overall capabilities in life sciences will be strengthened, making the state more competitive for research funding. Proposed improvements in research infrastructure include new investments in equipment and instrumentation, technical expertise, education, diversity and workforce development opportunities, computational capacity and cyberinfrastructure, and structures for alignment with other state efforts. With these investments, Rhode Island will be able to use cutting-edge molecular techniques to advance the understanding of how marine biological organisms and systems are affected by climate change.

The improved research infrastructure will allow Rhode Island to integrate state-of-the-art technology and resources and develop larger research programs and more extensive collaborations. The requested infrastructure can also be applied to a number of environmental problems outside the primary focus of the proposed research, thereby representing additional value. Intrastate collaboration is central to the conduct of the integrated research and education plan set forth in the proposal. The collaboration extends beyond the state. Participating investigators have existing relationships with other key scientific researchers regionally and internationally.

Scope and Organization: The proposal includes three Centers (Marine Life Sciences, Genomics, and Proteomics), a new bioinformatics capability, a new visualization capacity, and integration of all state predominantly undergraduate institutions (PUIs) that offer majors in science. Through the RII EPSCoR Academy, the project manages a statewide network of outreach, education, diversity, and workforce and its integration into the research focus areas.

Activities in Research and Education and their Integration: The research theme captures issues of broad scientific and societal interest that are approached by posing three specific questions: 1) What is the response of marine life to climate change? 2) How will climate change alter the structure and function of coastal marine food webs? and, 3) Will increased ocean temperatures result in greater rates of infection and disease among host populations? These specific questions are intentionally placed in a larger research context to provide a basis for development of broad research programs and collaborations. A benefit of this approach is that the research questions are broad enough to engage investigators at the core research institutions, Rhode Island School of Design (RISD), and the PUIs, and thereby promote collaborative proposal writing and research training. Research into each key question will be led by a core Research Team collaborating with the PUI’s, undergraduate and graduate students, and utilizing new infrastructure investments in the Marine Life Science Center (at the University of Rhode Island Graduate School of Oceanography, GSO), the Genomics Center (at the University of Rhode Island), and the Proteomics Center (at Brown University). New infrastructure investments in these Centers will provide the necessary experimental platform for conducting the proposed research, including new environmentally controlled chambers, cell-sorting capacity for genomic and proteomic analysis, specialized mass spectrometry instrumentation, a high-throughput sequencer for genome and transcriptomics, and high-performance computational capacity for bioinformatics. Infrastructure improvements will also be made at the RISD to increase its capabilities in technology and methods for the visualization of science and new approaches for public understanding of science.

Development of Human Resources: In addition to collaborations of researchers from the core institutions and the PUIs, the proposed infrastructure improvements will increase research productivity through support of 22 graduate students and 165 undergraduate students.
Diversity Plan: The goal of the diversity plan is to increase the exposure of underrepresented populations to opportunities to pursue studies and careers in marine sciences, life sciences, and associated high tech careers in general, and to provide mentoring and other support activities that reduce the perceived risk of their involvement in such pursuits. A projected outcome is to have participation of underrepresented populations in undergraduate and graduate studies in the life sciences to equal or exceed by the fifth year of the grant period the representation of underrepresented minorities in state demographics; this roughly triples the current level of participation. The strategies are: 1) exposure of middle and high school students to life sciences, particularly marine life sciences, through enrichment, tutoring, campus visits, tours, and other outreach activities; 2) role models and support, “mentoring”, on a comprehensive and collaborative basis to assist students from underrepresented populations to thrive in the subject matter areas set forth in this proposal; and, 3) proactive recruitment and retention of underrepresented undergraduate and graduate students and faculty.

Workforce Development: The goal of the Workforce Development Plan is to increase participation of individuals in STEM education pathways and careers, and stimulate entrepreneurship. The RI NSF EPSCoR Academy will: 1) grow pre-college activities to provide a wide variety of enrichment, tutoring and professional development programs for middle and high school students and teachers; 2) increase its flagship SURF program to enable 165 undergraduate students to conduct summer research in the marine and life sciences; 3) provide 11 two-year graduate research fellowships and 25 entrepreneurial fellowships, and sponsor a series of workshops and courses for the fellows; 4) support graduate fellowships at URI and Brown and expand graduate student support to include 15 students in the RIC biology masters program; and, 5) create networking opportunities for faculty and students to enhance collaboration.

Plans for Cyberinfrastructure: The proposed cyberinfrastructure investments are aligned with the state’s S&T plan, which emphasizes the importance of connectivity, computational capability, and bioinformatics expertise to improve the competitiveness of researchers across the state. Specific improvements in cyberinfrastructure are required as RI NSF EPSCoR researchers work with exponentially growing data sets and more complex interactive processes. The infrastructure improvements include: 1) a 96 processor cluster computer for data processing and bioinformatics support is proposed as critically needed infrastructure in this proposal; and, 2) the technical expertise required to support next generation sequencing based research programs and bioinformatics tools. A Facility Manager knowledgeable in Linux Server operating systems and cluster hardware will be vital to ensuring systems support across the state. Funds are also requested to support an Applications Scientist to assist RI NSF EPSCoR supported researchers with processing of the large amounts of data generated through the high-throughput DNA sequencing instrumentation requested in this application. Investments will also be made in RISD’s institutional capacity in the areas of visual communication of complex scientific data.

External Engagement: The external engagement plan will expand institutional participation, diversity, and private sector partnerships. Communications capabilities are critical to implementing the external engagement plan. Two outstanding capacities specific to Rhode Island that are being used to effectuate external engagement are the RISD and the Metcalf Institute. RISD will work to make research data more accessible, provide communication strategies and visual techniques to scientists and larger audiences, and enhance science education. The Metcalf Institute is a leading provider of science training for professional journalists. RI NSF EPSCoR and the Metcalf Institute will offer two science communication seminars per year to instruct science faculty and students in the development of rapport with journalists and prepare effective, audience-appropriate messages for journalists and the general public. Partnerships will be expanded with organizations serving the private sector, including the Greater Providence Chamber of Commerce, the Economic Development Corporation, the Tech Collective, STAC, and the Research Alliance. The EPSCoR Office will also publish a magazine and maintain a website.
Evaluation and Assessment: Three strategies are proposed to measure the impact and success of the RI NSF EPSCoR program: 1) collection of quantitative data as defined in NSF EPSCoR’s annual reporting template; 2) annual independent external evaluations; and, 3) the development and application of additional project specific evaluation metrics to assess the long term effects of the RI NSF EPSCoR investment. The results of these assessments will help to inform the RI NSF EPSCoR management in making decisions on the allocation of resources to maximize the return and to also to keep a focus on our overall goals.

Sustainability: RI NSF EPSCoR will secure sustainability through the capacity developed by the proposed research infrastructure improvements. This capacity will make Rhode Island more competitive for research funding. In addition, the Rhode Island Science and Technology Advisory Council (STAC) annually awards research seed funding, $1.3M per year, which is available to RI NSF EPSCoR researchers. STAC plans to support a $100M bond referendum on the 2012 ballot in Rhode Island to support the hiring of 20-30 top tier faculty, a federal match funding pool at URI, and the submissions of NSF STEP, GK-12, IGERT and other proposals in years 1, 3, and 5 of the award. The infrastructure improvement investment will contribute to streamlining “the pipeline between research ideas and new venture creation” as called for in the S&T Plan (p. 20). This will contribute to the potential for industry investment in R&D.

Proposed Management Structure: The proposed management structure consists of: 1) a Leadership team, including a Project Director (PI), two Co-Project Directors (Co-PIs), and an Associate Project Director; 2) Project Staff; 3) a Steering Committee; 4) an Advisory Council; 5) a Diversity Advisory Committee; 6) an External Evaluation Committee; and, 7) a Governing Committee (STAC).

INTELLECTUAL MERIT OF PROPOSED WORK
Changes in climate have the potential to influence numerous goods and services generated by marine organisms (e.g., fisheries, tourism, half of the oxygen in the atmosphere). The resilience of marine organisms to climate change will depend crucially on two factors: acclimation and adaptation. Moreover, the community composition and function of marine food webs provide a wealth of benefits to humans and are fundamentally important to the global biosphere and, locally, to Narragansett Bay. These ecologically complex communities fuel nutrient cycles and sustain biological production in the ocean, ultimately leading to the availability of seafood. Numerous studies have demonstrated that with ocean warming and acidification, many eukaryotic organisms will be under stress whereas many pathogenic microbes and eukaryotic parasites will thrive. Additionally, rising ocean temperatures are expected to expand the geographic range of familiar disease-causing organisms, resulting in more frequent outbreaks. Despite the ability to identify the causative agents of many marine diseases, the mechanisms of pathogenesis and disease resistance in marine organisms are only beginning to be understood. Collectively, these are challenging research questions that require integrative approaches that involve the monitoring of ecosystems and diagnosis and repair of ecosystem damage. With the proposed research and infrastructure improvements, Rhode Island will be well positioned to make a significant intellectual contribution to the assessment of climate change effects on marine organisms and ecosystems.

BROADER IMPACTS OF PROPOSED WORK
The proposed infrastructure investments will provide the capacity to conduct science that is of broad societal interest. By demonstrating relevance and in partnership with institutions uniquely skilled in the area of communication, the research discoveries will resonate widely within the community. This will further serve as a catalyst for getting young students interested in STEM. In addition to the Academy’s diversity and workforce development activities, the broader impacts of this proposal will be realized through use of new methods for visualization and communication of science, which will be developed at the RISD. A project goal is to achieve improved understanding of science by K-12 and non-traditional audiences.
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4-1. **Status and Overview**

The proposed RII plan builds on established capabilities in marine life science, genomics and proteomics in order to better understand and predict the response of marine organisms to climate change. This area of investigation aligns with the state S&T plan; it is regionally relevant, nationally significant, and takes advantages of unique RI resources and datasets centered around Narragansett Bay. Infrastructure investments in people, tools, and ideas will enable us to address three compelling questions: 1) What is the response of marine life to climate change?; 2) How will climate change alter the structure and function of coastal marine food webs?; and, 3) Will increased ocean temperatures result in greater rates of infection and disease among host populations? Not only will the proposed infrastructure investments enhance our research capabilities for a Center of Research Excellence in the Marine Life Sciences, it will advance our efforts to further develop and diversify the STEM workforce. The work will consist of an interdisciplinary, multi-institutional effort between nine of the state’s institutions of higher education (IHE), and will support pre-college, undergraduates and graduate students. Our vision is to be a jurisdiction with a diversified, “knowledge economy” that generates employment opportunities that support a good quality of life.

The RI NSF EPSCoR program is dedicated to assisting the state’s research universities to attract additional research funding in basic science and engineering (S&E), improve research infrastructures, increase efforts to convert ideas into jobs through technology commercialization, and address workforce needs by enhancing S&E training and education for all students, particularly those from underrepresented populations (UREP). There is widespread consensus among RI’s political, economic and academic leaders that the general economic health of the state will increase as the research capacity at our IHEs increases. The state’s movement toward a knowledge economy is driven by three predominant and interrelated forces: 1) As RI’s once dominant manufacturing economy has declined so too has 2) our ability to keep pace with the economic growth enjoyed by our neighbors in the Boston-Washington Northeast corridor. Recognizing that 3) knowledge-driven enterprises – rooted in transformative scientific discoveries and technological breakthroughs – will become increasingly critical to advancing our economy, RI must lay the foundation for developing a highly trained, and diverse workforce.

4.1.1. **Current Status of Academic R&D Enterprise**

RI leaders are investing in a new economic future, one founded on a strong life science research platform, harnessed to a well-educated, diverse workforce, and advanced by a focus on innovation. The state’s IHEs are leading the way. RI has the distinction of hosting more colleges and universities per capita than any other U.S. state. The state’s 11 IHEs range from research institutions to small liberal arts colleges and include: the University of Rhode Island (URI); Brown University; Rhode Island School of Design (RISD); Community College of Rhode Island (CCRI); Rhode Island College (RIC); Roger Williams University (RWU); Providence College (PC); Salve Regina University (SRU); and Bryant University. Each institution provides unique and complementary strengths in research and education.

The largest portion of the state’s academic R&D funding is at Brown U., with FY09 sponsored program awards at about $155M. URI, the state’s other research university, received $86M in grants in FY09, which represented a record year in sponsored program awards. R&D in marine life sciences is heavily focused at URI. URI’s Graduate School of Oceanography and departments within URI’s Colleges of Arts and Sciences, Environment and Life Sciences, Engineering, and Pharmacy that bear on ocean sciences receive nearly 50 percent of the institution’s annual grant and contract awards. Several of these Colleges also make significant contributions to the life sciences disciplines. Life and Health Sciences account for over 50 percent of annual awards at Brown U., particularly to the School of Medicine. Increased research collaboration between URI and Brown brought about by NSF EPSCoR and NIH INBRE awards has resulted in steady increases in R&D at both institutions. In FY 2008, RI ranked 43rd among the 50 states and D.C. in total academic R&D expenditures ($237M).
4.1-2. State Commitment to R&D Improvement

The RI and NSF EPSCoR partnership was inaugurated in 2003 with a NSF EPSCoR planning grant. Since that time, a number of inaugural activities have resulted. Key highlights follow: In 2004, the Governor targeted biotechnology and biomanufacturing as major focal areas for RI’s economic development, and charged the state’s research institutions to lead the way. In 2005, the Governor established the RI Science and Technology Advisory Committee (STAC) by Executive Order to advise the state on innovation policies that would help promote economic growth. STAC, which serves as our Governing Committee, receives an annual appropriation of $1.5M. In 2006, RI received its first NSF EPSCoR award, focused on catalyzing life sciences research, education and innovation. At the same time, the STAC recommended that the state leadership create the RI Research Alliance as a “platform for promoting collaboration, maximizing state and federal investment in research and enhancing the state’s R&D related economic development opportunities.” This program represents one of the most significant direct investments in research in state history. STAC will direct $800,000 annually in support of RI NSF EPSCoR activities. (See Letters of Support.) Most recently, in September 2009, the state’s S&T plan, Accelerating Innovation Through Collaboration, was formally adopted by STAC. The present proposal is aligned with the plans of the Greater Providence Chamber of Commerce, the Rhode Island Economic Development Corporation, the STAC, and the Rhode Island Economic Policy Council.

4.1-3. Strengths and Barriers

Strengths: From its inception, the goals of the RI NSF EPSCoR program were to build upon the foundations of all its academic institutions to develop and integrate their missions toward excellence in the life sciences. This statewide research platform – with core capacities in marine life sciences, genomics, and proteomics – directly engages and supports our IHEs. As noted by the AAAS (2009), “a clear strength of the RI NSF EPSCoR is its state-wide support and the involvement of a blend of research intensive universities and smaller PUIs.” Another major strength is the thematic focus on marine genomics and proteomics. Our growing research capacity and competitiveness as evidenced by a cadre of scientists in marine life sciences along with “the geography of the state and the economic, cultural and social consequences of its location,” prompted the AAAS to state that “a marine emphasis is very compelling.” Other major strengths include: strong leadership and state support and advocacy for the advancement of S&T; a unified vision; and institutional culture changes (See 4.2- 4.3). RI also has rapidly growing Hispanic, African-American and Southeast Asian populations as well as first generation students who can participate more fully in the STEM workforce, provided strategic investments are made in education and training.

Barriers: RI, like other EPSCoR states, has a low research capacity. Not a single university in the state ranks in the top 100 nationally in total R&D expenditures (Brown stands at 102 and URI at 147). Specific barriers that must be addressed relate to acquiring additional lab space and equipment upgrades; ensuring adequate technical and support staff; and nurturing relationships between university researchers and industry partners, in order to spur potential marketplace applications of research. The Governor’s Workforce Board has also warned of a widening skills gap between majority and minority populations, and the need to ensure sophisticated training and education, at all levels. (See 4.1-D).

4.1-4. Opportunities for Development, Strategy and Alignment

Rationale: Global climate change is widely recognized as one of the most important and challenging issues of the current era, and has prompted significant research to understand and combat its causes. Narragansett Bay, one of the State’s most treasured natural resources, has been studied extensively, resulting in a long-term data set of the marine food web composition and abundance of the Bay. This substantive historical knowledge provides an excellent basis for understanding past and long-term trends in the Bay’s biota and environmental conditions, an ecosystem that annually transitions from sub-polar to
subtropical environmental conditions. These long-term data sets are a key resource to examine questions of climate change responses, and provide the platform for this hypothesis-driven RII proposal.

**Goals and Strategy:** In the next five years, RI’s objectives are to: 1) bring together researchers across the state to encourage and engage in collaborative research in marine life sciences, and associated life sciences; 2) improve existing infrastructure, including RI’s capacity for technology transfer within and across S&T sectors; 3) build cyberinfrastructure (CI) capacity; 4) develop and diversify the workforce in this research area; 5) improve data visualization and public understanding; and 6) facilitate business innovation by streamlining the pipeline between research ideas and new venture creation. Our primary strategies are to: build core capacity by investing in technical expertise, equipment and support staff at three Centers (Marine Life Science, Genomics, and Proteomics); develop human resources through investments in the RI NSF EPSCoR Academy, and increase computational capability. (See 4.3-4.8).

**Proposed Alignment and Infrastructure Improvements:** The S&T plan holds that RI should use its size to enhance competitiveness through collaboration. To advance this goal, all RI PUIs that offer degrees in science are included to maximize the level of exposure to life science in general and marine science in particular and to integrate research, education, and workforce initiatives. To improve the alignment between marine life science and life science (Genomics and Proteomics) research and State goals for economic development, this proposal engages the science-technology-innovation-diffusion continuum (Tassey 2007). Accordingly, RI NSF EPSCoR will: 1) participate in entrepreneurship training; 2) build involvement with Bryant University, where all students, even those majoring in biology, receive a business degree, and with the “Blue MBA” program at the URI, which is a dual masters degree program in oceanography/marine life sciences and business administration; and, 3) incorporate into the research enterprise, collaboration with design thinking by engaging RISD. The infrastructure improvements will reduce barriers in analysis costs, data processing, and communication associated with marine life science research. RI scientists will then have the infrastructure needed to be competitive for additional research funding, and attain a nationally recognized Center of Excellence in Marine Life Sciences.

**4-2. RESULTS FROM RELEVANT PRIOR SUPPORT**

Since RI's initial NSF EPSCoR award in 2006 [#0554548], we have made measurable progress toward building research capacity and competitiveness as well as developing human resources. Broad accomplishments include: 1) strengthening the organizational capabilities of STAC and RI NSF EPSCoR administrative structure; 2) building the technical infrastructure and collaborative research network needed to attain focus and competitiveness in the marine life sciences; and 3) developing human resources, and 4) communicating RI NSF EPSCoR successes.

**State Leadership:** As noted, in 2006, STAC was established by the state legislature to help RI become a sub-regional hub for life sciences and biotechnology. Subsequently, the STAC created the RI Research Alliance. The Alliance has initiated a number of activities, including the Collaborative Research Award Program, which supports collaborative projects across the institutions. To date, the program has awarded approximately $3 million to 17 teams of researchers from 29 public and private institutions statewide (research universities, PUIs, hospitals, industry). In addition, the Alliance sponsors the Statewide Research Symposium, which provides a venue for NSF EPSCoR and NIH IDeA-funded researchers to share their research, explore cutting edge research trends, and discuss collaborative research projects stimulated by RI NSF EPSCoR. STAC adopted the state’s first-ever S&T plan in 2009.

“The past three years of funding has resulted in substantial changes in research direction, the development of educational and research opportunities at PUIs, formalization of workforce training efforts and significant outreach into the K-12 educational system.”

- AAAS, 2009
**Institutional Culture:** RI NSF EPSCoR has inspired a culture change at URI. The senior leadership – President, Provost and a newly appointed Vice President for Research (VPR) - understand the importance of academic R&D and commercialization. The newly appointed senior leadership includes President Dooley, Provost DeHayes, and VPR Alfonso, all of whom are experienced and accomplished researchers.

**Collaboration:** Increased engagement of IHEs, industry, and government demonstrates RI NSF EPSCoR’s collective resolve to achieve national competitiveness in the life sciences. The prior award involved 8 of 11 IHEs. This level of engagement particularly with regard to the PUIs is significant and an essential component of the diversity plans for our research and Academy/workforce development programs. Strong bipartisan political support, a shared commitment to building a marine- and life-sciences oriented economy and new capital investments at many of our partner institutions are setting the stage for additional competitive funding and is bringing greater connectivity to existing collaborative research and commercialization efforts.

**Research Infrastructure Accomplishments:** The prior award enabled three Research Centers in marine life science, genomics, and proteomics, respectively, to be established and/or enhanced. In so doing, we have been able to recruit and retain new faculty, post-docs, and graduate students; expand the user base at each of the core facilities; and support graduate research. The strategy of investing in core facilities and instrumentation for research has allowed the RI NSF EPSCoR program to provide infrastructure support to a broad cross section of state researchers. RI NSF EPSCoR has also sought to develop the research culture at PUIs by supporting summer salaries and release time for faculty, faculty travel funds for collaborations, training, and workshops, and equipment purchases that have broad support/use within the faculty of the institution.

**Diversity, Education and Outreach Accomplishments:** The RI NSF EPSCoR Academy was established as a catalyst to propel education, outreach, and workforce development activities through collaboration. It is the heart of RI NSF EPSCoR’s efforts to broaden participation, increase diversity, and to engage students at all levels in the science, technology, innovation and diffusion enterprise. Dr. Andrew Staroscik was appointed director of the Academy in 2008. Dr. Staroscik has moved quickly to collect baseline data, inventory existing programs, develop partnerships and coordinate efforts among successful existing programs. (See Table 1 for summary of specific prior award outcomes.)

This submission provides a hypothesis-driven core research infrastructure program, strengthened integration among research institutions, PUIs, K-12 and the public, and improved diversity and workforce plans. Specifically, it offers an overarching scientific research theme, key research questions, testable hypotheses, and a research infrastructure plan designed to build on the prior NSF EPSCoR award. New and creative techniques for dissemination and visualization of scientific data among Centers, researchers, K-12, and the public will be achieved through the unique strengths of RISD, thereby further enhancing research integration and communicating broader impacts. The diversity and workforce development plans provide a three-fold increase in the number of funded undergraduate, graduate and underrepresented minorities supported by RI NSF EPSCoR.
4.3. RESEARCH PROGRAM

4.3.1 Research Theme and Goals: The broad research theme of this proposal is to understand and predict the response of marine systems to climate change. This broad ranging topic encompasses physiological acclimation of organisms to environmental impacts through altered transcription profiles, microevolutionary shifts in genotype frequencies across environmental gradients, the development of genomic and proteomic biomarkers of environmental health, and the integration of biogeochemical processes across ecosystem-scale marine landscapes. The goal is to improve research infrastructure in marine life sciences, genomics, and proteomics that will enable Rhode Island to integrate cutting-edge technology and resources, forming the basis for development of larger research programs and more extensive collaborations. The requested infrastructure can be applied to a broad range of environmental problems outside the focus of the research proposed here, thereby representing additional value. The following sub-sections describe the proposed research infrastructure improvements, key scientific questions and hypotheses, the Centers at which the science will be undertaken, and the role of RISD in scientific data visualization. The research infrastructure improvement goals are to:

1. Advance Rhode Island’s competitiveness in marine life science by acquisition of genomic and proteomic techniques and tools, integration of three Centers and a diverse workforce team comprised of leading researchers and students.
2. Build collaboration among investigators in the state and integrate a more diverse undergraduate population with a less diverse graduate and faculty population.

RI is prepared to leverage its compact geography and densely connected networks of educational and research facilities to create optimal alignment among its key institutions and organizations (S&T Plan, p. 4). Collaboration is central to the conduct of the research set forth in the proposal. This collaboration
extends beyond the state. Participating investigators have existing relationships with other key scientific researchers regionally and internationally.

4.3.2. Infrastructure Improvements and Scientific Justification: The infrastructure improvements proposed here will provide the necessary foundation to understand and predict the impact of climate change on the function, goods, and services supplied by marine ecosystems. The improvements in infrastructure, organized by Centers, are summarized as follows:

1. The Marine Life Science Center (MLSC) at the Graduate School of Oceanography is now functioning to: 1) culture marine life from microbes to commercially valuable fish and shellfish in controlled temperature and salinity conditions; 2) provide the ability to sample marine life and prepare RNA and DNA extracts; and, 3) analyze the nutrients in seawater using a specialized mass spectrometer and a Latchet analyzer. The next step in strengthening the MLSC is to provide environmentally-controlled chambers, a Flow Cytometer for cell sorting capacity for genomic and proteomic analysis, specialized mass spectrometers for analysis of small molecules indicative of physiological stress, a visualization lab for teaching and interacting with RISD, and an in situ buoy for continuous monitoring of the seawater at the mouth of Narragansett Bay. The MLSC will need two full-time technicians specialized in the operation of mass spectrometers and optical instrumentation.

2. The Genomics Center (at URI) is now meeting the demands for sequencing within the state. However, the consistent yearly expansion of the user base and increased sophistication of the cutting-edge methodologies will necessitate additional Sanger sequencing capacity and the addition of a new high throughput next generation sequencer, as well as an additional sample handling robot. The Center will need three additional full-time personnel, including a research technician, a systems administrator for computers using bioinformatics programs, and a specialist in bioinformatics.

3. The Proteomics Center (at Brown) will advance toward high-performance bioinformatics and provide a statewide support structure for predicting chemical pathways and identifying proteins key to predicting the impact of climate change on marine life. This will require investment in bioinformatics expertise.

This proposal requests funding to advance analytical capabilities in marine life science, genomics and proteomics specifically through the purchase of the following new instruments: Flow Cytometer, FlowCAM, Roche 454 next generation sequencer, gas chromatography and stable isotope mass spectrometers, environmental chambers, and a 96-processor bioinformatics computer. Investments are also requested in new technical personnel in marine life science (2 technicians; 1 new), genomics (2 technicians; 1 new), and proteomics (2 technicians; 1 new), as well as in bioinformatics technical expertise (1 new technician and an applications biologist). The infrastructure improvements in instrumentation and technical personnel will be further enhanced through support of 22 graduate students and 165 undergraduate students. The new state-of-the-art technologies, technical personnel, and students will expand the capabilities of the Centers (discussed in further detail below) and greatly increase the potential for collaboration of scientists from a range of fields. In turn, this new research capacity will allow for improved workflow in collaborative projects that investigate organisms, from their behavior and ecology to their underlying DNA sequences, proteins and metabolites.

The scientific justification for this proposal is that changes in climate are having rapid and dramatic impacts on marine ecosystems, including marine life in Narragansett Bay (Nixon et al. 2009). This is a challenge requiring integrative approaches that involve the monitoring of ecosystems and diagnosis and repair of ecosystem damage (New Biology Report 2009). Rhode Island is well positioned to make a significant contribution to assessment of climate change effects on marine organisms and ecosystems. Narragansett Bay is the site of two long-term monitoring studies that together provide an unprecedented opportunity to examine decade-scale changes in nutrient cycling, phytoplankton, zooplankton, and fish
community dynamics (Collie et al. 2008; Smayda and Borkman, 2008). In Narragansett Bay, water
temperature began warming in the 1970’s (Nixon et al. 2004) and long term shifts have been observed
across the spectrum of marine organisms, from processes regulated by microbes (Fulweiler et al. 2007) to
changing species composition in communities of fish (Collie et al. 2008).

The research theme captures issues of broad scientific and societal interest that are approached by
posing three specific questions: 1) What is the response of marine life to climate change? 2) How will
climate change alter the structure and function of coastal marine food webs? and, 3) Will increased ocean
temperatures result in greater rates of infection and disease among host populations? These specific
questions were intentionally placed in a larger research context to provide a basis for development of
broad research programs and collaborations. A benefit of this approach is that the research questions are
broad enough to engage investigators at the core research institutions, RISD, and the PUIs and thereby
promote collaborative proposal writing and research training.

The infrastructure improvements include cutting-edge technology that will attract researchers
from outside Rhode Island and strengthen existing collaborations, such as those with the Woods Hole
Oceanographic Institute (Dhyrman, Saito, Sosik) and Princeton University (Levin, Ward).

**Research Question 1:** What are the stress responses and evolutionary potentials of marine organisms in
response to climate change?

**Hypothesis 1:** Marine life will respond to climate change using short-term metabolic acclimation and
long-term adaptive evolution.

**Team Leadership:** Rynearson (URI), Merson (RIC), and Rand (Brown).

Changes in climate have the potential to influence numerous goods and services generated by
marine organisms (fisheries, tourism, half of the oxygen in the atmosphere). The resilience of marine
organisms to climate change will depend crucially on two factors; acclimation and adaptation.
Acclimation is a short-term response to environmental conditions over the lifetime of an individual and
can include changes in developmental rates (O’Conner et al. 2007), reproductive rates (e.g. Holste et al.
2009; Rynearson and Armbrust 2000) and behavior (e.g. Menden-Deuer and Grünbaum 2006; Peck et al.
2009). Rapid responses of these individuals affect their reproductive outputs and thus are coupled to
long-term adaptive evolution by populations. Populations act as repositories of genetic adaptation and
variation for a species (Hartl and Clark 2007). Climate change will likely alter the type and strength of
selection on marine populations, as observed in terrestrial plants (Etterson 2004), changing the impact
organisms have on ecosystem dynamics and biogeochemical cycles. Although organismal responses to
climate change have already been observed (Walther et al. 2002), a daunting challenge remains in terms of
predicting how organisms will both acclimate and adapt to future changes in their environment.

The infrastructure acquired will leverage emerging research capacity in marine life science to
conduct experiments that examine how a subset of marine organisms acclimate and adapt to their
environment. Because climate change is predicted to alter many aspects of the marine habitat
(temperature, pH, nutrient availability), experiments will be designed to measure synergistic responses to
both single and multiple stressors using transcriptome, proteome and metabolome profiles as indicators
of physiological acclimation. Long-term adaptation experiments are unrealistic for many organisms and
so two different routes will be taken to address adaptation. First, adaptive “potential” will be determined
for natural field populations by measuring the strength of selection on individual loci over multiple
generations. Second, the actual processes of adaptive evolution will be examined by manipulating
 genetic diversity of experimental populations of marine phytoplankton (e.g. Gresham et al. 2008). These
single-celled, photosynthetic microbial eukaryotes form the very base of marine food webs and have
rapid reproductive rates that allow for real-time analysis of evolutionary processes.
**Research Methodology and Team:** To examine short-term acclimation responses, species will be selected that represent different functional groups in the marine environment including algae (Bertness, Brown; Jenkins, Lane, Rowley, Rynearson, Thornber, URI), zooplankton (Campbell, URI), invertebrates (Rand, Brown; Gomez-Chiarri, URI; Colin, RWU) and fish (Specker, Webb, URI; Merson, RIC; O’Shea, RWU). For each group of organisms, at least two species will be selected and experiments will be conducted that span environmental stress gradients (e.g., temperature, pH, nutrient limitation) to characterize physiological responses to different conditions. With the flowing seawater capacity at the MLSC, multifactorial experiments on marine organisms ranging from single cells to fish are realistic goals. The physiological status of small organisms, such as phytoplankton, bacteria and barnacle larvae, will be analyzed using proposed research infrastructure investments in high-throughput, laser-driven fluid analytics (Flow Cytometer and FlowCAM) to count and image organisms. The multiple lasers and sorting capability on the Flow Cytometer will enable researchers to simultaneously probe multiple aspects of cellular health (indicators of acclimation) and sort cells of interest for downstream transcriptome, proteome, and metabolome profiling. The addition of Inverted Fluorescence Microscopes at the MLSC will be used to assess the physiological health of larger organisms. Tissue samples for genome transcriptome and proteome profiling will be collected in the clean bench environment supported by prior NSF EPSCoR support. The resources made available through the Proteomics Center will be invaluable to document important changes at the level of proteins. Organisms that represent important functional groups in marine environments and have complete genome sequences (e.g., photosynthetic cyanobacteria (Rocap et al. 2003) and eukaryotic microalgae (Armbrust et al. 2004)) will be included, thereby enabling short-read sequencing technology to be used for transcriptional profiling. However, sequenced genomes of most marine organisms are not available. In these cases, expressed sequence tag (EST) libraries will be prepared and run using the proposed new high-throughput sequencing technology and expanded capillary sequencing capacity in the Genomics Center. Environmental, transcriptomic and proteomic data analysis will be conducted using the high-performance bioinformatics capacity. Data will be used to identify transcripts and proteins that are sensitive to environmental changes as well as those that show no response. These data will provide needed information to the broader research and monitoring community (e.g., Bowler et al. 2009) including: a) elucidating the physiological processes of acclimation; and, b) tools for future development of in situ ecogenomics sensors.

Insights into the long-term adaptive potential of marine organisms can be gained by measuring the strength of selection on individual loci over multiple generations. The question is whether adaptation to climate change will result from selection pressures that alter gene frequencies in local populations. For example, mannose phosphate isomerase (Mpi) controlled experiments using the acorn barnacle revealed that natural selection favors one allele of the Mpi is a glycolytic enzyme in marine invertebrates that affects growth and survivorship. Schmidt and Rand (2001) showed that in lab populations of the acorn barnacle, natural selection favored different alleles of the Mpi gene in high versus low stress environments. The next step is to examine selection on Mpi in natural populations of barnacles. Functional assays of individual barnacle larvae and identification of the plankton they consume will be obtained using the proposed Flow Cytometer and FluidImaging FlowCAM (Rand, Brown and Ryneearson, URI). Coupled with metabolomic analyses of adult barnacles enabled by the Proteomics Center, these data will allow testing of the hypothesis that environmental shifts in Mpi allele frequencies are causally associated with shifts in physical and dietary variables in the water column in Narragansett Bay (Rand et al. 2002). The Mpi protein is polymorphic in many invertebrates and suspected as sensitive to selection (Schmidt et al. 2008). Thus, proof of principle in barnacles will allow researchers to translate marker-assisted assays of selection in the wild to other species that are important players in marine ecosystems (e.g., fish (Merson, RIC; Specker, Collie, URI), shellfish (Gomez-Chiarri, URI) and copepods (Rynearson, URI)).
A complementary approach for unicellular organisms with shorter generation times will be to examine the processes of adaptive evolution using real-time, experimental manipulations (e.g., Bell 1997; Collins and Bell 2004; Gresham et al. 2008). Experiments will examine the phenotypic and genotypic consequences of elevated CO2 (increased acidity) and reduced nutrient concentrations (which may become more severe in increasing CO2 regimes, (Cermeno et al. 2008)). Model microbes with fully sequenced genomes (e.g., Rocap et al. 2003, Armbrust et al. 2004)) will be used (Jenkins, Lane, Rynearson; URI). Chemostat-enabled experiments will be run over 1000 generations using laboratory methods modified from Collins and Bell (2004). The Flow Cytometer and FluidImaging FlowCAM are key pieces of equipment that will allow a generation-by-generation examination of physiological status (e.g., growth rate, photosynthetic capacity). In marine ecosystems, the evolutionary responses of ecologically important microbes are virtually unknown and these data will provide insights into the rates of adaptation as well as potential adaptive trajectories under climate changes scenarios.

**Outcomes:** In addition to the research outcomes described above, the proposed infrastructure will allow researchers to not only understand but also begin to predict organism response to climate change. Competitiveness for research funding will increase through the building of a sampling, analysis and bioinformatics support structure, and the training of students and researchers on analysis of large datasets generated by the proposed infrastructure.

The integrative research team includes the leadership listed above and investigators including, but not limited to, at URI: Lane, Thorner, Rowley, Jenkins, Smith, Menden-Deuer, Specker, Webb, Campbell, Seibel; at Brown: Bertness, Leslie. The team also includes researchers from PUIs including at RWU: Wyso, Colin, Webb, O’Shea. Collaborations will be encouraged with the award of graduate and undergraduate fellowships. These research teams demonstrate the degree of integration that can be achieved with the proposed infrastructure investment.

**Research Question 2:** How are the structure and function of coastal marine food webs and biogeochemical cycling being redirected in response to climate change?

**Hypothesis 2:** Climate change will alter the structure and function of productive, producer-controlled, coastal marine food webs to resemble unproductive, consumer-controlled open ocean systems.

**Team Leadership:** Menden-Deuer (URI), Jenkins (URI), and Costello (PC).

The structure (community composition) and function (chemical transformation) of marine food webs provide a wealth of benefits to humans and are fundamentally important to the global biosphere and, locally, to Narragansett Bay. These ecologically complex communities fuel nutrient cycles and sustain biological production in the ocean, ultimately leading to the availability of seafood. Marine food webs are comprised of diverse organisms, from microscopic bacteria to macroscopic fishes and other vertebrates. Each element of this diverse assemblage plays a role in ecosystem function (Hooper et al. 2005). Microscopic organisms are responsible for the majority of the carbon fixation and nutrient recycling in the global ocean (e.g., Zehr et al. 2003). Macroscopic organisms, such as gelatinous zooplankton and fishes, have effects on community composition and abundance and there is increasing evidence that temperature shifts associated with climate change can have dramatically different effects on different components of marine communities (Beaugrand et al. 2008). There are significant feedbacks between disparate parts of marine food webs, including top-level predators and rates of primary production (Estes et al. 1998) Much of the ecology and functioning of coastal ecosystems is yet unknown, due to the significant taxonomic diversity and the dynamic nature of the habitat. However, this basic information is essential to understand and predict how nutrient cycles are driven, and how marine communities will respond to environmental change.

The structure and function of marine food webs are expected to undergo significant shifts in response to climate related changes in temperature, wind-induced mixing, pH, terrestrial nutrient and
toxicant run-off, and stratification (Chapin et al. 2000). Anticipating these shifts will be crucial for projecting the impact of global climate change on marine ecosystems and their feedbacks on biogeochemical cycles and climate. These phenomena are cornerstones to predicting what could be catastrophic changes that negatively affect coastal ecosystems and their economic value. For example, increases in temperature accelerate chemical reactions and increases the growth, development, predatory behavior and mobility of a broad phylogenetic range of organisms (e.g. Hansen et al. 1997). Rising temperatures can lead to higher abundances of zooplankton predators earlier in the season, resulting in a decrease in overall productivity and thus harvestable resource (Cloern et al. 2007). These temperature-induced changes in predation pressure will likely alter nutrient concentrations and affect other components of the food web. The nutrient thresholds that trigger significant shifts in the response of primary producers and predatory organisms at higher trophic levels are not well constrained. In addition to temperature, pH changes will likely affect the physiology of organisms, community composition and flow of energy through marine food webs. Due to their diverse chemical composition and structural components (e.g., carbonate, silicate exoskeletons), taxonomically-diverse marine organisms are expected to be affected by a reduction in oceanic pH levels, first by their own physiological responses (Seibel and Fabry 2003) and, second, by responses to shifts in their prey composition and abundance. Changes in predator abundance and predatory behaviors will have direct ramifications for species composition, abundance, and production rates of phytoplankton, and can effect important biological events such as the onset and timing of microalgal blooms (Menden‐Deuer 2008).

**Research Methodology and Team:** This hypothesis will be tested on a broad spectrum of marine communities utilizing the infrastructure enabled by this NSF EPSCoR proposal. Researchers will quantify the effect of temperature and pH on the structure and functioning of pelagic and benthic marine food webs, including microbial species. Availability of Flow Cytometers and a Coulter Counter will enable the automation of existing oceanographic methodology for quantifying both organism abundance and population dynamics across a broad size spectrum within the physical and chemical conditions in which they occur (Specker et al. 1999; Menden‐Deuer et al. 2000, 2005, 2008; Gavlik and Specker 2004). A combination of traditional (incubation and microscopy) and new, high-resolution approaches that support rapid assessment of species abundance and diversity as well as nutrient concentrations and fluxes (FlowCAM, Flow Cytometry, mass spectrometers) will be used. These measurements will only be possible with the research infrastructure investments requested in this proposal. The whole-system study will be complemented by autecological studies on the development, consumption rates, and behavior of key groups of species under manipulated environmental conditions.

The research infrastructure improvements will enable researchers to address directly the current challenge of sampling a naturally complex and dynamic habitat. High-resolution, high-throughput quantification and analysis instrumentation is essential for rapidly characterizing the abundance, diversity and composition of complex communities. The proposed Flow Cytometer, Flow-Cam, and Coulter Counter will allow the sorting of diverse planktonic communities into homogeneous populations. The GC-MS, MS-automated sampler, extractive high-resolution ion-trap MS, UPLC requested for the Marine Life Science Center will allow investigators to analyze small molecules associated with environmental stressors. The Environmental Chambers will enable precision control over environmental variables and allow prolonged maintenance, manipulation, and observation of organisms. High-resolution microscopy used for image capture and analysis is essential for predicting changes in behaviors of marine organisms due to environmental change. The work proposed will facilitate collaboration among researchers with expertise ranging from analyzing molecular components of cells (Jenkins, URI) to monitoring the migration patterns of sea ducks (Chase, SRU).

In experiments manipulating temperature and pH, nutrient flux and stable and radio-isotope measurements will be made to measure respiration and, metabolism of nitrogenous compounds, as well
as metabolism of organopollutants (Rich, Brown, Lohmann; URI). Short-term acclimation responses to changes in temperature, nutrient-limitation, and acidification of marine benthic environments, specifically microbenthic and meiobenthic biota, targeting protistan species, their prey (diatoms and other benthic algae), and their direct invertebrate predators will be studied (Langlois; Bryant). The metabolism of inorganic and organic pollutants by investigating changes in their bioavailability caused by climate change will be studied (McNally, Bryant, Crowley-Parmentier; Bryant). Radio-isotope and high-resolution visualization techniques, with in situ quantification (e.g., computer controlled video analysis, Flow Cytometry) will be used to quantify changes in bacterial, phytoplankton and micrograzer abundance (Menden-Deuer, Rynearson, Jenkins; URI) as well as metazoan predators. Molecular biological methods (quantitative PCR) will be used to enumerate unicellular taxa and high-throughput sequencing methods and bioinformatic analysis to compare metagenomic libraries of unicellular species (Jenkins, Smith, Rynearson; URI). The production of metabolites by phytoplankton and micrograzers will be measured using metabolomics (Rowley, Lohmann, URI). Long-term effects of whole system changes will be assessed by analysis of environmental data collected through existing buoy and time-series data, and the investigation of major predators (Chace, Matarese; SRU).

The seawater delivery and walk-in incubators at the MLSC are ideally suited to support maintenance and cultivation of marine organisms and are essential for researchers conducting long-term studies. Weekly sampling of the Bay for biological, chemical, and physical constituents provides constant access to seasonally varying communities. The in situ data buoy provides continuous measurements of Bay water conditions.

**Outcomes:** By gaining a quantitative understanding of the effects of climate-induced changes in environmental conditions on the structure and function of marine food webs, the possibility of predicting and mitigating those effects will be increased. This broad research question is appropriate for collaborations among the diverse set of researchers assembled here, and is well suited for recruiting of ethnically and academically diverse students; for example, via the CCRI biotechnology program, engagement in the RISD Innovation Studios, and onto four-year programs.

The research team leadership will work closely with faculty from RISD led by Dunnigan to communicate research results and integrate RISD students in the communication of science. Likely investigators include, but are not limited to, at URI: Smith, Campbell, Specker, Rynearson, Webb, Nixon, Oviatt, Lohmann, Seibel; at Brown: Rand, Rich, Bertness, Dunn, Leslie; and at PUIs RWU: Wyso, Colin, Rhyne; at RIC: Merson; at PC: Arevalo, Bailey, Baier, Ewanchuk; at Bryant: McNally, Crowley-Parmentier, Langlois, at SRU: Chace, Matarese, Zuccarelli. These researchers will provide rich learning opportunities to engage undergraduate and graduate student researchers.

| **Research Question 3:** How will global climate change affect the ecology of marine pathogens and parasites? |
| **Hypothesis 3:** Increased ocean temperatures will result in greater rates of infection and disease among host populations. |
| **Team Leadership:** Nelson (URI), Lane (URI), and Smolowitz (RWU). |

Studies have demonstrated that with warming and acidification of the oceans due to global climate change, many eukaryotic organisms will be under stress (Barua et al. 2008, Heino et al. 2006, Helmuth 2009, Weis 2008). In contrast, many pathogenic microbes and eukaryotic parasites will thrive and experience faster growth rates under warmer conditions and suffer smaller population declines during winter months. With potential host populations experiencing stress due to climate change, coupled with thriving parasite and pathogen populations, the hypothesis is that these conditions will result in greater rates of infection and disease among host populations. Additionally, rising ocean temperatures are expected to expand the geographic range of familiar disease-causing organisms, resulting in more frequent outbreaks (Colwell 1996). Marine diseases have been reported to be increasing (Harvell et al.
1999). Despite the ability to identify the causative agents of many marine diseases, the mechanisms of pathogenesis and disease resistance in marine organisms are beginning to be understood.

The requested infrastructure will improve the detection and hence management of future diseases in the marine environment. In turn, this will lead to better understanding and prediction of the factors regulating infections in marine animals, from both the hosts and pathogens. The long-term goal is to determine the effects of global warming on the host-pathogen/parasite interactions. The new research infrastructure will also improve the characterization of: 1) pathogen virulence factors and the effects of environmental changes upon virulence; 2) host responses to infection; and, 3) the effects of environmental stressors on the host’s immune response.

**Research Methodology and Team:** Researchers will examine the effect of temperature on the growth and survival of populations of selected marine eukaryotic parasites and bacterial pathogen species (e.g., *Aphanomyces invadans, Perkinsus marinus, Vibrio anguillarum* and *Vibrio harveyi*) in Narragansett Bay over years. Survival will be assessed seasonally in the field and under laboratory conditions that both mimic global warming trends and those in absence of global warming (historical temperature data sets for the Bay can be used to help define various temperature conditions). These data will allow for the prediction of how parasite and pathogen populations may change in response to specific temperature changes.

An important follow-up to population dynamics will be the detection and classification of selected, highly conserved bacterial virulence genes (e.g. *rtxA* and *vah1/htyA*) in environmental samples (from water and sediment). Their frequency in relation to abiotic factors will be investigated using real time quantitative PCR and gene-specific metagenomics using next generation sequencing to examine the change in abundance of potential pathogens of marine hosts in response to changes in the environment (Nelson, URI; Rand, Brown). Using these data, it will be possible to model not only the populations of pathogens but also the genetic potential of virulence of those populations in relation to abiotic factors, measured by the MLSC. Additionally, examining the amount and diversity of highly conserved virulence genes will provide investigators with insights as to the potential for the emergence of new pathogens that possess common virulence genes in response to changes in the environment (Nelson, Rowley, URI). Virulence potential will be linked with the expression of virulence genes by pathogenic species at various temperatures (measured transcriptionally using real time quantitative reverse transcriptase PCR and SAGE next generation sequencing technology, or translationally using western blot analysis) to reveal how temperature affects pathogenic virulence (Gomez-Chiarri, Lane, URI).

From the host perspective, the LD50 of infection by selected marine pathogens on specific marine fish and crustacean hosts under various temperature conditions will be investigated (Gomez-Chiarri, Nelson, URI). These experiments will elucidate the effect that differing pathogen population size and virulence has on host-pathogen interactions, by demonstrating how morbidity and mortality of the host is effected by temperature. Equally important is the expression of host resistance factors in selected hosts at various conditions and the identification of genes responsible for the immature response in hosts. Little is known about the innate immune response of most invertebrates, including shellfish commercially farmed in Rhode Island. Host response at the organismal and molecular level will be a critical component to modeling the effect of climate change in host-parasite dynamics.

an Aquatic Animal Health Center. The USDA awarded a National Need Graduate Program in Diseases of Marine Organisms (DIMO) to URI in 2007. Three doctoral students are currently supported by the USDA funded DIMO program, thereby leveraging the proposed NSF EPSCoR investment. DIMO includes investigators who are examining bacterial infections of fish and arthropods, bacterial and parasitic infections of bivalves, factors involved in the evolution of parasite gene expression, and the production of metabolites that will disrupt quorum sensing (QS) by invading pathogens; these investigations directly benefit from the NSF EPSCoR Centers. This effort will also involve undergraduate and graduate students funded by NSF EPSCoR fellowships, as well as separately funded graduate students, postdoctoral fellows, technicians, and faculty members.

**Outcomes:** The improved research infrastructure can lead to the development of new marine pathogen control strategies, including the development of vaccines against diseases of importance for aquaculture and the discovery of probiotic strains. This effort will involve a combination of microbiologists, pathologists, cell biologists, physiologists, evolutionary biologists and ecologists, as research will examine a range of questions including mechanisms of pathogenesis, host immunity, genomic interactions of host and parasite, host ecology, and microbial ecology. Collaborations will be encouraged with the award of graduate and undergraduate fellowships. Infrastructure improvements to the MLSC and the Genomics Center will expand the range of equipment needed to monitor in situ populations of disease-causing organisms and identify differences in metabolism under varying temperatures. The addition of equipment to the Genomics Center will substantially improve the scope of studies that can be performed and proposed to funding agencies. The implementation of an overarching bioinformatics framework for all Centers will significantly enhance the state’s existing research infrastructure by providing the hardware and technical support to perform complex data analysis and the rapid transfer of data between Centers for meta-analyses. The leadership serving this research team will work with a number of other participants including at URI: Rowley, Gomez-Chiarri; at Brown: Rand, Dunn; and faculty from PUIs including at RWU: Leavitt; at SRU: Greeley, at RIC: Kolibachuk. Undergraduate and graduate fellowships will invigorate the integrative research team.

### 4.3.3. Research Infrastructure Improvement Plan – Research Centers

The infrastructure investments requested in this proposal will serve to conduct the proposed scientific research, increase multidisciplinary collaboration, and strengthen research competitiveness. The adjacent figure illustrates the interaction among the three Centers established with prior NSF EPSCoR support. The MLSC makes possible the culture of marine life, the analysis of seawater and its nutrients, sample preparation for molecular ecology, and collection of environmental data corresponding to field observations and experimental variables. The samples of marine life and data prepared at the MLSC are further analyzed at the Genomics and Proteomics Centers. The cyberinfrastructure facilitates the analysis and exchange of large data sets among the Centers. The proposed improvements will enhance the analytical capacities at all three Centers and provide the foundation for researchers to compete for external funding and for colleges and universities to recruit and retain outstanding investigators.
a) Marine Life Science Center: The infrastructure investments to the MLSC will improve the state’s research competitiveness in key ways. First, high demand and growth in the area of climate change research requires precision temperature-control and thus four Environmental Chambers are requested. Second, analysis of biological responses to climate change scenarios requires instrumentation (i.e., Flow Cytometer, FlowCAM, Coulter Counter) for counting, imaging, and sorting small or single-celled marine organisms into homogeneous populations for subsequent genomic and proteomic analyses. Third, analysis of metabolic changes that occur in response to climate change scenarios requires addition of metabolomics instrumentation (i.e., exactive high-resolution ion-trap mass spectrometer, automated sampler, GC-MS, UPLC). Both the collaboration with RISD and the goal of broadening participation in science requires the addition of a Visualization Lab in the MLSC (dissecting and inverted fluorescence microscopes, high definition digital cameras, large screens). The Visualization Lab will be used for existing courses and courses taught in Continuing Education. The Academy will use the Visualization Lab as part of the training for undergraduates. Finally, an in situ DataBuoy is requested to continuously monitor water conditions at the mouth of Narragansett Bay to ground-truth experimental conditions. Two full-time technicians will oversee the mass spectrometers used for nutrient analyses and metabolomics, the optical equipment used to sort single-celled organisms, and the general instrumentation for molecular ecology sample preparation.

b) Genomics Center: This proposal will support the enhancement of the Genomics Center through increased DNA sequencing capability, capacity and staff, as follows. To address research questions relating to metagenomics, transcriptome analysis and whole genome sequencing, this proposal requests a Roche 454 FLX Titanium Series Genome Sequencer. An Applied Biosystems 3730 is requested to increase Sanger sequencing capacity to accommodate the greater number of small sequencing projects as more faculty and students routinely use molecular methods, and to close gaps in larger DNA sequencing projects. The addition of a second capillary electrophoresis genetic analyzer that is capable of analyzing up to 48 samples simultaneously will significantly enhance the ability to analyze DNA samples from the expanding research base. To efficiently process the anticipated increase in the number of samples, an additional liquid handling robot is also requested.

The proposed increase in the capacity and capability of this facility will require: 1) a second full-time technician to maintain and operate the Roche 454 sequencer; 2) a systems administrator for Linux-based computers used for most of the bioinformatics programs in the analysis of extremely large data sets generated by NexGen sequencing; and 3) a bioinformatics specialist to assist faculty and students in the use of programs and the organization and analysis of NexGen sequencing data. While these personnel will deal mostly with genomic data, they will also assist the other Centers with installation and maintenance of software for manipulation of large data sets.

In addition to allowing researchers statewide to conduct large sequencing projects, it is expected that other researchers in Rhode Island will benefit from the proposed investment in instrumentation and technical expertise at the Genomics Center. The proposed advancement in this research infrastructure will allow for an increase in user base, thereby enhancing institutional and interdisciplinary diversity, collaboration, and sustainability of the Genomics Center.

c) Proteomics Center: Within the Proteomics Center, the proposed high-performance bioinformatics will enable researchers to better identify proteins from MS data and improve chemical pathway prediction by reducing false positive database matches. More powerful, however, will be the exchange of data between Centers that will inform studies at each and increase the depth of tractable questions, accuracy of models, and understanding of each overall system under investigation. A critical capability to enable such proteomic level analysis is the enhancement of a statewide bioinformatics support structure. This will allow the proposed studies of biological adaptation to climate change through the lens of protein function. As new genetic polymorphisms are observed at the level of the environmental and microbial genomic analyses, those polymorphisms presumed to be in protein-encoding regions could be targeted
for focused analysis to determine the functional roles of the proteins. With this infrastructure investment in bioinformatics, the Proteomics Center will be able to: 1) serve the needs of the major group of life science researchers described in the research program; 2) broaden and expand the user base; 3) integrate more closely with the complementary instrumentation available at other locations; 4) develop a full-service operation that would accelerate the pace of research; and, 5) increase the engagement of high school students and teachers.

4.3.4. The Rhode Island School of Design (RISD)—Building Research Infrastructure by Strengthening Capabilities for the Visualization of Science: Complementary to achieving the goal of advancing research on the effects of climate change is the broader task of building the appropriate institutional, technological, and communications infrastructure for collaborative knowledge sharing and integrated research activity in RI. The participation of RISD provides RI NSF EPSCoR with an opportunity to address these complex issues by providing innovative design solutions across the research, education, and communication activities associated with specific activities, as well as contributing the same to the larger project of integration and capacity building. According to the State’s S&T plan (page 16), “(Design thinking) is an approach to problem solving that could be a powerful driver for successful collaboration and should be a major priority.

RISD brings to RI NSF EPSCoR unique resources for the visualization and communication of science. RISD-based artists and designers already collaborate successfully with scientists on a range of innovative projects. For example, RISD was recently selected by Oblong Industries to help beta-test and explore applications for g-speak (gesture speak), a highly advanced embodied interface system. Using an array of cameras and sensor-equipped gloves, g-speak Studios at RISD translate three-dimensional motions into digital information, helping to develop a promising new human-computer interface.

Visualization Infrastructure Improvements. RISD will put in place new technological infrastructure to develop its capacity for the visualization of scientific information. Specifically, RISD seeks to support and develop competencies in 3D and 2D modeling, mapping, and visualization of processes. With this EPSCoR proposal, RISD will build its technological capacity for the collection of field documentation, digital image processing, advanced data visualization, and interactive media design. Additional technical staff and external consultants will be engaged to develop visualization technologies. New faculty talent in the field of scientific visualization will be recruited to participate in co-teaching the EPSCoR studios. This enhanced infrastructure at RISD will provide the basis for the scientific visualization and communication research under RI NSF EPSCoR. By establishing itself as a leader in scientific visualization, RISD will attract the strongest researchers and students in this growing field, contributing to the larger goal of increasing Rhode Island’s research competitiveness.

Platforms for Collaboration. Innovation Studios, which are an acclaimed learning method (Bain, 2004), will provide a highly interdisciplinary environment in which scientists of different specializations collaborate with RISD designers and one another in exploring complex problems. RISD artists and designers will introduce scientists to the tools and methods of design, with a strong focus on human impacts; at the same time, scientists will transfer to working artists and designers the tools and methods of the life sciences. Innovation Studios run at RISD will examine research in areas that align with the scientific goals of the RI NSF EPSCoR proposal. These studios will bring Center scientists, outside policy makers, and others to explore the public consequences of these areas of study. Such work will help scientists see the broader impacts of their work and help define ways to communicate those impacts and the importance of the underlying science to a lay public.
The goals, outputs, and outcomes for the Innovation Studios are:

**Goal 1:** Making science visible: Developing visual techniques and communications strategies for scientists

**Output:** Improved tools and strategies for the visualization and communication of complex scientific information through interdisciplinary collaborations between scientists and RISD artists and designers.

**Outcome:** RI NSF EPSCoR scientists gain better understanding of data and make better predictions about the effects of climate change. New tools and methods for scientific visualization, with broad importance and potential implications across the life sciences. Exchange and collaboration between scientists and designers and artists have transformative effects, creating new opportunities for discovery and technology. Undergraduate and graduate students at participating institutions will be introduced to the interaction of data and visualization. RISD establishes itself as a leader in the field of scientific visualization, contributing to Rhode Island’s competitiveness.

**Goal 2:** Making science accessible: Developing visual techniques and communications strategies to assist scientists in communicating their work to broader audiences

**Output:** Improved techniques and strategies for the visualization and communication of scientific information for broader audiences.

**Outcomes:** Greater public understanding of the aims, accomplishments, and importance of RI NSF EPSCoR, and of the life sciences generally. Greater understanding among regional policy makers of the issues addressed by RI NSF EPSCoR. Scientific research perspectives and agendas in RI NSF EPSCoR informed through participation of policy makers in Innovation Studios. Innovative art and design methods for visualization and communication of science enhance K-12 science education.

**Goal 3:** Creating collaborative environments: Facilitating successful interdisciplinary research within and among the research Center teams

**Output:** RISD Innovation Studios bring together RI NSF EPSCoR scientists, outside policy makers and others with RISD designers and artists in a highly interdisciplinary setting to focus on challenges and opportunities at the intersection of science and art and design.

**Outcomes:** Better integration of research across RI NSF EPSCoR. New interdisciplinary research collaborations across RI NSF EPSCoR inspired and facilitated. RISD Innovations Studios often lead to further fundable projects that can be conducted in subsequent studios, or outside of the studio. In the first year, the leaders of the RISD team, John Dunnigan, Professor in Design and Architecture, and David Bogen, Associate Provost for Academic Affairs, will develop, with the participation of RI NSF EPSCoR participants, the Innovation Studios to be used during the period of the award. In Year 1, RISD will run the first RI NSF EPSCoR Innovation Studio. In Years 2-5, RISD will run two Innovation Studios each academic year. RISD will also develop two additional studios. Each studio-based research project will be faculty-led with 14 to 17 students working across disciplines on projects aligned with the central research themes of RI NSF EPSCoR. Projects will take the form of semester-long courses that successfully integrate research and education within the studio setting. Projects will draw faculty from across the college and particularly from departments such as Film and Video, Industrial Design, Illustration, Graphic Design, Digital Media, and the Architectures (for their policy expertise).

**4.4-4.5. Diversity Plan and Workforce Development – The RI NSF EPSCoR Academy**

Diversity and Workforce Development issues are inextricably linked. We therefore address them in a unified section. (Leaders: A. Staroscik, Academy Director; C. Watson, Diversity Coordinator and Diversity Mentor; T. Pelletier, Biotechnology Outreach Coordinator; J. Lemire, Undergraduate Research Coordinator)
The RI NSF EPSCoR Academy was established as an integral facet of RI NSF EPSCoR at the organization’s founding in 2006. Its mandate is broad: work to help coordinate and support the programs and organizations addressing RI’s STEM issues; recruit and nurture traditionally underrepresented populations; workforce development; and program development. Designed so that all the human-capital development components of the RI NSF EPSCoR program would be centralized, integrated, and closely aligned with the research objectives of the program, the Academy is emerging as a novel, statewide umbrella for integrative programming.

The Academy operates programs directly and through cross-sector collaboration and partnerships. This dual strategy permits the leveraging of existing funded programs to increase their emphasis on training the next generation of life scientists, emphasizing increased participation of traditionally underrepresented groups.

**Context: Changing Demographics:** The African American and Hispanic-Latino populations are growing. Between 2000 and 2007, the state’s Black/African American population increased from 5.3% to 6.6% of the total population, while the Latino/Hispanic percentage increased from 10.9% to 11.2%. For the RI to diversify its STEM workforce, we must offer and support academic and non-academic programs, and they must be available to ALL students at all levels. To a large extent, the Academy is an incubator for 1) infusing STEM college level students and faculty into K-12; and 2) integrating funded education programs in the state with the university-based marine and life science infrastructure. The work of the Academy spans the educational continuum, shown in the figure above, and provides a core set of capacities to enhance STEM education and workforce development from pre-college through Ph.D.

**Diversity Plan:** The goal is to triple the number of underrepresented populations in STEM education activities supported by the Academy, so as to be representative of the demographics of the state by the fifth year of the grant period. Key strategies are to: 1) expose middle and high school students to life sciences, particularly marine life science, through interactions with EPSCoR scientists, and 2) provide academic enrichment, tutoring and mentoring. We will also 3) actively recruit and retain underrepresented undergraduate and graduate students and teachers.

At the Pre-College Level, the Academy will: 1) facilitate interactions of high school and college students with researchers in the marine, genomics and proteomics center and with PUI faculty; 2) identify internship sites for rising high school juniors and seniors participating in the CCRI Upward Bound Program, which is focused on low-income and first-generation college students; 3) collaborate with the Paul Cuffee School, which integrates marine and environmental studies with an enriched, literacy-based curriculum for grades K-8, and serves a predominately minority (87%), lower SES (78% live in poverty) population; 4) assist the Director of the Educational Talent Search (ETS) (serves minority, low income and first generation college students at CCRI) to recruit and orient students toward STEM, by providing undergraduate and graduate tutors and mentors. The CCRI ETS program has counselors working with 720 students in 11 high schools in underserved communities; 19% of CCRI students are underrepresented minorities); 5) expand the partnership between CCRI and the URI Providence Biotechnology Center diversity and workforce programs to reach a greater number of middle and high school students and teachers: 100 teachers will participate in professional development activities over 5 years.
At the Undergraduate and Graduate Level, the Academy will: 1) collaborate with outreach and support programs at participating schools (e.g., the Leadership Alliance at Brown and the NSF LSAMP at URI) to recruit a diverse population of students into RI NSF EPSCoR supported programs. C. Watson, the LSAMP Director, will serve as staff for this project.; 2) work with other educational support programs, including the Talent Development Program at URI, campus multicultural centers, women's centers, and, importantly, the disability services offices at each of the participating institutions, to coordinate service offerings.; 3) engage 20 undergraduates in pre-college mentoring/tutoring that will provide the marine life science pipeline 100 promising middle and high school students over the 5 year award period.; 4) expand undergraduate research opportunities program from the current level of 25 per year to 60 in the fifth year of the proposed RII. Students will be recruited from all participating schools.; 5) award summer research fellowships to 165 undergraduate students, 20 of whom will be recruited to work in the pre-college enrichment and tutoring programs, as described above.; 6) offer 22 Graduate Research Fellowship awards as a joint URI, RIC, Brown enterprise, providing tuition and stipend support. We will award annually 5 Entrepreneurial Fellowships partnering with the Slater Technology Fund as well as award three stipends per year to RIC biology masters students and invite them to participate in the interdisciplinary graduate program activities at URI and Brown.

In addition, we will continue the Academy’s work to institutionalize the Statewide STEM Network for Underrepresented Populations. Groundwork for a statewide STEM network was accomplished during the first RII award. To extend and institutionalize this network, we will continue to develop partnerships, leverage existing programs; and support the establishment of student-managed STEM student groups on all participating school campuses. These STEM student groups will be modeled on chapters of organizations like the National Society of Black Engineers. Our work will be informed by the “best practices” of the successful URI LSAMP initiative in Engineering, which increased minority recruitment in engineering by 12% and graduation rates by 50% in its first three years. With undergraduate student groups as a foundation, the statewide network will be expanded to include pre-college students and teachers participating in RI NSF EPSCoR supported activities and college and university faculty who mentor minority STEM students.

Workforce Development Plan: The proposed Workforce Development Plan will increase participation in STEM education pathways, leading to careers in marine, life and environmental sciences. An initial first step in the workforce plan will be to bring together key private sector partners, including the Greater Providence Chamber of Commerce, the RI Economic Development Corporation, the Tech Collective, the Slater Technology Fund, and the RI Center for Innovation and Entrepreneurship, and representatives from URI and Brown Business Schools with the RI NSF EPSCoR participating institutions and organizations to execute the following RI Academy activities: 1) increase access to enrichment programs, leadership training, and professional development opportunities; 2) hold forums to identify gaps, needs, and opportunities in the existing system of services through the STEM network; 3) provide financial support for students to gain laboratory and work experience during the academic year and summer; and 4) sponsor an Annual Diversity/Workforce Conference to engage key business and educational program leaders from across the state to address the status and success of diversity/workforce efforts, identify needed actions, and propose strategies for the future.

Pre-College: Student Career Education and Enrichment – The Academy will expand outreach activities targeted at middle and high school students with mentors from the business community and participating institutions to provide more hands-on laboratory experiences in our focus areas. The Academy leadership will work with science education faculty to align training and experiences with RI’s Grade Span Expectations for science. Activities will be carried out at our Centers, partnering companies and participating PUIs. Student directed activities will be aligned with teacher professional development programs. Examples of activities that will integrate business, faculty and teachers to be initiated in year 1
include: Student Focused Initiatives-- biotechnology courses at URI and CCR, the RWU Marine Biology Camp for middle and high school students, the state supported Large Molecule – Small Molecule Interactions Project at RIC; Teacher Focused Initiatives—Workshops at the URI Biotech Center in collaboration with RI Department of Education (RIDE) bioscience program, NBC2 (an NSF funded ATE), RITES (an NSF MSP), and the STEM center at RIC. Workshops will be conducted at least five times a year, with a target of reaching 15-20 teachers per session. Once trained, teachers will partner with college and university faculty and then serve as workshop instructors. Workshop topics will be aligned with enrichment activities for pre-college students and will focus on biotechnology, climate change, marine life sciences, genomics, and proteomics. In years two through five, an expanded set of activities involving an anticipated 300 middle and high school students and their teachers will be offered annually.

**Undergraduate: Summer Undergraduate Research (SURF) Program** – The SURF program, a highly recognized and competitive undergraduate research program, is a 10-week intensive program that matches students with faculty mentors to conduct cutting-edge research, participate in career building workshops on topics such as scientific ethics, strategies for graduate school applications, and scientific poster preparation. As noted, over the course of the 5 years, 165 undergraduate students will be awarded summer research fellowships.

**Entrepreneurial Fellowships** – The Entrepreneurial Fellowship Program at the Slater Technology Fund involves students in life sciences and biotechnology entrepreneurship and assists fledgling RI companies in the commercialization of technological innovations. Five fellowships will be offered annually on a competitive basis to graduate students and advanced undergraduate students from all institutions.

**Graduate: Interdisciplinary Graduate Training in Research** – The Academy will provide Graduate Research Fellowships as a joint URI-Brown-RIC enterprise. The Academy will sponsor workshops and courses designed to strengthen knowledge across disciplines within the marine life sciences, build leadership and networking skills, and provide guidance for career development. The Graduate Fellowship program will build on the models provided by two interdisciplinary graduate programs at URI: 1) an NSF IGERT Fellows program with a focus on changes in coastal ecosystems; and, 2) a new USDA Fellowship program in diseases of marine organisms. The Fellowship program will be run as a recruiting program with a total of 11 two-year graduate fellowship awards, providing tuition and stipends. In addition, 15 RIC master’s level students will participate in the program.

**Post-graduate: Networking Opportunities to Enhance Collaboration**— Networking opportunities will be supported for researchers, graduate students and undergraduate students, through short conferences, workshops and lab-based courses, to discuss new developments in NSF EPSCoR-related research topics. The goal of this initiative is to bring together the state’s researchers and their students to facilitate communication and stimulate collaborative research.

### 4.6 Cyberinfrastructure Plan

Improved instrumentation, high throughput data acquisition, and the growing sophistication of modeling are transforming every corner of science. The line between computational biology and traditional biology is disappearing as computational approaches and tools become pervasive across the field. Meeting these computational challenges require improvements in both physical infrastructure and technical expertise (NSF Report 07-28, 2007). The research proposed in Section 4.3 will be data-rich. Thus, investments in cyberinfrastructure (CI) are critical to ensure that researchers in RI and throughout the world can access this information and contribute to its analysis and annotation.

The CI plan is designed to increase computational capability, data storage capacity, network connectivity, and technical expertise. Improvements in the area of cluster computing and the expertise needed to maximize its utility are proposed. These investments will ensure that researchers are able to
access and leverage the parallel investments in the core facilities, and will insure that data mining and other data analysis processes are scaled and accessible as they are generated.

Physical CI resources in RI’s academic community include computing clusters at Brown and URI. We propose to install a 96 processor cluster computer for processing of genomic, proteomic and other intensive databases collected as part of the research efforts proposed here. The clusters in the northern part of the state (including Brown) are connected to dedicated, nationwide, high-capacity fiber optic networks. Clusters further south (including URI) do not yet have access to these high-capacity fiber optic connections. However, recent NSF EPSCoR Track 2 and INBRE CI awards will improve the connectivity in the South. Additional CI in the form of 10GB/s fiber is being laid to assure that RI scientists are able to access intensive databases. The proposed new configuration with heterogeneous distribution of RAM across nodes will allow both intensive projects and RAM intensive assembly projects to be optimally distributed across the cluster. In addition, the technical expertise and human capital required to support next generation sequencing and bioinformatics resources are key components of the proposed physical CI investments. A Facility Manager knowledgeable in Linux Server operating systems and cluster hardware is essential to ensure systems support and to assist in connecting researchers across the state. Likewise, researchers pursuing the proposed research questions (Section 4.3) on the impact of climate change on the marine environment will require access to a highly skilled Applications Scientist to extract the complex information from the raw sequence data. Investments will also be required in RISD’s institutional capacity in the areas of visual communication of complex scientific data to assist in data interpretation and dissemination. RISD’s skills in this area will have a profound impact on external engagement of the general public presenting the science discoveries in graphically dramatic and compelling fashion.

RI’s high capacity fiber optic connectivity is maintained by OSHEAN, Inc., a non-profit organization founded by URI and Brown to enable access to Internet2 for institutions not capable of gaining access on their own. OSHEAN provides redundant Internet and Internet2 connectivity through its own fiber optic connections to the NOX in Boston, and through a regional network, NEREN (North East Research and Education Network). NSF EPSCoR Track 2 funding was awarded in August 2009 in collaboration with four other northeastern EPSCoR states to improve high capacity connectivity. These funds will “light dark” fiber connecting URI to OSHEAN’s network. With these improvements, the northeast will be well positioned to create a redundant fiber optic loop that connects southern Rhode Island to New Haven, CT.

Due to close geographical proximity, the RI research community is well positioned to increase its engagement in CI-dependent research. The proposed investments are in line with the science-driven new research techniques that require intensive data analysis and enhanced cyberinfrastructure. The benefits of increased computational capacity and the ability to transfer large data sets between sites will strengthen genomics and bioinformatics research as well as other research areas in which RI scientists are engaged. These include environmental monitoring, modeling, and 3-D visualization of complex systems. These investments will also prove beneficial to additional users, including Lifespan, the largest hospital system in the state involved in basic medical research.

4.7. EXTERNAL ENGAGEMENT PLAN
This plan will further: 1) solidify institutional participation and the involvement of the private sector, 2) provide activities that will facilitate the entry of UREP and women, and 3) communicate/disseminate results, benefits and processes of science to RI’s citizens.

Institutional Participation and Private Sector Collaboration: STAC’s Research Alliance is charged with bringing together collaborative, multidisciplinary resources throughout government, academia and industry in new, positive and creative ways. Nine of the state’s 11 IHEs will participate in this proposal. To ensure full participation, RI NSF EPSCoR and STAC will host a collaborative web portal and continue to sponsor an annual statewide research conference. In addition, we will undertake a statewide assessment plan
to identify research areas that are ripe for collaboration. To ensure effective participation and communication with the PUIs, a Project Advisory Council has been established, comprised of representatives from all PUI institutions. Likewise, to facilitate industry involvement and new ventures, RI NSF EPSCoR and the Slater Technology Fund have partnered to connect EPSCoR Entrepreneurial Fellows with new and emerging companies in the state. The Slater Technology Fund targets companies that are likely to create high paying jobs and locate more than 50% of their employees in RI.

**UREP and STEM:** The RI NSF EPSCoR Academy is responsible for facilitating the entry of women and members of other underrepresented groups into STEM fields. See 4.4-4.5 for a detailed discussion.

**Public Outreach:** Two outstanding capacities specific to RI that will be used to effectuate external engagement are the RISD and the URI Metcalf Institute for Marine and Environmental Reporting. The Metcalf Institute is a leading provider of science training for professional journalists. RISD will work to make research data more accessible, provide communication strategies and visual techniques to scientists and larger audiences, and enhance science education.

RI NSF EPSCoR and Metcalf will offer two science communication seminars per year to instruct science faculty and students in establishing rapport with journalists and prepare effective, audience-appropriate messages for journalists and the general public. As one example of external engagement, the RI NSF EPSCoR will start a Science Café based upon the successful model already demonstrated across the US (www.sciencecafes.org). Science cafés are casual meeting places where scientists join in with the general public to discuss engaging subjects in science and sometimes how it relates to other fields outside of science. The format will vary but science cafes will be held in public places throughout the state.

RISD will provide significant insight into developing high quality, visually engaging scientific representations. The collaboration with RISD will also fuse science and art, which will further facilitate public engagement. Distilling the data-intensive results of the proposed work (See 4.3) into a graphical, engaging format will provide a foundation for conversing with the general public in the science café forum. Measurable outcomes will include: 1) the production of articles for the general public covering issues relevant to the scientists’ areas of research; and, 2) participation of scientists and journalists in series of science cafes within the state.

Other outreach and communication efforts include: The Current – the news magazine, issued three times a year, describes the full range of RI NSF EPSCoR activities. It is distributed to over 1850 individuals from academia, industry, government, and the public. Issues are archived on the RI NSF EPSCoR website. Website - The RI NSF EPSCoR website is hosted collaboratively with STAC and the Research Alliance. This site is a portal to S&T research, funding availability, and student opportunities in the state. Over the next five years, this website will be made more interactive by incorporating multimedia, image, and video galleries. NSF staff will be invited to site visits and research conferences in areas of importance defined in the S&T plan. RI NSF EPSCoR is a co-sponsor of many of these events.

4.8 **EVALUATION AND ASSESSMENT PLAN**

To measure the impact and success of the RI NSF EPSCoR program, we will: 1) collect quantitative data as defined in NSF EPSCoR’s annual reporting template; 2) secure independent external evaluations; and 3) develop and implement additional project specific evaluation metrics to assess the long term effects of the investment. The evaluation program will be refined during the first year, based on the guidance of the NSF (see NSF 09-068). It will include appropriate benchmarks, milestones, and time scales for each individual activity. The data collected will be used for formative and summative assessments.

**NSF EPSCoR Annual Reporting Templates:** The NSF reporting templates require collection of data in 8 categories that define many of the quantitative objectives and milestones described in NSF’s strategic plan. RI NSF EPSCoR staff will collect and report funding and demographic data for all individual
participants in the award, from K-12 through university faculty. Staff will also report the number and values of patents and proposals, and the number of publications, new faculty, and center graduates generated by the RI NSF EPSCoR effort. In addition, the RI NSF EPSCoR steering committee will monitor performance on a quarterly basis against the metrics set forth in the post-award strategic plan.

**External Evaluation:** An External Evaluation Committee (EAC) will be recruited by the Principal Investigator (PI) to provide independent review, assessment, and guidance. The EAC will include three S&T professionals with expertise in research administration and/or in the major thematic areas of the award; and an academic or private-sector consultant with experience in evaluation of research and education programs. The EAC will convene annually (in advance of the report to the NSF) to: 1) describe and document RI NSF EPSCoR activities, processes, and participation for both improvement and accountability purposes; 2) assess the merit and value-added of specific programmatic components and elements, including how effectively the programs are meeting institutional and state needs; and 3) analyze process, output, and outcome goal attainment. Prior to the panel visit, data will be collected related to the various goals (See Table 2). The EAC will include visits to member institutions, PUIs included, to attain a broad overview of the state-wide effort. The panel will brief the RI NSF EPSCoR PI at the conclusion of each site visit; in addition, a formal report, inclusive of recommendations to strengthen the projects will be prepared and submitted to the PI.

**Post Award Evaluation and Independent Assessment:** The third evaluation method will assess the broader societal impacts of the RI NSF EPSCoR program. Aggregate measures will be used to assess revenue and economic impacts of individual initiatives. Indicators related to revenue and economic generation resultant from the RI NSF EPSCoR investment and related synergistic activities will be developed and assessed. Utilizing these data, an independent researcher, Kristin Johnson, Ph.D., will apply econometric modeling techniques to analyze the efficacy and strength of the particular programs as they relate to program goals; including research competitiveness, participation of underrepresented groups, revenue generation, economic stimulation, job creation, and research success. This approach generates forecasts of continued and anticipated effects of particular programs over time, which will be used to guide policy recommendations for immediate and long-term strategies. We anticipate that these efforts will lead to the publication of policy papers evaluating the efficacy of the RI NSF EPSCoR program with a 5-10 year time horizon.

**Timelines and Milestones:** Representative milestones for the EAC for the first year are to: 1) establish the EAC; 2) prepare and adopt, with the approval of NSF, a strategic plan that will include research protocols for post-award evaluation and assessment; 3) commence quarterly monitoring by Project Steering Committee; 4) conduct an initial review by the EAC. For years 2-5, there will be quarterly reviews by the Project Steering Committee and annual reviews by the EAC. (See 4.4, 4.5, 4.9, 4.10) for additional milestones. A comprehensive matrix will be developed during the first three months to track progress towards milestones and timelines as set forth in the post-award strategic plan.

<table>
<thead>
<tr>
<th>Goals</th>
<th>Indicators</th>
<th>Data Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Broaden workforce/diversity</td>
<td>Annual participation data for Academy programs</td>
<td>Attendance logs, program evaluation, progress toward achieving learning goals.</td>
</tr>
<tr>
<td>3. Build a more collaborative environment</td>
<td>Participation in Innovation studios. Collaborative research proposals and publications</td>
<td>Joint interdisciplinary inter-institutional grant submissions, patents, publications. Co-mentored students. Joint faculty appointments</td>
</tr>
<tr>
<td>4. Enhance core infrastructure</td>
<td>Genomics, proteomics and other analytical capacity</td>
<td>Quantitative measures of sequence throughput. Number and representation of users. Publications</td>
</tr>
</tbody>
</table>

**Table 2**

22
5. Improve data visualization and public understanding

Collaborative efforts to translate data into graphic visualization projects

Joint programs between researchers and RISD staff. Presentation of visualization pieces at public forums. Usage of graphical representations by the community. Impact of visualization projects on public awareness through outside organizations (media, government, private-sector)

6. Build capacity in cyberinfrastructure

Computer cluster capacity

Number of users, projects. Linkages to PUIs and other institutions. Fraction of capacity used, publications acknowledging CI support

4.9 Sustainability Plan

RI NSF EPSCoR will sustain the efforts supported in this RII by leveraging the capacity developed by the proposed research infrastructure improvements. The proposed and future efforts are specifically designed to make RI more competitive for research funding. The STAC annually awards research seed funding at $1.3M per year, which is available to RI NSF EPSCoR researchers. STAC plans to support a $100M bond referendum on the 2012 ballot in Rhode Island to support the hiring of 20-30 top tier faculty at URI and to establish a federal match funding pool at URI. Currently planned funding submissions to NSF include IGERT proposals to help support the graduate student training. Because infrastructure improvement investments will contribute to streamlining “the pipeline between research ideas and new venture creation,” further private sector investment in R&D is anticipated and will help to sustain the program. While the size of the private-sector reflects the overall size of the state, there are significant industry clusters that are in close proximity to Rhode Island, notably the Route 128 corridor, which is located approximately 50 miles away. This area is the home to many of the major biotechnology companies and opportunities to translate our marine science platform into private-sector opportunities.

4.9.1 Seed Funding and Emerging Areas: In 2007, STAC created the "Collaborative Research Grants Program" with support from the Governor and General Assembly. This program supports the goals of NSF EPSCoR and EPSCoR-like programs by providing seed funding of on average $180,000 for one year for collaborative multi-institutional faculty investigator teams that are well positioned to attract significant follow-on federal investment. STAC will continue to use a competitive application process to identify and provide investment to projects that have a bold vision and new directions. Young faculty are especially encouraged to solicit support and this commitment is demonstrated in seed awards made over the past few years. Awards will be made to: projects that: 1) are collaborative and catalytic in nature and lead to major new research opportunities; 2) have a high likelihood of being supported by federal agencies, corporations and/or foundations; 3) contribute to economic development in the state through technology development and/or commercialization potential; 4) show how the combined efforts of the institutions can lead to results that could not be achieved by either alone; 5) have strong translational components; and, 6) focus on infrastructure development that significantly advance the research competitiveness of scientists in RI for federal funding or directly enhance efforts to secure additional NSF EPSCoR awards. By exploring new opportunities, the RI NSF EPSCoR program will seek sustainability by establishing new avenues for investigation creating a dynamic process for program rejuvenation.

4.9.2 Education and Human Resources Development (EHR): The goals for EHR development include: 1) enhancing research culture and capabilities at URI, the state’s only public research institution; and, 2) working collaboratively with existing state programs to obtain additional federal funding for K-12 students and teachers, undergraduate students, CCRI, the only 2-year community college in the state, and graduate students through the RI NSF EPSCoR Academy.

The Academy was designed and created during the first NSF EPSCoR award to provide a
sustainable model for STEM outreach and education by establishing the Academy as the coordinating agent for new and existing programs in the state. The Academy will be a platform for submitting NSF STEP, S-STEM, GK-12 and other proposals in years 1, 3, and 5 of this award. Where appropriate support will also be solicited from other agencies including the Department of Education.

4.9.3 Post-EPSCoR Extramural Funding: For RI NSF EPSCoR investigators receiving support, there will be a clear expectation that they prepare requests for extramural funding during and/or following NSF EPSCoR support. This expectation will be part of the selection criteria for faculty receiving support, and assessed through regular reporting of NSF EPSCoR accomplishments. The Project Leadership Team will continue to work with URI’s Division of Research and Economic Development and Brown’s Office of Research Administration to identify funding opportunities and provide faculty with grant writing workshops and assistance.

4.10 MANAGEMENT PLAN

The RI NSF EPSCoR management structure has six components and a governing committee. Charges and relationships for each are described below.

1) Project Leadership: The Leadership Team: (PI) P. Alfonso (URI), two Co-Project Directors (Co-Pls) S. B. Moran (URI) and E. Hawrot (Brown), and the Associate Project Director, K. Payne (URI), will oversee the activities and programs of the proposal and assure they are conducted in accordance with NSF guidelines. They will also use the evaluation and assessment reports to make informed judgments on resource reallocation. The RI NSF EPSCoR will, on an ongoing basis, promote professional leadership development especially among the younger faculty.

2) Project Staff: Staff support will provide administrative and programming assistance, led by the Associate Project Director with the Project Administrator, D. Carrigg, Outreach and Communications Coordinator, S. MacSorley, and a Scientific Research Grant Assistant (TBA). The Academy staff will be led by a Director, A. Starosciak, and include a Minority Recruitment and Retention Coordinator, C. Watson, a STEM Minority Counselor (TBA), two new full time Graduate Assistants, (TBA), a Biotechnology Outreach Coordinator, T. Pelletier (CCRI) and an Undergraduate Research Coordinator, J. Lemire (RWU). The Academy staff will lead diversity efforts and workforce development programs.

3) Project Steering Committee: The PI and Co-Pls and the Center Directors, J. Specker (URI), D. Nelson (URI) and E. Hawrot (Brown), will oversee the scientific mission of the proposal, promote collaborative relationships, and guide research infrastructure development. RISD leadership, J. Dunnigan and D. Bogen, will provide direction regarding methods for visualizing the science conducted at the Centers and enhancing public understanding of science.

4) Project Advisory Council: The Advisory Council, representatives from all of participating institutions, will advise the steering committee with regard to matters of concern to their respective institutions and be responsible for collecting assessment data for their faculty, dissemination of relevant information to their campus communities, and acting as a liaison to have their faculty and student voices heard. The Advisory Council will meet quarterly. Members include: J. Webb (URI), P. Woodberry (CCRI), E. Anthony (RIC), L. Guralnick (RWU), J. Costello (PC), L. Zuccarelli (SRU), D. McNally (Bryant) and D. Bogen (RISD).
5) **Diversity Advisory Committee:** A Diversity Advisory Committee will be organized to advance RI NSF EPSCoR’s goals of broadening the participation in the workforce, education and research. This committee will report to the PI and will advise on expansions to the Academy and related initiatives.

6) **External Evaluation Committee:** An independent, external evaluation committee will be created consisting of subject experts in the field and an expert in program evaluation. This evaluation committee will be charged with an annual review of the RI-NSF-EPSCoR program (See 4.8).

7) **Governance:** STAC, a statutory body with representatives from academia, business and the private sector, and government, will be the governing committee. Its members are C. Briant (Brown), D. Farmer (URI GSO), P. Alfonso (URI), T. Babineau (RI Hospital), P. Corriveau (Naval Undersea Warfare Center), K. Hall (Amgen, Inc.), D. Hibbitt (ABAQUS, Inc.), S. Kaplan (Business Innovation Factory), M. Leinen (Climos), T. Rockett (RI Board of Governors for Higher Education), T. Ryan (CVS Corporation), D. Stanford (GTECH Holdings Corporation). Its major roles are to ensure RI NSF EPSCoR’s fidelity to State initiatives in S&T and human resource development, continue to be a catalyst for integrating relevant academic research into State S&T plans and priorities and advise on innovation policies that promote economic growth.

**4.10.1 Jurisdictional and Other Support:** Jurisdictional support for research infrastructure development, pertinent to this proposal, includes institutional investments in research infrastructure: 1) Brown University’s Sydney Frank Hall for Life Sciences, a $95 million building (the University’s single largest capital project to date); 2) URI’s new 40,000 square foot $15 million Pell Marine Research Library and Inner Space Center, opened in July 2009, which integrates key resources of the Graduate School of Oceanography that strengthens the School’s position as a leader in the study of the world oceans; and 3) URI’s new 140,000 square foot $60 million Center for Biotechnology and Life Sciences (CBLIS), opened January 2009, which provides state-of-the-art research and teaching facilities to students in the biological sciences. In addition to these investments, URI launched construction for a new 160,000 square foot $80 million College of Pharmacy in October 2009. Cyberinfrastructure improvements include OSHEAN, Inc., a non-profit organization founded by URI and Brown to enable access to Internet2 for institutions not capable of gaining access on their own. Other jurisdictional support includes an ongoing annual $1.5M appropriation from the RI State Legislature, of which $800K will be used directly as match for RI NSF EPSCoR. The organizational capabilities of the Economic Development Corporation, STAC, the Research Alliance, and the Slater Funds, are another form of important jurisdictional support.

**4.10.2 Summary Table of Requested RI NSF EPSCoR Support**

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<thead>
<tr>
<th>Activity</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
<th>5-Year Total</th>
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<td>$40,288</td>
<td>$41,257</td>
<td>$42,259</td>
<td>$201,605</td>
<td>1.0%</td>
</tr>
<tr>
<td><strong>Total Costs</strong></td>
<td>$4,000,000</td>
<td>$4,000,000</td>
<td>$4,000,000</td>
<td>$4,000,000</td>
<td>$4,000,000</td>
<td>$20,000,000</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

* Includes all employees and operating costs for RI NSF EPSCoR central office, technical assistance committee, external assessment team, evaluation, statewide conferences, statewide website, and statewide newsletter.

** Includes $984,114 for 165 Undergraduates for statewide Summer Undergraduate Research Fellowship (SURF) program.
5. References Cited