

## **Sea Grant College Program**

The National Sea Grant College Program supports research, education, and outreach activities that address critical problems in human use of the sea. The [MIT Sea Grant College Program](#) focuses on developing scientific and technological systems that can provide ever-increasing accuracy and range in exploration, data gathering, analysis, and understanding of marine processes. Essential to this purpose is the transfer of knowledge to and within the program's broad constituency: industry, government agencies, public and private educational institutions, and the general public.

MIT Sea Grant's research and outreach efforts fall under four general organizational groupings: Autonomous Underwater Vehicle Laboratory, Design Laboratory, funded research projects, and education and advisory services.

During the past year, MIT Sea Grant has directed its capabilities to addressing one of the most significant challenges of our time: climate change and its concomitant issues of sea level rise, ocean acidification, and damage to coastal areas from extreme weather events. We encourage our funded investigators to address these issues, and we will also direct our own staff expertise to discovering methods of preventing or mitigating the local, national, and global effects of a warming earth and a changing ocean.

For example, we have funded several relevant projects in this area through our core and regional competitions, as listed in the funded research section below. Dr. Stefano Brizzolara has collaborated with our principal investigator, Changsheng Chen of the University of Massachusetts, Dartmouth, in developing and validating numerical models that simulate coastal hydrodynamic processes in order to help devise protection strategies against inundation due to climate change.

### **Autonomous Underwater Vehicle Laboratory**

MIT Sea Grant is historically credited with the creation of autonomous underwater vehicles (AUVs)—small, inexpensive, artificially intelligent robotic submarines for undersea exploration. Through spinoffs, and through having trained a number of leading engineers in the field, the MIT AUV Laboratory may be considered largely responsible for founding a multimillion-dollar industry.

In April 2014 a vehicle developed by Bluefin Robotics, a 1991 spinoff from the AUV Lab, was deployed in the search for the wreckage of missing Malaysia Airlines Flight 370. The Bluefin-21 carries side-scanning sonars and moves back and forth above the seafloor in a "lawnmower" pattern. Depths in the search area were 12,000 to 13,000 feet, close to the vehicle diving limit.

In terms of contributions to technology and commerce, NK Labs, cofounded by part-time AUV Lab engineer Seth Newburg, announced this year that it has joined with Google to develop a new type of fully modular cell phone. MIT Sea Grant originated the portable technology now being developed for the Google/NK modular phone through the Ara Project. It began with water quality sensors designed for Sea Grant education

programs, to be mounted on small remotely operated vehicle (ROVs) built by students, and other techniques and sensors meant to expand underwater exploration and data gathering by students and citizen scientists. Now NK Labs will add \$6 million and 18 high-paying jobs to the local economy, not including the economic “multiplier effect” of dollars spent in the community, because of this portable technology. Seth left Sea Grant this year to work full-time on the Ara Project.

## Bluefin-21 search capabilities

Searchers deployed a torpedo-like self-propelled underwater search vehicle near where pings possibly from Malaysia Airlines 370 were last detected.

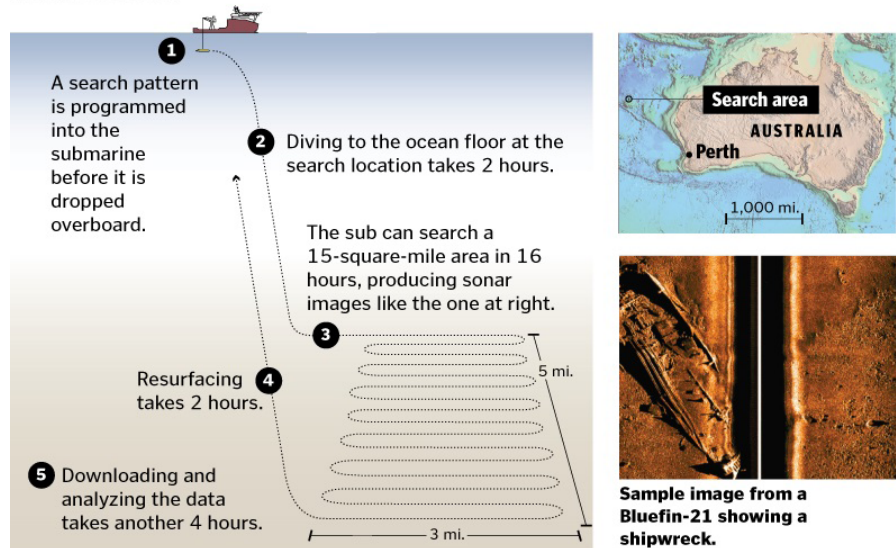


Figure 1: An autonomous submarine developed at an AUV Lab spinoff helped in the search for a missing aircraft.

In this reporting period, AUV Lab engineers made considerable progress in building *REX IV*, a robust and versatile vehicle based on earlier versions of *REX*. The vehicle is designed to be smaller, faster, and more responsive and to have much greater video transmission capability. *REX IV* will extend the public impact of the new technology incorporated into its systems.

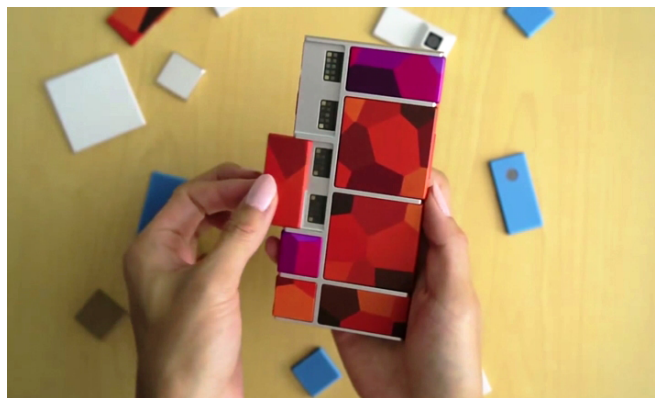


Figure 2: The Ara Project modular cell phone uses concepts and sensors developed by MIT Sea Grant.

## **Design Laboratory**

Under the general heading of the Design Laboratory, MIT Sea Grant carries out advanced work in naval architecture and ship systems. Designs of ship components, power and propulsion systems, and the hydrodynamics of various vessel hull shapes are modeled and tested using complex numerical simulations. The Numerics in Computational Engineering group, with its expertise in multiscale mathematics and high-performance computing, complements and supports the Design Lab's field tests of physical models of hulls, power systems, and propellers.

## **Electric Ship Research and Development Consortium**

Since 2002, the Electric Ship Research and Development Consortium has pursued its mission to design an all-electric vessel for the US Navy with MIT Sea Grant director Chryssostomos Chryssostomidis leading the effort at MIT. Funded since 2008 by a five-year grant from the Office of Naval Research (ONR), the Consortium successfully bid for a one-year extension for 2014 in the face of funding restrictions at ONR. MIT will play a more significant role as national leader of a key area: the development and validation of physics-based models.

MIT's mandate under this new phase of funding is to continue development of the design methodology described above and also to tackle the management of the thermal load of the electric ship. This is a critical problem in any electric or electronic system: how to manage and minimize the heat generated by the operating equipment. Extensive mathematical modeling and computational analysis is needed to create a system that does not overheat at maximum function.

Currently, our work involves a collaborative effort among MIT, Florida State University (FSU), and the University of South Carolina (USC) to develop a reliable and validated thermal management simulation tool that can be used in the initial stages of design to correctly evaluate and mitigate the adverse effects of increased heat loads in all-electric ships. To this end, we have modeled time-dependent fluid flow and heat transfer in an arbitrary pipe network using a quasi-one-dimensional model. All components are modeled in a lumped fashion via first principles and/or empirical measurements carried out at USC. The modeling results in a system of coupled one-dimensional partial differential equations with appropriate boundary conditions obtained from component modeling. At MIT Sea Grant, a robust computational tool has been developed and verified to solve the resulting equations using the discontinuous Galerkin method. The computational tool is combined with vemESRDC, developed at FSU, to predict heat loads for air-cooled equipment and spaces.

In addition, we are developing a heating/ventilation/air conditioning (HVAC) tool within the Smart Ship System Design (S3D) to handle air-cooled loads. This tool would enable testing at the ship level of the effects of new evaporator and condenser technologies, loss of cooling, habitability of ship spaces, and the impact of dynamic changes in air-cooled loads throughout the ship mission.

MIT Sea Grant has also developed a high-fidelity computational tool that solves three-dimensional, time-dependent two-phase-flow systems, in which we use phase-field

methodology to track different phases. The computational code has been verified with several benchmark problems. The code will be used as an optimization tool at the component level.

### **Funded Research Projects**

As mandated by the National Oceanic and Atmospheric Administration, MIT Sea Grant conducts a yearly funding competition through the National Sea Grant office. Grants are available to any university-based investigator in the Commonwealth of Massachusetts. Proposals are selected by peer review for scientific merit and to support the goals outlined in our strategic plan. Every \$2 in federal grant money must be matched with \$1 from nonfederal sources.

This year we chose for funding four new core research projects and one new six-year, focused research Marine Center project. In addition, we contributed funds to support two new regional projects in collaboration with other Sea Grant programs in the northeast. We continued to support the four core research projects, each two years in duration, that were initiated in February 2013, as well as a pair of six-year Marine Center projects, one of which ended earlier this year.

### **New Projects**

Investigators submitted proposals for comments by in-state stakeholders, peer reviewers recruited from outside of Massachusetts, and, finally, a panel of technical experts chosen by the director. The following projects were approved for funding:

Donald Anderson, Woods Hole Oceanographic Institution (WHOI)—Enhanced Monitoring of Harmful Algal Bloom Dynamics and Toxicity Using Real-Time Observations From Co-Deployed, Automated Biosensors

Jarrett Byrnes, University of Massachusetts, Boston—Food Web Structure as a Driver of Multiple Ecosystem Functions in New England Salt Marsh Ecosystems

A. Randall Hughes, Northeastern University—Functional Consequences of Invasion-Mediated Biodiversity Changes in a Marine Ecosystem

Changsheng Chen, University of Massachusetts, Dartmouth—Using a Global-Regional-Coastal FVCOM System to Assess the Impact of Sea Level Rise on Hurricane and Nor'easter-induced Flood Risk over Massachusetts Coast

### **New Northeast Regional Social Science Research Projects**

Porter Hoagland, WHOI—Buy Out or Build Back? A Comparative Assessment of Approaches to Employing Public Funding to Vulnerable Coastal Properties in the Northeastern United States

Robert Johnston, Clark University—Coastal Hazards and Northeast Housing Values: Comparative Implications for Climate Change Adaptation and Community Resilience

## Continuing Projects

Pierre Lermusiaux, MIT—High Productivity on a Coastal Bank: Physical and Biological Interactions

Cascade Sorte, University of Massachusetts, Boston—Are Blue Mussels Declining in the Gulf of Maine?: Population Trajectories, Connectivity, and Spatiotemporal Variation in Reproduction

Helen Poynton, University of Massachusetts, Boston —Development and Validation of the Coastal Biosensors for Endocrine Disruption (C-BED) Assay

Anna Michel, WHOI—Laboratory Development of a Quantum Cascade Laser-Based Sensor System for Measurement of  $\delta^{13}\text{C}$  ( $\text{CO}_2$ ) in Seawater and Air (seed)

## Continuing Six-Year Focused Research Projects

Michael Triantafyllou, MIT—Marine Center for Development of Biomimetic Underwater Sensors (begun 2013)

Franz Hover, MIT Department of Mechanical Engineering—Autonomous Vehicle Exploration and Sampling of Deepwater Corals (begun 2008)

## Advisory, Education, and Outreach Program

MIT Sea Grant has an active advisory, education, and outreach program whose staff members have strong ties to the community. Their work ensures the transfer of research results and ocean science information to the appropriate constituents and also ensures that our research and programs address issues important to local, state, and regional government agencies; coastal municipalities; businesses; and citizen groups and organizations.

To strengthen our campaign to raise awareness and motivate a response to climate change, the MIT Sea Grant advisory team convened the three-day (June 16 to 18) Climate Change Symposium on Sustaining Coastal Cities at the Tang Center. Leaders in academia, government, and private industry spoke to a large and engaged audience on the problems and dangers of sea level rise, storm surges, and extreme precipitation and flooding and the options for adapting to these risks.

## Marine Invasive Species

Nonnative species adversely affect native communities or organisms, fisheries, and ecosystem functions. In summer 2013, a rapid assessment survey was conducted by taxonomic experts, students, and others to identify nonnative and native species on floating docks from Maine to Rhode Island. The survey findings showed that there were 34 introduced species, four of which had not been reported in earlier surveys, and two summer ephemerals. These results suggest that warm water species are moving northward and that hull fouling may continue to introduce new species and facilitate their spread. A report will be completed and made available to harbor masters and port authorities.

The Chinese mitten crab impacts ecosystems, causes erosion in banks, preys on fish and other species, and causes economic damage. MIT Sea Grant examined estuaries and rivers in the Gulf of Maine and throughout the coast from Maine to New York City to identify high-priority areas for potential crab invasions. The suitable habitat areas are based on several criteria, such as estuaries with mixed ocean and fresh water, areas with long residence times in the estuary, and the size of the estuary and watershed. The results indicated that there are few riverine/estuary systems in the Northeast that are comparable to the successful invasion of the Chinese mitten crab based on habitats in Europe and the West Coast.

Ballast water management remains a primary target of preventing new introduction of marine and freshwater species. The Canadian Department of Fisheries and Oceans' Centre of Expertise on Aquatic Risk Assessment conducted a peer-reviewed process to address levels of risk from ships in transit to and from Canada and assess the current regulations in terms of level of protection. MIT Sea Grant's Dr. Judy Pederson was asked to serve on the panel to assess the proposed approach to determining risk. A final report noting that the current ballast water exchange is inadequate for preventing introductions in coastal waters was prepared for Transport Canada and submitted in September 2013. It has not yet been officially accepted.

### **Social Impact Assessments for Fisheries Management**

Social impact assessments (SIAs) of proposed changes in fisheries management regulations have long been required by law. MIT Sea Grant fisheries anthropologist Madeleine Hall-Arber provides regulators with studies that determine the effects of regulations under consideration on the fishing communities that must adapt to these regulations. In April 2014, MIT Sea Grant submitted a final report on a three-year collaborative project focusing on herring fisheries management in which five community researchers, five students, and an economist from the University of Massachusetts, Amherst, interviewed 60 herring stakeholders to identify the social impacts of past regulatory actions and determine how SIAs might better reflect consequences of change in the future. Her study considered herring, a species critical to commercial lobstermen and recreational fishermen (for bait), to humpback whales, seabirds, groundfish, striped bass and other sea life for prey, and an important source of protein for humans in some cultures. Dr. Hall-Arber's research will be used by New England Fishery Management Council members and staff to develop regulations for herring and other fish species.

### **Education**

A key component of outreach is a comprehensive and varied educational program, mostly directed at K–12 students. One effective tool in our educational toolkit is the *Sea Perch*, a simple remotely operated vehicle that young people can build out of inexpensive, easily available materials. The original *Sea Perch* teacher training has evolved into a suite of programs and activities to exploit the outstanding success of this ongoing effort.

Among other activities, the MIT Sea Grant education team conducts public outreach in the community using the *Sea Perch* interactive demo podiums. These were built in 2010 to maneuver the *Sea Perch* in a large fish tank without the traditional control box;

a joystick and pushbuttons on the podium can withstand a large volume of users. The podium has a camera and a monitor that display the *Sea Perch's* point of view. During the fall of 2013, the podiums were renovated and standardized. The demo was featured at events such as the Cambridge Science Festival; World Ocean Day, hosted by the New England Aquarium; the Boston Minuteman Council's SOAR (Scouting's Outdoor Adventure on the River); Know the Coast, hosted by the University of New Hampshire; and the American Association for the Advancement of Science's Family Science Days. In the last four years, more than 50,000 members of the general public have been reached directly through these events.

### ***Maritime RobotX Challenge***

As part of our educational outreach, we have provided seed funding to support the team representing the United States in the 2014 Maritime RobotX Challenge in Singapore. The team leader is Michael Benjamin of the MIT Center for Ocean Engineering and the Computer Science and Artificial Intelligence Laboratory (CSAIL). The team includes students and personnel from both MIT and Olin College.

One of the RobotX competition's stated objectives is to advance **science, technology, engineering, and mathematics (STEM)** education as it relates to marine autonomy; a requirement of the competition is that 75% of the work be conducted by students. In addition to the potential to integrate the vehicle-building process into MIT coursework, students will learn core STEM concepts and, more important, tackle challenging technical problems.

### ***The Ocean Engineering Experience and Beyond***

The popular Ocean Engineering Experience (OEX) program was held for the final time in summer 2013. The education team now plans to integrate OEX content into minority summer programs in collaboration with the Minority Introduction to Engineering, Entrepreneurship, and Science program. We will also work to use the methods and practices developed through OEX to enrich our other collaborations with the MIT Office of Engineering Outreach Programs. Finally, we will integrate OEX content into teacher professional development classes at the Museum Institute for Teaching Science and the undergraduate programs we conduct with the MIT Mechanical Engineering Department.

Over the four years of the program, OEX enrolled 57 participants from 13 US mainland states as well as Guam, Greece, and India. Of the 15 students who have moved on to college studies, three (20%) are attending MIT and plan to study ocean engineering. The only undergraduate mentor who has graduated has gone on to graduate studies at MIT in ocean engineering, and three of the four mentors who are still undergraduates plan to major in ocean engineering. Overall, 95% of the students say they would recommend the program to their friends. We do not yet know what direction the 16 students in the 2013 program have taken, but several expressed an interest in majoring in engineering and science in college.

### **Blue Lobster Bowl**

This year's Blue Lobster Bowl, one of the 25 academic tournaments that the National Ocean Sciences Bowl (NOSB), included high school students from Acton-Boxborough, Brookline, Cambridge Rindge and Latin, Chelmsford, Fitchburg, Jeremiah E. Burke, Lexington, Lincoln-Sudbury, Marblehead, Newton North, Newton South, North Andover, and North Reading, as well as the Community Academy of Science and Health and Phillips Academy. In addition to the competition itself, students were invited to showcase their creativity and video production skills by entering the Living on the Ocean Planet video contest sponsored by the NOSB. The 2014 theme, ocean acidification, encouraged increased awareness of the impacts of excessive CO<sub>2</sub> on our changing ocean.

This year's winners, Lexington High School, went on to compete in the 17th Annual National Ocean Science Bowl, where they placed eighth overall and sixth in the science expert briefing competition. All Blue Lobster Bowl participants were also eligible to apply for four summer internship slots.

### **Communications**

Communicating research results and accurate, marine-related information is a key function of the Sea Grant outreach program. Different media are used to target audiences with varied levels of sophistication and interest.

Sea Grant publications include technical reports reprinted peer-reviewed journal articles, conference papers and presentations, and online videos and pamphlets providing marine science information for the general public. Forty-six publications were created and distributed during this reporting period, including "MIT Sea Grant College Program: Where Ocean Science Meets Cutting Edge Technology," a specially designed and printed informational brochure about MIT Sea Grant that highlights the program's research, outreach, and education services.

MIT Sea Grant's collection of short videos has continued to grow and has received acclaim in the wider MIT community and the National Sea Grant Network. One short film, *Celebrating America's Largest Commercial Fishing Port Community: Keeping maritime traditions alive*, highlighted the work of MIT Sea Grant and anthropologist Hall-Arber, who was featured on the front page of the National Sea Grant Program's website. The total number of views on MIT Sea Grant's YouTube site grew from 4,000 to more than 10,000.

### **Students Supported by MIT Sea Grant**

MIT Sea Grant promotes and administers a number of programs and awards that directly support aspiring scholars who are pursuing studies and careers in marine research.

The 2014 Dean A. Horn Award for Undergraduate Study in Marine Research was presented to Jacqueline Sly, a graduating senior in mechanical engineering, for her documentation of the construction and operation of the prototype aluminum-gallium power system for the Remus 600 unmanned undersea vehicle.



## Undergraduate Research Opportunities Program

MIT Sea Grant offers, and benefits from, Undergraduate Research Opportunities Program (UROP) appointments throughout the year. It is not unusual for students to have a series of appointments with us, either developing one of their projects at a more advanced level or taking the skills they have learned and applying them in a new area. In many cases, a UROP appointment with MIT Sea Grant is a significant step in the career of a young ocean scientist or engineer.

This year the following students had UROP appointments at MIT Sea Grant:

Raymond Jansen, junior (Aeronautics and Astronautics)

Amanda Parry, sophomore (Civil and Environmental Engineering): survival of the Chinese mitten crab in northeastern estuaries (fall 2013)

Lampros Tsontzos, sophomore (Mechanical Engineering): *Sea Perch* project (fall 2013)

Kira Schott, sophomore (Mechanical Engineering): hull design education project (summer 2013)

Stephen Rodan, sophomore (Mechanical Engineering): summer intern and program mentor, Ocean Engineering Experience program (summer 2013)

Brian Gilligan, Freshman and OEX alumnus): *Sea Perch* engineering education program (with Kathryn Shroyer; summer 2013)

Natasha Rodriguez, junior (Sloan School of Management): Sea Grant national directory of social scientists (summer 2013)

Karl Sorensen, sophomore (Biology): updating and improving the accessibility of the MITIS (Marine Invader Tracking and Information System) database (fall 2013)

## Staffing and Oversight

MIT Sea Grant is overseen by a joint advisory committee consisting of faculty members from MIT and other Massachusetts colleges and universities, leaders of Massachusetts marine-related industries, and representatives of state government and key nongovernmental organizations.

The program's management team consists of director (Chryssostomos Chryssostomidis), principal researcher (E. Eric Adams), and assistant director for research (Stefano Brizzolara). Professor Chryssostomidis is responsible for overall program management; Professor Adams' focus is on coastal processes; and Dr. Brizzolara directs work in computational fluid dynamics. The management team is jointly responsible for planning the program's strategic direction.

MIT Sea Grant's administrative staff consists of assistant director Timothy Downes (supported by two administrative employees), program coordinator Katharine de Zengotita, and information technology professional Ben Bray. Judith Pederson has led the program's advisory group for a number of years but will soon be retiring.

The advisory, education, and outreach program currently has five professional staff members, including Pederson, who provide expertise in climate change mitigation, coastal ecosystems, invasive species, educational programming, fisheries anthropology, and data and communications. The advisory group has one administrative support staff member. In addition, Sea Grant employed six research engineers, two postdoctoral associates, and three research scientists in the AUV Lab and in the Design Lab, working in support of externally funded projects.

To replace Dr. Pederson as advisory leader, we conducted a series of interviews in May 2014, and in June we hired Dr. Robert Vincent, an estuarine ecologist previously employed with the National Oceanic and Atmospheric Administration (NOAA) Fisheries Service in Gloucester, MA. Dr. Vincent began work in mid-June and is already proving to be of significant assistance in the management of MIT Sea Grant and the conduct of our research.

### **Special Awards and Funding**

Each year MIT Sea Grant awards the Doherty career development chair for ocean utilization, a two-year appointment at \$25,000 per year for a young professor working on a marine-related research topic. The 2014 winner is assistant professor Niels Holten-Andersen (Department of Materials Science and Engineering) for his project Metal-Coordinating Polymers: Using Marine Biological Tricks to Assemble New Functional Materials.

**Chryssostomos Chryssostomidis**

**Director**

**Henry L. and Grace Doherty Professor in Ocean Science and Engineering**