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 headings and are described below:

- Autonomous Underwater Vehicle Laboratory
- Design Laboratory
- Funded research projects
- Education and advisory services

Autonomous Underwater Vehicle Laboratory

MIT Sea Grant is historically credited with creating and developing 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 Lab may be considered largely responsible for founding a multi-million dollar industry.

In the past year, Bluefin Robotics, a 1991 spinoff from the Lab, received a $30 million contract from the Naval Surface Warfare Center to deliver up to 30 small, hovering AUV for the Office of Naval Research (ONR). This technology, developed in collaboration with MIT Sea Grant, allows for autonomous ship hull inspection without a priori knowledge or haul-out. The little vehicles will be used to sweep ship hulls for magnetic mines, or to detect contraband being smuggled on the undersides of vessels. With Bluefin's expansion into the Fore River Shipyard in 2010, the AUV Lab has had a substantial and beneficial local impact on jobs, wages, and corollary businesses such as vendors and raw material suppliers.

Figure 1: Small, hovering AUVs designed for inspecting ship hulls for explosives or contraband.

The Lab's own hybrid AUV/remotely operated vehicle, the *Reef Explorer* (*REX*), was deployed this year in support of environmental research. Underwater video surveys were conducted off Hull, MA, to map the prevalence of the invasive species *Didemnum vexillium* using sensor technologies developed by our colleague Emmanuel Boss of the University of Maine, Orono, and refined in our laboratory.

Technological developments in the AUV Lab include:

- Installing improved lighting under the vehicle for a downward-looking camera
- Adding a laser beam for measuring objects on the sea floor, plus new sensors and probes
- Construction of a NiMH battery pack for the *Didemnum Cruiser* AUV to allow deployment of the acoustic modem video transceiver
- Design of a novel catamaran hull surface presence for the next-generation *Reef Explorer* vehicle (*REX4*)
- Design of hydrodynamic control systems for 1/32 scale Navy destroyer hull for dynamics research

Certain of our funded projects are helping to expand the AUV capabilities of MIT Sea Grant:

- Harold Hemond of the Department of Mechanical Engineering is working on an optical sensor that uses fluorescence to measure chemicals in the water such as algal pigments, hydrocarbons, and other organic substances in real time.
- Jeffrey Lang, Michael Triantafyllou, and Franz Hover of Mechanical Engineering are developing flexible arrays of pressure sensors modeled after the lateral line of nerves that fish use to navigate. The arrays will be mounted on the outside of an AUV and, using the proper algorithms, will detect, locate, and classify objects in the flow environment around the hull.
- Milica Stojanovic of Northeastern University is working on an underwater acoustic communications system to integrate AUVs into a network of sensors, transmitters, vessels, and docking stations for ocean observation.

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 multi-scale 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, the Consortium successfully submitted a new five-year proposal to ONR this year.

The Consortium consists of members from a number of universities around the nation. The MIT group includes professors Michael Triantafyllou and Franz Hover of the Department of Mechanical Engineering, professors Steve Leeb and James Kirtley of the Department of Electrical Engineering and Computer Science, and professor George Karniadakis of Brown University, who holds an appointment as research scientist at MIT. The group is assisted by research scientist Julie Chalfant. Research engineer Mirjana Milosevic Marden, who previously worked on this project, is leaving MIT Sea Grant in July 2012.

Current work is organized into three major areas:

- Collaborative Design Environment—The MIT group will create a naval architecture design tool that allows for cross-disciplinary collaboration. The tool will allow participants to design, select, and combine hull types, payloads, power requirements, and other components of an all-electric ship to test stability, speed, seakeeping capabilities, power balance, and efficiency.

- Innovative System Technologies—MIT will write the algorithms for modeling and simulation of hydrodynamic flows, motor power output tests of different configurations, ship maneuverability and seakeeping under various conditions, and simulations to test intelligent sensor control of the electrical system—specifically the Z-Source DC Circuit Breakers.

- Design Tools and Methods—MIT will refine the Electric Ship Research and Development Consortium procedure for using stochastic modeling tools based on polynomial chaos, produce a three-dimensional viscous flow simulator, develop mathematical models of ship maneuverability, and develop and implement sensitivity analysis and uncertainty quantification for subcomponents and the entire system.
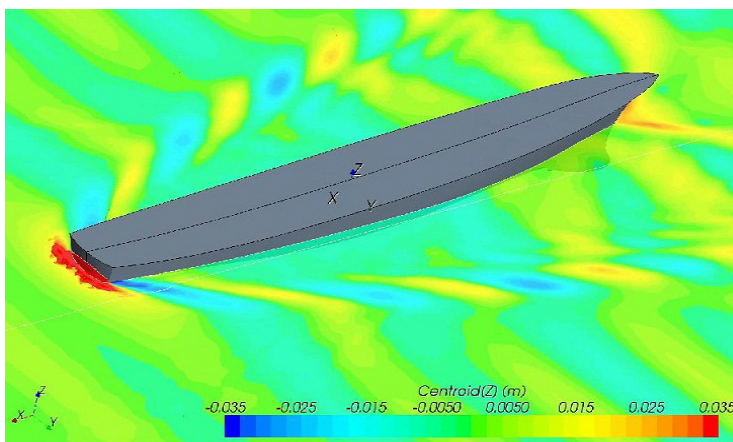

Figure 2: Simulated modeling of hydrodynamics of a hull design going astern at 10 to 24 knots.

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 selected four new core research projects for funding. We continued to support the six, two-year projects initiated in February of 2011 and also several six-year Marine Center projects, two of which are continuing and one of which ends this year. We have also provided partial support for two projects funded through the Northeast Regional Sea Grant Consortium.

New Projects

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

> Matthew Charette, Woods Hole Oceanographic Institution—Development of an Automated Seepage Meter for Quantifying Submarine Groundwater Discharge in the Coastal Zone

> Changsheng Chen, University of Massachusetts Dartmouth—Development of an Inundation Forecast System for Massachusetts Coastal Water

> Philip Gschwend, MIT—Assessing the Bioactivity of Estrogens, Including Halogenated Derivatives, in Chlorinated Sewage Effluents and Coastal Seawater

> Jennifer Bowen, University of Massachusetts Boston—Microbial Community Composition of Permeable Reactive Barriers: Who Is Really Doing the Work?

Continuing Projects

> Donald Anderson, Woods Hole Oceanographic Institution—Development of Real-time Instrumentation for the Robotic Detection of Paralytic Shellfish Poisoning Toxins in Massachusetts Coastal Waters

> Harold Hemond, MIT Department of Mechanical Engineering—Combating Nitrogen-driven Coastal Eutrophication: A Selective Ion Array Approach to Rapid In-situ Measurement of Nitrate and Ammonium

> Di Jin, Woods Hole Oceanographic Institution—Development of a Scientific Management Framework to Support the Ecosystem-Based Management of Coastal Resources

> Michael Triantafyllou, MIT Dept of Mechanical Engineering—Energy Efficient AUV using a Lateral Line Sensor

> Seth Tuler, Social and Environmental Research Institute, Inc.—Improving Understandings of Consequences, Vulnerabilities, and Adaptation Strategies to Climate Change Related Hazards

Continuing Six-Year Focused Research Projects

Jeffrey Lang, MIT EECS (begun 2006)—Touch-at-a-Distance, Pressure Microsensor Arrays for AUV Navigation

Milica Stojanovic, MIT Sea Grant (begun 2007)—Acoustic Communication Networks for Distributed Autonomous Underwater Platforms

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

Northeast Regional Social Science Research Projects

In addition, MIT Sea Grant is responsible for two Marine-related Social Sciences projects, selected by the Northeast Regional Sea Grant Consortium of which we are a member.

John Duff, University of Massachusetts in Boston—Governance Role of Local Authorities in Marine Spatial Planning: a Legal Assessment of Prospects and Problems

Robert Johnston, Clark University—Climate Change Adaptation and Ecosystem Service Resilience in Northeast Coastal Communities: Quantifying Economic Values and Tradeoffs for Regional Decision Support

Research to Startup

In September 2011, professor Douglas Hart founded Lantos Technologies, a $3.8-million startup with offices in Kendall Square. The Lantos 3D Intra-Aural Digital Scanner is a handheld imaging device that audiologists use to quickly and easily fit patients for customized hearing aids. This medical device resulted directly from a Sea Grant project that closed in 2010: *Versatile, High-Resolution, Low-Cost AUV 3D Sensor*. The project was originally intended to provide 3D surface profiling capabilities for underwater inspection, mapping, and AUV navigation.

Advisory, Education, and Outreach Program

MIT Sea Grant's research and development work carries with it the excitement of possibility and exploration, the hopefulness of "what if?" Equally satisfying is to see our investigators' efforts come to fruition in the real world.

MIT Sea Grant has an active advisory, education, and outreach program whose staff members have strong ties to the community and who transfer ocean science information and technology developments to our constituents. Advisory makes sure that Sea Grant addresses issues important to local, state, and regional government agencies; coastal municipalities; businesses; and citizen groups and organizations.

Boston Harbor Cleanup

A case in point is the decades-long cleanup of Boston Harbor, in which MIT Sea Grant was involved from the beginning as an "honest broker" of factual, science-based information and research throughout what proved to be a lengthy, politicized, and litigious process. Since 1985, Boston waterways have gone from being "a national

shame" and "the filthiest harbor in America" to 2012 when it was announced that "Some of the region's beaches… are safe for swimming nearly every day and rank among the cleanest urban beaches in the nation." The improved recreational opportunities were the result of leadership by Judith Pederson, advisory leader, and a committee that reviewed the scientific data suggesting removal of stormwater and combined sewer overflows was necessary. Through a non-government organization's advocacy and committed state and municipal agencies that funded the improvements, the beaches are used by hundreds of Boston residents throughout the summer.
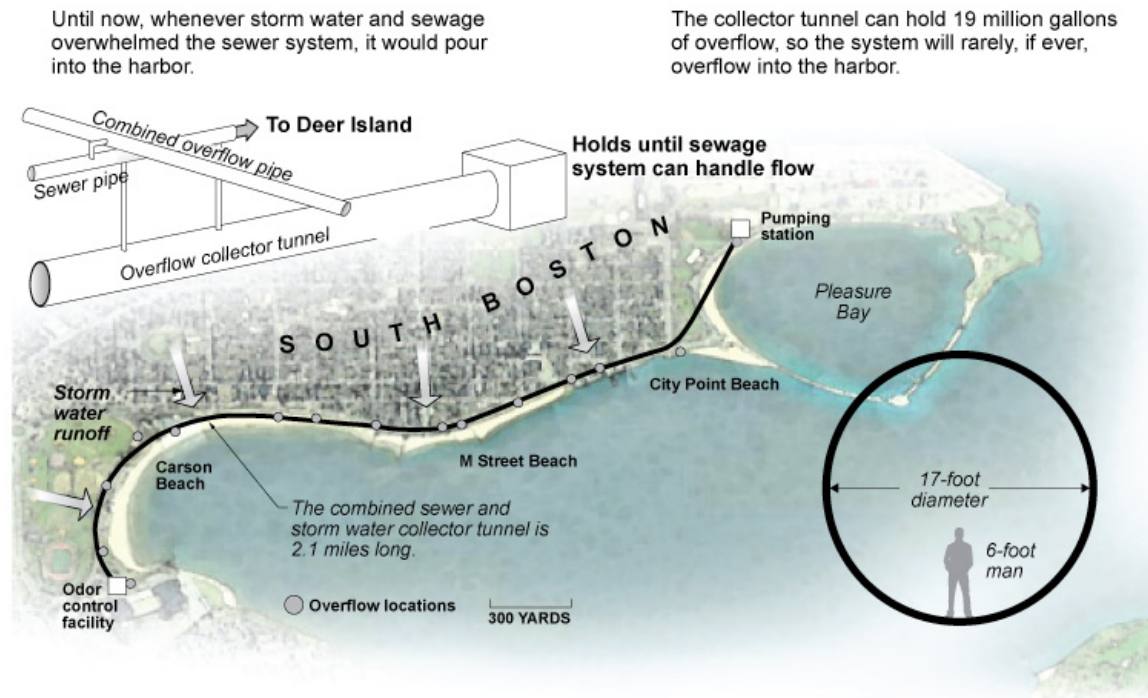
Until now, whenever storm water and sewage overwhelmed the sewer system, it would pour into the harbor.

The collector tunnel can hold 19 million gallons of overflow, so the system will rarely, if ever, overflow into the harbor.

Combined overflow pipe

To Deer Island

Sewer pipe

Holds until sewage system can handle flow

Overflow collector tunnel

Pumping station

S O U T H   B O S T O N

Pleasure Bay

Storm water runoff

City Point Beach

Carson Beach

M Street Beach

17-foot diameter

The combined sewer and storm water collector tunnel is 2.1 miles long.

6-foot man

Odor control facility

Overflow locations

300 YARDS

Figure 3: Boston's system pipes hold treated sewage and storm water runoff in a combined sewer overflow connector tunnel.

Monitoring the Harbor Ecosystem

Sea Grant continues its involvement in protecting the ecosystem of Boston Harbor and maintaining the vitality of coastal waters. Each summer, high school students participate in the Sea Grant Ocean Science internship program, collecting data from the beaches of the Boston Harbor islands in order to track changes in water quality and the distribution and prevalence of native and exotic marine species.

The students are trained in the proper methods of measuring, identifying, and collecting samples, and gain a general understanding of marine biology and ecology that that will help them pursue careers in ocean sciences. Interns, who are paid, learn to problem-solve in the field, recognize many species of marine wildlife, and contribute their findings to MIT Sea Grant's growing database of invasive species and water quality, which is used by environmental professionals worldwide. The program is open to rising high school sophomores, juniors, and seniors, and runs each year for six weeks starting mid-July.

Stormwater Pollution on the South Shore

During the summer and fall of 2011, MIT Sea Grant's coastal ecologist Juliet Simpson provided expertise to local communities by systematically sampling for bacteria and suspended sediment originating from stormwater runoff to Kingston Bay from the towns of Kingston, Duxbury, and Plymouth.

The towns will use the data to identify drains and areas that are "hot spots" for either bacteria or nitrogen and eliminate them. Applying the results of Simpson's work will enhance the quality of swimming beaches, reduce shellfish bed closures, and improve fishing and aquaculture in this area.

Marine Invasive Species

MIT Sea Grant has collaborated with other Sea Grants in the region to fund an integrated research effort on the invasive sea squirt *Didemnum vexillum*. This included modifying an optical sensor for detecting *Didemnum* and adapting it for use on the MIT Sea Grant *Reef Explorer II* hybrid autonomous underwater vehicle, as well as continuing to use photography and grab samples to evaluate the impact of *Didemnum* in hard substrate habitats to support fisheries management.

As part of his training in the National Marine Fisheries Service leadership development program, Doug Christel served the Sea Grant advisory program for a ten-week rotation from May to July, 2011. While a visiting researcher, Christel worked with Judith Pederson on the *Didemnum* effort focusing on George's Bank. Christel prepared a detailed and industry-specific survey and map of the area and worked with scallopers, lobstermen, and fishermen to collect *Didemnum* sightings during their fishing runs.

Figure 4: High school intern collects samples for Boston Harbor island species survey.

Education

A key component of outreach is a comprehensive and varied educational program, mostly directed at K–12 students. The most 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 trainings have evolved into a suite of programs and activities to exploit the outstanding success of this ongoing effort.

Sea Perch Institute Challenge 2012

The Sea Perch Institute is a multi-year program that allows veteran Sea Perch schools in our area to build on the basic Sea Perch course with a more advanced and multidisciplinary curriculum. Schools are selected to participate in the annual Sea Perch Challenge event based on demonstrated support from their school's administration and the involvement of multiple teachers and classrooms

On May 3, 2012, 80 high school and middle school students from four local schools made their way to MIT's Zesiger Athletic Center pool to test their engineering prowess. Their challenge was to respond to a simulated underwater oil well pipe blow out with *Sea Perches* the students had modified.

A six-foot offshore drilling rig platform was modeled in PVC pipe, wood and other materials. Oil leaking from the "hole" at the bottom of the pool was simulated by black ping-pong balls. The leaking pipeline (played by a length of garden hose) gushed out oil in the form of hot water, with bubbles for visual effect. The jet of hot water dispersed and spread, creating a measurable plume. Using the underwater cameras and temperature sensors on their *Sea Perches*, students deployed nets and scoops to capture the ping-pong oil. Then some students monitored the underwater disaster site with cameras, while others cut away debris and the damaged section of the riser pipe. Finally, students set out a massive modified *Sea Perch* carrying a mechanism capable of capping the pipe.

The day ended before the leak was capped but the students enjoyed the overall success of their mission. The emphasis for this year's challenge was on teamwork, dynamic adaptability, and engineering skills that students would need for a career in marine science and ocean engineering.

Blue Lobster Bowl

This event is one of the 25 academic tournaments that comprise the National Ocean Sciences Bowl. Competition questions come in two forms: the rapid-fire buzzer-rounds of multiple-choice and short-answer questions, and more substantive in-depth team challenges that require cooperation and critical thinking skills.

On February 4, 2012, 120 students from 12 Massachusetts high schools arrived on campus for the daylong Blue Lobster Bowl. Topics ranged from marine biology, chemistry, geology, physics, navigation and geography, to ocean history, literature, and public policy. The winning team from Lexington High School went on take fourth place in the National Ocean Sciences Bowl Finals in April in Baltimore. Their prize was an all-expenses-paid, four-day trip to the coast of North Carolina for SCUBA diving and exploring the Shackleford Banks barrier island system aboard the research vessel *Susan Hudson*. All Blue Lobster Bowl participants are also eligible to apply for four summer internship slots with MIT Sea Grant College Program, as listed in the 'Students Supported' section

The Ocean Engineering Experience 2011

Ocean Engineering Experience is a hands-on residential camp at MIT that introduces high school students to the fields of marine science and ocean engineering as applied to marine vehicles and marine structures. Students from around the world may apply and are selected to participate on the basis of their enthusiasm for engineering, academic achievements, and personal goals. Participants tackle a real-world problem that takes teamwork, science, and engineering to solve.

The 2011 Ocean Engineering Experience project focused on alternative energy. During their week-long July stay on campus, 17 students attended lectures from MIT professors and graduate students, and learned how to design and build mechanical structures and electrical systems. In the lab, they constructed a radio-controlled boat, solar panels, and a wind turbine that they deployed on the Charles River. At the end of the week, they publicly demonstrated their technology at the MIT Sailing Pavilion and presented the design process at the MIT Museum.

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 2012 Dean A. Horn Award for Undergraduate Study in Marine Research was awarded to Katy Olesnavage, a senior in Mechanical Engineering, for her thesis "The Design and Testing of a Procedure to Locate Fresh Submarine Groundwater Discharge in Cyprus."

The Dean John A. Knauss Marine Policy Fellowship places graduate students with host organizations in legislative or executive branches of government. Fern Gibbon, a graduate of the MIT/Woods Hole Oceanographic Institution Joint Program, was selected during this reporting year to serve on the Republican staff of the US Senate Commerce Committee.

Undergraduate Research Opportunities Program

The following students conducted Undergraduate Research Opportunities Program projects, supervised by Sea Grant staff in the lab or in the field:

> Xianzhen Zhu, junior (Electrical Engineering & Computer Science)—Sea Perch Sensor Suite (fall 2011)
>
> Kathryn Olesnavage, senior (Electrical Engineering & Computer Science)—Acoustic Video Transmission System for Modular Underwater Vehicle (fall 2011)
>
> Jordan Marks, sophomore (Materials Science and Engineering)—Socioeconomic Impact of Federal and Interstate Management of Herring in the Northeast U.S. (spring 2012)
>
> Siyi Zhang, freshman (Wellesley/MIT Program)—Risk Assessment and Monitoring of Chinese Mitten Crab Habitat (spring 2012)

Internships

> Husayn Karimi, high school sophomore at Buckingham Browne and Nichols in Cambridge, MA. Project: Collecting Water Temperature Data (summer 2012)

> Blue Lobster Bowl participants Isabelle Holt, senior, Watertown (home schooled); Jeffrey Ho, senior, Sudbury High School; Pavlina Karafillis, senior, The Winsor School; and Carolann Schack, graduate, Glastonbury CT High School. Project: Intertidal Ecology of the Boston Harbor Islands (summer 2012)

Staffing and Oversight

MIT Sea Grant is overseen by a joint advisory committee consisting of MIT faculty members and leaders in Massachusetts marine-related industry, colleges and universities, state government, and key non-governmental organizations.

The program's management team consists of a director (Chryssostomos Chryssostomidis) and an associate director for research utilization (E. Eric Adams). Professor Chryssostomidis is responsible for overall program management; Adams's research portfolio is in coastal processes. The management team is jointly responsible for planning the program's research direction.

Judith Pederson leads the program's advisory group. MIT Sea Grant's administrative staff consists of assistant director Timothy Downes and program coordinator Katharine de Zengotita, supported by two administrative employees and an information technology professional Ben Bray. The advisory, education, and outreach program currently has five professional staff members, including Pederson, providing expertise in climate change mitigation, coastal ecosystems, invasive species, educational programming, fisheries anthropology, and data and communications. Advisory has one administrative support staff member. In addition, Sea Grant employed six research engineers and two research scientists in the AUV Laboratory and in the Design Lab, working in support of externally funded projects.

Changes this year include the departure of Nancy Adams as communications specialist and Rachel VanCott as educator and ocean literacy communicator. We are currently in the process of hiring replacements for these two positions.

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 2012 winner is assistant professor Timothy Lu of the Department of Electrical Engineering and Computer Science for his project, Engineering Hybrid Biological-Electrical Systems for Ocean Engineering.

Chryssostomos Chryssostomidis
Director
Henry L. and Grace Doherty Professor in Ocean Science and Engineering