

## **Sea Grant College Program**

The National Sea Grant Program supports research, education, and outreach activities that address critical problems in the human use of the sea. At the MIT Sea Grant College Program, the focus is 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.

The program can be loosely organized into three areas of endeavor:

- The Autonomous Underwater Vehicle (AUV) Laboratory
- Funded research projects
- Education and advisory services

This year has seen an unprecedented increase in the geographic scope of our endeavors. Our program's impact has expanded beyond the local to the regional, national, and, finally, to the international level.

### **Regional Projects**

The National Sea Grant Office has increasingly recognized that marine science and policy should be aimed at natural ecosystems rather than organizing our efforts around artificial political divisions. MIT Sea Grant has taken the lead in providing a framework for planning and coordinating research in the Northeast Marine Region, extending from the Gulf of Maine to the New York Bight. We acquired funding and organized the Regional Ocean Science Council (ROSC) to oversee development of a Gulf of Maine Regional Ocean Science Plan. The plan will set research priorities so that state, regional, and federal policymakers can make decisions based on sound and sufficient scientific findings.

Members of our advisory staff have long been active in tracking invasive species on a regional scale and have continued that work this year. We also provided experimental engineering support for the aquaculture industry in our region by designing and testing a system that makes open-ocean aquaculture cages mobile under their own power.

### **National Projects**

Nationally, we have continued to expand the activities of the AUV Laboratory and its corollary educational outreach effort, the Sea Perch program. The lab's developing technology and increasingly diverse fleet of vehicles have resulted in collaborations in the Hawaiian Islands of the Pacific and in the Northeast region. The Sea Perch program continues to build in popularity; we carried out teacher training sessions in Massachusetts and a number of other states (as listed in the section on education).

## International Projects

This year program director Chryssostomos Chryssostomidis took a six-month sabbatical in Europe, where he was able to follow up on a number of connections with overseas colleagues who have expressed interest in the lab's activities and capabilities. Having met with his contacts in France, England, Spain, Italy, Greece, and Cyprus, he is in the process of developing several concrete plans for research and educational collaboration abroad for the lab.

On Cyprus, implementation will begin this September with Sea Perch training for 100 students, teachers, and mentors, initiating the development of a trained cadre of underwater vehicle students, technicians, and educators. At the same time, Chryssostomos Chryssostomidis is working with the Cyprus government to develop a program to explore and monitor the waters of the eastern Mediterranean using AUVs of our design. We are proposing that our lab staff will train an AUV research unit to build, maintain, deploy, and operate AUVs from ships of opportunity and research vessels. This unit, supported by the Cyprus government, would then support research into climate change, the marine environment, energy exploration, and underwater archaeology in the seas around the island.

In France, we are preparing a plan to integrate the Sea Perch program into the curriculum of the country's colleges and technical schools. Professor Chryssostomidis and his French colleagues will be collaborating with the national university system ("*écoles normales*"), while the funding for at least the first phase of the work would largely come from the French oil company Total.

Our Acoustic Communications group has also actively developed international collaborations, including a mutually beneficial agreement with a university in Spain that has resulted in valuable opportunities for its graduate students and excellent research support for us. Other international collaborations for the lab are also under consideration and are expected to develop quickly over the next few years.

## Autonomous Underwater Vehicle Laboratory

The MIT Sea Grant College Program is historically credited with the creation and development of AUVs—small, inexpensive, artificially intelligent, robotic submarines for undersea exploration.

The lab's newest vehicles are Odyssey IV, a deep-water AUV with hovering capability, rated to 6,000 m and designed for high-speed dives and ascents, and Reef Explorer, designed to maneuver in delicate underwater ecosystems without harm.

### Odyssey IV

The Chevron Corporation has provided funding for the lab to develop both vehicles and underwater wireless communications networks in support of its interest in ultra-deep-water exploration and production. The company envisions a subsea system without dependence on expensive oil rig platforms or the surface vessels required to support remotely operated vehicles (ROVs). In the subsea system of the future, AUVs would

function first as trucks to deliver equipment; then as independent, mobile monitoring stations; and finally as intelligent workstations that can move into place and do upkeep or repair on pipelines and other equipment. Odyssey IV is being developed with these functions in mind.

We tank-tested Odyssey IV at MIT and then at the University of New Hampshire's Center for Coastal and Ocean Mapping/Joint Hydrographic Center, and we made considerable improvements to the vehicle this year. Sea trials were successfully carried out in early June on short trips out of Woods Hole on the Cape.

In July, Odyssey IV will be deployed on its first full mission, a two-week expedition to the fishing grounds of George's Bank in the Gulf of Maine to track the extent and spread of an infestation of *Didemnum sp.*, an invasive species of tunicate. Sailing on a National Oceanic and Atmospheric Administration (NOAA) research vessel, *The Bigelow*, we will determine the potential damage of *Didemnum* to the spawning grounds of many commercially important species through photographs and DIDSON sonar imaging.

The impetus for the vehicle's mission originates with our regional research partnership (ROSC), described more fully below. Our intent is to provide the broader northeastern oceanographic community with models to predict the spread and growth potential of *Didemnum* and to evaluate its ecological impact



*Odyssey IV being loaded.*

The lab currently has the following wish list for future improvements to this vehicle:

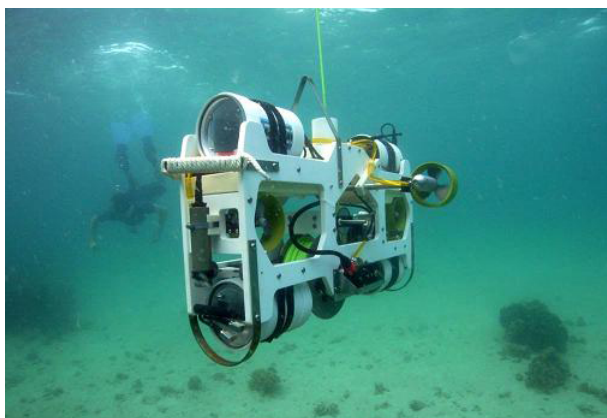
- Camera upgrade (ethernet interface/higher resolution)
- Lighting upgrade (faster charging strobe or continuous lighting solution)
- Iridium modem or beacon as a location failsafe
- Aluminum tail fin for radar visibility (painted day-glow orange)
- Actuated tail fins
- Faster central processing unit (CPU)

### **Reef Explorer**

Reef Explorer (or REX), a lightweight, hybrid AUV/ROV, is particularly well suited to shallow water missions. It has a substantial payload volume in spite of its light construction, and it is exceptionally easy to deploy and maneuver.

Last year, our lab and education staff went to Hawaii to conduct Sea Perch training for high school teachers. There we were introduced to scientists from the Hawaii Institute of Marine Biology, and a plan was developed to return to the islands in May and August

of 2007 with Reef Explorer to explore coral reefs far offshore. These reefs are of particular interest to our colleagues but very difficult for researchers to access. After the shakeout cruise in May, the vehicle performed extremely well and captured numerous pictures and data of interest to the Hawaii researchers in August 2007. We expect this collaboration to be ongoing, with missions planned for later this year.



*Reef Explorer in action.*

### **Underwater Acoustic Communication**

Networking AUVs with other subsea devices calls for a dramatic improvement in underwater signal processing capability, both to enable navigation and to collect and transmit data. Our underwater communications group is led by Dr. Milica Stojanovic, who is a key participant in major research projects funded by the National Science Foundation, NOAA, the Office of Naval Research, and industry. She is a frequent participant in international conferences and her publications for this reporting year are:

- [“Design and Capacity Analysis of Cellular Type Underwater Acoustic Networks”](#) (*IEEE Journal of Oceanic Engineering*, in press)
- [“Multicarrier Underwater Acoustic Communications over Fast-Varying Channels”](#) (with B. Li, S. Zhou, L. Freitag, and P. Willet; *IEEE Journal of Oceanic Engineering*, in press)
- [“Efficient Processing of Acoustic Signals for High Rate Information Transmission over Sparse Underwater Channels”](#) (*Physical Communication*, June 2008)
- [“Distributed Space-Time Cooperative Schemes for Underwater Acoustic Communications”](#) (with M. Vayapeyam, S. Vudentam, U. Mitra, and J. Preisig; *IEEE Journal of Oceanic Engineering*, in press)
- [“Underwater Acoustic Communications and Networking: Recent Advances and Future Challenges”](#) (with M. Chitre and S. Shahabodeen; *Marine Technology Society Journal*, Spring 2008)
- [“On the Relationship Between Capacity and Distance in an Underwater Acoustic Communication Channel”](#) (*ACM SIGMOBILE Mobile Computing and Communications Review*, October 2007)
- [“Distance Aware Collision Avoidance Protocol for Ad-Hoc Underwater Acoustic Sensor Networks”](#) (with B. Peleato; *IEEE Communication Letters*, December 2007)

Recently Dr. Stojanovic’s group has focused on demonstrating the feasibility of wireless underwater video transmission. The group proposes to combine the latest video compression technology (e.g., MPEG4) with recent advances in high-speed underwater acoustic signal transmission. Real-time, underwater video transmission would constitute an important breakthrough in the field of oceanography.

Over the past five years, the acoustics group has been aided by the work of a number of visiting students from the Polytechnic University of Barcelona, who spend between 9 and 12 months working on a subject within the area of underwater wireless communications. Their work at MIT, under Dr. Stojanovic's supervision, both supplements our research and contributes toward the completion of their graduate theses (equivalent to our SM degree). The students are self-funded and selected through a competitive local program in which the winners choose from a list of participating foreign schools. So far, six students have visited MIT Sea Grant, and two are currently on site.

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

As MIT Sea Grant director, Chryssostomos Chryssostomidis has become increasingly active in the nationwide Electric Ship Research and Development Consortium (ESRDC). In this effort, he is supported by a team of MIT researchers: James Kirtley, Michael Triantafyllou, Franz Hover, and Steve Leeb of MIT and George Karniadakis of MIT and Brown University. The team has access not only to MIT Sea Grant facilities but also the Center for Ocean Engineering's Propeller Tunnel and Design Laboratory, the Marine Hydrodynamics Laboratory, the Laboratory for Electromagnetic and Electronic Systems (LEES), and the Center for Advanced Scientific Computing and Visualization at Brown University. We have also purchased a Tyan Personal Supercomputer, housed at Sea Grant, to support the intensive computing and modeling needs of this project.



*Artist's conception of the electric ship.*

The basic mission of ESRDC is to design an all-electric vessel for the US Navy. The group is managed by the federal Office of Naval Research with participation from leading electric power research institutions and senior naval officers. In addition to the problem of electric ship design, the consortium addresses the national shortage of electric power engineers by providing educational opportunities to students, such as Julie Chalfant, currently working at the Sea Grant lab in support of the MIT ESRDC research team.

The broad goals of ESRDC are as follows:

- Design all-electric warships for all systems: propulsion, pulsed power weapons, sensors, and all other functions
- Substantially reduce vessel volume and weight through the all-electric design
- Establish naval facilities for the vessels and assemble trained staff to evaluate and monitor emerging technologies and costs



- Work with university partners to assess longer term options and train students in electric ship technology

Currently, ESRDC's research and development program has five major thrusts:

- Creating computational tools for early-stage ship design
- Designing the electric power and propulsion system
- Developing a total ship system solution to thermal management
- Designing a load management component to track and adjust the condition and electricity needs of all systems
- Implementing the Next Generation Integrated Power System (NGIPS) requirement

The MIT team is responsible for the stochastic modeling of the electromechanical components of this new kind of fighting ship. Our objective is to provide the vessel with a supervisory "brain" that can quantify the sensitivity of the system and adjust its performance according to operating conditions, varying material properties, and diverse mission scenarios.

MIT Sea Grant hosted an ESRDC workshop on campus in the Stratton Center in May 2007, and our group attended ESRDC team meetings and industry workshops in Austin, Texas, in May 2008. Other universities involved are Florida State University, Mississippi State University, the US Naval Academy, Purdue University, the University of South Carolina, and the University of Texas at Austin.

### **Funded Research**

MIT Sea Grant conducts a yearly funding competition as mandated by NOAA through its National Sea Grant Office. Grants are available to researchers throughout Massachusetts. Proposals selected support the goals outlined in our strategic plan, and we are required to match every two dollars from our federal grant money with one from nonfederal sources. This year we are supporting the following major research projects with grants that average \$75,000 to \$80,000 per year for two years, one of which is a regional project to study plant pathogens in wetlands. We are also currently supporting a larger, six-year focused research project. This class of project is intended to address an issue of national importance, and our current focused research project is in the area of acoustic communications.

### **New Projects, Begun February 2008**

- Richard Limeburner, Woods Hole Oceanographic Institution  
*Data Assimilation and Optimal Observing System Design Experiments in Massachusetts Waters: Moored and Drifter Measurements*
- Changsheng Chen, University of Massachusetts-Dartmouth  
*Data Assimilation and Optimal Observing System Design Experiments in Massachusetts Waters: Modeling*

- George Karniadakis, MIT/Brown University  
*Data Assimilation and Optimal Observing System Design Experiments in Massachusetts Waters: Adaptive Sampling*
- Jonathan King, MIT Department of Biology  
*Enzymes from Marine Viruses for the Biotechnology Industry*
- Philip M. Gschwend, MIT Department of Civil and Environmental Engineering  
*Assessing the Narcosis Hazard of Marine Sediments: Application of GCxGC Analysis*
- Elmer Caruso, University of Massachusetts-Amherst  
*Role of Plant Pathogens in Sudden Wetland Dieback in Connecticut and Massachusetts (Regional)*
- Judy Pederson, MIT Sea Grant College Program  
*Assessing Risk of Marine Introductions by Vessels in Small New England Ports: A Community Development Program*
- Michael Triantafyllou, MIT Department of Mechanical Engineering  
*Biomimetic Optimal Force Generation for Underwater Manipulators*
- Steve Leeb, MIT Department of Electrical Engineering and Computer Science  
*Low-Cost Diagnostic System for Shipboard Environments*
- Franz Hover, MIT Department of Mechanical Engineering  
*Autonomous Vehicle Exploration and Sampling of Deep-Water Corals*

### **Continuing Projects, Begun February 2007**

- Wendell Brown, University of Massachusetts-Dartmouth  
*An Investigation of Transient Tidal Eddies in the Western Gulf of Maine*
- Matthew Charette, Woods Hole Oceanographic Institution  
*Development of a Radon/Nitrate Mapping System for a Large Scale Assessment of Submarine Groundwater Discharge and Non-Point Source Pollution to Coastal Waters*
- Douglas Hart, MIT Department of Mechanical Engineering  
*Versatile, High-Resolution, Low-Cost AUV 3D Sensor*
- John J. Leonard, MIT Department of Mechanical Engineering  
*Adaptive Mapping of Complex 3-D Marine Environments*
- Milica Stojanovic, MIT Sea Grant College Program  
*Acoustic Communication Networks for Distributed Autonomous Underwater Platforms (Six-Year Focused Research Project)*
- Tim Verslycke, Woods Hole Oceanographic Institution  
*Development and Validation of in Vitro Bioassays for Pesticides in Coastal Waters*

### **Advisory Services, Outreach, and Education**

Part of Sea Grant's mandate is to provide practical assistance and useful information to local communities, industries, educational institutions, coastal managers, fishermen, and the general public. Our advisory and education groups supply these services and

transmit our research results to end users for practical application. Advisory activities at the lab have also expanded in geographic scope, to the regional, national, and international levels.

In mid-May 2008, the advisory group hosted the Northeast Sea Grant College Programs biennial meeting in Gloucester, MA, with a theme of regional cooperation and collaboration, the priorities set by the National Office of Sea Grant and the federal government.

### Center for Coastal Resources

The function of this advisory program is to provide information, assessments, and recommendations to government and industry decision makers so that policies and practices that affect our coastal waters will be based on good science. The leader of the Center for Coastal Resources (CCR), Dr. Judy Pederson, took the initiative to tap available National Sea Grant funding to form the Northeast Regional Ocean Science Council, consisting of the Northeast Sea Grant Program directors. The council has met several times this year to work on identifying priorities and issues for the Gulf of Maine Regional Ocean Science Plan and to create mechanisms to allow the group to function as an entity capable of receiving grants.

CCR is responsible for guiding the development of the science plan and managing the funding effort for ROSC. The science plan is envisioned as a living document that changes and adapts to new information and, as appropriate, new initiatives. Using a “bottoms-up” approach, CCR will identify management and societal priorities for the Gulf of Maine, conduct workshops to develop scientific needs to address these concerns, and prepare the science plan, including an outreach and education plan that transfers technology and information to stakeholders and integrates students and postdoctoral fellows in research and scientific information acquisition efforts.

One of the projects initiated within the context of the regional plan is collaboration with NOAA in identifying the spatial extent of the highly aggressive sea squirt, *Didemnum sp.*, found in large areas of Georges Bank. This project will use MIT Sea Grant’s AUV, Odyssey IV, fitted with a variety of probes, sensors, and video equipment to measure environmental conditions and document the presence or absence of *Didemnum*.

In New England, *Didemnum* is found in ports and harbors, on near-shore ledges and hard surfaces and offshore on gravel beds in Georges Bank. Although its presence was documented in Maine during the 1980s, it was not until 2000 that its widespread dispersion to new habitats was reported. *Didemnum* grows over many other species, including mussels, scallops, barnacles, and other encrusting organisms, with known impacts to oyster aquaculture in



A clump of the invasive sea squirt, *Didemnum*.

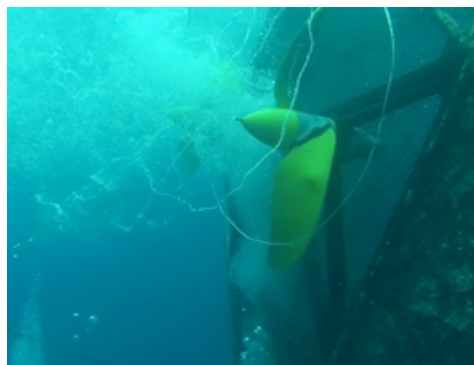


Massachusetts and changes in local flora and fauna in some areas. This project is focused on documenting the ecological and economic impacts of *Didemnum* in Georges Bank, where it was first reported in November 2003.

### Center for Fisheries Engineering

The Center for Fisheries Engineering has a long history of providing innovative engineering solutions to problems with traditional gear used in local fisheries, as well as in the newer business of commercial offshore aquaculture.

This year, with funding from NOAA's Marine Aquaculture Program, fisheries engineer Cliff Goudey designed and tested an offshore aquaculture cage that is self-propelled and remotely controlled. Final tests were done at Snapperfarm Inc. in Culebra, Puerto Rico. The farm has been raising cobia offshore in spherical, submerged cages developed by Ocean Farm Technologies Inc. of Searsport, Maine. These cages must be periodically dragged by boats to new locations to avoid buildup of disease-causing waste in and around the cages. Goudey's design involved eight-foot-diameter, electrically powered propellers with 6.2-horsepower underwater motors. These are mounted on a frame that can be snapped onto each aquapod by divers, turning the entire spherical cage into a twin-screw vessel capable of propelling itself at between 0.5 and 0.6 knots. The next phase is to assess the system's economic viability, both for routine maintenance in offshore fish farms and in a business strategy involving mobile cages that travel to market using predictable ocean currents or tidal gyres as well as propulsion. This future work will involve the collaboration of ocean modelers and aquaculture businesspeople.



*Aquaculture cage propellers in action.*

### Center for Ocean Technology Education

Educating students and the general public about the sea and its resources is also a mandate of the advisory group. Our education programs, under the leadership of Brandy Moran Wilbur, have become more successful and expanded in scope in recent years. To manage the expansion, especially of the Sea Perch program, we have hired new personnel and given the education group "center" status in the lab.

This year, the Center for Ocean Technology Education (COTE) continued to manage the Finfish Hatchery and Education Center (<http://web.mit.edu/seagrant/edu/hatchery/index.html>) at the Maritime Heritage Center in Gloucester. This facility conducts research on the egg, larvae, and juvenile stages of marine finfish to determine whether they are viable candidates for aquaculture. The hatchery has a display on aquaculture and is open to the public for tours and field trips. Programs managed from the hatchery are:

- Aquaculture in the Classroom, which outfits several Commonwealth schools with recirculating aquaculture systems for student participation and study
- The Classroom Eelgrass Cultivation Program for Massachusetts, where students learn to cultivate eelgrass as part of a polyculture recirculating aquaculture system

### Sea Perch

Striking progress was made this year in our most groundbreaking educational initiative, the Sea Perch program, which trains teachers and students in the construction and deployment of a small ROV called a Sea Perch.

Teachers from dozens of schools around the country have participated in Sea Perch training. The table below shows the Sea Perch workshops hosted by MIT Sea Grant from July 2007 to June 2008.



*Sea Perch.*

### Sea Perch Workshops Hosted by MIT Sea Grant College Program, July 2007 to June 2008

Location	Date	Partners	Sponsors
MIT	Sept. 2007	MIT Sea Grant, MIT Center for Ocean Engineering	MIT Sea Grant, ONR
George Mason University	Oct. 2007	SNAME, ONR, MIT Sea Grant, George Mason University	MIT Sea Grant, ONR
Montgomery College	Oct. 2007	SNAME, ONR, MIT Sea Grant, Montgomery College	MIT Sea Grant, ONR
Harbor Branch Oceanographic Institution, Ft. Pierce, FL	May 2008	Harbor Branch Oceanographic Institution, Link Foundation, MIT Sea Grant	Harbor Branch Oceanographic Institution, MIT Sea Grant
University of North Carolina at Wilmington	June 2008	COSEE-SE, MIT Sea Grant, University of North Carolina at Wilmington	COSEE-SE, MIT Sea Grant

Note. SNAME = Society of Naval Architects and Marine Engineers; ONR = Office of Naval Research; COSEE-SE = Center for Ocean Sciences Education Excellence-Southeast.

### ***Summer Internships***

In the summer of 2007, the AUV Lab hosted two high school students who developed an underwater sampling device that can be deployed via the Sea Perch. In addition to building and testing this apparatus, they wrote a step-by-step protocol on the construction that will be a useful addition to our Sea Perch teacher workshop materials.

This summer (2008) we are hosting an intern at the MIT Sea Grant Marine Finfish Hatchery and Education Center in Gloucester. This student has just completed high school, where he participated in the Sea Perch program each of the past two years. He is acting as an assistant at the two-week Sea Perch “summer camp” for middle school students that we are offering in partnership with the Gloucester Maritime Heritage Center and the MIT Edgerton Center. The student also does maintenance and husbandry at the Marine Finfish Hatchery.

### ***Sea Perch Ambassadors***

The idea of this initiative is for former MIT students who have worked with Sea Perch to return to their high schools and spread the word on the program. This year we recruited our first ambassador, Heather Brundage. She will return to Hammond High School in Maryland and give a seminar to the senior class describing her career to date and assisting students interested in engineering with their college and career choices. Heather will also work with the science teachers to pique their interest in the school becoming a Sea Perch school.

### ***Partnerships***

We worked closely with the Link Foundation to host a workshop at the Harbor Branch Oceanographic Institution in Florida for 15 teachers in May 2008. Part of our time at Harbor Branch was spent taking staff members through the steps of running their own workshops, facilitating their own program in Florida, and discussing funding sources and strategies to bring Sea Perch to the teachers of Florida. We also continue to work closely with the Society of Naval Architects and Marine Engineers (SNAME) on developing a national model for Sea Perch. This model will include recruiting a school district, training teachers within that district, assisting in setting up district Sea Perch competitions, and locating local mentors, sponsors, universities, and nonprofit organizations that will support the classrooms constructing the vehicles. Sea Perch training staff conducted two training sessions for their pilot groups in October 2007.

### ***Presentations***

The National Science Teachers Association annual conference was held in Boston, MA, in March 2008. We had a booth at the trade show in collaboration with SNAME presenting the national model of the Sea Perch program. We had close to 1,000 visitors over the three-day trade show and conducted a session for 12 teachers on Sea Perch and how to integrate the program into their classrooms.

The COTE staff will have major responsibility, along with support from AUV engineering personnel, for conducting Sea Perch training in Cyprus this fall and for supporting future developments related to the Total proposal in France.

## **Faculty, Staff, and Oversight Committees**

The MIT Sea Grant College Program's management team consists of a director (Professor Chryssostomos Chryssostomidis), an associate director (Dr. Milica Stojanovic), and an associate director for research utilization (Dr. E. Eric Adams). Dr. Adams' research portfolio is in coastal processes and Dr. Stojanovic's is in underwater communications. Professor Chryssostomidis is responsible for overall program management. The three are jointly responsible for planning the future research direction of the program.

MIT Sea Grant is under the oversight of a presidential committee consisting of faculty members from the Sloan School of Management and departments from the School of Science and the School of Engineering. One of the principal tasks of the committee is to advise the MIT Sea Grant management team on research directions and opportunities. Four members can rotate out of the committee each year. The MIT Sea Grant Committee is supported and complemented by the State-Industry Committee. This external committee includes leaders of local industry, faculty members from neighboring universities, and representatives of state government and key nongovernmental organizations. The breadth, flexibility, and dedication of these two committees are key ingredients in the success of the MIT Sea Grant College Program.

Sea Grant funds research in various MIT departments. In addition, it is home base for undergraduates doing in-house research, visiting students, and graduate students. We also support young MIT faculty by awarding the Doherty Career Development Chair for Ocean Utilization. This year there are two recipients: Franz Hover, assistant professor in the Department of Mechanical Engineering, for his project Autonomous Underwater Intervention in an Unstructured Environment and Eric Alm, assistant professor in the departments of Biological Engineering and Civil and Environmental Engineering, for Modeling and Harnessing Genetic Diversity in Ocean Bacteria.

### **Chryssostomos Chryssostomidis**

#### **Director**

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

*More information about the Sea Grant College Program can be found at <http://web.mit.edu/seagrant/>.*