INSTITUTIONAL INTERVIEWS - 2009

December 2009

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Virginia Institute of Marine Science (VIMS)

Featured Institution Interview

*In a recent analysis of Essential Science Indicators*SM data from Thomson Reuters*, the Virginia Institute of Marine Science (VIMS) entered the top 1% among institutions publishing in the field of Environment & Ecology with the highest total citations, with 124 papers cited a total of 1,706 times between January 1, 1999 and June 30, 2009. Their current record in this field includes 137 papers cited a total of 1,807 times up to August 31, 2009. VIMS is also in the top 1% in the field of Plant & Animal Science, with 315 papers cited 2,936 times for the current period.*

This month,* ScienceWatch.com *takes a closer look at VIMS, its history and research projects, and talks with some of the scientists who have contributed to its citation achievements.

A Rich History in an Ideal Setting

VIMS was founded in 1940 as the Virginia Fisheries Laboratory, part of the College of William and Mary. The VIMS main campus is in Gloucester Point, Virginia, on a 40-acre plot at the mouth of the York River, which opens to Chesapeake Bay and the Atlantic Ocean. VIMS also has two satellite campuses: the Eastern Shore Laboratory in Wachapreague, Virginia, and the Kauffman Aquaculture Center on the Rappahannock River. The main campus's site was a strategic point during both the Revolutionary and Civil Wars, and as such, any construction on campus is preceded by archaeological surveys.

The School of Marine Science at VIMS is the graduate school in marine science for the College of William and Mary, and confers both Master's and doctoral degrees. Currently there are 113 graduate students, and 58 faculty members. There are four main academic departments: Biological Sciences, Environmental and Aquatic Animal Health, Fisheries Science, and Physical Sciences.

A few of the scientists whose work contributed to VIMS's citation record in *Essential Science Indicators* talked with *ScienceWatch.com* Editorial Coordinator Jennifer Minnick about their research and their life at VIMS.

Robert J. Orth on the Biology & Ecology of Seagrasses

Dr. Orth is Professor of Marine Science at VIMS. He first came to VIMS in 1969 as a graduate student, and joined the faculty in 1974. The focus of his research is seagrasses, particularly in terms of habitat conservation and restoration. When asked how he became interested in seagrasses, he traces it back to graduate school at VIMS: "When I was in grad school, one of my professors at VIMS was working on a project with animals in seagrasses and needed some people to get involved in it, and I said, 'Ooh, that's me! Here I am!' and that's how all that started."

Lay people look at seagrasses and likely think, "So what?" But Dr. Orth sets the record straight: seagrasses are actually quite fascinating. "There are a number of ecosystem services they provide," he says, "For example, they act as habitat for various creatures, as food for others; they spread nutrients through the system, and they can be water-quality indicators."

Seagrass habitats are in decline worldwide, and two or Orth's high-impact papers, written with colleagues from other institutions in the same field, deal with this fact. The papers were the result of a series of workshops held in California to discuss the growing concern over seagrass losses. The first paper, "A global crisis for seagrass ecosystems," (Orth RJ, *et al., Bioscience* 56[12]: 987-96, December 2006), "synthesizes all the information about seagrasses, tells the world about seagrasses and that we're really concerned," says Orth.

The second paper, "Accelerating loss of seagrasses across the globe threatens global ecosystems," (Waycott M, *et al., Proc. Nat. Acad. Sci. USA* 106[30]: 12377-81, 28 July 2009), took a comprehensive look at seagrass studies being done around the world, and showed quantitatively that in the overwhelming majority of papers, seagrasses were reported to be in decline.

When asked what the reaction to this news was in the research community, Orth reports that response was good. "We're very encouraged by the response that we've gotten from our colleagues around the world. They've provided more quantitative data, showing that the things seagrasses face are no different than those that coral reefs and marshes and mangroves are facing," he relates.

The next step is to get something done about the situation, and that's where the challenge comes in. "Now we have to work with our local groups to impress upon them how important these seagrasses are—it's that old adage, 'think global, act local.' People are concerned most about their own backyard, so you have to convince people that their backyard is important," Orth says.

This is where the second part of Orth's research comes in: seagrass seed germination and dispersal studies, with the aim of restoration. One of the advantages to Orth's approach is that he uses seeds; many other restoration programs focus on the use of mature plants. By using seeds, Orth and his team can learn more about seagrasses at the most basic levels, because, surprisingly, there has not been a lot of research done with seagrass seeds.

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>
> -Emmett Duffy

Orth's main efforts are focused close to home in the Chesapeake Bay, but he also has his finger in restoration projects in other locations worldwide, including Australia. The restoration of Chesapeake Bay is a huge, multi-dimensional project, crossing many different disciplines, not to mention state lines. "Water quality issues are important, and seagrasses are a part of that," Orth concludes.

Emmett Duffy: The Importance of Biodiversity and Putting It to Work

Dr. J. Emmett Duffy, currently the Loretta and Lewis Glucksman Professor of Marine Science, came to VIMS in 1994, which, he jokes, "seems like yesterday in some ways but another geologic era in others." Clearly, this is a good thing, as he adds, "I think VIMS has a lot going for it—there's a very diverse group of scientists here, it's right on the water, so we have access to various field sites, and I think there's a really good interactive community spirit."

Duffy has a broad interest in marine biodiversity—the ecology, evolution, and conservation of marine organisms. As to what lit this spark of interest in him, he relates, "I've been interested in animals since I was a kid. Early on, I became interested in invertebrates, just because they're so wildly diverse. There are all kinds of strange animals, and some of them have something to say about the early origins of life—that always fascinated me, some of the strange, primitive marine creatures. And then the first time I ever went snorkeling on a coral reef I was completely hooked, and knew that I had to figure out a way to do that for a living."

Duffy was part of a large team that collaborated on a 2006 *Science* paper that generated a lot of citations. "Impacts of biodiversity loss on ocean ecosystem services" (Worm B., *et al*., 314[5800]: 787-90, 3 November 2006) was the result of an extensive literature search to quantify whether and how the diversity of marine animals and plants matters in terms of how ocean ecosystems function and in terms of what they provide to humans as far as natural products and services.

"We looked at a wide range of types of evidence, and the message that came out of all of these sources was consistent, and that was that as diversity declines—whether for natural or human-induced reasons—there are fairly consistent reductions in productivity of systems and also, to some degree, stability of the systems."

Duffy's biodiversity work in the Chesapeake Bay focuses on seagrass bed habitats. "Seagrass beds throughout the world are very important ecologically and economically and there is a key interaction that goes on in these beds that involves these small invertebrate grazers, essentially like the bugs of the sea that provide janitorial services, so to speak, for the grasses. They feed on the algae that grow on the grasses and therefore, they can enhance the growth rate of the grasses," he explains, "so we're interested in this key positive interaction between those small grazers and grasses and basically how changing diversity—loss of species, gain of new species, changes in the foodweb structure—influence the health of the seagrasses."

Duffy isn't just studying biodiversity—he's also looking into ways to make biodiversity work for us. "After spending years studying how biodiversity influences functional ecosystem processes, we're now beginning to get interested in how to employ biodiversity to do jobs in a way that is sustainable and compatible with a healthy, natural environment," he shares. "What I'm talking about in particular here is using natural, wild algal communities to clean up pollution and use as a feedstock for biofuel. We've just recently gotten some seed money to start off a project in this area, and we're working with a group of partners from the College of William and Mary, the University of Arkansas, the Smithsonian Institution, and the University of Maryland."

What makes their new project so different from other biofuel projects, Duffy explains, is that "the vast majority of those other projects are focusing on fairly high-tech bio-reactor systems, where they take a particular strain or species of algae that's bred to be good under certain conditions and use that. Our approach is quite different in that what we're trying to do is use wild, diverse communities—rather than trying to figure it out ourselves, we're letting Nature's three billion years of experience with algal evolution figure out which ones work best. Our hope is that by having a number of different species in our portfolio, so to speak, we'll be able to weather environmental changes better than any one particular algal species would—in the same way that a stock portfolio is more stable when you have some diversity to it."

Michael Unger and Eclectic Environmental Chemistry

Another one of the researchers involved in the wild algal biofuel project is Dr. Michael Unger, Associate Professor of Marine Science, who came to VIMS as a researcher in 1990. Unger's overall research goal is to "establish an environmental chemistry program known for conducting high-quality research on the fate of environmental contaminants." On the surface, environmental chemistry and the biodiversity of wild algal communities may not seem related, but Unger's interests are, in his words, "a bit eclectic."

"I have studied a variety of contaminants and have done everything from analytical method development to toxicity studies. My work has included very basic research but always there is an applied end goal of a better understanding of the environmental effects of pollution," he says. So how does that tie into the biofuels project? "Because of my interest in contaminant fate, I'm looking at how the algae concentrate and/or degrade contaminants during the growing process. We could potentially use this as a remediation technique but must simultaneously be aware of the fate of the contaminants throughout the algae-growth-to-fuel-to-waste life cycle," Unger explains.

One of Unger's highly cited papers is the 2000 *Human and Ecological Risk Assessment* article, "A probabilistic ecological risk assessment of tributyltin in surface waters of the Chesapeake Bay watershed" (Hall LW, et al., 6[1]: 141-79, February 2000). This paper, coupled with earlier publications, were the result of a collaboration with Len Hall, Jr., at the University of Maryland. Together, they were able to show that even low concentrations of tributyltin (TBT) could affect key species, such as copepods, which are important to marine food webs.

[+] details

"At VIMS, my group had been monitoring TBT concentrations near marinas in the lower Chesapeake Bay since the late 1980s and we had one of the most extensive environmental datasets in existence for the compound. We were able to use this monitoring data to show that state and federal regulations passed in the late 1980s, which restricted TBT use on vessels below 25 meters in length, had been successful at reducing TBT concentrations near marinas, but that there was still risk to sensitive estuarine organisms in areas where TBT use had been high or commercial TBT use continued," Unger explains. "Reduced degradation of TBT in sediments at these sites or continued use on vessels larger than 25 meters long had maintained water concentrations that were still potentially harmful. Recently, the International Maritime Organization (IMO) has passed international regulations prohibiting TBT use on the larger vessels as well."

The banning of TBT is a success story that brings Unger a great deal of satisfaction. "It's been gratifying to work on a research area (TBT) that began over 25 years ago with identification of a potential problem and development of the analytical tools to study its fate and effects and has followed it through to regulations that will *eventually* eliminate it as a concern in the marine environment. Many of the pollution-related things we study are focused on finding bad news so it's been nice to be involved with something that has resulted in positive change," he says.

Collaboration with like-minded researchers has been a critical factor throughout Unger's career. "As an undergraduate I majored in zoology, and worked with an aquatic ecologist—Dr. William Cooper—and while I ended up specializing in environmental chemistry later on, that interest in understanding the ecological significance of pollution sticks with me and makes collaboration a necessity," he relates.

Apart from the project with Emmett Duffy, Unger is also collaborating with another VIMS researcher, Dr. Steve Kaattari, on the development of antibody-based biosensors for measuring aquatic contaminants. "Steve's research focus is fish immunology. We have a graduate student working with us, Candace Spier, who is now testing a biosensor she developed that can measure polycyclic aromatic hydrocarbons (PAH) in environmental water samples at concentrations below 1 ppb in minutes! This would normally take us days in my lab with conventional techniques," he enthuses. "These types of analytical developments will enable us to monitor contaminants in near real-time and conduct studies we thought were impossible a few years ago."

1 | 2 Next Page

PDF

back to top

Institutional Interviews : 2009 : Virginia Institute of Marine Science (VIMS)

View larger images and descriptions for figures above

ScienceWatch Home
Inside This Month...
Interviews

Featured Interviews
Author Commentaries
Institutional Interviews
Journal Interviews
Podcasts

Analyses

Featured Analyses
What's Hot In...
Special Topics

Data & Rankings

Sci-Bytes
Fast Breaking Papers
New Hot Papers
Emerging Research Fronts
Fast Moving Fronts
Corporate Research Fronts
Research Front Maps
Current Classics
Top Topics
Rising Stars
New Entrants
Country Profiles

About Science Watch

Methodology
Archives
Contact Us
RSS Feeds

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Previous Page 1 | 2

Zooplankton Ecology and Climate Change: Deborah Steinberg

Dr. Deborah K. Steinberg came to VIMS in 2001, and is Professor of Marine Science. Her work deals with zooplankton ecology and physiology, coastal and deep-sea food webs, nutrient cycling, particle flux in the ocean, and using long-term datasets to study the effects of climate change on zooplankton. A big order, and her research takes her all around the world, from the Antarctic to the Amazon. "I just love looking through the microscope at zooplankton because they're very diverse," she says. "Every time I look at a sample, I always see things I haven't seen before. And because I work in different environments, from tropical and polar areas to the Chesapeake Bay, the zooplankton communities are different in all of these different places."

One of Steinberg's papers that has garnered attention in the research community is the 2004 *Marine Ecology-Progress Series* article, "Production of chromophoric dissolved organic matter (CDOM) in the open ocean by zooplankton and the colonial cyanobacterium *Trichodesmium spp*.," (Steinberg DK, *et al*., 267: 45-56). "Oceanographers are interested in dissolved organic matter in the oceans because bacteria use it in their metabolism, and it's another source of carbon in the ocean, which is a hot topic now because of global warming," she explains.

What Steinberg and her coauthors discovered is that zooplankton produce CDOM as well—previously, it had been thought that this was the realm of phytoplankton, the microscopic plants. "And not only do zooplankton produce CDOM, but different types of zooplankton produce unique color signatures related to the types of CDOM they produce.

The amount of carbon in the ocean is a hot topic with regard to the matter of global warming. "The oceans take up about half the carbon dioxide that enters the atmosphere through fossil-fuel burning—this carbon dioxide diffuses into the surface waters of the ocean and phytoplankton take it up during photosynthesis, and then this carbon gets transferred down into the deep ocean in a number of different ways. The deeper you can transport that carbon into the deep oceans the longer it stays there because of the way oceans circulate," Steinberg explains. "The problem is as the oceans take up more carbon dioxide the delicate balance of its carbonate buffering system is disrupted and the ocean is slowly acidifying. It's a problem in terms of coral reefs, and basically anything that makes a calcium carbonate shell, including some zooplankton and phytoplankton."

"There are a number of ecosystem services [seagrasses] provide. For example, they act as habitat for various creatures, as food for others; they spread nutrients throughout the system, and they can be water-quality indicators."

-Robert Orth

Part of Steinberg's research involves studying how that carbon circulates in the ocean. Some of the ways include zooplankton consuming phytoplankton, then excreting fecal pellets that sink into the ocean; there are also zooplankton that migrate daily through the "twilight," or mesopelagic zone of the ocean—an area between the reach of the sun and the deep, dark ocean—transporting the carbon with their movements.

Steinberg is also involved in a long-term project at the Palmer Antarctic Research Station, looking at the effects of climate change on the ecosystem, on everything from bacteria to penguins. Her role is, of course, to look at the effects on zooplankton. "This area is one of the fastest-warming areas on earth—the amount and duration of the ice there is shrinking all the time, and this has an effect on the ecosystem," she says.

Robert Diaz Looks at Bioturbation and Dead Zones

Dr. Robert Diaz has been with VIMS since 1979, and says it's "like what you think a marine lab would be—very laid-back, and a beautiful setting by the sea. That has never changed, although the country has become much more built up than it was 30 years ago, it's still a nice place with good vistas and lots of interesting work going on." Diaz's work focuses on two main areas: bioturbation, or the way in which marine animals interact with sediments from the shallow waters to the deep sea, and dead zones, areas of low dissolved oxygen in the water.

Bioturbation is actually a concept that dates back to Charles Darwin; he postulated that animals living in the soil greatly affected processes within the soil, and he was right. The composition of organic matter, the cycling of nutrients, the burial of organic matter on geological time-scales—whether on land on in the water, bioturbation plays a key role in all of these things.

The term "dead zones" was first popularized by Nancy Rabalais, the executive director of the Louisiana Universities Marine Consortium, and it's an apt term. "What happens in a dead zone," Diaz explains, "is that oxygen becomes too low to support fish, crab, and shrimp, and so they leave, creating an area where fisherman can't catch anything."

Dead zones are in constant flux—some can last a few months, such as in Chesapeake Bay, the Gulf of Mexico, or Lake Erie, whereas others can last year-round, such as in the Baltic Sea. The cause of dead zones is mainly too much primary production. "Basically," says Diaz, "the waters are too 'green.' If you look at the dead zones around the world, you can see that the main source of the problem is connected to runoff from land—agricultural land in particular. It's a land-sea interaction gone bad. You have the nutrients coming in from the runoff, and they stimulate the phytoplankton in the water—just like fertilizers on land stimulate the growth of crops. When this happens in the sea, if you get too much of it and nobody harvests it, it settles to the bottom, decomposes, and uses up the oxygen, and if the physics are right, you get a dead zone."

There is a fair amount of work being done by both researchers and resource managers to mitigate dead zones throughout the world. There are programs within the United Nations, as well as programs local to the Gulf of Mexico, Lake Erie, and Chesapeake Bay to reduce nutrients being drained into the waters to eliminate dead zones. Diaz is confident that applying management strategies will lead to improvement. "The trouble with these big dead zones is the problems are coming from diffuse sources, which are a lot harder to control and regulate. It's going to take a long time to see any effect," he cautions.

"There is one really good example of a system that basically went from the world's second-largest dead zone to having no oxygen problems in a mere three years," Diaz offers, "and that's the Black Sea's northwest continental shelf. When the Soviet Union collapsed, the agricultural subsidies to the farmers in the area, which included land around the Danube, were simply gone. In a matter of one to two years the nutrient additions to that area fell by a factor of three to four. In 1990, the dead zone was measured at 40,000 square kilometers, and by 1993 it was at zero because of the nutrient reductions."

"So," he concludes, "you can see that if you regulate nutrients going into the water, you can get rid of these dead zones but I certainly don't recommend economic collapse as the way of doing it!"

Robert Hale on Persistent Organic Pollutants

Dr. Robert Hale came to VIMS in 1987 from the Mobil Oil Corporation, Environmental Health & Science Laboratory in Princeton, NJ. His interest in pollution dates back to growing up in Michigan in the 1970s, which was, as he says, " highly industrialized and we had issues such as polybrominated biphenyls in cattle, lampreys in the Great Lakes, and other problems."

One of his major research concentrations at VIMS is the study of persistent organic pollutants (POPs), such as polybrominated diphenyl ethers (PBDEs) and polychlorinated biphenyls (PCBs) in the aquatic environment. "As POPs, PCBs & PBDEs represent long-term hazards, they degrade only slowly. They also can become widely distributed in the environment, affecting human and wildlife long distances from their points of usage—for example, from cities to remote polar zones—and the impacts persist long after their release," Hale says.

As far as mitigating the effects of various POPs, Hale says the key is prevention. "Once in the environment, POPs are difficult to remove. The best approach is prevention. This is one reason for my interest in so-called 'emerging contaminants.' The 'train has left the station' for PCBs; their use has been stopped and they have already become distributed globally. In contrast, PBDEs are still present in common household products. Production of some PBDE formulations stopped in late 2004, another (Deca) remains in use. Better industrial stewardship would help for Deca. All PBDEs in products may find their way into the environment."

"Biosolids," or sewage sludge, their composition and their re-introduction into the environment as agricultural amendments are another interest of Hale's.

Pollution and Its Effects: Michael Newman

Professor Michael Newman has been with VIMS for just over a decade, where he now holds the title of A. Marshall Acuff Jr. Professor of Marine Science. "My research and teaching involves pollutant effects," he says. "Like many my age, an awareness of environmental pollution was as much a part of coming of age as the Vietnam War and Kennedy's push for science education. I remember sitting on a Connecticut beach as a child watching for dolphins on the horizon, as smoke from a burning dump floated by. In the drift line of the beach were rusty aerosol cans and tar balls in addition to skate egg cases and shells. Pollution issues that needed to be solved were obvious even to young children."

"I just love looking through the microscope at zooplankton because they're very diverse. Every time I look at a sample, I always see things I haven't seen before."

-Deborah Steinberg

Several of his highly cited papers deal with the effects of polycyclic aromatic hydrocarbon (PAH) contamination, specifically in *Fundulus heteroclitus,* the common mummichog. Newman explains, "My wife and I spent a decade prior to coming to VIMS studying pollutant impacts on animal populations. The molecular genetics we applied before coming to Virginia were easily applied to fish populations in the heavily polluted Elizabeth River. We were able to show that PAH exposure for many generations of this common fish*, F. heteroclitus*, resulted in changes in the population genetics: the exposure was serious enough that the populations underwent microevolution."

Another of Newman's major projects is to update statistical methods used in ecotoxicology. "The approaches established in the 1970s to address very real and immediate problems became the standard methods applied by pollution scientists and incorporated into EPA regulations. These methods were borrowed hastily from human toxicology, a field that correctly focuses on the well-being of the individual. But, except in cases of endangered or especially charismatic species, environmental scientists are more concerned about the well-being of ecological populations and communities," he relates, "A growing number of scientists now realize that the standard methods applied in ecotoxicology are outdated, generating unsound scientific conclusions and indefensible regulatory decisions about population viability or community biodiversity."

Newman views teaching as a key responsibility as well. "Expertise and innovation in ecological toxicology are essential as the human population grows and our technologies become more sophisticated and widespread. Useful new and old ideas must be drawn upon to address concerns as they emerge. So exposing each generation of environmental scientists to useful ideas and helping them develop skills for selecting the best approach in the presence of uncertainty are essential to our well-being," he concludes.

Sound Science, Informed Management, Brighter Tomorrows

The mandate of VIMS is "sound science for informed management," and this mandate is carried out in a three-pronged path of research, education, and advisory service. The goals of VIMS are to "make seminal advances in understanding marine systems through research and discovery; translate research findings into practical solutions to complex issues of societal importance; and provide new generations of researchers, educators, problem solvers, and managers with a marine-science education of unsurpassed quality."

The work that VIMS engages in does bring results in all three areas—as we have seen through the researchers who spoke with *ScienceWatch.com*. But their work is only a small portion of what goes on at VIMS—the institution has hundreds of other projects underway locally and throughout the world. Some of its historic achievements that are still in play today include oyster ecology research as well as juvenile fish and blue crab surveys in Chesapeake Bay. The annual shark survey begun in 1973 is now the longest running such survey worldwide. VIMS scientists were key players in the establishment of the national Sea Grant and Coastal Zone Management programs in the 1960s. The founding of the Eastern Shore Laboratory helped kick-start the state's hugely profitable hard clam industry. VIMS' seagrass restoration programs are among the most successful in the world.

With its state-of-the-art laboratories, fleet of research boats, libraries, and collections, as well as its partnerships with the US government and international research institutes, VIMS is well-positioned to lead marine science research for years to come.

Virginia Institute of Marine Science
Gloucester Point, VA, USA

Virginia Institute of Marine Science (VIMS)'s current most-cited paper (Biology/Biochemistry) in *Essential Science Indicators*, with 333 cites:

Beck MW, *et al*., "The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates," *Bioscience* 51(8): 633-41, August 2001. Source: *Essential Science Indicators* from Thomson Reuters.

Additional Information:

This interview is based on the Virginia Institute of Marine Science's citation record in the field of Environment & Ecology, for which the current-most cited paper from *Essential Science Indicators*, with 264 cites is:

Worm B, *et al.*, "Impacts of biodiversity loss on ecosystem services," *Science* 314(5800): 787-90, 2 November 2006.

Previous Page 1 | 2

KEYWORDS: MARINE SCIENCE, AQUACULTURE, HABITAT CONSERVATION, HABITAT RESTORATION, SEAGRASSES, WATER QUALITY, SEED GERMINATION, SEED DISPERSAL, CHESAPEAKE BAY, BIODIVERSITY, INVERTEBRATES, OCEAN ECOSYSTEM SERVICES, WILD ALGAL COMMUNITIES, BIOFUEL FEEDSTOCK, ZOOPLANKTON, CHROMOPHORIC DISSOLVED ORGANIC MATTER, FOOD WEBS, NUTRIENT CYCLING, PARTICLE FLUX, CLIMATE CHANGE, OCEAN CARBON CONTENT, BIOTURBATION, DEAD ZONES, LOW DISSOLVED OXYGEN, PERSISTENT ORGANIC POLLUTANTS, PCB, PBDE, DECA, BIOSOLIDS, POLYCYCLIC AROMATIC HYDROCARBONS, ECOTOXICOLOGY, ENVIRONMENTAL CHEMISTRY, TRIBUTYLTIN, AQUATIC POLLUTANTS, FISH IMMUNOLOGY, EDUCATION, PARTNERSHIPS.

PDF

back to top

Institutional Interviews : 2009 : Virginia Institute of Marine Science (VIMS)

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PDF

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Return to interview.

Figures and Descriptions

Figure 1:

Figure 1 description:

Researchers at VIMS harvest and sow seeds from the fruits of the eelgrass *Zostera marina* to help restore these grasses and their ecosystem services to Chesapeake Bay and Virginia's seaside lagoons. Photo courtesy of Robert Orth, Virginia Institute of Marine Science.

Figure 2:

Figure 2 description:

VIMS researcher broadcasts eelgrass seeds in the seaside bays of Virginia's Eastern Shore. Photo courtesy of Robert Orth, Virginia Institute of Marine Science.

Figure 3:

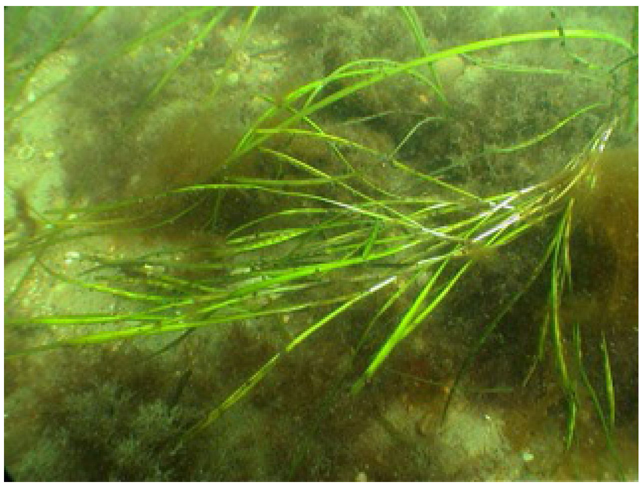

Figure 3 description:

The reproductive shoots of an eelgrass plant (*Zostera marina*). Photo courtesy of Robert Orth, Virginia Institute of Marine Science.

Figure 4:

Figure 4 description:

VIMS professor Deborah Steinberg studies the role of copepods in the global carbon cycle. Photo by Stephanie Wilson, Virginia Institute of Marine Science.

Figure 5:

Figure 5 description:

VIMS researchers work to restore seagrass meadows and the ecosystem services they provide. Photo courtesy of Robert Orth, Virginia Institute of Marine Science.

Return to interview.

PDF

back to top