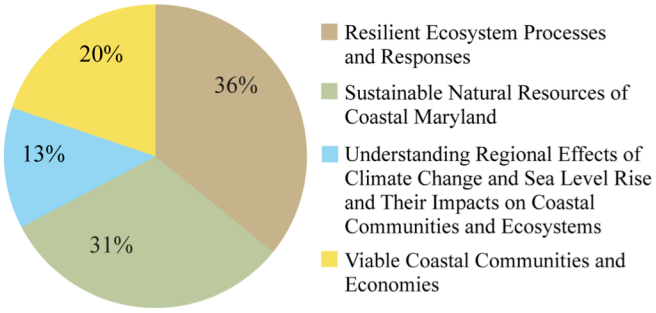
Program Introduction

The Chesapeake Bay watershed extends into parts of six states, but in Maryland it reaches into 20 of our 24 counties, drains 93 percent of our land, and dominates our history, ecology and economy. For Marylanders, the health of the Bay is a "quality of life" issue. No other state is so closely tied to the fate and future of Chesapeake Bay.

It should be no surprise that the multi-state effort to restore the health of the Bay ecosystem began in Maryland. Over the last 25 years, the Bay cleanup has grown to include a mix of federal and state agencies, non-governmental organizations, local municipalities, and universities. In 2010, this massive effort moved into a new, more regulatory phase in response to growing concerns over missed milestones.

Funding by Focus Area, 2008-2011



In this complex landscape, Maryland Sea Grant occupies a unique niche. Our strategic plan calls for research that combines with extension, education, and outreach to create measurable outcomes and impacts that benefit the ecology and the economy of the region. Our approach starts with supporting strong science drawn from the region's major universities and labs. But it also includes synthesizing and translating findings to help guide science-based approaches to restoration. A key step towards applying findings is our facilitation work. We create a platform for active discourse, often around difficult issues, in order to drive the development of scientific consensus — and to inject that consensus into management.

• **RESEARCH.** Building on our earlier work, we designed a research program for 2008-2011 that focused on improving our understanding of the processes underlying the Bay's ecosystem dynamics and building a scientific underpinning for adaptive resource management. A key research effort investigated ecosystem thresholds and resilience indicators and followed up with outreach events to clarify for resource managers the complexities and applications of crucial concepts such as ecosystem tipping points. A similar research and outreach effort focused on techniques for managing introductions of non-native species. Our long-running support for blue crab research contributed to management changes credited with reviving blue crab populations. Our review and report on oyster restoration identified critical shortcomings in past efforts and influenced plans for future restoration. In all these projects and others we made significant progress towards our goals of improving scientific knowledge and enriching adaptive management responses to the challenges facing the state's estuarine and coastal waters.

• **EXTENSION.** Sea Grant Extension specialists translated research findings into practical applications needed in a number of coastal industries. They provided technical and economic analyses for the state commission that revived oyster aquaculture in state waters, and they organized training sessions to prepare new oyster farmers. For seafood processors, they created new freezing and packaging techniques, expanding markets for blue crab products. Our watershed specialists consulted with communities now faced with designing new projects to restore water quality in their watersheds and to prepare for the potential impacts of climate change.

• **EDUCATION.** Maryland Sea Grant enriched science content throughout the educational system and provided educational opportunities for undergraduates, graduate students, and teachers. During 2008-2011, we expanded our K-12 programs in environmental education to include at-risk teenagers and inner city students in Baltimore. Our Research Experience for Undergraduate program continued to receive high ranking from the National Science Foundation and recognition for increasing diversity in marine science. We awarded fellowships for graduate students to work with Sea Grant researchers and for schoolteachers to work in marine labs.

Maryland Sea Grant is administered by the University of Maryland Center for Environmental Science and is funded by the National Oceanic and Atmospheric Administration and the State of Maryland.

Maryland Sea Grant Performance Review Panel Summary Report

RESILIENT ECOSYSTEM PROCESSES AND RESPONSES
(Healthy Coastal Ecosystems)

Our research projects funded under Resilient Ecosystem Processes and Responses focused on supporting science that can be applied to reversing major declines and restoring the health of the Chesapeake Bay ecosystem. And our outreach work focused on interpreting these findings and on synthesizing the best science to help inform decision making by policymakers and resource managers. In addition, our outreach to educational communities enriched science content at all levels of the educational system, from elementary school through graduate school, and provided educational development opportunities for undergraduates, graduate students, and teachers.

In Maryland waters, declines in ecosystem health include worsening water quality, growing dead zones of low oxygen, the widespread loss of underwater grasses, episodes of harmful algal blooms that can be toxic for animals and humans, and invasions of non-native species that can drive out native organisms and disrupt food webs.

The need for effectively dealing with these issues is pressing: twenty-five years after the historic 1987 Chesapeake Bay Agreement set out ambitious restoration goals, important indicators of the Bay's overall health have not improved — and in some cases, they have declined. As a consequence, in 2009 the Chesapeake Bay Action Plan, an initiative led by federal and state governments, set new levels of oversight buttressed by stringent sanctions if protection and restoration targets are not met.

To meet our strategic goals, we supported research in 2008-2011 in four major areas: (1) understanding thresholds in ecosystem recovery, (2) restoring submerged aquatic vegetation, (3) managing aquatic invasive species, and (4) limiting harmful algal blooms. These projects provided new knowledge that MDSG is now making available through a variety of outreach and communication efforts. Here we highlight specific projects and their outcomes to date.

2008-2011 IMPACTS

- Facilitated a workshop and published a scientific synthesis on the role of thresholds in ecosystem dynamics to inform Chesapeake Bay modeling efforts and restoration plans.
- Quantified conditions that promote growth and resilience of submerged aquatic vegetation, providing data that informed Chesapeake Bay management targets for underwater grass restoration.
- Printed 10,000 "Stop Aquatic Hitchhikers" bumper stickers to raise public awareness about risks posed by zebra mussels and other invasive species to the Chesapeake Bay watershed.
- Developed a rapid response planning template and complementary web-based tool that numerous states adopted to improve their response to invasive species introductions.
- Supported development of fluorometer probes that state officials adopted to detect and predict conditions conducive to harmful algal bloom (*Karlodinium veneficum*) events.
- Partnered with Maryland Juvenile Services to train incarcerated youth in aquaculture technology, with 50 youth earning certificates of completion annually.
- Conducted a workshop and REU pilot project partnering with a Puerto Rican minority-serving undergraduate University expanding access to marine science research for an underserved community.

Understanding Thresholds in Ecosystem Recovery
Strategic Plan goal: Build scientific understanding of ecosystem processes and responses

Since thresholds play a critical, little-understood role in estuarine restoration efforts called for in the Chesapeake Bay Action Plan, MDSG supported the brainstorming and the research that explored how thresholds affect natural resources in the estuary. To clarify the thresholds concept, MDSG collaborated with the Chesapeake Bay Program to organize a conference that brought together leading environmental scientists from the Chesapeake Bay, Pamlico Sound, Europe, and elsewhere. Led by researcher Michael Kemp of the University of Maryland Center for Environmental Science (UMCES), participating scientists presented a number of case studies that demonstrated the complexities of generalizing about thresholds. Some rivers in certain systems improved after nutrient reductions, but some did not. Some responded in certain areas but not in others. The conference concluded with a consensus: ecosystems do respond to restoration efforts — but often in unpredictable, nonlinear ways once certain thresholds, or "tipping points" are crossed. Managers must take those effects into account in their planning.

The idea for the conference was sparked by articles on resilience and thresholds[1] written by MDSG science writer Erica Goldman in *Chesapeake Quarterly* magazine, who was in turn influenced by earlier MDSG-supported seminal work by Kemp et al.[2] The conference led to a joint synthesis report[3], edited by Kemp and Goldman, that suggested a framework to help Chesapeake Bay decision-makers adapt restoration efforts to the complexities of ecosystem dynamics. As part of MDSG outreach efforts after the conference report appeared, Goldman wrote more feature articles for *Chesapeake Quarterly* magazine, this time using the example of the Corsica River estuary,[4] a system near a "tipping point" for nitrogen loading where a 50 percent reduction in nitrogen loading would produce a 70 percent decline in summer algae. Both issues of the magazine helped introduce the complex concepts of threshold and resilience to non-technical audiences.

In the MDSG synthesis report, scientists hypothesized that across the Chesapeake Bay, environmental parameters will respond differently to variability in local conditions and processes, resulting in large and sudden changes in some places and slow or minimal changes elsewhere. Current research and theoretical models are beginning to quantify these complex responses, helping natural resource managers evaluate the potential effects of their intervention strategies.

To inform these adaptive management decisions, MDSG supported research during 2008 to 2011 that focused on ecosystem dynamics and threshold responses. In one project, fisheries scientist Dave Secor examined white perch responses to specific levels of hypoxia to identify thresholds below which white perch production and activity were compromised. At a population level, such threshold responses indicate loss of resilience and the possibility of tipping points beyond which the carrying capacity becomes diminished at an ecosystem scale. In another MDSG-funded study, Secor highlighted how mounting environmental stresses (e.g., shoreline development, beach nourishment, nutrient inputs, sea level rise, and dredging) can affect the ecological function of coastal bay and near-shore ocean nursery habitats.

Restoring Submerged Aquatic Vegetation
Strategic Plan goal: Build scientific foundations for implementing ecosystem restoration

Bringing back sustainable species of native grasses has been a major objective in Chesapeake Bay restoration. Submerged aquatic vegetation (SAV) provides critical habitat for many Bay species, plays an important role in nutrient and sediment cycling, and helps buffer extreme weather events, which appear to be increasingly prevalent. Long-term monitoring data show SAV in 2010 at only 43 percent of totals estimated for the early 20th century, clear evidence of a historic decline that may have brought Baywide SAV to a possible "tipping point." MDSG-

[1] On the Road to Restoration? Chesapeake Quarterly Magazine, October 2004, volume 3, number 3. Maryland Sea Grant. http://www.mdsg.umd.edu/CQ/V03N3/

[2] Kemp, W.M., W.R. Boynton, J.E. Adolf, et al. 2005. Eutrophication of Chesapeake Bay: historical trends and ecological interactions. Marine Ecology Progress Series 303:1-29.

[3] Kemp, W.M. and E.B. Goldman. 2008. Thresholds in the Recovery of Eutrophic Coastal Systems. Maryland Sea Grant, UM-SG-TS-2008-01. http://www.mdsg.umd.edu/store/reports/thresholds/

[4] Restoring the Bay, One River at a Time. Chesapeake Quarterly Magazine, September 2010, volume 9, number 3. Maryland Sea Grant. http://www.mdsg.umd.edu/CQ/V09N3/

supported research has strengthened our understanding of SAV dynamics and provided a strong underpinning for adapting management to declining water quality and changing climate.

In 2008-2011, MDSG funded research by Michael Kemp to determine optimum conditions for restoring and conserving SAV in multiple locations in Chesapeake Bay. Building on earlier MDSG-supported research, these recent studies quantify a positive feedback process in which SAV beds alter their local environment in ways that improve conditions for further growth of the plants, for example, by increasing availability of light. His findings[5] underscored how improving or degrading certain environmental parameters could potentially lead to abrupt changes — tipping points — in SAV bed survival. Kemp suggested that restoring SAV beds requires more stringent management goals and water quality targets than those needed for simply maintaining SAV beds. The SAV Workgroup for the Chesapeake Bay Action Plan is using these MDSG-funded study results to inform restoration of vital SAV beds. Presented at semiannual meetings with federal and state agencies, these findings provided critical information to resource managers as they constructed models to simulate the effects of different management methods and of climate variation on the Bay's SAV restoration.

Another MDSG project approached restoration of underwater grasses from the perspective of genetic diversity. Working with MDSG funding, scientists Katia Engelhardt and Maile Neel of the University of Maryland tested the hypothesis that greater genetic diversity of seed stocks improves chances for restoration and long-term survival. For a model, they used wild celery (*Vallisneria americana*), once a dominant species in Chesapeake Bay, and grew multiple genetically distinct individuals (or genotypes) from the same population under common environmental conditions. With this approach the researchers were able to identify significant variation in growth responses and show that growth characteristics are sometimes just as varied within populations as across populations. In light of the variability in environmental conditions in an estuary, the researchers recommend that different genotypes with varying growth characteristics be included in designs for restoring SAV beds. This approach, they believe, could increase resilience by providing a variety of genotypes for a variety of environmental conditions.

Managing Aquatic Invasive Species

Strategic Plan goal: Build scientific foundations for implementing ecosystem restoration

In many ecosystems around the world, aquatic invasive species (AIS) remain a continuing threat. In the Chesapeake Bay, recently introduced invasives include the oyster disease parasite MSX, the northern snakehead (*Channa argus*), and the blue catfish (*Ictalurus furcatus*) — all of which threaten biological biodiversity and the integrity of productive food webs. It is unclear at what point the introduction of non-native species to Maryland waterways may reach a threshold that significantly alters current ecosystem function. MDSG-supported work on dealing with non-native species focused on preventing and responding to new introductions.

An important part of this work was a nationally significant collaboration with Sea Grant programs in other states in the Mid-Atlantic region. Since 2007, Sea Grant programs in the Mid-Atlantic have worked collaboratively through the Mid-Atlantic Panel on Aquatic Invasive Species (MAPAIS) to support research and outreach. Taking a leadership role in MAPAIS, MDSG Assistant Director Fredrika Moser organized several workshops over the last decade that prioritized species threats and set out action plans. For example, MDSG leveraged funding to produce a template[6] that a number of states now use in designing rapid response plans for managing new AIS introductions.

Beginning in 2007, MDSG supported work by the Smithsonian Environmental Research Center to establish an early detection and reporting system for the Chinese mitten crab (*Eriocheir sinensis*), a species that has wreaked havoc on the West Coast where it outcompetes native species and damages water treatment and power plants. Through MDSG support, Smithsonian researchers expanded a reporting network for Chinese mitten crabs that is fully operational today from North Carolina to Maine.

Preventing the introduction of new invasives is, of course, the most effective mechanism for protecting ecosystems. To that end, MDSG collaborated with MAPAIS in 2009 to organize and lead a workshop on developing prevention protocols through improved vector management. The workshop outlined critical research

[5] Guber, R.K. and W.M. Kemp. 2010. Feedback effects in a coastal canopy-forming plant bed. Limnol. Oceanogr. 55:2285-2298; Gruber, R.K., D. Hinkle, W.M. Kemp. 2011. Spatial patterns in water quality associated with submersed plant beds. Estuaries and Coasts. 34:961-972.

[6] Rapid Response Planning for Aquatic Invasive Species: A Maryland Example. http://www.mdsg.umd.edu/images/uploads/siteimages/MarylandPlanFinal.pdf

priorities, management and regulatory needs, education and outreach opportunities, and recommendations for management actions.

Led by MDSG, the Mid-Atlantic Sea Grant programs successfully competed for NOAA funding to assess the live-bait trade as a vector for AIS introductions. The research examined the biological and socioeconomic factors associated with the live-bait trade in order to devise hands-on strategies for preventing non-native introductions. The research is focused on the marine blood worm (*Glycera dibranchiate*) and the brown algae worm weed (*Ascophyllum nodosum*), a packing material that may carry "hitchhiker" invasives in shipments of blood worms to bait dealers and anglers throughout the U.S. and Europe. Biologists have been working with social scientists on best practices for managing the bait vector: while biologists investigated propagule pressure and organism resilience, social scientists studied socioeconomic factors and the behavior of people who harvest, distribute, and fish with worms. The project has demonstrated the effectiveness of regional cooperation: extension agents not only helped researchers reach anglers and live-bait dealers and distributors in many states, they also set up contacts with natural resource managers.

Public participation is one of the keys to preventing the introduction and spread of invasives. To alert the public about the spread of zebra mussels, MDSG funded the printing of 10,000 "Stop Aquatic Hitchhikers" bumper stickers for distribution by Maryland's Department of Natural Resources (DNR). This non-native species, known to be economically and environmentally devastating, is threatening the Chesapeake Bay region. In addition, MDSG made AIS the focus of several in-depth features published in *Chesapeake Quarterly*,[7] a magazine targeted at a broad readership. We also continued distributing *Alien Ocean*, an earlier film about non-native species invasions that was featured in 2010 at the Hampton Environmental Film Festival.

Detecting and Limiting Harmful Algal Blooms

Strategic Plan goal: Build scientific understanding of ecosystem processes and responses

High nutrient inputs to Chesapeake Bay can drive large and recurring harmful algal blooms (HABs) that threaten fish health and human health and hamper management efforts to restore estuarine ecosystems. These blooms have caused brown tides and mahogany tides and the closing of shellfish beds and swimming beaches. As they decay, algal blooms can do further damage by increasing hypoxia and anoxia that stress benthic organisms and can cause fish kills. Responding to a key need for resource managers responsible for public safety, MDSG has supported research to develop new tools for quickly identifying specific HAB species. The studies below highlight several highly successful outcomes from our strategic focus on nutrient and plankton ecosystem dynamics.

Already implicated in numerous fish kills, *Karlodinium veneficum* is a mixotrophic alga that grows quickly in the presence of cryptophyte prey. To help forecast *Karlodinium* blooms, MDSG supported molecular biologist Allen Place in developing two phycoerythrin (PE) fluorometer probes for detecting and predicting cryptophyte prey availability in subestuaries of the Chesapeake Bay. When researchers deployed the probe, they successfully detected a PE fluorescence peak prior to a *Karlodinium* bloom that killed 2,000 menhaden. After this success in detecting a real time HAB episode, managers at Maryland's DNR added the probes to two of their "Eyes on the Bay" monitoring stations.

Since urea, a nitrogenous compound, is a suspected contributor to brown tide algal blooms, MDSG funded biogeochemist Pat Glibert to develop a new autonomous instrument for monitoring urea presence in water bodies. Working with two sensors developed under previous MDSG funding, Glibert's research showed how the increasing use of urea as a fertilizer is resulting in high concentrations in Chesapeake Bay tributaries. It also demonstrated that urea is, as suspected, a likely contributor to brown tide algal blooms, particularly in coastal bays. A publication[8] resulting from this research has been cited by algal bloom researchers and developers of other tools for remote and in situ monitoring.

Because some blue-green algae, also known as cyanobacteria, are linked to human and animal illness, MDSG funded Diane Stoecker to investigate how cyanobacteria interact with nutrients and sediments in a tidal freshwater tributary of the Chesapeake Bay. By sampling biological and biogeochemical processes before, during, and after a major, mid-summer bloom of cyanobacteria, she was able to examine a bloom cycle in its entirety. Her

[7] Blocking Species Invasions in the Bay. Chesapeake Quarterly magazine, June 2009, volume 8, number 2. Maryland Sea Grant. http://www.mdsg.umd.edu/CQ/V08N2/.

[8] Glibert, P.M., V. Kelly, J. Alexander, et al. 2008. *In situ* nutrient monitoring: a tool for capturing nutrient variability and the antecedent conditions that support algal blooms. Harmful Algae 8:175-181.

research revealed that cyanobacteria appear to alter the biogeochemistry of water and particles in ways that perpetuate blooms and make their reoccurrence more likely. Her findings reinforced the need to limit the influx to the Bay of nutrients from terrestrial sources.

Reducing nitrogen and phosphorus loadings is also critical for controlling harmful blooms and maintaining the health of the coastal bays and lagoons along the Delmarva Peninsula. Working with MDSG support, ecologist Lora Harris developed another needed tool: an ecosystem model for nitrogen loadings that covers the watersheds of all coastal bays and lagoons along the Delmarva Peninsula. Using monitoring data from 22 sub-watersheds, Harris and her colleagues calibrated a model that generated total nitrogen loads to each lagoon and proved capable of predicting changes in primary producer dominance and thresholds. Her model also highlighted the importance to lagoon dynamics of light attenuation and inputs of nutrients from offshore waters. The modeling tool resulting from this research will be capable of identifying management targets for nutrient load reductions that can decrease nuisance blooms, improve water quality, and support eelgrass restoration and conservation.

Promoting Coastal Science Education

Strategic Plan goal: Build knowledge, research, and stewardship capacity in coastal communities

Our outreach efforts have always reached beyond professional research and management audiences. During 2008 to 2011, our outreach to educational communities built on a notable track record of enriching science education at all levels and offering educational opportunities to students and teachers.

MDSG education extension specialist Adam Frederick continued his successful work with middle and high school students and teachers. Using his program "Aquaculture in Action," Frederick introduces students to the aquaculture of commercially valuable Maryland species like striped bass. This innovative program engages students in raising and releasing fish right in their classrooms, where they build and maintain aquaculture tanks, grow the fish, and then release them back into the Chesapeake Bay. In the process they learn to integrate chemistry, physics, biology, and mathematics in solving practical, real-world problems.

The success of the program led to a partnership with the Maryland Department of Juvenile Services (DJS) that brought these same lessons to teenage criminal offenders. For their teachers, the program provided professional-development workshops, enabling them to offer the program in four separate detention facilities. For the offenders, the program provided marketable skills that might prepare them for jobs in an expanding local aquaculture industry. Youth who completed the aquaculture training were eligible to receive Aquatic Sciences Certificates; the state of Maryland awarded those to an average of 50 juveniles per year from 2009 to 2011.

Another opportunity for professional development was our program that awards summer research fellowships to teachers of grades 6-12 to advance their scientific inquiry skills and their understanding of regional ecological and environmental issues. Twelve teacher fellows spent the summers of 2009 and 2010 working with scientists on research projects at one of four University of Maryland laboratories. Out of that experience the teacher fellows developed classroom lessons related to coastal science while meeting state science standards. These lessons were then used in the classroom and shared with colleagues at professional-development conferences, expanding the ultimate outreach of the program to thousands of students.

The national need for well-prepared scientists has been well documented, and MDSG has committed to meeting that need by supporting graduate and undergraduate student training programs. Since 1989 the National Science Foundation has funded MDSG's Research Experiences for Undergraduates (REU), a summer program that brings undergraduates from across the country to laboratories at the University of Maryland Center for Environmental Science (UMCES) where each student is paired with a science/mentor for 12 weeks to work on a specific research project. This experience is, for many students, their first serious exposure to research. In a new effort, MDSG collaborated with the University of Maryland's Gemstone Program, a multidisciplinary, four-year research program for select undergraduate honors students of all majors. With guidance from faculty mentors and Gemstone staff, teams of students have designed and conducted coastal or marine-focused research often, but not exclusively, exploring the interdependence of science and technology with society.

To advance the careers of graduate students, MDSG has continued funding research and public-policy fellowships for work in coastal and marine sciences. Many fellows have gone on to postdoctoral fellowships and eventually to jobs in state and federal resource management agencies.

Since a diverse workforce is another priority for MDSG education efforts, MDSG has supported minority students who attend national meetings and participate in the REU program. In 2011, with funding from NSF, and in collaboration with scientists from UMCES, MDSG catalyzed the development in Puerto Rico of a pilot marine

science REU program. This new effort couples education and research to build capacity in Puerto Rico and to expand participation in marine science by students and scientists from underrepresented groups.

IN THE RESILIENT ECOSYSTEM PROCESSES AND RESPONSES FOCUS AREA, MDSG has made solid progress toward our strategic goal of building the scientific foundation for ecosystem restoration and has provided strong support for adaptive management in the process. Our research, outreach, and education efforts have not only clarified the critical importance of identifying thresholds and tipping points, they have also outlined management strategy options for reducing threats to ecosystem health and for responding to opportunities for ecological recovery.

MARYLAND SEA GRANT PROGRAM-WIDE METRICS

In the table below we offer some key additional, quantitative measures about MDSG's achievements that advanced coastal science and helped inform policy makers and the public about Maryland's coastal environment.

Some Measures of the Impacts Across All MDSG's Four Focus Areas, 2008-2011	
Education and Outreach	**Numbers**
Workshops and Meetings Organized or Supported	346
Presentations at National Meetings	316
Students/Teachers Reached	54,278/310
Curricula Created	38
Research	**Numbers**
Proposals Funded	66
PIs and Co-PIs Supported[1]	30/41
Unique Institutions Supported	24
Undergraduate/Graduate Students Supported[1]	103/42
Peer-Reviewed Journal Articles Submitted to Pell	90

[1] *PI, co-PIs and students funded for multiple years are only counted once.*

Maryland Sea Grant Performance Review Panel Summary Report

SUSTAINABLE NATURAL RESOURCES OF COASTAL MARYLAND
(Safe and Sustainable Seafood Supply)

Our strategic goals for Sustainable Natural Resources focus on creating the scientific foundation for managing, conserving, and restoring the fisheries of the Chesapeake Bay region. As a result, in 2008-2011 we directed research towards clarifying the causes of declines, rebuilding stocks, achieving sustainable fisheries, and developing workable aquaculture options. Research pays off when it shapes policy, so our outreach goal has focused on developing extension, communication, and collaboration projects that advance the overall goal of eventually implementing ecosystem-based fisheries management in Chesapeake Bay.

Since 2008, a series of historic policy decisions regarding fish and shellfish management have been adopted, all of which reflect findings and policy options recommended by Maryland Sea Grant research and outreach efforts. In 2008, state agencies in Maryland and Virginia put aside historical conflicts to jointly enforce cutbacks on the harvesting of female crabs, a policy shift that helped increase the blue crab population. In 2010, the state of Maryland finally decided to encourage oyster farming by revamping traditional laws hampering oyster aquaculture and by opening up new leasing areas for oyster farming. And in 2011, the Atlantic States Marine Fisheries Commission took a major step towards ecosystem-based fisheries management by voting more restrictive caps on the commercial harvesting of menhaden, the principal food fish for several popular fish and bird species.

2008-2011 IMPACTS

- Organized expert teams that produced the first scientific review and synthesis of the research basis for implementing ecosystem-based fisheries management for four key species in the Chesapeake Bay.
- Organized and led the Oyster Restoration Evaluation Team that published the first scientific assessment of oyster restoration efforts in the Chesapeake Bay.
- Provided expert consultation to the Oyster Advisory Commission that included an in-depth background report: Maryland Oyster Aquaculture History and Policy.
- Developed a more detailed understanding of factors affecting the return of blue crab larvae to Chesapeake and Delaware bays.
- Began identifying key up-estuary nursery sites for juvenile blue crabs.
- Provided an economic analysis for a buy-back program that purchased and retired 783 commercial crabbing licenses.
- Developed a technique for flash freezing blue crab meat that is now used by six seafood processing companies to ship their product around the world.

This is the new world of fisheries management, a world that Maryland Sea Grant (MDSG) helped bring about. Our research has been building a body of findings and outlining options for science-based management in a state with a history of highly politicized management of its commercial fisheries. Our pioneering synthesis reports on oyster restoration and ecosystem-based fisheries management helped provide the scientific basis for new policies on the planting of oysters and the harvesting of menhaden. And MDSG staff served on and advised the commissions that produced major policy shifts in management of both blue crabs and oysters. The following pages present highlights from these research and outreach efforts.

Building a Sustainable Blue Crab Fishery
Strategic Goal: Improve the scientific foundations for managing, conserving, and restoring our fisheries

Blue crabs are the most important fishery in the Chesapeake Bay with a harvest value of $108.8 million in 2010, contributing approximately $326.4 million in total economic activity in Maryland and Virginia. To support

management of this valuable fishery, MDSG research has helped build a more detailed explanation of population dynamics that helps to explain why blue crab harvests have been so unpredictable in the past. Research projects are now identifying in-Bay nursery areas for juvenile blue crabs and developing estimates of their carrying capacity.

MDSG has supported long-term studies that are revising our understanding of blue crab population dynamics. The new model documents how most crab larvae spend key life stages in offshore coastal waters where winds and currents control larval retention and return, a finding that helps explain the long-standing mystery of unexpected jumps and drops in blue crab harvests. MDSG extended this research line by supporting work by University of Maryland scientists Elizabeth North, Bill Boicourt, and Mike Roman that suggests the dominant forces behind blue crab population shifts are large-scale climate patterns like the North Atlantic Oscillation that drive winds and current conditions in offshore waters. Their field research has also provided new evidence that offshore crab larvae can sense estuarine water, change behavior, and improve their chances for returning to the estuary. New modeling work based on the researchers' field data suggests that blue crab ingress can vary by a factor of ten from one year to the next, evidence important for blue crab management that creates new pressure to conserve the in-Bay populations of blue crabs.

To inform management, MDSG spent years working with the Bi-State Blue Crab Advisory Commission in a long, contentious search for consensus on blue crab policy. One result was a Blue Crab Action plan, complete with the first scientifically derived numbers — based in part on research supported by MDSG — that managers could use for setting target and threshold levels needed for maintaining a sustainable fishery.

The Action Plan, however, was only put in place after a crisis: by 2007 the annual blue crab survey had completed a decade of low population numbers, creating a sense of urgency that finally led to new policies. In 2008, Maryland and Virginia and the Potomac River Fisheries Commission agreed to reduce the harvest of female crabs by 34 percent. The result has been a dramatic rise in the population of young blue crabs, a rise shaped both by seasonal weather events and by smart management. By 2012, an annual stock assessment had documented the highest crab population count since 1993.

MDSG-funded research has also focused on in-Bay nursery areas for blue crab juveniles, critical to estimating estuarine carrying capacity. Using field sampling, in-Bay experiments, and spatial modeling, scientists Denise Breitburg, Eric Johnson, and Tuck Hines of the Smithsonian Environmental Research Center showed that survival of blue crab juveniles remains higher in low-salinity, up-estuary sites, and they began identifying key nursery areas where management can focus its conservation efforts.

Reducing the harvest of female crabs can, of course, reduce income for crabbers and raise opposition to a management policy that is essential for maintaining a sustainable fishery. To mitigate these hardships and work around a traditional political roadblock, University of Maryland fishery scientists Tom Miller and David Brunnel, along with MDSG Extension leader Doug Lipton, completed a bioeconomic model that fishery managers can use to set policies that help crabbers maximize their revenues while reducing harvest to sustainable levels. The model compares the profitability of hard-shell versus peeler fishing and develops harvest reference points that reflect both the biology of the crab and the economic opportunities of the marketplace. Fishery managers with Maryland's Department of Natural Resources (DNR) are now using the model to analyze regulatory options and to refine blue crab fishing reference points.

Reducing the number of unused crab harvesting licenses was another policy step that would help Maryland's DNR manage a sustainable fishery. To advance DNR's proposed license buy-back effort, MDSG economists Jorge Holzer and Doug Lipton produced an analysis that helped set attractive and affordable prices. Working with their analysis and NOAA Disaster Relief funds, DNR was able to buy back 683 Limited Crab Catcher Licenses and 100 Tidal Fish Licenses at a cost of $2.25 million. The program lowered the likelihood that increases in the number of crabs will lead to sudden increases in the number of crabbers, an outcome that would disrupt current efforts to rebuild crab populations and maintain a sustainable fishery.

Expanding Blue Crab Markets

Strategic Goal: Develop technology for restoration, aquaculture, and marine products

To help the crab industry maximize profits during an era of harvest cutbacks and increasing market competition from imported crab meat, MDSG responded to a request from the Chesapeake Seafood Industries Association for new techniques for extending the shelf life of processed crab meat. Sea Grant Extension specialist Tom Rippen investigated, tested, and refined a flash freezing technique that could be used to freeze crab meat without compromising the unique creamy flavor of freshly picked Chesapeake blue crabs. Six processing companies are

now using this cryogenic freezing technique, allowing them to ship Maryland crab meat around the country and the world during all seasons of the year.

Promoting Oyster Aquaculture
Strategic Goal: Develop technology for restoration, aquaculture, and marine products

No fishery resource has drawn more management and restoration efforts over the decades than the oyster fishery — and no resource decline has proved as intractable. The last four years, however, may mark a historic turning point in the management of this fishery, a turning point that draws on several decades of MDSG-funded research and extension work on developing the potential of aquaculture. In 2010, the state of Maryland announced a new legal framework for aquaculture, opened up new areas for leasing, and began a number of programs to encourage and support new private investments in oyster farming. It also stepped up enforcement efforts to curtail poaching on oyster sanctuaries and private oyster leases.

The new approach grew out of work by the governor's Oyster Advisory Commission that was staffed in part and advised in depth by MDSG personnel. The commission's report provided the foundation for a new regulatory approach — and MDSG's work, in turn, helped provide the foundation for the commission's work. MDSG extension specialist Don Webster created for the commission a detailed historical and technical overview, a report that reviewed past aquaculture efforts and restrictive legal structures and outlined current aquaculture practices that could prove effective in Maryland waters. In addition, his report explained the concept of Aquaculture Enterprise Zones that could attract oyster growers and concluded with recommendations for renovating the leasing program and simplifying state laws, regulations, and programs. All of these are the new tools needed for improving oyster aquaculture.

The primary source for oysters used for restoration and aquaculture has been the Horn Point Shellfish Hatchery managed by MDSG Extension specialist Don Meritt. During 2008-2011, through improved technologies, the hatchery produced at an annual rate of 550 million spat on shell to supply multiple oyster restoration and aquaculture projects throughout the Chesapeake Bay. These included the government-supported Oyster Recovery Partnership, private oyster farmers, and oyster gardening programs organized by the Chesapeake Bay Foundation and other regional groups. The hatchery also supplies eyed larvae for use in remote spat setting tanks located around the state, including six sites used for training new oyster growers.

Restoring Oyster Populations
Strategic goal: Improve the scientific foundations for managing, conserving, and restoring fisheries

Successful oyster restoration depends on a science-based approach. To meet this need, MDSG put together an Oyster Restoration Evaluation Team to investigate and evaluate the scientific lessons from 17 years of oyster restoration. The goal was to assess restoration effectiveness — a critical issue for the scientists, fishery managers, watermen, seafood processors, political leaders, and environmental groups now committed to rebuilding oyster reefs in Chesapeake Bay. MDSG recruited a team of scientists and statisticians who sought to review data on 1,035 sites in Maryland and Virginia where restoration and monitoring projects took place between 1990 and 2007.

Challenges for completing this review included a reluctance on the part of some scientists and agencies to share data, a lack of consistency in data gathering and record keeping, and a lack of clarity about whether restoration was designed to advance ecological restoration or increase commercial harvests. Despite these difficulties the team collected 78,000 records of five types of restoration work: transplanting of wild seed, planting of hatchery seed, bar cleaning, bagless dredging, and the planting of oyster shell and other substrates.

The study produced a major paper in 2011 in the *Journal of Shellfish Research*,[1] an inventory of restoration work, and a set of recommendations, many of which are now being adopted to guide future oyster restoration work. The primary recommendations call for clarifying the goals of each restoration project, improving coordination between those who restore reefs and those who monitor them, setting up a stock assessment program to track the effects of restoration, and sharing data about both restoration and monitoring work, perhaps through a central collaborative database.

MDSG has continued to support research that advances science-based approaches to restoring and managing oyster populations. Research led by Denise Breitburg of the Smithsonian Environmental Research Center

[1] Kennedy, V. S.; D. L. Breitburg, M.C. Christman, et al. 2011. Lessons learned from efforts to restore oyster populations in Maryland and Virginia, 1990 to 2007. Jour. Shellfish Res. 30(3):719-731.

probed the linkage between two persistent problems: episodes of low oxygen (hypoxia) that intermittently extend from the deeper waters into the shallower zones and outbreaks of Dermo, a disease that kills oysters throughout Chesapeake Bay. In lab experiments the researchers examined the effects of short-term hypoxia cycles on the progression of the disease in shallow oyster-growing waters, work that helps identify suitable habitats for oyster restoration. Research begun by Roger Newell in 2011 is clarifying the connections between weather patterns, climate, and spat sets. Other research by Newell and his colleagues is investigating the ecological effects of oyster aquaculture operations. Their work will help also improve understanding of habitat and help target the best areas for planting new oysters — whether for restoration or aquaculture.

Understanding Striped Bass and Menhaden Population Dynamics
Strategic goal: Improve the scientific foundations for managing, conserving, and restoring fisheries

A decade ago, the recovery of striped bass stocks seemed to stand as the best evidence that smart, tough management can save a fishery. A fishing moratorium imposed during the mid-1980s was followed by a biological quota system imposed on both commercial and recreational fishermen. The result: fish stocks for striped bass rose from less than 9 million in 1982 to more than 70 million by 2004.

While that recovery seemed to be a success for single-species management, recent drops in populations of both striped bass and menhaden, its principal prey species, have highlighted the need for a more sophisticated approach based on ecosystem-based fisheries management. Findings in 2008-2011 from a number of fisheries scientists, some supported by MDSG, suggest that the striped bass recovery was driven not just by management policies alone but also by little-understood food-web relationships between predator and prey species and by less-understood weather-driven recruitment patterns that affect population levels.

One of the key goals in the MDSG strategic plan calls for implementing an ecosystem-based approach to fisheries management. By placing primary focus on the health and structure of the ecosystem, this approach considers both the economic benefits of sustainable yields as well as the ecosystem services a fish species provides. It is an approach requiring more detailed research on the population dynamics that control recruitment and on the interconnections among species sharing an ecosystem.

To better understand the factors underlying striped bass recruitments, MDSG-funded researchers Tom Miller, Dave Secor, and Allen Place of the University of Maryland are complementing traditional fish sampling approaches with chemical analysis and molecular genetics to investigate the little-understood role of genetic diversity in creating population resiliency in fish stocks.

As part of this research, these scientists became the first to sequence and publish the entire striped bass mitochondrial genome. Based on this sequence, they were able to confirm that all the temperate bass species are monophyletic, descended from one common ancestor. By using otolith counts to construct hatch dates and microchemistry and mulitvariate analysis to identify patterns in their dispersal histories, the researchers found evidence that young-of-the-year fall into two groups: one which tends to remain nearby and one which disperses. The ultimate goal is to determine whether age diversity among spawning females plays a central role in creating resiliency in a species.

Another essential need for ecosystem-based fisheries management is a more precise understanding of the role of ocean conditions in controlling the annual inflow of fish larvae into an estuary, especially for species like menhaden, an essential food source for striped bass and a profit center for Omega Protein whose plant in Reedville, Virginia is now the last remaining menhaden processing company along the Atlantic coast.

During 2008-2011, MDSG funded University of Maryland scientists Ed Houde, Elizabeth North, and Bill Boicourt to study patterns of larval ingress and identify the mechanisms affecting those patterns based on 18 sampling cruises (across the mouth of the Chesapeake Bay and Delaware Bay, over several seasons), followed by extensive analysis and modeling work.

Among their findings: more than 90% of the menhaden larvae entering the Bay had hatch dates prior to December 15, most of them arrived 30 to 60 days after hatching, and when they arrived their dominant prey species was copepods. One surprise was the poor correlation between larval ingress in winter and the young-of-the-year survey in August by the Maryland Department of Natural Resources, a finding that may lead to a reworking of sampling techniques used in regional monitoring programs. In addition, they reported a nine-fold difference between a good year for menhaden recruitment and a poor one, a finding that highlights the need for adaptive management strategies to consider climatologic influences in regulating fishing practices for both prey species like menhaden and predator species like striped bass.

Rethinking Fisheries Management

Strategic goal: Implement ecosystem-based fisheries management in Chesapeake Bay

As part of our commitment to advancing ecosystem-based fisheries management, MDSG launched a major multi-year project in 2008 to review and analyze the existing literature on this approach. The project recruited 85 scientists from more than half a dozen agencies and asked them to evaluate the existing scientific foundation, create synthesis statements to guide future research, and clarify the management adaptations that this approach might require.

The need for this kind of synthesis was clear. The drive for ecosystem-based fisheries management has met with push back: can fishery science identify, describe, quantify, model, and link up all the interactions that affect the fate and ecological role of fish species like striped bass and menhaden in an ecosystem as complex as the Chesapeake Bay?

This MDSG review project was the kind of pioneering work needed for advancing and applying ecosystem-based management. Organized into teams, these experts reviewed the literature and met in MDSG workshops to examine ecosystem needs and services and food web interactions of four key species: blue crabs, striped bass, menhaden, and the alosine group. As a result, in 2009 MDSG published a series of synthesis reports: each species was the focus of an in-depth Background and Issue Brief.[2] In addition, the program published short summaries.

The growing confidence in ecosystem-based fisheries management can be seen in last year's controversial decision by the Atlantic States Marine Fisheries Commission to decrease commercial harvests of menhaden in hopes of increasing the spawning stock of this important prey species. The decision gave strong weight both to the economic value of the commercial harvest and to the ecosystem services menhaden provide because of their central position in the food chain of the Chesapeake Bay. Scientists, sportsmen, and environmental organizations hailed the decision as "a historic step" toward ecosystem-based fisheries management.

The complexities of fisheries management will likely increase under an ecosystem approach, but confidence is clearly growing that the kind of sophisticated science and expert outreach supported by Maryland Sea Grant and other major funding agencies may be able to provide the tools that are needed for smarter, more adaptive management of the Chesapeake Bay's recovering fisheries.

MARYLAND SEA GRANT PROGRAM-WIDE METRICS

In the table below we offer some key additional, quantitative measures about MDSG's achievements that advanced coastal science and helped inform policy makers and the public about Maryland's coastal environment.

Some Measures of the Impacts Across All MDSG's Four Focus Areas, 2008-2011	
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Research	**Numbers**
Proposals Funded	66
PIs and Co-PIs Supported[1]	30/41
Unique Institutions Supported	24
Undergraduate/Graduate Students Supported[1]	103/42
Peer-Reviewed Journal Articles Submitted to Pell	90

[1] *PI, co-PIs and students funded for multiple years are only counted once.*

[2] Ecosystem-Based Fisheries Management: Species Team Background and Issue Briefs and Summary Briefs (for striped bass, menhaden, blue crab, and alosines). 2009-2011. Maryland Sea Grant. http://www.mdsg.umd.edu/store/reports/ebfm/

Maryland Sea Grant Performance Review Panel Summary Report

VIABLE COASTAL COMMUNITIES AND ECONOMIES
(Sustainable Coastal Development)

The Chesapeake Bay, its tributaries, and their associated biological communities are woven into the daily lives of people who live in Maryland's coastal communities. Bay residents depend on these natural resources for fishing, seafood-industry jobs, and recreation. Additionally, much of the local culture and history, as well as the sense of place enjoyed by many Marylanders, revolves around the Bay. The cumulative effects of human activities and rapid urban growth, however, have in many cases placed a strain on this environment, challenging the sustainability of the goods and services it provides.

To meet the goals in our focus area on Viable Coastal Communities and Economies, Maryland Sea Grant (MDSG) strategically directed our research, education, extension, and outreach efforts during 2008-2011 in ways that built on our tradition of successfully engaging with multiple audiences. We collaborated across disciplines to develop new and innovative projects to help local communities respond to and manage diverse challenges, including excess nutrients, stream degradation, and threatened fisheries resources. MDSG Extension agents also worked to provide new tools for officials and planners in local and regional governments to prepare for and manage urban growth while maintaining the viability of the surrounding environment and the survival of long-held cultural traditions.

MDSG efforts were developed in concert with a federal and state effort known as the Chesapeake Bay Action Plan. This plan, called for by a 2009 presidential order, incorporates unprecedented levels of oversight that tie funding to implementation, ensuring that protection and restoration targets for the Bay are met.

Such targets require the effective management of natural resources, a goal MDSG pursued while simultaneously working to encourage economic growth in the region. These efforts included projects addressing the health and restoration of Chesapeake Bay oyster populations, which have plummeted over the last 30 years. To accelerate the development of the Chesapeake Bay's oyster aquaculture industry, MDSG launched several new projects in 2008-2011 that expanded oyster production and created new job opportunities, both priorities under the Chesapeake Bay Action Plan. Simultaneously, MDSG Extension facilitated efforts to improve management of the blue crab fishery and to improve seafood product development and safety.

2008-2011 IMPACTS

- Partnered with Watershed Stewardship Academies to train 100 Master Watershed Stewards who worked with 700 volunteers planting more than 300 trees, installing over 300 rain barrels, and implementing over 14,000 square feet of rain gardens and 4,000 square feet of conservation landscaping to control urban stormwater runoff.
- Funded research on denitrification capabilities of restored streams and created maps of buried streams throughout the watershed to assist decision makers with stream restoration and permit decisions.
- Supported research to develop web-based models and GIS resources for land use managers to work with in planning for different land-use scenarios on Maryland's Eastern Shore.
- Assisted oyster aquaculturists in obtaining 26 low-interest startup loans totaling $1.7 million; helped develop new state policies encouraging oyster aquaculture.
- Developed and tested improved methods for crab meat product preservation that were adopted by six Maryland seafood-processing companies, increasing product value and providing an estimated $6.3 million increase in revenues in 2011.
- Partnered with a Maryland seafood company to improve the packaging and marketing of its crab soup, a project that is expected to produce 25 new jobs by the end of 2012.
- Collaborated with other Sea Grant programs to design and distribute 245 beach signs to warn swimmers about the dangers of rip currents; devoted an issue of our magazine *Chesapeake Quarterly* to rip current science.

Two other highlights of MDSG's Viable Coastal Communities and Economies portfolio were efforts to inform the management of dredged material and to educate swimmers about the dangers of rip currents.

In sum, MDSG's projects on Viable Coastal Communities and Economies in 2008-2011 significantly advanced our progress toward meeting the goals, performance measures, and objectives in our strategic plan. Many of these projects, and their associated benefits, continue today. We highlight the most significant of our impacts below and identify the MDSG strategic plan goals they meet.

Community Assistance to Protect Chesapeake Bay Watersheds
Strategic Plan goal: Support and enhance sustainable coastal land use and restoration

Decades of studies, many supported by Maryland Sea Grant, show that fluxes of nitrogen, phosphorous, and sediment into the Chesapeake Bay have increased eutrophication, degraded critical habitat, and reduced fisheries resources, threatening the economic and recreational benefits provided by the Bay. Federal and state efforts to reverse these trends and protect waterways through the Chesapeake Bay Action Plan require municipalities to meet new targets (Total Maximum Daily Loads or TMDLs) for improving water quality and reducing stormwater inputs. Most communities, however, lack the information and funding needed to adapt to these new management requirements.

Recognizing its unique role in fostering community understanding of these new management challenges, MDSG developed a number of programs during 2008-2011 to help communities with planning and implementing watershed restoration projects. In 2009, MDSG helped create the Watershed Assistance Collaborative by partnering with the Chesapeake and Coastal Program of the Maryland Department of Natural Resources (DNR) and the Chesapeake Bay Trust. In 2010, the Collaborative leveraged $1.05 million through the Watershed Assistance Grant Program. Watershed specialist agents from MDSG Extension trained volunteers and gave technical assistance to 38 separate communities, helping them to identify, design, and engineer shovel-ready Bay restoration projects such as rain gardens and stormwater retention ponds for managing urban runoff. The Collaborative also worked with the University of Maryland Environmental Finance Center (a program founded by MDSG in 1992) to develop financing strategies to support restoration activities in two Maryland Eastern Shore watersheds.

By coordinating with officials from five different counties and the District of Columbia, MDSG helped create and operate Watershed Stewardship Academies to expand outreach about watershed restoration to more communities and individuals. Using "train-the-trainer" curricula, these academies teach volunteer community leaders to identify pollution sources and reduce stormwater runoff by implementing best management practices. The academies have reached out to high school teachers and students and have fostered a number of high-profile restoration projects. Dozens of master watershed stewards have also graduated from the program (see Impacts box).

Supported by a grant from the Chesapeake Bay Trust, MDSG communications staff member Erica Goldman and Extension specialist Amanda Rockler worked together in collaboration with the consumer website, Angie's List, to broadcast information about watershed restoration to an even wider audience. MDSG produced five short videos for the Angie's List How-To Video website that offer viewers step-by-step instructions on how to install and maintain rain gardens. To evaluate the videos, MDSG conducted two focus group meetings with local citizens. In conjunction with the videos, Rockler was also interviewed about rain gardens for the Angie's List print magazine, which has more than 1 million subscribers. We also uploaded the videos to the Maryland Sea Grant YouTube Channel and featured them on a newly created rain garden page on our website. Coupled with this effort, MDSG Extension agents helped to install 21 residential rain gardens and five large stormwater retention areas as demonstration projects.

Restoration Science Informs Management Decisions
Strategic Plan goal: Develop tools for improved coastal management

During 2008-2011, MDSG strategically shifted its focus to research that will improve our understanding of nutrient cycling and stream water ecosystem function in the Chesapeake Bay watershed and in coastal bays along the Atlantic Ocean. These studies cut across two goals in our strategic plan: (1) Develop Tools for Improved Coastal Management and (2) Support and Enhance Sustainable Coastal Land Use and Restoration. Scientists investigated whether stream restoration projects hold the potential to significantly increase rates of denitrification and reduce nitrogen inputs to other waterways and the Bay.

In 2008, researcher Sujay Kaushal and collaborators quantified the denitrification potential of several restored streams in nine study sites across the Baltimore region. They found that stream restoration designs can

accelerate nitrogen uptake and denitrification rates by building in structures that increase hydrologic residence time, amplify exchange between surface and groundwater, and expand organic carbon availability. This research provided key data for the team's current efforts to build a large scientific database to catalogue information on design features, numbers, costs, and river miles of implemented stream restoration projects. This database tool will allow scientists to collate existing data on best management practices for stream restoration and assess their effectiveness in improving water quality and quantity. With input from MDSG Extension watershed experts, the researchers met repeatedly with local water-quality managers and policy makers to discuss the implications of their findings for watershed management practices and implementation. Their research also informed water quality targets and goals set by the Chesapeake Bay Action Plan.

In a related stream restoration project, MDSG funded ecologist Andrew Elmore and his graduate student to map buried streams in much of Maryland's Chesapeake Bay watershed. Many streams buried by development have lost important ecosystem function. Uncovering and restoring them to their natural condition, however, can regain their ecosystem function. The team combined old satellite data with USGS land-cover information from aerial photography to produce land-cover data dating back to 1975, including the locations of buried streams. These maps are now accessible over the web to land managers. Their importance is already clear, as they were quickly adopted by the Maryland Department of Natural Resources and used to set permit requirements for a mine in Garrett County, Maryland and increase the total stream area protected around that mine.

Closer to the coast, MDSG strategically supported research and outreach that equipped Maryland communities with tools and guidance to help them respond to their changing landscapes and the corresponding pressures on ecosystem health and resilience. MDSG funded Glenn Moglen and his team to develop a modeling tool for municipalities on the Delmarva Peninsula to inform discussions on the impacts of urban growth on the environment. Called GISHydro, this tool allows planners to easily test the effects of different future scenarios of land use on local nutrient loading and water use. Working alongside MDSG Extension agents, the researchers conducted workshops that showed planners how to use to this free, web-based tool.

In a related project, MDSG supported systems ecologist Lora Harris to develop a different watershed modeling tool for use by planners along Maryland's coastal bays. Using this simple tool for predicting how nitrogen, phytoplankton, and zooplankton respond to changes in watershed land use, planners can generate information on how to best manage land use to meet state and federal water quality targets. Such tools will become increasingly important as state and federal agencies require Maryland municipalities to drastically reduce their nutrient loads.

Lastly, MDSG supported research to guide efforts at restoring native marshes around the Chesapeake Bay. These natural communities provide valuable ecosystem services to the region, contributing to reductions in nutrient loads and sediments to the Bay and its tributaries. In 2008-2011, soil scientist Brian Needelman investigated the effectiveness of prescribed burns for expanding marsh and plant growth. The team showed that this approach can, indeed, effectively support the restoration of certain marsh species, a finding that had yet to be documented despite the widespread use of prescribed burns in regional management.

Restoring Native Oysters

Strategic Plan goal: Foster sustainable coastal economic development

During 2008-2011, MDSG continued our strong research and outreach program to complement state and federal efforts to protect and restore Maryland's native oyster (*Crassostrea virginica*) population. Today, the Chesapeake Bay's wild oyster population, decimated by disease, overfishing, and habitat loss, sits at about one percent of its historic level. Research supported by MDSG and others has documented the role of oyster reefs in cycling nutrients, removing suspended particulates, improving regional water quality, and expanding the hard bottom habitat for fish and invertebrates. Extension work supported by MDSG aided restoration projects that could revive these ecosystem services and help develop aquaculture options.

Recognizing the need to expand job opportunities and increase oyster production in the region, MDSG Extension worked to develop public policies supportive of oyster aquaculture. An Extension Aquaculture Action Team collaborated with policy makers to pass new legislation in 2009 that now permits greater numbers of Marylanders to obtain oyster aquaculture leases in more Maryland Bay waters — historic legislation that makes it easier to farm oysters. Through this effort, the state opened 600,000 acres for future private aquaculture leases in 2010. The Maryland Department of Natural Resources also began accepting applications for leases under new rules that were shaped by recommendations from our Extension agents.

In 2011, MDSG Extension agents similarly worked to encourage watermen to transition from wild oyster harvesting to aquaculture by organizing a week-long training course at the University of Maryland Center for

Environmental Science (UMCES) hatchery, four regional workshops on oyster growing, and a statewide conference on aquaculture. Since the costs of oyster seed and aquaculture equipment necessary to launch an aquaculture operation are a roadblock to many potential oyster farmers, MDSG Extension worked with individuals to help them improve their business plans and strengthen their applications to gain aquaculture start-up loans offered by the state in 2011. That state program awarded 26 low-interest loans (starting at 3%) totaling $1.7-million. Based on an analysis by a MDSG Extension economist, expanding aquaculture in Maryland is projected to create and sustain 250 jobs and have a $25 million economic benefit to the state over the next several years.

The primary source for oysters used for restoration and aquaculture has been the Horn Point Shellfish Hatchery managed by MDSG Extension specialist Don Meritt. During 2008-2011, the hatchery used improved technologies to produce 550 million spat on shell annually, an output that supplied oyster restoration and aquaculture projects throughout Maryland's Chesapeake Bay. Clients included the government-supported Oyster Recovery Partnership, private oyster farmers, and oyster gardening programs organized by the Chesapeake Bay Foundation and other regional groups. The hatchery also supplies eyed larvae for use in remote spat setting tanks located around the state, including six sites used for training new oyster growers.

To improve public understanding of the Chesapeake's oyster fishery, MDSG filmmaker Michael W. Fincham produced an hour-long documentary film that explored research on the causes of the oyster decline and examined options for oyster restoration in the Bay. *Who Killed Crassostrea virginica?* focused on the effects of overfishing, disease epidemics, habitat destruction, and sediment runoff and portrayed the ongoing effort to rebuild oyster reefs. A national broadcast on C-Span in 2010 was followed by regional broadcasts in 2011 and 2012 organized by Maryland Public Television, reaching an estimated 400,000 viewers in eight states. In addition, the filmmaker also participated in a series of public film screenings and film festivals that included discussions about oyster restoration options.

Promoting Effective Methods in Seafood Safety and Crab Meat Processing
Strategic Plan goal: Foster sustainable coastal economic development

Even with the recent progress in oyster cultivation, the blue crab (*Callinectes sapidus*) fishery remains, by far, the largest commercial fishery in Maryland, providing income to many fishermen and seafood processors. To support the industry's profitability and ensure a safe seafood supply, Maryland Sea Grant Extension agent Tom Rippen expanded his critical work in 2008-2011 to help seafood processors maintain standards of sanitation. His efforts helped processors decrease *Listeria* bacteria contamination in crab meat, thus improving the industry's reliability in the region. MDSG estimates that participating companies experienced a 20-percent increase in revenues in 2011, amounting to a sales increase of about $4.6 million in 2011.

In another industry effort, the Chesapeake Seafood Industries Association worked with Rippen to develop a new method of preserving crab meat (cryogenic freezing) as a more-attractive alternative to pasteurization. Surveys have shown that some consumers dislike the taste of pasteurized product. Rippen used federal funds provided to the crab industry to explore flash freezing as a method to generate a product that could be frozen, thawed, and then sold without compromising its flavor. MDSG researchers studied and defined ideal production methods and conducted cost-benefit analyses of three different freezer sizes. Six processing companies now use cryogenic freezing techniques, providing them with an estimated $6.3 million increase in revenues in 2011. The Chesapeake Bay Seafood Industries Association praised MDSG for its efforts.

Additionally, in an effort to build up coastal communities and create jobs, Rippen partnered with a Maryland seafood company to improve the packaging and marketing of its crab soup, a project that is expected to produce 25 new jobs by the end of 2012.

Disposing of Dredged Sediments
Strategic Plan goal: Support and enhance sustainable coastal land use and restoration

To support the viability of the Port of Baltimore, the largest driver of Maryland's economy, Jonathan Kramer, MDSG's then-director, led a scientific synthesis that evaluated options for disposing of sediments dredged from Baltimore Harbor. Facing limitations at its existing disposal sites, the Maryland Ports Administration sought a scientific and technical review of sediment quality in the harbor along with guidance on state and federal criteria for sediment quality assessment. Funding for the study was provided by the Maryland Environmental Service. The recommendations that came out of the study are now used to guide dredged material management strategies. MDSG communications helped produce a study report for the Maryland Ports Administration, then published a

technical report[1] summarizing the study and a 4-page summary brief explaining the findings of this report to the general public. All of these reports are available on the MDSG website.

Educating Swimmers about Rip Currents
Strategic Plan goal: Build knowledge, research, and stewardship capacity in coastal communities

MDSG's outreach and research also address coastal hazards, including the dangers that rip currents pose to swimmers. In 2008, MDSG supported civil engineer Tony Dalrymple to improve rip current forecast capabilities and, ultimately, provide lifeguards and other safety personnel with better information on rip current patterns.[2] MDSG also reached out to beach goers in Maryland and elsewhere through innovative signage to educate them about the dangers of rip currents, distributing 50 signs to be placed on Ocean City beaches in 2006. In 2009, several Sea Grant programs became aware that there were a large number of Spanish speakers at various beaches who should be targeted for rip current awareness. To better educate this portion of the public, MDSG took the lead in creating a bilingual Spanish/English sign. MDSG Extension specialist Vicky Carrasco, a native-Spanish speaker, translated the signs and served as a consultant for the design. A total of 245 signs were distributed: 50 by MDSG in Ocean City, Maryland and the rest by Sea Grant programs in Texas, Massachusetts, Delaware, Wisconsin, and Michigan.

To reach an even wider audience, MDSG published a special issue of our magazine *Chesapeake Quarterly* focusing on rip currents.[3] In 2010, the United States Life Saving Association reprinted the magazine's lead story in full in its national publication, *Lifeguard*, which the Association distributed to more than 15,000 lifesaving professionals across the country.

IN 2008-2011, FOR THE VIABLE COASTAL COMMUNITIES AND ECONOMIES focus area, Maryland Sea Grant worked with multiple audiences in diverse ways to sustain Maryland's coastal communities and economies through our projects to improve water quality, land-use planning, and to assist the aquaculture and seafood industries. MDSG strategically planned projects to meet local, regional, and national goals, and the results were of high quality and impact.

[1] Kramer, J.G., J. Smits, and K.G. Sellner. Sediment in Baltimore Harbor. 2009. Maryland Sea Grant. http://www.mdsg.umd.edu/programs/policy/coastal/dredging/

[2] Dalrymple, R.A., J.H. MacMahan, A.J.H.M. Reniers, and V. Nelko. 2011. Rip Currents. Annual Review of Fluid Mechanics 43:551-81.

[3] Keeping Swimmers Safe. Chesapeake Quarterly magazine, August 2009, Volume 8, Number 3. Maryland Sea Grant. http://www.mdsg.umd.edu/CQ/V08N3/index.html

MARYLAND SEA GRANT PROGRAM-WIDE METRICS

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Maryland Sea Grant Performance Review Panel Summary Report

UNDERSTANDING THE REGIONAL EFFECTS OF CLIMATE CHANGE AND SEA LEVEL RISE AND THEIR IMPACTS ON COASTAL COMMUNITIES AND ECOSYSTEMS
(Hazard Resilient Coastal Communities)

Our strategic goals for climate change and sea level rise focus on building the knowledge base needed for meeting the risks and challenges that climate change raises for Maryland communities, both human and natural.[1]

Climate change is both a global and local issue. Like the residents of many coastal regions, Marylanders living in the Chesapeake Bay watershed face a number of climate change-related threats. Perhaps the most pressing is the potential increase in extreme precipitation events predicted by many climate change models. Thousands of residents in scores of communities could be at risk from severe flooding that could threaten economies and built environments. Since 2010, Extension specialists from Maryland Sea Grant (MDSG) have been engaging these communities through a number of educational programs designed to explain the risks climate change poses, to help them prepare for these changes, and to aid them in developing policies that can counter those potential impacts. MDSG's communications staff has been producing print and multimedia publications to advance public understanding about the local impacts of global climate change.

For 35 years, the strength of MDSG's programs has been our support for foundational science to help build the knowledge base to inform the decisions of Maryland stakeholders, from policymakers and resource managers to citizens in Chesapeake watersheds. In addressing the complexity of climate change, a relatively new focus area for MDSG, we are continuing this science-based approach. We have funded two new research projects: the first focuses on how local marsh communities are likely to respond to rising sea levels, changes in CO_2 emissions, and the invasion of the common reed *Phragmites*; the second supports paleoclimate research to decipher past and future ecosystem responses to sea level rise in the Chesapeake Bay region. The findings from these research projects will help MDSG provide natural resource managers and communities with new insights into conserving these habitats.

2008-2011 IMPACTS

- Conducted forums with citizens in several rural Maryland counties to raise awareness about flood risk under changing climate conditions.
- *Chesapeake Quarterly* magazine issue on climate change and sea level rise.
- Funded research to elucidate potential regional trajectories of relative sea level change in response to changing climate conditions.

Helping Coastal Communities Adapt to Climate Change

Many municipalities on the low-lying shores of Chesapeake Bay and its tributaries are highly vulnerable to sea level rise and storm surges. In 2010 and 2011, MDSG worked to educate residents and policy makers in Maryland about these risks and to help them plan for the future.

To this end, MDSG's Extension staff, led by Vicky Carrasco, designed a pilot outreach program in partnership with the Maryland Department of Natural Resources (DNR) that informed citizens in three rural areas in Talbot County about storm water management, shoreline erosion, and flooding hazards. Extension staff helped convene public forums to work with residents and identify areas in their communities that are vulnerable to flooding. Based on resident comments, a consulting firm then ranked possible responses by costs and benefits. MDSG plans to replicate these forums in other shoreline communities.

MDSG Extension also took a leadership role in helping to fund a statewide Climate Change Needs Assessment. For this project, researchers interviewed and surveyed regional land use planners about climate change and

[1] Najjar, R., C.R. Pyke, M.B. Adams, D. Breitburg, C. Hershner, M. Kemp, R. Howarth, M. Mulholland, M. Paolisso, D. Secor, K.Sellner, D.Wardrop, and R.Wood. 2010. Potential climate-change impacts on the Chesapeake Bay. Estuarine Coastal and Shelf Science 86:1-20. [doi:10.1016/j.ecss.2009.09.026]. MDSG support.

its effects. This information will help MDSG and its partners identify funding and information needs for local communities to help them plan for climate change. Our Extension and communications staff also designed a new educational website focusing on climate change (http://www.mdsg.umd.edu/climate).

Communicating about Climate Change through Print and Online Media

To inform decision making by citizens and government agencies, MDSG's communication staff creates products designed to explain complex science and policy issues to diverse audiences. In 2010, MDSG's magazine *Chesapeake Quarterly* devoted an issue to climate change,[2] providing in story form the latest findings from regional climate change research and its management implications. One article, titled "Going to Extremes: The Storm over Hurricanes," clarified the science underlying the forecasts that predict stronger storms and heavier rainfalls in the Atlantic basin. Another article, "Before the Next Flood: Contending with Climate Change on Maryland's Eastern Shore," discussed proposals for new land-use regulations and building codes aimed at protecting Bayside homes from floods. In another effort, MDSG Communications worked with Professor Michael Kearney of the University of Maryland Geography Department and with the Maryland DNR to create digitally altered photographs that demonstrate dramatic visualizations of the impact that predicted sea level rise could have on many well-known landmarks in Maryland. This educational tool was used by DNR and is now available on MDSG's website.

Exploring the Impact of Climate Change on Marsh Species

Marshes provide critical ecosystem services in the Chesapeake Bay: they can retain and transform nutrient inputs and help reduce nutrient flows to estuarine waters. In addition, marshes can act as sediment sinks, a process that can raise marsh height, armor shorelines against erosion, and maintain marsh integrity. Research-based studies are critical for improving our understanding of how marshes may respond to accelerated rates of sea level rise and extreme storm events — both are likely scenarios under current climate change predictions.

To study responses of Chesapeake Bay marshes to climate change, MDSG directed program development (PD) funds to the Smithsonian Environmental Research Center (SERC) to develop new field experiments with their Global Change Research Wetland project that will examine the invasion patterns of the non-native marsh species *Phragmites australis* under different climate change scenarios. While sea level rise presents significant risks to many marsh species, elevated CO_2 in the atmosphere may actually help plants like *P. australis* to disperse upland and inland from existing stands of wetlands. The researchers are exploring whether elevated CO_2 might increase the common reed's growth, paradoxically decreasing marsh plant diversity while potentially increasing marsh resilience.

To test this hypothesis, biogeochemist Patrick Megonigal and colleagues at SERC successfully designed, tested, built, and deployed open-top CO_2 treatment chambers at the interface of invasive *P. australis* and the native plant community in a brackish marsh. These chambers allowed the team to monitor the displacement of native marsh plants by the common reed as atmospheric CO_2 increased. This work continues as a larger project now funded through MDSG's 2012-2014 biennial omnibus award.

In a second study supported by MDSG PD funds, paleoclimatologist Hali Kilbourne explored how local sea level in the Bay controls the composition of communities of microfauna in marshes. The team discovered that sea level influences the distribution of foraminifer species in predictable ways in marshes in Maryland and Virginia. Such a relationship could be used to determine trajectories of relative sea level change in marshes around the Chesapeake in response to changing climate conditions and sea level rates; these findings could help guide policy and management decisions on how to best adapt to the changing coastal environment through a more complete understanding of marsh response to sea level rise.

THOUGH CLIMATE CHANGE IS A RELATIVELY NEW FOCUS AREA FOR MDSG, our work with multiple partners is expanding research and outreach efforts to increase our understanding of and adaptation to the effects of climate change. Recent efforts include several new research projects supported with funding from our 2012-2014 omnibus research cycle. As new research keeps broadening our knowledge of how ecosystems might respond to climate change, our outreach work will keep exploring ways in which Marylanders might prepare for the future.

[2] Ready for Rising Waters? Chesapeake Quarterly magazine, December 2010, Volume 9, Number 4. Maryland Sea Grant. http://www.mdsg.umd.edu/CQ/V09N4/

MARYLAND SEA GRANT PROGRAM-WIDE METRICS

In the table below we offer some key additional, quantitative measures about MDSG's achievements that advanced coastal science and helped inform policy makers and the public about Maryland's coastal environment.

Some Measures of the Impacts Across All MDSG's Four Focus Areas, 2008-2011	
Education and Outreach	**Numbers**
Workshops and Meetings Organized or Supported	346
Presentations at National Meetings	316
Students/Teachers Reached	54,278/310
Curricula Created	38
Research	**Numbers**
Proposals Funded	66
PIs and Co-PIs Supported[1]	30/41
Unique Institutions Supported	24
Undergraduate/Graduate Students Supported[1]	103/42
Peer-Reviewed Journal Articles Submitted to Pell	90

[1] *PI, co-PIs and students funded for multiple years are only counted once.*