SEPTEMBER 1980 - JANUARY 1983

# PROGRESS REPORT

University of Delaware

# Sea Grant

COLLEGE PROGRAM

Partnerships in Progress

# PROGRESS REPORT

## University of Delaware Sea Grant COLLEGE PROGRAM




This annual report was produced by the University of Delaware Sea Grant College Program under Grant No. NA80AA-D-00106 from the Office of Sea Grant, National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce. The U.S. Government is authorized to produce and distribute reprints for governmental purposes notwithstanding any copyright notation appearing hereon.

Published by the University of Delaware Sea Grant College Program
Newark, Delaware 19716
DEL-SG-07-85

Dear Friends,

The Sea Grant College Program at the University of Delaware has been active in research, education, and service for the past 14 years. This report discusses the program's progress from 1980 to 1983 and is entitled "Partnerships in Progress." We have chosen this theme because we attribute much of our progress in the better understanding and usage of marine and coastal resources to partnerships with the state of Delaware, the federal government's National Oceanic and Atmospheric Administration (NOAA), and marine business and industry interests from the private sector.

We believe that such partnership endeavors are consistent with the University of Delaware Sea Grant College Program's goal of stimulating practical marine resource development and use through application-oriented research, education and training, and advisory services. And we believe that these partnerships are vital to our success. They have provided valuable intellectual and financial resources, enabling the University of Delaware Sea Grant College Program to take an effective, coordinated, and objective approach to marine issues that affect not only Delaware and the Mid-Atlantic region, but the nation at large.

In the instance of research partnerships, the associations between Sea Grant scientific investigators and their counterparts in the laboratories of federal research insitutions and private industry have been characterized by a high level of cooperation and collaboration.

In education, the University of Delaware Sea Grant College Program and partners in industry and business have joined to train young professionals in marine studies. Other educational efforts have been made through the Marine Advisory Service, where our specialists have made partners at every level of the marine industry—from marina owners who need help in solving small boat berthing and storage problems to local business groups who want to conduct a study to document the economic impact of recreational fishing on Delaware's economy.

Highlighted in the pages that follow are a number of important unions that have been established between the University of Delaware Sea Grant College Program and industries, universities, state and federal agencies, and individuals concerned about marine-related issues. While the impact of every partnership cannot be measured in dollars, each has contributed in its own specialized way to a better understanding of marine and coastal issues.

Sincerely yours,

Carolyn A. Thoroughgood

Carolyn A. Thoroughgood
Executive Director

Andrew T. Manus

Andrew T. Manus
Assistant Director,
Sea Grant
Director, Marine
Advisory Service

University of Delaware
Sea Grant College Program

# *MARINE RESOURCE UTILIZATION*

*In the late 1960s, a microscopic parasite killed half of the Delaware Bay's oyster propulation. A predatory snail is victimizing further the shellfish that many of us enjoy eating and some rely on for a living. How can we protect and enhance this declining fishery?*

*Roughly 95% of the earth's water resources are too saline to grow crops. Every year, over 500,000 acres of the world's prime farmlands become too salty to raise food. How will we grow food in the future?*

*Delmarva crab processors generate an estimated 2,500 tons of blue crab shells every year. Because the shells are so foul-smelling, local officials are beginning to close county landfills and dump sites to processors. Now how will the processors get rid of the shells?*

*These are some of the problems that University of Delaware Sea Grant researchers in Marine Resource Utilization have been working to solve. During the proposal period from September 1980 to January 1983, our mariculturists succeeded in designing and operating a model system for growing oysters and clams indoors. What they learned from the model's full year of operation may enable us to grow shellfish as easily as poultry some day. Delaware Sea Grant biochemists also moved closer to developing a chemical bait to control the oyster drill, a predatory snail. Confident that halophytes could provide many areas of the world with needed food some day, our experts continued to grow the salt-tolerant plants, producing stronger strains than ever before. And in chitin research, our scientists took major steps toward the development of chitin sutures and chitin animal food additives, turning what was once waste—crab shells—into valuable products.*

## Mariculture System Technically Feasible, But Premature to Operate Economically

R/A-4 Controlled-Environment Mariculture: Management and Supportive Services—Ellis T. Bolton.

From the mariculture project's inception at the University of Delaware, researchers pursued development of a commercially viable, intensive system for the production of oysters and clams—a system requiring, at a minimum, a dependable supply of molluscs including broodstock and their offspring, a nutritionally adequate and ample feed supply, and a seawater medium compatible with the bivalves and their microalgae feed.

According to project manager Dr. Ellis Bolton, little was known about the fundamental requirements for life support of shellfish and algae in confined, artificial environments at the onset of the project. "But thanks to more than a decade of research efforts," he says, "we largely satisfied these requirements, successfully building a controlled-environment recirculating-seawater system, which demonstrates the technical feasibility of 'the Delaware process.' "

Crucial to the model's operation were developments made by Delaware researchers over the past ten years in the following areas:

- Conditioning and maintenance of broodstock
- Rearing of larvae through metamorphosis
- Rearing of spat and seed
- High-rate production of algae at high concentrations under bright light
- Rearing of oysters at high temperatures by delivering large amounts and high concentrations of algal feed with pulse-feeding techniques.

Although the operation of the intensive mariculture model is technically feasible, it is not yet economically feasible primarily because only certain species of microalgae support the growth and development of commercially desirable bivalves throughout their life cycles, and the cost of producing these algae is high—from \$20 to \$50 per pound (dry weight). For every pound of algae, three to five pounds of oysters (live weight, including shell) can be produced. Thus the cost of oyster production attributable to feed is \$4 to \$17 per pound of oysters (live weight, including shell). In the current marketplace, the retail price for adult oysters ready for human consumption ranges from a few cents to one dollar per pound (live weight, including shell).

"It appears that any process dependent on cultured algae as principal feed has little if any potential for economically producing adult bivalves," Bolton says. "Yet our system might be commercially viable for producing seed oysters, which currently retail at between $100 and $300 per pound (live weight, including shell). In the future, we plan to explore further this possibility as well as work to develop a less costly way to produce oyster feed."

### Partners Sharing Mariculture Technology

The following commercial enterprises have made use of some or all of the Delaware mariculture project's improved technical methods:

- System Culture Incorporated, Kahuku, Hawaii
- Aquatic Farms, Inc., Kaneohe, Hawaii
- Cultured Clams, Inc., Dennis, Massachusetts
- Indian River Mariculture Corporation, Massey's Landing, Delaware
- SATMAR, La Saline, Barfleur, France
- International Shellfish Enterprises, Inc., Moss Landing, California

## Growing Oysters in an Artificial Environment: The Operation of Delaware's Prototype Unit

R/A-6 Design, Construction, and Test Operation of an Oyster Production Prototype Unit—Jeffrey Thielker.

A few decades ago, the microscopic parasite *Minchinia nelsoni* (also known as MSX) severely threatened Delaware Bay's oyster population; consequently, researchers began thinking of ways to grow oysters like poultry—in a controlled environment. At the University of Delaware, Mr. Jeffrey Thielker and a technical team aplied the results of more than a decade of work by his colleagues and succeeded in completing the design and operating continuously for over a year, a recirculating seawater prototype for the production of oysters and clams.

During the operational period (from 1980 to 1981), 300,000 gallons of seawater from Indian River Inlet, Delaware, were transported by tank truck to the University of Delaware's Smith Laboratory in Lewes, diluted with tap water, fertilized

Dr. Ellis Bolton monitors the water in an algae-growing tank in the "greenhouse," part of the University of Delaware Sea Grant's mariculture project conducted at the Marine Studies Complex in Lewes.

with mineral nutrients, and recirculated through the system, which was made up of three integrated subsystems—for oyster production, algal production, and water and waste handling.

The schematic diagram in Figure 1 shows the major components of the system and the direction of material transfer. Two species of marine algae—the diatom *Thalassiosira pseudonana,* strain 3H and the flagellate *Isochrysis galbana,* strain Tahiti—were released sequentially from culture tubes to oyster tanks at a rate sufficient to maintain a relatively constant cell density during each feeding period. Overflow was collected in a sump, where a recirculation pump moved water back into the oyster tanks, providing flow velocities necessary for algae and oxygen dispersion. A liquid-level limit switch activated a pump to transfer water from the sump back to the algae culture tubes to control the sump volume during continuous additions. Thus most of the water passing through the parallel oyster tanks was recycled internally, while a volume equal to that, metered in as algal medium, was returned to the tubes. Metabolism and respiration of the oysters increased $NH_3$ in solution and reduced levels of dissolved oxygen in the water returning to the algae culture tubes, thus enhancing phytoplankton productivity. The dissolved organic load of this water supported a bacterial population, further decreasing the $O_2$ content.

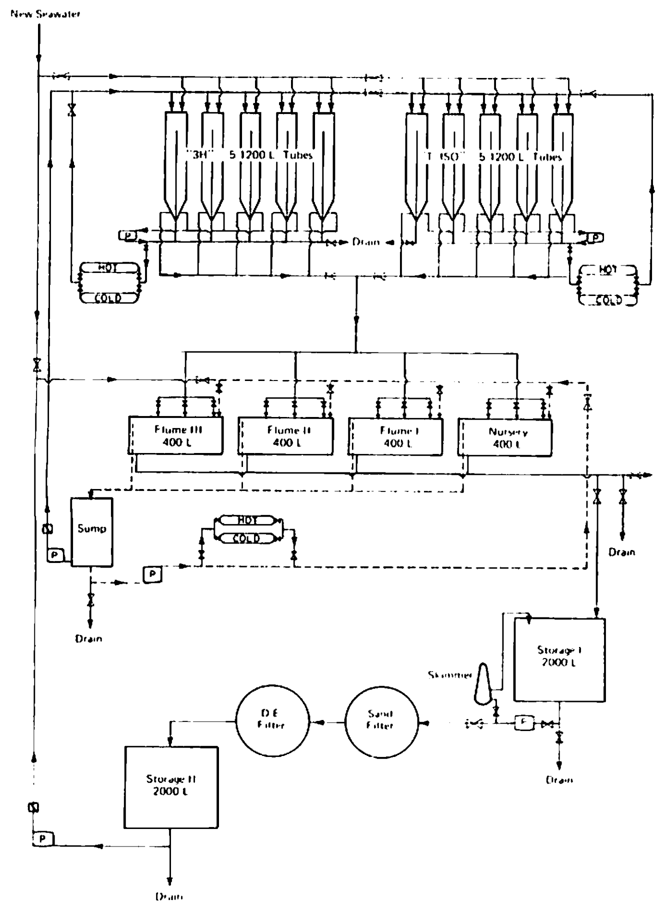



Figure 1. Schematic diagram of Delaware's controlled-environment recirculating seawater prototype.

The steps taken between the sequential feeding periods are outlined in Table 1. At time zero, the flow from the algal production units was terminated, while recirculation in the oyster tanks proceeded. During this one-hour period, oysters were allowed to clear most of the cells from the water. Recirculation was then terminated and the water was drained into Storage Tank 1. The foam fractionator was then activated to remove dissolved organics and a portion of the suspended solids from the water in Storage Tank 1 before it was passed through the filters and into Storage Tank 2 for disinfection procedures. After the algae distribution and circulation loop was flushed with fresh water, the oyster tanks were refilled from Storage Tank 2, containing seawater originating from the previous cycle. The feeding cycle was then reestablished.

This scheme provided for two feeding periods per day. One reactor module containing a single algae was involved in each cycle, thus maintaining species isolation.

## Results

On the average, oysters grew at a constant rate, but reached about one-fifth of their specified size, converting only 3% of the algal food they filtered. Although typical amounts of water, ash, protein, glycogen, and fat comprised the oysters' meat, and typical amounts of mineral and organic matter made up their shell, the shell was fragile.

**OPERATIONAL SEQUENCE BETWEEN FEEDING CYCLES**

| Hour | Operation | Description |
|---|---|---|
| 0 | Valves 1 or 1' -- CLOSE | Stop algae introduction into oyster flumes.<br>Prevent pump A from activating, as no additional increase in sump volume occurs. |
| 1.0 | Pump B -- OFF<br>Valves 2, 2', 6 -- OPEN | Stop water flow through flumes.<br>Drain effluent from flumes and sump into storage tank I. |
| 1.5 | Valves 3, 4 -- OPEN<br>Pump C -- ON<br>Valve 2, 2' -- CLOSE<br>Valve 5 -- OPEN | Begin foam fractionator.<br>Flush solids to drying bed. |
| 2.0 | Valve 5, 6 -- CLOSE<br>Valve 7 -- OPEN<br>Valve 2, 2' -- OPEN | Flush lines with fresh water to drain. |
| 2.5 | Valve 7 -- CLOSE<br>Valves 2, 2' -- CLOSE<br>Valve 8 -- OPEN<br>Pump D -- ON | Fill flumes and sump with water from storage tank II. |
| 3.0 | Pump D -- OFF<br>Valve 8 -- CLOSE<br>Valve 1 or 1' -- OPEN<br>Valve 9 or 9' -- OPEN<br>Pump B -- ON | Begin feeding cycle. |
| 3.5 | Valve 10 -- OPEN<br>Valve 4 -- CLOSE | Filter water passing from storage tank I to storage tank II. |
| 4.0 | | Disinfection procedure of water in storage tank II. |

Table 1. Operational Sequence Between Feeding Cycles.

Oysters being cultivated in a controlled environment.

### For Future Research

The failure of oysters to grow to specified size, the apparent lack of spawning, the relatively fragile shell, and the low conversion of algal food to oyster organic material signified stress, according to Thielker. "We don't know what caused it," Thielker says. "To find out, we need to study mechanically induced stress—the result of handling; physically induced stress—such as prolonged cultivation at high temperatures; and nutritionally induced stress—the result of one or more deficiencies."

Other research needs targeted by Thielker are as follows:

- Experiments to improve oyster lines and strains for intensive controlled cultivation under artificial conditions.
- Ways of economically providing the carbon dioxide necessary for photosynthesis while removing the deleterious oxygen generated in the process.
- Nutritious diets and rations that can economically serve as alternatives or supplements to microalgae diets for oysters and other commercially interesting bivalves.

## Researchers Developing Artificial Encapsulated Diets for Oysters

R/A-7 Nutrition of *Crassostrea virginica*—Christopher J. Langdon and Ellis T. Bolton.

One of the key objectives of Delaware mariculturists Drs. Chris Langdon and Ellis Bolton has been to develop non-algal diets and supplements for algal diets to reduce the cost of culturing oysters and other shellfish.

In early experiments, the researchers fed *Crassostrea virginica* nylon-protein encapsulated diets made up of an artificial diet of 15% w/v hemoglobin, 10% w/v starch, 1.25% w/v yeast cells, 0.5% w/v DNA and 1% w/v phosphorus (as phosphate). Growth rates of juvenile oysters fed on the encapsulated artificial diet were only one-fifth of those of spat fed on a full algal ration, and the addition of capsules to a half ration of algae did not have any measurable positive supplementary effect.

Finding that nylon-walled capsules were permeable, Langdon and Bolton began working to develop lipid-walled microcapsules. And to better provide oysters with a portion of algal feed, the researchers developed alginate microgel particles.

Then using these particles, lipid-walled microcapsules, kaolin, and a freely dissolved trace-metal mixture, the researchers prepared an artificial diet. When the diet was fed continuously to oysters held in beakers, growth rates as high as 73% were obtained; however, much poorer growth occurred if the oysters were fed on the same diets in a flow-through apparatus. Postulating that the better growth of oysters continuously fed on artificial diets in beakers was due to the relatively high numbers of bacteria present, compared with lower numbers present in the flow-through apparatus, the researchers believe that bacteria could be important in the growth of oysters fed on the artificial diets by acting as a nutrient source and/or by aiding in the breakdown and digestion of food particles. In the future, the researchers will examine further the role of bacteria in oysters grown on artificial diets.

### Partners Sharing Encapsulation Technology

Researchers from the following institutions have applied Langdon and Bolton's methods and findings:

- Scripps Institute of Oceanography, for nutrition work with the rock scallop.
- Virginia Institute of Marine Studies, for nutrition work with oysters.
- National Marine Fisheries Service, for nutrition work in delivering trace metals and vitamins to bivalves.

## Delaware Researchers Grow Plants in Saline Soil

R/B-12 Domestication and Improvement of Salt-Tolerant Angiosperms—G. Fred Somers and Jack L. Gallagher.

Farmers struggle to get fresh water to their crops by irrigation, yet, paradoxically, irrigation often eventually renders the land useless because it forms salt deposits. "It's getting harder and harder for farmers to get better yields by trying to improve soil and water quality," Delaware's Dr. Jack Gallagher says. "So we've approached the salt problem from the other end. We're experimenting with previously uncultivated plants that can live and reproduce in salty soil or in soil that is irrigated with salt water."

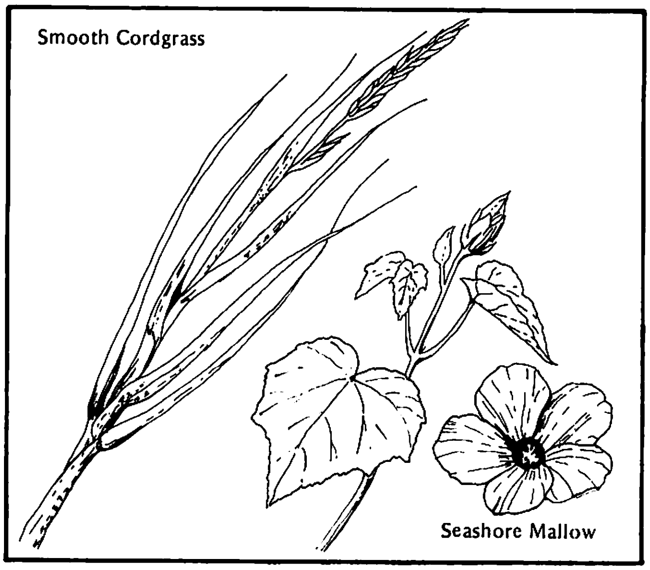
A new food supply for the hungry world, a new agricultural technology that will save money and conserve fresh water—these are the proposed end-products of Gallagher and Somers' work. The two hope to achieve their goal by identifying wild halophytes (salt-tolerant plants) with hardy genetic traits and sound nutritional content and then selectively breeding them for desirable characteristics in taste, texture, and color.

Currently the researchers are growing *Spartina alterniflora* (smooth cordgrass)—the predominant marsh plant of the Atlantic Coast of North America, *Atriplex triangularis*—a leafy, annual vegetable that grows on the edge of the high marsh from Newfoundland to South Carolina, and *Kosteletzkya virginica* (seashore mallow)—a bushy, perennial halophyte that produces seeds of approximately 30% protein and 33% unsaturated oil. Periodic harvests of the three plants have been made, providing the valuable seed that will enable the researchers to continue their studies of nutritional value, product development, and salt tolerance.

So far, apparently nutritionally superior strains of *Atriplex* and high-yielding individuals of *Kosteletzkya* have been selected.

Another significant gain has been establishment of halophyte seed exchange programs with institutions in Pakistan, Egypt, Australia, and Mexico, as well as with the U.S. Salinity Laboratory in California and the Aridlands Improvement Laboratory in Arizona.

"Our set of environmental conditions in Delaware is very different from the arid, saline conditions in Egypt or western Australia," Gallagher notes. "So this exchange will allow us to verify laboratory work performed here with field studies performed in other locations."




Smooth cordgrass *(Spartina alterniflora)* and seashore mallow *(Kosteletzkya virginica)* are two salt-tolerant plants that Delaware researchers currently are breeding for desirable traits in taste, texture, and color.

**Partners Sharing Halophyte Technology**

- Dr. Gallagher visited research plots at Lake Texcoco near Mexico City, where *Distichlis spicata* is being grown for grazing and for reclamation of salinized soils. Delaware researchers have been studying the plant and plan to give it more attention in the future, both as a potential forage and as a possible cereal.
- As part of a mitigation process associated with enabling a land developer to dredge several silted canals, the researchers used a *Spartina alterniflora* selection to rehabitate a damaged marsh at Quillen Point in Indian River Bay in Delaware.
- Drs. Gallagher and Somers have shared information with researchers in Bolivia, Saudi Arabia, and Israel, and requests for collaborative work have been made by San Diego State University Foundation and the U.S. Salinity Laboratory, Riverside, California.
- The American University in Cairo has been testing Delaware's plants using U.S. Agency for International Development (AID) money. Test plots at three sites in Egypt will be established in 1983.

## Exploring Halophytes' Nutritional Potential

R/B-14 Nutritional Evaluation of Halophytes for Their Potential Use as Food, Feed, and Forage Crop—Mir Islam and Thomas Watkins.

While Drs. Somers and Gallagher worked to raise strong strains of several varieties of halophytes, Drs. Mir Islam and Tom Watkins analyzed the plants' nutritional potential. In studies of seashore mallow *(Kosteletzkya virginica)*, the researchers have reported results attesting to the plant's future as a coffee extender, cereal, cooking oil, batter for fried chicken, and flour for corn muffin and rye bread.

Roasted seashore mallow seeds were used as a coffee extender in an experiment involving a test panel of professors, and graduate and undergraduate students. More than a third of the panel preferred the extended coffee over the regular brew. First, a perked mixture of 20% *K. virginica* and 80% coffee was compared to 100% perked coffee. Ten of 31 subjects correctly identified the extended sample. Then a mix of 30% *K. virginica* and 70% coffee was compared to whole-strength coffee; 21 of 31 subjects correctly identified the extended sample. Of those 21, 13 preferred the extended beverage.

Ground into flour, the seashore mallow worked as an emulsifier like egg does, and although it reduced the volume of the final product, it enhanced softness and moisture retention.

In other studies, Islam and Watkins analyzed leaves of the spinach-like halophyte *Atriplex patula* for beta-carotene and ascorbic acid content. Using the chromatographic method of the Association of Vitamin Chemists, they found that *A. patula* contains an average of 33.6 mg B-carotene/g wet weight, which compares well with a value of 50-60 mg in fresh spinach since it is likely that some carotene was lost during storage.

As for ascorbic acid content (vitamin C), an average value of 85.6 mg ascorbic acid/100 g sample was found. Raw spinach has 51 mg/100 g and leafy lettuce has 18 mg/100 g.

In future work, Islam and Watkins will examine further the nutritional potential of the halophytes mentioned above, as well as several new selections.

**Partners Sharing Halophyte Nutrition Technology**

- Buhler-Miag, Inc., Minneapolis, MN, aided Islam and Watkins in developing a way to mill seashore mallow seed. The Delaware researchers plan to send samples to the company's headquarters in Germany for identification of a more efficient milling system.

## Researchers Seek Chemical Bait to Control Oyster Drills

R/B-13 Investigation of Chemical Ecology of Feeding and Reproductive Behaviors of Oyster Drills as a Means of Drill Control—Melbourne Carriker, Daniel Rittschof, Robert Shepherd, and Les Williams.

Oyster drills *(Urosalpinx cinerea)* cost the U.S. shellfish industry an estimated $50 million each year. The predatory snail endemic to our East Coast—*Urosalpinx Cinerea*—and the drill introduced to the United States from Japan—*Ocenebra inornatum (japonica)*—locate their victims through distance chemoreception and then use an arsenal of organic and inorganic chemical and mechanical tools to perforate the shell and feed on the soft exposed parts.

What can stop the oyster drill? Dredging, trapping, bounties, flaming, and poisoning have been only marginally successful since the drill is extremely hardy, resistant to desiccation, and reportedly able to survive at least six months of starvation.

Drs. Melbourne Carriker, Dan Rittschof, Robert Shepherd, Les Williams and several graduate assistants have worked at developing a control method for the oyster drill by identifying the most potent available distance chemoattractant molecule, (which is released by the local common barnacle), through studies of the newly hatched drill, a voracious miniature version of the adult.

The scientists identified the chemoattractant by developing what is the most powerful behavioral bioassay to date. A sensitive analytical tool for determining effects of reagents on oyster drill chemotactic behavior, the bioassay consists of placing snails in modified 2 ml pipettes through which flows a homogeneous chemoattractant solution produced by intact living barnacles. After snails are loaded, flow is initiated at 7.5 ml/minute and continues for 10 minutes. At the end of this time, positive responses are recorded for snails that crawl a given distance up the pipette into the flow.

Delaware Sea Grant researchers have already used the bioassay to determine the behavioral effects of water-borne pollutants as well as to monitor levels of chemoattractants in the waters of the Delaware Bay, and they have developed an inexpensive, low-volume high-sensitivity assay for measuring developmental effects of water-soluble substances on snail embryos.

The researchers note that once the balanoid chemoattractant has been purified further and other attractants and suppressants have been characterized, it will be possible to determine what type of chemical bait can be used to lure drills away from oyster beds.

### Partners Sharing Oyster-Drill Control Technology

- Battelle Marine Research Laboratories, Sequim, Washington, have used the bioassay to assess the behavioral effects of oil components.
- The University of Washington is using the standard barnacle chemoattractant to test the chemoattractant response of the Japanese oyster drill.
- Rohm and Haas provided the Delaware researchers with water purification resins including specially prepared resin for use in high performance liquid chromatography.
- Waters Corporation and Spectraphysics Corporation generously loaned the researchers highly sophisticated equipment and expertise.
- A trip to the West Coast by Dr. Daniel Rittschof provided interaction and technology transfer with the University of Chicago, the University of North Colorado, Oregon State Marine Laboratory, the University of Washington, Battelle Marine Research Laboratories, Moss Landing Marine Laboratories, the University of Southern California, and Ohio State University.
- Researchers at Rockefeller Institute and Temple University report successful utilization of concentration and desalting techniques the Delaware researchers developed on peptides and sperm attractants, respectively.
- Researchers at the Virginia Institute of Marine Science provided the Delaware group with giant oyster drills and information.
- DuPont is collaborating with the researchers on the sequencing of peptides.

## Chitin: From Waste to Treasure

R/N-4 Crab Waste Chitin Development—John E. Castle and Paul R. Austin.

Drs. Paul Austin and John Castle are working toward turning waste into treasure—converting empty blue crab shells into surgical sutures and animal feeds.

The key to this miraculous transition is chitin, an important structural component in the blue crab's shell. Chitin ranks second only to cellulose (or plant matter) as the most plentiful organic substance on earth, comprising the shell of marine crustaceans including crabs, shrimp, and lobsters, as well as the shells of non-marine creatures—insects, fungi, and yeasts.

With such an abundant organic substance around

Sea Grant chitin researcher Dr. Paul Austin displays sources of chitin found in the marine environment.

them, chemical researchers looked for ways to use chitin in industrial applications as early as the 1930s, but development never surpassed pilot stages since no one could find a suitable solvent for the biopolymer. In 1977, however, Dr. Paul Austin discovered an organic lithium chloride solvent for chitin and patented it for assignment to the University of Delaware.

Since then, Austin and Castle have been working at developing new uses for chitin. So far they've found that chitin can be extruded into strong, thin filaments, remarkably like surgical sutures. Currently, the two researchers are working with a Japanese pharmaceutical firm to refine the filament-making technique. According to the Japanese, the chitin sutures have several advantages over those presently used: the fibers are non-allergenic, and although the fibers are strong, the body will break them down and absorb them.

Chitin also possesses interesting wound-healing properties. In the future, the Delaware group hopes to develop and patent an ointment from it as well as test it for any possible antimicrobial and antiviral properties.

**Partners Sharing Chitin Technology**

- The researchers supplied the A.I. DuPont Institute and Lescarden, Inc., New York City, with information on chitin as a wound-healing agent, and Polaroid Corporation with information on chitosan as a dip coating for film.
- A Japanese pharmaceutical firm has discussed licensing of Delaware patents and has taken options on several of them.
- Contacts and information exchange have continued with BioShell, Inc. (formerly Madera Products), a U.S. supplier of chitin and chitosan.

## Animals Thrive on Chitin and Whey Mix

R/N-5 Chitinase, Chitin, and Chitosamine Glucosides for Improving the Digestion of Whey—John Zikakis.

While studying chitin, Delaware researchers found so much promising evidence that it could be used in animal feed that a separate project developed under the leadership of Dr. John Zikakis. In particular, Zikakis and his team of agricultural biochemists wanted to produce nutritional additives for animal feed by mixing chitin, a waste product of the shellfish industry, with whey, a waste product of the dairy industry.

Although whey is high in protein, low in fat, and rich in vitamins, millions of tons are discarded annually because of lactose, which is difficult for many humans and animals to digest. Zikakis and fellow researcher Dr. Paul Austin found that chitin promotes the growth of specific bacteria in the guts of chickens and cattle that allow them to digest lactose.

Zikakis fed a group of Delaware broiler chickens a diet containing 20% whey and 2% chitin. The birds grew as well as those fed normal, commercial diets, and they seemed to have less fat. Zikakis then decided to test a less expensive feed additive than purified chitin, so he turned to the structures that house it—crab shells.

Using calves borrowed from a local dairy farmer, Zikakis tested an experimental feed containing 12% decalcified crab shells and 25% whey. The calves grew well, gaining an average of 65 pounds each in thirty days.

Surmising that as much as 60% of the total feed could be composed of chitin and whey and still provide cattle with good nutrition, Dr. Zikakis is optimistic that what were once waste products—crab shells and whey—could provide farmers with substantial savings and well-fed animals.

**Partners Sharing Chitin Nutrition Technology**

The following companies have been made aware of this Delaware project:

- Mid-American Dairymen, Inc., Springfield, MO, one of the largest producers of whey.
- USDA, Eastern Regional, Eastern Center, Philadelphia, PA
- Pfanstiehl Laboratories, Waukeegan, WN
- Borden, Inc., Columbus, OH
- BioShell Products, Inc., Albany, Oregon, a producer of chitin and chitosan.
- Campbell Soup Co., Camden, NJ
- Ross Laboratories Division of Abbott Laboratories, Columbus, OH
- General Mills, Inc., Minneapolis, MN
- Ralston Purina Co., St. Louis, MO
- National Agricultural Commodities, Eastville, VA

# COAST, BAY, AND SHELF ENGINEERING AND DYNAMICS

*In March 1962 a major storm caused $125 million in damage to the Philadelphia District of the U.S. Army Corps of Engineers. In some places, the beach receded 100 feet horizontally and lowered from four-to-six feet vertically. Fortunately, storms of such destructive caliber do not occur every year, but beach erosion does—costing state and federal governments and owners of seashore homes and businesses thousands of dollars. How does the erosion occur? How fast? And what can we do to stop it?*

*Delaware Sea Grant researchers in Coast, Bay, and Shelf Engineering and Dynamics are trying to find solutions to the problems caused by wind and waves not only through experiments on the beaches themselves but also through experiments in the Air-Sea Interaction Laboratory in Lewes. Dr. John Kraft has developed a new theory on beach erosion which may help beach-dwellers to stablilize the shore. Dr. Robert Dean has prepared a model for the simulation of shoreline response to storms and long-term sea-level rise, while Drs. Ron Lai and Jin Wu have focused on wind- and wave-induced current distribution, a problem that has received little attention to date. Dr. Carlos Lozano has concentrated on wave transformation, improving hindcasting programs that will aid coastal engineers.*

## Delaware's Findings on Beach Erosion Suggest New Management Techniques

R/G-10 Erosion and Deposition Processes and Patterns in the Nearshore Zone of Western Delaware Bay and the Atlantic Coast of Delaware—John C. Kraft.

In 1981, more than $825,000 in state and federal funds were spent on beach nourishment projects in Delaware. But recent findings made by Sea Grant geologist Dr. John Kraft and his colleagues indicate that coastal erosion is not only occurring on the beach, it's also happening offshore at depths of 30 feet and more.

In the past, beach managers have concentrated on nourishing beaches with sand and using methods to retard erosion on others, but they have never

Dr. John Kraft studies the geology of a sandy barrier.

dealt with shoreface erosion. Consequently, as erosion makes the slope of the shoreface steeper, waves hit it with greater force, and the beach incurs more damage than ever before.

"Along Delaware's beaches," Kraft explains, "about 500,000 cubic yards of sand are moved each year by erosion; about 350,000 to the north into Delaware Bay at Cape Henlopen, and about 150,000 to the south toward Fenwick Island. If you're a beach manager, you could probably keep the beach stable by replenishing it with 350,000 cubic yards of sand each year. But you'd probably spend $5 per cubic yard to do this—at an annual cost of $1.7 million. But suppose I told you that ten times this amount of sediment is moving along the beaches into Delaware Bay and out on the inner shelf area. You'd have to spend ten times as much—$17 million per year—to keep the beaches stable."

Spending up to ten times the present amount on beach nourishment may not be practical, but establishing building setback lines up to 300 feet from high water lines or limiting coastal development are feasible alternatives, according to Kraft.

Presently, Kraft is attempting to prove his theory of shoreface erosion by developing a sediment budget for Delaware's barrier system. The budget will show the total amount of sediment being eroded on the inner continental shelf, shoreface, and beaches of Delaware, as well as where the sediment is going—information which should aid not only environmental planners and decision-makers but members of the petroleum industry since ancient barrier islands are often associated with oil and natural gas deposits.

### Partners Sharing Coastal Erosion Technology

- As a participant in a nine-day conference sponsored by the International Geological Congress and UNESCO, Dr. Kraft joined experts from 17 countries in a working session on world sea-level change and rise. The group worked in the laboratory and in the field in South Carolina and Georgia and then traveled to Delaware for the last part of the trip, which Dr. Kraft hosted.

- The Department of Natural Resources and Environmental Control has used the research group's work on the coastal zone and nearshore zone of western Delaware Bay, as well as their analyses of the geology of the shorelines of Rehoboth Bay and the nearshore zone of Rehoboth Bay.
- Dr. Kraft and his group have advised further DNREC and legislators on the continuing problem of coastal erosion at the Indian River Inlet bridge facility and road abutment.
- DNREC provided over $50,000 for the taking of forty-two cores in the shoreface of Atlantic coastal Delaware.
- The Sussex County Council, Delaware, the Department of Interior, and a subcommittee of Congress called on Dr. Kraft for testimony regarding the results of his research.

A strong northeaster eroded the beach, and storm waves hit the city of Rehoboth Beach in 1962, causing massive destruction.

## Examining Shoreline Response to Storm and Sea Level Rise

R/T-40 Development and Application of a Method to Simulate Shoreline Response—Robert G. Dean.

Dr. Dean's objectives in this project were to develop an understanding of the geometric characteristics of equilibrium beach profiles with special emphasis on the effects of sediment size, and to develop an efficient procedure for the computation of shoreline response to storm tides and storm waves.

### Geometric Characteristics Of Equilibrium Beach Profiles

Dean's earlier studies of 502 beach profiles extending from Montauk Point on Long Island to the Texas-Mexico border had suggested that an equilibrium beach profile is closely approximated by:

$$h(x) = Ax^{2/3} \qquad (1)$$

in which $h(x)$ is the water depth at a distance $x$ from the shoreline. The parameter A depends primarily on sediment characteristics and to a lesser extent on wave characteristics. The interpretation of Equation 1 is that this relationship corresponds to the beach profile configuration such that the energy dissipation per unit volume is uniform across the surf zone. A graduate student working with Dr. Dean, Brett Moore, has defined the relationship between the parameter A and sediment characteristics. Laboratory and field data were available for sediment particle diameters ranging from 0.1 to 0.5 mm; however, data were lacking for sediments of larger size. Moore located a number of profiles from Russia with particle sizes up to 300 mm (approximately one foot in diameter and worked with Dean to plot the diameter (D) versus the parameter A. "Based on our data and the agreement with predictions," Dean says, "it appears that a reasonable basis is available for predicting equilibrium beach profiles for the complete range of sediment sizes found on natural beaches."

An unexpected application of the mechanics of equilibrium beach profiles is in the interpretation of breakwater failure and in the design of breakwater cross sections. Breakwaters are constructed in a layered sequence with the finer material in the core of the breakwater, progressing gradually by coarser layers to the outer armor layers. A breakwater in a substantial water depth will typically comprise four layers with the outer layer composed of large natural rock or manufactured units with high interlocking characteristics. Armor unit weights in excess of 100 tons have been used. But some limited model data indicate that much lighter breakwaters could be designed if a more natural profile were incorporated, according to Dean.

### Computation of Shoreline Response

As noted earlier, Equation 1 corresponds to a profile that causes a uniform rate of wave energy dissipation per unit volume. Denoting the equilibrium dissipation rate, $D_*$, and the actual dissipation rate, D, it is reasonable on physical principles, according to Dean, to consider the offshore sediment transport, $Q_s$ to be given by

$$Q_s = K(D - D_*) \qquad (2)$$

in which K is a rate constant. Equation 2 can be combined with the continuity equation

$$\frac{dh}{dt} - \frac{\partial Q_s}{\partial x} = 0 \qquad (3)$$

as the basis for finite difference numerical model. These models allow the *evolution* of a beach profile from a condition out of equilibrium to an equilibrium condition to be examined. Numerous such tests have been conducted to examine the plausibility of the results. If an equilibrium profile is "perturbed," the evolution to equilibrium can be simulated by Equations 2 and 3. Various types of perturbations include the removal or addition of a volume of sand resulting in an anomalous mound or depression on the profile, and the increase or decrease in water level and/or wave height.

According to Dean, the disadvantages of numerical modeling are (1) the expense of simulating a long time period (on the order of decades), since the required time steps can be relatively small (on the order of hours), (2) usually it is only the *shoreline* change that is of interest, and (3) usually the shoreline response during and for several months following major storms is of greatest interest, rather than the *entire* time history of shoreline change of a one-or more-decade period.

Based on a consideration of shoreline response to storms, Dean notes that it is reasonable to hypothesize the shoreline recession, r(t), as

$$\frac{dr}{dt} = K_* \left[r_\infty(t) - r(t)\right] \qquad (4)$$

in which $K_*$ represents a rate constant (different than that appearing in Equation 2), $r_\infty(t)$ represents the equilibrium shoreline recession that would result if the prevailing conditions persisted indefinitely, and r (t) represents the current shoreline recession. The variable $r_\infty(t)$ depends on time since the wave and tide conditions establishing $r_\infty(t)$ depends on time. The relationship for $r_\infty(t)$ will be presented later. According to Dean, Equation 4 is "a simple first-order linear differential equation and clearly oversimplifies the process. However, it does capture the essential expected features of the process, namely that the time rate of change of recession is proportional to the degree of disequilibrium." Although Equation 4 is hypothesized, Dr. Dean has substantiated the general form through detailed numerical modeling, finding that shoreline response to an increase or decrease in storm tide is in accordance with Equation 4.

### Partners Sharing Wave Refraction Technology

- The following expressed interest in wave propagation schemes: National Ocean and Atmospheric Administration (NOAA), the Department of the Interior, and NASA.
- The following organizations provided assistance to the project: CERC, Vicksburg; New York Sea Grant, and Cornell University.

## Studying Wave Energy in Nearshore Regions

R/T-42 Progressive Gravity Waves Over Water of Varying Depth—Carlos Lozano.

Although deep-water waves do not vary greatly over short distances, the effect of irregular bottom bathymetry can cause considerable changes in wave energy over relatively short distances in nearshore regions, according to Delaware Sea Grant researcher Dr. Carlos Lozano. During his one-year study, Lozano worked at extending existing refraction methodologies to address several practical problems encountered in wave transformation across the continental shelf. He developed models of wave propagation in a refraction zone, including diffraction and reflection, as well as a numerical code to calculate diffraction-refraction effects. He also created a nonlinear model of wave propagation on a flat beach and completed a study on partial reflection due to submerged obstacles and a study describing "whispering gallery" waves at breakwaters.

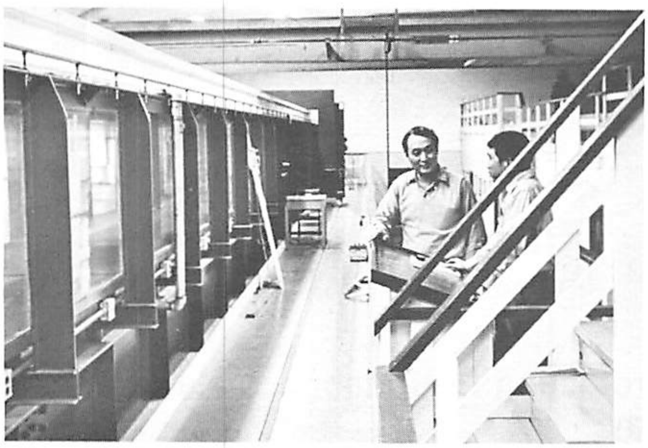
Useful in engineering design and shoreline protection, Dr. Lozano's data will be used to predict waves for the Delaware coast and other regions.

## Measuring the Power of Wind and Wave

R/T-43 Currents and Turbulence Produced by Wind and Waves on Sloping Beach—Ron Lai and Jin Wu.

In summer, low-energy waves and breezes form gentle, sloping beaches on Delaware's shoreline, yet waves and winds are far from harmless. Storms gouge out tons of sand from beaches while imperiling the lives and property of coastal residents, and currents caused by wind and waves distribute pollutants and other chemicals that man has dumped into coastal waters.

At the University of Delaware's Air-Sea Interaction Laboratory in Lewes, Sea Grant physical oceanographers Drs. Ron Lai and Jin Wu have been working to define precisely how a combination of wind and wave affects currents and turbulence in shallow coastal waters like Delaware's. Their goal is to develop a predictive model for the transportation of sediments and pollutants in coastal waters, which could be used by engineers and scientists in monitoring the effects of erosion and pollution.



Sea Grant physical oceanographers Drs. Jin Wu and Ron Lai at work in the Air-Sea Interaction Laboratory in Lewes.

To simulate the nearshore area for experimental purposes, Lai and Wu used the 142-foot-long wind-wave tank at the University of Delaware's Air-Sea Interaction Lab. Approximately two and one-half feet deep and three feet wide, the tank contains a model beach with a slope of 10:1. Attached to it are a mechanical wave generator capable of creating waves one and one-half feet high and a wind generator able to blow winds up to 37 miles per hour. A laser Doppler anemometer measures the speed of water flow.

In a series of in-tank experiments, the researchers generated waves with constant height and length and recorded water velocities with the anemometer while varying wind speeds. They found that wind speeds as low as 8 miles per hour could drastically increase the speed of water flow.

Then, to understand how wind conditions affect turbulence in the nearshore environment, Lai and Wu measured turbulence caused by wave action. Using the same wave height and length, they then added wind to the tank and measured turbulence. After collecting data on the two experiments, they created a computer program to subtract the wave-induced turbulence from the wind- and wave-induced turbulence, giving them an estimate of the wind-induced turbulence created in the tank.

In the future, Lai and Wu plan to build a device for use in the wind-wave tank to measure shear stress distribution. And when they are finished analyzing data on wind effects, turbulence, and shear stress, they hope to develop a computer model that will predict current speeds and turbulence. "It will provide coastal engineers and geologists with a good tool for predicting the movement of sediment and pollution in the nearshore environment," Lai says.

# *MARINE ENERGY AND MATERIALS*

*Islands are surrounded by water, but ironically, islanders have a difficult time obtaining a glass of water to drink. Little fresh water is available for consumption, and what is, is very expensive because most desalination plants require electricity or fossil fuels. The cost of the energy often comprises more than one-third the market price of the fresh water, which can reach $10 to $20 per thousand gallons. Can a solution be found to the islanders' dilemma?*

*The sea wages a constant battle with the shoreline to reclaim its land. Port Mahon in Delaware Bay has resisted this inevitable process for years, but Kelly Island, the harbor's natural protector, is eroding away. What can be done to save an important harbor, one of a few in the Delaware Bay that is deep enough for ships?*

*Sea Grant researchers have recently made major* *inroads in solving both of these problems. Thanks to Dr. Mic Pleass and graduate student Doug Hicks's work, DELBUOY, a wind-powered desalination system, is providing Magueyes Island, Puerto Rico, with fresh, inexpensive drinking water. At Port Mahon, Drs. Robert Biggs and Mic Pleass are working to develop a dynamic breakwater system to save the harbor.*

## Researchers Develop Revolutionary Seawater Desalination System

R/T-50 Construction and Deployment of DELBUOY, a Prototype 1500-Gallon-Per-Day, Sea-Wave-Powered Desalination Buoy—Charles M. Pleass.

While traveling in the Caribbean during the mid-1970s, chemist Mic Pleass was amazed by the shortage and high price of freshwater on many of the islands. Desalination plants provided many communities with water, but the desalination process was costly because it required electricity and fossil fuels.

But Pleass was also impressed by the amount of renewable energy available on many of the islands—solar, wind, and wave energy. Five years later he and graduate assistant Doug Hicks watched DELBUOY sputter to life off Magueyes Island, Puerto Rico, and begin producing crystal-clear drinking water.

DELBUOY is a buoy system that uses wave energy to desalinate sea water. A 10-foot-long high-pressure pump is anchored in 60 feet of water and is kept upright by a buoy 6 feet in diameter. As the buoy rises and falls with the waves, it drives the pump's piston rod. The pump draws sea water up from the sea bottom through a sea well that filters out sand and other particles and into a reverse-osmosis (R-O) module. The R-O module contains a thin membrane that permits fresh water, but not salt, to pass through. The salts are flushed out of the R-O module, and the pump sends the fresh water into a storage tank onboard a boat or back to shore through low-pressure hoses.

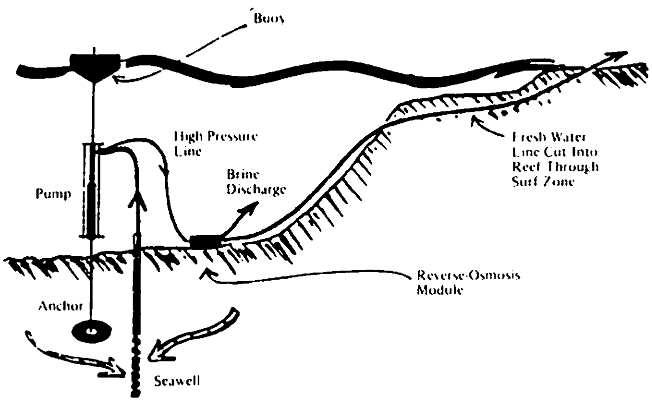
Pleass and Hicks call DELBUOY a "plain jane" because it operates with a minimum of maintenance and sophisticated technology. Almost all of the components can be bought off the shelf, and the system can be quickly assembled and installed by a few scuba divers using a small boat.

The prototype system is capable of producing up to 1,000 gallons of fresh water every four days at a cost of about $5.00. DELBUOY operates at roughly 8% efficiency. Pleass and Hicks say that a more efficient system would be much more complicated and expensive, not very helpful to developing countries.

Through the next few years of testing, Pleass and Hicks will have to solve engineering problems as they appear. But they are optimistic about the system's potential for areas of the world which have consistent wind conditions. And they believe that they can ultimately bring the cost of fresh water down to $1 per thousand gallons.

### Partners in DELBUOY Technology

- Sea Grant served as a catalyst for the DELBUOY project, sparking interest from the U.S. State Department's Agency for International Development (AID). AID has agreed to fund the deployment of 10 DELBUOY systems throughout the Caribbean over the next three years.
- The University of Puerto Rico Sea Grant Program has provided Pleass and Hicks with valuable laboratory, boat, and diving support.
- Colombia, French Polynesia, and several European sources have shown interest in the prototype.




DELBUOY deployment at typical coral reef profile.

## Protecting Port Mahon, Delaware Bay

R/T-52 Data Acquisition Preceding the Development of an Active Wave-Absorbing System for the Protection of Port Mahon in Delaware Bay—Charles M. Pleass and Robert B. Biggs.

Waves have taken their toll on Kelly Island, which protects the harbor at Port Mahon in the Delaware Bay. In a few years, the island will be eroded away, exposing the harbor unless protective measures are taken, according to Delaware researchers Drs. Robert Biggs and Mic Pleass.

Pleass and Biggs have been working at designing a dynamic breakwater system to protect Port Mahon. So far, the researchers have gathered a year's worth of wind speed and direction data, and surveyed the Kelley Island Marsh Front for use as a marker to identify future shoreline movement. They now have a basis for the design of the breakwater and will seek funding for completion of the project.

# MARINE ENVIRONMENT SYSTEMS

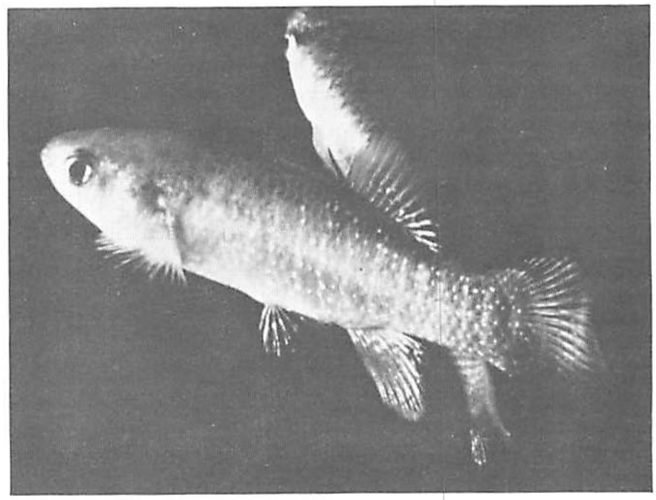
*During the summer months, mosquitoes relentlessly pester wildlife and residents of many coastal areas of Delaware, spreading encephalitis and canine heartworm while driving away tourists. What can be done to control the nuisance?*

*The Delaware Estuary has a bad reputation. Many believe that the bay is polluted beyond repair, yet it continues to support a wide variety of activities—from sewage disposal to fishing. How healthy is the estuary and how does it function?*

*In 1977, the Delmarva surf clam industry was devastated by anoxic water, but the water that killed off many of the surf clams also killed off the clam's predators. Those surf clams that survived, flourished and will soon be ready to harvest. What effect will this recovery in surf clams have on the industry?*

*Blue crabs mean big business on the Delmarva peninsula. The savory crustacean is vital to the economic health of the area, but little is known in scientific circles about the crab's life cycle in respect to how the crab disperses itself throughout the waters of the mid-Atlantic region. Can we find out?*

*Sea Grant researchers in Marine Environment Systems have been working to find the answers to these questions. In partnership with the Delaware Department of Natural Resources and Environmental Control (DNREC), Delaware Sea Grant researchers are studying a small mosquito-eating fish as a natural method of mosquito control. Another team of researchers is studying the Delaware Bay, a reasonably healthy estuary, to better understand how it functions and to determine whether it will be able to support increased marine activities in the future. Yet another team has developed a computer model that can predict the future of the surf clam industry. In other work, Sea Grant biologists have undertaken a comprehensive study of blue crab reproduction in the mid-Atlantic area, research that should provide biologists and fisheries managers with information never available before.*



Delaware researchers have found that adult mummichogs consume about 15% of their body weight in mosquito larvae per day—approximately 400 to 2,000 larvae.

## DNREC and Sea Grant Work to Control Delaware's Mosquito Population

R/B-4 The Role of *Fundulus heteroclitus* in Tide Marsh Dynamics—Victor Lotrich.

R/B-6 Influences of Tides and Habitat Restriction on *Fundulus* Reproduction—Malcolm Taylor.

For many years, scientists have worked to develop an effective mosquito control. Now it looks like Mother Nature may have the best method—a small fish called the mummichog *(Fundulus heteroclitus).* Sea Grant researchers Drs. Victor Lotrich and Malcolm Taylor, working with biologists in the Delaware Department of Natural Resources and Environmental Control's (DNREC) Mosquito Control Division, have found that in marsh areas inhabited by the mummichog, as much as 98% of mosquito larvae can be devoured before becoming winged adults.

Delaware has waged war on the mosquito since the early 1930s, working to control the nuisance that has spread encephalitis and canine heartworm. Though DNREC has used chemicals to control the pest, it has continually looked for a less costly means of control as well as a safer one, minimizing any possible health and biological hazards associated with insecticides. Thus the mummichog is a very attractive possibility.

In the state's Open Marsh Water Management (OMWM) system, where test sites free of pesticides are set aside for research, Drs. Lotrich and Taylor are studying the mummichog's ability to feed, reproduce, and convert nitrogen. Dr. Lotrich has found that one adult mummichog consumes about 15% of its body weight in mosquitoes per day—approximately 400 to 2,000 larvae. Dr. Taylor, a leader in mummichog reproduction studies, conducted research to determine whether the OMWM system altered the fish's semilunar spawning cycle or its sexual maturity. Although a few dry periods occurred, he found that egg survival was no worse than what it would be in an unmodified marsh.

According to DNREC Mosquito Control Division's Dr. William Meredith, Sea Grant's work in evaluating the role and adaptation of the mummichog in the experimental OMWM has been invaluable. "Thanks to Dr. Taylor's work, we feel a lot more confident that the populations of mummichogs so vital to the system will be abundant and in good condition," he said. "And Dr. Lotrich's findings give us a good starting point for developing a model of the predator-prey relationship in the OMWM system."

## Delaware Findings Disprove Former Theories on Bacterial Nitrogen Cycle Reactions

R/B-5 Community Physiology of Bacterial Nitrogen Cycle Reactions in a Delaware Tide Marsh—David Smith.

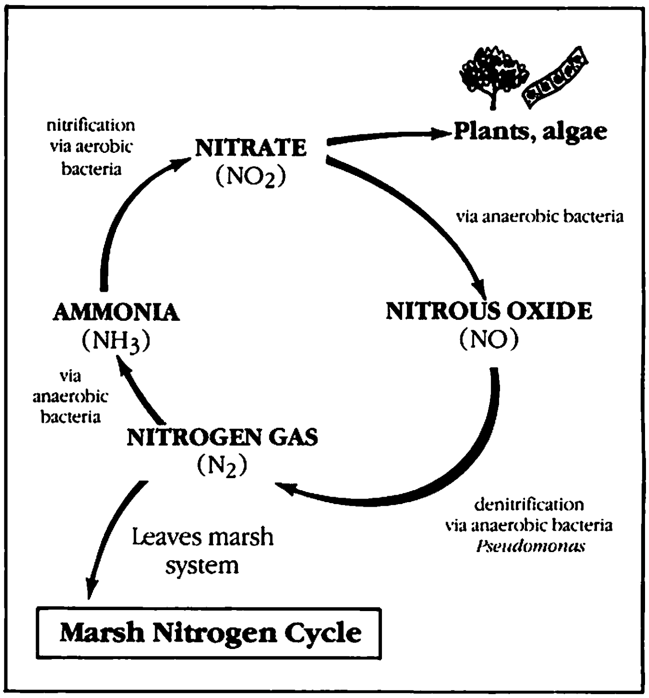
Over the past twenty years, ecologists have described the exchange of nitrogen and sulfur between salt marshes and coastal waters by measuring ammonia or detritus (decaying organic material) present in the marsh and coastal waters at various times. However, according to Dr. David Smith, some researchers made assumptions and extrapolations from their data that have led to inaccurate assessments of marshes and coastal waters.

"In some cases," Smith explains, "researchers have noted large amounts of detritus flowing out of the marsh and into coastal waters—waters that are rich with productive commercial and recreational fisheries. This detritus outwelling theory has sometimes been extrapolated to say that juvenile fish swim into the marsh and feed on detritus, that detritus from the marshes is the basis for all coastal fisheries. The problem with this theory is that it's composed of inaccurate assumptions and cause-and-effect relationships, and it's based on a few observations that are currently impossible to prove."

These theories can mean big problems if they are used to make decisions about how to manage salt marshes, according to Smith, who decided to go back to the basics in studying marsh nutrient cycles to take a more narrow, fundamental look at the processes that drive the ecosystem and ultimately affect coastal fisheries.

Because sulfur and nitrogen are vital to the growth and productivity of marsh animals and plants, Smith decided to examine these nutrient cycles in the marsh. In sediments containing oxygen, aerobic bacteria convert nitrogen into nitrate, and sulfur into sulfate, forms that plants and animals can use for growth. In sediments devoid of oxygen, anaerobic bacteria convert nitrate into nitrogen gas via denitrification. Once nitrogen gas leaves the system, it denies the primary producers of the marsh a valuable nutrient. A similar process occurs with sulfur in sediments lacking oxygen. Anaerobic bacteria such as *Desulfovibrio* use hydrogen to reduce sulfate to hydrogen sulfide, a highly toxic gas that gives marsh sediments their characteristic rotten egg-like smell.

Smith first examined denitrification in the marsh by measuring the amount of nitrate denitrified by the bacteria *Azotobacter* and identifying the compounds that stimulate denitrification. He found that contrary to the findings of other microbial ecologists, amino acids stimulate *Azotobacter* to

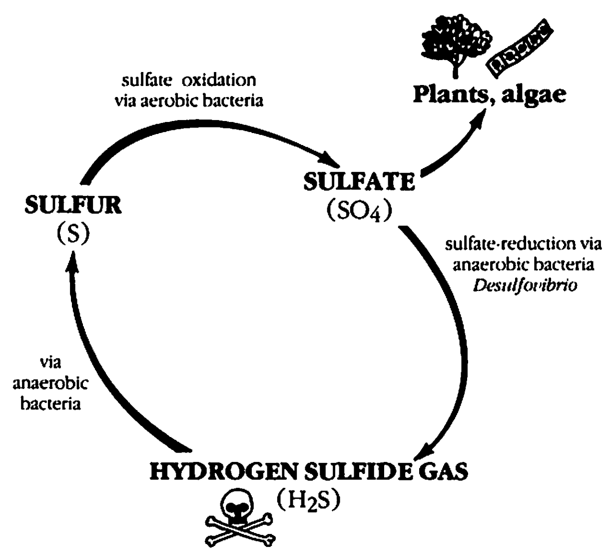


Marsh Nitrogen Cycle

denitrify nitrate much more than sugars do. Because researchers in the past found that bacteria would denitrify bacteria in lab conditions when they were fed sugars, it was believed that sugars acted similarly in the marsh environment. But this is not the case. "Our findings point to the reality of the situation," Smith says, "decaying animal and plant matter contribute a plentiful supply of amino acids, but there is really very little sugar available to bacteria in the marsh."

Smith then experimented to see what compounds stimulate sulfate-reducing bacteria to change sulfate, which is an important growth nutrient for plants and algae, to hydrogen sulfide, a highly toxic gas. He found that, contrary to accepted theory, alcohols such as ethanol and propanol stimulate sulfate reduction much more than acids such as lactic acid or acetic acid do. Previously, alcohols were not seriously considered to be food for sulfate-reducing bacteria because ecologists did not find large concentrations of alcohols in the marsh sediments. However, the measured turnover rate of alcohols in the marsh is approximately ten hours, which indicates that alcohols are used up very rapidly by bacteria in the system.

"This result shows how the easy answer—measuring how much alcohol is present at any one time—won't give you an accurate picture of the process," Smith says. "Imagine how much error you would have if you simply measured the amount present in a small sample and then extrapolated your results to represent the whole marsh area. This is what happened in the past with a number of nutrient cycles."




**Marsh Sulfur Cycle**

According to Smith, part of the reason why extrapolation occurs is that scientists are often called upon to provide broad generalizations of nutrient cycles for resource management plans. For Smith, part of the solution to the extrapolation problem is for ecologists to clearly define the limits and boundaries of their results. "I have heard researchers say 'These are my data; I have no accountability for what you interpret from them.' But we, as ecologists, should never make a conclusion or even allow a conclusion to be made, beyond which we can support."

**Partners Sharing in Bacteria And Marsh Ecology Research**

- Dr. Smith provided researchers from the following institutions with the results from his study: State University of New York at Stony Brook, University of Rhode Island, and the Virginia Institute of Marine Science.

## Remote Sensing Provides Valuable Data on Delaware Estuary

R/B-7 Remote Sensing of Estuarine Detrital Flow and Surface Water Productivity—Vytautas Klemas and Franklin Daiber.

Drs. Vytautas Klemas and Franklin Daiber have worked at developing and testing remote-sensing techniques to provide data on the distribution and flow of inorganic and organic coastal matter in the Delaware Estuary. Using eigenvector analysis and airborne laser fluorosensing, the researchers are mapping the concentration and flow of detritus and chlorophyll from the marsh into the estuaries and coastal waters to determine how these contributions influence life processes and dynamics of the Delaware Estuary.

Over the past two years, the scientists have conducted nine field experiments to coincide with satellite or aircraft coverage and have analyzed their information in the laboratory. Since assumptions regarding vertically homogeneous, optically deep water may produce erroneous results when applied to vertically inhomogeneous, optically shallow water, the researchers have developed mathematical models to describe variations in water color for vertically inhomogeneous and optically shallow water. These models provide a means for assessing chlorophyll and detritus concentrations in the bay.

However, one of the most important findings made by the scientists results from principal component analysis. By using this technique, the research team has been able to use remotely sensed data to map coastal water properties, such as pollutants and suspended sediments, and thus differentiate between organic and inorganic effluents.

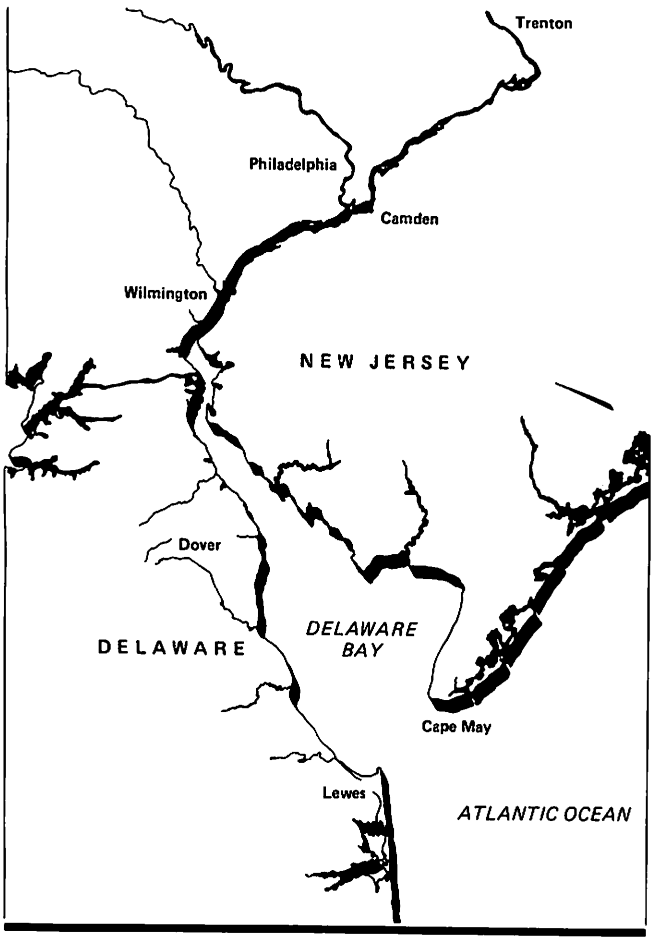
**Partners Sharing Remote-Sensing Technology**

- The U.S. Coast Guard provided helicopter support in sample-collecting.
- NASA provided image analysis support.

## How Healthy Is the Delaware Estuary?

R/B-8 Water Quality, Biological Production, and Management Strategies for the Delaware Estuary—Robert Biggs, Thomas Church, Charles Culberson, and Jonathan Sharp.

The Delaware Estuary is commercially and biologically vital to the well-being of the United States, yet it is one of the most poorly understood estuaries in the nation. To determine how the estuary works and what may happen to it in the future, Delaware Sea Grant researchers have initiated a comprehensive study of the estuary—from the upper freshwater tidal reaches near Trenton, New Jersey, to the mouth of the Delaware Bay. With the help of the New Jersey Marine Science Consortium, they hope to define the hydrographic, chemical, geological, and biological factors that determine the health of the Delaware Estuary.




Discovered in 1609, the Delaware Estuary supports over 7 million people.

One popular myth about the Delaware Estuary is that it is hopelessly polluted. It is not, according to Sea Grant researchers studying the estuary. They note that the estuary is "a healthy aquatic environment, functioning successfully not only as a major waste receptacle, but also as a commercial and recreational fishery, a resource for tourism, and a transportation corridor."

How does the estuary support such seemingly incompatible uses? According to Delaware Sea Grant scientists, the lower estuary possesses effective natural cleansing abilities, and the upper estuary, though high in nutrients, does not experience excessive algal production (eutrophication) because of high turbidity and natural flushing. Most of the algae is consumed through the food chain so that overall biological production in the estuary is relatively high, especially in the lower estuary where major fisheries are found.

But can the Delaware Bay continue to operate so efficiently and support growth in marine activity? According to preliminary results made by 36 Sea Grant researchers from the University of Delaware, Rutgers, Princeton, Lehigh, and the Stevens Institute of Technology, the outlook for the estuary is encouraging. A brief summary of their findings follows:

- *Circulation.* The bay's circulation patterns are indicative of a healthy estuary. Flood tide moves upstream for roughly six hours and reverses to ebb for another six hours. Complete flushing of the bay occurs about every 80 days, primarily by freshwater flow from the Delaware River and partially (about 10%) by the Schuylkill River in Philadelphia. Freshwater intrusion into the bay greatly affects the salinity levels and, consequently, plant and animal life in the estuary.
- *Chemistry.* Dissolved oxygen content is an indication of the estuary's ability to support life. Throughout the bay the dissolved levels are normal, except in the municipal Philadelphia area where $O_2$ levels are low, the probable result of sewage and industrial effluents, which remove oxygen from the water. Trace metals, such as

iron, are present in the upper reaches at moderate levels; others, such as cadmium and magnesium, have been significantly identified in sediments at various locations, but at present do not exist in toxic concentrations. There is some concern, however, about the release of chlorinated effluent into the bay, for when a reaction occurs between certain dissolved organic substances and chlorine, highly toxic halogenic compounds can result. Because these compounds could present a serious environmental health hazard, close monitoring of chlorinated effluents should be required.

- *Geology.* Delaware Bay is extremely turbid, which results in high levels of suspended silt and sediment throughout the water column. These sediments exist primarily because of agricultural runoff. Because of the very turbid upper and middle regions of the estuary, algal primary production is reduced locally and eutrophication does not become a problem. Interestingly, most of the sediments are from natural sources, which indicates fairly efficient sewage treatment along the Delaware.
- *Biology.* The biological health of the bay compares fairly closely to other similar estuaries throughout the world. In spite of exceptionally high nitrogen and phosphorous levels, algal build-up does not occur. Project director Dr. Jonathan Sharp believes eutrophication does not exist because turbidity limits light available to algae, and the high flow-rate flushes nutrients quickly. "Were it not for this combination of conditions," he notes, "the health of the Delaware Bay would be very poor."

  Oyster, crab, and finfish are the most important commercial fisheries in the bay. After a disastrous decline in the early 1950s due to MSX disease, the oyster fishery has stabilized at about 200,000 bushels per year. The blue crab catch, however, fluctuates widely, for no apparent reason. Seatrout are the most significant finfishery in the bay; several hundred metric tons are landed by commercial and recreational fishermen annually. According to the researchers, flounder and bluefish have recently replaced weakfish as the most frequently caught fish.

### For Future Research

Delaware Estuary Project researchers have found that the bay is capable of sustaining substantial economic and recreational development, but they note that crucial to future growth is a carefully administered and monitored plan that closely coordinates all future projects.

In the future, they will undertake additional work on the interaction of biological, chemical, and geological processes in the estuary. Their goal is to produce a model that resource managers can use to evaluate and predict how changes in water flow, agricultural activities, and sewage treatment facilities will affect the future health of the Delaware Bay and estuaries like it.

### Partners Sharing in Delaware Bay Research

- The Delaware River and Bay Authority (DRBA) provided the project with $1.2 million for the period from May 1981 through mid-1983.
- Delaware researchers shared much information with the Fisheries Division and Division of Environmental Control of the Delaware Department of Natural Resources and Environmental Control.
- The U.S. Coast Guard, Cape May, provided the researchers with sampling assistance for cruises in October and November 1980; and January, March, and June 1981.
- The Delaware River Basin Commission provided the researchers with computer data from their previous work in the upper estuary.

## FISH5 Predicts Future for Surf Clammers

R/E-3 Simulation of Unified and Multipurpose Fleets in Multistock Fisheries—Lee Anderson and Adi Ben-Israel.

Combine basic scientific research with economics to get a look into the future. In a nutshell, that's what Sea Grant fisheries economists Drs. Lee Anderson and Adi Ben-Israel have done. The researchers have developed a computerized model to predict the future of the surf clam industry. Called FISH5, the model takes information on surf clam biology and the economics of the industry and uses them to predict future surf clam landings, profits, movement of the industry, and even the sociological changes affecting the surf clammer. Although FISH5 can be adapted to study any fishery, the researchers chose surf clamming because changing biological conditions in the industry promise to change the economic scene for surf clammers in the mid-Atlantic very soon.

In 1976, anoxic water conditions (low oxygen concentrations) off northern New Jersey killed practically all of the surf clams in the area. The

Graduate student Bill Lovejoy (left) and Dr. Lee Anderson work on FISH5, a computer model that combines basic scientific research with practical economics.

anoxic water conditions soon spread southward, devastating the surf clam population off the Delmarva Peninsula in 1977. However, the anoxic water that destroyed the surf clam also destroyed its natural predators, and the few surviving clam beds thrived. Young clams spawned in 1976 had a high survival rate, and since it takes about five years for a young clam to reach harvestable size of five and one-half inches, large supplies of harvestable clams are expected off northern New Jersey and Delmarva this year.

This increase in surf clam population is bound to have profound repercussions on the industry, but no one knows exactly how. That is where FISH5 comes in.

Dr. Anderson and his students received Sea Grant funding in 1977 to begin work on a computer model that could be used to predict how fisheries react to different economic and biological conditions. The economists had to consider the demand for surf clams, the current work force involved in the fishery, the biological cycles of the shellfish, and management schemes regulating the fishery.

After spending time aboard a clam boat, the researchers returned to the computer, and starting with statistics on clam landings, worked backwards through the entire surf clamming process to determine the relationships between the various aspects of the industry. They examined profits, geographic distribution of surf clammers, man-hours of work, the number of clam boats in operation, and many other factors. All equations and relationships were then combined into a simulated model of the entire surf clam industry.

One of the most attractive features of the FISH5 model is that it is interactive. "The user can enter any economic or biological variables and see what would happen to the fishery before it ever happens," Anderson says. "For example, you can put a tax on clams, change the number of vessels in the industry, change the demand for the product—anything, and see what results you would get."

To test FISH5, the researchers decided to see how the presence or absence of yearly and quarterly quotas affected the supply of surf clams. When they entered all current data on the industry, they found that surf clams were virtually unaffected. Furthermore, using the demand model in FISH5, they saw that with the anticipated increase in surf clam supplies this year, the market price soon dropped to zero—a simulated market glut. Other tests of the model have shown that it can predict catch levels and movements of the fleet between various areas with acceptable degrees of accuracy.

A population upsurge such as this simulated supply increase may catch processors and clammers off guard. Anticipated high recruitment in this year's class could result in a change in the demand for clams and also show a different market condition based on increased supply.

Future use of FISH5 requires that the model be able to accurately predict changes in population and market demand. These revisions for recruitment and demand will be difficult to perfect, but are crucial to FISH5's success. With the inclusion of this data, the model should have the capability of providing substantial information for improving the management of the surf clam fishery.

**Partners Sharing Fisheries Modeling Technology**

- Delaware researchers have provided information on FISH5 to researchers at the University of Massachusetts: Mid-Atlantic Fisheries Management Council; National Marine Fisheries Service; Korea Ocean Research and Development Institute, Seoul, Korea; and Marine Resource Analysts, Ltd., Dartmouth, Nova Scotia.
- Both the New England Fisheries Management Council and the Mid-Atlantic Fisheries Management Council supplied Drs. Anderson and Ben-Israel with information and advice.

## Blue Crab Recruitment Is Tri-State Effort

R/M-4 Dispersal and Recruitment of Blue Crab Larvae—Charles Epifanio and Richard Garvine.

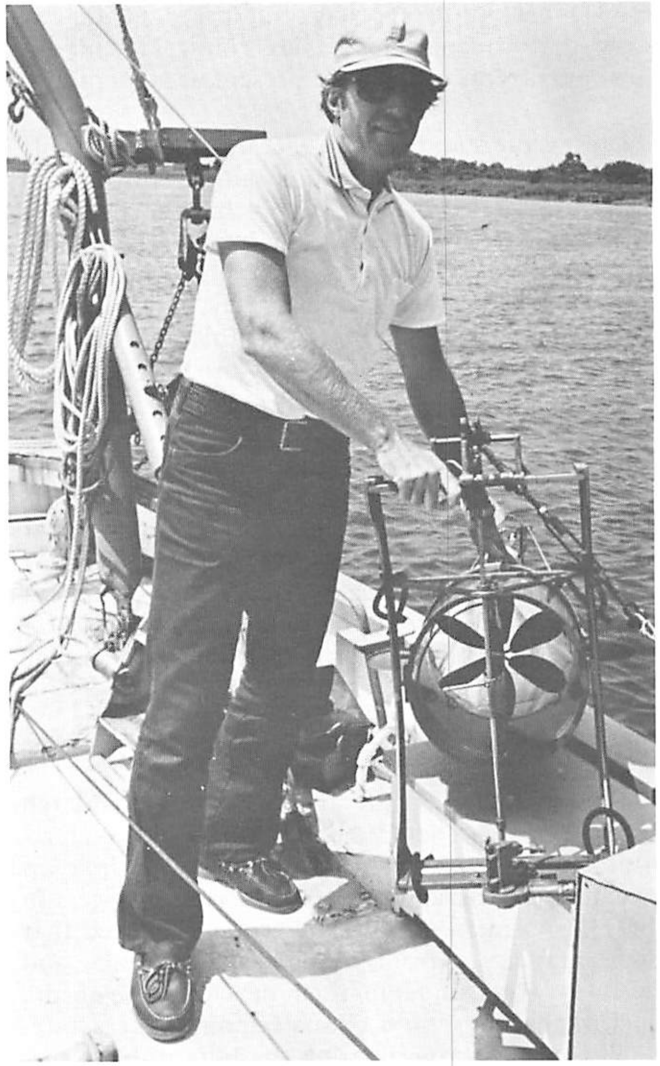
Blue crab landings in Delaware, Maryland, and Virginia comprised over 30% of each state's total fish catch in 1979, but scientists still knew little about the mechanisms that control crab populations. Determined to find out how blue crab populations are controlled in the mid-Atlantic region and interested by the discovery of crab larvae on the continental shelf, Dr. Charles Epifanio hypothesized that instead of remaining in the estuary to mature, the crabs migrated out of the Delaware Bay and onto the continental shelf where they could be swept away by currents. To test the hypothesis, Epifanio asked for help from Dr. Stephen Sulkin, University of Maryland, and Drs. Anthony Provenzano and John McConaugha, Old Dominion University, Virginia.

Research responsibilities for the tri-state project broke down into two parts: Dr. Sulkin and his staff at the University of Maryland would perform laboratory studies to determine the behavioral responses of blue crab larvae to environmental stimuli that could potentially affect larval migration and distribution, such as light, pressure, and salinity; Drs. Epifanio, McConaugha, and Provenzano would head efforts in Delaware and Virginia, respectively, to study the circulation patterns of the Delaware and Chesapeake Bays and describe the geographic distribution of the crab larvae with respect to these circulation patterns.

In Delaware, Epifanio enlisted the help of physical geographer Richard Garvine to study the circulation of the Delaware Bay. Assisted by graduate student Edwin Pape, Dr. Garvine devised an experiment to measure the residual flow of the bay—the net movement of water averaged over several tidal periods. Through cooperative efforts with the U.S. Coast Guard, a series of 7,000 plastic markers was distributed in eight locations throughout the Delaware Bay and continental shelf. Garvine and Pape found that Delaware Bay exhibits classical estuarine circulation—the residual flow of surface waters is seaward while the bottom currents' residual flow is from the continental shelf landward, into the bay. A north-to-south running current that flows along the shelf deflects the surface water emerging from the estuary to the south.

What do wind and water currents have to do with where crab larvae go? Dr. Epifanio and his team of researchers set out to find the answer.

Epifanio knew from Garvine's results that the bay's surface waters flow offshore and the continental shelf's bottom waters flow onshore. So the researchers set up a sampling station onboard the R/V *Wolverine* at the mouth of the Delaware Bay to sample for larval quantities and developmental stages.



Dr. Charles Epifanio with the Clarke-Bumpus plankton sampler, which is used to collect blue crab larvae at specific depths.

"We made two important discoveries," Epifanio said. "First, we found only two out of eight possible larval states present: the first zoeal state and the final megalopa state. Second, the first stage larvae were predominantly in the surface waters, while the megalopa were dispersed throughout the water column." From these results, the researcher inferred that the first larval stages were moving out of the bay with the surface waters, and, somehow, the megalopa stages were migrating back into the bay. The remaining six larval stages were found on the continental shelf, but not in statistically significant numbers to assess the situation. However, samples collected farther up Delaware Bay revealed zero larvae.

So it seemed that the first stage larvae were moving out of the bay and onto the continental shelf. Therefore, the megalopa larvae had to be moving back into the bay, but the data did not show that the megalopa were riding in with the bottom currents—they were present at all depths.

During the summers of 1980 and 1981, Epifanio and his group at Delaware took samples throughout the entire tidal cycle and found that the megalopa stage often moved upwards with the flood tides and downwards with the ebb tides. The pattern could not be verified quantitatively, but nevertheless, the researchers believed that this tidal locomotion might help the megalopa return up the bay to mature.

The Virginia and Maryland researchers' findings generally concurred with the Delaware team's results. Dr. Provenzano's studies showed a similar concentration of first stage larvae in the outflowing waters of the Chesapeake; Dr. Sulkin's team at Maryland showed that the blue crab's behavior in the laboratory reinforced the distribution of larvae found in both bays.

**Management Implications**

At a meeting of the tri-state study in March 1982, the researchers prepared a new blue crab recruitment model from their findings and drew up several recommendations for fisheries managers in the mid-Atlantic region. The group suggested that since the larvae from both the Chesapeake and Delaware Bays undergo their development on the shelf, managers should take a regional, not a statewide, approach in evaluating the blue crab population in the mid-Atlantic area. The group maintained that the blue crab recruitment process and population trends could be predicted once the physical driving forces of the continental shelf and bays were incorporated into a series of mathematical models. However, the researchers warned that since the recruitment process is governed by physical forces, beyond human control, it is not likely that management practices can effectively manipulate blue crab recruitment.

**For Future Research**

Work on blue crab recruitment is far from over. Delaware researchers are in the midst of a comprehensive study of the currents on the continental shelf off Delaware Bay. The study was stimulated by new data from Dr. William Boicourt, Johns Hopkins University, that suggest current reversal on the shelf may be a regular occurrence during the summer months. "If this really is the case," Dr. Epifanio says, "it will tell us a lot about where our crabs are going."

**Partners Sharing Blue Crab Recruitment Research**

- The U.S. Coast Guard provided Dr. Epifanio with a helicopter and crew during the drifter study.

## Project COAST (K-12 Marine Education)

E/Z-9 Project COAST—Les Picker.

Through Dr. Les Picker's Project COAST, school children in Delaware may take part in a variety of learning experiences about the marine and coastal environment. Dr. Picker recently led several workshops familiarizing teachers with the project's concept and available teaching units. In the future, he plans to revise outdated Project COAST materials for dissemination to targeted audiences.

**Partners Sharing in Project COAST Development**

- Dr. Picker has supplied the following with Project COAST information: Ministry of Education and the Academy of Scientific Research and Technology, Egypt; Underwater Conservation Society, United Kingdom; National Marine Education Association; Mid-Atlantic Marine Education Association; Center for Environmental Education; Delaware Museum of Natural History; Temple University; College of Education, University of Delaware; Philadelphia Friends School; Delaware Nature Education Society; Endicott Group; City of Newark Department of Parks and Recreation.

# *MARINE ADVISORY SERVICE*

*The Marine Advisory Service (MAS) is the principal outreach component of the University of Delaware Sea Grant College Program. The MAS is charged with helping to improve the productivity of marine resources and the quality of life of the people who enjoy them, who are affected by them, or who depend on them for a living. Specialists in marine resource management, marine education, fisheries development, marine business, seafood* *technology, and recreation and tourism promote the overall goal of the Marine Advisory Service—to encourage more effective use, development, and conservation of marine and coastal resources—through workshops, seminars, publications, radio, television, demonstrations, and individual consultations. In these ways, they share information and expertise with industry, government, and individuals.*

### Publications

One effective means of reaching a large audience is through the printed word. During the proposal period, the MAS developed the following publications to reach audiences ranging from home economists to state resource managers. In many cases, these publications were developed through partnerships with the state of Delaware, national organizations, and other groups:

*The Delaware Bay Oyster and the MSX Problem*—Developed in conjunction with the Delaware Department of Natural Resources and Environmental Control, this educational leaflet reviews the natural history of the oyster-attacking, microscopic parasite MSX *(Minchinia nelsoni)*, the extent of the problem, and management strategies to cope with it.

*The Pinelands Nature Trail*—Developed in conjunction with the Delaware Division of Parks and Recreation, this brochure provides visitors to Cape Henlopen State Park with information on the park's flora and fauna.

*Aquaculture and Coastal Zone Planning*—A joint effort between the University of Delaware Sea Grant College Program and the University of California Sea Grant College Program, the revised and updated report provides coastal planners and decisionmakers with technical information on the siting and policy considerations associated with aquaculture. Much of this information is transferable to other state and local jurisdictions.

*Seafood Samplers*—These two-page flyers provide readers with holiday and seasonal recipes featuring fish. The samplers stress the low-calorie, low-sodium


The Marine Advisory Service reaches a wide audience through publications such as those shown above.

attributes of seafood and introduce consumers to underused species, such as shark and squid.

*Delaware's Recreation and Weather Guide*—Developed with the support of the National Oceanoggraphic Center's Environmental Data and Information Service, this booklet explains the special weather conditions that recreationists using the Delaware Bay and ocean beaches might encounter. Popular with tourists, the guide also succeeded well as a promotional tool for area marine recreational businesses.

### Technology Transfer

To provide more specialized audiences—lobster fishermen, marine resource managers, and others—with technical information that they could apply in their day-to-day operations, the Marine Advisory Service developed the following activities. Many were in cooperation with local fishermen and regional and national organizations:

- A seminar on proposed and ongoing research on the Delaware Estuary was held for university researchers and state agencies, focusing on the estuary's water quality and biological production as well as on management strategies to preserve it.
- A demonstration project to assess the feasibility of onboard gutting and skinning of sharks was performed in conjunction with a commercial shark fisherman and with the support of the Mid-Atlantic Fisheries Development Foundation (MAFDF). The objectives of the project were to help develop a more efficient shark fishery in the Mid-Atlantic region and to provide markets for the underutilized species.
- MAS participation on Delaware's coastal management advisory board provided state and local agency officials with Delaware Sea Grant-supported research that was applied to, and helped solve, coastal management problems.
- Assistance to local commercial fishermen in developing a market for Jonah crab claws enabled them to obtain four times the price for their product; lobstermen learned improved holding methods for lobsters.
- Dissemination of sea-surface water temperatures helped fishermen pinpoint warm-water locations (which offshore gamefish ususally inhabit) as well as conserve fuel and keep harvesting costs low. This outreach venture was performed in conjunction with the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service and area offshore commercial fishermen.
- Industry briefings provided W. L. Gore and Associates, Delmarva Power and Light Co., Bordens Co., and the DuPont Company with Sea Grant research findings.
- A conference to discuss mariculture research and its application to industry was held in conjunction with the University of Delaware's College of Marine Studies and the Massachusetts Institute of Technology's Marine Industry Collegium.
- The executive summary and industrial panel charter for the National Sea Grant Program on Marine Corrosion were completed. In addition to principal investigators from five universities, the advisory panel is comprised of twelve industry representatives. The advisory panel's primary objectives are to interact with principal investigators and provide industrial viewpoints on marine corrosion problems and assist investigators in technology transfer.
- Proper handling techniques for fresh dogfish shark and the subsequent storage stability of fresh and frozen dogfish are being investigated through a competitive grant from the Mid-Atlantic Fisheries Development Foundation (MAFDF).
- Socioeconomic analysis of the 1981 Milford World Championship Weakfish Tournament was developed with support from the Milford Chamber of Commerce. The report analyzes fishermen's impact on the economies of Milford and of the state, examines the socioeconomic characteristics of tournament participants, and provides marketing and management recommendations for improving the tournament.
- Membership on the Governor's Task Force on Marine Recreation, a group of individuals from the public and private sectors, resulted in a report recommending future courses of action in marine recreation to marine recreation businesses throughout the state, public sector officials, and the Delaware General Assembly.

### Educational Outreach

Educating the general public and more specific groups about marine-related issues is another major role of the Marine Advisory Service. The activities listed below demonstrate the wide range of audiences the MAS works to reach—from school teachers to home economists. In many cases, partnerships between the state and other groups allowed the MAS to realize its educational objectives:

- Summer Shore Talks, a casual evening series featuring reputable speakers on a variety of scientific and natural resource topics, were held in conjunction with the Delaware Division of Parks and Recreation.

- Marine Education Programs for 4-H camps were developed with the University of Delaware Cooperative Extension Service.
- Marine Fisheries Education Short Courses were developed in cooperation with the Indian River School District's Gifted and Talented Program. The purpose of the course was to involve students in as many aspects of the area's fishery as possible—from catch to consumption. The students learned about the agencies and instituions that regulate the fishery, and they learned about the business aspects of the industry by catching and then marketing their catch via a seafood banquet, which they planned, developed, and executed.
- "Marine Family Experiences," a three-day program introducing families to the marine environment, as well as to management's role in conserving it, was held.
- The Fisherman's Hotline, a twenty-four-hour service providing callers with Delaware fishing and weather conditions, was developed. A one-minute recorded telephone message updated each day from May to September informed callers where the fish were biting, what bait should work best, what weather conditions to expect, and other fishing tips. Charter vessel and headboat captains, and bait and tackle shops from Bower's Beach to Fenwick Island provided the information.
- Seafood-Sense training workshops for home economics teachers and extension home economists were held in conjunction with the Department of Public Instruction and the University of Delaware Cooperative Extension Service and sponsored by the Mid-Atlantic Fisheries Development Foundation.
- Seafood education and promotion were provided through membership on the Mid-Atlantic Fisheries Development Foundation marketing team. The team promotes seafood from the mid-Atlantic region at the U.S. and International Food Show and in area media and market blitzes for the Seafood USA Marketing Campaign.
- Beach safety awareness program was held in cooperation with several organizations, state agencies, and other concerned groups, in response to a request by a Delaware state legislator. The program included a Delaware State Travel Service/Sea Grant safety brochure alerting beach goers to potential hazardous situations along the shore, and "Beach Safety on the Delmarva Peninsula," a slide/tape presentation prepared with the assistance of the Delmarva Aquatics Council, the University of Maryland Sea Grant Marine Advisory Service, and the Virginia Institute of Marine Science, College of William and Mary.

## PUBLICATIONS

### Sea Grant Reports

DEL-SG-01-81. "Vibracoring in Coastal Environments: The R.V. *Phryne II* Barge and Associated Coring Methods," W. H. Hoyt and J. M. Demarest.

DEL-SG-07-81. "Design and Test Operation of an Intensive Controlled Environment Oyster Production System," J. L. Thielker.

DEL-SG-12-81. "Remote Sensing of Optically Shallow, Vertically Inhomogeneous Waters: A Mathematical Model," W. D. Philpot and S. G. Ackleson.

DEL-SG-18-81. "A Drifter Study of the Lagrangian Mean Circulation of Delaware Bay and Adjacent Shelf Waters," E. H. Pape.

DEL-SG-25-81. "1981 Milford World Championship Weakfish Tournament: A Socio-Economic Analysis," J. M. Falk, et al.

DEL-SG-05-82. "Oceanographic Data Report Num-2: SalsX Cruises," C. H. Culberson, et al.

DEL-SG-07-82. "Intensive Marine Bivalve Cultivation in a Controlled Recirculating-Seawater Prototype System," E. T. Bolton.

DEL-SG-10-82. "Chitin and Whey Formulations for Animal Nutrition," P. R. Austin.

DEL-SG-13-82. "Proceedings of the Seafood Science Technology Workshop: A Selection of Unsolved Problems," C. A. Thoroughgood.

DEL-SG-14-82. "Chitin-Whey and Related Papers Presented at the Second International Conference on Chitin and Chitosan, Sapporo, Japan," J. P. Zikakis, et al.

DEL-SG-16-82. "A Transgressive Facies Model for a Shallow Estuarine Environment: The Delaware Bay Nearshore Zone, from Beach Plum Island to Fowler Beach, DE," thesis by K. F. Maley.

DEL-SG-17-82. "A Dynamic Model for an Estuarine Transgression Based on Facies Variants in the Nearshore of Western Delaware Bay," thesis by P. R. Marx.

DEL-SG-01-83. "Decisions for Delaware: Sea Grant Looks at the Inland Bays," S. L. Scotto, R. B. Biggs, B. Brown, A. T. Manus, and J. M. Lyman.

DEL-SG-03-83. "Head/Charter Boat Fishing in Delaware: An Analysis of Customers and Their Economic Impact," J. F. Falk, A. R. Graefe, C. Alkire, and D. Swartz.

DEL-SG-11-83. "Seascapes II: Glimpses of Our Water World," J. Hardin.

DEL-SG-16-83. "Optical Properties, Suspended Sediments, and Chemistry Associated with the Turbidity Maxima of the Delaware Estuary," R. B. Biggs, T. M. Church, J. H. Sharp, J. M. Tramontano.

DEL-SG-02-84. "Bathygraph: A Program Package for Mapping Bathymetric Surfaces. A Marine Sciences Oriented Graphic Package for Interdepartmental Use on the Burroughs B-7700 at the University of Delaware," C. H. Fletcher and M. J. Petit de Mange.

DEL-SG-03-84. Excerpts from "The Delaware Estuary: Research as Background for Estuarine Management and Development: A Report to the Delaware River and Bay Authority," J. H. Sharp, editor.

DEL-SG-05-84. "Sea Grant Program on Marine Corrosion, Final Report Volume One—Technical Summary," S. C. Dexter and W. H. Hartt.

**Journal Reprints**

DEL-SG-08-80. "Lateral and Vertical Facies Relations of Transgressive Barrier," J. C. Kraft and C. J. John.

DEL-SG-09-80. "Holocene Geomorphic Evolution of a Barrier Salt Marsh System, SW Delaware Bay," I. Kayan and J. C. Kraft.

DEL-SG-10-80. "Physiological Ecology of Acetylene Reduction (Nitrogen Fixation) in a Delaware Salt Marsh," H. J. Dicker and D. W. Smith.

DEL-SG-02-81. "Acetylene Reduction (Nitrogen Fixation) in a Delaware, USA, Salt Marsh" H. J. Dicker and D. W. Smith.

DEL-SG-03-81. "Differences Between Cell Division and Carbon Fixation Rates Associated with Light Intensity and Oxygen Concentration: Implications in the Cultivation of an Estuarine Diatom," G. D. Pruder and E. T. Bolton.

DEL-SG-18-82. "Three-Dimensional Analysis of Pleistocene and Holocene Coastal Sedimentary Units at Bethany Beach, Delaware," K. A. McDonald.

DEL-SG-20-82. "The Rate and Causes of Shore Erosion Around a Transgressive Lagoon, Rehoboth Bay, Delaware," thesis by M. L. Swisher.

DEL-SG-05-81. "Effects of Temperatures and Ration on Gametogenesis and Growth in the Tropical Mussel *Perna perna*," A. Velez and C. E. Epifanio.

DEL-SG-06-81. "Accumulation of Benzo [a] Pyrene in a Larval Bivalve Via Trophic Transfer," C. J. Dobroski, Jr. and C. E. Epifanio.

DEL-SG-09-81. "Tidal and Diurnal Influences on Food Consumption of a Salt Marsh Killifish *Fundulus heteroclitus*," S. B. Weisberg, R. Whalen, and V. A. Lotrich.

DEL-SG-10-81. "A Comparison of *Phaeodactylum tricornutum* and *Thalassiosira pseudonana* as Foods for the Oyster *Crassostrea virginica*," C. E. Epifanio, C. C. Valenti, and C. L. Turk.

DEL-SG-13-81. "Shell Penetration and Feeding by Naticacean and Muricacean Predatory Gastropods: A Synthesis," M. R. Carriker.

DEL-SG-16-81. "Salinity Requirements of a Marine *Thiobacillus intermedius*," D. W. Smith and S. F. Finazzo.

DEL-SG-17-81. "The Case for Sea Grant," C. A. Thoroughgood.

DEL-SG-21-81. "Metals in Estuarine Sediments: Factor Analysis and Its Environmental Significance," F. Bopp, III and R. B. Biggs.

DEL-SG-22-81. "Preservation Potential of Transgressive Coastal Lithosomes on the U.S. Atlantic Shelf," D. F. Belknap and J. C. Kraft.

DEL-SG-23-81. "Effects of Salinity on Acetylene Reduction (Nitrogen Fixation) and Respiration in a Marine Azotobacter," H. J. Dicker and D. W. Smith.

DEL-SG-24-81. "Nutrient Procurement Strategy of a Deposit-Feeding Estuarine Neogastropod, *Ilyanassa obsoleta*," L. A. Curtis and L. E. Hurd.

DEL-SG-02-82. "Clastic Depositional Strata in a Transgressive Coastal Environment: Holocene Epoch," J. C. Kraft, et al.

DEL-SG-03-82. "Special Characteristics of Estuaries," R. B. Biggs and L. E. Cronin.

DEL-SG-04-82. "An Empirical Test of Community Stability: Resistance of a Fouling Community to a Biological Patch-Forming Disturbance," G. W. Smedes and L. E. Hurd.

DEL-SG-06-82. "Progress Report: 1970-1982. Research in Recirculating Aquaculture Systems for Growing Commercially Valuable Bivalves," conducted through the University of Delaware Sea Grant College Program.

DEL-SG-08-82. "Halophytes from Coastal Salt Marshes: A Potential Source of Crop Plants for Arid Lands," G. F. Somers, et al.

DEL-SG-11-82. "The Importance of an Infrequently Flooded Intertidal Marsh Surface as an Energy Source for the Mummichog *Fundulus heteroclitus:* An Experimental Approach," S. B. Weisberg and V. A. Lotrich.

DEL-SG-12-82. "Functional Ultramorphology of the Dissoconch Valves of the Oyster *Crassostrea virginica,"* M. R. Carriker, et al.

DEL-SG-15-82. "An Exploratory Study with the Proton Microprobe of the Ontogenetic Distribution of 16 Elements in the Shell of Living Oysters *(Crassostrea virginica)*," M. R. Carriker, C. P. Swann, and J. W. Ewart.

DEL-SG-21-82. "Ingestion, Egestion, Excretion, Growth, and Conversion Efficiency for the Mummichog, *Fundulus heteroclitus*," S. B. Weisberg and V. A. Lotrich.

DEL-SG-22-82. "A Comparison of Dispersal Strategies in Two Genera of Brachyuran Crab in a Secondary Estuary," R. Lambert and C. E. Epifanio.

DEL-SG-23-82. "Seasonal Abundance and Vertical Distribution of Crab Larvae in Delaware Bay," A. I. Dittel and C. E. Epifanio.

DEL-SG-02-83. "Nutritional Evaluation of Seashore Mallow Seed, *Kosteletzkya virginica*," M. N. Islam, C. A. Wilson, and T. R. Watkins.

DEL-SG-08-83. "The Chemistry of the Delaware Estuary: General Considerations," J. H. Sharp, C. H. Culberson, and T. M. Church.

DEL-SG-09-83. "The Estuarine Character of the Gulf of Nicoya, an Embayment on the Pacific Coast of Central America," A. D. Voorhis, C. E. Epifanio, D. Maurer, A. I. Dittel, and J. A. Vargas.

DEL-SG-10-83. "The Physical Definition of Salinity: A Chemical Evaluation," J. H. Sharp and C. H. Culberson.

DEL-SG-13-83. "Seasonal Changes in Nutrients and Dissolved Oxygen in the Gulf of Nicoya, A Tropical Estuary on the Pacific Coast of Central America," C. E. Epifanio, D. Maurer, and A. I. Dittel.

**Marine Advisory Service**

Report of the Governor's Task Force on Marine Recreation in Delaware, September 1980.

Delaware's Weather and Recreation Guide. Richard DeAngelis and James M. Falk.

Tourism and Recreation in Delaware: Report to the Third Governor's Conference.

The Delaware Bay Oyster and the MSX Problem. Christopher R. Dyckman, editor.

Delaware Seafood Samplers—Holiday, Spring, Summer, and Fall Samplers.

*Delaware Sea Grant Reporter*—Volume 1, Numbers 1-4.

Seadrifts—Volume 5, Numbers 9-12; Volume 6, Numbers 1-12; Volume 7, Numbers 1-8.

Marine Policy Reports—Volume 3, Numbers 1-5; Volume 4, Numbers 1-5; Volume 5, Number 1.

## SEA GRANT BUDGET SUMMARY
September 1, 1980 - January 31, 1983

| | NOAA GRANT FUNDS | MATCHING FUNDS |
|---|---|---|
| **Marine Resource Utilization** | | |
| Aquaculture—Molluscs | $288,278 | $333,751 |
| Aquaculture—Plants | 234,945 | 139,444 |
| Marine Biomedicinals and Extracts | 150,772 | 75,462 |
| Biological Oceanography | 140,863 | 120,133 |
| **Marine Environment Systems** | | |
| Open Marsh Water Management | 204,860 | 86,403 |
| Environmental Assessments | 262,393 | 82,783 |
| Marine Fisheries Economics | 296,118 | 100,848 |
| **Geological and Coastal Dynamics** | | |
| Coastal Erosion | 162,580 | 95,773 |
| Ocean Engineering | 125,345 | 59,785 |
| **Marine Energy and Materials** | | |
| Resource Recovery and Utilization | 68,311 | 33,193 |
| **Education and Policy Studies** | | |
| Education | 135,308 | 71,700 |
| **Advisory Services** | | |
| Extension Programs | 181,229 | 321,389 |
| Other Advisory | 118,965 | 138,918 |
| **Program Management** | | |
| Program Administration | 136,410 | 418,358 |
| Program Development | 77,323 | 5,368 |
| **Total** | **$2,583,700** | **$2,083,308** |

| | | FY80 | FY81 | FY82 |
|---|---|---|---|---|
| **RESEARCH AND DEVELOPMENT** | | | | |
| **Marine Resource Utilization** | | | | |
| R/A-4 | Controlled Environment Mariculture: Management and Supportive Services (Bolton) | C | C | C |
| R/A-6 | Design, Construction, and Test Operation of an Oyster Production Prototype Unit (Thielker) | N | C | C |
| R/A-7 | Nutrition of *Crassostrea virginica* (Langdon, Bolton) | -- | N | C |
| R/B-12 | Domestication and Improvement of Salt-Tolerant Angiosperms (Somers, Gallagher) | R | C | C |
| R/B-13 | Investigation of Chemical Ecology of Feeding and Reproductive Behaviors of Oyster Drills as a Means of Drill Control (Carriker, Rittschof, Shepherd, Williams) | C | C | C |
| R/B-14 | Nutritional Evaluation of Halophytes for Their Potential Use as Food, Feed, and Forage Crop (Islam, Watkins) | -- | N | C |
| R/N-4 | Crab Waste Chitin Development (Castle, Austin) | R | C | C |
| R/N-5 | Chitinase, Chitin, and Chitosamine Glucosides for Improving the Digestion of Whey (Zikakis) | R | C | C |
| **Coast, Bay, and Shelf Engineering and Dynamics** | | | | |
| R/G-10 | Erosion and Deposition Processes and Patterns in the Nearshore Zone of Western Delaware Bay and the Atlantic Coast of Delaware (Kraft) | N | C | C |
| R/T-40 | Development and Application of a Method to Simulate Shoreline Response (Dean) | N | C | C |
| R/T-42 | Progressive Gravity Waves Over Water of Varying Depth (Lozano) | N | C/T | -- |
| R/T-43 | Currents and Turbulence Produced by Wind and Waves on Sloping Beach (Lai, Wu) | -- | N | C |

N = New, C = Continued, T = Terminated, R = Revised

| | | FY80 | FY81 | FY82 |
|---|---|---|---|---|
| **Marine Environment Systems** | | | | |
| R/B-4 | The Role of *Fundulus heteroclitus* in Tide Marsh Dynamics (Lotrich) | N | C | C |
| R/B-5 | Community Physiology of Bacterial Nitrogen Cycle Reactions in a Delaware Tide Marsh (Smith) | N | C | C |
| R/B-6 | Influence of Tides and Habitat Restriction on *Fundulus* Reproduction (Taylor) | N | C | C |
| R/B-7 | Remote Sensing of Estuarine Detrital Flow and Surface Water Productivity (Klemas, Daiber) | N | C | C |
| R/B-8 | Water Quality, Biological Production, and Management Strategies for the Delaware Estuary (Biggs, Church, Culberson, Sharp) | -- | N | C |
| R/E-3 | Simulation of Unified and Multipurpose Fleets in Multistock Fisheries (Anderson, Ben-Israel) | C | C | C |
| R/M-4 | Dispersal and Recruitment of Blue Crab Larvae (Epifanio, Garvine) | C | C | C |
| **Marine Energy and Materials** | | | | |
| R/T-50 | Construction and Deployment of DELBUOY, a Prototype 1500-Gallon-Per-Day Sea-Wave-Powered Desalination Buoy (Pleass) | N | C/T | -- |
| R/T-52 | Data Acquisition Preceding the Development of an Active Wave-Absorbing System for the Protection of Port Mahon in Delaware Bay (Biggs, Pleass) | -- | N/T | -- |
| **Education and Policy Studies** | | | | |
| E/Z-9 | Project COAST (Picker) | -- | N | C |
| **ADVISORY SERVICES** | | | | |
| **Marine Advisory Service** | | | | |
| A/I-1 | Marine Advisory Service—Administration (Manus) | C | C | C |
| A/I-5 | Public Information (Danberg) | C | C | C |
| A/I-7 | Marine Resource Development (Manus) | C | C | C |
| A/I-8 | Recreation and Tourism (Falk) | C | C | C |
| A/I-9 | Food from the Sea (Seymour) | C | C | C |
| A/I-15 | Marine Education and Awareness (Hall) | C | C | C |
| A/I-16 | Industry-Research Interaction (Wagner) | C | C | C |
| **Management** | | | | |
| M/M-1 | Program Management (Thoroughgood) | C | C | C |
| M/M-2 | Program Development—New Initiatives (Gaither) | -- | C | C |

N = New, C = Continued, T = Terminated, R = Revised