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June 1990

Governor Michael N. Castle and the General Assembly
State of Delaware
Legislative Hall
Dover, Delaware 19901

It is an honor to submit for the sixteenth year a report on the University of Delaware Sea Grant College Program. The primary goal of the program is to stimulate practical marine resource development and use through research, education, and advisory services. This report highlights our accomplishments in marine research, education, and outreach over the past year and accounts for the expenditure of the line-item appropriation of $373,000 allocated by the state to the university in support of the fiscal-year 1990 University of Delaware Sea Grant College Program.

Executive Summary

Marine research and education at the University of Delaware reached a major milestone this year. On June 6, 1990, the Graduate College of Marine Studies celebrated its 20th anniversary. On the occasion of our 20th anniversary, it is a time for celebration and also a time for reflection. What has the college accomplished? Does our progress to date hold promise for future achievement?

Accomplishment, of course, must be measured against a statement of purpose. This is the mission of the Graduate College of Marine Studies:

> *To advance the acquisition and application of knowledge related to global estuarine, coastal, and oceanographic environments through a program of excellence in research, teaching, and service.*

To accomplish this mission, the college has adopted a comprehensive framework of "marine studies" compared to the more limited field of marine sciences. This decision was based on the belief that it is essential to cover all aspects of human interaction with marine and coastal resources, ranging from conflict resolution studies of multiple-use situations in estuaries to understanding the natural science principles at work in the environment to the application of engineering solutions that benefit both humankind and the environment.

When the University of Delaware Board of Trustees approved formation of the college 20 years ago, they not only created an academic home for marine-oriented faculty and students, but they also assigned management of the university's Sea Grant Program (which began in 1968) to the new college. Early quotations from annual reports of each of these programs indicate the expectation for synergy:

"It is fair to say that the National Sea Grant College Program was the critical stimulus necessary for the University of Delaware to establish a College of Marine Studies in 1970."—*Annual Report, College of Marine Studies, July 1971*

"The University of Delaware made a positive commitment to the Sea Grant concept by establishing the College of Marine Studies in 1970. . . . This means providing leadership, a management structure, and a solid working base from which the Sea Grant problem-solving approach can be shared with other units in the University, with regional industry, and with government."—*University of Delaware Sea Grant Annual Report, 1971–72*

In a sense, the Graduate College of Marine Studies and the Delaware Sea Grant Program have grown up together, complementing and benefiting the evolution of each other over the past 20 years. The University of Delaware was the first university in the country to start with a single Sea Grant project award and progress through various stages of maturation, finally achieving Sea Grant College status in 1976. Along the way, a working university-private sector-government partnership has been forged. During the almost 23 years of University of Delaware Sea Grant's operation, the program's coordinated research and outreach activities have attracted an

investment of $35 million ($20 million federal; $15 million match). This consistent financial base, especially in the early years, permitted the university to expand its marine-oriented talent pool. Today, there are 78 faculty members and research scientists engaged in marine-related teaching and research at the University of Delaware. Of these, 34 are core faculty, 3 are research ladder scientists, and 3 are emeritus faculty directly affiliated with the Graduate College of Marine Studies; the others have joint appointments to the college from other university departments, or are adjunct appointees.

Historically, marine programs at the University of Delaware have emphasized research and educational efforts on coastal and estuarine systems that are of economic and environmental importance to Delaware. The faculty's research and teaching interests cover a broad spectrum: law of the sea, fisheries management, marine transportation and ports, estuarine and coastal oceanography, influence of oceans on climate, air-sea interaction, geochemical cycles, biochemical ecology, larval ecology, fisheries biology, benthic ecology, halophyte biology, marine biotechnology, marine surface chemistry, marine colloidal science, corrosion, and biofouling. Faculty publications and patent activity mirror this diversity. Each year, on average, the faculty publishes 3 books and 75 refereed journal articles and files 5 patent applications.

Research activity is fully integrated with the education of graduate students. Over its 20-year history, the college has granted 216 magisterial degrees and 84 doctoral degrees. Our graduates are now faculty and staff at major universities, research institutes, state and federal environmental agencies, industry, and public service institutions. Specifically, 40% have entered the private sector, 32% have accepted public employment, and 28% have taken academic positions.

From its academic home in the Graduate College of Marine Studies, the Delaware Sea Grant College Program continues to be the stimulus in fostering partnerships in which the university, government, and private sector pool their human and financial resources to address marine and coastal issues. Sea Grant Program components currently include marine biotechnology, estuarine environmental assessment, coastal engineering, habitat management and fisheries, policy studies, and marine programs outreach. Sea Grant serves Delaware with a comprehensive program of research, education, and advisory service. The following are examples:

- The Delaware Estuary is a major source of commercial and recreational growth for the Mid-Atlantic region—from fisheries to resort development. Researchers are continuing a major study of the bay to define how the system functions and to assess its health. Results of the study are being used by resource managers and the private sector to make decisions on future development on and around Delaware Bay.
- Geologists and coastal engineers are working to predict future shoreline changes as well as to determine which erosion structures will be most effective in counteracting rising sea level along the Delaware coast.
- The Marine Advisory Service recently undertook a cooperative project with the Department of Natural Resources and Environmental Control (DNREC) to evaluate the feasibility of applying remote setting technology to enhance the oyster population in Delaware Bay.
- The Graduate College of Marine Studies and Sea Grant annually cosponsor Coast Day to describe ongoing research in marine and coastal environments and to heighten public awareness of the importance of marine and coastal resources.

One very quantitative measure of a program's achievement and perceived worth is its ability to attract additional investment. The Graduate College of Marine Studies has achieved its current position in only 20 years because of its success in multiplying its university support with external contract, grant, and private funding two for one. During its 20-year history, the university has contributed a total of $28.7 million to college operations. The faculty, through marketing their research ideas, have generated another $62.8 million of which 30% ($19.2) has come from Sea Grant. In addition to all of the qualitative contributions of the college to the state of Delaware, the quantitative benefit of total economic impact (direct and indirect expenditures) by the college to the state equals $211.5 million for the 1970–1990 period.

Today, the Graduate College of Marine Studies and the Delaware Sea Grant College Program have become one, sharing the same philosophy of approach to marine issues. The cornerstones of this philosophy are a multidisciplinary approach to problem-solving and rapid, effective dissemination of research findings. Since its inception in 1970, the Graduate College of Marine Studies has developed a nationally recognized marine research program that integrates its graduate students intimately into the program and has a strong tradition of service to the state and nation.

An assessment of the accomplishments of the first 20 years gives confidence that the marine programs at the University of Delaware will continue to yield significant advances in man's effective use of the marine environment and that our many graduates will multiply these efforts even further in their professional careers.

SEA GRANT'S PROGRESS REPORT

The following articles provide a record of the progress made in research and outreach by the University of Delaware Sea Grant College Program during fiscal-year 1990.

Maintaining a Balance: The Health of the Delaware Estuary

More than 7 million people live near the shores of the Delaware Estuary. This waterway supports industry, commerce, transportation and recreation. It supplies water, power, and food, as well as habitat for numerous species of aquatic and terrestrial life. With this heavy usage, and the often competing demands placed on the estuary, the health of the waterway has been a concern for some time.

Assessing the health of the estuary and gaining a better understanding of the complex processes at work within it is a major goal of the Delaware Sea Grant Program. Current research includes a continuing study of the cycling of potentially toxic trace metals through the estuary, development of satellite imaging techniques as a diagnostic tool, a long-term biogeochemical study that is currently focusing on the effects of phosphorous on biological production in the estuary, and a study of the physical and biological variables that control dissolved oxygen concentration in the water.

Sources and Fates of Toxic Metals

Traces of elemental metals occur naturally in unperturbed estuarine environments. Certain trace metals (copper and zinc) are essential micronutrients; if they do not occur at high enough concentrations, they limit phytoplankton growth. However, if they occur at higher concentrations, or take a different chemical form, they become toxic. Other trace elements are toxic even at trace levels.

Trace metal pollution of estuaries is closely associated with human activities (e.g., atmospheric emissions, industrial processes, sewage outfalls, corrosion protection). Dr. Thomas Church has been studying trace elements in the Delaware Estuary for six years. He has determined the concentrations of the various trace metals in the estuary and the quantities of the metals that enter and leave the estuary. He has determined that precipitation, with acid rain, can add 200–1000% of the trace elements in the river, and discharges in the Philadelphia area can double the concentrations of some metals in the lower estuary.

This year, Dr. Church and his colleague Dr. George Luther are studying the speciation (the form the metals take) in the estuary. They have developed instrumentation for speciation of metalloids, such as arsenic, and are investigating new electrochemical techniques for speciation of other metals. These techniques will be used for sampling in the marshes and in the estuary.

Cycling of toxic metals in salt marshes was the subject of two graduate student theses. They identified important digenetic redistribution of toxic metals between solid and pore water phases after deposition and revealed that this distribution is a function of season and tide. They also identified organic sulphur phases that can contribute to the complexing and distribution of toxic metals. Currently, techniques using natural radionuclide tracers are being developed to document the rates of toxic metal redistribution.

This Sea Grant research continues to yield results that can be used to reduce pollution levels in the estuary.

Phosphorus and Dissolved Oxygen—Keys to the Health of the Estuary

Gaining a thorough understanding of the complex biochemical processes at work in the Delaware River and Bay is an important goal in maintaining the health of the estuary and continuing to improve its water quality. Dr. Jonathan Sharp and his associates have been studying biological productivity in the estuary for the past nine years. His current research is revealing the importance of phosphorus cycling in the estuary's overall productivity.

The primary production of algae is the engine that drives the rest of the life in the estuary. All life ultimately depends upon that primary production. Traditional thinking holds that the amount of nitrogen limits the primary production of algae in the ocean. However, Dr. Sharp points out that phosphorus limits the spring bloom of microscopic plants in the estuary. Most of these plants are not used by the rest of the food chain; they die and

drop to the bottom. But Dr. Sharp believes that they then break down into the nutrients that fuel production during the rest of the year.

To support this hypothesis, Dr. Sharp notes that nitrogen levels have remained relatively constant over the last decade or two, while total phosphorus levels have dipped dramatically as a result of sewer discharge cleanup. If nitrogen limited primary production, then production levels should have remained constant. However, evidence indicates that production has dropped considerably since the 1950s, suggesting a link to phosphorus.

While total phosphorus levels have dropped, the levels of phosphate (phosphorus dissolved in water) have increased. But there is a phosphate buffer effect in the Delaware Estuary that leaves a relatively small amount of phosphate in a form that can be used for plant production. Dr. Sharp is now studying that buffer effect in an effort to clarify the link between phosphorus and primary production in the estuary.

In a related study, Dr. Richard Geider and his colleagues are studying the factors that influence the concentration of dissolved oxygen in the water. Dissolved oxygen levels are recognized as one of the driving factors in the health of a body of water.

Dr. Geider is examining the balance between photosynthetic production of oxygen by microscopic plants and consumption of oxygen by bacteria in three different environments. In the region of the estuary where turbidity is highest, primary production is low, bacterial production is high, and oxygen levels are partially depressed. In the lower bay, primary production generally exceeds bacterial production, and oxygen levels are usually high. The third study site is Rehoboth Bay, a relatively shallow area where both primary and bacterial production can be intense, and dissolved oxygen concentrations vary markedly.

By analyzing and comparing the physical and biological variables that influence these three different environments, Dr. Geider is gaining a better understanding of how dissolved oxygen is regulated in the estuary.

The results of both Dr. Sharp's and Dr. Geider's research will aid resource managers in making decisions that ensure the health of estuaries.

Satellite Imaging as a Diagnostic Tool

Light and other electromagnetic radiation reflected from the earth's surfaces is different from the radiation that falls on those surfaces. Parts of the spectrum are missing from the reflected radiation.

For the past 15 years, Dr. Vic Klemas and his colleagues have been studying these differences, primarily in the visible-light spectrum. By analyzing data collected by sensors aboard satellites and aircraft, and conducting research at selected sites on the ground and from ships, they have amassed a wealth of information about the hydrological optical properties of water and the ecological properties of wetlands.

In the current Sea Grant study, Dr. Klemas, and his colleagues Drs. David Lyzenga and Richard Geider and their graduate students are developing a method of estimating the quality of habitat characteristics and living resource production of estuaries. They gathered extensive data from satellites, aircraft, and shipboard sensors in both the Delaware and Chesapeake estuaries. From this data analysis, a sophisticated optical model has been developed. They are now in the process of inverting the model; that is, converting it from an accurate assessment of the data they gathered into a tool that can be used to interpret satellite imagery. When the inversion is completed, they will test the model on remote sensing data from other estuaries such as Pamlico Sound and Narragansett Bay by gathering data from the ground to see how well it performs.

With a diagnostic tool such as this, resource managers can monitor the health of the estuary without the need for costly, time-consuming shipboard data collection.

Engineering and Coastal Dynamics

Along most of Delaware's ocean coast, the shoreline is moving landward at a rate of 2–3 feet per year. The reasons for this phenomenon are the natural processes of erosion, caused primarily by wave action and the slowly rising level of the sea. Moreover, violent coastal storms can cause massive erosion in a few brief hours, as well as damage valuable property.

Several Delaware Sea Grant researchers are examining the natural processes that cause erosion and are investigating methods of coastal protection. The results of this research will help coastal resource managers make the best decisions regarding Delaware's shores.

Offshore Breakwaters

Breakwaters are a proven method of reducing coastal erosion. By placing structures, usually mounds of stone, in the water beyond the surf zone, the energy of the waves striking the beach can be greatly reduced. In fact, under certain circumstances, beaches will even begin to grow seaward.

Dr. Tony Dalrymple has been studying coastal processes for several years. He has developed numerical models to produce the behavior of various types of waves in the coastal zone. Currently, his Sea Grant research addresses the use of breakwaters and the behavior of waves in and around them.

If we were to construct one massive breakwater along the entire coast, it would certainly protect the beach, but it would be very expensive and probably be unsightly as well. So Dr. Dalrymple is studying arrays of smaller breakwaters, breakwaters with gaps between them. He has developed numerical computer models to predict the behavior of both long and short waves as they strike the breakwater arrays. He has found that shorter waves, with wavelengths roughly proportional to the size of the gaps between breakwaters, can move in several different directions after passing the breakwater arrays. Behind the breakwaters, the resulting waves can combine to form rip currents, a condition that breakwater design should avoid because it accelerates erosion. Since breakwaters are not solid structures, a certain amount of wave energy does pass through them.

Dr. Dalrymple has also analyzed these wave fields. The computer models have been developed and refined. Dr. Dalrymple feels confident that they are capable of predicting the behavior of waves and currents in and around breakwaters. The research is now moving into the laboratory to test the models.

The results of this research will give coastal managers the knowledge of how to use breakwaters effectively should Delaware decide to use them to reduce coastal erosion in the future.

Coastal Dynamics

A thorough understanding of near-shore hydrodynamics and sediment transport is a necessary part of effective control of coastal erosion. One aspect of the hydrodynamics of waves breaking on a beach is a phenomenon that scientists call surf beat, low-frequency water movements in the surf zone caused by the conflicting forces that result from waves breaking, rushing up the beach and back to the sea. Surf beat increases wave run-up on the beach. It may cause the formation of sandbars. It may have an important influence on the movement of sand along the beach.

Dr. Nobuhisa Kobayashi has analyzed surf beat and developed a numerical model to produce wave actions in the surf zone. He will now test the model in the laboratory, and then in the field. Also this year, he will apply the model to predict cross-shore sediment transport and beach profile changes.

Dr. Ib Svendsen has been working to develop a mathematical numerical model of the complicated action that occurs within the near-shore region where the waves are breaking. The first step in this process is predicting wave and current movements and their effects on sediment motions. Dr. Svendsen has developed a model for the simplified case of a long straight coastline. In contrast to previous work, this model includes Dr. Svendsen's latest research results showing that both strength and direction of the currents vary between surface and bottom. This feature will influence sediment motions significantly, which means it is crucial for accurate predictions.

On a more general coastal topography, many other complications occur. In the coming year several additional physical mechanisms will be analyzed. Mathematical descriptions will be developed and tested, and the results will be incorporated into the computer model. The ultimate goal of this research is to develop a tool that can predict the erosion and accretion of beaches.

Marine Biotechnology

Marine biotechnology is an exciting aspect of the Delaware Sea Grant College Program because it applies advances in science and technology to the solution of human problems and the improvement of the quality of life.

Current Sea Grant projects include a continuing study aimed at improving the corrosion resistance of metals in seawater, further research on uses for chitin—the giant polymer found in crustacean shells, genetic manipulation of salt-tolerant plants to produce heartier strains that can be grown as food and feed crops in areas unsuitable for conventional agriculture or to restore damaged coastal habitat, and research aimed at finding an economical diet for bivalves that will support their growth in intensive cultivation systems.

Biofouling and Marine Corrosion

Any metal will begin to rust or corrode when placed in seawater. Some metals are more resistant than others, and methods of retarding the process are known, but sooner or later the sea takes its toll on everything from marine shipping to offshore oil and gas rigs. The cost of marine corrosion in the United States alone has been estimated at $20 billion per year.

It has long been known that, in addition to electrochemical corrosion, biological attachment (fouling) also occurs when metals are immersed in seawater. These two processes were studied independently, until recently.

With Sea Grant funding, Dr. Stephen Dexter was one of the first scientists to combine metallurgical and biological techniques to examine the effects the two processes have on each other when they occur simultaneously on a metal surface. He found the effects to be significant. Colonization by bacteria produces a "slime" or biofilm that can accelerate corrosion even before the entire metal surface is covered. He is now investigating whether that corrosion acceleration continues or whether it peaks in time and then reduces. How quickly the acceleration factor takes effect and how long it lasts will be major factors influencing marine corrosion rates.

Dr. Dexter's most important discovery this past year is that sunlight plays a part in the process; this fact was previously unknown. His research indicates that when undersea metals are exposed to sunlight and colonized by photosynthetic algae, the accelerating effect of the bacteria is minimized or disappears altogether. Conversely, corrosion appears to progress faster when metals in the dark are colonized mostly by bacteria. This year, Dr. Dexter plans to study the corrosion processes over longer periods as well as conduct more in-depth work on the chemical processes that occur within the layer of bacteria and biofilm.

Taking the multidisciplinary approach one step further, Dr. Dexter is collaborating with Dr. Herbert Waite, a biochemist, in a study of the effect of proteins isolated from marine mussels on the corrosion of stainless steel. Even adding a little of the mussel protein to the water in which the stainless steel is immersed appears to provide some protection at least initially, according to Dr. Waite. The critical concentration of protein needed to protect the metal is not yet known. But the past year's results show that the mussel protein has a very significant protective effect over a few hours at a pH of 2. The next step is to study longer-term exposure of the steel to bacteria and compare the effects of proteins from other types of mussels.

Dr. David Kirchman is also studying the effect of proteins on bacterial fouling. Thus far, he has been working with RuBPCase, which is perhaps the most abundant protein found in nature. He has coated various surfaces with the protein, then dipped them in seawater and counted the number of attached bacteria.

So far, he has found that surfaces like glass, over which water spreads easily, tend to have a weaker protein attachment, and bacteria seem to grow more quickly on them. Other surfaces, like teflon, exhibit slower bacteria growth, at least initially.

In the future, he plans to work more extensively with metal surfaces, use other types of proteins, and study the effects of bacteria on metal welds. Previous studies have shown that corrosion rates are particularly high on steel weld areas.

Stress-Tolerant Plants for Agriculture and Ecosystem Restoration

Sea Grant research in the Halophytes Biology Laboratory continues to improve the tolerance of selected marsh plants to salinity and stresses from drought and heat, which often accompany salinity. Food and feed crops

are being developed that can be cultivated in developing countries on marginal lands. At the same time, these stress-tolerant plants can be used in developed agricultural regions to maintain high crop yields while reducing expenditures of valuable resources such as fresh water, fertilizers, and pesticides.

This research is progressing on two fronts. Drs. Jack Gallagher and Denise Seliskar, their students and technicians, continue to study the biology of marine and estuarine halophytes (salt-tolerant plants) with a view toward production of food and forage crops using seawater irrigation.

A second focus is halophyte tissue culture, with one goal being the exploitation of somaclonal variation. The new generation of plants regenerated from undifferentiated plant cells contain more "mutants" (plants with different characteristics than the parent plants). By testing and selectively breeding for desirable traits, the researchers are essentially speeding up the process of evolution.

Scientists are also studying the use of tissue-culture techniques in the restoration of natural ecosystems. Man's increasingly heavy, multiple uses of wetland habitats is more and more frequently resulting in damage and destruction of these habitats by forcing a variety of stresses on wild plants so rapidly that they do not have time to evolve mechanisms to cope. The "accelerated evolution" technique is being used to develop plants resistant to the imposed stresses in areas where the natural balance can not be restored.

In addition to these studies, Drs. Gallagher and Seliskar are now experimenting with protoplasts, cells without hard protective cell walls. The aim is to grow a protoplast, then add genetic material from another plant, and then regenerate the growth of cell walls. The resulting plant would contain characteristics of more than one plant. To date, they have caused salt-tolerant cells to regrow cell walls, but they have not yet added genetic material from other plants. If the technique proves successful, they hope to add cells from salt-sensitive grasses to produce a salt- and drought-tolerant plant with the crop value of the salt-sensitive grasses.

Chemical Cues in Shellfish Diets

Clams, oysters, and mussels are an important seafood crop on the Atlantic coast and in other parts of the world. The industry's value in the U. S. alone is estimated at $290 million per year, and demands often exceed supplies.

For more than 20 years, scientists have been working to develop a method of intensive cultivation of these desirable bivalves. To date, they have achieved only limited success because the diet of the shellfish is not well enough understood. Traditional mariculture systems, such as the pioneering research conducted at CMS in the early 1980s, used microscopic algae as the food source. However, the cost of producing algae is too high to be feasible in a large-scale production operation, and the nutritional value of algae can be unreliable.

Much research has been directed toward developing non-algal diets such as microencapsulated nutrients. But to date, no artificial diet has been found that can equal the growth of animals fed natural diets. Dr. Nancy Targett suspects that this is not because the artificial diets are less nutritious, but rather, because the bivalves do not know that the artificial diets are good to eat. She postulates that in the natural environment, bivalves first perceive chemicals exuded by the microscopic algae and then use these chemical cues to distinguish between nutritious and non-nutritious particles. Microalgae exude chemicals called ectocrines in both dissolved and particulate forms.

Dr. Targett began her research using the blue mussel *(Mytilus edulis)* and six species of microalgae. She studied filtration rate and particle selection. This early research soon proved that adult mussels do indeed respond to pre-ingestive chemical cues from the microalgae. Dr. Targett and her associates identified five algal species that either stimulate or inhibit filtration rate or particle selection.

Further studies determined that dissolved ectocrines from certain microalgae inhibit filtration rates of mussels, but there was no evidence of stimulation. Adsorbed ectocrines, however, produced both rejection and preferential ingestion depending on the species of microalgae. This indicates that contact chemoreception may be more important than distance chemoreception. Thresholds of activity for the bioactive mixtures were found to be dependent on concentration.

Recently, Dr. Targett has expanded the research to include two more bivalves. Preliminary filtration rate studies indicate that chemistry is important, but there can be substantive differences in responses between species.

If Dr. Targett and her associates can isolate the chemicals and concentrations that cue different bivalves to feed, then these chemicals can be incorporated into non-algal diets to reduce the cost and increase the feasibility of intensive cultivation of these species.

Biopolymers from Shellfish Waste

Over ten years ago, Sea Grant researcher Dr. Paul Austin and his colleagues developed a method to extract the biopolymer chitin from blue crab shells and extrude it into fibers, thereby converting millions of tons of waste generated annually by the shellfish industry on the Delmarva Peninsula into a potentially valuable resource.

Since that time the Delaware Sea Grant College Program has been at the forefront of research and development of applications for this substance, which is found in the shells of all crustaceans. Many processes have been patented, and considerable interest has been generated in industry, resulting in development of applications of chitin products, primarily in the health-related sciences and in agriculture.

Dr. Austin and his associates, Dr. Charles Albisetti and Dr. John Castle (who recently retired), have continued to define economic applications for chitin and its derivatives. To date, the major applications include wound-healing promoters, nutritional additives, nonallergenic cosmetics, and preservatives.

The most recent development and the most recent patent are associated with making chitin paper sheets using new aqueous dispersion techniques. Laboratory-size batches of chitin paper have been produced, and work is under way to scale up process variables to produce larger batches. This technology was presented to a division of the Du Pont Company; they subsequently formed a chitin products subsidiary called DuCon.

The Chitin Company recently completed work on chitosan salts. Using a Sea Grant recipe, they produced 250 pounds of salt for evaluation in cosmetics and water treatment. Dr. Austin continues to study new routes in dissolving chitin to make useful products.

In other Sea Grant research, Dr. Dietrich Knorr, a food scientist, continues to develop uses for chitosan in plant biotechnology. He uses chitosan to facilitate recovery of waxes, gums, pigments, flavorings, fragrances, and pharmaceutical and other plant-cell products. With his associates, he has recently developed an array of colorimetric and enzymatic assays that will be used to study how carrot and chenopodium are affected by or make use of chitosan. His research also recently identified chitosan as an inducer of carvone biosynthesis in dill cultures. The goal of Dr. Knorr's research is the derivation of substances from plants that will overcome limitations in the supply of natural food ingredients and pharmaceuticals.

Habitat Management and Fisheries

Research to provide resource managers with the knowledge necessary to make wise decisions is of major importance in the Delaware Sea Grant College Program. Researchers are studying methods of controlling the reedy marsh plant Phragmites australis *and investigating the die-out of American beach grass along the Atlantic coast. Other research is gaining a detailed understanding of water circulation and exchange in the Inland Bays. Another research project is investigating the causes of the wide fluctuations in summer flounder populations.*

Controlling Phragmites

Sea Grant researcher Jack Gallagher says that if one tried to design a weed, he could probably do no better than *Phragmites*. Many people appreciate the beauty of the tall, reedy plant with its tassels waving in the breeze. What some people do not realize is that *Phragmites* is gradually replacing more valuable marsh plants. Nearly a third of the state's tidal marshes are now dominated by the plant.

Dr. Gallagher reports that the plant is amazingly hearty. In his laboratory, plants have continued to grow for as long as two years after being completely cut off from light. He has been trying to improve methods of controlling the spread of *Phragmites* so that the marshes can produce other, more valuable plant life. In the past he has worked with DNREC to determine when *Phragmites* is most susceptible to herbicide spraying.

This past year, Dr. Gallagher has turned his attention to other ways of controlling the plant. His research indicates that regulating water level may very well help control the spread of *Phragmites*. If the top of the plant is knocked down, either by burning or mowing, the roots have a difficult time surviving if water levels cover the surface during the growing season. Water-level regulation could provide another way of controlling *Phragmites*, either without using expensive herbicides or in conjunction with herbicides. By adjusting the growth environment, resource managers may be able to prevent *Phragmites* from returning after spraying.

Investigating Beach Grass Die-out

Dr. Denise Seliskar has been investigating the cause for the die-off of American beach grass *(Ammophila breviligulata)* along the Atlantic coast. During the last ten years, the grass has been dying in large patches between Massachusetts and North Carolina, and nowhere has the die-off been worse than in Delaware. Some 65% of Delaware's dunes have been affected at one point or another.

This die-out is a serious threat to the coastal environment because beach grass roots help stabilize sand dunes. The barrier dunes are natural erosion control structures, protecting back barriers from the fury of coastal storms.

Dr. Seliskar has conducted research on sand deposition, acidity, and nutrients. Her results indicate that placing sand around the plants seems to stimulate more vigorous growth as the plants try to keep up with the rising sand. With the assistance of DNREC, in site selection and placement of snow fences, she is studying sand accretion as a means of stimulating growth.

Areas of beach grass die-off have been notable for the acidity of the sand, perhaps because of the dead and decaying grass material. Dr. Seliskar has found that adding lime to those areas has significantly increased the number of new plants that survive. When a dead area is replanted, survival is 14% greater when lime is applied than when it is not. Dr. Seliskar reports, "DNREC used to say they couldn't plant an area that had died for five years. Now with the sand accretion and liming, I think they could replant right away." Preliminary results also indicate that adding macronutrients such as nitrogen and phosphorus also increases vigor.

In the coming year, Dr. Seliskar plans to expand the research to investigate the hypothesis that a genetic defect in a particular strain of the beach grass is responsible for the die-out.

Hydrodynamic Cycling in the Inland Bays

In recent years, the water quality in Delaware's Inland Bays (Rehoboth, Indian River, and Assawoman) has deteriorated significantly, resulting in environmental problems including bacterial contamination of shellfish beds and eutrophication. Rapidly expanding use of the bays and the ever-increasing population in the area threaten to degrade water quality even further.

Dr. Kuo-Chuin Wong, a physical oceanographer, is studying water circulation in the bays and exchange of water between the bays and ocean. In the fall, he installed tide gauges and placed current meters at key locations to record water circulation. In December, he retrieved the current meters and began analyzing the records.

He first constructed a simplified model of the overall exchange of water between the bays and the ocean. He is now developing and refining the model to include all details in the pattern of water circulation. Thus far, he has examined the volume exchange between the bays and the ocean via Indian River Inlet and the Lewes-Rehoboth Canal, and the volume exchange between Indian River Bay and Rehoboth Bay.

When the model is completed, it will provide an in-depth understanding of the water circulation and exchange processes that affect the Inland Bays. The results of the study can be used by resource managers to make informed decisions on a wide range of issues. Dr. Wong plans to conduct another field survey in fall 1990 to include current and sea-surface observations.

Variations in Population of Summer Flounder

Summer flounder occur in estuarine and continental shelf waters from Nova Scotia to the Atlantic coast of South Florida. Abundance is greater in the Middle Atlantic Bight, from Cape Cod to Cape Hatteras, where important fisheries exist. Summer flounder spawn on the continental shelf, and the young are transported shoreward on coastal currents. The post-larval stage that enters the estuary is about the size of a thumbnail. They suffer heavy mortality during the first few weeks or months.

As with other species, the number of flounder that survive the early, critical period determine, in large part, the annual contribution to the adult population. In 1987, the Mid-Atlantic Fishery Management Council issued a Fishery Management Plan that stressed the fact that there has been considerable fluctuation in year-class strength, particularly during the last five years.

Sea Grant researcher Dr. Timothy Targett is searching for the cause of these variations in population size. He feels that northern estuaries are more important to flounder populations than was previously thought; however, the northern populations have to deal with very cold winter water temperatures.

In controlled laboratory conditions, he is testing the effects of various temperatures and salinity levels on growth and survival of summer flounder. He has found that flounder will not grow at temperatures much below 10°C, but they can survive at temperatures as low as 3°C. At lower temperatures, the flounder suffer heavy mortality. (In the cold snap this past December, Dr. Targett measured water temperatures as low as -2°C). Early results indicate that variations in salinity have relatively little effect on the flounder.

In the coming year, Dr. Targett plans to look more closely at the 1–4°C temperature range. He will also compare how well juvenile flounder from North Carolina survive under the same temperature and salinity conditions. If they react differently, that would suggest the possibility that northern and southern flounder may actually be two separate fishing stocks, a fact that would have important implications for management of the fisheries. Results of Dr. Targett's research will assist resource managers in better regulating summer flounder fisheries.

Marine Policy Studies

Marine policy professors in the University of Delaware Sea Grant College Program examine the political, legal, economic, and social aspects of man's interaction with the marine environment. The studies are designed to help policy makers make wise decisions regarding resource management and conflict resolution. Two Sea Grant studies address the issues of coastal erosion and recreational fisheries management.

Economic Analysis of Beach Preservation

The nation's shorelines are moving landward at an alarming rate. Coastal erosion coupled with rising sea level claim 2–3 feet of Delaware's ocean coast each year, and as many as 10 feet per year at some places along the bay. Residential property and public beaches are threatened as well as environmentally sensitive areas such as wetlands. Moreover, some experts say that the rates of erosion and sea-level rise are increasing. If so, these problems will become even more serious in the near future.

What can be done? Dr. George Parsons points out three alternatives. We can nourish beaches, to replace the sand being taken away; we can build structures, such as sea walls or breakwaters, to protect the current shoreline; or we can retreat, allowing the natural processes to run their course.

Dr. Parsons is conducting an economic analysis, not to choose one alternative over the others, but to identify the optimum timing for implementing each of the options. For example, it may make economic sense to nourish a beach today. But at some point in the future, the increased rates of erosion and sea-level rise may make beach nourishment too costly and short-lived to be practical.

Dr. Parsons is developing a formal beach preservation decision model that will help communities choose the best alternative at the proper time. As part of the economic analysis, Dr. Parsons is currently taking an inventory of structures on Delaware's coastline from Ocean City, MD, to Indian River Inlet. This stretch of coast was chosen in conjunction with Governor Castle's task force on beach preservation. When the inventory is complete, Dr. Parsons can begin to estimate the social cost of retreat and assess the economic loss.

Dr. Parsons' study includes the policy issues that the Department of Natural Resources and Environmental Control considers to be of prime importance. When the decision model is complete, it will not only suggest the best choice of options and timing, it will also recommend the choice of laws and institutions to support the chosen policy. In this way, it will assist the state and local coastal managers in making the best decisions.

Toward a Complete Theory of Recreational Fishery Management

It's not unusual for recreational and commercial fishermen to find themselves on opposite sides of a controversy. A few years ago the two groups clashed as Delaware tried to develop a finfishing law. More conflicts resulting from competition for tightly schooled sea trout during the spring spawning season may prompt the introduction of legislation this year.

Over the past 35 years, many studies have addressed the economics of fisheries utilization. However, most of those studies have been directed at commercial fisheries. Dr. Lee Anderson is developing a complete model of the economics of recreational fishing. He has surveyed the economics of commercial fisheries and adapted those

theories and approaches that can be applied to recreational fisheries. At the same time he has expanded the model to encompass those areas where recreational fishing differs significantly.

The model can explain participation rates, activity levels, and the relative private and social benefits from unregulated and regulated fishing. By understanding the effects of common regulations, such as bag limits, closed seasons, and minimum sizes, fisheries managers can better understand how these restriction rates and levels of participation can meet individual satisfaction.

A creel limit, for example, could significantly alter the makeup of the fishing population. It is possible, Dr. Anderson says, that a creel limit would, in the short run, force better fishermen out of fishing, and in the long run encourage less successful people to start fishing.

Dr. Anderson is presently fine-tuning his model. When completed, it should be of value to fisheries resource managers. In the future, Dr. Anderson plans to study joint management of commercial and recreational fisheries.

Marine Advisory Service

The five specialists in the Delaware Sea Grant Marine Advisory Service (MAS) provide the vital link between Sea Grant research and the general public. Through publications, radio and television programs, seminars, and workshops, they reach a wide variety of people in marine-related industry, resource management, and other, specialized user groups.

Jim Falk, Program Leader and Marine Recreation and Tourism Specialist

Recreation and tourism is the third largest industry in the state and the lifeblood of coastal communities. In 1986, travelers spent more than $709 million in Delaware, much of it in the coastal area. Jim Falk's efforts are directed at strengthening this industry. He works closely with resource managers, tourism officials, businessmen, recreational boaters, sportfishermen, and summer visitors, providing information and helping to solve problems.

One recent project is an opinion survey about the Delaware Estuary. The random telephone survey solicited opinions from 918 estuary residents in Delaware, New Jersey, and Pennsylvania. The survey solicited opinions on environmental quality issues and the effectiveness of current management practices. Nearly every respondent surveyed expressed concern for the health of the estuary and strongly felt that anyone caught polluting the waterway should be held financially and legally responsible for any damages. The results of the survey will be useful to Delaware Estuary officials as important public input as they develop their Comprehensive Conservation and Management Plan for the estuary.

Last spring, Falk helped conduct a workshop for sportfishing tournament directors. The workshop focused on the growing economics of tournament fishing, marketing, and promotional techniques, and motivational aspects of anglers, and highly encouraged conservation, including catch-and-release fishing. Falk reports that some directors who attended the workshop have changed tournament rules to make their events more conservation-oriented.

Falk also completed a survey of visitors to the Rehoboth Beach-Dewey Beach resort area. Demographic information on visitors and their favorite activities help chamber of commerce officials and local businesses better promote the area as well as their products and services.

Doris Hicks, Seafood Technology Specialist

With the increasing emphasis on nutrition and eating healthy foods, seafood consumption is up and diners are looking for more and better ways to enjoy the bounty of the sea. That's where Doris Hicks comes in. Her educational activities help promote increased consumption of Delaware and Mid-Atlantic seafood products.

Her educational efforts include seafood sense workshops for educators and culinary heart courses for people who have health concerns. Teachers who attend the seafood workshops learn how to better use seafood and then incorporate the material into their curricula for their students—future seafood consumers. By attending the culinary hearts course, often at their doctor's recommendation, people can improve their health and quality of life by learning how to incorporate more seafood prepared in a heart-healthy manner into their diets. She also tapes

about 18 shows each year for the KYW-TV (Philadelphia) "Farm, Home and Garden Show," which has an audience of approximately 75,000 homes in the Delaware Valley region.

With the support of the Delaware Department of Agriculture, Hicks and MAS colleague Joe Farrell published the *Delaware Seafood Directory*, a popular booklet listing seafood markets in the state. It also includes a seafood availability chart.

Recently, Hicks has been working on a pilot survey of consumers to determine how often they eat seafood and what kinds of seafood they enjoy. The survey data is currently being analyzed and the results should assist seafood retailers in better serving the needs of their customers.

Hicks and Farrell also conducted the *Profits in Seafood* seminar for restaurant managers. Participants discussed new seafood products and how to maintain seafood quality. The success of that seminar has spawned interest in another seminar this year. One restaurant manager requested nutritional information from Hicks on his recipes. He now includes that information on his menu.

Bill Hall, Marine Education Specialist

As undergraduates, few teachers receive formal training in marine or aquatic sciences despite the fact that 72% of the world is water and our lives clearly depend on the liquid. Thus, much of Bill Hall's work focuses on making Delaware's teachers aware of how critical and limited a resource water is and how important it is for teachers to instill water awareness into their students. "Water will be the environmental issue of the next decade and making our students responsible stewards of this resource is critical to our quality of life," he says.

Working closely with the Department of Public Instruction, Hall conducted or was involved in 20 marine workshops for teachers during the past year. These weekend and week-long sessions include everything from classroom curricula and boat cruises to seining in the bay and trips to the National Aquarium. These workshops have introduced or reinforced the water curricula of nearly 650 Delaware educators and have helped the teachers to incorporate water-related curricula into their classrooms.

Hall has been working with the University of Delaware Office of Computer-Based Instruction for two-and-a-half years on a novel teaching tool for elementary students. The computer program, called "Design-a-Fish," will be available soon. It allows children to build a fish by selecting fins, body types, etc. Then an artificial intelligence program analyzes the design to see if it can survive in the ocean. The program will teach children how animals evolve to cope with their environment and thrive within their physical habitat.

Joe Farrell, Marine Business and Resource Management Specialist

Delaware's marine businesses generate nearly $2 billion in sales annually and are responsible for over 10,000 jobs. Joe Farrell conducts numerous educational activities to support marine businesses' needs.

Farrell and aquaculture specialist John Ewart conducted two workshops focusing on aquaculture possibilities for Delaware, providing production and marketing information. They also teamed up with other professionals to assist a local farmer in developing a crawfish operation near Frankford. Farrell also serves on the Marketing Subcommittee of the Governor's Task Force on Aquaculture chaired by Lt. Governor Dale Wolf.

Farrell is also active in marine resource management. He is involved with land-use and water-use issues as a member of the Citizens Advisory Committee of the Inland Bays Estuary Program and oversees the Delaware Sea Grant Mariner Report (MAREP) Program. The MAREP radio operator collects up-to-the-minute weather information from mariners at sea and relays that information to the National Weather Service in Washington, DC, where it is used to update and refine forecasts. Last year, 6,000 reports were collected, and according to H. Thurm, regional marine meteorologist for the National Weather Service, the reports *do* make a difference, by providing up-to-date weather information for southern New England and Mid-Atlantic marine forecasts.

Last year, Farrell organized a Mid-Atlantic Marine Users Forum, where boaters and National Weather Service officials met to discuss mariners' concerns and find ways to make the program even more effective. Users made several suggestions to make the National Weather Service more responsive to user needs.

John Ewart, Aquaculture Technology Specialist

John Ewart spent much of the last year working with Farrell on aquaculture workshops and helping a local farmer develop his crawfish pond. Since then, the MAS has fielded more than 300 inquiries about aquaculture. Ewart reports that information on the biology and cultivation of fish and shellfish has been in great demand.

Ewart is co-chairman of the Research and Technology Subcommittee of the Governor's Task Force on Aquaculture and is helping the newly formed Delaware Aquaculture Association develop goals. Ewart and Farrell, working with Delaware Cooperative Extension, are preparing a series of fact sheets to be called the *Delaware Aquaculture Information Series.*

The Aquaculture Task Force is charged with assessing the future of aquaculture in Delaware. Ewart sees a bright future as interest in aquaculture rises dramatically across the nation. He feels that it can make a significant contribution to Delaware's economy.

Marine Communications

The Marine Communications staff aids the Delaware Sea Grant College Program's administration, researchers, and Marine Advisory Service. The staff produces a newsletter, radio series, audiovisuals, and many other outreach products. The staff is comprised of a production manager, two media/information specialists, a graphic artist, and staff assistant. This five-member staff provides communications support to not only the Sea Grant College Program but also to the Graduate College of Marine Studies.

The major Sea Grant projects handled by the office include the *Delaware Sea Grant Reporter*, a newsletter that keeps over 3,500 readers abreast of marine-related issues affecting Delaware, the *SeaTalk* radio series, which is broadcast over nearly 40 AM and FM stations in the region, and *Delaware Estuary Situation Reports*, a series devoted to issues affecting the estuary and geared to resource managers, decision makers, and the general public. The staff also works closely with the Marine Advisory Service to produce *MAS Bulletins, MAS Notes,* slide/tape presentations, videos, displays, and specialty publications.

FINANCIAL REPORT

The following chart reveals the the University of Delaware Sea Grant College Program's major funding sources and the amount provided by each source from July 1, 1989, to June 30, 1990.

Program Area	State Funds	Federal & Other Matching
Graduate Education	13,326	389,944
Environmental Assessments: Estuaries	57,676	203,329
Coastal Engineering/ Coastal Dynamics	34,809	146,357
Marine Biotechnology	82,779	241,106
Habitat Management & Fisheries	34,172	101,908
Policies Studies	19,269	56,365
Marine Programs Outreach	130,969	425,594
Totals	**$373,000**	**$1,564,603**
Grand Total		**$1,937,603**

FUTURE OF SEA GRANT

During the Reagan administration, the National Sea Grant College Program was slated for termination; however, under President Bush's administration, with increasing interest in the environment, the outlook for Sea Grant has become more positive. With the increased talent pool of marine-oriented faculty that have been recruited over the last five years, the University of Delaware will be well-positioned to compete for any additional appropriation made to the National Sea Grant College Program.

Throughout the coming months, the University of Delaware Sea Grant College Program will be preparing its 1991-1993 proposal for submission to the National Office of Sea Grant. This proposal package will continue to emphasize research, education, advisory service, and communications projects that address important marine resource management, conservation, and development. The goal of each project included in the proposal is to increase public benefits through the wise conservation, development, and use of our state's, region's, and nation's resources. As always, the program remains committed to serving Delaware and increasing knowledge of the complex and fragile marine environment.

Should you require any additional information about the University of Delaware Sea Grant College Program, we would be pleased to meet with you at a mutually convenient time.

Respectfully submitted,

Carolyn A. Thoroughgood

Dr. Carolyn A.Thoroughgood
Director

Richard W. Tarpley

Mr. Richard W. Tarpley
Executive Director

cc: President David P. Roselle
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Senator Joseph R. Biden, Jr.
Representative Thomas R. Carper
Mr. Edward J. Sheehy, Chairman
Sea Grant Advisory Council
Sea Grant Principal Investigators
National Office of Sea Grant