Annual Report 1978-79

Delaware Sea Grant College Program

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Director's Message

By Dr. William S. Gaither

In 1968, when the University of Delaware began its first Sea Grant project, this new federal program concerned with the "wise development and use of the nation's valuable marine resources" was looked upon with enthusiasm by some and skepticism by many. Since that beginning, the Sea Grant Program has made a place for itself in the value system of universities and in the minds and pocketbooks of state legislatures and industries. The reason is simple. Sea Grant has held true to its congressional mandate. It has brought a fresh breeze of research relevance into universities. It has established an advisory service to convert the results of research to useful products and understanding that benefit large portions of the taxpaying public. It has, possibly most important of all, promoted foresight in university research and a willingness to take risks where the potential reward is great. No other federal- or state-supported marine research program does what Sea Grant does.

The Delaware Sea Grant Program is proud of the quality of faculty and students it attracts to its projects. It is also proud of the research initiatives that are included in the Delaware Sea Grant Program. The foundation has been well laid for understanding and developing our nation's marine resources during the coming decades as we now understand and use our land-based resources for the benefit of mankind and the economic well-being of the United States.

Seated (l. to r.): Dr. Carolyn A. Thoroughgood; members of the University of Delaware Sea Grant Advisory Board, Dr. Robert Pigford, Dr. Robert Gilbert, Dr. Arnold Clark, and Dr. Sylvia Farnham-Diggory (Dr. Gerard J. Mangone is missing from photo); and President of the University, Dr. E. Arthur Trabant. Standing (l. to r.): Dr. William S. Gaither and University Provost, Dr. L. Leon Campbell.

Executive Director's Message

By Dr. Carolyn A. Thoroughgood

This eleventh annual report describes the accomplishments of the University of Delaware Sea Grant College Program during the year ending August 31, 1979. The 25 projects supported were segments of nine major program areas. Expenditures under the Sea Grant Program for the 1978-79 academic year are recapitulated in the chart on page 2. Approximately 72 percent of the expenditures have been directed toward applied research; 19 percent toward advisory services and pre-college education; and 9 percent toward program administration.

Project leaders are found in many colleges of the University. For 1978-79, 7 departments or units of the University had representation in Sea Grant. These projects made possible the involvement of about 37 students in marine-related studies. Of these, 65 percent were graduate students in a wide variety of disciplines and 35 percent were undergraduates.

The University's acceptance of its designation as a Sea Grant College constitutes a commitment to identify and serve the needs of the state. This commitment is underscored by sharing of costs. Recipients of Sea Grant funds must match their federal funds on a one for two basis. A tangible dollar commitment must be made. The Legislature of Delaware has provided a portion of the matching dollars since 1975. In addition, matching funds were also provided by industry partners, private foundations, and philanthropists. The ability to attract a broad range of investors is one measure of worth. The Delaware Sea Grant College Program has had a history of being able to generate broader matching support than required by law, thereby being able to amount to a more effective research and action program.

An important factor in the success of the Sea Grant Program is that it provides a mechanism for identifying and bringing together consideration of all aspects of marine and coastal resources. For Delaware, Sea Grant is important to state agencies, legislative committees, industries, and individuals who have learned that the program is providing relevant answers to problems of the coastal zone and marine environment.

FY79 Sea Grant Budget

	SEA GRANT	MATCHING
Program Management		
Administrative and Supporting Services	$ 58,200	$ 70,100
New Initiatives	23,100	
Marine Resource Development		
Aquaculture	218,700	230,300
Living Resources	28,500	9,500
Marine Extracts	39,400	30,000
Socio-Economic and Legal Studies		
Marine Economics	63,900	19,900
Marine Technology Research and Development		
Ocean Engineering	193,600	168,900
Marine Environmental Research		
Environmental Models	108,500	34,200
Education		
Education K-12	4,400	2,200
Advisory Services		
Agent Activities and Communications	151,700	136,100
Add-Ons		
Seawater Pump	11,400	
Fright Behaviors of Oyster Drills	73,600	
Internship	18,500	1,200
Site Selection (NSTS)	30,500	
Total	**$ 1,024,000**	**$ 702,400**

Mariculture Research

Research on bivalve molluscan mariculture has been part of the Delaware Sea Grant College Program since its beginning 11 years ago. The ultimate goal is to be able to grow good-tasting, disease-free bivalves in a controlled environment faster than nature can, but at a price that is competitive in the marketplace. An intensive controlled environment system has been designed to grow oysters from larval stage to market size, feeding them mass-produced algae.

With the prospect of the new EDA-funded laboratory for mariculture/halophyte research at the Lewes Marine Studies Complex, the efforts of the Sea Grant mariculture team turned toward developing a demonstration prototype. Faced with the challenge of reducing the cost of algae production, the researchers re-evaluated the original prototype design this year.

Nutrition studies showed: 1) bivalves have difficulty digesting yeast; 2) encapsulated diets of protein, starch, and vegetable oils did not support animal growth; 3) shellfish feeding behavior is not related to a biological clock; and 4) growth efficiency of oysters fed algae was greatest at low algae density and an intermediate temperature (23°C).

Investigation of the role of calcium in mariculture oysters indicated that most of the calcium in oysters comes from calcium in the seawater surrounding them and not from a dietary source.

In the last year of a three-year project studying the shell of cultured oysters, researchers discovered a new mineralized layer (ligostracum) in the hinge that binds the oyster shell to the ligament. Mineralogical studies showed that this new layer is composed mainly of aragonite.

Commercial Controlled Environment Mariculture Production Prototype System and Commercial Controlled Environment Mariculture, Closed-Cycle Systems

Dr. E. Bolton, Dr. G. Pruder

Filter-feeding bivalves develop and grow on single-celled marine algae. Algae use solar energy for photosynthesis. The focus of the University of Delaware's program in mariculture research has been to take advantage of these natural phenomena by devising an intensive controlled environment mariculture system with the oyster as the bivalve of primary interest. In the most recent past, the chief objective has been to develop and operate a prototype bivalve culture system with an eye toward exploitation by commercial interests. The prototype would

- provide for continuing production of molluscs;
- provide detailed technical and economic analysis of the process and products; and
- serve as a research tool and a model for the departure into a commercial system.

Research and development of such a mariculture system require interdisciplinary work. The Delaware program involves biologists, microbiologists, chemists, engineers, and advisory specialists working on intensive culture of marine organisms, improvement of algae production, shellfish nutrition, mineral requirements for meat and shell production, observation of shell biosynthesis at the microstructural level, microbiology, waste removal and reclamation, and technology transfer to university and industrial communities.

The design for this mariculture prototype is unique, having evolved during ten years of research by the Delaware Sea Grant team. It will be an integral part of the new laboratory for mariculture and halophyte research at the College of Marine Studies, Lewes Marine Studies Complex. Construction delays with the new laboratory prevented the prototype from being put into operation this Sea Grant year, but work continued on optimizing the process, looking for ways to reduce costs, seeking alternative raw materials, and experimenting with non-algal foods for the animals.

The original prototype design incorporates all essential elements of an intensive, controlled environment mariculture system: oysters growing in reactors, algae growing in reactors, a recirculation loop to feed the oysters with algae, a mechanism for removing waste materials from the oyster tanks, and a method for bringing in seawater and cooling, heating, and treating it. The algae reactors are vertical transparent tubes that allow solar energy in. They are of a size that allows the most efficient production of the single-celled algae needed by the oysters.

But setting up and operating a facility based on the original design was determined to be quite expensive, and the cost of producing oysters under that scheme was high. With help from a large chemical manufacturing company, investigators cost-analyzed a theoretical model based on the production of 8,000 bushels per year, and found that algae costs accounted for 80% of the total process. There was no doubt that pulling down the cost of algae production was the hurdle to cross; since then, this has been the primary goal.

Researchers found it difficult to maintain the high production of algae required by the vertical tube design because the cost of control was high. Thus, various feeding regimes were considered and tried. Batch-feeding algae at high temperatures and high densities did not support the process. Continuous, relatively low density feeding schemes did. The system was redesigned to include those findings but there has been no long-term experience with it. This redesigned system is the one that will be in operation in the new laboratory.

The mariculture team has been involved in several cooperative projects during the past year. They have worked with scientists in South Carolina on immunological identification of shellfish predators in the field, and with scientists at the University of Maryland on steroid uptakes in oysters from algae and natural waters, and on a power plant siting survey in Chesapeake Bay. In addition, the system's hatchery and algae production units act as "lending libraries" for oyster spat and algae for experimental purposes.

Funds from a private foundation have supported four graduate students this year, working on mariculture research.

Nutrition of Bivalves in Controlled Environment Mariculture
Dr. C. Epifanio

Researchers looked at the value of the yeast *Candida utilis* as a food for clams and oysters. Last year, they determined that diets containing as much as 50% yeast supported growth comparable to standard algal diets. The present study investigated the causes of poor growth on diets containing more than 50% yeast. This was done by measuring ingestion, assimilation, respiration, and growth of clams and oysters fed diets of varying proportions of yeast and algae. As expected, ingestion, assimilation, and growth were high in groups fed diets containing more than 50% algae, while growth was low in groups fed diets high in yeast. Investigators were unable to account for all of the diminished growth, but much of it was explained by lowered rates of ingestion and assimilation, i.e., digestion; respiration was the same regardless of diet. These findings have led to the conclusion that bivalves have difficulty in digesting yeast and that diets high in yeast may effectively clog the digestive system of the bivalves, ultimately resulting in decreased ingestion.

In a second nutritional study, the Sea Grant team continued investigations into the development of encapsulated feeds for bivalves. Several encapsulated diets composed of varying quantities of protein, starch and vegetable oils were made in the laboratory, but none supported growth of bivalves.

A third study concerned endogenous feeding periodicity in oysters. Through the use of an automated turbidostat constructed in the laboratory, it was determined that feeding behavior in hatchery-reared oysters is controlled by the presence or absence of food. Feeding behavior in these shellfish is not at all related to exogenous factors such as time of day or tidal stage, i.e., feeding behavior is not on a biological clock.

The final study involved the combined effect of density of algal suspension and temperature on efficiency of growth in oysters. The use of a specially designed and constructed device enabled the most accurate estimation so far of production of food waste by these bivalves. Thus, researchers were able to calculate extremely accurate estimates of assimilation and growth efficiencies. Efficiency of growth was greatest at a low concentration of algae (5×10^4 cells/ml) and an intermediate temperature (23°C); it declined rapidly at concentrations above 5×10^5 cells/ml.

Microbiology of Closed System Mariculture

Mr. K. Smith

Bacterial monitoring of the recirculating seawater and effluents continued. The microbiology laboratory is also equipped to test for algae, fungi, and protozoa to assure the general microbial well-being of the mariculture system. Activities of bacteria in the algal cultures are monitored regularly.

Bacterial cultures were provided to the Sloan-Kettering Cancer Research Institute in New York for research on immunological responses of clams and oysters.

Mineral Requirements Necessary for Optimum Growth and Shell Deposition in Intensely Cultured Oysters

Dr. L. Sick, Mr. C. Johnson

A primary objective of investigators was to determine the role of calcium in cultured oysters. Specifically they sought to answer the questions: What are the oyster's exact requirements for calcium? What amounts are necessary to maintain growth and to promote rapid growth?

It was found that the major source of calcium for cultured oysters was ambient, not dietary calcium. It's probable that at higher levels of ambient calcium, growth of oysters could be increased. An article describing this particular research has been accepted by the *Journal of Marine Biology*.

In further investigations, a series of experiments was initiated to investigate the synergistic effects of the ambient levels of calcium and salinity. Analysis of results is underway.

Monitoring of the production of the enzyme carbonic anhydrase was begun, and may be able to provide a clearer picture of shell growth and the effects of salinity and changing calcium concentrations.

Ultramorphology, Mineralogy, and Elemental Composition of Shell of Cultured Oysters

Dr. M. Carriker

This three-year project was undertaken to provide clues for assessing and improving shell form and structure in cultured oysters. The past year was the final one of the study.

A detailed ultrastructural analysis of the different stages of the larval shell (prodissoconch) was completed and published in the *Proceedings of the National Shellfisheries Association*. Also published in this same volume was a comparative study of growth of oysters in three different maricultural environments. Scanning electron microscopy of major regions of the adult shell (dissoconch) is being completed during the fall and will be published as a companion report to that on larval valves. A new mineralized layer (ligostracum) was discovered in the hinge which binds shell to the ligament; a report has been published in *Science*.

Mineralogical studies with x-ray diffraction and Feigl's stain, in addition to confirming that oyster shell is calcitic (except for aragonitic muscle scars), showed that the new ligostracal layer is also aragonitic.

In collaborations with other researchers, atomic absorption spectrophotometry analysis of mineral elements in right and left valves (bulk samples) was completed. A manuscript has been accepted for publication in the *Journal of Experimental Marine Biology and Ecology*. With the exception of Ca, which was uniformly distributed, concentration of other elements studied (Mg, Sr, Mn, Fe, Zn, Cd) varied, in some cases markedly.

Surface spectral analysis with the proton microprobe of the 14 detectable elements present in prismatic, foliated, and myostracal shell, indicated heterogeneous distribution for most of the elements. Ti, Cr, Mn, Cu, and Br, for example, were present only in the prismatic layer. Where Sr was uniformly distributed, Mg was most abundant in the prismatic layer.

The three-year study disclosed three potentially useful indicators of growing conditions (in addition to shell size and form): growth bands in hinge ligostracum and ligament, prism size (larger in faster-growing oysters), and shell density (less chalky shell in oysters from closed systems). This paves the way for experimental studies on the effect of shell structure and chemistry of enrichment and impoverishment of various minerals in oyster culture water.

The Otis H. Smith Laboratory for Mariculture and Halophyte Research. Dedicated May 16, 1980.

Crab Waste Chitin

Chitin (kite'n), the cellulose-like natural material in the shells of crabs, shrimp, and other crustaceans (and exoskeletons of insects and arachnids) is being studied at Delaware and other Sea Grant institutions as a potential source of varied industrial products and as a means of alleviating the waste disposal problem. Delaware's interest in chitin has been on-going for about seven years; research has concentrated primarily on purifying raw chitin, developing nondegrading solvents, converting chitin into forms such as filaments for use as sutures, and films for optical uses; and investigating chitin's basic chemical unit, N-acetylglucosamine (NAG).

During the past year, Delaware's chitin research program has had three components: a continuing search for practical applications for chitin and its derivatives; basic studies of chitin composition and structure; and liaison with industry, university, and government groups that have potential interest in chitin development.

A promising application involves the use of NAG derivatives or a special microcrystalline chitin for promoting the digestion of lactose-rich cheese whey by animals.

Crab Waste Chitin Development

Dr. P. R. Austin, Dr. J. E. Castle, and Dr. V. Klemas

Various forms of chitin from several sources have been provided to Dr. Zikakis for further testing in the whey studies. The chemical nature of the microcrystalline chitin is being studied, and samples are being distributed for other nutritional and pharmaceutical applications.

A start has been made on the casting of unsupported films of chitin and chitosan (deacetylated chitin) with controlled dextro or levo optical rotation depending upon the helical or random coil configuration of the polymer chains. Study of the polarizing properties of these structures is underway.

In its natural state chitin is always associated with protein. Delaware researchers have found that this association includes strong covalent chemical bonding and gives rise to a family of closely related chitins whose compositions differ. This basic information could account for variation in the behavior of chitin from different sources and could also assist in setting specifications for chitin to be used in the several applications.

Methods for preparing the bio-active glucosamine of NAG, the monomer unit of chitin, have been elaborated because these glucosides promote the growth of bifidobacteria and the digestion of whey. Yields of the bio-active isomer have been increased and the products are being made available for experimental use by a chemical supply firm.

Chitosamine Glucosides for Improving the Digestion of Whey

Dr. J. Zikakis

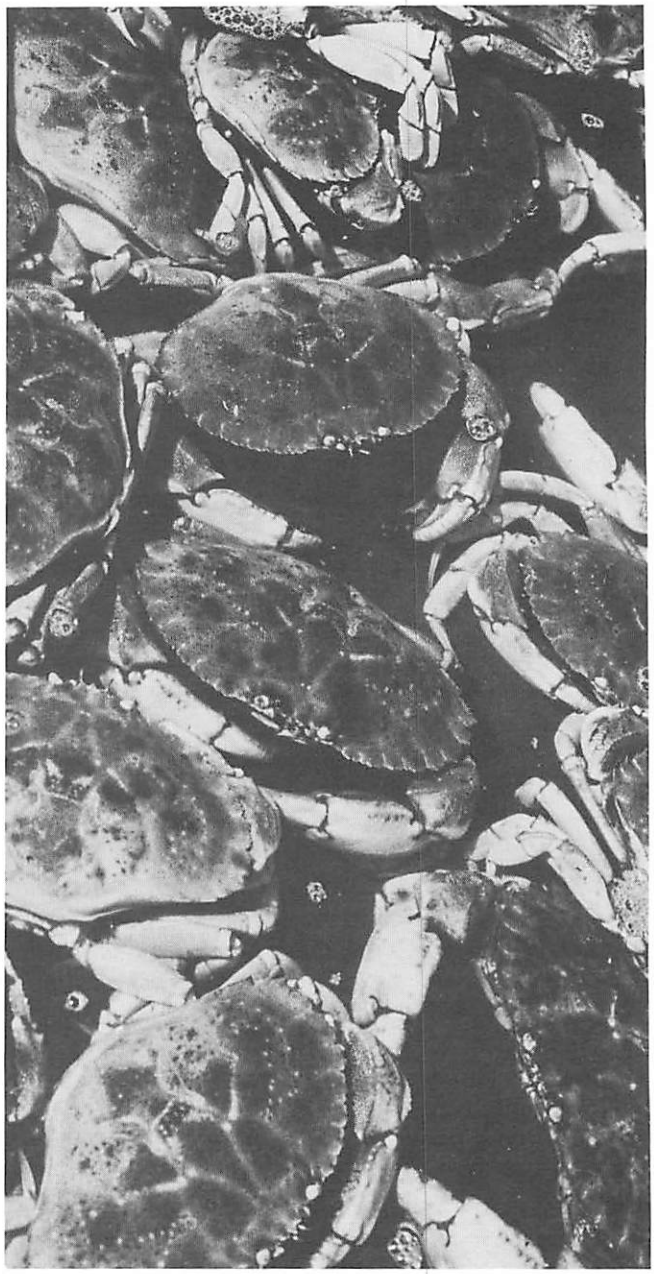
Each year between 8-10 billion kilograms of cheese whey are dumped into nearby landfill disposal sites, streams, and municipal sewage systems. This practice creates a pollution problem for many communities and is a great waste of a valuable nutrient. Dry whey contains nearly 13% protein of high biological value and about 70% lactose. But, nearly 80% of the world's adult human population is lactose-intolerant, an incidence also true for most species of adult animals. Finding a way to promote the digestion of cheese whey and lactose would help make whey available as a protein source and relieve pressure on the world's food supply.

The ultimate goal of researchers is to improve the digestion of whey through the use of chitin. *Lactobacillus bifidus* and related bifidobacteria have the ability to synthesize lactase, thus enabling an individual to utilize dairy products. It is known that these bacteria predominate in the intestine and feces of breast-fed infants; however, they are nearly absent from the intestine and feces of infants fed cow's milk. Studies have suggested that the factor promoting growth of bifidobacteria in human milk may be a bioactive compound closely resembling N-acetylglucosamine (NAG), which is the monomer of chitin. NAG is virtually absent from cow's milk.

If this is true, the addition of the right bioactive derivative of chitin to animal diets containing large amounts of whey or other lactose-rich dairy products would increase the ability of animals to tolerate and digest this dairy by-product. To test this hypothesis, animals were fed varying amounts of whey plus certain amounts of NAG along with a regular feed. Diets were made isocaloric and isonitrogenous. Analysis of fecal samples from rat feeding trials showed an increase in the *L. bifidus*-like population within three weeks on the test diet. After eight weeks, rats on a diet with 30% whey and 1.2% propyl-NAG grew faster and looked healthier than rats on the same diet without supplementation. The latter group developed severe diarrhea and eventually died from dehydration and malnutrition. Ethyl-NAG and, to a lesser degree, propyl-NAG tended to depress the appetite and thus limit growth.

Because it was reported recently that the chicken gastrointestinal tract contains chitinase activity, researchers initiated a chicken feeding trial where the diet containing whey was supplemented with microcrystalline chitin (MCC). Birds receiving 20% whey plus 2% MCC grew significantly faster than their controls, indicating that MCC was effective in improving the metabolism of whey. Also, after an initial adjustment period of about 20 days, MCC effectively controlled diarrhea.

Animal feeding studies as well as bacteriological assay tests are continuing.



Crab shells are one source of chitin.

Optimization of Tide Marsh Resource Use

Seven defined studies comprised the tidal marsh research program during 1978-79.

The production of smooth cordgrass, Spartina alterniflora, *was investigated in the area of Canary Creek marsh in Lewes, Delaware. Water control structures were used and basic data were collected for parameters such as mean stem height and density, above-ground biomass, and carbon:nitrogen ratio.*

To look at the flow of detritus out of the marsh, studies were initiated on monitoring organic particle fluxes from small drainage ditches. In addition, researchers began analyzing the decomposition of S. alterniflora *to eventually determine how detritus is used in estuarine food webs.*

In studying nutrient exchange, biologists have determined that the marsh acts as a consumer of dissolved oxygen and hydrogen ions, and that dissolved organic carbon increased in impounded water.

Nitrogen fixation research determined that most fixation occurs after active plant growth has stopped; measured fixation rates are predictable in how they are affected chemically; and the fixation data cannot be translated into absolute numbers to reflect the activity of the whole ecological system.

Laboratory data showed that the mummichog, Fundulus heteroclitus, *excretes enough nitrogen to be potentially important in nitrogen cycling within the tidal marsh. Researchers found that* Fundulus *feeds based on tidal rhythms.*

The experiments with spawning site selection by Fundulus *continued. It was determined that during the 1978 and 1979 spawning seasons,* Spartina *plants were used less than ribbed mussel shells as spawning sites. Researchers interpreted this shift in site preference as temporary because of winter weather conditions that delayed growth of* Spartina *plants and killed many mussels.*

Halophyte research this year placed major emphasis on Spartina alterniflora, Kosteletzkya virginica *and* Atriplex patula. K. virginica *seed is attractive as a potential food/feed for a number of reasons, including the discovery this year that it contains 30% of an oil with an iodine number comparable to corn oil.*

This year's work confirmed that Atriplex patula *does not grow well in water-logged soils.*

Canary Creek marsh.

Nutrient Flux, Energy Flow, and Production in Delaware Salt Marsh Ecosystems
Dr. F. Daiber

Primary Production in Relation to Water Control Structures

Primary production studies of *Spartina alterniflora* (both tall and short forms) have been conducted in association with water control structures located in the Canary Creek marsh in Lewes, Delaware. Objectives of this research, coordinated by Dr. F. Daiber, are to assess the above-ground primary production of *S. alterniflora* and to analyze this production to determine such chemical parameters as organic/inorganic content and carbon/nitrogen content. The water control structures can be used to manipulate the marsh's natural character in terms of nutrient additions or alteration of hydrographic regimes. These extensive baseline grass data, representative of a fundamental link to the marsh/estuarine ecosystem, are necessary to the assessment of any impacts incurred by such

perturbations. These data are also part of a continuing effort to monitor *S. alterniflora* production dynamics in the Canary Creek marsh on a long-term basis.

During a 17-month period in 1978 and 1979, *S. alterniflora* production data were collected on a near monthly basis from 15 "tall" stations and 24 "short" stations in the immediate vicinity of the water control structures. The following determinations were made for each of the 39 field stations: mean stem height and density, above-ground biomass, ash percent, ash-free dry weight, carbon and nitrogen percent, and carbon:nitrogen ratio.

Material Flux from Ditches. An ultimate objective of the Canary Creek research is to assess the flux of organic materials (detritus) from the marsh and study the role of these materials in terms of incorporation into estuarine food webs. To evaluate the many processes that contribute to these marsh functions, studies have been initiated on monitoring organic particle fluxes from small drainage ditches. These preliminary studies should more clearly define the dynamic nature of organic fluxes associated with the entire Canary Creek marsh ecosystem.

S. alterniflora in situ Decomposition. To study *S. alterniflora* decomposition in the marsh, a litter-bag study was conducted from March through the fall, 1979. The decomposition rates acquired can be related to detritus flux from the marsh. Additional studies are currently being conducted to analyze the chemical and structural composition of decomposing *S. alterniflora*. These types of data are essential to evaluating the incorporation of detritus into estuarine food webs.

Nutrient Fluxes in Relation to Water Control Structures

Following several years of studying nutrient flux, Drs. D. Smith and F. Daiber have begun studies of processes within the tidal marsh that determine nutrient exchange. Artificial impoundment structures have allowed them to entrap water on the marsh surface and follow changes in various chemical parameters. They have established that the marsh acts as a consumer of dissolved oxygen and hydrogen ions, reflected by a decline in pH. The marsh acts as a producer of total dissolved nitrogen, particularly in the form of ammonium. Dissolved organic carbon, a purported energy source for many organisms, was also found to be increasing in the impounded water. Work is in progress to determine the relative contributions of many of the sources of these changes.

Microbial Nitrogen Fixation

Dr. D. Smith

Dr. D. Smith characterized nitrogen fixation by bacteria in the Lewes marsh system. The characterization comprised three components:

1) *A seasonal pattern exists for marsh nitrogen fixation with the majority of the year's fixation occurring after active plant growth has stopped.* This addresses the presumed dependence of nitrogen-fixing bacteria on plants for carbon and energy. Delaware investigators confirmed that the major contribution of plant biomass is realized after the plant growing season.

2) *Measured fixation rates are affected by chemical amendments in physiologically predictable ways.* This is a significant advancement for field nitrogen fixation studies into the question of controlling factors of the natural process. The effects observed with field samples were predicted from laboratory results; thus they are valuable demonstrations of relevant *in situ* physiological ecology considerations.

3) *The fixation data obtained from such a nitrogen fixation survey cannot be reliably translated into absolute numbers reflecting the activity of the whole system.* Environmental planners and managers charged with making decisions related to marsh use should see this as significant. The contribution of the Delaware studies is that it is not possible to base decisions solely on scientific observations, since the absolute meaning of the measurements made does not reflect the true natural activity.

Investigation of marsh nitrogen cycle activity was extended by studies involving light-dark chambers placed in drainage ditches. These chambers were monitored for chemical changes in an attempt to distinguish the activities of the planktonic (water column) and benthic (sediment) communities. Effects of photosynthesis (O_2 production, NH_4^+ consumption) were seen to be mediated by the planktonic, rather than benthic, organisms in these short-term experiments.

Energetics and Nutrient Cycling in *Fundulus Heteroclitus*

Dr. V. Lotrich

Research aimed at understanding the energetics and nutrient cycling in the mummichog, *Fundulus heteroclitus,* was continued this year by Dr. V. Lotrich. Laboratory studies showed that

Fundulus excretes nitrogen at rates that can be potentially important in nitrogen cycling within the tidal marsh. Nitrogen excretion and growth was shown to vary greatly with types of diet.

Laboratory data also showed great disparity between energetic utilization of different diet types. Field studies were concerned with the way these fish choose their food items in nature, leading to an understanding of their predatory effects. It was established that *Fundulus* has a tidally modulated feeding rhythm, which suggests that organisms found on the marsh surface represent an important prey source to these fish. To study this, caging studies in the field have been conducted on a preliminary basis.

Halophyte seedlings are being tested in the laboratory for salt tolerance.

Spawning Site Selection in *Fundulus Heteroclitus*

Dr. M. Taylor

Dr. M. Taylor's work centered on determining the characteristics of *Spartina alterniflora* plants and related habitat required for successful spawning of *Fundulus heteroclitus.* Last year, in the first year of the study, use of plants as spawning sites was found to be much less than had been predicted from preliminary observations. This was interpreted as a temporary shift in site preference because of winter weather conditions that delayed growth of *Spartina* and killed large numbers of mussels. A comprehensive analysis of the use of mussel shells as spawning sites was conducted; it was found that *Fundulus* selected shells of the Atlantic ribbed mussel, *Geukensis demissa.*

In the summer of 1979, availability of mussel shells was reduced, and large *Spartina* plants were available early in the spawning season. A comprehensive sampling regime quantified plant utilization and identified factors that might be important in selection of particular plants as spawning sites.

During the summer, more than 5,000 plants were examined, 28 of which contained *Fundulus* eggs. Most eggs were found by picking plants that "looked like" potential spawning sites, then examining all plants within a one-meter square centered on that plant. Under these selection conditions, 2.9% of the plants contained eggs.

A group of 20 plants that contained eggs averaged about 90 cm tall and were located in the first meter from the center of a mosquito ditch. A comparable sample of plants that didn't contain eggs averaged about 72 cm tall.

Domestication and Improvement of Salt-Tolerant Plants, Especially Those from Tide Marshes

Dr. G. F. Somers

The ultimate objective of this continuing research program is to find or develop crops that will tolerate salinities characteristic of coastal and estuarine waters and that could be used as food for man and/or domesticated animals and/or for the improvement of tidemarshes. Concentration has been on plants that grow naturally in saline habitats.

Over the first four years, about 60 species have been examined in detail, and many others more casually. Most of these have been rejected. Testing has been done in field plots irrigated with saline water and in laboratory growing trays with recirculated seawater. Generally seeds and seedlings are tested for salt tolerance first. Then, species that show laboratory promise are further evaluated in field plots. Seeds are collected from various sources. During the past year researchers have given major emphasis to *Spartina alterniflora* (smooth cordgrass), *Kosteletzkya virginica* (seashore mallow), and *Atriplex patula* (orach). With *S. alterniflora,* the differences among seed sources with respect to flowering phenology persisted—the plants from Maine flower first and those from Virginia, last. A report of this finding has been submitted for publication.

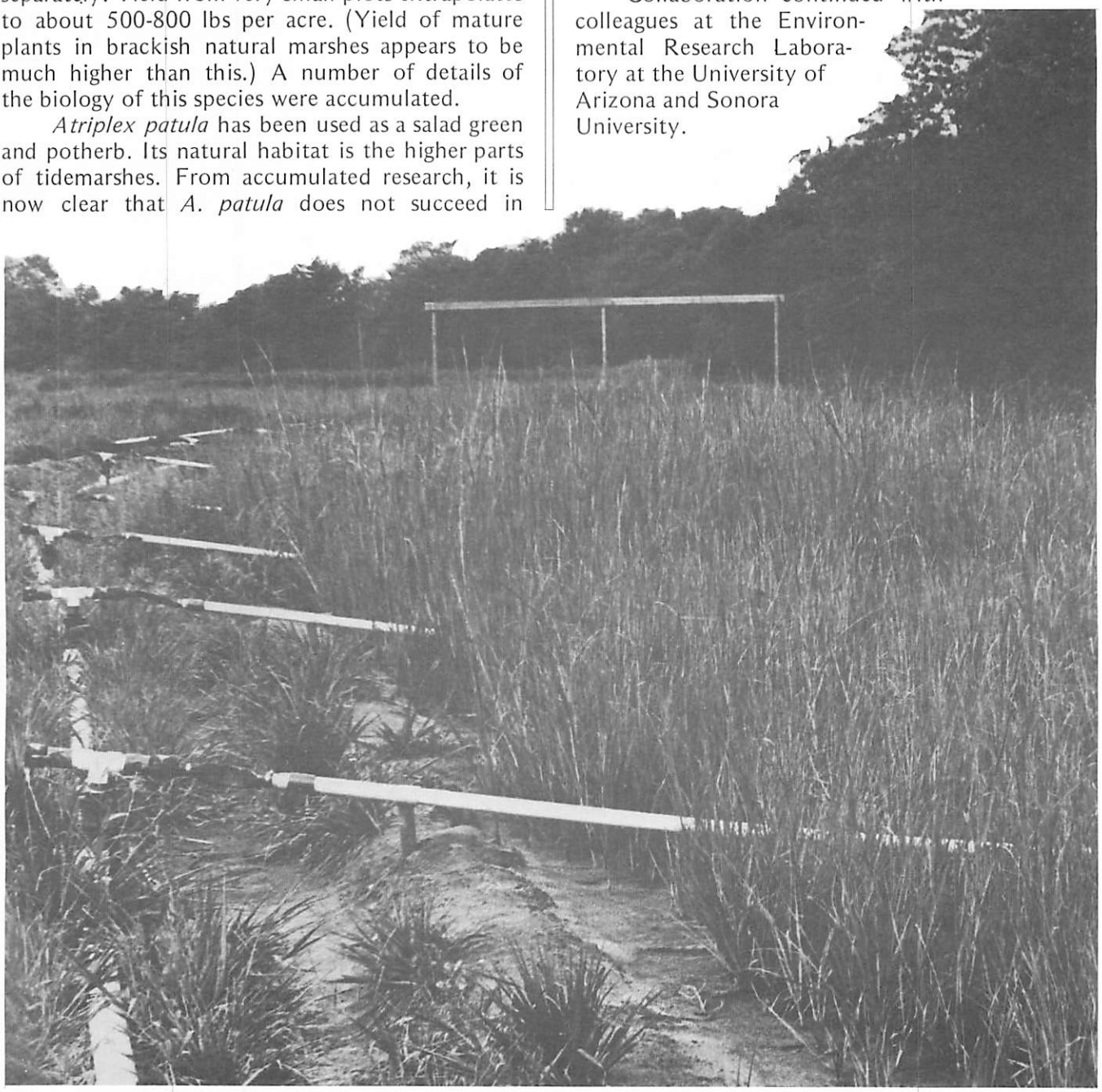
Harvests were made periodically throughout the growing season. Analyses are not yet complete, but June and July stems and leaves (combined as for a forage) contain about 8-14% protein (N x 6.25). Clones of this species transplanted into field plots from "short" and "tall" areas of a nearby marsh continued to display differences in growth. Those from the "short" area grew substantially less than those from the "tall" area.

Mulching with straw provided protection of *K. virginica* from frost killing during the severe winter. Again this year, *K. virginica* was grown successfully from seed to seed in one season. Yield of seed was greatly increased by using a "slow-release" source of nitrogen *(Osmocote)* as compared with a comparable rate of nitrogen from "10-10-10" commercial fertilizer. The attractiveness of the seed of this species as a potential food/feed was enhanced by the finding that the seed contains about 30% of an oil with an iodine number comparable to corn oil. Selection of more vigorous plants was made and seed from them was collected separately. Yield from very small plots extrapolates to about 500-800 lbs per acre. (Yield of mature plants in brackish natural marshes appears to be much higher than this.) A number of details of the biology of this species were accumulated.

Atriplex patula has been used as a salad green and potherb. Its natural habitat is the higher parts of tidemarshes. From accumulated research, it is now clear that *A. patula* does not succeed in waterlogged soils. However, good growth was obtained from plants grown on the mounds between furrows in a well-drained plot flooded three times weekly with water of up to 32°/oo salt (mostly 25°/oo).

Other species that grew successfully when flooded three times a week with water up to about one-half seawater salinity were *Asparagus officinalis, Panicum amarulum, P. virgatum, P. dichotomiflorum,* and *Sporobolus virginicus.* The growth of the two-year-old plants of *P. virgatum* and *P. amarulum* was excellent. Salinity in the soil profile was monitored with *in situ* sensors.

Collaboration continued with colleagues at the Environmental Research Laboratory at the University of Arizona and Sonora University.



A Spartina alterniflora *test plot.*

Coast, Bay and Shelf Engineering and Dynamics

How can sediment transport processes be used to predict erosion statistics? What role do sand dunes play in protecting a coastline? How is Cape Henlopen affecting the future of Lewes Harbor? How can wave-climate models be improved to provide a better basis for coastal engineering designs?

These were some of the questions that researchers in the Coast, Bay and Shelf Engineering and Dynamics functional group set out to answer this year.

Ocean engineers began incorporating results of previous and current Sea Grant studies on erosion, washover processes, sea level rise, and sediment transport into computer models to project shoreline responses over long time periods.

Recommendations were determined for stabilizing existing sand dunes and for extending studies of wind effects on dunes.

A sedimentary and hydrothermal study of Lewes Harbor concluded that the inner harbor probably has a remaining life of 25 to 50 years. Geologists project that the Cape Henlopen spit will continue to accelerate its rate of supplying coarse sediment to the inner (Breakwater Harbor) and outer (Harbor of Refuge) areas and that in 25 years the Cape may connect with the inner breakwater. Hydrothermal studies showed that the harbor will have a solid ice cover about once every 30 years.

The wave climate model research resulted in improved procedures for determining the distribution of wave energy losses within the surf zone.

Shoreline Erosion due to Extreme Storms and Sea Level Rise

Dr. R. Dean

Primary efforts this year have been directed toward: (1) a detailed investigation and modeling of sediment transport and beach profile response within the surf zone; and (2) the incorporation of all results developed thus far into a computer model to simulate shoreline response due to storm events.

The detailed modeling work was primarily pursued as research toward a Master's degree by B. Dally, and a thesis has been completed. Important contributions from this study include an improved representation of wave breaking within the surf zone, a recognition of the role of the *distribution* over depth of wave-associated momentum flux, and the incorporation of suspended and bedload sediment transport into the transport and beach profile evolution calculations.

Immediately following the initial wave break, relatively intense breaking occurs so that the resulting wave height is less than normally considered. Based on a first-order reaction type equation fit to laboratory data, the following relationship was established:

$$\frac{d\,(EC_G)}{dx} = \frac{KC_G}{h}(E - E_s)$$

in which E = wave energy density ($= \frac{\gamma H^2}{8}$); γ = specific weight of water; x = horizontal coordinate directed toward shore; h = local water depth; C_G = group velocity; E_s = "Stable Wave Energy" ($= 0.10\frac{\gamma h^2}{8}$); and K = constant (= 0.08).

The role of wave-associated momentum flux is well-known in causing set-up and longshore currents. In this study, the distribution of momentum flux over the water column was examined and found to be related to the bottom currents near and within the surf zone. If the governing equations are linearized, the biharmonic equation expressed in terms of the stream function, ψ, results,

$$\frac{\partial^4 \psi}{\partial x^4} + \frac{2\,\partial^4 \psi}{\partial x^2\,\partial z^2} + \frac{\partial^4 \psi}{\partial z^4} = 0$$

and the solution indicates that just outside and inside the surf zone, the bottom currents would be directed toward the break point.

The final computation scheme includes the effects of suspended and bed load transport combined with the mass transport water velocity distribution over the water column. The wave breaking model described above is incorporated into the computations. It is found that the occurrence of single and multiple offshore bars can be simulated as can other phenomena observed in nature.

The methodology available for representing sediment transport processes has been incorporated into a computation procedure which combines the statistical characteristics of storms in a region with simplified nearshore hydrodynamics. The procedure is being evaluated and will be used to predict the statistics of erosion (including the trend due to sea level rise) in a particular area.

Wind-Induced Effects on Coastal Sand Dunes and Structures

Dr. R. J. Lai, Dr. J. Wu

A three-year critical examination of sand dunes, including the effects of wind on the surface, the shape of the dune, and the effects of structures on the top of dunes, has yielded information that can be used by coastal planners and managers. Dunes are a natural form of protection along a coast and the more information available to land-use managers, the better equipped they will be to deal with problems of erosion caused by storms or normal wave action.

During the first two years of the project, investigators developed a numerical model to calculate the sand transport along a dune surface. Laboratory and field studies were done subsequently to confirm the numerical model. Researchers have cooperated with the computer science and mathematical science departments at the University. The *shape* of the dune was found to be the most important factor in studying sand transport on a coastal dune area (i.e., the shape affects the rate of sand transport and the areas of actual erosion and deposition).

Based on results obtained in the first two years, recommendations have been determined for stabilizing existing dunes. In addition, recommendations for further work include a modification of the program to more fully understand high dunes, a study of dune migration, a study of sand transport in the oscillatory boundary layer of the dune, and a study of how wind and waves interact.

Sedimentary and Hydrothermal Study of Lewes (Breakwater) Harbor

Dr. J. Kraft, Dr. R. Dean

Twenty-six estuarine/marine vibracores from Breakwater Harbor, west of Cape Henlopen, Delaware were analyzed. The analyses show that Holocene sediments that have filled the harbor are generally fining upward muds from gravel bases (perhaps Pleistocene), but are punctuated by frequent coarse storm-surge sediments (sands) originating from erosion of the sandy spit during northeastern storms. The storm-deposited sediments are up to 30 cm thick 500 meters west of the Cape but are less than two cm thick two km west. This decreasing thickness toward the west reflects increasing distance from the sandy source area and, since 1831, the sheltering effect of a man-made breakwater.

Between storm-deposited sandy layers, muddy sediments display a distinct cyclic character, probably annual. The sediments consist of alternating units (one to five cm) of: 1) heavily bioturbated, non-laminated muds (probably summer deposits); and 2) non-bioturbated, thinly laminated muds, silts, and fine sands (probably winter deposits) up to 20 laminations per centimeter. Decreased burrowing and increased storm activity during the winter months accounts for the annual cyclic character. Using coal fragment horizons (debris from steamships anchoring in the harbor starting in the 1850s), time lines may be drawn through cor-

Sand dunes are a natural form of protection for Delaware's coast.

relative sections. In central Breakwater Harbor, shoaling rates of 1.5–4.4 cm/yr (average 2.50 cm/yr) were found over the last 125 years. This shoaling is about an order of magnitude more rapid than typical surrounding shallow areas in southeast Delaware Bay.

These analyses are useful in predicting future rates of in-fill of Breakwater Harbor and the adjacent Harbor of Refuge. Projections suggest that the spit, Cape Henlopen, will continue to increase or accelerate its rate of supply in coarse sediment to the inner (Breakwater Harbor) and outer (Harbor of Refuge) areas. Approximately 25 years from now, the Cape may connect with the inner breakwater. Thus a 25- to 50-year remaining life for the inner Breakwater Harbor might be projected. However, this harbor will not be suitable for navigation unless a dredging program is initiated.

In view of the direction and source of sediment supplied to the harbor, the investigators recommended that the dredging and development of Breakwater Harbor (if this is to be done) be around the west end of the inner breakwater into the western end of the harbor. The eastern end of the harbor will increasingly shoal and needs frequent dredging to keep that end of the harbor open. On the other hand, the rates of sedimentation in areas that could be dredged in the western end of the harbor around the western end of the inner breakwater are such that a dredge maintenance program would be highly feasible to assure a harbor of significant size over the next 50 years.

Using historical data, investigators examining hydrothermal aspects of Breakwater Harbor determined that about every 30 years, the harbor will have a solid ice cover. By closing one entrance to the harbor, the return period of icing decreases to 15 years.

Development on Wave Climate Models
Dr. C. Lozano

A wave breaking on a coastline dissipates energy accumulated as it propagates across the open sea. The distribution of energy along the shoreline can be determined using wave climate models and studies that describe wave transmission by means of wave rays, following an analogy to the rays of geometrical optics.

In this one-year project to describe wave behavior in regions where ray convergence or crossing and caustics (ray envelopes) occur, investigators developed a uniformization technique for use with wave climate models. Results were published in the *Journal of Applied Ocean Research.* The uniformization technique yields a more valid theory of wave propagation.

The test case involved diffraction around a breakwater. Better predictions of the distribution of wave energy along a beach are obtained by using diffusion approximations (assuming a flat bottom and correcting for differences) rather than ray theory.

The numerical model developed could possibly be used when large distances are involved in the wave propagation area, for instance, in following rays from the continental shelf.

Ultimately, this information will be useful in predicting waves along the Delaware coast, and will help coastal zone planners be more effective in dealing with engineering designs and shoreline protection.

Delaware researchers are studying sand transport along dune surfaces.

Point of Use
Marine Energy Extraction

Mathematical and physical modeling of a sea wave-activated reverse osmosis desalination system have been accomplished in the three years since the system concept was detailed. This year's highlight was the testing of a quarter-scale model in the ocean at the U.S. Army Corps of Engineers Research Center pier in North Carolina. Results from two separate trials were very encouraging: the system (a surface wave follower connected to a seawater pump, connected to the submerged reverse osmosis unit) demonstrated that it scaled up well from laboratory tests and functioned effectively in a real sea.

Preliminary cost estimates indicated 1,000 gallons of fresh water per day could be produced for under $2, substantially lower than most trade wind countries (where this operation would be most beneficial) pay now.

The next step is to deploy and monitor a full-scale prototype; researchers have determined that Puerto Rico is the most suitable location.

A Desalination Unit Powered by Sea Wave Energy

Dr. C. M. Pleass

Project investigators continued work on this novel system for producing fresh water through means of desalination. Using sea wave energy to operate a desalination buoy could lead to greatly reduced freshwater costs for residents in trade wind coastal zones where potable water is scarce.

In the first two years of this research, a model was developed and laboratory wave tank tests at 1/15 scale were done. The system consists of a buoyant wave follower tethered to a seawater pump, with submerged reaction plates housing the reverse osmosis module. The arrangement has a three-point mooring.

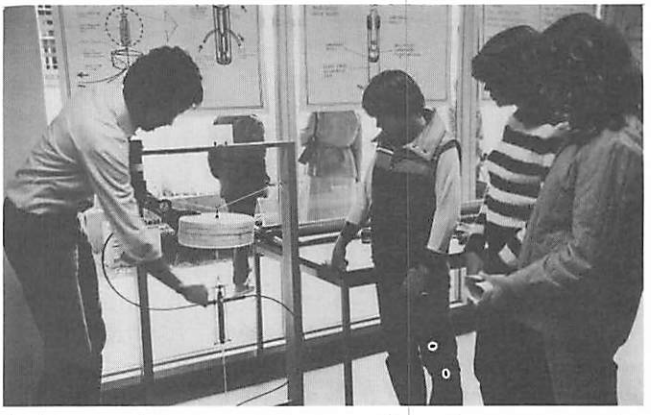
During this year, the model was scaled up to 1:4 and tested at the U.S. Army Corps of Engineers Research Center pier at Duck, North Carolina. Tests were performed in September 1978 and June 1979. Both trials indicated that the system scaled up well and functioned in a real sea at about the same level of efficiency as the 1/15-scale tests. However, there was a tendency for the reaction plate to rise incrementally because the fall time was greater than the rise time—this can be corrected for the full-scale deployment, scheduled during the next year.

Cost analyses at the end of this funding year indicated that the system could probably produce 1,000 gallons per day of product water for about $2 (assuming a two-year life for the reverse osmosis module). This is considerably below the current cost of potable water in most less-developed countries. It is hoped that further simplification of the pump design will lead to even further reduced costs for water output.

During this year, Douglas Hicks completed his Master's thesis based on the desalination buoy work. The practical component of his Ph.D. work will be the actual construction and deployment of a full-scale prototype in Puerto Rico. The University of Delaware and the University of Puerto Rico (Center for Energy and Environment Research) are cooperating in this endeavor. Several suitable locations for deployment have been identified.

Also this year, with an add-on project begun in February, work continued on the testing of materials to be used in the seawater pump. The use of urethane elastomers and PVC combinations are anticipated, because elastomers are extremely resistant to abrasion, and underwater, frictional wear between the materials appears almost negligible.

In the coming year, experiments will be conducted on the pre-filtering of seawater through the use of sand wells jetted into the sea bottom. Tests will need to be done comparing the quality of the water output and the dimensions of the sand wells.



Graduate student Doug Hicks uses 1/15-scale model to explain desalination buoy function.

Research in Support of Marine Resource Management

The appropriate bioeconomic goals of fisheries management are to produce that amount of effort in the proper places and times so as to maximize the net benefit to society (measured in socio-economic terms). With the expansion of research efforts internationally in the past decade, there has been a gratifying increase in the availability of reliable fisheries data. Management options can now be subjected to more quantitative, rather than qualitative analyses. Mathematical modeling and optimization methods are naturally suited to this environment, and this Sea Grant research includes both the application of known methods to the fisheries situation, and the development of new methods that can exploit the specific attributes of a renewable resource in a market economy.

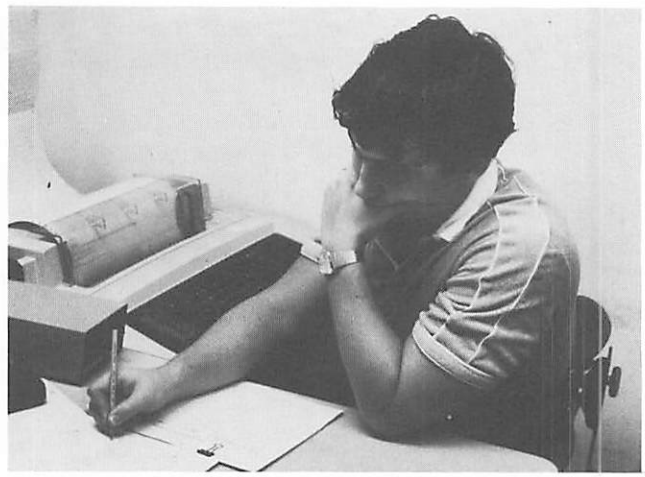
Simulation of Unified and Multi-Purpose Fleets in Multi-Stock Fisheries

Dr. L. G. Anderson and Dr. A. Ben-Israel

The major research effort during the past year has been a revision of a mechanistic fisheries simulator, FISH 2 *(FISH 2: Program and User's Guide,* by C. C. Sarabun). This is a multi-fleet, multi-stock, multi-age class fisheries model that addresses the major mechanisms involved in fisheries exploitation. The model is compartmentalized into interacting biological and economic sectors.

The biological sector predicts stock and cohort sizes as a function of natural growth, fishing mortality, and natural mortality (including predation-prey situations). The economic sector predicts fishing effort as a function of fishermen's profits, which includes fixed and variable costs of vessel operation and price of fish (demand) as a function of the amount of fish harvested. Effort fluctuates over time on a seasonal basis and as a result of vessel entry/exit from the fishery. The interaction between the two sectors is via fishing effort, which is produced in quantities predicted by the economic sector and yields fish in quantities predicted by the biological sector. This in turn generates revenues that determine new effort levels. Throughout this process, the value to society of the comprehensive operation is accumulated as the discounted sum of profits and consumer surplus over time.

In August, 1979, at the NATO Symposium on Applied Operations Research in Fishing, Trondheim, Norway, Drs. Anderson and Ben-Israel presented a paper describing the model and example calculations ("Modeling and Simulation of Interdependent Fisheries, and Optimal Effort Allocation Using Mathematical Programming," by L. G. Anderson and A. Ben-Israel). Some of the updates presently being made to the model are the result of suggestions by conference participants.



David Rockland, graduate student in fisheries economics.

FISH 2 was rewritten this year with the following revisions:

a) Operational capability on the DEC-10 computer, with special attention given to standardizing the FORTRAN (minimizing the machine-dependent attributes) so that the completed model can be shipped to other sites and machines with as little trouble as possible.

b) Inclusion in the model of vessel switching behavior; i.e., vessels can switch their concentrated attention to other fish stocks by paying some "switching cost" (such as the

cost of gear revision). This capability is extremely important in predicting the response of entire multi-fleet, multi-stock fisheries, because pricing or direct controls on one fleet or stock as part of a regulation program could prompt migration of vessels to alternate target species, with increased potential for over-exploitation. Obviously, any management plan that simply shifts the "bad news" from one stock to another will not be holistically effective. The inclusion of this model, while necessitating major coding changes, is considered important enough to justify the time and labor.

Dynamic programming procedures explicitly handle time dependence, thus naturally lending themselves to fisheries applications. DYFISH: Program and User's Guide," by G. Custis, done this year, reports dynamic programming results that were restricted to discrete allowable population states and effort levels. This could introduce an unrealistic constraint unless a very large number of discrete levels is used. Two methods are being investigated to resolve this problem. The first, an interpolation scheme using the discrete results as points on a continuous line, is being used to calculate the optimal distribution of effort in a two-species fishery. The second involves a combination of dynamic programming and optimal control to directly consider a continuum of state and decision levels.

The bulk of the FISH 2 revisions and published results of the dynamic programming effort are expected to be completed by the middle of the next grant year.

Researchers maintain a close working relationship with the Mid-Atlantic and New England Fishery Management Councils. Copies of the user's guide for FISH 2 and other papers resulting from this research are shared with the councils' members and staffs.

Commercial fishermen operating in Delaware Bay.

Research on Estuary and Shelf Interaction

The hypothesis being tested in this project assumes that blue crab larvae spawning in the lower part of the bay are carried out to the continental shelf and return to the bay as post-larvae in residual bottom waters.

Studying the movement of blue crab larvae in the Delaware and Chesapeake Bays can provide significant information about major coastal circulation patterns and what kinds of physical and chemical changes are affecting the larvae.

Researchers have collected preliminary data from plankton sampling trips in the Delaware Bay. In addition, plastic drifters dropped from U.S. Coast Guard helicopters have shown a general southerly flow of surface waters and westerly flow of bottom waters.

Dispersal of Blue Crab Larvae

Dr. C. Epifanio

This new project focused on testing the hypothesis that a significant proportion of blue crab larvae spawned within the lower Delaware estuary are carried onto the continental shelf and that the post-larvae reinvade the estuary by way of residual onshore drift in the bottom waters. Investigations involved weekly plankton sampling in the mouth of Delaware Bay, monthly sampling along a transect out of the bay onto the continental shelf, periodic release of surface and bottom drifters in the bay mouth area, and analysis of preliminary data on larval crab distribution in the mouth of Delaware Bay from the summer of 1978.

In this grant year, plankton sampling and study of water movement in the bay mouth was begun in April 1979, because the spawning season of *Callinectes sapidus* begins in late spring.

Results from the 1978 plankton sampling indicate that while the number of blue crab larvae in the bay was relatively low (presumably because of a decline in the number of spawning adults associated with the severe winters of 1977 and 1978), peak occurrence was in late July and early August in the surface waters at the bay mouth. This would indicate that larvae are indeed flushed from the estuary only to return weeks later in landward-flowing bottom water. Partial analysis of plankton sampling data from 1979 supports this conclusion.

Drifters are mushroom-shaped plastic devices dropped at specific locations from a helicopter (with the cooperation of the U.S. Coast Guard). The devices move freely with the water and are used to infer water movements. Each drifter is stamped with a return address and phone number, and a reward is given for each return.

Study of drifter returns indicates a generally southerly flow of surface waters leaving the bay, while bottom waters generally flow westward. Surface drifters have been returned from as far away as the outer banks of North Carolina, indicating that transport of larvae from Delaware to Chesapeake Bay is a distinct possibility.

Analysis of plankton samples and drifter returns is continuing. If the original hypothesis ultimately proves correct, it would be important to devise a regional, rather than state-by-state, management system for the blue crab fishery.

Researchers complete a plankton tow in Delaware Bay.

Education and Training

Drawing upon the many educational resources produced by Project COAST since the early 1970s, this year's goal for the education group was to train teachers, in fields ranging from science, to social studies, to the humanities, to be more knowledgeable about the marine environment. This emphasis, on the teacher rather than the student, theoretically results in multiplied benefits when each teacher brings new ideas and materials into classrooms that expose him to at least one hundred students each day.

Secondary Teacher Education
Dr. R. Stegner

In essence, the group of about 30 secondary school teachers assembled for this project received a graduate-level oceanography course, but with constant emphasis on the passing of this information on to their classes. Since even the brightest scholars among us are of little value to society if they cannot channel their thoughts and energy into useful forms—in the case of a teacher, this means good organization and communication—exposure to Project COAST's wide repertoire of learning materials was invaluable. This included over 85 "learning experiences" (curricula complete with homework assignments, tests, and audio-visual aids or suggestions); a source catalog for audio-visual aids, games, and art; a catalog of curriculum materials for marine environment studies; and annotated lists of young people's books on the marine environment and periodical sources for marine environment studies.

As a key exercise in the oceanography course, teachers were required to design a lesson plan for actual use in their classrooms that would incorporate Project COAST or other materials discussed. Dr. Julius Gordon, a research associate with the College of Marine Studies who was primarily responsible for the training course, felt that the teachers responded favorably to this program, in spite of the extra effort required from humanities-based teachers to keep abreast of the course's scientific content.

Dr. Julius Gordon.

Marine Advisory Service

Marina operators, small business owners, teachers, students, oystermen, commercial fishermen, sportfishermen, industry representatives, newspaper readers, and radio listeners are some of the audiences that got to know the Delaware Sea Grant Marine Advisory Service this year. Through individual meetings with agent/specialists, seminars, workshops, telephone calls, radio programs, and publications, they received information to help them become better users of marine and coastal resources.

Administration, Public Information, Marine Resource Development, Recreation and Tourism, Food From the Sea, Marine Education, and Industry-Research Interaction
Dr. C. Thoroughgood, Dr. P. Jensen, Ms. K. Danberg, Mr. J. Falk, Mr. W. Hall, Ms. K. Jensen, Mr. H. Seymour, and Dr. R. Wagner

The primary responsibility of the Marine Advisory Service is information and technology transfer. Five agent/specialists, two communication specialists, and one administrator joined forces during the 1978-79 Sea Grant year to help the people who live, work, and vacation in Delaware's coastal zone reap the greatest benefits from their relationship with the sea. Helping coastal zone users to identify problems, cooperating with university researchers to find solutions, educating and assisting users on a wide variety of topics—these comprise the daily activities of Marine Advisory Service personnel. Following are some highlights from the past year.

- The second annual University of Delaware Coast Day, sponsored by the MAS and the College of Marine Studies, was held at the College's Lewes complex in October 1978. Close to 6,000 people attended the day-long "marine fair" to learn about university marine research programs; federal, state and local government programs; and other marine-related groups. They also came to eat seafood—2,000 clams, 25 gallons of fish chowder, 9 gallons of oysters, and 40 cases of soft drinks.
- MAS was a co-sponsor of the 1977 and 1978 Governor's Conference on Tourism and Recreation in Delaware. One of the recommendations of the 1977 conference was that a task force be appointed to study marine recreation in the state. MAS, represented by Dr. P. Jensen, has chaired that Governor's task force since its inception in 1978. After Dr. Jensen's departure from the Sea Grant program in May 1979, Mr. J. Falk assumed the role. The task force is charged with assessing the state of marine recreation, identifying potential sites for new facilities, and making recommendations for improvements.
- A preliminary survey of the marina industry in Delaware was begun to determine specific problems for which MAS can provide assistance.

The Coast Day marine petting zoo always attracts attention.

- MAS agent/specialists have worked with area chambers of commerce and other groups to organize spring and fall sport-fishing tournaments, boating races, and vacation packages that will help extend the summer season for providers of recreation and tourist facilities and services.
- Fishermen's Hotline, in operation since 1972, continued to provide callers with daily messages on fishing and weather conditions. Approximately 57,385 calls were made to the Hotline during the 1979 season.
- Help was provided to the state's Department of Natural Resources and Environmental Control and area watermen in revising commercial finfish legislation.
- At the 1979 Delmarva Watermen's Expo in Ocean City, Maryland, Delaware's fisheries specialist conducted a survey of commercial watermen to get reactions to a proposed fishing port for the Delmarva area.
- The technical practicality of raft culture of oysters in the Broadkill River was demonstrated. More work is necessary on depuration and reducing labor and transport costs, but it is possible that a significant "cottage" industry could develop along Delaware's tidal rivers.
- About 4,200 teachers and students representing 33 schools and many other civic groups participated in MAS-sponsored marine education programs, including field trips to the dunes, marshes, and beaches; educational cruises aboard the *R/V Wolverine;* slide/talk presentations; and teacher workshops.
- In mid-year, a new agent/specialist for industry-research interaction was hired. The scope of responsibilities of the position was expanded to include work with all Delaware Sea Grant research programs that show promise of commercial application of technology. Discussions were initiated with investigators in the chitin and halophytes programs, as well as those involved in mariculture research.
- An evaluation was begun of the existing Industry Partners Program in the College of Marine Studies to determine how best to enhance industry participation in Sea Grant research activities.
- The first draft of a slide/tape program on marine careers, developed by the MAS communications specialists, was shown at the annual meeting of the National Marine Education Association in August, 1979. Based on reactions and suggestions, the program is being finalized and will be available for agent/specialists to use with school groups and eventually for rent or purchase by other institutions.
- Publication of *OCS Update,* the newsletter on Atlantic offshore oil and gas development, continued, as did the publication of *Seadrifts,* a monthly compilation of marine-related news clippings. A pamphlet on oysters joined others on finfish, crabs, and clams in the Delaware Seafood Recipes collection. The *SeaTalk* public service radio spots continue to be used consistently by about 40 stations in Delaware, Maryland, New Jersey, and Pennsylvania. To improve quality and delivery time, production of the program was moved from the student-operated university radio station to a local professional studio. A 38-page illustrated manual on keeping a saltwater aquarium was published and has been distributed to about 500 people.
- During the summer, weekly newspapers in Delaware received and used topical marine-related articles written and illustrated by the MAS communications group. The series of articles, *Seascapes,* was published as a collection and the booklet offered to area teachers as a classroom resource.

Publications

Marine Biology

Semilunar Hatching Periodicity in the Mud Fiddler Crab *Uca pugnax* (Smith). Diana E. Wheeler. DEL-SG-1-79. (From *Estuaries* 1(1978): 268-269.)

Production Dynamics of a Tidal Creek Population of *Fundulus heteroclitus* (Linnaeus). William H. Meredith and Victor A. Lotrich. DEL-SG-2-79. (From *Estuarine and Coastal Marine Science* 8(1979): 99-118.)

Mariculture

Effect of pH, Carbon Dioxide, Oxygen, and Light on the Growth of *Thalassiosira pseudonana* (Hustedt) Hasle and Heimdal Clone 3H, an Important Food for Bivalve Molluscan Mariculture. Gary David Pruder. DEL-SG-3-79.

Comparison of Yeast and Algal Diets for Bivalve Molluscs. C. E. Epifanio. DEL-SG-4-79. (From *Aquaculture* 16(1979): 187-192.)

The Role of CO_2 Enrichment of Aerating Gas in the Growth of an Estuarine Diatom. Gary D. Pruder and Ellis T. Bolton. DEL-SG-5-79. (From *Aquaculture* 17(1979): 1-5.)

Growth of Bivalve Molluscs: Nutritional Effects of Two or More Species of Algae in Diets Fed to the American Oyster *Crassostrea virginica* (Gmelin) and the Hard Clam *Mercenaria mercenaria* (L). C. E. Epfanio. DEL-SG-6-79. (From *Aquaculture* 18(1979): 1-12.)

Halophytes

Natural Halophytes as a Potential Resource for New Salt-Tolerant Crops: Some Progress and Prospects. G. Fred Somers. DEL-SG-7-79. (From *The Biosaline Concept,* Alexander Hollaender, ed. 1979. New York: Plenum Publishing Corp. pp. 101-115.)

Marine Policy

Maritime Boundaries: Canada vs. the United States. Luc Cuyvers. Marine Policy Reports, February 1979.

United States Policy in Antarctica. Joseph Macknis. Marine Policy Reports, May 1979.

The EEC's Common Fisheries Policy. Robin Churchill. Marine Policy Reports, November 1979.

Program Administration

Delaware Sea Grant College Program Annual Report, 1977-78.

Marine Publications, 1979.

Advisory Services

OCS Update. *Newsletter on mid-Atlantic oil and gas development (three issues).*

Seadrifts. *Monthly compilation of marine-related news clippings from local and regional newspapers (12 issues).*

Jellyfish—Regular Summer Visitors to Delaware Shores. Les Watling (revised).

Seascapes. Jan Hardin. *Illustrated, 42-page collection of short articles about the sea and shore. Originally written for Delaware's weekly newspapers during the 1978 summer.*

Keeping a Marine Aquarium. Christopher Valenti. *Illustrated 37-page manual that describes setting up an aquarium, selecting or collecting marine plants and animals, and maintaining the system.*

Program Summary

	FY77	FY78	FY79
Program Management	C	C	C
Mariculture Research			
Controlled Environment Mariculture Production Prototype (Bolton)	C	C	C
Controlled Environment, Closed Cycle System (Pruder)	C	C	C
Shellfish Nutrition in Closed System (Epifanio)	C	C	T
Mineral Requirements in Intensely Cultured Oysters (Sick)	N	C	T
Microbiology of Closed System Mariculture (Smith)	C	C	C
Ultramorphology/Mineralogy of Controlled System Oysters (Carriker)	N	C	T
Economic Aspects of Closed System (Anderson)	N	T	
Crab Waste Chitin as a New Marine Resource			
Crab Waste Chitin Development (Austin)	C	C	C
Chitosamine Glucosides (Zikakis)		N	C
Optimization of Tidal Marsh Resource Use			
Nutrient Flux, Energy Flow, Production (Daiber)	C	C	T
Halophytes as Potential New Food Crops (Somers)	C	C	C

	FY77	FY78	FY79
Coast, Bay and Shelf Engineering and Dynamics			
Geological Structure, Evolution and Destruction of Coastal Barriers (Kraft)	T		
Beach Erosion Control at Roosevelt Inlet (Dalrymple)	N/T		
Shoreline Erosion Due to Extreme Storms and Sea Level Rise (Dean)	N	C	T
Coastal Erosion Induced by Rip Currents (Dalrymple)	N	T	
Wind-Induced Effects on Sand Dunes (Lai, Wu)		N	T
Sedimentary and Hydrothermal Study of Lewes Harbor (Kraft)		N	T
Development of Wave Climate Models (Lozano)			N
Marine Energy Extraction			
Desalination Unit Powered by Sea Wave Energy (Pleass)	N	C	C
Marine Resources Management			
Simulation and Control of Multi-Stock Fisheries (Anderson)		N	C
Estuary and Shelf Interaction			
Dispersal and Recruitment of Blue Crab Larvae (Epifanio)			N
Coastal Zone Management			
Local Governmental Capacities Related to Onshore Impacts from OCS Development (Warren)	N/T		

N = New, C = Continued, T = Terminated

	FY77	FY78	FY79
Education			
Distribution of Marine Environment Studies (Stegner)	N/T		
National Marine Education Policy (Schaadt)	N	T	
Marine Advisory Service			
Management (Thoroughgood)	C	C	C
Test Planting of Hard Clams (Keck)	T		
Public Information (K. Jensen/K. Danberg)	C	C	C
Coastal Zone Development (P. Jensen)	C	C	C
Recreation and Tourism (Falk)	C	C	C
Commercial Fisheries (Seymour)	C	C	C
Industry/Research Interaction (Wagner)		N	C

	FY77	FY78	FY79
Add-On Projects			
Seawater Pump (Pleass)			N
Fright Behaviors of Oyster Drills (Carriker)			N
Sea Grant Internship (Mangone)			N
Site Selection—NSTS (Dean)			N
New Initiatives			
Drifter Work on Dispersal and Recruitment of Blue Crab Larvae (Garvine)			N
Hatchery Raised Seed Oysters (Lesser)			N
Lobster Hemolymph Protein (Wriston)			N
Extending Oyster Shelf Life (Islam)			N
Materials for the Marine Environment (Pipes)			N

Design and layout: K. Maas
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