ANNUAL PROGRESS REPORT FOR 1971

SEA GRANT REPORT
DEL-SG-1-72

UNIVERSITY OF DELAWARE, NEWARK, DELAWARE

Annual Progress Report

of

Sea Grant Program

September 1, 1970 to August 31, 1971

Conducted by

University of Delaware

under grant number GH-109

Report no. Del-SG-1-72

March 1972

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1.0 INTRODUCTION

This document reports the work of the University of Delaware coherent project performed under Sea Grant GH-109 during the period of 1 September 1970 through 31 August 1971. The report is organized along the lines of project groupings within major program areas considering first Shellfish Resource Development, a continuation of research performed under earlier project grants. The second major area deals with the set of projects subsumed under the title of Coastal Resource Analysis and Development. Many of these were exploratory in nature and were intended to help identify additional fruitful areas for research in subsequent program years. Abstracts of published documents have been appended to project reports where appropriate; participating graduate students and other project personnel have been noted, together with the name of the principal investigator at the beginning of each project.

Shellfish Resource Development was continued with emphasis upon controlled environment closed cycle systems. Breeding research was also continued in an effort to combine the more desirable attributes of the American and Japanese oyster. Additional work was accomplished on the development of methods for opening bivalves meeting with some success as reported in a subsequent section of this report. This work however has been terminated.

In the coherent program area of Coastal Resource Analysis and Development, three principal foci are evident. The first of these included projects on System Analysis of Coastal Resource Development, Marine Research Related Development, and Sociological Aspects of Seashore Recreation. These projects interfaced strongly with the Governor's Task Force on Marine and Coastal Affairs which worked to define a Coastal Zone development policy. Through interplay between State, local, private and University personnel a declaration of State policy emerged in legislative form as H.B. 300. Sea Grant researchers contributed to both the conception and writing of the Task Force report. As a result, a Program rationale and plan was developed as a guide for new Sea Grant projects which will help realize the goals defined by the Task Force for the State and region.

The second principal focus was upon the interaction of man and the coastal zone as related to meteorological and geological processes. This effort has resulted in information of substantial value to groups concerned with shore-line development.

Third, and finally, some exploratory work was undertaken to determine the type and extent of data available in the area of mollusc product and market development.

2.0 SHELLFISH RESOURCE DEVELOPMENT

In the coherent program area of Shellfish Resource Development, the principal set of projects to be reported are those related to the artificial culture of shellfish, particularly the oyster. The subjects range from consideration of culture techniques to the evaluation of oyster feeding and blood circulation from a fluid dynamics viewpoint, all however, performed under the umbrella of a system engineering model for optimizing shellfish production.

The project concerned with Methods for Opening Bivalves reports the final phase of work accomplished toward the objective of simplifying and improving the economics of processing the cultured product, also an element of the system engineering model.

2.1 SYSTEMS ENGINEERING OF SHELLFISH PRODUCTION

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2.1a RESEARCH PLANNING FOR IMPROVED OYSTER PRODUCTION

Introduction

For the past year the question of the allocation of resources in support of applied research has been investigated. One of the project goals is to reduce the cost of a bushel of plant-produced oysters. It would seem therefore, that the best place to start is with profitable research. However, since it is not always evident which research will give the greatest yield, a method has been devised for evaluating the costs/benefits of alternative research projects.

Method

The objective function selected for optimization in the evaluation model is the expected return from the chosen projects as measured by cost savings per bushel of oysters within an acceptable

"Probability of Ruin" where conceptually, "Ruin" is defined as a gain from a selected set of projects insufficient to sponsor the least expensive project. The probability of ruin can be calculated merely by estimating the cost, expected gain, and the probability of success for each project, for whatever combination of projects is being considered. It is the combination which thus becomes important.

The overall allocation problem is one of finding that combination of projects yielding the largest gain when 1) their cost is within budget and 2) the probability of ruin is less than some maximum acceptable value. This is tantamount to requiring present research to support at least some future research; a somewhat conservative but reasonable policy. The solution is complicated by two problems:

1. Projects interact so that the results from one project may influence the results of another, and

2. A computerized optimization technique which solves the problem easily and quickly must be developed.

Interacting Projects

In complex systems such as those encountered in mariculture, there is potential for significant interaction between projects, that is, the results of one project may exclude or reduce the gain from another or even depend upon the success of another project. Table 1, which gives an example of proposed projects to improve the algae system, resulted from interviewing research investigators. They suggested a percent change in some input variable that would result from their research. For example, in Table 1, a 50 percent reduction in light requirement was the proposed result from the Reduced Light project. From this information and a knowledge of the costs of these variables, an estimate of the resulting gain was then made. The numbers are based on an original cost per bushel of oysters before any optimization on the system was performed. The table does not include interaction, even though interaction does exist.

A look at two such interacting projects may aid the explanation. "Artificial Food" is a project which suggests that a food such as cornstarch may be substituted for a portion of the oysters' algae requirement. This in effect reduces the amount of algae which has to be grown, thus reducing cost by the amount in the table. "Algae Recovery" proposes that recovering a portion of the algae which the oysters do not consume and which usually is discarded along with the waste given off by the oysters, would yield a 10 percent reduction in the amount of algae that would have to be produced.

TABLE 1

ANALYSIS OF COST-REDUCTION PROGRAMS[1]
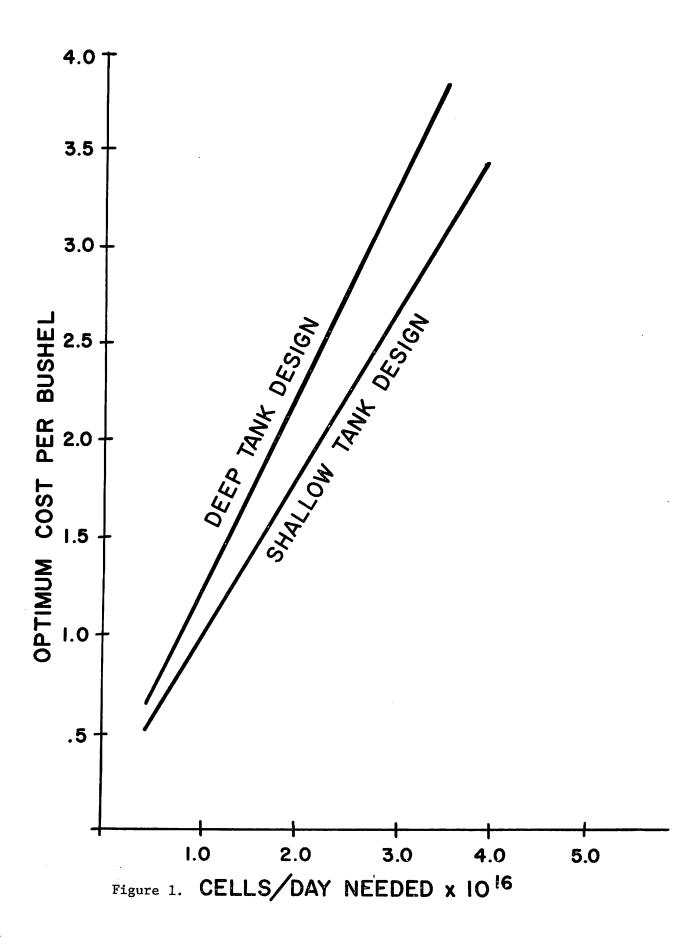
1. ALGAE	Duration (years)	Cost ($1000)	Gain ($/Bu)	Probability of Success
Nutrition Requirements	3	15	*	
Artificial Food	1	15	0.20	0.10
	2	30	0.50	0.50
	3	45	1.00	0.75
	4	50	2.50	0.90
Reduced Light	0.5	4	0.51	0.70
Algae Storage	2	15	*	0.90
Algae with Oysters	1	4	1.78	0.50
	3	12	1.78	0.90
Algae Recovery	0.5	4	0.25	0.90

In Table 1 the expected gain for each project is given when each project is considered separately. Figure 1 is a graph that shows the direct relationship between algae requirement and the optimum cost of the algae system per bushel of oysters.

If "Artificial Food" is supported and gives a reduction of 5 percent in cell requirement, a $0.20 gain is realized. A further reduction of 10 percent of the algae requirement due to our research support of "Algae Recovery" would only yield an additional gain of $0.10 rather than the $0.25 gain as suggested in the table. The difference is due to the interaction of the two projects. Similar interactions may result between other projects.

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* Gain is in confidence.

[1] The table is taken from a talk given by Dr. Costello at the University: "Controlled Environment Production of Oysters" presented as a public lecture at the University of Delaware, April 6, 1971.

Figure 1. CELLS/DAY NEEDED x 10^{16}

Efforts are being made to put these interactions into a gain function for each project sensitive to three factors 1) whether chosen, 2) whether successful, and 3) how success relates to the success of other chosen projects.

Optimization Technique

The problem of optimization can be solved by enumerating the results for each possible research combination and then choosing the combination that gives the largest gain. Since this technique becomes particularly complicated as the number of projects increases, a new evaluation technique is being sought and should be fully developed in the next few months. The solution may be the use of distribution functions and their parameters.

Simulation Program

The simulation program developed in earlier work is proving to be very valuable in determining what factors affect the process the most. It also shows which research would be most profitable from the viewpoint of contribution to reducing product cost.

Figure 1 presents a typical result derived from several different runs of the simulation program with respect to algae tank design parameters.

Results

During this period, available allocation techniques have been reviewed for applicability to the mariculture optimization problem. From those techniques one has been developed which is well suited to the needs of the project while also being applicable to other problems. However, further research is necessary into the development of an optimization scheme and the analysis of interacting projects. The present state of completion is sufficient to permit the use of the selection tool for planning the FY 73 research program and for allocating new initiative funds within the Food from the Sea program structure.

2.1b OPTIMIZATION OF OYSTER PRODUCTION SYSTEM
IN THE PRESENCE OF UNCERTAINTY

Introduction

The purpose of this project has been to model a closed cycle system for rearing commercially valuable marine animals. In most cases, the optimization of large systems is performed on the basis that the process represented is deterministic. In the real world, especially in biological systems, such an approach is often unrealistic. Therefore, research over the past year has been conducted on stochastic optimization (that is optimization in the presence of uncertainty) for a closed-environment oyster production facility. Three types of uncertainty important to the oyster production system have been considered:

1. Uncertainty in primary system process parameters (e.g., effect of cell concentration on oyster growth).

2. Uncertainty in design variables (e.g., heat exchanger outlet temperature).

3. Uncertainty in subsystem process functional relations (e.g., algae growth rate versus illumination).

Method

Much research has been done in the area of optimization with stochastic parameters but work in the chemical process industry (e.g., Rudd and Watson) appears to be especially relevant to the oyster production system. The approach used is to first develop analytic or empirical distribution functions for the stochastic parameters and then to obtain an expected cost which is a function of deterministic parameters and design variables only. This is known as the expected value criterion method.

Although the expected value criterion can be used with confidence in linear problems, evidence indicates that the oyster problem is non-linear; thus, extension of existing methods and development of new methods applicable to non-linear problems is the heart of the technical problem of optimizing the oyster-production process.

Although a linearization process can be used in problems with uncertain parameters, the expected value criterion is not so easily applied since stochastic design variables must be retained

in the problem for optimization, and the distribution functions
cannot be integrated a priori. Thus, not only must distributions
for these variables be determined, but the distribution for the
system cost function must also be obtained. Then either the ex-
pected value criterion may be applied, or some other similar
objective might be used, such as using the probability of success
as a divisor to the cost, in order to effect a penalty for less
successful designs.

A major problem with the above approach is that the dis-
tribution for the system cost function is almost never obtainable
analytically and is difficult and time-consuming to compute numeri-
cally. An alternative procedure is considered by Marsh and Costello
in a mini-problem being studied that involves the characteristic
non-linearities of the oyster-production system. A paper is being
prepared for publication that describes the results of their work
on the mini-problem concerning the optimization of convective fins,
where the fin dimensions are stochastic. Specifically, a root-
mean-square (RMS) approximation is used to obtain the variance of
an appropriate approximate distribution function for costs. The
method when verified by numerical computation of the cost distri-
bution proved to be very accurate. This method will have important
application in the optimization of the oyster production system.

With linearization being used for uncertainty in param-
eters and the RMS method being used for uncertainty in design
variables, the only remaining problem in this treatment of the
oyster production system is uncertain subsystem process functional
relationships, especially when productivity is the dependent vari-
able. In a general approach to such cases, arguments of the function
would be chosen using the best data available and then additional
data carefully collected and correlated into the function, thereby
attempting to substitute design variable uncertainty for function
uncertainty. However, for the oyster production system, data for
correlation is expensive or difficult to obtain. As an alternative,
a systems analysis and cost sensitivity study is being made to help
identify those functional relationships which must be defined ex-
perimentally to permit accurate optimization in contrast to those
which can be tolerated as uncertain.

Results

The sensitivity analysis and optimization methods are being
applied, in that order, first to the algae production system. Table
2 shows the costs of the baseline algae system, which uses the con-
cepts in the American Cyanamid study but which has been optimized
(thereby reducing the cost per bushel of oysters by approximately
$2.50).

TABLE 2

COST SUMMARY OF BASELINE ALGAE PRODUCTION SYSTEM

	Shallow Tank	Deep Tank
Depth of Tank	19.50	22.00
Width of Tank	60.00	49.50
Cost per Tank (5 used)		
Culture tank with lining	54221.32	94861.79
Recirculation pump	1079.28	590.18
Recirculation Piping	2696.00	285.17
Illumination System	17017.00	25844.00
Cooling System	2355.61	1173.42
Air Delivery System		4311.03
TOTAL	77369.21	127065.59
System Initial Cost		
Culture Tanks (5)	386846.06	635327.95
Nutrient solution tanks (4)	6713.60	6713.60
Metering Pumps (2)	32.45	32.45
Compressor with accessories	7320.97	11447.66
Greenhouse Structure	140752.16	120650.69
TOTAL	541665.24	774172.34
System Annual Cost		
Investment Depreciation	32499.91	46450.34
Maintenance	37916.57	54192.06
Interest	32499.91	46450.34
Housing Utilities	13855.44	11091.34
Pumping Energy	1533.47	775.23
Illumination energy	34254.52	51769.23
Air compression energy	9651.05	16390.96
Nutrients	119538.23	119538.23
Collant system energy	144.72	6.78
TOTAL	281893.82	346664.52
Cost per bushel	2.82	3.47

TABLE 3

SENSITIVITY STUDY OF STOCHASTIC VARIABLES IN ALGAE PRODUCTION SYSTEM

(to supply food for 100,000 bushels of oysters)

Variable	+20% +10% Value nominal -10% -20%	Shallow Tank Initial Cost, $(x 10^{-6})	Deviation	Deep Tank Initial Cost $(x 10^{-6})	Deviation	Shallow Tank Equivalent Annual Cost $(x 10^{-6})	Deviation	Deep Tank Equivalent Annual Cost $(x 10^{-6})	Deviation
A	37.68	.625	.083	.906	.132	.334	.052	.412	.065
	34.54	.538	.041	.841	.067	.308	.026	.379	.032
	31.4	.542		.774		.282		.347	
	28.26	.498	-.044	.706	-.068	.256	-.026	.314	-.033
	25.12	.455	-.087	.641	-.133	.230	-.025	.281	-.066
B	1.2×10^{10}	.471	-.071	.662	-.112	.260	-.022	.312	-.035
	1.1×10^{10}	.502	-.040	.714	-.060	.270	-.012	.328	-.019
	1×10^{10}	.542		.774		.282		.347	
	$.9 \times 10^{10}$	.587	.045	.848	.074	.296	.014	.370	.023
	$.8 \times 10^{10}$	.643	.101	.939	.165	.314	.032	.398	.051
REQNUT	72	.542	.000	.775	.001	.282	.000	.347	.000
	66	.542	.000	.775	.000	.282	.000	.347	.000
	60	.542		.774		.282		.347	
	54	.541	-.001	.774	.000	.282	-.001	.345	-.001
	48	.541	-.001	.774	.000	.284	-.002	.346	-.001
REQCO2	256.8	.543	.001	.774	.000	.284	.002	.347	.000
	235.4	.542	.000	.774	.000	.283	.001	.347	.000
	214	.542		.774		.282		.347	
	192.6	.541	-.001	.774	.000	.281	-.001	.347	.000
	171.2	.540	-.002	.774	.000	.280	-.002	.347	.000

TABLE 3 (continued)

SENSITIVITY STUDY OF STOCHASTIC VARIABLES IN ALGAE PRODUCTION SYSTEM
(to supply food for 100,000 bushels of oysters)

Variable	+20% +10% Value nominal -10% -20%	Shallow Tank Initial Cost, $(x 10^{-6})$	Deviation	Deep Tank Initial Cost $(x 10^{-6})$	Deviation	Shallow Tank Equivalent Annual Cost $(x 10^{-6})$	Deviation	Deep Tank Equivalent Annual Cost $(x 10^{-6})$	Deviation
FRECS	.12	.543	.001			.282	.000		
	.11	.542	.000			.282	.000		
	.1	.542				.282			
	.09	.541	-.001			.282	.000		
	.08	.541	-.001			.281	-.001		
FRECD	.12			.774	.000			.347	.000
	.11			.774	.000			.347	.000
	.1			.774				.347	
	.09			.774	.000			.347	.000
	.08			.774	.000			.347	.000
AIRREQ	.02			.778	.004			.351	.004
	.01833			.777	.003			.349	.002
	.01666			.774				.347	
	.015			.773	-.001			.345	-.002
	.01333			.771	-.003			.343	-.004
XILUMS	600	.556	.014			.291	.009		
	550	.549	.007			.286	.004		
	500	.542				.282			
	450	.531	-.011			.277	-.005		
	400	.524	-.018			.272	-.010		
XILUMD	1200			.794	.020			.360	.013
	1100			.784	.020			.353	.006
	1000			.774				.347	
	900			.763	-.011			.340	-.007
	800			.753	-.021			.333	-.014

variables) a systems analysis is prohibitively time consuming and cumbersome when performed by hand.

An Algol program which performs this task has recently been written and has proved useful analyzing the algae production system. The program uses the Fortran algae production system simulation computer program as input and produces as output:

1. A listing of the source data, i.e., the algae system simulation program.

2. A list of all variables found in the source program along with an identifying number.

3. A matrix which relates all equations to all variables. Each column of the matrix represents a different variable while each row represents a different equation. Additionally, the dependent variable of each equation is printed. In the case of subroutine calls, the subroutine name is listed. The elements of the matrix indicate the existence, position, and number of occurrence of each variable in each equation. For example "1R" indicates that the selected variable appears once in the selected equation and is on the right-hand-side of the equals sign. "2B" indicates that the variable appears twice in the equation and that it is on both sides of the equals sign. Additionally "C" means the variable is set equal to a constant, "L" indicates a variable on the left-handed-side, and "A" designates a subroutine argument. "-" indicates the selected variable does not occur in the equation.

4. A second matrix in which entries for intermediate variables have been eliminated. For example, if $y=f(x)$, $z=f(y)$, $c=f(z)$, then the second matrix reflects the fact that $c=f(x)$.

5. A summary of the cost variables giving the independent variables associated with each.

The output makes possible rapid and accurate selection of independent variables over which optimization may take place. More importantly, significant stochastic variables may be identified for further study.

2.2 CONTROLLED ENVIRONMENTAL SYSTEM FOR CULTURING OYSTERS

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Introduction

The advantages of an environmentally controlled, closed system of oyster culture over open systems are many, including increased growth rate, uniformity of product, controlled time of harvesting, improved harvesting efficiency, and control of pollutants, diseases, and predators. Therefore, this project together with the project on Shellfish Culture and Breeding have a major role within the scope of the University's Food From the Sea Aquaculture Demonstration program. Each of the interrelated subprojects contributing to the solution of the overall closed cycle problem will be discussed individually in the following sections.

Objectives

The primary objective of this project has been to develop an environmentally controlled, self-supporting closed system for economic production of shellfish. A second objective has been to assist in nutrition studies concerning the acceptability and utilization of natural and manufactured feeds by the oyster.

Specifically, efforts were made to:

1. Define parameters needed to develop a self-supporting closed system for oyster production.

2. Develop instrumentation and techniques to employ radio tracer methodology in order to investigate acceptability and utilization of various feed ingredients.

3. Develop instrumentation and techniques for the electrophysiological investigations of the taste sensors of the oyster.

Results

a. Filtering Requirements

In the closed system of oyster culture, water filtering is highly dependent upon the type of feed utilized. Preliminary investigations using algae (Dunaliella) alone, algae and cornstarch, and milk

protein (Lacatalbumin) and cornstarch indicated that greater gains can be expected by combinations of commercial ingredients as part or all of the feed. However, the use of commercial ingredients put great stress upon the original filters and allowed ammonia and microbial organisms to build to a fatal level after several months.

Mechanical-biological filters for ammonia removal require sufficient bacteria to convert ammonia to nitrate and require a continuous flow through the filter to maintain a stable bacteria population. Since it is essential that filtering cease during the feeding operation to prevent food removal and overloading of the filter, the filters were initially operated with an on-off cycle resulting in a decline of bacteria population during the off cycle. A new system has been developed utilizing one filter for two oyster tanks which have alternate feeding cycles allowing continuous flow through the filter.

When materials other than algae are fed, a flow rate through the filter of approximately 1 gal/min per 40 gallons of total tank capacity is needed for ammonia control for oysters stocked at the rate of 1.25 per gallon. At least .5 gal/min per sq. ft. of filter area is required to maintain the bacteria population.

When milk protein and starch were fed, microbial growth could not be controlled at a satisfactory level by germicidal lamps.

b. Feeding

Sufficient agitation to keep food particles suspended is essential during the feeding period. Agitation of hydraulic or mechanical origin is preferred over air, as excessive bubling of air inhibits oyster feeding due to physical disturbance. Agitation is continued during the filtering period to keep the waste products in suspension.

The possibility of a closed loop system of oyster and algae culture should be investigated since water in the oyster tanks may be capable of supplying the nutrients for algae production without harmful effects. Algae would be used for feeding the oysters and also work as nitrogen filters by fixing nitrogenous by-products of the oysters.

c. Oyster Nutrition Studies

Investigations in the field of oyster nutrition were initiated because a lack of knowledge in this area has been the main block in the course of development of a closed system of oyster culture. Two approaches were used as described below:

1. Radiotracer Studies

Labeled feeds were used to check acceptance, rejection and utilization levels of oysters for a given feed. Instrumentation and techniques were developed for these studies including a hexagonal shaped apparatus with six independent compartments each with a bottom separator plate to keep pseudofeces and feces separate (Fig. 2 and Fig. 3). An equal rate of flow through each compartment is maintained using airlifts and a central feeder tube. The experimental set up is such that a positive control over environmental factors such as light intensity, temperature, feed density, Ph., salinity, etc. is possible. An electronic device was built that utilizes two photo-cells to keep feed density to a set value in the apparatus. Actual experiments will be run during the next program year.
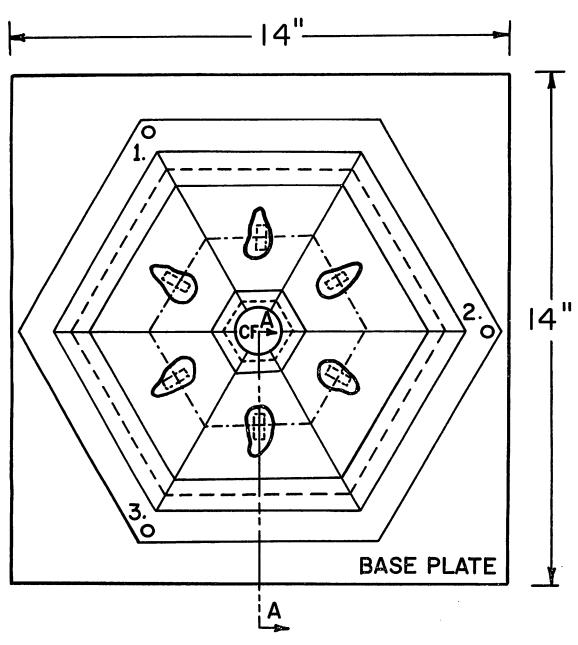
2. Electrophysiological Studies

It has been stated by some research workers that the oyster has the capability to discriminate feeds not only on the basis of its particle size but also on its food value.

Preliminary studies have indicated the presence of chemo-receptors on the labial palps. Instrumentation is such that it allows the recording of shell movement and response from the chemoreceptors simultaneously.

Tungsten microelectrodics, insulated except for their tip, were successfully used to pick up receptor potential from labial palps of the oyster in response to several chemicals. The block diagram in Figure 4 shows the arrangement of major equipment.

Figure 2.

1,2,3   AIR LIFTS FOR CIRCULATION OF FEED.
_____   COMPARTMENT DIVIDERS.
_ _ _ _   BAFFLES.
_ .. _ .. _   FECES-PSEUDOFECES SEPARATORS.
CF   CENTRAL FEEDER TUBE (1 1/2" DIAM.)
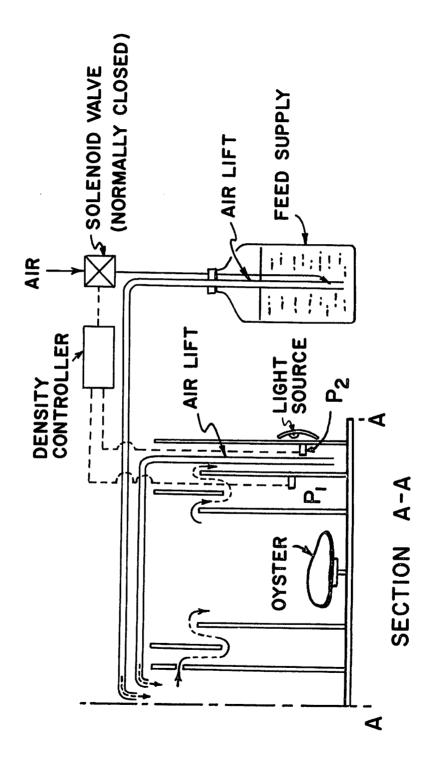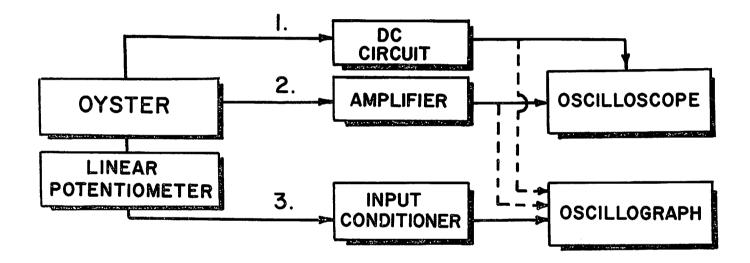
Figure 3: A schematic cut-view of feeding apparatus (section through A-A). P_1, P_2 are photocells. ──→ indicates feed flow.

I.   LATENCY MEASUREMENT

2.   RECEPTOR POTENTIALS

3.   SHELL MOVEMENT

Figure 4: Block diagram showing the arrangement of major equipment for electro-
physiological studies of oysters chemoreceptors.

2.3 SHELLFISH CULTURE AND BREEDING

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Introduction

The purpose of this project is to develop and refine shell-fish culture techniques which can be used to generate a pilot shell-fish hatchery. Specific objectives are: (1) to refine techniques and facilities for brood stock maintenance and command spawning, (2) to study problems in larval rearing, (3) to determine methods of controlling larval setting and to produce cultchless oysters, (4) to develop a reliable algal culture facility and initiate a study of oyster bioenergetics, and (5) to continue investigations into fish breeding.

A number of interrelated research subprojects, all under the general heading of shellfish culture and breeding, were pursued during the program year. Each dealt with a critical area of shellfish culture and will be discussed individually. Despite some specific disappointments, results of the past year have been generally encouraging and have contributed to the refinement of some crucial processes.

Results

a. Brood Stock Maintenance

A concentrated effort was made to further define optimum conditions for holding brood stock. Problems were encountered during the fall of 1970 with the deterioration of an epoxy coated, copper cooling coil used to supply cold water to the brood stock. Copper poisoning in some of the brood stock oysters delayed some spawning attempts during the fall but did not prove to be a serious problem. The coils have subsequently been coated with liquid neoprene and have been operated without further difficulty.

During the winter months brood stock oysters are held in heated sea water supplied by two karbate heat exchangers. It was found that the system produced water supersaturated with atmospheric gases. Exposure of the brood stock to this water caused the formation of nitrogen bubbles in the gills and tissues of the animals. The brood stock eventually lost gonadal condition. Many of the oysters eventually died from a gas bubble disease similar to one described in

fin fish by a number of authors. The disease can be prevented if the excess gases are driven off by allowing the water to run over a series of baffles or by strongly aerating water in a head tank before it enters the brood stock tank. A short paper describing symptoms of the disease and methods of prevention has been submitted for publication.

b. Larval Rearing

During the project year, approximately 500 million larvae, the result of 40 spawning attempts, were reared in 51 separate cultures at least to the straight hinge stage. The larvae were used in a wide variety of rearing and setting experiments.

To investigate seasonal variations in available natural food, several groups of larvae were reared without supplemental feeding at different times of the year. The growth rate of these larvae was carefully monitored. The results show that oyster larvae to setting size can be reared in three weeks or less without using cultured algae during June, July, August, and September provided larval densities are kept relatively low. During the other months, larvae may require up to 60 days to reach metamorphosis unless supplement feeding is employed. This study demonstrates the importance of a dependable supply of cultured algae to year around larval culture. It also provides at least a rough picture of local fluctuations in natural plankton food for larvae. The study will provide guidelines for predicting supplemental food requirements for year around larval culture.

Mass cultures of larvae were established in a 6,000 gallon plywood tank and in a 2,000 gallon cinder block tank located in two greenhouses.

The tanks were about 20% full when the fertilized eggs were added. Additional water, filtered through a 5 micron filter bag, was added on the flood tide each day. After the tanks were full, the over flow standpipes were covered with nitex screens to prevent the loss of larvae as more water was added. When the larvae reached setting size, shell cultch was placed in the tanks.

This mass culture technique represents considerable saving in labor compared to standard larval rearing methods. Millions of larvae can be reared without daily water change and without the use of cultured algae.

The mass culture technique did not always prove successful. In some cases, larval survival and growth were poor. These culture failures may be attributable to inadequate temperature control in the greenhouses, to occasional blooms of phytoplankton that were toxic

or at least of no food value to the larvae, and to invasion of the tanks by large numbers of copepods and barnacle and polychaete larvae. However, because these mass cultures have shown the technique to be potentially useful, efforts will continue to further refine it.

c. Setting Experiments

Research into the setting of oyster larvae has been directed toward perfecting suitable methods of producing cultchless oysters in large numbers and toward studies of the "chemical signals" or pheromones that stimulate oyster larvae to set. A detailed account of the pheromone research was published by Keck, et al in June 1971 in the Proceedings of the National Shellfisheries Association, Volume 61, so only a brief summary of more recent work will be given here.

It has been shown that adult oysters and spat produce a material that is chemically detected by oyster larvae and that acts as a stimulant to setting.

In a joint effort with chemists of the DuPont Experimental Station, Wilmington, Delaware, experiments were conducted to identify and refine the setting stimulant. The DuPont chemists produced a number of chemical fractions from oyster tissue. The response of setting sized larvae to the presence of these fractions and other materials was tested by treating porous ceramic tiles with them and releasing the larvae into a shallow setting tank containing the treated tiles. Early experiments showed a very significant response in favor of commercially produced oyster glycogen. More than 40 times as many larvae set on the six tiles treated with oyster glcogen than on an equal number of untreated control tiles. A later experiment yielded similar results. In subsequent experiments difficulties were encountered with the fractions supplied. Most of the fractions were soluble only in ether or alcohol, and despite all efforts to dry the tiles, treating them with these fractions apparently left traces of solvent that interferred with the experiments. In spite of these difficulties, the promising early experiments together with the almost unlimited potential applications for a setting stimulant in oyster culture justify continued efforts in this area of research. Experiments with oysters and other bivalves are in progress.

The advantages of cultchless oysters, particularly in hatchery operations, have encouraged experimentation with a variety of techniques for removing metamorphased larvae from different cultch materials. Good success has been achieved in removing young spat from nitex screens, from filon sheets, and from plastic sheets. Recent results indicate that it is advantageous to remove the oysters from the cultch material only after they are large enough to be relatively unaffected by siltation.

Continued research into the use of micro spat floats veri-
fied some of the advantages in using this technique over conventional
methods of producing cultchless oysters. Larvae set on floating
pieces of cultch are suspended from the silt until their weight ex-
ceeds the buoyancy of the floats. This initial period free from silta-
tion has increased spat growth by as much as 30% over growth on bottom
cultch. Pieces of chopped cork, small rubber beads, polystyrene balls,
and chopped plastic were all used as micro spat floats.

It was found that oyster larvae did not set in large numbers
on the floating cultch, but preferred to set on or near the bottom of
the tanks. To improve the setting on the floating cultch in more re-
cent experiments the floats were held down on the bottom of the setting
tanks while the larvae were setting. After a set had been obtained the
cultch was allowed to float to the surface. This technique will be
used in future experiments in conjunction with a setting stimulant
to obtain better sets on the spat floats.

d. Algal Culture and Nutrition Studies

Algal culture facilities were perfected and now provide
a reliable source of food for larval and adult oysters on a year around
basis. The facility is now capable of producing about 150 liters of
dense algal culture every 24 hours. Four algal species are now being
cultured, Monochrysis lutheri, Isochrysis galbana, Phaeodactylum
tricornium, and Dunaliella tertiolecta. Future plans call for work
with additional algal species.

Maximizing the utilization of food by the oyster is of
primary importance to the success of a closed culture system. Experi-
ments were conducted by Mr. Curt Langefoss, a Sea Grant supported
graduate student, to determine the assimilation efficiency of adult
oysters under different conditions. That is to determine under what
set of conditions the oyster produces the least feces and pseudofeces
relative to the amount of food consumed. As a part of this study,
the ash and caloric content of the algal foods were characterized.
Preliminary results show that an oyster can assimilate at least 85%
of the caloric value in the food it consumes.

Other oyster feeding experiments jointly supervised with the
agricultural engineers involved feeding a variety of substitute foods
to young adult oysters in closed aquaria. Miss Prosser found that
species of bacteria varied from aquarium to aquarium depending on the
type of food being fed to the oysters. Aquaria with the same food
seemed to develop similar microflora.

e. Shellfish Breeding Studies

Studies with the Japanese oyster, Crassostrea gigas, indicate that it is more resistant to disease and environmental stress than the American oyster, C. virginica. The Japanese oyster also appears to grow faster and certainly reaches a larger size than our native oyster. However, people on the East Coast of this country consider the flavor and texture of Japanese oyster inferior to the American oyster. In efforts to hybridize these two species it is hoped to produce an oyster that combines the best characteristics of both species.

Adults of C. gigas from California and Oregon were obtained for use as brood stock. Every effort was made to minimize the chances of the accidental introduction into local waters of C. gigas or diseases and parasites associated with the species. The oysters were held in a special tank that drained into a larger sand trench. The water filtered slowly through several feet of sand before entering the Broadkill River.

Hybridization efforts consisted of a series of reciprocal crosses made with the stripped eggs and sperm of both species. Controls of each species were reared concurrently. In addition one year old hybrids from the previous year's work were successfully spawned and back crossed with C. gigas and C. virginica. The hybrids were also crossed among themselves to produce F_2's.

The growth and development of the resultant larvae was closely monitored. Many abnormalities, particularly in larval shell morphology, were noted. Very few of the hybrids survived to metamorphosis. Only 29 spat were obtained from over 100 million eggs in the first experiment. In no case did the hybrid spat survive more than two months after setting.

Work done by Longwell at the National Marine Fisheries Service Laboratory in Milford, Connecticut indicates that there should be no gross structural barrier to the pairing of chromosomes in hybrids involving C. gigas and C. virginica. However, the unacceptably high mortalities experienced with the hybrid larvae suggests that the hybridization may not be feasible at least on a commercial basis. It is believed that in our work both species were not always in prime spawning condition. This problem together with expected genetic incompatibilities may have contributed to the inordinately high mortality of hybrid larvae. Future research will involve adults of both species in prime reproductive condition.

Recent Publications

THE DELAWARE OYSTER INDUSTRY: A REALITY?

Don Maurer, Les Watling, and Richard Keck
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University of Delaware, Lewes, Delaware 19958

Abstract

Delaware oyster beds in the Bay and associated tributaries were studied from 1968 to 1970 to determine their general condition following mass mortalities from MSX *(Minchinia nelsoni)* during the late 1950's and 1960's. Estimates of standing crop of oysters yielded a total of 54,582 bushels covering 236.9 acres (95.9 hectares) in the river beds and 65,482 bushels covering 941 acres (380.8 hectares) in the bay beds. Bay beds were badly depleted whereas certain rivers showed potential as seed areas. The association of high oyster production with a hard shell substrate was demonstrated which emphasized the need for a regular shell planting program. Spat monitoring indicated that setting occurred in two waves and extended from July 4 to early in September. River mouths generally received the heaviest set. Since there has been practically no oystering in Delaware for twelve years, an experimental planting of seed on three planted beds was carried out in 1969-1970. Although all the experimental beds were not productive, one bed showed promise and indicated that with proper management Delaware oyster beds can be rehabilitated. Finally, examination of histological sections for MSX suggested that the incidence of this disease was probably always lower in the river beds than the bay beds. The incidence of MSX in the bay beds was not as high as it was in the mid-1960's.

CHEMICAL STIMULANTS AFFECTING LARVAL
SETTLEMENT IN THE AMERICAN OYSTER

Richard Keck, Don Maurer, James C. Kauer and William A. Sheppard
College of Marine Studies, University of Delaware
Lewes, Delaware
and E. I. duPont deNemours and Company
Wilmington, Delaware

Abstract

Laboratory experiments confirmed that the presence of spat on shells stimulated spatfall of the American oyster *(Crassostrea virginica Gmelin)* and prompted a search for the mechanism of the

stimulation. Shell liquor, feces and pseudofeces of the oyster were assayed for presence of natural set stimulants. Highest activity was found in shell liquor which was then subjected to separation techniques including lyophilization and ether extraction to concentrate the set stimulant. The lyophilized residue and an ether extract of oyster liquor as well as a commercial sample of "shellfish glycogen" were found to have a high set stimulant activity.

2.4 TRANSPORT PROCESSES IN OYSTERS

Dr. Jon H. Olson   Graduate Student:
College of Engineering   Dady B. Dadyburjor
Department of Chemical Engineering

Introduction

Although the oyster has received ample research attention from marine biologists, the viewpoint of basic engineering has played only a minor role in this body of research. Accordingly, this project has used basic fluid mechanics to evaluate the performance of the oyster for filter feeding and blood circulation.

This summary of a relatively simple analysis contains little of the details of the development, and is divided into three parts, a description of the filter-feeding and respiration circulation system, and finally an analysis of the dynamics of the connection between the two circulation systems.

a. External Circulation System

The classic work of Galtsoff*(1) has summarized the structure of the external (water) circulation system of the oyster and provided some very preliminary calculations of energy dissipation in portions of the gill.

Figures 5 through 8, from the same source, provide a basic description of the oyster's flow channels. Opening and closing motion of the shell creates an inlet stream which brings fresh fluid in contact with the lobes of the gills. These lobes, the size of which can be estimated from Galtsoff's studies, describe internal flow channel zones of two types; between two lobes (the internal pair) and between a lobe and the shell (the external pair).

Circulation flow into the gills is complex. Cilia on the outer surfaces of the gill grooves give rise to secondary flow between the gill lobes. The fill grooves define a series of small channels into which fluid is driven by the motion of the transverse cilia in the still smaller channels (ostium) between the water tubes and the gill grooves. These highly differentiated channels provide the mechanical energy for the external circulation system.

Although the mechanical action of individual cilia has been investigated by Sleigh (2) and Gray (3), the mechanical action of the entire body of cilia, examined in this project, has not been previously described quantitatively. The approach taken is

*
Numbers in parentheses refer to notes on pages 44 and 46.

31
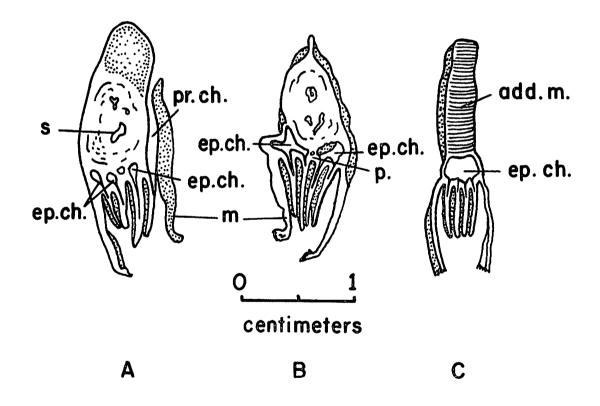
Figure 5: Gill lobe structure from Galtsoff (1). Add.m. = adductor muscle; ep. ch. = epibranchial chambers; p. = pyloric process; pr. ch. = promyal chamber; s. = stomach.
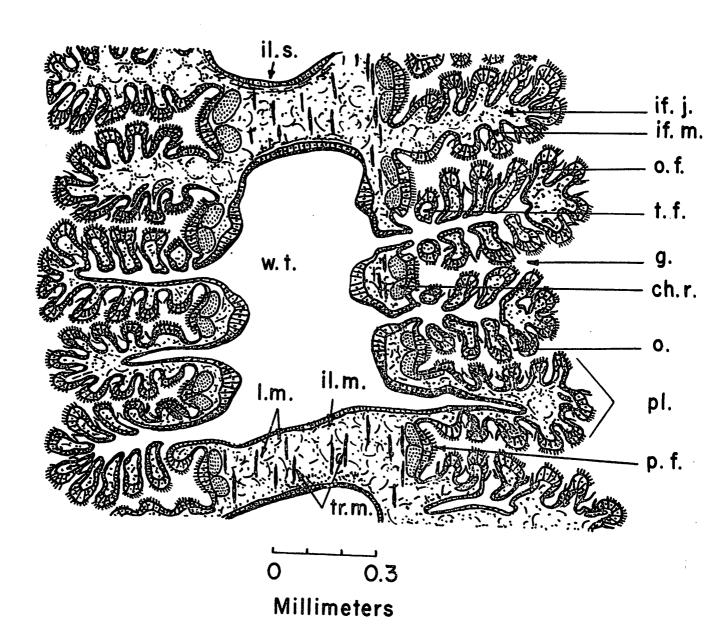
Figure 6: Gill groove and water tube structure from Galtsoff (1)
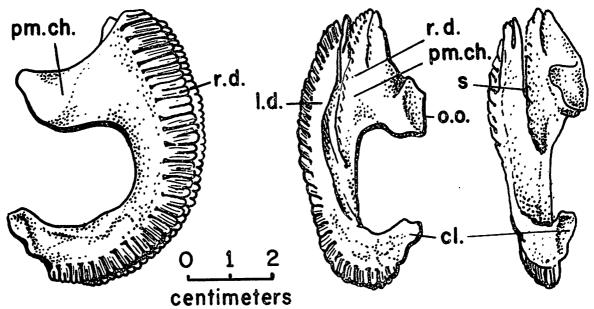
Transverse section of the demibranch of C. vir-
ginica. ch.r. = chitinous rods; g. = groove;
if.j.= interfilamentar junction; il.m. = inter-
lamellar muscles; il.s. = interlamellar septum;
l.m. = longitudinal muscles of the interlamellar
septum; o. = ostium; o.f. = ordinary filament;
p.f. = principal filament; pl. = plica; t.f. =
transitional filament; tr.m. = transverse muscle
of the interlamellar septum; w.t. = water tube.

0   60
MICRONS

Figure 7: Ostium "film pumping" (1)   ▲

Transverse section through ordinary filament of C. virgin-
ica. Vertical chitinous rods (stippled areas) and blood
space are at the center. fr.c. = frontal cilia; lf.c. =
laterofrontal cilia; l.c. - lateral cilia; o. = ostium.

Figure 8: Water excurrent system (1) ▼

0   1   2
centimeters

Gills of C. virginica. Plaster of Paris cast of a large
specimen. Left = view from the right side. Center = view
at sharp angle from the left. Right = view from the poster-
ior side of the gills; cl. = cloaca; l.d. = left demibranch;
o.o. = outside opening (aperture) of the promyal chamber;
pm. ch. = promyal chamber; r.d. = right demibranch; s. =
septum separating the right and left demibranches.

relatively simplistic. Motion of the cilia is regarded as "film pumping" with a reduced mechanical efficiency, where film pumping is the energy imparted by the linear motion of the boundary of a two-dimensional channel. When the liquid motion is laminar, this is equivalent to the slipper block problem of lubrication theory (4).

Energy dissipation for the respiration flow through the oyster was estimated by developing various flow channel analogs. Flow between the lobes of the gills was represented as lubrication flow into trapezoidal notches with uniform transverse flow into the gill surfaces as shown in Figure 9. The irregular curved shape of the lobes from the standpoint of dissipation was found to be equivalent to the simple trapezoidal shape. Secondary flow in this system was found to yield less than five percent of the total losses.

Flow in the gill grooves is geometrically similar to flow between the gill lobes, consequently energy dissipation was found by changing the parameters in the model developed for the latter. This analysis again demonstrated the unimportance of secondary flow to the total energy dissipation.

Flow into the water tubes was represented as uniform radial flow through the walls of a tapered cylindrical tube. Whitaker (5) has shown that the uniform wall flux assumption is a good approximation for the pressure distribution in a longitudinally-slotted circular manifold, and therefore the distribution of flow in the radial direction is not a critical parameter. The effect of the form of the taper in the water tube was more difficult to evaluate, and a numerical program was developed which indicated that the contribution of the assumed taper and the radial flow is less than ten percent of the total dissipation in the water tubes.

The epibranchial chambers were treated as a series of merging tubes leading to the exit with a flow estimated at forty percent of the flow to the cloaca.

Integration of the Navier-Stokes equation for the film pumping action in the ostium gives an estimate of the energy addition to the fluid providing an independent check of the model.

The results of this analysis provided in Table 4 indicate that the conventional application of fluid mechanics provides a self-consistent evaluation of the energy demand for respiration and filter feeding. The total energy demand is really very low; a result which stems from the fairly low flowrate and the lack of any kinetic energy or static head demands.
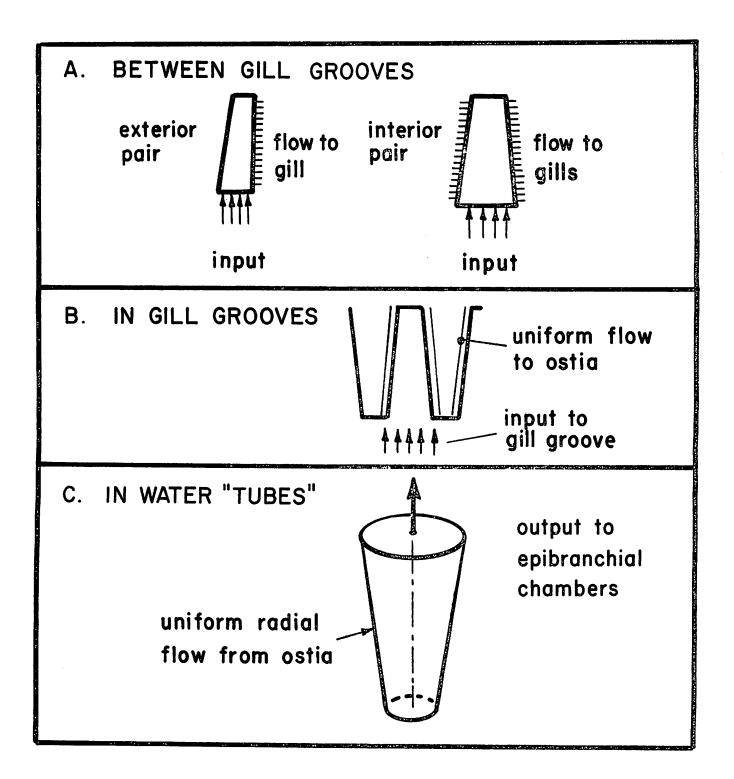
Figure 9: Models for gill flow.

TABLE 4

Energy Balance on a Mature Oyster
Q (ℓ/hr.) total flow through the animal

Dissipation between gill surfaces	$7.0 \ Q^2$ ergs/sec.
across gill grooves	$0.2 \ Q^2$ ergs/sec.
in water tubes	$0.015 \ Q^2$
in epibranchial chambers and cloaca	$0.06 \ Q^2$
Total Dissipation	$7.3 \ Q^2$ ergs/sec.
Dissipation at 1.1ℓ/hr. (basis)	$\underline{\underline{8}}$ $\underline{\underline{\text{ergs/sec.}}}$
Energy Addition at 1.1ℓ/hr. (computed from an alternate equation).	8 ergs/sec.

b. Circulatory System

A detailed description of the blood circulation system of
the oyster can be simplified to yield the "pipeline" model shown on
Figure 10. Organs supplied by the blood circulation system are
grouped as "black boxes"; details of the black boxes are developed
later when considering the dynamic model.

Flow from the heart is in two vessels. A smaller posterior
aorta whose branches serve the adductor muscle and wall of the rectum,
and the larger anterior aorta whose branches serve the viscera, kid-
neys and gonads, gastric region, palps, and the anterior end of the
body. Beyond this point the aorta, now known as the common palial
artery, splits into two serving the left and right sides of the
mantle. Each of these further divides into a dorsal and a ventral
portion, which meet at the posterior end of the oyster. Circulation
through these is aided by the accessary hearts.

Characteristically in the oyster, blood from the organs
flows to various sinuses; from these it travels by the afferent veins
to the gills, and thence to the heart by the efferent veins. (However,
some portion of the blood from the palial and renal sinuses bypasses
the gills and proceeds directly to the heart.) The sinuses are
"potential space" throughout the body of the oyster.
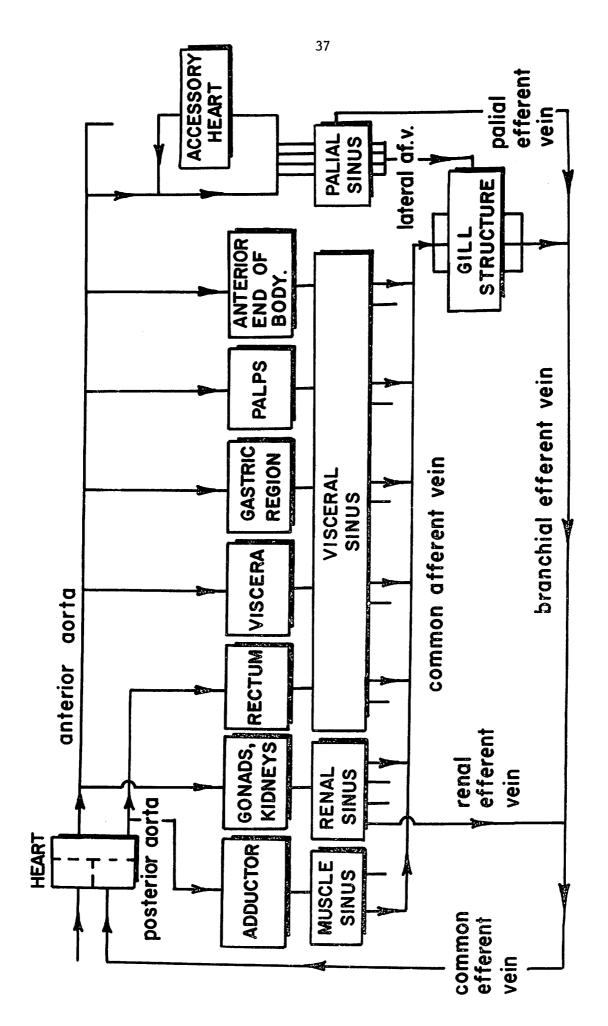
Figure 10: Circulation system. Block diagram.

The circulation system of the oyster was treated as a set of curved tubes. For the major vessel, the anterior aorta, the flow-rate was assumed to 4 cc/min. (0.2cc/beat, 20 beats/min.), and consequently the Reynolds number ($N_{Re} = (dpv/v)$ is about 50. This was assumed constant in all of the arteries, and application of the Dean number analysis (6) indicates that the curvature of these arteries is not important. Additionally the analysis of Hershey and Song (7) shows that the pulsating flow in the arteries requires an energy consumption which is less than five percent greater than the consumption for uniform flow; therefore the energy consumption was developed from the steady state model. Table 5 lists the dimensions of the major vessels of a mature oyster.

TABLE 5 - i

Geometry of Major Blood Vessels

(ℓ/d) values for the major arteries

Name	ℓ, cm.	d, cm.	ℓ/d
Anterior aorta	6.7	0.2	33.5
Adductor artery	2.7	0.005	540
Right palial artery	30.5	0.06	510
Left palial artery	30.5	0.06	510
Renogonadial artery	5.3	0.05	106
Visceral artery	2.7	0.05	53
Gastric arteries	5.9	0.05	118
Labial arteries	3.6	0.03	120
Cephalic artery	1.2	0.03	40

TABLE 5 - ii

(ℓ/d) values of one set of the venous system

Name	ℓ, cm.	d,cm.	ℓ/d
Common afferent vein	9.6	0.1	96
Cephalic vein	2.8	0.05	56
Labial vein	0.9	0.05	18
Gastric vein	2.5	0.05	50
Hepatic vein	2.2	0.05	44
Renal vein	0.4	0.05	8
Renogonadial vein	1.0	0.03	33
Posterio-ventral vein	3.5	0.05	70
Palial dorsal vein	10.7	0.06	180
Palial ventral vein	10.4	0.06	173
Lateral afferent vein	10.0	0.08	131
Branchial efferent vein	10.0	0.10	100
Common efferent vein	1.3	0.10	13
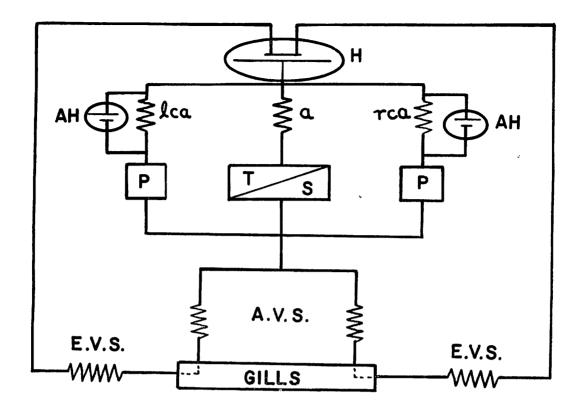
The energy loss for blood flow through the tissues of the oyster was estimated from application of Darcy's "law" for permeation.

$$\frac{Q}{A} = D \frac{dP}{d}$$

where Q is the volumetric flow rate in cm^3/sec.; A is the cross-sectional area for flow in $cm.^2$; dP/d is the pressure gradient in cm.Hg/cm.; and D is the permeability in "Darcy's". A nominal value of D for cold-blooded animals is 0.004 cm^2/sec. cm. Hg. (8).

A modified analysis of the flow system is given in Figure 11. The flow from the heart (H) is split into two parts, the major flow is through the arteries (a) to the tissue/sinus zones, (T/S) then through the afferent veins (A.V.S.) to the gills and from the gills through the efferent veins (E.V.S.) back to the heart. A minor portion flow through the palial artery to the palial sinus (P) before returning to the gills. The flow in the palial zone is aided by the accessory heart (AH) which provides flow in the right and left circumpalliel arteries (LCA and RCA). The total energy consumption is estimated as twice the demand of the simplified loop. The detail of this model is consistent with the one significant figure estimates of the basic flow parameters.

Table 6 describes the results of this analysis. The pressure distribution in the oyster is found to be very modest and consequently in the absence of constrictions in the circulation vessels, the energy demands appear to be very low.

A. COMPLETE SYSTEM

B. HALF SYSTEM
   MODEL
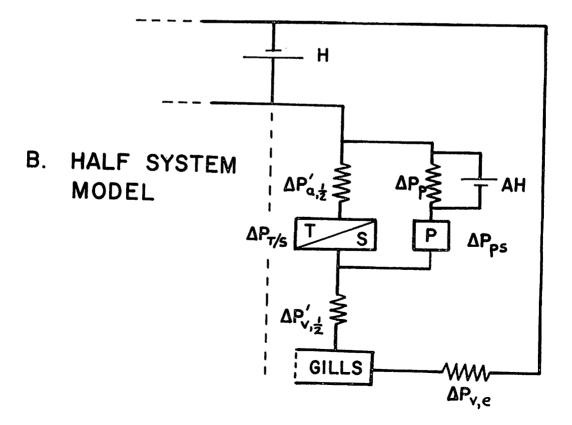
Figure 11: Modified steady state. Block diagram.

TABLE 6

Steady State Flow in the Oyster
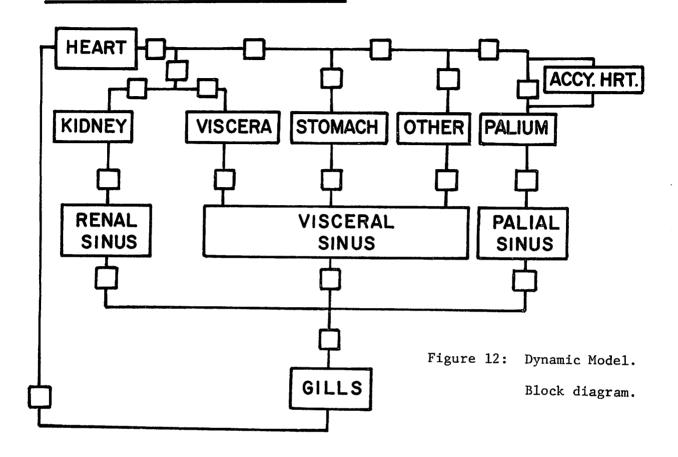
Unit	P,mm. Hg.	Energy, ergs/sec.
Major arterial system	1.1	50
palial artery	1.1	75
Major tissue/sinus	2.9	20
palial tissue	2.7	30
Afferent veins	1.9	100
Efferent veins	0.25	____
		275
Total loss		550 ergs/sec.

c. Dynamics of the Circulation System

The dynamics of the circulation system were developed to gain some idea of the efficiency of transport from one organ to another. The approach used follows Bischoff's (9) development for human physiology. As shown on Figure 12 each organ is assumed to have a volume of intercellular fluid surrounded or at least connected to the capillary tissue. Blood flows by convection through the two "well stirred" regions of the blood vessels. Diffusional transport occurs between the capillary region and the intersitial fluid and between the intersitial fluid and the intercellular zones. Thus four first-order differential equations are needed to represent each major organ of the animal.

The circulation system is simplified in the dynamic model to contain only five major organs, the kidney, viscera, stomach, palium and a zone called "other". The "other" zone contains a set of organs regarded as equivalent when considering the dynamics of the entire system. The "duplicate" upper and lower portions of the circulation system are assumed equivalent in this model. Hence, only one circumpalial artery and venous system are shown. Following Bischoff the circulation system is represented as a series of stirred tanks; this approach yields a better approximation of the residence time distribution of blood than a simple transportation lag. The dynamics to be investigated is the transfer between the gills and the stomach; for example, oxygen is brought in through the gill and consumed in the intercellular zone of the stomach. These dynamics can be extended easily to other organs.

TOTAL DYNAMIC SYSTEM

Figure 12: Dynamic Model.

Block diagram.

TYPICAL BLOOD VESSEL REPRESENTATION

(STIRRED TANK)

SUBDIVISION OF TYPICAL ORGAN, GILL

Figure 13: Basic circulation period. Pulse forcing. Dynamic model.

The problem was attacked by two methods, the direct solution of the 43 differential equations representing the oyster and an indirect solution of the complete set of trans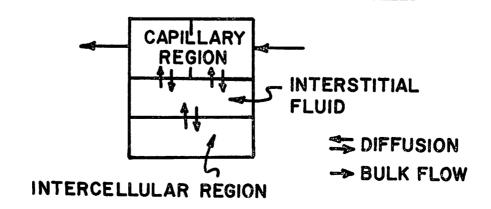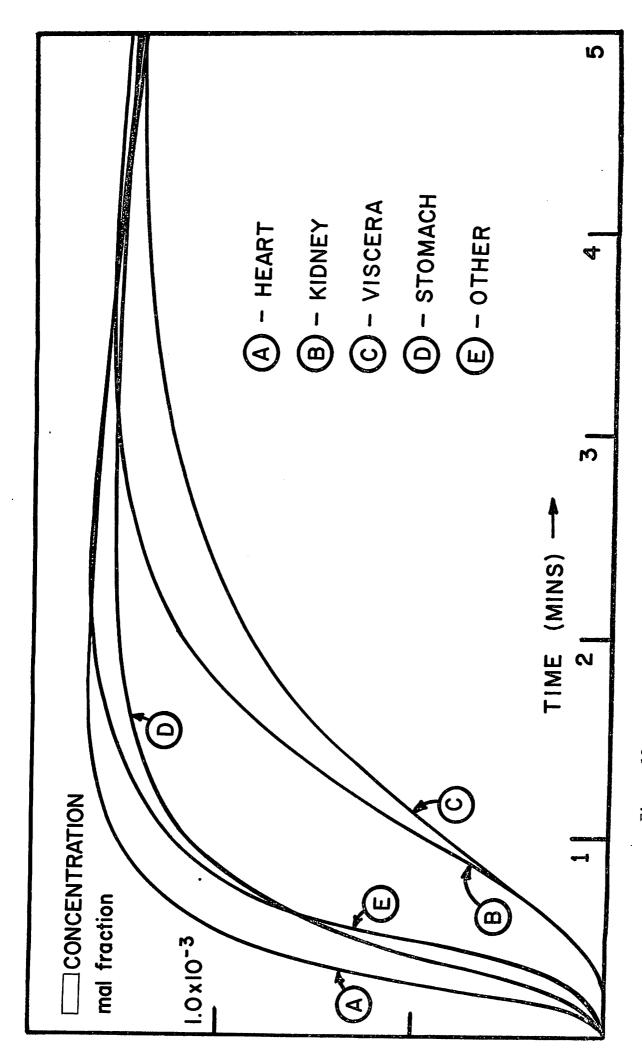fer functions of the system. The direct solution represents the relative intracellular concentration of a trace substance with time in the heart, kidney, viscera, stomach and "other" organ of the oyster when the water external to the gill is given a rapid spike-like change in the concentration of the trace substance. These results are shown on Figure 13. Using rate parameters from Bischoff's work, the concentration of the trace species rises to a maximum about two to three minutes after the external pulse and decays slowly to zero in about twenty minutes. Thus the oyster appears to have substantial inertia to external chemical pollution. This result can be tested very effectively by making some dynamic measurements upon an oyster. The model connects the external water concentration, easily controlled, to the internal concentration of any organ.

The transfer function attack upon this problem provides an alternate description of the dynamics of the oyster. In this analysis the exterior water is given a sinusoidal variation in the range of 0.01 to 100 radians/sec. The amplitude ratio is the magnitude of the sinusoidal concentration in the stomach compared to the steady state amplitude. The phase shift gives the angular lag of the internal signal to the external stimulus. The data on Figure 14 demonstrate in another way the substantial inertia of the oyster. In addition, the dynamic response of the oyster can be represented by a much simpler transfer function than derived from the 43 differential equations. These two attacks provide a method for developing a system engineering description of the oyster based upon physiological structure. Dynamic experimentation on the oyster yields a connection between conventional biological description and the system description of the entire organism.

These preliminary results need experimental confirmation because the diffusional exchange parameters are mere guesses. On the other hand these dynamic models point toward some interesting experiments, for it may be possible for a skilled marine biologist to monitor concentrations of oxygen and other trace materials in the organs of the oyster. At the very least this research indicates that the oyster should be modeled by algebraic system equations.

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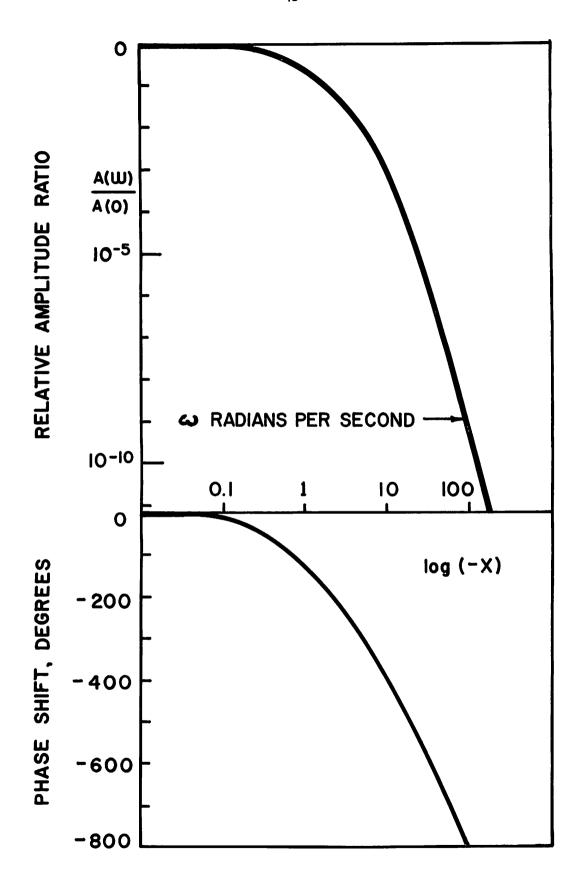
Figure 14: Dynamic response. Bode diagram.

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2.5. METHODS FOR OPENING BIVALVES

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Introduction

Oyster meat must be separated from the valves before additional processing for human consumption takes place. Except for steamed oysters, this oyster shucking operation is presently being accomplished by industry with hand labor and its associated problems of scarcity, high cost, and low production rates. If a process is developed to extract the oyster meat from the shell, the disadvantages associated with hand labor would be eliminated. The oyster industry could face a critical labor situation unless an acceptable shucking device becomes available soon.

The objective of this project was to determine external physical stimuli that would induce valve separation in the American oyster without changing the raw food quality of the meat, a preliminary step in mechanizing the oyster shucking process.

Process Methods and Results

Solution of this problem was sought by two methods during this grant period. They were whole body electromagnetic radiation with microwaves, and thermal energy concentrated in the muscle area.

a. Microwaves

Microwaves energy can be utilized in the raw oyster shucking process. Irradiation of oysters in microwave cavities at 2.45 gigahertz causes an internal temperature rise which weakens the adductor muscle. This allows easier insertion of the shucking knife between the valves thus reducing the shucking time.

The basic energy equation for controlling the process was found to be:

$$\left[Pt = M\,1.73\,(40 - Ti) + B \right]$$

where M is the total weight in grams of the oysters in the microwave cavity, Ti is the internal temperature of the oysters before exposure in degrees Centigrade. The energy loss factor, B, will have to be determined for each type of microwave cavity used. This energy loss should be very small if the cavity is designed with no openings. The exposure time, t, should be held constant at approximately 60 seconds to obtain the maximum percentage of oysters actually gaped. The microwave power, P, in watts would then be varied proportionately to the weight of the oysters in the microwave cavity. Approximately one kilowatt of microwave power will sufficiently irradiate 11 oysters per minute.

The salinity differences of the water within oysters will have no noticeable effect on the controlling process equation. Also, various size oysters can be irradiated together and will heat at approximately the same rate, thus precluding a grading operation before irradiation.

About 3 percent of the oysters irradiated by this process will show enough heat damage to reject them for raw oyster markets. This damage, however, usually appears in the small, undesirable oysters.

b. Concentrated Thermal Energy

Raw oyster meat can be effectively removed from the shell by concentrating heat energy in the area where the adductor muscle attaches to the valves.

The technique for accomplishing this is as follows. A chilled oyster (10°C) is inserted in an asbestos and stainless steel heat shield with two 3/4 inch diameter holes in the area where the muscle attaches to valves. Heat is applied for 35 seconds. The oyster is then removed from the shield and a small mechanical impact removes the meat from the shell.

The heat source was two number A-11 Barber impinged jet burners with two number 640 jets each. The heat energy output for each burner was approximately 20,000 BTU per hour at a pressure differential of 12 inches of water. The fuel was propane. The burners were located 2-1/2 inches from the left oyster valve and 4-1/2 inches from the right oyster valve. With a flame temperature of 1260°C, the temperatures at the outside of the valves in the muscle area were 1030°C and 820°C for left and right valves respectively. These outside shell temperatures brought the muscle-valve bond to 60° in 35 seconds, and caused the oyster meat temperature to rise only about 5°C.

Since the entire muscle is removed intact with the oyster meat by this method, there is improved appearance over hand shucked meats. With a sample size of 200, this method proved to be 95 percent effective in the laboratory.

This method could be readily adapted to a mechanized oyster shucking process with some further work on machine development.

c. Conceptual Mechanized Raw Oyster Shucking Process

The following is a description of a conceptual mechanized raw oyster shucking process that could possibly be produced with further research and development.

Referring to the diagram (Figure 15), oysters are placed in a feeder (1) with the left or bottom valve toward the right. When the heat shielded cups (2) come into position under the feeder, a gate (3) is opened temporarily by a motor controller (4). The oysters then drop into the heat shielded cups and are heated in the muscle area by the flame from burner jets (5). Propane fuel is supplied from a tank (6) and regulator (7). After 35 seconds, the motor-controller rotates axle (8) bringing more heat shielded cups into position to repeat the preceeding process. The heat treated oysters (9) fall out of the heat shielded cups as the axle rotates and strike an impact anvil (10) causing the shell and meat to separate. The separated oyster meat and shell then fall into a salt water bath (11) where the meat floats and the shell sinks. The shells (12) are brought out of the water bath by a continuous chain conveyor (13) where they drop onto another conveyor (not shown) to be transported out of the plant. The floating oyster meats flow with the salt water out of opening (14)

onto a strainer (15) where the meats and the salt water separate. The salt water is recirculated to the bath by a pump (16). The oyster meats (17) slide off the strainer onto a conveyor (not shown) to be transported to an inspection and packaging line.
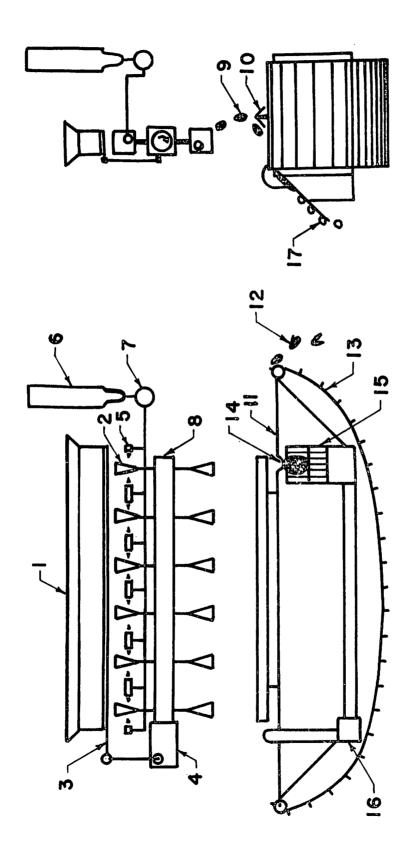
Figure 15. OYSTER SHUCKING PROCESS

3.0 COASTAL RESOURCE ANALYSIS AND DEVELOPMENT

The Coastal Resource Analysis and Development program is expected to become the planning guide for future development of Delaware's valuable marine resources.

A system analysis of coastal resources has been made of alternate development strategies and their impact on the social, economic and environmental fabric of the community.

The sociological aspects of seashore recreation have been explored and plans made for additional work.

A plan for marine research related industrial development consistent with existing planning and zoning considerations was made and shows that expansion of the College of Marine Studies in the Lewes area will have a beneficial effect on the community.

3.1. SYSTEM ANALYSIS OF COASTAL RESOURCE DEVELOPMENT

Mr. Joel M. Goodman
College of Marine Studies

Introduction

The valuable but limited marine resources of Delaware can be developed in a haphazard fashion or in response to systematically recognized needs of the community at large. Implicit in the systematic approach is recognition of alternative development strategies, an understanding of the impact of a strategy upon the social, economic, and environmental fabric of the community, and the evaluation of alternative strategies within a set of criteria that satisfy the objectives of those in the affected area. In this project, therefore, parallel efforts were expanded (1) to identify and establish a descriptive baseline of the Delaware's bay and coastal region upon which to superimpose alternative strategies for satisfying perceived needs, (2) to examine local developments and the development of analogous areas elsewhere in order to better understand the impact of selected strategies, and within the limits of existing information and understanding, (3) to recommend management policies that would minimize risks inherent in decisions with respect to irreversible processes, while initiating research that would better define the potential of alternatives.

The Descriptive Baseline

The development of a descriptive baseline of Delaware was a responsibility shared by the University and appropriate state agencies under the sponsorship of a Task Force for Marine and Coastal Affairs appointed by the governor. The Task Force brought a broad spectrum of interests and capabilities to bear upon the question of the Coastal Zone. It also offered the community at large and special interest groups an opportunity to express their feelings and concerns about the development of the State's coastal resources. The baseline did not comprise a detailed land use or facilities inventory, but rather a disciplinary description of the environment, a recommended definition of the coastal zone based upon environmental interaction considerations, and a functional description of land use and usage/environmental conflicts.

Two documents resulted from this effort. The first was a preliminary report containing definitions, statements of pressing problems and recommendations for coping with them together with supporting rationale. This publication was widely distributed throughout the State. The second document is the supporting data which led to the recommendations contained in the preliminary report. It is these reports that bring to focus the principal problems associated with developing the marine resources of Delaware and the Middle Atlantic Region.

Local Development and Analogs

Although many activities take place in the Coastal Zone, it became apparent from the emerging recommendations of the Governor's Task Force that three groups of activities warranted early analysis from the regional development viewpoint. These were industry, recreation and marine research.

With respect to industry the research objective was to define the impact of core industrial modules upon the economic and social structure of the Coastal Zone. The term "core" in this context referred to those industries which were constrained to locate in the coastal zone for a combination of technical and economic considerations. Each "core" industry was then the subject of an input-output type of analytical procedure aimed at quantifying its local impact. Thus, at the level of plant operations, a plant of a specific industry might be described by a requisite utilities capacity, transportation capacity, number of households, commercial support and primary land allocation. At the next level of analysis certain of these activities could be expected to similarly define support functions, service requirements, households, etc. The investigation of up to third and fourth order effects is planned in order to gain sufficient insight into the diffusion potential and aggregate demands of each of the pertinent industry groups as an aid to Coastal Zone resource management.

Initial investigations into recreation sought to establish planning factors for levels of participation in marine activities differentiating between In-state and Out-of-state populations. A reassessment was made of earlier published estimates of the facilities requirements developed in Delaware Comprehensive Outdoor Recreation Plan (DCORP). The results of this reassessment appear to be leading to a significant variation from those developed earlier. The significance of this modification is continuing to be explored with special emphasis devoted to design criteria for multiple use and environmental impact. The data being developed are also being evaluated for potential use in guiding industrial development.

The area of Marine Research was evaluated in the light of analogous developments elsewhere. Unique marine, economic, and social attributes were considered as they might affect the establishment of a research orientation in the Delaware region.

Critical Problem Alternatives

The question of location, configuration, economic impact, and environmental effects of an East Coast deep draft port in the proximity of Delaware was one of the pressing problems recommended for early evaluation by the Governor's Task Force on Marine and Coastal Affairs. There was obviously insufficient information available concerning impact on the Bay as a natural resource to permit a low risk commitment. The Governor of Delaware has appointed a committee chaired by the Sea Grant Program Director and supported technically by the Deputy Director and other Sea Grant participants to more completely define alternatives and their local implications.

Continuing Work

Principal future efforts are being devoted to the continuing definition of the effects of local developments and the evaluation of critical problem alternatives.

3.2 MARINE RESEARCH RELATED INDUSTRIAL DEVELOPMENT

Dr. F. R. E. Durr
College of Business and Economics
Department of Business

Introduction

The accelerating expansion of the marine research facilities of the College of Marine Studies located at Lewes, Delaware can be expected to attract supportive and related industrial development to the area. The purpose of this report is to analyze the development that is probable and further to predict the impact of this growth on the town of Lewes and its immediate environs and to aid in planning for the orderly assimilation of those operations. At the outset it must be made clear that development that cannot be classified as "industrial" as such, must be considered also, for nonindustrial growth (educational facilities, tourism and the like) must necessarily have an impact upon the locality.

A Brief Economic History of Lewes

The immediate marine-oriented growth potential for Lewes, stems from increasing recognition of the known and potential value of developed marine resources to the nation as a whole. Historically, the economic growth of Lewes like that of the United States has been closely tied to the oceans. Lewes' beginnings as a fishing and trading center date back to the late 17th century. Industrial growth was slow until the arrival of the railroad in 1870. Several mills and processing plants were established which thrived for a while and then declined or closed although some level of fisheries associated individual activity has always maintained a foothold. In summary, the economic history of Lewes shows an evolution from a marine-oriented beginning, through an agricultural and manufacturing cycle, and back to the water as the expanding pressures of population and industry focus on the marine environment. It is the availability of a combination of marine recreational activities that attracts the tourists which provide a substantial portion of the economic base of the town, and it is Lewes' unique position as a window to the Sea and Bay that has attracted the operations of the College of Marine Studies at the University of Delaware.

The Present Economy of Lewes

The economy of Lewes presently suffers from a lack of diversity (it has a one-crop economy). Using employment as an indicator, the following characteristics of Lewes' economy become evident:

1. Employment increases by about 30% during the summer season.
2. On the order of 60% of the year round workers are engaged in manufacturing.
3. Approximately half of the manufacturing employment is directly related to marine-oriented activities (such as Doxsee, Barcroft, etc.).

The town of Lewes has neither accurate records nor, for that matter, reliable estimates of past numbers of tourists and summer visitors. The State Planning Office estimates the seasonal population at slightly over 3,000; therefore, the influx of people during the summer exceeds the nonseasonal population.

Future Prospects for Lewes

The State Planning Office estimates more than a doubling of tourists population influx by 1990. A particularly relevant question which must be explored, is the ability for Lewes to absorb that load and any other opportunities which manifest themselves.

From the viewpoint of physical facilities, the town appears, with few exceptions, to be in a position to absorb growth of economic activity as shown by the following evaluation table:

1. Power – Adequate
2. Water – Adequate at present but probably needs new wells for substantial expansion.
3. Sewers and Sewage Treatment – Adequate; storm sewers inadequate – remedial action required
4. Traffic and Parking – Not a pressing problem but may need expansion in the beach area.
5. Education – No problem at present.
6. Housing – Most pressing problem must be alleviated to attract newcomers to the area. Partial solution anticipated from the planned Pilot Point project which will accommodate more than 700 people and ease pressures for seasonal housing but leaving continuing problem for permanent single dwellings.
7. Medical Facilities – Adequate
8. Legal Facilities – Adequate
9. Police and Fire Protection – Fire protection adequate. Police protection – adequate at times.

From the viewpoint of labor force, there is a net migration. Except for lack of opportunities given the job prospect, it appears that the environment otherwise is satisfactory. If population is considered to be an indicator of economic growth, projections of the Delaware State Planning Office show that the population of Sussex County as a whole will increase about 25% between 1970 and 1990. If this same factor were applied to Lewes the population would increase to more than 3300. Because of the unique position of Lewes it is believed that its population growth will be substantially greater.

Interviews with 40 businessmen concerning their perception of Lewes' economic prospects indicated polarized feelings on the subject with slightly more than half being optimistic and the remainder markedly pessimistic. The need for stabilized growth instead of only

seasonal growth was recognized by all and is reinforced by the data
in Table 7 showing the dependence of sales upon seasonality.

Dissatisfaction among businessmen was explicitly expressed
on the subjects of employment opportunities for young people, and the
state and local government attitude toward industrial development.

Most suggest some form of light, controlled, and ecologically
oriented industry to solve their problems.

The University's marine facilities fit the criteria suggested
by the businessmen. However, the present economic impact is slight ex-
cept for marine-related firms.

The two major forces that should shape and guide this growth
will be the growth in tourism and the University's Marine Science fa-
cilities. The latter, perhaps not so dramatic as the influx of summer
visitors, can certainly be a more stable factor for the growth of the
town.

A direct outgrowth of the University facility is the Marine
Science Consortium consisting of twelve colleges and universities that
generally do not have a direct access to the ocean and the associated
marine activities. This year consortium programs were attended by
about 2,500 students for periods ranging from a weekend to the summer;
a total of 13,000 student days.

The College of Marine Studies has projected its ten year
growth pattern in its community design plan. The 1978-79 projection
indicates over 350 additional people and families will be located at
Lewes (about 664 in total).

The use of land for one specific purpose will normally in-
fluence the use of adjacent parcels of land - a phenomenon commonly
known as "Linkage." Primary linkages which might derive from the basic
economic activity of a College of Marine Studies and its associated re-
search programs include:

1. Sea food culture and processing
2. Marine light manufacturing
3. Industrial research and
4. Government research and operations

Elements of the first two already exist in the roster of industries
present.

TABLE 7

Seasonal Variation

Type of Business	Average Estimated Percentage Sales Increase During Summer Months
Boating Supply	40%
Clothing and Department	35-40%
Fishing Supplies	50%
Grocery	25%
Hardware, Home and Auto	25%
Liquor	30%
Motels and Hotels	35%
Pharmacy	25%
Plumbing and Heating	50%
Restaurants	80%
Seafood Retail and Wholesale	N/A
Service Stations	30%
T.V. and Appliance	None
Variety	33%

Although the possibility that the College will attract marine-oriented product and service companies is a reality, according to Portras[1] it will not be sufficient if other locational requirements such as transportation, local amenities and availability of labor are lacking.

The addition of these people, therefore, plus the normal growth to support increased tourism will accentuate the present problem of adequate housing - both in numbers and in quality. Other areas that might become problems include education, particularly in the lower grades, traffic and police and fire protection.

Another critical factor in any economic expansion is land. The Delaware State Planning Office has set up a Comprehensive Development Plan for the City of Lewes which, if implemented, should meet the projected growth.

Conclusion

The College of Marine Studies operations in Lewes will certainly have an impact upon the community.

1. The consortium operations will continue to grow.

2. Logical growth in the private sector will center in the Marine related industries.

3. A promising area of growth is that of governmental operations. The Lewes area would provide an excellent avenue for the governments at all levels to join in the challenging marine problems that not only loom in the future but also provide possible solutions to many of our environmental problems.

Economic growth for Lewes seems assured. It seems reasonable to conclude that the cooperative efforts of all parties concerned should allow the growth to be orderly and fruitful.

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[1] Ronald A. Portras, "Locational Characteristics of Marine-Oriented Products and Services Industries." Unpublished M.A. Thesis, University of Rhode Island, 1970.

3.3. FOOD AND NUTRITION PLANNING AND CONSULTATION

Miss E. J. McCreary
College of Home Economics

Introduction

The efforts being undertaken regionally to revive the oyster
industry through natural means or culture technology can have signi-
ficant impact upon the availability of oysters in the market place. A
survey was therefore planned to determine if research currently being
undertaken offered sufficient insight into new product opportunities
to absorb the potential yield.

The results were as follows:

Oysters can make a substantial nutritional contribution to
the diet. The values present in 1 cup of raw oyster meats according
to the U. S. Department of Agriculture (Home and Garden Bulletin No.
72, 1970) include the following: Water - 85%; Food Energy - 160 k cal;
Protein - 20 gm; Fat - 4 gm; Carbohydrate - 8 gm; Calcium - 226 mg;
Iron - 13.2 mg; Vitamin A - 740 I.U.; Thiamin - .33 mg; Riboflavin -
.43 mg; Niacin - 6.0 mg.

Present food fish consumption patterns are roughly approxi-
mated by the zones indicated in Figure 16, a distribution one should
intuitively expect based upon both tradition and economics. Figure 17
indicates the level of oyster production from Delaware Bay (New Jersey
and Delaware landings during the past 90 years). Those surveyed were
therefore contacted to determine what product development research
was currently in progress that might effectively market a forty (40)
fold increase in production assuming increased penetration into lower
areas of seafood consumption.

Visits were made to the Chesapeake Bay Seafood Industries
Association in Easton, Maryland and the Oyster Institute of North
America in Sayville, Long Island.

The following persons were contacted by phone:

Crawford, D.   Department Food Science, Oregon State
                University, Corvallis, Oregon

Liston, J.   Institute Food Science and Technology,
                University of Washington, Seattle, Washington

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Figure 16.

Figure 17: Oyster production from Delaware Bay.
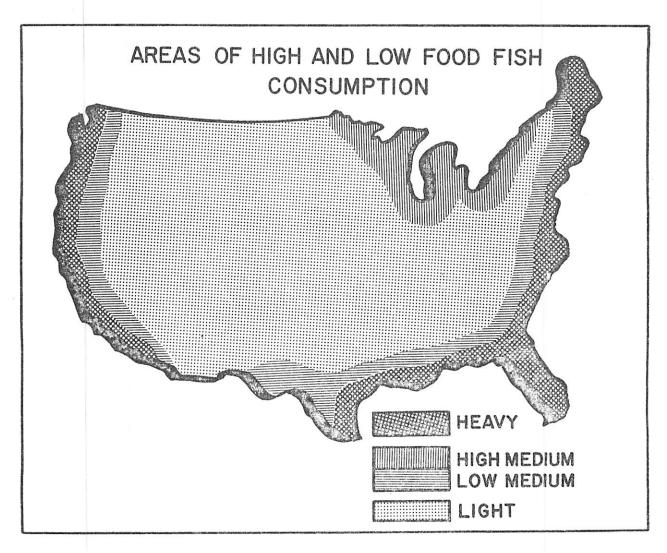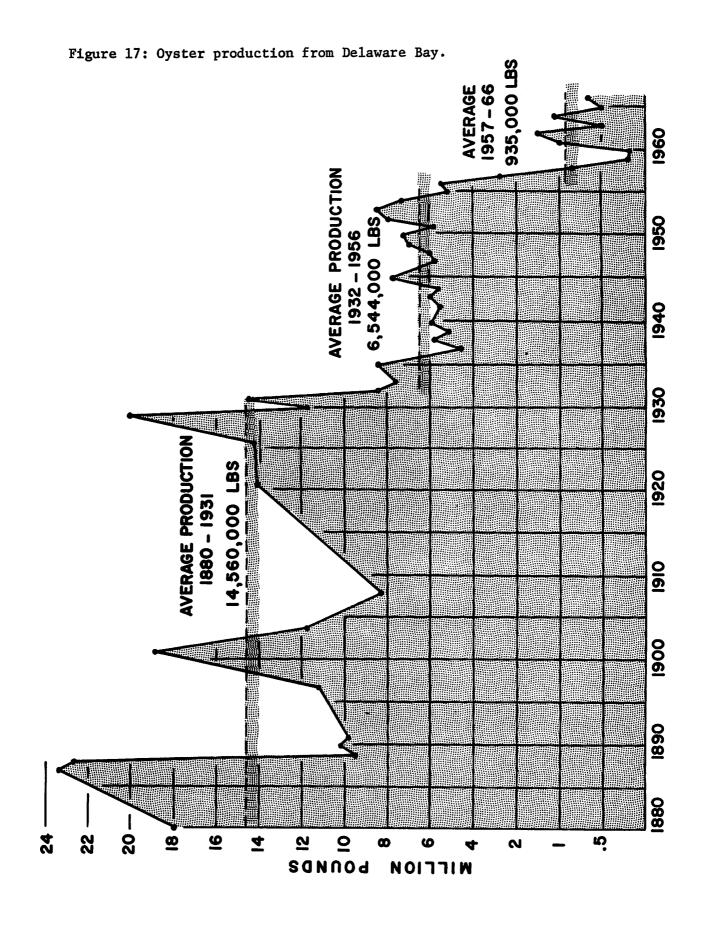
Meade, T.	Department of Fisheries, University of Rhode Island
Myers, S.	Department of Food Science, Louisiana State University, Baton Rouge, Louisiana

After surveying the literature and making personal contacts with researchers in the area of marine studies, and persons in the seafood industry, it was found that there was a very limited amount of work being done, from the viewpoint of mass market appeal, in developing new products from shellfish. It was recommended therefore that research be undertaken for this purpose at the University of Delaware. The Office of Sea Grant programs did not concur.

3.4. SOCIOLOGICAL ASPECTS OF SEASHORE RECREATION

Dr. Wallace H. Dynes
College of Arts and Science
Department of Sociology

Introduction

The objective of the project during FY 70 was the assessment of the feasibility of establishing a research program in the current and potential recreational uses of the bays, coastal waters and shores of Delaware and areas to the south. Based upon what has been learned, such a program is feasible but considerably more complex than originally imagined.

While the investigators had intended to conduct a sample survey of the persons using two seashore state parks in Delaware, a pretest of the interview schedule led to a reconsideration of intentions. For example, the great variety of activities in which the target population engaged made standarized interviewing rather complex, particularly when it became apparent that the purposes of the interview were none too clear.

Thus, it was decided to carry out trial data collection with modest goals on a population much smaller than that originally intended. On July 4, 1970, the two investigators collected data from 69 respondents chosen systematically from the two seashore state parks.

In keeping with the limited goals, the results were modest but have had major effects upon the planning for future efforts. The following section will outline the more important conclusions based upon

the original analysis of results. The final section shall indicate
the implications of these conclusions and attempts to deal with these
implications.

Results and Conclusions

        Initially it was expected that the respondents would be
somewhat similar to the forest campers studies by other investigators
in that there would be significant differences in orientation and at-
titudes. These differences were thought to be linked somewhat to
occupational status but more importantly to different types or styles
of camping. Additionally, it was expected, based partly upon prior
work on Delaware campers, that there would be significant differences
between the campers at the two campsites as Cape Henlopen State Park
(Henlopen) has more room, privacy, hills and shrubs than Indian River
Inlet Campground (Inlet) and appeared to be perceived as a "nicer"
place.

        The expectations generally were not met. Based upon these
results, it was concluded that campers in the coastal state parks
do not evidence large or consistent differentials in their camping
orientations, are not generally concerned with crowding in the parks,
fail to perceive changes in the state parks that some claim are "de-
grading" the camping experience, and generally do not express dis-
satisfaction with the camps as they existed in the summer of 1970.

        While there were some differentials among campers and these
differences may be of some immediate interest to campground managers,
they do not provide the knowledge necessary for drawing conclusions
about the nature of the camping experience or the probable future
development preferences of the sample. For example, the most con-
sistent differences found were those between the campers at the two
state parks and between campers who had camped more than twenty times
in the previous five years.

        In the comparison between the two state parks, a larger pro-
portion of the Henlopen campers thought the comfort stations to be
better and in better condition, and engaged in sightseeing and hiking
more often in comparison to the Inlet campers. For their part, the
Inlet campers were more likely to perceive the Inlet campground as
crowded and were more likely to desire sewage hook-ups in comparison
to the Henlopen campers.

        In the comparison based upon camping experience, those with
more experience were more likely to perceive the campground as littered
and their fellow campers as interfering with their enjoyment of camping.

        But, there were no other systematic differences between the
campers at the two campgrounds or between campers who differed in ex-
perience. In no other comparison did the campers vary systematically

and significantly in group composition, extent of camping experience, equipment currently in use, perception of litter or trash conditions, perception of the type and living habits of other campers, or in their immediate purposes in camping. While there were a few other statistically significant findings, the results generally showed no systematic differences that would lead to firm conclusions.

Implications

The reaction of the investigators to the results was a searching examination of the bases of their original expectations. It was discovered that many expectations were based upon implicit value assumptions in the prior literature (e.g., that a "wilderness" orientation is a necessary component to the camping experience), as well as value preferences. An extensive search was begun in the theoretical as well as the applied literature. This search, which occupied most of the attention in the remainder of FY 70, has begun to produce a more realistic but also more theoretically defensible scheme of analysis.

For example, it has been learned that several of the traditional socio-economic variables have been found to correlate moderately with gross recreational participation rates and to be useful in the generation of gross recreational demand functions. On the other hand, these traditional factors have not been useful in accounting for current recreational preferences. At this time, the survey of literature has failed to discover any empirically based factors that are systematically related to recreational preferences. Moreover, the current lack of such systematic relations makes the assessment of support for various development options moot at this time.

While the current outlook for the systematic analysis of demand for various development options is pessimistic, there are several possibilities that appear promising. These possibilities include several suggestions in literature not obviously related to recreation as well as some suggestions of a theoretical nature within the recreational literature itself. Several of these suggestions were incorporated into the paper, "Some Implications of Recreational Participant's Motivation for Recreational Development Options," presented at the Second Coastal and Shallow Water Conference on October 10, 1971. The immediately relevant point of this paper may be summarized by the following assertions. First, the understanding of recreational preferences probably will depend upon the examination of the meanings attached to the recreational activity by the recreationist. Second, while work and leisure are quite different kinds of behavior, the type or conditions of work probably have significant effects upon the type and conditions of recreational activity. Finally, there are theoretical reasons why one may expect to find interrelations between work behavior, leisure behavior and the meanings attached to leisure behavior.

Current efforts, in addition to a continuing search of various literatures, are first, the specification of a conceptual scheme that is both theoretically fruitful and empirically grounded, and second, the development of a focused interview schedule by which one may expect to gather data relevant to our developing theory. Initially, the interviewing will be concerned with campers.

4.0. INTERACTION OF MAN AND THE COASTAL ZONE

        The geological features and characteristics of Delaware Bay
have been the subject of extensive coordinated research; coordinated
in the sense of maximizing the information acquired for a given in-
vestment in facilities and manpower by common field efforts. Each
project, however, is separately represented below in order to gain
adequate visibility into their respective findings since their in-
dividual focus is substantially different, ranging from coastal pro-
cesses to sources and diagensis of organic matter in lower Delaware
Bay sediments.

4.1. GEOLOGY OF DELAWARE BAY

4.1.a. GEOLOGIC HISTORY OF SHORELINE CHANGES
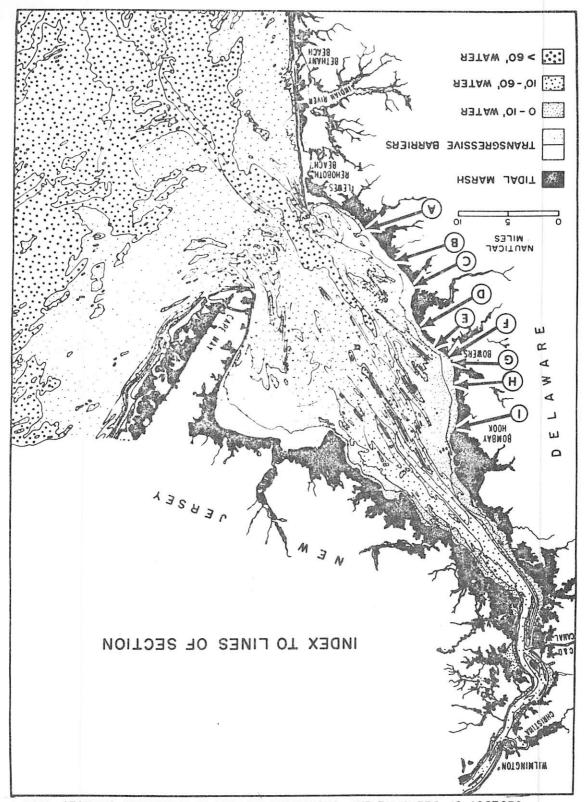
Dr. John C. Kraft   Graduate Students:
College of Arts and Science   D. Coreman
Department of Geology   A. Crossan
                                            C. W. Weil

        Previous work by the U. S. Army Corps of Engineers, based on
analysis of the historic map record of the United States Coastal Sur-
vey and U. S. Coast and Geodetic Survey, clearly showed that the shore-
lines of Delaware Bay and Delaware's Atlantic Coast were undergoing
rapid erosion, with resultant coastal damage. Work by Kraft (1971)
showed that a more precise understanding of the nature of coastal
change could be formed by analysis of vertical sediment sequences
in the rapidly changing coastal area. Accordingly, this subproject
on rate of change of the shorelines of Delaware Bay was initiated.

        To date, nine detailed study sections of variants in the geology
of Delaware Bay's western coastal area have been formed. Figure 18
shows the location of the areas of detailed study. The locales have
been selected on the basis of accessibility and potential geologic variants
in addition to logical sites for extension into offshore geophysical stu-
dies presently ongoing.   Eleven holes were drilled with a truck mounted
auger rig. These holes provide data on the nature of the third dimension
or vertical sequence of sediment lithosomes that are forming and moving
at the leading edge of the Holocene-Present marine transgression. Sedi-
ments collected and other data from the first field season are now un-
dergoing study and analysis.

INDEX TO LINES OF SECTION

GEOLOGY OF DELAWARE BAY - GEOLOGICAL HISTORY OF SHORELINE CHANGES - KRAFT

Figure 18.

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Nine preliminary coastal Delaware Bay cross sections are shown in Figure 19. These diagrams show 4 basically different coastal retreat situations. One type, such as the Fowlers Beach, Bennetts Pier, Bigstone Beach, and possibly Broadkill Beach, includes a thin, narrow sand gravel beach moving landward and upward in space and time over a thin Holocene sequence. Compaction effects should be relatively unimportant in these areas. In a second type, as at Slaughter Beach and South Bowers, a thin sand-gravel beach is moving over a thick Holocene marsh and lagoonal mud section deposited in the areas of river valleys tributary to the ancestral Delaware River of Early Holocene time (7-12,000 years before present). In these "old valley" loci, sediment compaction could be an important factor in coastal movement. Third, as at Bowers beach and Kitts Hummock, the eroding coastal strandline is moving landward over Pleistocene sediment highlands. The erosion of these relative highlands is possibly a major source of sediment in the natural processes of beach nourishment, that occur as the present transgression continues. The fourth geologic setting identified is that at Port Mahon. The broad marshes of Port Mahon are rapidly eroding at the shoreline, which is starved of coarse clastic sediments.

An exception to the general coastal retreat has occurred in the Broadkill Beach area, Figure 19. Here a spit-like projection moved through the coastal area in the nineteenth century, leading to significant coastal accretion. However, the situation is now back to normal. With a cut-off of the littoral drift stream supplying the spit projection, Broadkill Beach is massively eroding. Previous studies by the Principal Investigator show that the Broadkill Beach coastal oscillation was controlled by events in the Cape Henlopen-Lewes Harbor area to the southeast.

Five major factors bear on the rate of coastal change in western Delaware Bay. These are: erosion by wave action; transport of sediment along shore by littoral drift processes; tectonic subsidence and sediment compaction; relative sea level rise; and the intrusion of man into the area. The relative importance of each coastal change factor is under investigation.

Ongoing research includes more precision in delineating the morphologic and sediment parameters of each study area. In addition, an attempt is being made to formulate a mathematical basis for understanding rates and volumes of materials moved or in motion in the coastal sedimentary environments and their resultant lithosomes or sediment units (Figure 20). As the University of Delaware's geophysical and coring program develops offshore the onshore studies will be directly linked to them so that a better understanding of variants in the complete system of change in the morphology of Delaware Bay can be established.

Future research extensions of this project - Geologic History of Coastal Change - now appear to require an expansion of the drilling program to the north, more precise air photogrammetry and

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Figure 19.

Figure 20.

CROSS SECTIONAL AREA COMPUTATIONAL
MODEL OF THE DUNE AND BEACH AREA AT
SOUTH BOWERS, DELAWARE.
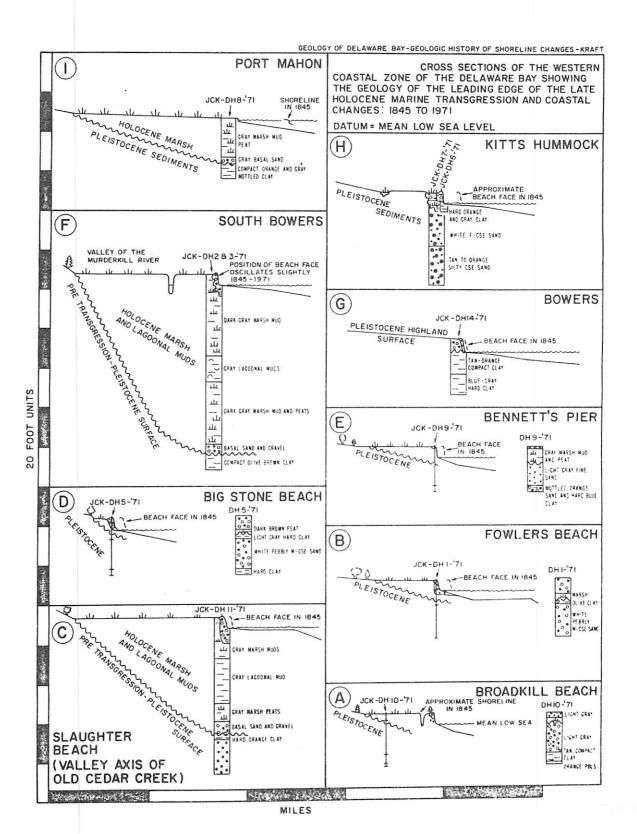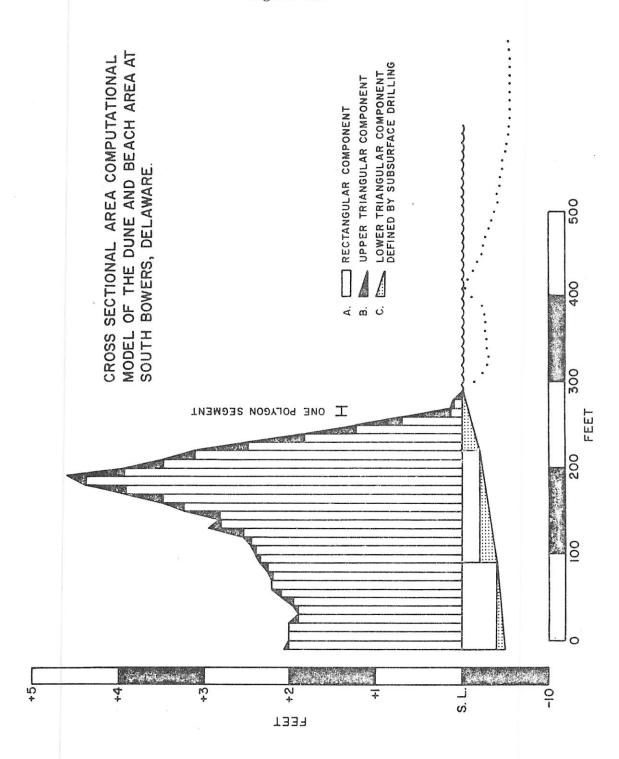
analysis of the historic record, and the introduction of radioactive tracer studies for a precise understanding of sediment movement paths. Ultimately, it will be possible to clearly identify and recommend corrective actions (or abandonment) for coastal erosion problems along the entire Delaware Bay shoreline. The models resultant may well apply elsewhere on the United States Atlantic shore and on a broader world-wide basis. A brief feasibility study of model applications should conclude this research effort.

4.1.b. SEDIMENTS AND SEDIMENTARY PROCESSES OF THE DELAWARE BAY

Dr. Robert R. Jordan
College of Arts and Science
Department of Geology

In order to advance the basic objective of understanding sediment transport in the Delaware Estuary it is necessary to sample materials in motion at and near the sediment-water interface. As no suitable devices are commercially available, the design, construction, and testing of such a sampler was undertaken. This has resulted in a bedload sediment sampler of original design utilizing the pressure difference principle to trap saltating detritus and riffles to retain this material and larger, rolling particles. The final design (Figure 21) consists of an elongate box, diverging front to rear, that orients into the prevailing current when lowered and equipped with doors that close upon lifting to retain the sediment. A trial sampler was built to test designs and three samplers of the selected design have been fabricated. Testing was conducted in a local stream, and preliminarily, in the Estuary off Lewes, Delaware. The testing has indicated that the sampler is efficient and provides a reasonable representative sample. It is planned to utilize the sampler, teamed with a current direction and velocity meter, to determine sediment transport in relation to currents in the Delaware Estuary. Planning and progress will be dictated by the availability of future funding.

4.1.c. THE PALEOECOLOGY OF THE OYSTER BEDS OF DELAWARE BAY

Dr. Robert E. Sheridan
College of Arts and Science
Department of Geology

Graduate Student:
Roger Moose
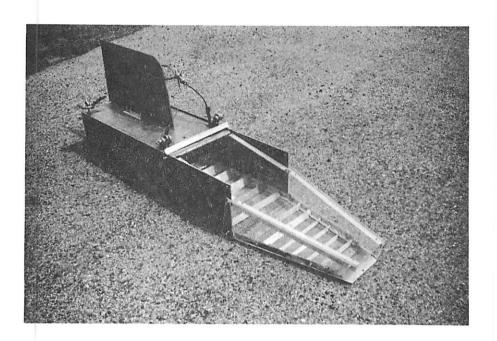
Figure 21: Bedload sediment sampler.
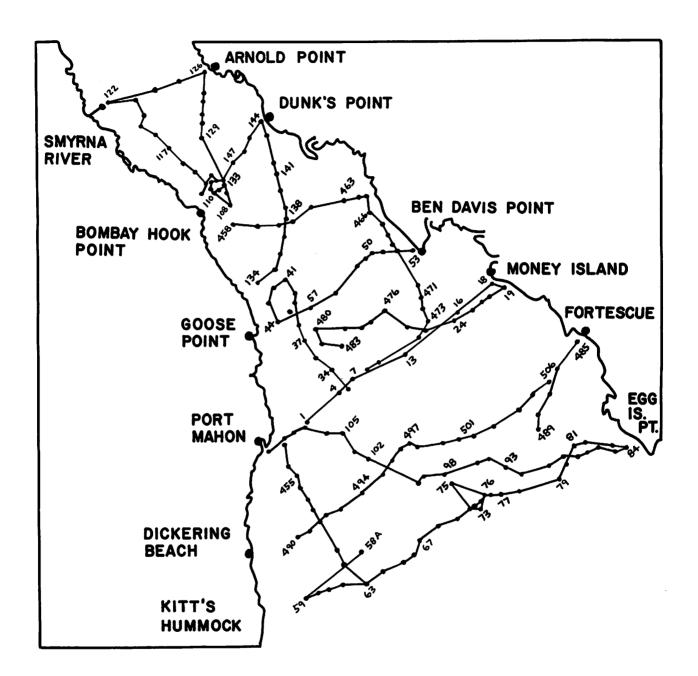
Figure 22: High resolution 7kHz seismic profiles.
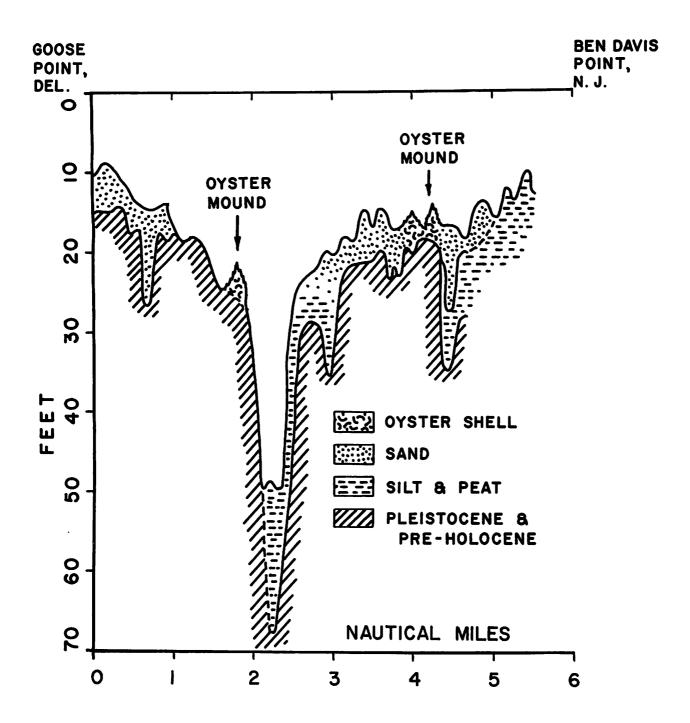
Figure 23.

The project involving the paleoecology of the oyster beds of Delaware Bay accomplished several things over the past year including the purchase and adoption of a high resolution 7KHz seismic-reflection profiler for surveys of the oyster areas. Seven cross-bay transects were run at about a 2 mile spacing between Kitts Hummock and Smyrna River on the Delaware side, to between Egg Island Point and Arnold Point on the New Jersey side (Figure 22). These covered the area of the producing oyster beds. Also, several longitudinal tie-lines were run to intersect the cross-bay transects.

On these profiles several features were identified (Figure 23):

1. The rough, incised Pleistocene surface over which 5-20 ft. of Holocene deposits are laid.

2. Holocene deposits of silt with peat layers of 4000-5000 years B.P. age.

3. Holocene sand deposits forming longitudinally elongate shoals.

4. Oyster mound structures.

Some conclusions can be made concerning the distribution of oyster beds, identified on the profile records as sharp-peaked mounds with relief up to 7-8 ft. built over horizontal sediment horizons. The oyster beds seem to thrive on bottoms formed on outcrops of the Pleistocene or Holocene silt and drowned marsh deposits, which provide muddy sediments and firm substrates. Where the sands are beginning to accumulate over the marsh muds into shoal bed forms, the oyster mounds appeared to be destroyed and buried. No oyster mound structure was identified on the records as a subsurface structure. This may indicate that as the sand nears the oyster mound, the living forms depart to avoid choking by the sand and the remaining weakly cemented structure disintegrates under the influence of bottom currents before burial. Consequently, only a flattened bed of shell debris is buried by the sand.

4.1.d.   COMPARATIVE CARBOHYDRATE GEOCHEMISTRY OF BAY,
SALT MARSH AND DEEP GULF SEDIMENTS

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Introduction

As part of a continuing program of study of carbohydrate geochemistry (Palacas, J. G., 1959; Rogers, M.A., 1965; Swain, 1967; Swain, et al, 1969; Swain, 1970, 1971) core samples of sediments from Broadkill Marsh, Delaware; Delaware Bay, Delaware-New Jersey; and from the southern part of the Gulf of California, Mexico have been analyzed. The purpose of this work was to compare the distribution and origin of the sedimentary carbohydrate residues and to consider possible reasons for the variations found.

The Delaware Bay sediments contain 3 times as much total sugars as the Broadkill Marsh sediments and the Gulf of California sediments have an order of magnitude more total sugars than those of Delaware Bay. The differences between the marsh and bay are believed to be caused by the relatively greater degree of oxidation and humification of the organic matter in the tidal marsh and tidal creek environment than that taking place in the estuarine environment of Delaware Bay. The organic carbon content of the marsh sediments averages about 0.5% (range 0.3 to 3%) while the marsh sediments have up to 25% C in the peaty layers and average much higher than the Bay sediments.

The oxidation rates of the Gulf of California sediments evidently are much lower than the other two environments because of low-energy reducing conditions and high hydrostatic pressures and as a result the sugars are preserved in the deep marine sediments to a much higher degree than in marsh and bay sediments.

In marked contrast to marsh samples, as shown in Table 8, acid extractable monosaccharides of the Delaware Bay sediments range from 1.3 µg/g at 40.6-45.7 cm. to 206.9 µg/g at 192.7-177.8 cm. The increase with depth, however, is not uniform. These low values show strikingly that the carbohydrate source material that occurs so plentifully in the nearby marshes is not being deposited in the bay; either it is not reaching the area or is being carried by tidal activity out of the bay. Both factors are believed to be important in this instance with much of the source material having undergone degradative oxidation before reaching the bay. At several levels in the sediments, mannose is the predominant monosaccharide. As shown in Table 9, this sugar is also prominent as a constituent, especially in free form of several species of marsh grasses that are common in the area: Spartina patens, S. alterniflora, and Disticlis spicata. The enrichment in mannose in Delaware Bay sediments may be related to a source in the marsh plants or it may be due to growths of yeast cells in the bay. Mannans are an important component of yeasts.

Table 8

Acid Extractable Sugars in Core Samples from Delaware Bay;
Core 21; in Micrograms Per Gram of Dry Sediment

Depth (cm)	gal	glu	man	ara	xyl	rib	rha	other	Σ
40.6-45.7	0	1.3	0	0	0	0	0	0	1.3
50.8-55.9	5.5	8.6	9.8	3.7	1.3	2.1	1.0	0	32.0
61.0-66.0	5.6	4.0	2.0	0.9	2.6	0.3	1.5	0	16.9
71.1-76.2	7.3	4.6	3.1	2.4	4.5	1.4	3.7	0	27.0
81.3-86.4	Separation not attained because of high salt content, but sugars present								
91.4-96.5	3.4	4.3	3.3	2.6	1.4	0.7	0.6	0	16.3
101.6-106.7	7.6	10.9	11.1	1.7	1.6	0.7	0.2	0	33.8
111.7-116.8	8.7	12.2	20.2	3.3	4.2	1.0	2.6	0	52.2
121.9-127.0	5.6	9.9	22.0	2.4	2.5	0	2.4	0	44.8
132.1-137.2	11.2	7.4	17.3	6.3	9.5	3.5	8.6	0	63.8
142.2-147.3	7.8	5.3	13.8	4.6	6.7	1.5	5.8	0	45.5
152.4-157.5	4.1	6.7	5.2	3.3	4.4	0	4.8	0	28.5
162.6-167.6	4.9	4.1	103.6	5.2	7.4	1.5	5.3	obligo-sacch?	132.0
172.7-177.8	4.9	6.7	171.3	6.9	8.7	0	8.4	0	206.9

Table 9

Carbohydrates of Marsh Plants

Free sugar contents of marsh plants, in mg/g

Species	gal	glu	man	ara	xyl	rib	rha	∑
Spartina patens	0.61	0.63	1.71	0.91	0.09	0.10	0.11	4.16
Spartina alterniflora dwarf var.	0.09	0.05	0	0.39	0.09	0.04	0.03	0.69
Spartina alterniflora tall var.	0.19	0.13	0.53	0.14	0.07	0	0	1.06
Disticlis spicata	0.55	0.65	2.03	0.26	0.08	0.08	0.03	3.68

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Rogers, M. A., 1965, Carbohydrates in aquatic plants and associated sediments from two Minnesota lakes, Geochim. Cosmochim. Acta, 29, 183-200.

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4.1.e. SEDIMENTATION ON SHELL BANKS IN DELAWARE BAY

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Introduction

The basic objective of FY 1971 research was to typify geological aspects of the environment which supports oysters in Delaware Bay. Recognizing that the distribution and abundance of oysters was much greater in the past than at present (Moore, 1911), we have used data presented in Maurer et al (1971) from recent oyster surveys to establish the limits of the area of investigation (Figure 24).
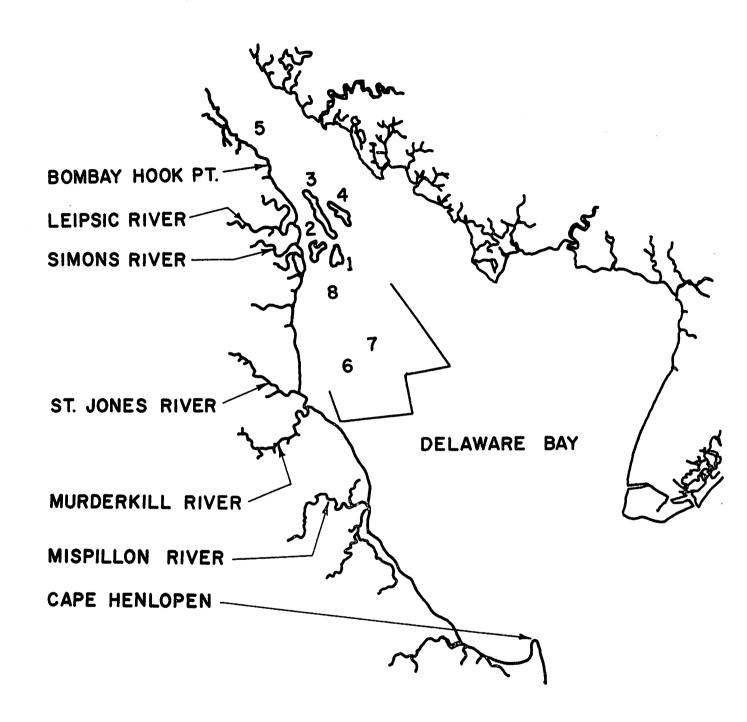
Figure 24: Location of oyster beds in Delaware Bay (from Maurer et al, 1971).

Procedure

A total of 96 bottom samples were taken with a Peterson grab or a piston corer with two meter barrel. Samples were numbered as follows; all samples are identified by the letters "SG" (Sea Grant) followed by the station number, followed by the letter "W" (R. V. Wolverine) or "S" (R. V. Skimmer) followed by the last two digits of the year ('71). The station number of each sampling location is illustrated in Figure 25 and the longitudes and latitudes (to the nearest .05 minute) are presented in Table 10. The designation of a letter (usually "A" or "B") after the station number in Table 10 indicates that more than one sample drop was made at the same location.

Grab samples were brought on board and dumped on a wooden deck, after which a gross description was made and a subsample placed in a plastic sample bag. Core samples were extruded from their plastic liners immediately after sampling and roughly described, then cut longitudinally and carefully described, measured, and subsampled. These results are documented and are available upon request. Core subsamples were also stored in plastic bags.

Preliminary data on the subsurface structure beneath the bottom of Delaware Bay was obtained by jetting a three-fourths inch aluminum pipe through the bottom sediments. The washings which returned to the surface were examined and described and the depths beneath the bottom were noted. These sampling locations are illustrated in Figure 25 and located by longitude and latitude in Table 10 tions of these samples is designated by the letters "BH"). Detailed descriptions of the logs of the wash holes are also available upon request. No samples of material washed from these holes were taken because of the biased nature of the sampling technique.

Samples were wet sieved through a 63 micron sieve and the material retained on the sieve was designated the sand fraction. The material passing the sieve was separated into a silt fraction (63 microns - 3 microns) and a clay fraction (less than 3 microns) by pipette analysis. Each of the three fractions was dried and weighed. Calculation of the weight percentage of each fraction was then performed.

Redox potential (Eh) of each grab sample was measured using an "ORION" specific ion pH meter with sleeve type calomel and platinum electrodes. Hydrogen ion activity (pH) was measured on the same samples using sleeve type calomel and glass electrodes. Both pH and Eh were measured several days after sample collection and this could cause biasing of the results. All sediment samples were stored in airtight plastic bags so oxidation was minimized and results are probably usable on a relative scale.

Portions of each sediment sample have been catalogued and retained for future analyses.

Table 10

Location and grain size data on all sediment samples taken
for Sea Grant during 1971. The letters "A" and "B" after sample
numbers indicate two sampler drops for an individual station.
Sample type "C" indicates piston core, "G" indicates Peterson grab,
and "BH" indicates deep boring probe. Water depths are in feet.
Sand is defined as particles coarser than 63 microns, silt is parti-
cles between 63 microns - 3 microns, and clay is particles finer than
3 microns.

SAMPLE NUMBER	TYPE	DEPTH	LATITUDE	LONGITUDE	WEIGHT PERCENT SAND	SILT	CLAY
1A	C	18	39-15.40	75-15.40			
1B	G	18	39-15.40	75-15.40	82.6	14.7	2.7
2	G	20	39-14.70	75-16.75	85.0	11.5	3.5
3	G	25	39-14.15	75-17.90	87.0	9.6	3.4
4A	G	50	39-14.00	75-18.25	49.0	41.5	9.5
4B	G	50	39-14.00	75-18.25	43.3	47.4	9.3
5	G	15	39-13.60	75-19.05	96.0	4.0	0.0
6	G	10	39-13.35	75-19.55	94.5	0.9	4.5
7	G	28	39-13.25	75-19.85	91.8	3.0	5.1
8A	G	11	39-13.10	75-20.20	67.8	15.3	16.9
8B	G	11	39-13.10	75-20.20	85.0	8.0	6.9
9	G	10	39-12.60	75-21.05	62.0	25.6	12.2
10	G	9	39-11.95	75-22.20	69.9	15.4	14.6
11	G	18	39-22.50	75-29.05	63.4	25.3	11.2
11	C	18	39-22.50	75-29.05			
12	G	9	39-22.40	75-29.65	79.3	12.6	8.1
13	G	60	39-22.55	75-28.15	100.0	0.0	0.0
14	G	18	39-22.80	75-27.30	99.2	0.7	0.0
15	G	15	39-23.00	75-26.35	70.3	16.3	13.4
16	G	16	39-23.15	75-25.90	3.9	28.0	68.0
17	G	27	39-23.10	75-26.10	79.0	10.1	9.9
18A	G	17	39-22.85	75-26.75	93.3	5.8	0.9
18B	G	17	39-22.85	75-26.75	76.8	13.1	10.0
19	G	11	39-19.40	75-25.75	25.2	58.1	16.6
20	G	25	39-19.60	75-20.55	3.3	74.6	22.0
21	G.	50	39-20.00	75-25.10	3.7	37.5	58.6
22	G	25	39-20.25	75-24.75	54.5	31.6	13.9
23	G	17	39-20.90	75-24.35	98.6	1.4	0.0
24	G	11	39-21.20	75-24.10	100.0	0.0	0.0
25	G	8	39-06.60	75-20.35	1.9	72.5	25.5
26	G	12	39-07.00	75-21.05	33.0	56.6	10.3
26	C	12	39-07.00	75-21.05			
27	G	10	39-07.60	75-20.05	72.7	27.3	0.0

Table 10 (Con't.)

SAMPLE					WEIGHT PERCENT		
NUMBER	TYPE	DEPTH	LATITUDE	LONGITUDE	SAND	SILT	CLAY
28	G	15	39-06.45	75-19.45	87.0	12.3	0.7
29	G	21	39-07.30	75-19.25	95.0	4.8	0.1
29	C	21	39-07.30	75-19.25			
30	G	17	39-07.75	75-18.55	96.7	3.3	0.0
31	G	21	39-08.10	75-17.65	75.8	19.4	4.5
31	C	21	39-08.10	75-17.65			
32	G	15	39-08.15	75-17.45	81.9	14.1	4.0
33	G	33	39-08.40	75-16.65	95.1	4.2	0.7
34	G	10	39-08.75	75-15.85	98.3	1.7	0.0
35	G	45	39-09.05	75-14.75	93.7	6.3	0.0
36	G	16	39-09.35	75-14.10	95.9	3.8	0.3
37	G	15	39-10.10	75-12.50	99.6	0.4	0.0
38	G	11	39-10.90	75-11.50	99.5	0.5	0.0
39	G	16	39-10.70	75-09.80	87.8	11.4	0.8
40	G	20	39-23.00	75-26.85	91.0	5.5	3.5
41	C	24	39-25.15	75-26.20			
42	C	12	39-23.20	75-26.00			
43	G	13	39-21.50	75-23.85	97.6	2.4	0.0
44	G	14	39-20.50	75-24.55	97.7	2.3	0.0
45	C	49	39-19.90	75-25.20			
46	C	35	39-19.65	75-25.50			
47A	G	11	39-15.00	75-23.40	79.9	16.6	3.4
47B	G	11	39-15.00	75-23.40	8.9	68.0	23.0
48	G	15	39-15.35	75-22.30	82.5	12.6	4.8
48	C	15	39-15.35	75-22.30			
49	G	24	39-15.65	75-21.75	75.3	19.1	5.6
49	C	24	39-15.65	75-21.75			
50	G	22	39-15.85	75-21.35	95.2	4.7	1.1
51	G	50	39-16.10	75-20.60	94.3	4.6	2.0
51	C	50	39-16.10	75-20.60			
52	G	18	39-16.65	75-19.75	68.6	22.3	11.1
52	C	18	39-16.65	75-19.75			
53	G	12	39-17.25	75-18.95	97.3	2.7	0.0
54	G	17	39-17.35	75-18.80	97.6	2.3	0.0
55	G	15	39-17.35	75-17.80	PEATY SILT NOT ANALYZED		
55	C	15	39-17.35	75-17.80			
56	C	17	39-15.35	75-15.50			
57	C	50	39-13.95	75-18.35			
58	C	25	39-13.20	75-20.00			
59	C	13	39-13.00	75-20.35			
60	G	12	39-13.90	75-21.10	77.5	18.9	3.6
60	C	12	39-13.90	75-21.10			
61A	G	12	39-14.30	75-21.70	90.8	7.2	2.0
61B	G	12	39.14.30	75.21.70	55.8	35.6	8.6

Table 10 (Con't.)

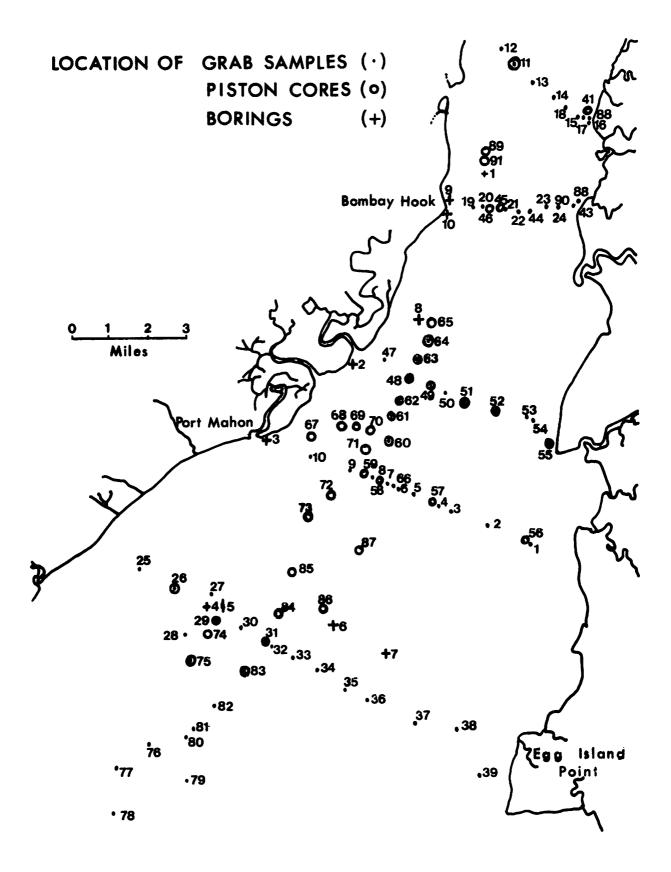| SAMPLE NUMBER	TYPE	DEPTH	LATITUDE	LONGITUDE	WEIGHT PERCENT SAND	SILT	CLAY
61	C	12	39-14.30	75-21.70			
62	G	15	39-14.80	75-21.90	59.8	35.1	5.0
62	C	15	39-14.80	75-21.90			
63	G	14	39-15.85	75-22.70	78.6	14.2	7.2
63	C	14	39-15.85	75-22.70			
64	G	19	39-16.25	75-23.00	52.5	34.0	13.5
64	C	19	39-16.25	75-23.00			
65	G	18	39-16.70	75-23.40	65.1	32.3	2.6
65	C	18	39-16.70	75-23.40			
66	G	14	39-13.30	75-19.70	98.3	0.5	1.2
67	C	13	39-12.35	75-22.75			
68	C	14	39-13.05	75-22.40			
69	C	14	39-13.35	75-22.05			
70	C	14	39-13.60	75-21.70			
71	C	12	39-13.25	75-21.30			
72	C	9	39-11.75	75-20.75			
73	C	12	39-10.95	75-20.60			
74	C	22	39-06.90	75-19.10			
75	G	46	39-06.15	75-18.85	72.5	25.9	1.6
75	C	46	39.06.15	75-18.85			
76	G	29	39-03.95	75-16.95	88.4	11.6	0.0
77	G	13	39-02.85	75-16.90	90.8	7.1	0.1
78	G	44	39-02.05	75-15.65	91.0	9.0	0.0
79	G	10	39-04.25	75-15.15	69.8	25.0	5.2
80	G	29	39-04.95	75-16.50	97.4	2.6	0.0
81	G	25	39-05.20	75-16.55	97.9	2.1	0.0
82	G	23	39-06.00	75-16.80	99.2	0.8	0.0
83A	G	24	39-07.20	75-17.20	55.8	40.2	3.9
83B	G	24	39-07.20	75-17.20	28.3	59.6	12.0
83	C	24	39-07.20	75-17.20			
84	C	19	39-08.75	75-18.25			
85	C	16	39-09.70	75-19.10			
86	C	21	39-09.80	75-17.40			
87	C	20	39-11.15	75-18.60			
88	G	13	39-21.70	75-23.80	97.2	2.7	0.0
89	C	18	39-20.35	75-27.10			
90	G	15	39-21.20	75-24.10	93.8	3.5	2.7
BH-1		3	39-15.70	75-23.25			
BH-2		5	39-14.20	75-24.00			
BH-3		5	39-11.25	75-23.60			
BH-4		7	39-07.30	75-19.80			
BH-5		11	39-07.30	75-19.80			
BH-6		8	39-09.75	75-16.80			
BH-7		8	39-10.50	75-14.95			
BH-8		9	39-16.40	75-24.10			
BH-9		9	39-18.95	75-26.50			
BH-10		8	39-18.65	75-26.20			
BH-11		5	39-21.50	75-25.75			

85

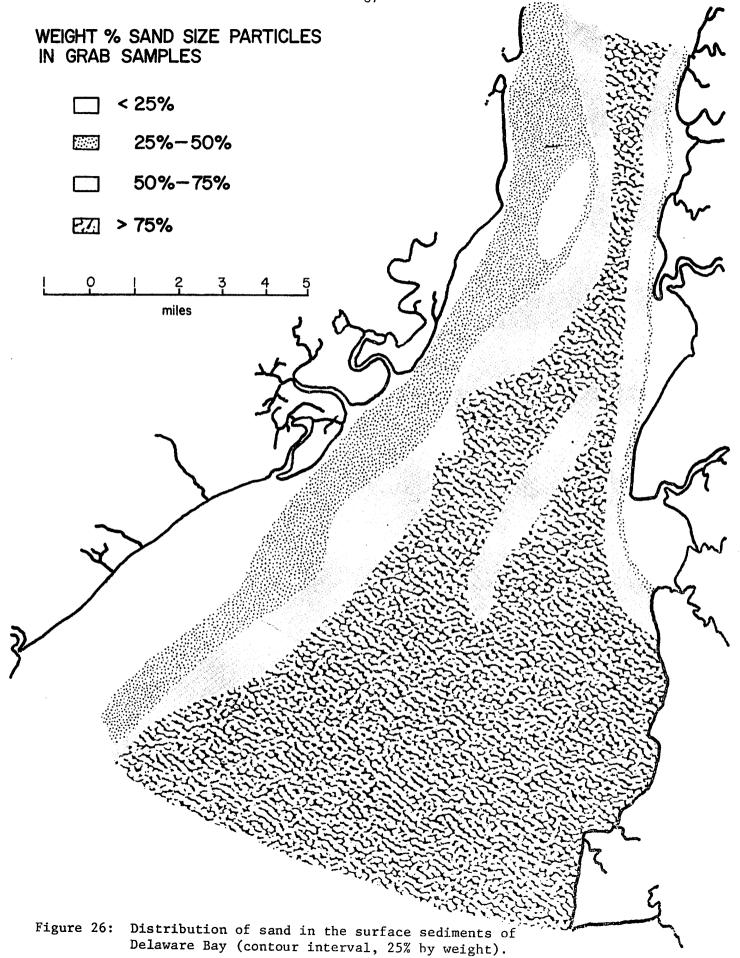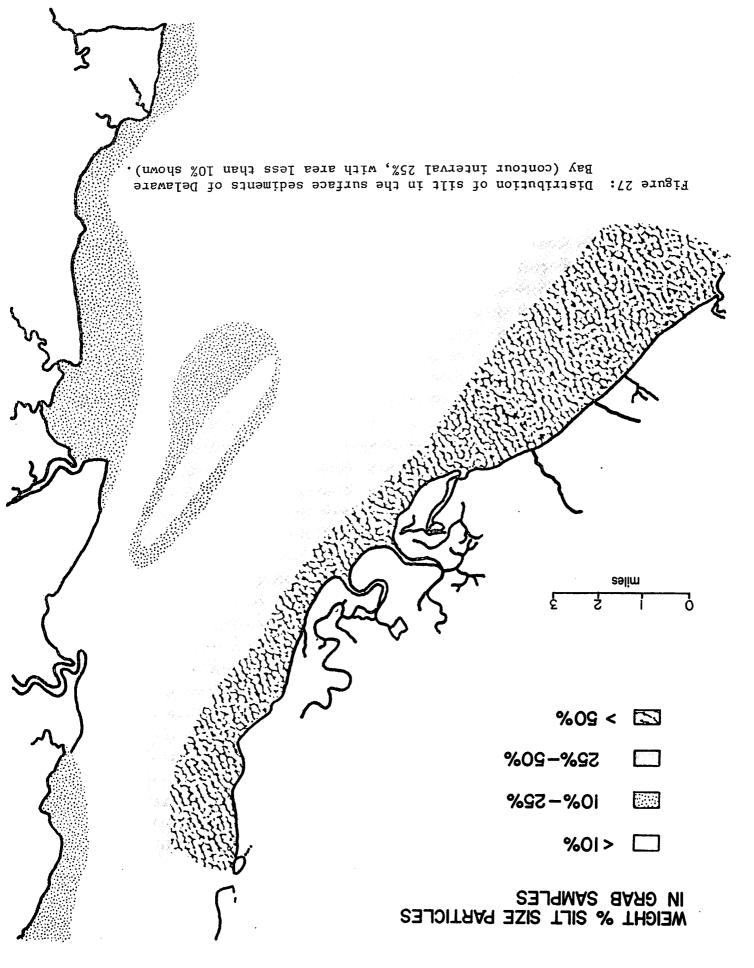Figure 25:   Location of sampling stations for FY '71 Sea Grant study.

Results

Surface Sediments. Sediment particle size, redox potential, and pH were measured on the surface sediments of mid-Delaware Bay.
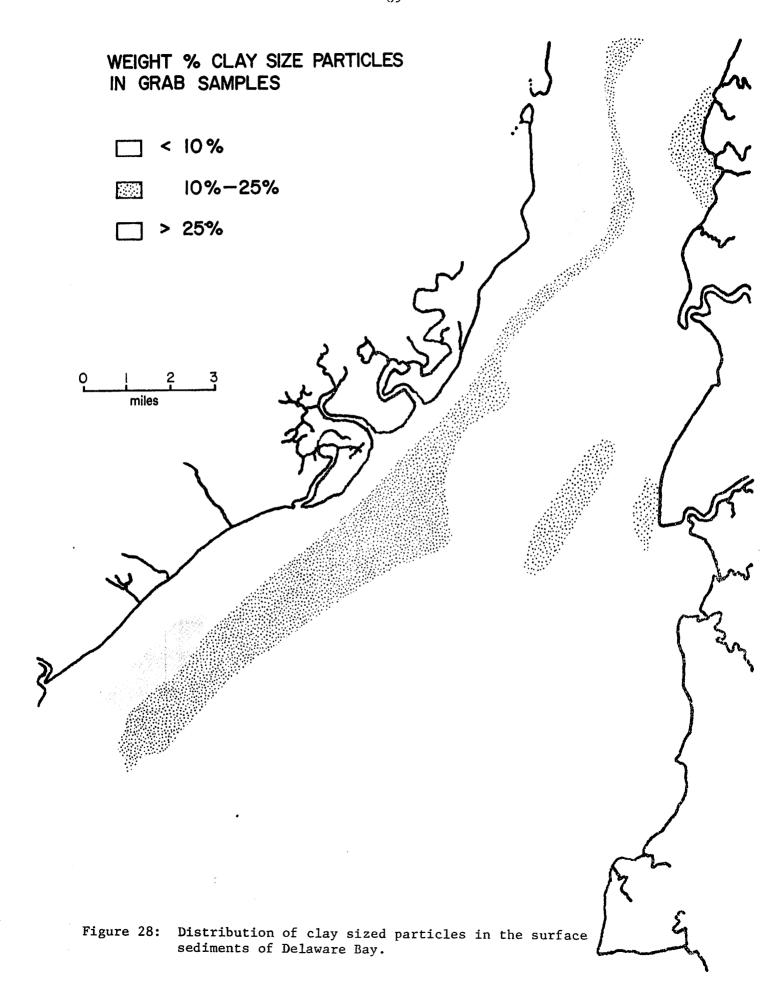
Results of size analysis are presented in Table 10 and are illustrated in Figures 26, 27, and 28. The general distribution of sediment types is clearly illustrated on the drawings. Sands characterize the central portion of the Middle Bay while sediments with large silt and clay components form belts near and parallel to the shores, particularly along the Delaware side. This suggests a silt and clay source along the Delaware shore and/or preferred deposition of fine sediments along the Delaware side. Most of the oyster beds along the Delaware side are positioned on black or gray silty sands or sandy silts.

Redox potential and pH of soils and sediments have been measured by many investigators and have been used to describe composition, chemical reactivity, biological populations, and other properties of recent sediments. Most authors agree that pH and Eh of sediments are primarily a result of the balance between types of bacteria, organic matter, buffering and poising capacity of the sediments and interstitial water and the rate of oxygen diffusion in the pore water. The pH and Eh of Delaware Bay sediments (Figures 29 and 30) are distrubuted in a manner generally correlated with grain size distribution. Lowest pH and most negative Eh values are associated with sediments having a large silt and clay component. Fine grained sediments frequently contain higher concentrations of organic matter than sandier materials, perhaps because deposition of organic matter requires low physical energy environments usually associated with fine grained materials. Fine grained sediments have low permeability and resist diffusion of dissolved oxygen into interstitial waters. Dissolved oxygen is utilized in the pore waters and anaerobic conditions which sulfate reducing bacteria can develop. The relationship between particle size and pH and Eh is valid when viewed on a gross scale (e.g. in the illustrations) but not when examined for regressions, etc. This is because factors (chemical composition, mineral composition, rate of turnover by burrowing organisms, etc.) other than grain size partly control Eh and pH.

If one were to speculate that the Delaware liner supplies the Middle bay with silt and clay size sediment, then the deposition of this fine material is biased toward the Delaware side, perhaps because of the Coriolis effect. If extraneous materials (trace metals, pesticides, etc.) are attached to fine suspended particles, carried downriver, and deposited preferentially on the Delaware shore, then the Delaware side of the Bay is more susceptible to pollution sources from up-river.

WEIGHT % SAND SIZE PARTICLES
IN GRAB SAMPLES

- < 25%
- 25%–50%
- 50%–75%
- > 75%

Figure 26: Distribution of sand in the surface sediments of
Delaware Bay (contour interval, 25% by weight).

Figure 27: Distribution of silt in the surface sediments of Delaware Bay (contour interval 25%, with area less than 10% shown).

WEIGHT % SILT SIZE PARTICLES
IN GRAB SAMPLES

☐ < 10%

▨ 10%-25%

☐ 25%-50%

▧ > 50%

0 1 2 3
miles

WEIGHT % CLAY SIZE PARTICLES
IN GRAB SAMPLES

☐   < 10%

▦   10%-25%

☐   > 25%

Figure 28:   Distribution of clay sized particles in the surface
             sediments of Delaware Bay.

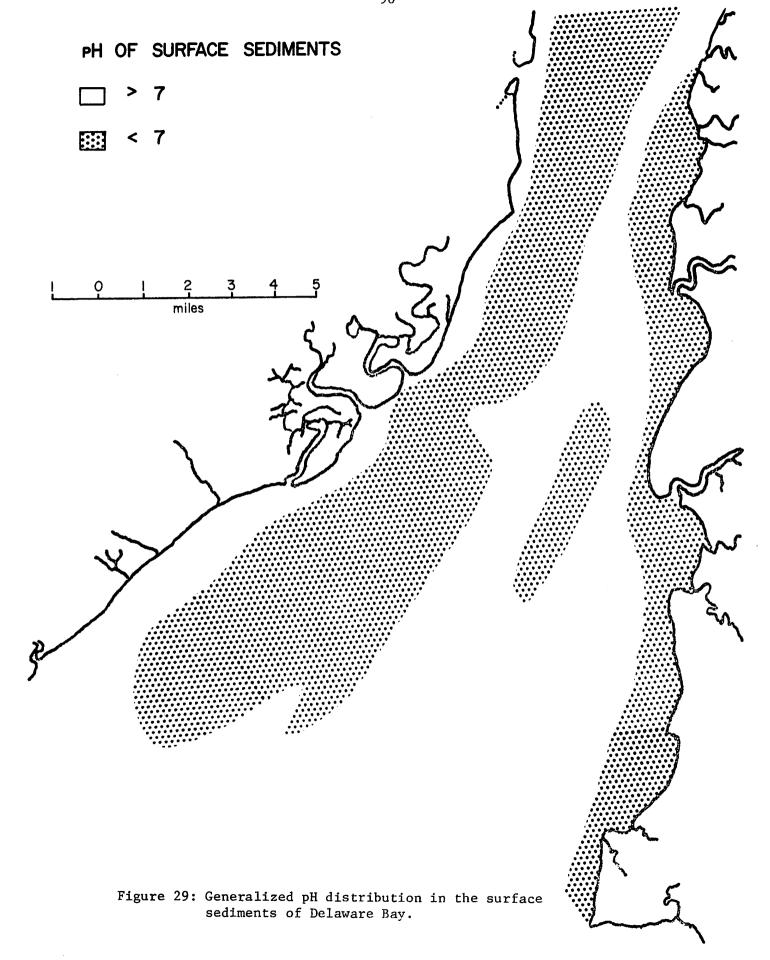Figure 29: Generalized pH distribution in the surface sediments of Delaware Bay.

Figure 30: Generalized Eh distribution in the
surface sediments of Delaware Bay.

Literature Cited

Maurer, D. L., L. Watling, and R. Keck. (1971). The Delaware Oyster
    Industry, A Reality? Trans. Amer. Fish. Soc.; 100 (1):
    100-111.

Moore, H. F. (1911). Condition and Extent of the Natural Oyster Beds
    of Delaware. Bur. Fish. Doc. No. 745:1-29.

4.2. INFLUENCE OF CLIMATIC WATER BALANCE

Dr. John R. Mather   Graduate Students:
Mr. Frank J. Swaye, Jr.   Gary Grunkemeyer
College of Arts and Science   Bruce Hartmann
Department of Geography

Introduction

Climatic conditions over the watershed of the Delaware River directly affect fresh water receipts in the estuary. Thus, they become primary controls of both water quality and quantity in the estuarine system. Understanding the interactions between the elements of the climatic water balance and the resultant conditions in the estuarine environment is of paramount importance in any program seeking to develop desirable marine resources.

The primary objectives of this project have been to utilize available climatic and hydrologic data to: (1) determine the net inflow and outflow of water in the Delaware Estuary during the period 1949 through 1968 and to relate fresh water inflow to specific conductance (chlorinity) levels in the estuary; and (2) determine the effects of changing land use on runoff from a subbasin of the Delaware River.
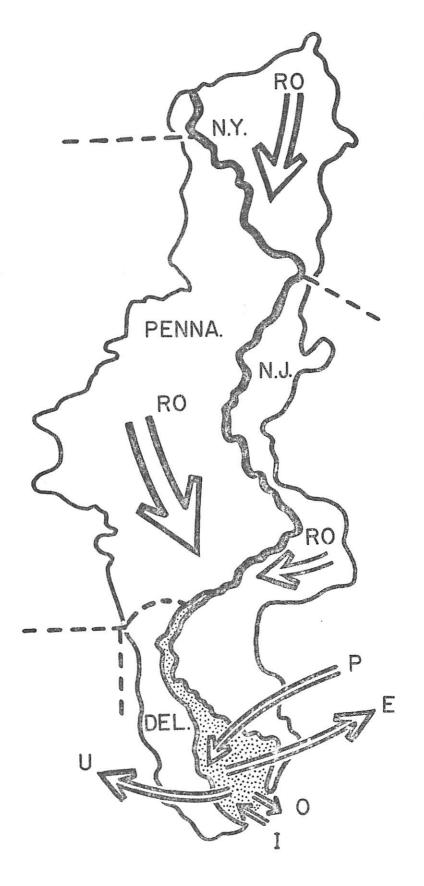
Net Flow and Specific Conductance Variations in the Delaware Estuary

In a coastal estuary, such as that indicated in Figure 31, a simple equation of water flow may be written as:

$$RO + P - E \pm U = I/O$$

RO is runoff from the water shed of the estuary.

P is precipitation onto the estuary surface.

$$RO + P - E \pm U = I/O$$

Figure 31.

E   is evaporation from the estuary surface.

U   is the volume of inflow or outflow through the channel
    bottom.

I/O is the net inflow or outflow of water to or from the
    ocean.

The Delaware River Basin Commission (1970) has estimated
the mean annual outflow at the mouth of Delaware Bay at some 20,200
cubic feet per second from stream gages and extrapolated records.
Carter (1958) had earlier calculated mean monthly outflow on the
basis of average monthly climatic data. The present study has
been more concerned with seasonal, annual, and spatial variations
in inflow and outflow in the estuary on the basis of a more detailed
evaluation of P, E, and RO in the aforementioned equation over a
series of individual years.

Several assumptions and limitations were necessary to achieve
these results. First, values for U in the equation were considered to
be negligible. Second, it was assumed that there were no unmeasured
additions, withdrawals or diversions of water downstream from Trenton,
New Jersey. Third, evaporation from the estuary was assumed to
approximate the potential evapotranspiration as computed from tem-
perature records at perimeter stations.

The net annual and mean monthly outflows at the mouth of
Delaware Bay resulting from these assumptions indicate a progressive
decrease in net annual outflow during the period 1949 through 1968.
Annual fluctuations are evident with a maximum average annual flow
of +30,000 cfs in 1952 and a low of +8,000 cfs in 1965. During the
1950s outflows varied with no distinct trend. Average annual outflow
for the 20-year period was 18,500 cfs, slightly less than estimates
by Carter and the Delaware River Basin Commission. Of a total of
240 months, only July, 1955 recorded a minus value indicating a net
flow of 300 cfs of marine water from the Atlantic into Delaware Bay
for that month. During 17 of 20 years the highest net outflow occurred
in March or April when reduced evaporation, melting snow, and apprec-
iable amounts of precipitation coincide.

Minimum outflows varied widely during the period from July
through October, when high evapotranspiration and low precipitation
combined to reduce runoff. Most years experienced a 10 to 20-fold
difference between high and low flows.

Various combinations of runoff using time lags of from one
to three months to account for the slow flow of water in the estuary
system, were correlated with specific conductance values at four
sampling stations in the estuary – Rudy Island, Delaware Memorial
Bridge, Chester, and the Ben Franklin Bridge. Correlation coefficients

varied little between stations - from -0.932 at Chester, Pennsylvania, to -0.794 at Reedy Island. Highest correlations resulted from a combination of the sum of the past two months' river flow at Trenton, the past two months' runoff from the basins below Trenton, plus the current month's precipitation and evaporation over the estuary.

Monthly runoff for the 1380 square mile area in Delaware and New Jersey seaward of an east-west line at Liston Point, Delaware has also been calculated from 1959 through 1968. All major streams in the area flow directly into Delaware Bay. Runoff ranged from a maximum of 7,600 cfs for February, 1961 to the minimum flow of 13 cfs in December, 1965. The portion of the total fresh water inflow contributed by this area varied from 29.5% (February 1964) to less than 1% (several months). Average annual contributions of fresh water was 8.25% and varied from 5.7% in 1965 to 11.6% in 1967.

Peak discharge periods occurred in February and March almost two months before maximum flows in the basin above Trenton. Thus, the primary impact on the estuary of these tributaries occurs in the late winter and early spring before peak runoff arrives from the upper basin.

According to Ketchum (1952) flow at Trenton is increased some 57% by fresh water runoff from the basin below Trenton. Between 1959 and 1969, however, the flow at Trenton was augmented by only 36%. In that period the portion of the total flow coming from above Trenton ranged from 55% to 72% with an average of 65%. Apparently, in recent years as total flows diminished, the contribution from the upper basin has become more critical to the maintenance of desirable water quality levels in the estuary.

Runoff into Delaware Bay south of Liston Point, Delaware comes from water-sheds in either Delaware or New Jersey. Runoffs from both areas were proportional to the respective areas in each state - Delaware contributed about 44% and New Jersey 56% of the total input below Liston Point.

Effects of Urbanization on Water Yields from the Chester Creek Water-shed in Southeastern Pennsylvania*

One of the subtle effects of urbanization is that of modifying the processes of the hydrologic cycle especially the quantity of runoff from a given area. This phase of the project sought to investigate the long range effect that urbanization has had upon annual water yield from the Chester Creek watershed, a tributary to the

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*This study was carried out by Bruce Hartmann, a graduate student at the University of Delaware. It served as his Master's thesis.

Delaware River in southeastern Pennsylvania. The study covered the
period 1936 through 1968 and utilized the climatic water balance
methodology (Thornthwaite and Mather, 1955) and existing streamflow
records.

The effect of urbanization on water yield was studied by
comparing long term trends of measured and computed annual water
yields. Computed yields were based on actual climatic data for
each year but the water balance model assumed the land usage which
existed in 1957. Thus, later differences between the computed and
measured runoff values must be attributed to later actual changes
in land usage.

Urbanization of the basin increased annual water yield
approximately 0.1 inches (.5%) or about 100,000,000 gallons per
year. From 1936 through 1968, water yield increased 3.13 inches,
or about 17%.

As urbanization continues in the Delaware basin modification
of the landscape may effectively alter the time lag and volume of fresh
water supplied to the Delaware River. The nature of these changes
should be studied in more detail.

Other Investigations

Water temperature, chloride and turbidity data from 1964
through 1970 in the upper estuary have been summarized and maps
(similar to Figures 32, 32A, and 32B) showing the monthly position
of various isochlors between Ship John Light and Philadelphia have
been prepared.

In addition, a permanent station to collect meteorological
data has been established at the mouth of Delaware Bay near Lewes,
Delaware. Solar radiation, precipitation, wind velocity and direction,
air and soil temperatures are continuously monitored.

A detailed Final Report on all project work has been com-
pleted and is being submitted for publication as a monograph.

Conclusions and Results

Results of this study reemphasize that the climatic water
balance approach provides an accurate and useful method to determine
runoff and thus the quantity of fresh water and associated isochlor
movement within an estuarine environment. It also appears that the
climatic water balance approach is a useful tool for evaluating the
impact of urbanization upon the run-off contribution of fresh water
input. Further, significant correlations between time-lagged
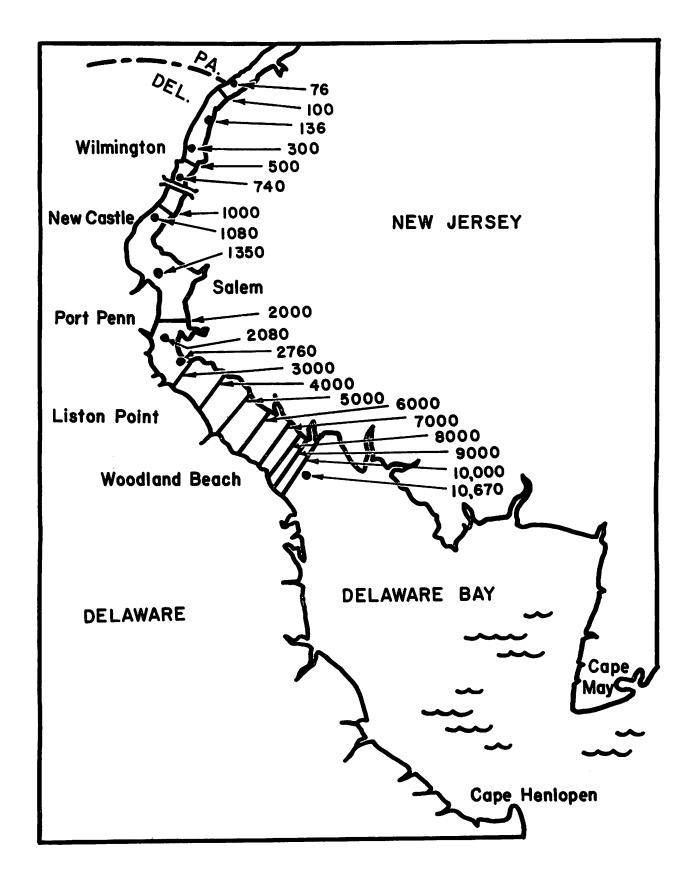
Figure 32: Typical monthly positions of isochlors.
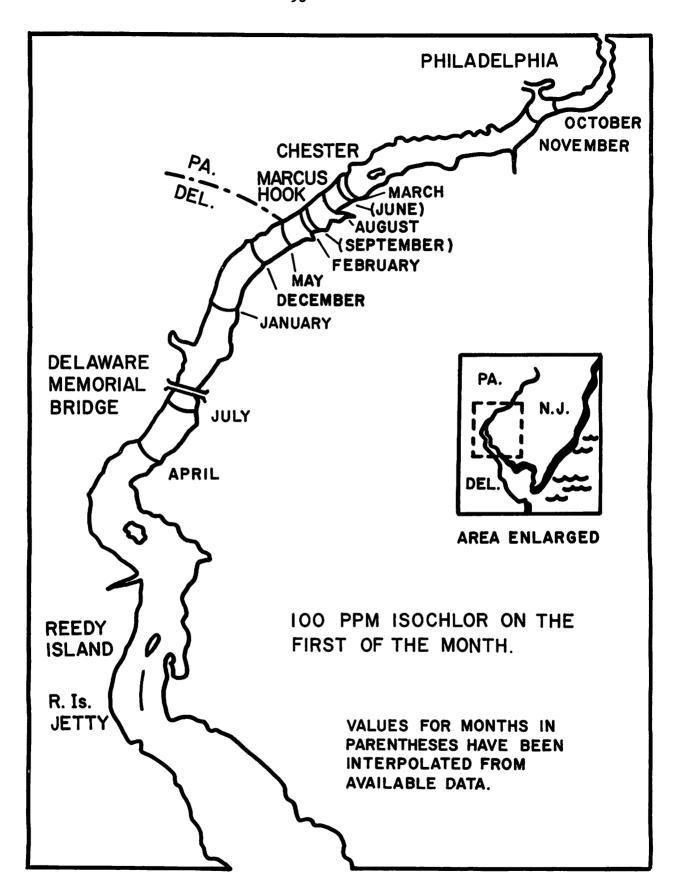
Figure 32A: Typical monthly positions of isochlors.

PHILADELPHIA

CHESTER

PA.
DEL.

MARCUS HOOK

— OCTOBER
— NOVEMBER
— SEPTEMBER

— OCTOBER
— JUNE
— SEPTEMBER & NOVEMBER
— MARCH

DELAWARE MEMORIAL BRIDGE

— AUGUST
— FEBRUARY
— DECEMBER & FEBRUARY

— AUGUST
(JUNE)
— JANUARY & DECEMBER

JULY —
— MAY

JANUARY

REEDY ISLAND — JULY

R. Is. JETTY

PA.
N.J.
DEL.

AREA ENLARGED

———— 500 PPM ISOCHLOR ON THE FIRST OF THE MONTH.

······· 1,000 PPM ISOCHLOR ON THE FIRST OF THE MONTH.

Figure 32B: Typical monthly positions of isochlors.

contributaries to water outflow from the estuary and specific con-
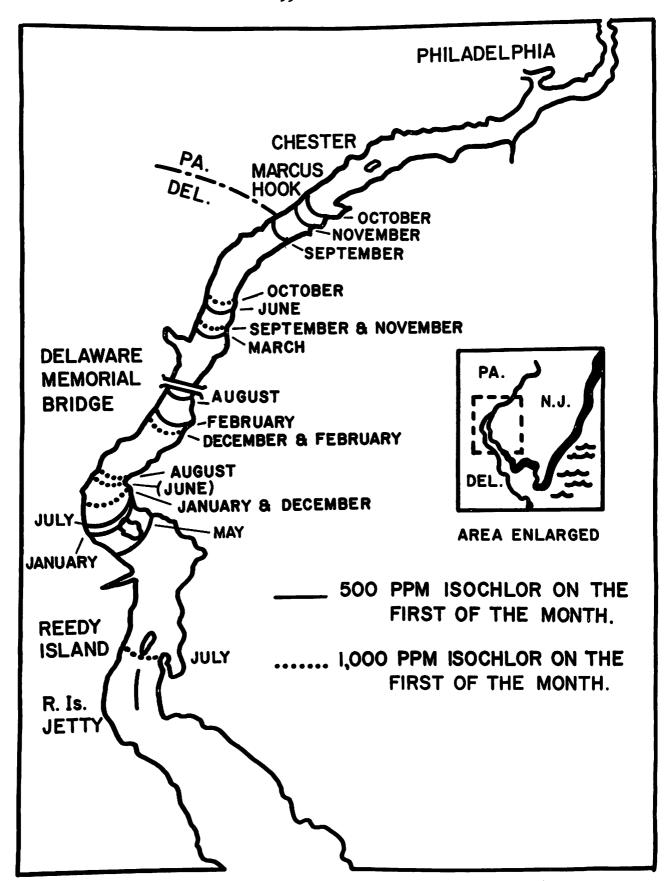ductance within the estuary point up the close relationship between
the water balance and estuarine water quality as influenced by
residence time.

Detailed quantitative values for the outflow of water at
the mouth of Delaware Bay have been computed for a 20-year period.
New distributions of runoff, precipitation, and evaporation within
the total Delaware Basin and various portions of the basin have been
developed providing an improved data base for evaluating other water
flow and quality dependent historical events.

The results indicate the impact and dominance of the Dela-
ware River and its tributaries on the past, present, and future of
the Delaware estuary.

References

Carter, D. B., 1958. The Average Water Balance of the Delaware Basin,
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     XI, No. 3, pp. 249-269.

Delaware River Basin Commission, 1970. Seventh Water Resources Pro-
     gram, Trenton, New Jersey.

Ketchum, B. H., 1952. Distribution of Salinity in the Delaware
     River, Woods Hole Oceanographic Institution, Mass. Ref.
     53-31.

Thornthwaite, C. W., and J. R. Mather, 1955. The Water Balance,
     Publications in Climatology, Laboratory of Climatology,
     Vol. VIII, No. 1, 104 pp.

5.0 EDUCATION AND TRAINING

This program is designed to establish a strong and balanced competence in oceanographic studies by encouraging growth in the areas of ocean engineering and oceanography.

In order to promote a higher level of understanding of the marine environment in the community at large a program to accomplish this has been structured for inclusion in the elementary and secondary school curricula.

5.1 FACULTY IMPROVEMENT

Dr. Frederick E. Camfield
College of Engineering
Department of Civil Engineering

During the past year development continued on the ocean engineering program within the Department of Civil Engineering. One new ocean engineering course was added, Marine Soil Mechanics, bringing the total to seven. In addition a new graduate course, Geophysical Fluid Mechanics, was added. Substantial revisions were also made to the courses previously originated under this program in a continued improvement of the program.

Enrollment in the courses varied from 4 to 16 students. This included undergraduates taking elective courses in the area of ocean engineering, and graduate students taking ocean engineering either as a major or a minor subject area within the existing degree program. Five students completed masters degree programs with thesis topics in the area of ocean engineering, and another two students with thesis topics in this area are continuing into the next school year. Five new graduate students are entering the program this year.

In addition to the curriculum, continued improvements have been made to the space and equipment available for this program. A new suite of offices in DuPont Hall has allowed the consolidation of ocean engineering faculty in one location. Continued efforts have also been made to add additional laboratory space, and an additional room has been obtained for this purpose in the general vicinity of the faculty offices.

A new wave channel, 80 feet long by 2 feet wide by 4 feet
high was added to the department's laboratory facilities during the
year. Some wave generating equipment was also ordered for the larger
120 feet long by 8 feet wide by 4 feet deep wave and towing tank.
Work is continuing on the development of these and other facilities.

5.2 MARINE ENVIRONMENTAL CURRICULUM STUDY

Dr. James P. Schweitzer
College of Education

Introduction

The long term Sea Grant program objective of marine re-
source development makes it appear advantageous to promote a gener-
ally higher level of understanding of the marine environment in the
community at large. It has been the objective of this study to
structure such a program for inclusion in the elementary and secondary
school curriculum.

An initial premise in the evolution of the concept has been
that the objective can best be accomplished by focus and enrichment
within the context of existing requirements for education in basics,
rather than by creating competitive educational opportunities of
principal value to small special interest groups. Put in other words,
improved perception of the marine environment with associated atti-
tudinal changes on a large scale is preferred to a more limited scale
of special knowledge acquirable through elective courses.

Results and Conclusions

The basic framework for two conceptual schemes was com-
pleted based upon the following specifications:

1. The conceptual scheme should consist of an expanded outline
   of marine and wetland related concepts and subconcepts
   appropriate to all disciplines for study in the K-12 school
   program. Equal application of subconcepts is not necessary
   at all grade levels. Thus, a geography teacher should be
   more concerned with a definition of the territorial limits
   of coastal nations than would a physics teacher. However,
   when dealing with topics in physics, the primary youngster
   should understand, for example, that the earth receives

energy from the sun, while a treatment of the earth's solar constant would be appropriate for a much older child.

2. Each of the concepts should be expanded and subdivided until it results in a teachable subconcept. The variability of sill-depth in time and place is a concept that allows wide teaching opportunities. That the sill-depth of the Bering Strait is 55 m is a fact and is not teachable.

3. The scheme should identify concepts that have immediacy and relevance for the student. Wherever possible, illustrative materials for concept attainment should be drawn from familiar surroundings, but it will also be necessary to expand the geographic concepts of students in order to establish the marine environment as part of the earth's natural system.

4. The scheme and its suggested learning activities should present evidence that will support intelligent, nondestructive attitudes regarding the marine and wetlands environments. Since teachers will be important in effecting these attitudinal changes, the Marine Environment Curriculum Study must provide whatever assistance they may need.

5. The scheme should show that the ocean-atmosphere-land interaction is a singular system of which man is a part and that the system is magnificent in scope, wondrous in variety and detail, but has its limitations.

Both schemes contain essentially the same concepts and subconcepts; they differ in organization. Table 11 presents the first level in the hierarchy of information content for both approaches, side by side to facilitate comparison. The principal difference between the two approaches lies in the way in which basic concepts concerning energy-oceanic-atmospheric-land interrelationships and dependencies are presented. In this context the second of the two approaches contains considerably more technical detail. The final selection of the conceptual scheme for further development has not yet been made.

The development of rough conceptual schemes has facilitated the preparation of a twelve item questionnaire to be used as a measuring instrument to assess the status of marine environment attitudes in Delaware school children. A 30 item cognitive measure questionnaire has also been developed to aid in the evaluation of the instructional program. Further development of evaluation techniques will be the subject of later efforts, particularly those designed to identify the relationship between actions and verbalized understanding.

Teacher training has progressed in parallel with the other program development efforts. During the regular academic year, thirty

Table 11

MARINE ENVIRONMENT CURRICULUM STUDY

Proposed Conceptual Scheme

Approach #1	Approach #2
I. The earth is unique in the solar system in that it can support and sustain complex life systems.	I. The earth is unique in the solar system in that it has an abundance of surface water.
II. Stable, life-supporting conditions on earth result largely from dynamic processes in the marine and wetlands environments.	II. Dynamic processes in the marine environment are powered by solar energy.
III. The marine environment has influenced human society.	III. The marine environment is much affected by land-ocean interactions.
IV. The activities of man are affecting the marine environment in a variety of ways.	IV. The marine environment has influenced the development of life on earth.
	V. The marine environment has influenced human society.
	VI. The activities of man are affecting the marine environment.

teachers participated in two seminar courses in marine environment education. An intensive summer institute was attended by 18 teachers. Activities included instruction, field trips, and the preparation of learning activities appropriate for use by teachers.

A bibliography of popular books on marine-related topics was edited and published. This 24-page booklet contains annotations and prices, and is a valuable purchasing guide for teachers and librarians. Several hundred books and other material serving as the primary resource material for the Marine Environment Curriculum Study were reviewed and/or ordered for the resource center being developed at the University. Also, work was initiated on compiling a national directory of teachers and schools involved in K-12 marine science education.

6.0 SEA GRANT MARINE ADVISORY FIELD SERVICE PROGRAM

Dr. Samuel M. Gwinn   Dr. Kent S. Price
College of Agricultural Sciences   College of Marine Studies

The efforts of this group were directed toward the practical utilization of new and improved techniques by the user in the field, as well as the encouragement of innovative and sound operating methods by involved business and industry.

To encourage growth in marine related activities, lectures, slide presentations and demonstrations have been given covering the work done at the Shellfish Laboratory at Lewes, the local marine environment (Lewes), and the ocean and its environment.

Introduction

Perhaps the most pressing problem of the University's newly established Marine Field Service is to make the public aware of its presence and its potential to serve. Two marine extension agents (one agent was hired October 1, 1970 and the other January 1, 1971) were primarily responsible for this activity. The dissemination of information was accomplished with brief lectures, slide presentations, and visits to a demonstration area located in the Shellfish Laboratory that shows actual research conditions and results. Presentations were made to 3,500-4,000 school students and at least another 1,000 people from various service groups, government units and laymen from Delaware and Pennsylvania. Another innovation was a summer lecture series, consisting of five lectures about the local marine environment and directed at the lay permanent and vacationing public. Hopefully, this will be a continuing series as the results from this first attempt were most gratifying.

By visits to other states with established marine extension programs, the agents became familiar with extension problems and solutions in other areas that gave them further insight into their own situation. It also served to acquaint them with many other agents and opened reliable channels of information which should prove invaluable.

Through the efforts of the agents and SODA (Stop Offshore Dumping Association) a Senate Subcommittee on Water Pollution met at Rehoboth Beach, Delaware, in 1971. Although the results were less than positive, the public was made aware of the many facets of water pollution and the consequent shellfishing restriction placed on 120 square miles of Delaware Bay.

An attempt has been made to reach the commercial fishermen in the areas, learn of their grievances and problems, and act as

liaison for them with the proper governmental agencies and the University. Both the commercial clammers and lobstermen have proposed rule and regulation changes to the Department of Natural Resources with the help of our agents. The Bureau of Commercial Fisheries sent a diver to accompany one from the Department of Natural Resources and our extension agent to examine the condition of the natural oyster beds located in Delaware; this information should prove most helpful in keeping oystermen advised of the beds' rehabilitation. The Marine Field Service plans to issue a newsletter or bulletin in order to make the commercial fishermen aware of the practical applications of current research, the problems of others in their field and possible solutions, and to serve as a liaison with industry. The Service is also planning to issue a fishing guide of Delaware Bay for sports fishermen, in the coming year. Contacts have been made with Technical Services of the State Division of Fish and Wildlife who have agreed to initiate various aids for the fishermen, a few of which include new legislation, changes in catch limits and state supported programs. The Lewes agent has been working closely with an organized group of sport fishermen on the design and construction of an artificial underwater reef for the enhancement of local fishing.

Several informal research projects arose during the past year which involved the extension agents. A project is in the planning stage for submission to the Environmental Protection Agency to determine the feasibility of turning a waste product from a commercial surf clam industry into a useful, saleable product.

A number of fish "kills" occurred in the lower Delaware area that caused considerable public concern; there were many calls and an informal investigation was conducted to determine the cause. It was felt that the "kills" were the result of a natural occurrence and because of the scope of the inquiries, attempts were made to reassure the public. This effort appeared to be successful.

Although many of these projects are still in the formative stages, the general feeling received from public response is one of imminent success.

7.0 SEA GRANT PROGRAM MANAGEMENT

Dr. William S. Gaither
Sea Grant Program Director
College of Marine Studies

Mr. Joel M. Goodman
Deputy Sea Grant Program Director
College of Marine Studies

During the course of the program year a Sea Grant management concept evolved which contained the following elements.

1. The conduct of periodic technical reviews of ongoing projects by an interdisciplinary group in order to broaden the investigator's outlook and identify potential project interactions.

2. The conduct of program development reviews by members of the community of users and institutional participants in order to provide the program directorate with relevance and prioritization guidance.

3. The restructuring of program content along functional rather than disciplinary lines, and the appointment of Functional Group Directors responsible for group coordination and the development of new project ideas.

The exercise of new management initiatives led to three project decisions. First, funds were allocated for long lead time procurements in support of the Mariculture Demonstration Program to be initiated in FY 72. Second, funds were allocated to initiate investigations into concepts of process control of value to closed cycle mariculture. Third, research was undertaken to examine the selective absorption of toxicants in clam tissue. The results of this last effort appears in the following project report.

7.1 SELECTIVE ABSORPTION OF TOXICANTS IN CLAM TISSUE

Dr. Richard A. Nystrom
College of Arts and Science
Department of Biological Sciences
  Marine Biological Laboratory
  Woods Hole, Massachusetts

Graduate Student:
David P. Hamilton

Introduction

A common assumption is that insecticides, hydrocarbons, and other pollutants currently appearing in the waters bathing clam beds of commercial importance have an immediate and persistent deleterious effect upon clams. Previous investigations on the pharmacological modification of neural control of smooth muscle of the surf clam and the quahog suggested a functional barrier to the free diffusion of drug molecules at the surfaces of the exposed tissues. The implication of a diffusion barrier is that these organisms may be more resistant to acute chemical alteration of their environments than commonly supposed.

Summary of Research

The action of the pesticide Malathione (Ortho) (and, in a few cases, DDT, Eastern Scientific) was compared with those of MS222 and tetrodotoxin (nerve blockers), acetylcholine and 5-hydroxytryptamine (potential neurotransmitters), and physostigmine (anticholinesterase) on the mechanical (and, in a few cases, electrical) activity of the nonstriated muscle tissue in isolated parparations of rectum, esophagus, mantle, foot, and heart of the surf clam Spinsula solidissima. Mechanical parameters included rate and tone of spontaneous contractions and threshold and size ratios of phasic and tonic contractions during stimulated activity. The preparations were mounted between transducers at lengths and resting tensions equivalent to those found in vivo; they were kept submerged in a bath of aerated sea water (containing test substances) maintained at room temperature (20-25°C). Analysis of existing data shows that both Malathione and DDT, in all cases where effects were noted, produced their effects within 5 minutes of application. This is in contrast to the longer times noted following application of the pharmacological agents listed above. If these tissues possess a functional barrier to free diffusion of small molecules across their surfaces, as suggested by the previous experiments with the pharmacological agents, which are all charged molecules, these two nonpolar pesticides penetrate it freely.

Malathione generally enhances the quick phasic contractions during either spontaneous or stimulated activity. These contractions become greater in amplitude, shorter in duration (suggesting an improved coordination among the muscle cells in the population composing the tissue), and occur more frequently. The clam heart, however, is inhibited by Malathione. DDT, in the limited cases examined, appears to have similar actions. Most experiments which evoked dramatic changes in contractile activity occurred in baths containing approximately 10^{-5} moles/liter Malathione or more. The concentration around the affected cells is undoubtedly less than this because of the limited solubility of Malathione in aqueous media. These pesticides also

shortened the lifespans of the isolated preparations. For example, a heart in a bath containing 10^{-5}M DDT stopped irreversibly within an hour while its control partner continued to beat 24 hours later. The action of Malathione paralleled, but with more pronounced effect, that of physostigmine and it is generally considered to be an anticholinesterase agent. These data suggest that the pharmacological effects produced by Malathione and DDT will disrupt normal functions of these organs in an intact clam. It can be predicted that concentrations of these pesticides in the sea water around clam beds that are equivalent to those used in these experiments will have such an immediate deleterious effect upon several vital organs as to seriously impair the viability of that clam population.

NATIONAL SCIENCE FOUNDATION Washington, D. C. 20550	RESEARCH GRANT BUDGET & FISCAL REPORT	Form Approved Budget Bureau No. 99-R0013

Please read instructions on reverse side carefully before completing this form.

INSTITUTION AND ADDRESS	NSF PROGRAM	REPORTING PERIOD
University of Delaware Newark, Delaware	Sea Grant Programs	FROM 9/1/71 THRU 11/30/71
	PRINCIPAL INVESTIGATOR(S) Gaither	[X] FINAL REPORT [ ] INTERIM REPORT (See Instructions)

Grantee Account Number	GRANT NUMBER GH-109	DURATION 1 Year	GRANT AMOUNT $ 449,900

A. SALARIES AND WAGES	NSF Funded Man Months			NSF GRANT BUDGET	GRANTEE CUMULATIVE EXPENDITURES Do Not Round
	Cal.	Acad.	Summ.		
1. Senior Personnel				$	
a. ___ (Co)Principal Investigator(s)	79	21	2	131,716	
b. 39 Faculty Associates				131,716	
Sub-Total					$ 91,375.07
2. Other Personnel (Non-Faculty)					
a. ___ Research Associates—Postdoctoral					
b. 14 Non-Faculty Professionals	23		1	29,940	
c. 10 Graduate Students				38,650	
d. 4 Pre-Baccalaureate Students				4,000	
e. 13 Secretarial—Clerical				22,565	
f. 12 Technical, Shop, and Other				38,620	
TOTAL SALARIES AND WAGES				265,491	240,053.68
B. FRINGE BENEFITS When Charged as Direct Cost					---
C. TOTAL SALARIES, WAGES, AND FRINGE BENEFITS (A+B)				265,491	240,053.68
D. PERMANENT EQUIPMENT				13,855	31,688.59
E. EXPENDABLE EQUIPMENT AND SUPPLIES				14,032	37,223.30
F. TRAVEL 1. Domestic				17,060	19,902.79
2. International					---
G. PUBLICATION COSTS				7,500	---
H. COMPUTER COSTS When Charged as Direct Cost				6,070	933.50
I. OTHER COSTS (Itemize)					
*See Attached Sheet				18,542	22,814.48
J. TOTAL DIRECT COSTS (C through I)				342,550	352,616.34
K. INDIRECT COSTS **See Attached Sheet See "Remarks" below				107,385	97,283.66
L. TOTAL COSTS (J plus K)				449,935	449,900.00
M. TOTAL BUDGET ROUNDED—AMOUNT OF AWARD				449,900	
N. UNEXPENDED BALANCE (M. budget minus L. expenditures)					- 0 -
O. COST SHARING—GRANTEE PARTICIPATION				$ 241,183	$ 241,394.07

REMARKS: Use extra sheet if necessary

$101,775	X	68.2%	=	$ 69,411
37,000	X	50.5%	=	18,685
45,591	X	34.0%	=	15,501
18,940	X	20.0%	=	3,788
$203,306				$107,385

William S. Gaither
Dean, College of Marine Studies

I CERTIFY THAT ALL EXPENDITURES REPORTED ARE FOR APPROPRIATE PURPOSES AND IN ACCORDANCE WITH THE AGREEMENTS SET FORTH IN THE APPLICATION AND AWARD DOCUMENTS

SIGNATURE OF AUTHORIZED OFFICIAL	TYPED OR PRINTED NAME & TITLE Henry J. Sawoska, Jr., Manager, Contract/Grant Acctg.	DATE Feb. 1972

FOR NSF USE ONLY

Org. Code	F.Y.	Fund ID	Prog. Code	Obj. Class O/D res.	Award No.	grad.	Inst. Code	Unexpended Balance	Trans.	Lot
				41				$		

*Other Costs

Rigging Equipment	$ 642.80
Communications	683.12
Central Duplicating	1,421.90
Photographic Services	607.25
Physics Shop	596.55
Analysis	3,662.06
Equip Mariculture Lab	15,200.80
	$ 22,814.48

**Indirect Costs

Salaries & Wages		O/H Rate	Overhead
$ 92,526.49	x	68.2%	$ 63,103.07
27,834.84	x	51.5%	14,334.95
48,800.92	x	34.0%	16,592.32
12,247.00	x	20.0%	2,449.40
2,934.00	x	27.4%	803.92
$ 184,434.25			$ 97,283.66

SEA GRANT