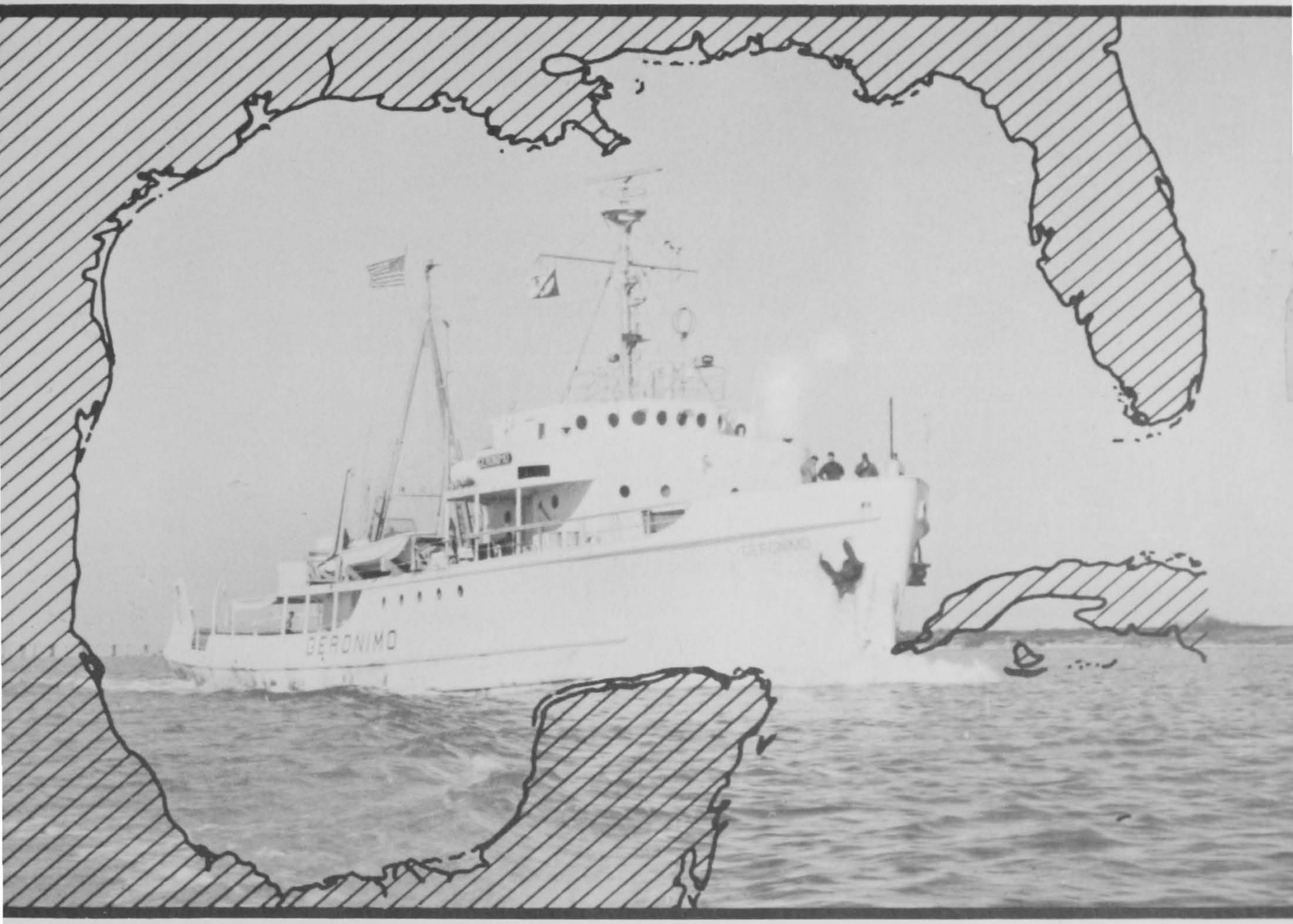
R. L. BURGNER

REPORT OF THE BUREAU OF COMMERCIAL FISHERIES BIOLOGICAL LABORATORY, GALVESTON, TEXAS, FISCAL YEAR 1968



UNITED STATES DEPARTMENT OF THE INTERIOR
U.S. FISH AND WILDLIFE SERVICE
BUREAU OF COMMERCIAL FISHERIES

Circular 295

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REPORT OF THE BUREAU OF COMMERCIAL FISHERIES BIOLOGICAL LABORATORY, GALVESTON, TEXAS,

Fiscal Year 1968

Milton J. Lindner, Director
Robert E. Stevenson, Assistant Director

Contribution No. 286, Bureau of Commercial Fisheries
Biological Laboratory, Galveston, Texas 77552

Circular 325

Washington, D.C.
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The Bureau of Commercial Fisheries Biological Laboratory, Galveston, Tex., and its field station in Miami, Fla., conduct fishery research in the Gulf of Mexico as part of the work of the Bureau's Gulf and South Atlantic Region (Region 2), which comprises the eight coastal States from North Carolina to Texas.

Office of the Regional Director, Seton H. Thompson, is in the Federal Office Building, Room 668, 144 First Avenue South, St. Petersburg, Fla. 33701.

Biological Research:

Biological Laboratory, Beaufort, N.C.
Radiobiological Laboratory, Beaufort, N.C.
Biological Laboratory, Brunswick, Ga.
Biological Laboratory, Galveston, Tex.
Tropical Atlantic Biological Laboratory, Miami, Fla.
Biological Laboratory, St. Petersburg Beach, Fla.
Biological Field Station, Gulf Breeze, Fla.
Biological Field Station, Miami, Fla.

Industrial Research:

Exploratory Fishing and Gear Research Base, Pascagoula, Miss., auxiliary base at St. Simons Island, Ga.
Marketing--Marketing offices in Atlanta, Ga.; Dallas, Tex.; Pascagoula, Miss.; and St. Petersburg, Fla.
Technology--Technological Laboratory, Pascagoula, Miss.

Resource Development:

Loans and Grants office, St. Petersburg, Fla.
Statistical Center and Market News office, New Orleans, La.

CONTENTS

REPORT OF THE BUREAU OF COMMERCIAL FISHERIES BIOLOGICAL LABORATORY, GALVESTON, TEXAS,

Fiscal Year 1968

ABSTRACT

Progress of research is reported. Emphasis is on shrimp, and the research involves the fields of biology, population dynamics, ecology, and oceanography.

REPORT OF THE DIRECTOR

General

Several programs at this Laboratory were reorganized during the year. We consolidated the Experimental Biology Program with the Shrimp Biology Program, and directed the combined effort of both groups toward the problem of raising shrimp (mariculture). The project, "Larval Distribution and Abundance," previously in the Shrimp Biology Program, was transferred to the Gulf Oceanography Program and entitled "Biological Applications." In the Estuarine Program, two projects were consolidated into one in an effort to utilize their resources more efficiently.

On March 14, 1968, the BCF (Bureau of Commercial Fisheries) R/V Geronimo was deactivated. The vessel, assigned to this Laboratory the first of fiscal year 1967, completed five oceanographic cruises throughout the Gulf this year. In addition to regular oceanographic studies, the vessel also was used to provide "ground truth" (obtaining hydrographic measurements in the area photographed) while photographs of the Gulf of Mexico were taken from Gemini spacecraft.

Research objectives of our four programs are diversified but are designed primarily to obtain a better understanding of shrimp stocks in the Gulf of Mexico. Because the leaders of these programs have summarized research accomplishments of the past year, a review of their work is not provided in this section. Summaries are provided at the beginning of each program discussion.

Laboratory Facilities

A transfer of land (0.8 acre) and building (3,360 square feet of floor area) from the U.S. Air Force to the U.S. Department of the Interior was completed in July by the General Services Administration. The building had been vacant for 2 years. Our maintenance force renovated and redecorated the interior to house the Gulf Oceanography Program.

Plans and specifications for rehabilitating the exterior of all buildings were completed by the U.S. Army Corps of Engineers District Office in Galveston, Tex., and a contract was awarded to a local firm. Work should begin immediately and be completed on or about December 31, 1968.

Our two, 1/8-acre shrimp-culture ponds at the East Lagoon Laboratory were divided into four equal units, and an additional pond was constructed to provide five ponds for the next phase of our shrimp-culture work.

Public Relations

This year nearly 800 people visited our Laboratory. Represented in this group were Federal and State agencies, private industries, foreign countries, universities, high schools, and grade schools. In response to this interest, we provided Laboratory tours, field trips, training sessions, private consultations, and lectures.

Of the 800 visitors, 27 were from 14 foreign countries. These countries and the number of representatives are listed below:

Australia (2)	Nigeria (1)
Brazil (6)	Philippines (1)
East Pakistan (1)	Portugal (2)
El Salvador (1)	Portuguese East Africa (1)
England (1)	Scotland (1)
Honduras (1)	Taiwan (1)
Japan (1)	
Mexico (7)	

Laboratory Activities

On August 4, 1967, staff members were highly honored with the visit of Vice-President Humphrey. Other distinguished visitors in the Vice-President's party included: Congressman Jack Brooks; County Judge Ray Holbrook, Galveston; and Earl Rudder, President, Richard Geyer, Department of Oceanography, and Horace R. Byers, Dean, College of Geo-Sciences, Texas A&M University. Vice-President Humphrey was welcomed by BCF Laboratory Director, Milton J. Lindner; Assistant Laboratory Director, Robert E. Stevenson; Administrative Officer, Raymond H. Niblock; and Director of the Texas A&M University Marine Biological Laboratory, Sammy Ray. Milton Lindner gave a short briefing on shrimp and shrimp culture after which the party proceeded to the Recirculating Sea-Water Laboratory where Harry L. Cook demonstrated techniques of rearing larval shrimp.

Eleven staff members discussed research findings and the Laboratory's role in fisheries before school and civic groups. In addition, Stevenson, Richard J. Berry, Richard A. Neal, and Charles R. Chapman presented papers at scientific meetings.

Lindner traveled to Mexico City as a member of the U.S. Delegation for the Second Meeting of Governments to negotiate the continuance of United States traditional fisheries off coasts of Mexico. He also participated as a member of the team that made a site visit to the Texas A&M University campuses in connection with Sea Grant Institutional support, after which the team traveled to Galveston to visit the Texas A&M Marine Laboratory and this Laboratory.

Lindner, Stevenson, and Program Leaders presented a public services information program to the Galveston Chamber of Commerce. The program consisted of a Seminar on the Structure and Function of the BCF Biological Laboratory.

Stevenson attended the International Meeting, 100th Anniversary of Norddeutsche Seewarte, Hamburg, West Germany, and presented a paper entitled "The Ocean and Its Atmosphere as Seen From Gemini Spacecraft." In addition, he completed a lecture tour in Germany sponsored by the U.S. Information Service. On the tour, Stevenson gave lectures concerning the aforementioned paper in seven German cities. More than 1,000 German scientists, students, and interested citizens heard his presentations.

Berry acted as a consultant and judge for the Graduate Systems Engineering Course at Texas A&M University, College Station, Tex., during the spring semester.

Chapman left on a year's training assignment with the BCF Branch of Shellfisheries, Washington, D.C.

Library

The statistical summary of the library collection (table 1) shows that 394 volumes of books and continuations as well as 2,735 reprints and miscellaneous publications were added during fiscal year 1968, making a total collection of 29,512 items.

Table 1.--Statistical summary of library collection, 1967-68

Item	On hand 1967	Additions 1968	On hand June 30, 1968
	Number	Number	Number
Books	3,108	187	3,295
Journals (bound)	717	9	726
Journals (unbound)	2,076	198	2,274
Reprints	4,002	413	4,415
Publications from State and foreign offices, etc.	14,814	2,206	17,020
Other	1,666	116	1,782
Total items	26,383	3,129	29,512

During the year the use of the library facilities by other institutions and offices increased. Users have included the faculty and students of the Texas A&M Marine Laboratory and other educational institutions in the area as well as personnel of the Texas Parks and Wildlife Department.

In addition to routine activities, work continued on the preparation of indexes needed for reference use. Also, selected publications no longer needed are being transferred to other laboratories. The list of library acquisitions continued to be distributed to the Laboratory staff and other laboratories.

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A method of rearing penaeid shrimp larvae for experimental studies. Proceedings of the World Scientific Conference on the Biology and Culture of Shrimps and Prawns. FAO (Food Agr. Organ. U.N.) Fish. Rep. (10 MS. pp., 2 figs.).

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SHRIMP BIOLOGY PROGRAM

This year we began investigating factors that we consider essential to the commercial culture of shrimp. A prototype hatchery was established with one 1,700-liter (450-gallon) and four 940-liter (250-gallon) tanks. In the first experiment with this equipment, 220,000 brown shrimp were reared to postlarvae. One of the highlights of the year was the shipment of 80,000 of these postlarvae to the Louisiana Wild Life and Fisheries Commission Laboratory at Grande Terre, La., where they were stocked in ponds. Also, for the third straight year we were able to grow shrimp rapidly in ponds that had been fertilized, but to which no supplemental food was added.

Two major problems still remain. The first is to develop an artificial food that will support rapid growth of dense populations of subadult and adult shrimp in ponds. The second is to induce adult shrimp to develop to sexual maturity and reproduce in captivity. Once this has been accomplished we will try to develop techniques for regulating sexual development so that the time of spawning can be controlled. We already have made some progress on the development of a suitable food, but during the coming year, the major effort of the Food and Artificial Environment Project and the Adult and Juvenile Culture Project will be directed specifically toward this objective.

Personnel in the Florida Bay Ecology Studies Project completed an extensive ecological survey of Florida Bay and the Florida Keys.

Harry L. Cook, Acting Program Leader

Larval Culture

Hatchery facilities for rearing larval shrimp were modified the past year, and four 940-liter (250-gallon) tanks were added as rearing containers. In our first experiment with the new tanks and the 1,700-liter (450-gallon) tank, an estimated 220,000 brown shrimp were reared to postlarvae. The hatch was poor--we think because of the low salinity of 27 p.p.t. (parts per thousand). Of these larvae that did hatch, survival from first nauplius to first postlarva was 70 to 88 percent. The largest number of postlarvae reared in one 940-liter tank was 61,000. We established that it was not necessary to change the water during the culture or to filter the water when the larvae were in the mysis stage.

We shipped about 80,000 postlarvae to Louisiana where they were placed in ponds at the State of Louisiana research facility at Grande Terre Island. For shipment, postlarvae were placed in water in plastic bags; the bags were then filled with oxygen, sealed, and placed in styrofoam boxes. These boxes (5,000 to 10,000 postlarvae per box) were then sealed. The Louisiana Wild Life and Fisheries Commission flew the postlarvae to Louisiana in one of their planes, and although the postlarvae were boxed for about 6 hours, mortality was less than 1 percent.

We completed an experiment to determine the effects of different temperatures on survival of brown shrimp larvae. Four temperatures were tested at a salinity of 30 p.p.t. The tolerance of the larvae appeared to vary considerably between stages; nauplii survived best at 24° C. (75.2° F.), and as the shrimp became older, i.e., protozoeae and myses, survival usually increased with an increase in temperature (table 2).

We completed two feeding experiments with brown shrimp larvae this spring. In one, protozoeae were fed four kinds of algae as well as a mixture of the four types. Algae used were *Cyclotella nana*, *Isochrysis galbana*, *Skeletonema costatum*, and *Thalassiosira* sp. *Skeletonema* was fed at rates of 500, 1,000, and 1,500 cells per milliliter, and numbers of the other algae used were adjusted to concentrations that gave cell volumes equal to those of the *Skeletonema*. Even the highest concentrations of algae apparently were too low, and all larvae died. We were, however, able to draw some tentative conclusions as to the relative value of the different algae from the lengths of time the larvae survived and the stage of development attained (table 3). *Isochrysis galbana* was the poorest food; the mixed algae and *Thalassiosira* were best.

In a second feeding experiment, first myses were fed newly hatched *Artemia* nauplii. Those fed at a rate of three nauplii per milliliter of water had an 82-percent survival and consumed an average of 18 *Artemia* per day. Those fed at the rate of five *Artemia* per milliliter of water had only 65-percent survival but consumed about 70 percent more *Artemia*. The groups took the same time to reach the first postlarval stage.

We also cultured stone crabs (*Menippe mercenaria*) from eggs deposited in a 378-liter (100-gallon) tank. On the first day after hatching, the larvae did not appear to feed on *Artemia* nauplii, so we fed them algae. By the

Table 2.--Percentage survival of brown shrimp larvae at selected temperatures

Temperature		Nauplius I to protozoea I	Protozoea I to mysis I	Mysis I to postlarva I
°F.	°C.	Percent	Percent	Percent
68.0	20.0	7	0	88
75.2	24.0	84	63	93
82.4	28.0	44	73	94
89.6	32.0	28	68	98

Table 3.--Survival and stage of development attained by brown shrimp protozoeae fed selected algae

Algae fed	Survival time	Stage of development attained 1/
	Days	
Isochrysis galbana	2	PI
Cyclotella nana	3	PI
Skeletonema costatum	4	PI
Mixture	4	PII
Thalassiosira sp.	5	PII

1/ PI is first-stage protozoeae.
PII is second-stage protozoeae.

second day, however, they appeared stronger, and brine shrimp nauplii were added. Both foods were fed throughout the remainder of the larval stages. Temperature ranged from 23° C. (73° F.) to 24° C. (75° F.), and salinity from 20.5 to 18.4 p.p.t.

The survival of the crabs in the zoeal stages was high but decreased during the megalops stage because of cannibalism. When the megalops were placed in a tank with an abundant growth of attached algae, they hid in the algae, thus reducing mortality. The young crabs would not feed on fish meal but would eat shredded fresh shrimp. The larval stage lasted about 1 month, and at the end of 2 months we had an undetermined number of crabs whose size ranged up to 10 mm. (0.5 inch) carapace width.

A small greenhouse built for the mass culturing of algae used to feed larval shrimp enabled us to begin research to find a satisfactory enrichment for growing algae in large cultures in natural sea water. We are currently investigating three methods of mass culture: (1) inducing blooms of naturally occurring phytoplankton in sea water that has been screened, but not filtered; (2) inoculating filtered and enriched sea water with several diatoms that have differing physiological requirements; and (3) making assays with several diatoms and various combinations of additives before we inoculate the large tanks.

Because of past difficulties in culturing algae in enriched sea water, we completed a series of experiments to determine if a medium made with artificial sea salts could be used. Instant Ocean[1] sea water supported growth of Skeletonema when supplemented with Tris buffer, potassium nitrate, sodium phosphate, and iron. Growth of Cyclotella required a vitamin mixture as well as the other additives.

Harry L. Cook, Project Leader

Culture of Juvenile and Adult Shrimp

Experimental rearing of penaeid shrimp in two 0.05-hectare (1/8-acre), brackish-water ponds continued this year. We distributed rice husks in one pond to increase the surface area of the bottom (thus encouraging growth of micro-organisms) and to fertilize the pond's water inexpensively. The second pond was untreated. We put about 9,000 brown shrimp postlarvae in each pond, which then had one shrimp per 0.05 $m.^2$ (0.5 $ft.^2$) of bottom. These postlarvae were reared from eggs spawned in the laboratory.

As in previous years, initially rapid shrimp growth in both ponds was followed by a period of slow growth (tables 4 and 5). Toward the end of the study, shrimp in both ponds were fed a commercially prepared rabbit "chow" at the rate of 5 percent of their body weight per day. This addition of food increased the average daily rate of growth.

Table 4.--Lengths and numbers per pound (whole shrimp) of brown shrimp held in an untreated, brackish-water pond, 1967

Date	Length				Whole shrimp per pound
	Average		Daily increment during period		
	Mm.	Inches	Mm.	Inches	Number
Apr. 28	6.5	0.26	--	--	567,500
May 18	29.3	1.15	1.14	0.044	1,892
June 15	79.9	3.14	1.81	0.071	114
July 13	87.0	3.42	0.25	0.009	91
Aug. 17 1/	80.8	3.18	-0.18	-0.007	116
Sept. 19	88.6	3.48	0.24	0.009	86

1/ Feeding began Aug. 31.

Table 5.--Lengths and numbers per pound (whole shrimp) of brown shrimp held in a fertilized, brackish-water pond, 1967

Date	Length				Whole shrimp per pound
	Average		Daily increment during period		
	Mm.	Inches	Mm.	Inches	Number
Apr. 28	6.5	0.26	--	--	567,500
May 18	26.0	1.02	0.98	0.038	2,838
June 15	75.7	2.98	1.78	0.070	126
July 13	86.1	3.39	0.37	0.014	93
Aug. 17 1/	91.8	3.61	0.16	0.006	74
Sept. 19	103.7	4.08	0.36	0.014	49

1/ Feeding began Aug. 4.

[1] Trade names referred to in this publication do not imply endorsement of commercial products.

Because of the threat of Hurricane Beulah, we harvested the shrimp prematurely on September 19, 1968, from the fertilized and untreated ponds. Shrimp in the fertilized pond attained an average total length of 103.7 mm. (4.1 inches) and a weight of 9.3 g. (0.3 ounce) over the 145-day study period. Thirty-one percent of the shrimp survived to produce an estimated projected yield of 314 kg. of tails per hectare (280 pounds per acre). Shrimp in the untreated pond attained a total length of 88.6 mm. (3.5 inches) and a weight of 5.3 g. (0.2 ounce); 23 percent survived to produce an estimated projected yield of 135 kg. per hectare (120 pounds per acre).

The low survival (31 and 23 percent) of shrimp in the ponds was attributed to oxygen depletion rather than cannibalism or disease. The levees surrounding the ponds partially obstruct the wind and thereby limit circulation and aeration. On several occasions when a bloom of phytoplankton was dense, the depletion of oxygen in the ponds caused distress and mortality among shrimp. In the future we will attempt to eliminate this cause of mortality by aerating the ponds' waters mechanically.

To gain better understanding of the ecology of the ponds as related to shrimp growth, we periodically examined water samples to determine the density of algal growth, the abundance and composition of zooplankton, and the physical and chemical conditions of the water. Also, samples of substrate were analyzed for bottom organisms. The succession of nutrients, phytoplankton, zooplankton, and populations of bottom fauna were in close agreement, but contrary to what was expected, shrimp grew best early in the study when populations of zooplankton and bottom organisms were lowest.

The abundance of organisms in our ponds tended to follow, in general, the rise and fall of the temperature during the year. Organisms were most plentiful in the summer and least abundant in the winter. The ratio between the number of bottom organisms collected in the summer and winter was 4:1; for plankters, it was 94:1.

In mid-October a single pond was stocked with about 2,900 laboratory-reared postlarvae (brown shrimp) averaging 12 mm. (0.5 inch) total length to determine their ability to overwinter. When we harvested the shrimp on May 31, we learned that 42 percent of the shrimp survived temperatures which decreased to a 3-month average low of 8.9° C. (48° F.) in January-March. Average daily growth was greatest in the spring when temperatures were increasing and least in the winter when temperatures were lowest (table 6). Burrowing was most pronounced in the winter.

Earthen levees were recently built across our two ponds to form four smaller ponds, each about 0.02 hectare (0.05 acre). The de-

Table 6.--Growth of brown shrimp stocked as postlarvae in a brackish-water pond, between October and June, 1967-68

Time period	Average water temperature		Average daily growth		Size attained during period	
Date	°C.	°F.	Mm.	Inches	Mm.	Inches
Oct. 19 to Dec. 31	21.1	70	0.43	0.017	43.7	1.72
Jan. 1 to Mar. 31	8.9	48	0.05	0.002	47.8	1.88
Apr. 1 to May 31	22.8	73	1.09	0.043	115.6	4.55

pression formed by removing soil to construct these levees created an additional pond. All ponds were drained, and we are now in the process of restocking them with brown shrimp about 75 to 100 mm. (3-4 inches) long. The purpose of this study is to find means of accelerating the growth which became slow at about this size in previous years.

Ray S. Wheeler, Project Leader

Food and Experimental Environments

To grow shrimp rapidly to maturity in artificial environments, we must know the types and amounts of food eaten and preferred by shrimp. Juvenile penaeid shrimp fed live brine shrimp (Artemia) nauplii in the laboratory decreased in growth rate after reaching 50 mm. (2 inches) total length. In pond experiments, shrimp have all but ceased growth after reaching 127 mm. (5 inches) total length. Although environmental factors such as light, salinity, oxygen level, or population density may influence the growth of shrimp, the amount and qualify of food probably have more effect. Accordingly, we began experiments during the past year to evaluate the nutritional value of prepared foods.

In our initial study with juvenile pink shrimp from Florida, a food with a fish-flour base supplemented with vitamins supported better growth (as indicated by the frequency of molting) and survival than did a diet of Artemia nauplii (fig. 1). Only 2 of 23 shrimp fed Artemia were alive at the end of 90 days; both had opaque, white flesh and were generally inactive. In contrast, 22 of 23 fed the fish flour plus vitamins survived the same period; all survivors had clear, transparent flesh, were active, and were continuing to grow.

In a second experiment, postlarval brown shrimp from Galveston Bay were fed several prepared foods containing various amounts of fish meal and vegetable flours in the form of pellets and an agar-base gel. Postlarvae fed the experimental diets did not attain the size of those fed Artemia nauplii. Foods containing large amounts of vegetable proteins--soy flour or cottonseed meal--were not eaten by either juvenile or postlarval brown shrimp. Foods

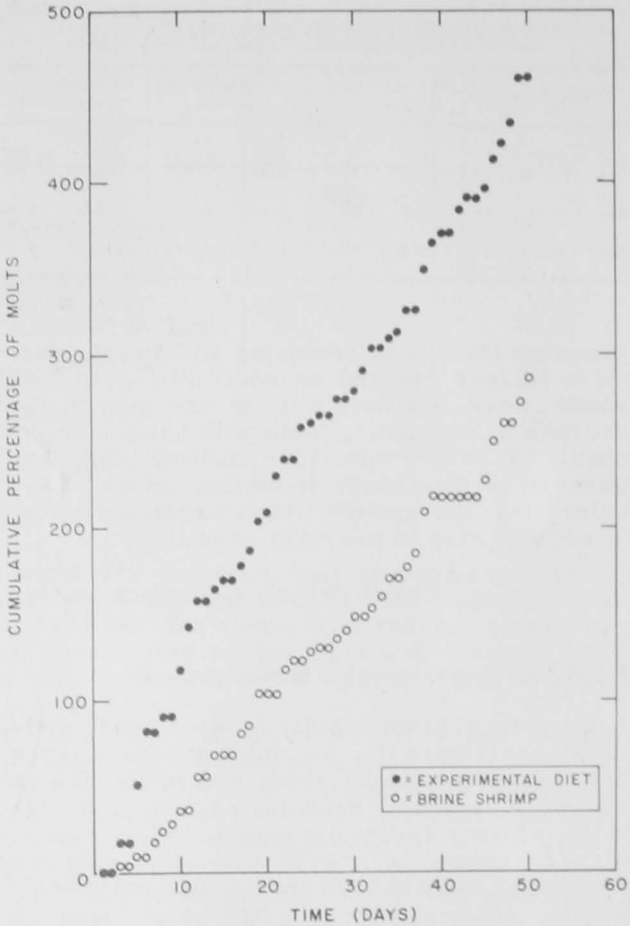

Figure 1.--Cumulative percentage of molts of pink shrimp fed enriched experimental diet and brine shrimp nauplii.

with a fish-flour base (with or without a vitamin supplement) were readily and continuously eaten by postlarval and juvenile shrimp. The postlarvae, however, were extremely cannibalistic and less than 50 percent survived for 1 month. The contrast in cannibalism between juveniles and postlarvae suggests that postlarvae may require a greater density of food, a different method of feeding, or a different combination of foods than juvenile shrimp.

Several natural foods also were fed to juvenile shrimp. These included shucked mussels and clams; several species of polychaete worms; amphipods; nauplial and adult brine shrimp; postlarval seabobs; and a natural mat composed chiefly of small tube-dwelling polychaetes, amphipods, a few mollusks, and small nematode worms, all bound in a rich organic matrix. Each food was eaten when presented alone, but the response to simultaneous presentation of combinations of foods varied. Polychaetes were usually a preferred food, but a shrimp tended to continue eating whichever type food it first contacted. For example, the shrimp that first ate Artemia continued to eat Artemia, and shrimp that first ate mussels continued to search for mussels.

The food preference of the shrimp depended somewhat on the size of the shrimp tested. Juvenile brown shrimp less than about 25 mm. (1 inch) total length did not react to the presence of the natural food mat and did not graze on the mat even if it remained in the aquarium for 2 or more days. When food was introduced, animals of 38 mm. (1.5 inches), however, became excited and fed actively.

The size and speed of the food organism are additional factors in the choice of food for shrimp that are being cultured. Brown shrimp 25 mm. (1 inch) total length were able to catch and eat slowmoving adult Artemia about 10 mm. (0.4 inch) long. These same animals however, were able to eat water boatmen 6 mm. (0.3 inch) long only when the insects swam into the mouth appendages. In contrast, brown shrimp 75 mm. (3 inches) long ate all the small foods as well as postlarval seabobs 18.9 mm. (0.8 inch) to 25 mm. (1 inch) total length.

Direct observation of the feeding behavior of juvenile and adult shrimp suggests two distinct processes in locating food. First there is a nondirectional swimming in response to the presence of dissolved chemicals in the waters. Secondly, the animals return to the substrate and search actively for the food. During this latter process, the chelated legs of the shrimp must touch the suspected food, which may be rejected at the mouth. The function and action of the food-gathering appendages are being studied through the use of slow-motion films.

Laboratory-hatched postlarval seabobs were exposed to selected combinations of temperature and salinity for a 24-hour tolerance and a 28-day growth experiment. Because previous studies suggested that these animals were less tolerant of environmental change than either the brown or white shrimp, we exposed them to a narrower range of salinities and increased the acclimation period. The postlarval seabobs were exposed to salinities of 10, 15, 25, 29, or 35 p.p.t. at temperatures of 15° C. (59° F.), 18° C. (64° F.), 25° C. (77° F.), or 32° C. (90° F.). No animals survived 28 days at any salinities at 15° C. (59° F.), and only 11 percent survived at the control salinity (29 p.p.t.) at 18° C. (64° F.). Between 40 and 50 percent survived salinities of 25 to 35 p.p.t. at 25° C. (77° F.), but less than 30 percent survived salinities of 10 and 15 p.p.t. at 25° C. (77° F.) and each salinity tested at 32° C. (90° F.). The high mortality and the slow growth that accompanied it suggest that this species is not suitable for pond culture, although the postlarvae might be a good food for other penaeid shrimp.

Studies of digestive enzymes indicate that penaeid shrimp possess the three major types--carbohydrases, lipases, and proteases. More detailed work is in progress.

During the year, we equipped the invertebrate culture facility being used by the National Aeronautics and Space Administration Lunar Receiving Laboratory. T. A. Tyler has several organisms in culture, and is assisting in the identification of various micro-organisms occurring in both sea water and shrimp tissue.

Zoula P. Zein-Eldin, Project Leader

Ecology of Pink Shrimp in Florida Bay

Ecological studies in Florida Bay and the Florida Keys (fig. 2) have produced a variety of information on young pink shrimp, Penaeus d. duorarum, not previously available. These shallow waters are the prime nursery grounds for pink shrimp of the Tortugas fishery.

Postlarvae of the pink shrimp enter the Florida Bay estuary from the Atlantic Ocean through channels in the Florida Keys and live on the bottom in suitable, shallow-water, grassy areas. These shrimp settle in greatest numbers near shorelines, and apparently prefer bottoms with growths of shoal grass, Diplanthera wrightii.

Quantitative samples of planktonic postlarval shrimp entering Florida Bay via Whale Harbor Channel were taken monthly for 30 months. Seasonal peaks of shrimp abundance were in the spring, summer, or fall. The numbers of incoming planktonic postlarvae are reflected by the numbers of benthic postlarvae caught at selected sampling stations in Florida Bay and the Keys (fig. 3). Planktonic and benthic postlarvae were most abundant from June to December in 1967.

The numbers of shrimp in samples from 18 selected stations in October 1967 give a general picture of shrimp distribution in Florida Bay and the Florida Keys (fig. 2). Northeastern Florida Bay has little water exchange with the Atlantic Ocean and contains a relatively small number of shrimp. The central Bay, with water circulation somewhat restricted by shallow mud banks, has moderate numbers of postlarval and juvenile shrimp, whereas the western Bay, with a large volume of incoming Atlantic water, has an abundance of young pink shrimp. The Lower Keys have moderate numbers of shrimp; the limiting factor here may be the shallow substrates that restrict the growth of seagrasses.

Thomas J. Costello, Project Leader
Donald M. Allen

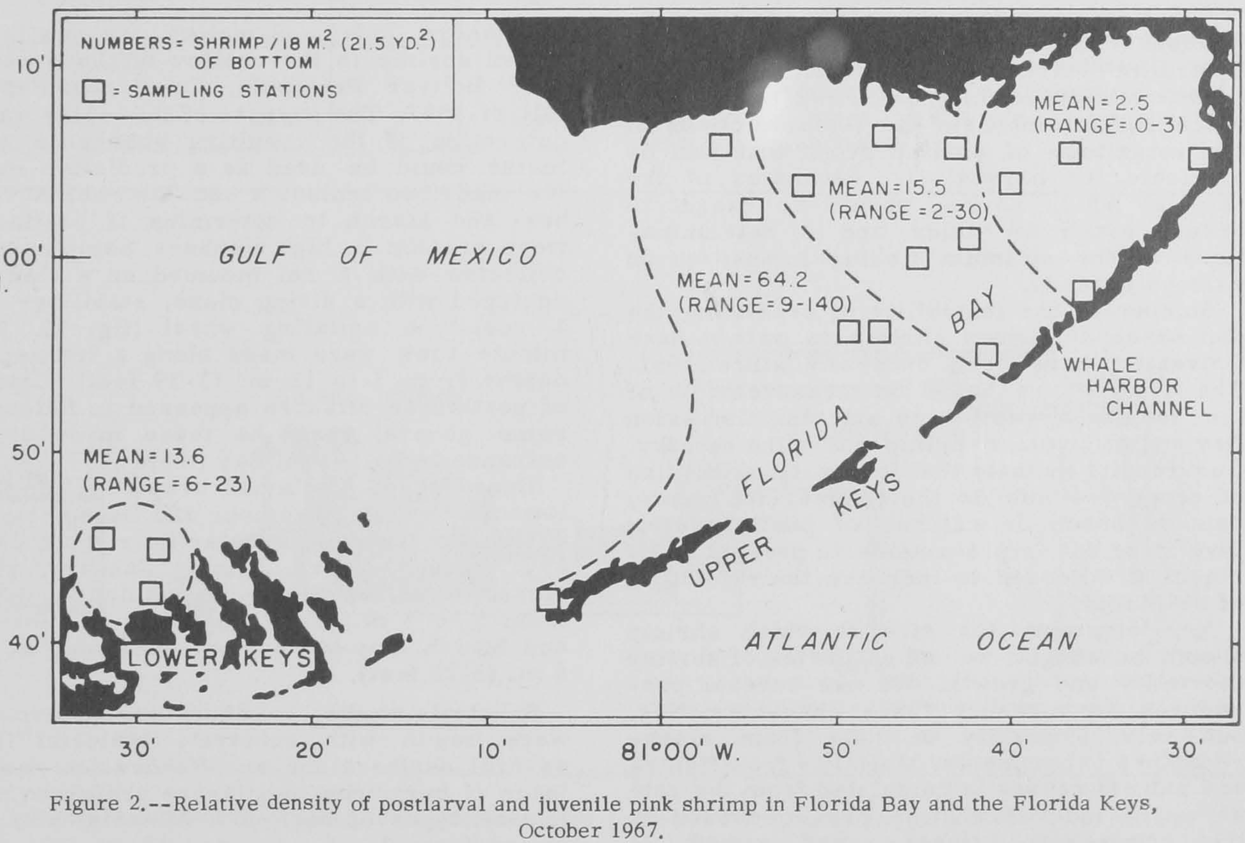

Figure 2.--Relative density of postlarval and juvenile pink shrimp in Florida Bay and the Florida Keys, October 1967.

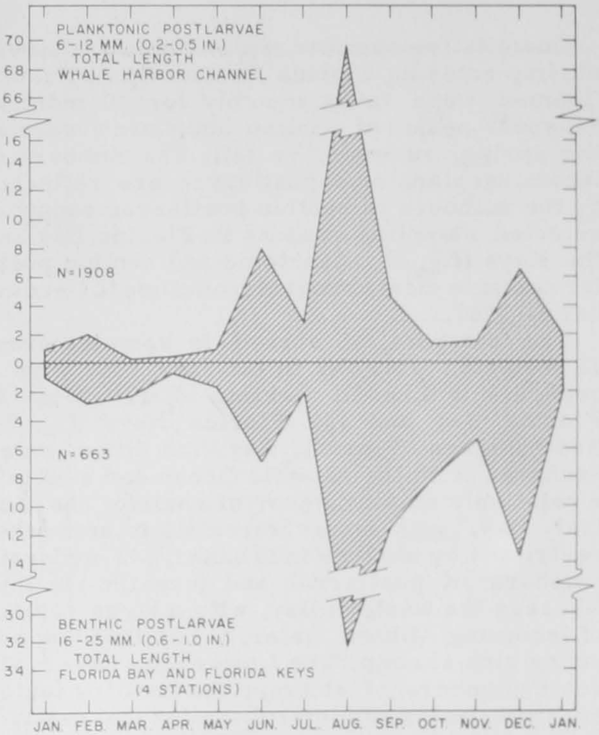

Figure 3.--Seasonal relation between planktonic and benthic postlarvae (Penaeus) in the Florida Bay area.

SHRIMP DYNAMICS PROGRAM

Research in this program is designed to determine the benefits that can be realized from management of the shrimp fishery. We place major emphasis on: (1) predictions of the magnitude of shrimp crops that will be available for harvest, (2) estimates of the size at which shrimp should be caught to ensure maximum yields, and (3) determinations of the optimum fishing intensities on various grounds.

Studies of the feasibility of predicting the abundance of brown shrimp in waters near Galveston have been underway since 1960. The studies are based on measurements of the density of postlarvae entering Galveston Bay and of juvenile shrimp within the estuary. Our results indicate that forecasts of the size of crops available to the commercial fishery can be based on catches of postlarvae or juveniles, but improvements in present techniques are needed to increase the reliability of predictions.

To determine the size at which shrimp should be caught, we use estimates of shrimp mortality and growth. We use several procedures to measure these characteristics, but rely primarily on data from mark-recapture experiments. Mortality from fishing and natural causes is calculated from the rate at which marked shrimp are recovered by the commercial fishery, and growth is determined from the change in size of shrimp between the time they are released and recovered. Although we have used good methods for staining and tagging shrimp for several years, we are still finding ways to improve them and, hence, to obtain better estimates of population size.

Decisions on the optimum intensity of fishing in various areas rest largely with those agencies responsible for management. Our task is to estimate the influence of intensity on total yields and on fishermen's earnings. Preliminary results have suggested that the weight of shrimp landed could be maintained and that earnings would increase significantly if present levels of fishing were reduced. Considerably more research must be completed, however, before final conclusions can be drawn.

Richard J. Berry, Program Leader

Predicting Shrimp Abundance

We began three new phases of research on postlarvae this year. These studies are designed to (1) develop a prediction index from catches of shrimp offshore, (2) learn if burrowing postlarvae preferred specific types of sediments, and (3) provide for continuous sampling of immigrating postlarvae. In addition, we continued collecting data on the landings of bait shrimp from Galveston Bay.

Offshore index.--Sampling for postlarval brown shrimp in the shallow offshore waters near Bolivar Peninsula, Tex., began in the fall of 1967. The purpose of this study was to determine if the resulting abundance estimates could be used as a prediction index. We made two cruises a week between November and March to determine if postlarvae were present in high numbers. Samples were collected with a net mounted on a sled and equipped with a diving plane, stabilizer, and a reel-type agitating wheel (fig. 4). Ten-minute tows were made along a transect in depths from 1 to 12 m. (3-39 feet). Catches of postlarvae offshore appeared to follow the same general trend as those made at the entrance to Galveston Bay (table 7).

Densities of postlarval brown shrimp were low offshore in November and December, but numbers increased substantially from January through March. During January, postlarvae appeared to be distributed in depths from 5 to 8 m.(15-25 feet), but in February and March they were most numerous at 1 to 6 m. (3-20 feet).

Substrate studies.--Laboratory experiments were begun with substrate material from several depths along an offshore transect to learn if burrowing postlarvae preferred particular types of sediment. Material was obtained from 3-, 6-, 9-, and 12-m. (10-, 20-,

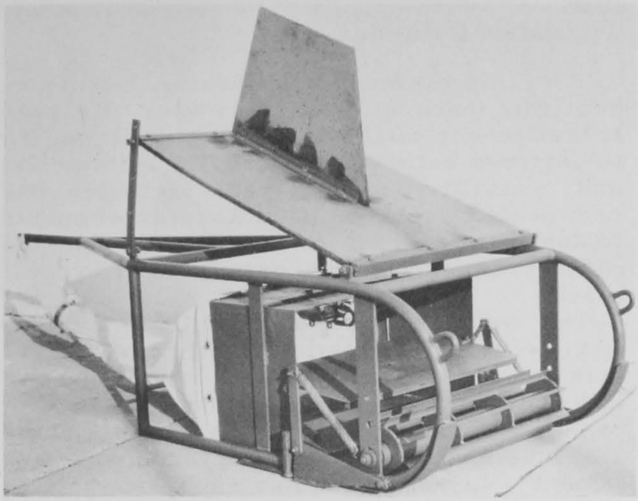

Figure 4.--Sampler used to collect postlarval shrimp in near-shore waters.

Table 7.--Average catch of postlarval brown shrimp from the Gulf of Mexico and at Galveston Entrance, 1967-68

Month	Gulf of Mexico		Galveston Entrance	
	Tows	Shrimp per tow	Tows	Shrimp per tow
	Number	Number	Number	Number
1967				
November	17	5.8	3	1.0
December	26	4.0	No sample	
1968				
January	50	59.3	8	17.3
February	34	245.5	9	166.0
March	12	618.9	3	402.6

30-, and 39-foot) depths, and placed in a partitioned tray. Postlarvae of brown shrimp (11-12 mm. or 0.4 inch total length) were added to the tray, and the water temperature was lowered slowly from 21° to 4° C. (70°-39° F.). All postlarvae burrowed and most apparently preferred the substrate from 6 m. (20 feet). To ascertain whether this preference could be attributed to factors other than particle size, postlarvae were tested in an inorganic substrate--silicon carbide. Over half burrowed in the material with the smallest particle size ($<$ 0.06 mm.) which approximated the size of particles from the natural bottom at 6 m. (20 feet).

Refinement of postlarval index.--We have assembled and are testing an automatic sampler designed to collect postlarval shrimp hourly (fig. 5). This unit, consisting of a pump, diesel generator, inverter, timer, and battery, will be placed on a platform in the entrance to Galveston Bay.

To determine the depth where the pump intake should be placed to catch a constant proportion of passing postlarvae, we studied the vertical distribution of immigrating postlarval shrimp. We used an iron framework to support five plankton nets (0.3-m. or 1-foot mouth) in a vertical plane. With nets spaced at 1-m. (3-foot) intervals, we sampled the water column from surface to bottom in 5 m. (16 feet) of water. Samples were collected for 1 hour on flood tides during a 6-week period of peak immigration of postlarval brown shrimp. According to preliminary results, postlarvae were distributed throughout the water column (table 8).

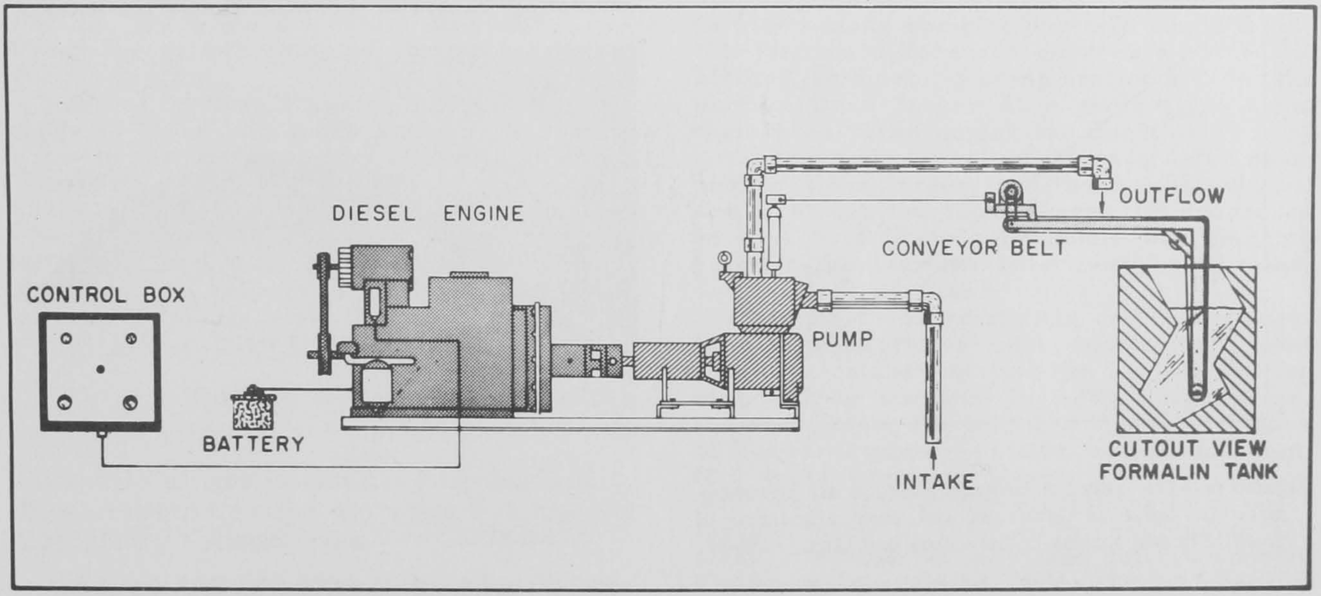

Figure 5.--Schematic drawing of automatic sampler designed for continuous sampling of postlarval shrimp.

Table 8. --Relative abundance of postlarval brown shrimp collected at various depths near the entrance to Galveston Bay

Depth from surface		Postlarvae
Meters	Feet	Number
1	3	980
2	7	2,264
3	10	1,988
4	13	1,760
5	16	1,279

Juvenile shrimp index.--On the basis of weekly landings and effort data from bait-shrimp fishermen of Galveston Bay, the 1967 crop of juvenile shrimp was the largest recorded since our detailed statistical survey began. Juvenile brown shrimp dominated a catch of almost 1.1 million pounds.

Analysis of data from the bait shrimp fishery in Galveston Bay and air temperatures recorded by the U.S. Weather Bureau at the Galveston Post Office shows that the timing of peak abundance of juvenile brown shrimp is directly related to temperature. Average air temperatures for April and the timing of the highest catches of juvenile brown shrimp show a direct relation during the 8 years for which shrimp data are available (fig. 6).

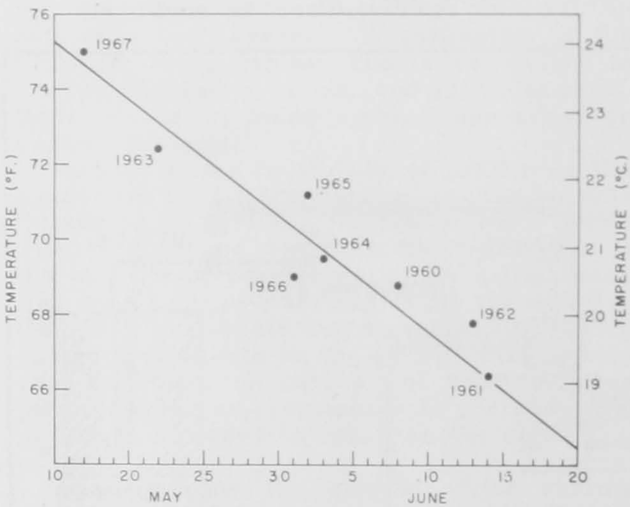

Figure 6.--The relation between average air temperatures in April at Galveston and peak abundance of juvenile brown shrimp in Galveston Bay, Tex., 1960-67.

Kenneth N. Baxter, Project Leader

Population Dynamics

The improvement of marking techniques received much attention this year. We need to refine our methods of marking if we are to improve estimates of growth, movements, and mortality through mark-recapture experiments. We made laboratory experiments to test new methods of marking and used the most promising techniques in field experiments.

The tag used most successfully is a small, flexible piece of plastic with numbers or letters printed on both sides. It was used as an internal tag to identify shrimp marked with biological stains. The tag was inserted into the musculature of the first abdominal segment through the articular membrane joining the carapace and the exoskeleton of the first abdominal segment (fig. 7). Loss of tags from shrimp held in the laboratory was negligible, and the mortality rates of stained shrimp were not increased significantly by insertion of the tag.

We modified the Petersen disk used in previous studies. First, we reduced its weight by two-thirds. Second, changed the place where we inserted the tag. Shrimp are now tagged between the first and second abdominal segments rather than through the center of the first abdominal segment. This placement of the pin reduces the difficulty shrimp encounter in freeing themselves from their exoskeleton when molting.

Antibiotic ointment was applied to the pins of Petersen disk tags and to internal tags before they were inserted into the shrimp to determine if infections and deaths caused by the marking procedures could be reduced by inhibiting bacterial growth. Under laboratory

Figure 7.--Site and method used for inserting small plastic tag.

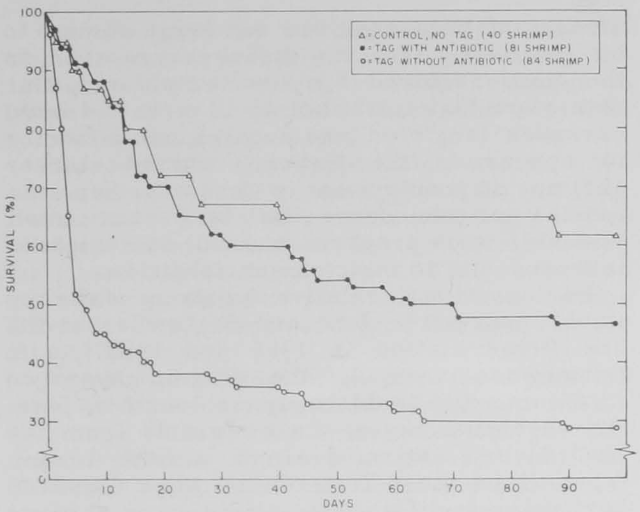

Figure 8.--Comparative survival of tagged shrimp with and without antibiotic, and untagged shrimp.

conditions, the use of an antibiotic apparently reduced the number of mortalities due to tagging (fig. 8). Studies are continuing to determine which antibiotic is best for our work.

We completed several marking experiments in the field during the year. The first was a study of movement, mortality, and growth of brown shrimp in the spring and summer of 1967. Nearly 26,000 stained brown shrimp were released at four locations between the mouth of Galveston Bay and a point 39 km. (21 nautical miles) south of Freeport, Tex. Shrimp were marked individually with either an internal tag or a secondary fluorescent pigment mark. We consider the tag to be preferable to the pigment as a secondary mark for shrimp larger than 100 mm. (4 inches) total length, but less satisfactory for smaller shrimp. We could not detect differences between the growth rates of shrimp marked in these two ways.

Another shrimp marking experiment was made to learn how much small white shrimp grow in the winter. From November through February about 30,000 stained and tagged shrimp were released in the Galveston ship channel near the entrance to Galveston Bay. Although less than 1 percent of the shrimp released was recovered, adequate data were collected to describe the growth of small white shrimp at low temperatures.

Richard A. Neal, Project Leader

Seasonal Changes in Relative Abundance of Postlarvae of Penaeus duorarum Entering the Everglades National Park

Plankton samples were collected at Buttonwood Canal and Little Shark River, Everglades National Park, Fla., to determine the seasonal and diurnal changes in abundance of postlarval pink shrimp at the edge of the Everglades National Park estuary and to find the possible relations of these changes to hydrographic conditions. Sampling was carried out on each moon phase throughout the summer and on new and full moons from September through December.

The abundance of immigrating postlarvae appeared to be related to several factors. Catches were highest on night floodtides and during new and first-quarter moon phases; bottom sampling was consistently more productive than surface sampling. Catches were high in spring and summer, with peaks in July or August. Temperature appeared to be the most important environmental variable affecting catch.

The age of postlarvae, indicated by the dorsal rostral spine count, showed a lunar periodicity that may be related to the timing of spawning. Postlarvae with higher spine count were collected during the new and third-quarter moon phases (those in which the flood occurs during the dark of the moon) than during the full and first-quarter moon phases. Shrimp collected from Buttonwood Canal had a greater average spine count and were considered older than those from the Little Shark River.

Postlarvae with more than seven dorsal rostral spines apparently may or may not add an additional spine with each molt. The variance of the carapace length per spine count increases from 4.7 for seven-spined shrimp to 25.1 for eight-spined shrimp.

The multimodal distribution of the older postlarvae indicated that comparisons of "age" should be made from carapace length per spine count of shrimp with seven or fewer spines. Comparisons showed no differences in size among samples during a single floodtide and no differences between surface and bottom samples. Shrimp collected on the ebbtide were larger at a given spine count than those taken during the floodtide. Shrimp collected on the new and third-quarter moon phases were larger than those taken on full and first-quarter moon phases. No difference in size at a given spine count was detected between the samples from Buttonwood Canal and Little Shark River.

Attempts to correlate the catches of postlarvae immigrating into Buttonwood Canal with the catches of juvenile shrimp leaving met with no success. In Little Shark River, the correlation was significant between catches of postlarvae and juveniles less than 13 mm. (0.5 inch) carapace length if no lag period was used. The catch per cubic meter of postlarvae taken in the bottom net during the night floodtide at new and full moon was closely correlated with the catches of 68-and-over-count (tails per pound) shrimp in commercial landings from specific areas (1, 2, and 3) of the Tortugas grounds.

The coefficient of determination for the combined Buttonwood Canal and Little Shark River stations indicated that 61 percent of the monthly variation in commercial catches for the 17 months examined could be explained with the index of immigrating postlarvae. If data from Buttonwood Canal alone are used, the coefficient of determination is 58 percent.

C. P. Idyll and M. A. Roessler
Project Leaders

Institute of Marine Sciences,
University of Miami
(Contract No. 14-17-0002-241)

Variations in Abundance of Juvenile Pink Shrimp Emigrating From the Everglades National Park Estuary, in Relation to the Commercial Catch

Studies continued on the biology of juvenile pink shrimp emigrating from the nursery areas in Everglades National Park and on abundance of shrimp in two estuaries in relation to the commercial catch.

Sampling with wing nets continued through December 1967 in Buttonwood Canal near Flamingo and in the upper Joe River, the western opening of Whitewater Bay. Sampling began in July 1965 and was carried out twice a month on new and full moon phases for 30 months. A total of 471, 30-minute samples was taken at the Buttonwood Canal station, and 484 samples were taken in the upper Joe River. These materials have been processed, and the data transferred to computer cards.

Three periods of high relative abundance of juvenile shrimp were apparent in Buttonwood Canal during 1967. The first and smallest was in February, the second in June, and the largest in August. During the 30 months of sampling at this station, the periods of highest relative abundance consistently appeared in the summer (July or August) and at a time when shrimp were less than 11.5 mm. (0.5 inch) carapace length. The average size of the shrimp was largest--up to 17.5 mm. (0.7 inch) carapace length--in the early spring when relative abundance was low.

The relative abundance of emigrating shrimp at the Buttonwood Canal station has declined each year since 1965. This trend agrees with the index of abundance established for the smallest shrimp (68-and-over tails to the pound) caught commercially. Although there is a positive correlation in these trends of relative abundance, considerable variation is introduced because of the wide size range of the emigrants in most months and the apparent differences in the amount of time required for large shrimp to be recruited into the fishery compared to the time required for smaller shrimp. Our data show that most shrimp 12 mm. (0.4 inch) carapace length or less require 2 to 3 months to appear in the fishery, whereas larger shrimp may only require 1 month. Separate indices of abundance for large and small juveniles were prepared and will be compared independently to the commercial index.

Periods of high relative abundance of shrimp were apparent in June and September at the Joe River station in 1966 and 1967. As in Buttonwood Canal, the shrimp averaged 13.8 mm. (0.5 inch) carapace length or less. On an annual basis, the emigrants from the Joe River station average almost 1 mm. larger than those from Buttonwood Canal. In particular months, this difference in average size may range to over 4 mm. (0.2 inch).

The relation between the relative abundance of shrimp in Joe River and the commercial index also shows considerable variation. Some of this variation is probably due to the more complex hydrography of western Whitewater Bay compared to the Coot Bay-Buttonwood Canal system. Understanding of the relation will probably be improved by separation according to size as described for the Buttonwood Canal station.

With multiple regression we are analyzing shrimp catches and selected environmental variables at Buttonwood Canal. Current velocity, water temperature, salinity, and moon phase were tested against the numbers of shrimp. Seventy percent of the variation in the transformed catch data can be attributed to variation in current velocity and water temperature.

C. P. Idyll, E. S. Iversen, and
B. J. Yokel, Project Leaders

Institute of Marine Sciences,
University of Miami
(Contract No. 14-17-0002-242)

Biochemical Identification of Adult and Postlarval White Shrimp, *Penaeus setiferus*; Brown Shrimp, *P. aztecus*; and Pink Shrimp, *P. duorarum*, in the Gulf of Mexico

During the past year abdominal muscle tissues were analyzed biochemically to characterize and identify species-specific proteins of white, brown, and pink shrimp. The techniques have included electrophoresis (migration of protein molecules in an electric field) in two types of support media--cellulose acetate and polyacrylamide gels--as well as the fractional precipitation of proteins by ammonium sulfate.

Muscle proteins of the intact shrimp abdomens are apparently unchanged during the initial period of storage; drastic changes in protein occur, however, if the tissue is stored following homogenization.

Reproducible electrophoretic patterns were established for all three species. In addition, we compared proteins from white and brown shrimp from Galveston, Tex.; Vermilion Bay, La.; and Apalachicola Bay, Fla., and also examined proteins of pink shrimp from Corpus Christi, Tex.; Panama City, Fla.; and Florida Bay, Fla.

Fractional precipitation of muscle proteins with various concentrations of ammonium sulfate was followed by immunological gel diffusion studies of the precipitated fractions. Several antigens with different molecular weights are shared by the three species. The nonshared antigens are of higher molecular weight than those shared.

A Perkin-Elmer atomic absorption spectrophotometer was used to study the concentration of manganese, iron, calcium, and sodium in adult brown and white shrimp. Sodium content was 34.0 p.p.m. in white shrimp and 19.5 p.p.m. in brown shrimp. The significance of this difference cannot be determined without more extensive investigations on a number of samples to learn effects of age of animals, source, and length of storage time.

Jerome V. Shireman, Project Leader
University of Southwestern Louisiana
(Contract No. 14-17-0002-233)

ESTUARINE PROGRAM

The Estuarine Program is concerned with the estuarine environment as it pertains to the life history, food chain, and nursery grounds of shrimp and other marine species. Major objectives are to provide coastal fishery resources with adequate protection by reviewing and making recommendations on water-development projects, document the effects of specific types of construction projects on the environment, determine the value of various habitat types in terms of fishery production, and develop techniques for managing estuarine habitats for increased fishery production.

The organizational structure of this program was altered during the year to use our staff more efficiently. Three projects were reduced to two. The project "Evaluation of Estuarine Data" was combined with the "Effects of Engineering Projects" and is now entitled "Evaluation of Engineering Projects and Estuarine Data." The project, "Ecology of Western Gulf Estuaries" continued as in the past, but with the additional responsibility of studying the effects of habitat modification and the rehabilitation of estuaries.

Except for supplemental sampling of sediments in Galveston Bay, we suspended all field work the first half of this fiscal year. Since then, we have been analyzing back data, preparing manuscripts, and continually reviewing the water-development projects.

All brown shrimp data collected from 1963 through 1967 were analyzed to determine the relative number and size of brown shrimp in relation to habitat type in the Galveston Bay system. Results indicate that brown shrimp were: (1) most abundant in peripheral and shallow-channel habitats, (2) slightly less abundant in open-water habitats, and (3) least abundant in deep-channel habitats bordered by open bays. The mean total length of shrimp varied slightly between habitats, but, except for shallow channels bordered by marsh areas, it tended to increase from peripheral to open-water to channel habitats.

Significant progress was made in studying the effects of habitat modification. Contributions include manuscripts prepared or being prepared covering (1) environmental data collected from 1958 through 1967 in the Galveston Bay system, (2) an analysis of environmental data taken in Clear Lake, Tex., an area that is being altered rapidly, and (3) an analysis of the hydrological data from the Galveston Bay system (1963-66).

The distribution of four species of sciaenid fishes in relation to various temperatures and salinities observed in Galveston Bay has been analyzed. Two of the species--croaker and spot--occurred frequently in most of the temperatures and salinities sampled in the Bay. The other two--sand seatrout and southern kingfish--were caught most frequently in high temperatures. The sand seatrout inhabited water of a wide range of salinities, but the southern kingfish appeared to prefer high salinities.

Our examination of sediment distribution maps of the Galveston Bay system developed in previous years indicated that we needed additional samples to complete the study. This year we took and analyzed these samples and are now plotting them for final presentation.

The U.S. Army Corps of Engineers issued 433 public notices this year--an indication of how man continues to encroach on Texas estuaries. The signing of a "Memorandum of Understanding" by the Secretaries of Army and Interior early this fiscal year showed the national concern over the rapid rate of environmental modification. This agreement is the result of a legislative compromise and possesses no legal authority, but it is a step forward in that problems in the conservation of fish and wildlife will be given more consideration.

Richard J. Hoogland, Acting Program Leader

Evaluation of Engineering Projects and Estuarine Data

The Corps of Engineers now is empowered to grant excavation or construction permits in navigable waters. In compliance with the memorandum of understanding, representatives of the Army and Interior will seek agreement before the final decisions are made by the Corps. This memorandum has increased our work and responsibilities.

Because estuary-dependent species comprise most of the fishery resources on the Texas coast, we exerted considerable effort to make sure that the interests of the fisheries were represented in determining how estuarine waters would be shared. With the Division of River Basin Studies (Bureau of Sport Fisheries and Wildlife), we reviewed each construction application, proposal, and plan on the Texas coast. We appraised these from the standpoint of remedial measures that would eliminate or reduce adverse effects on fishery resources. Additionally, we provided consultatory services and assisted in interagency meetings to coordinate proposals and problems relative to estuarine fishery resources.

Project personnel contributed to and reviewed numerous reports on private and Federal construction projects. We handled 34 Bureau of Sport Fisheries and Wildlife reports and one Bureau of Outdoor Recreation report. Table 9 lists the number, type, and location of private construction projects reviewed.

Model tests of hurricane protection plans.--The Corps of Engineers at the Waterways Experiment Station, Vicksburg, Miss., completed this year the model testing of the two proposed hurricane protection plans ("Alpha" and "Gamma") for Galveston Bay. The Corps made these tests to determine how the two protection systems affect tides, salinities, and circulation. Initially, the Corps completed a model verification test (prototype) by using mean daily tidal prisms for the Water Year 1965 and incorporating weekly hydrographs for all important tributaries of the system. Base conditions were then established by simulating anticipated future conditions without the project. This work included a partial

Table 9.--Number, type, and location of proposed private construction projects in northwestern Gulf of Mexico coastal areas reviewed during fiscal year 1968

Location	Mineral development		Navigation channels	Bulkheading and fill	Other1/	Total
	With channel dredging	Without channel dredging				
	Number					
Sabine Lake	1	2			2	5
Galveston Bay	4	11	5	17	9	46
Matagorda Bay	4	13		4	3	24
San Antonio Bay	12	5	2	1	6	26
Aransas-Copano Bay	4	11	3	15	5	38
Corpus Christi Bay	5	11	1	14	11	42
Laguna Madre	7	14	2	6	3	32
Gulf of Mexico		60		2	6	68
Rivers and streams		2	15	64	71	152
Total	37	129	28	123	116	433

1/ Such as pipelines, wharves, piers, bridges, and jetties.

diversion of streamflow from the Trinity River to the San Jacinto River and a stream electric plant that diverted 3,000 to 3,500 c.f.s. (cubic feet per second) from upper Galveston Bay and the Houston Ship Channel into Trinity Bay (fig. 9).

The testing procedure was as follows:

Test 1. Existing conditions (no protective barriers) with hydrographs for model verification.

Test 2. Existing conditions (no protective barriers) and year 1980 regulated hydrographs for establishing a base.

Test 3. Gamma barrier plan installed and 1980 regulated hydrographs reproduced.

Test 4. Alpha barrier plan installed and 1980 regulated hydrographs reproduced.

Dye was released in the upper Houston Ship Channel twice during each test to obtain information on the rate and pattern of pollution dispersion. The first release was made at the beginning of a sustained high fresh-water inflow, and the second release was during low fresh-water inflow. The dye was released at a continuous uniform rate over one complete tidal cycle in sufficient quantity to be measurable at the end of 30 tidal cycles. Because mean daily tidal prisms were used as base conditions, this represented about 30 days prototype.

The Corps made weekly measurements of dye concentration and salinity throughout the Bay at the surface and bottom of the Bay at the time of local high-water slack (fig. 9). The purpose was to determine the long-period changes at each location and depth. Salinity measurements were made hourly at surface and bottom at all stations during periods of high and low inflow to determine maximum and minimum values as affected by tidal phase.

Personnel at the Waterways Experiment Stations are preparing a formal report based on the analysis of the test results. This report will not be completed until at least the latter part of fiscal year 1969, but the Corps of Engineers has provided us with basic testing information for our evaluation of the proposed plans. According to our preliminary analysis, some differences were evident in annual average salinities between 1980 base conditions and Alpha and Gamma protection plans. Table 10 shows annual average differences for surface and bottom salinities by subbay between 1980 and 1965 conditions without barriers, and comparison of each protection plan against 1980 base conditions.

Although the model study demonstrated that essentially no change in tidal ranges resulted from either of the protection plans, data provided us indicate that the Gamma barrier would create a buildup or concentration of

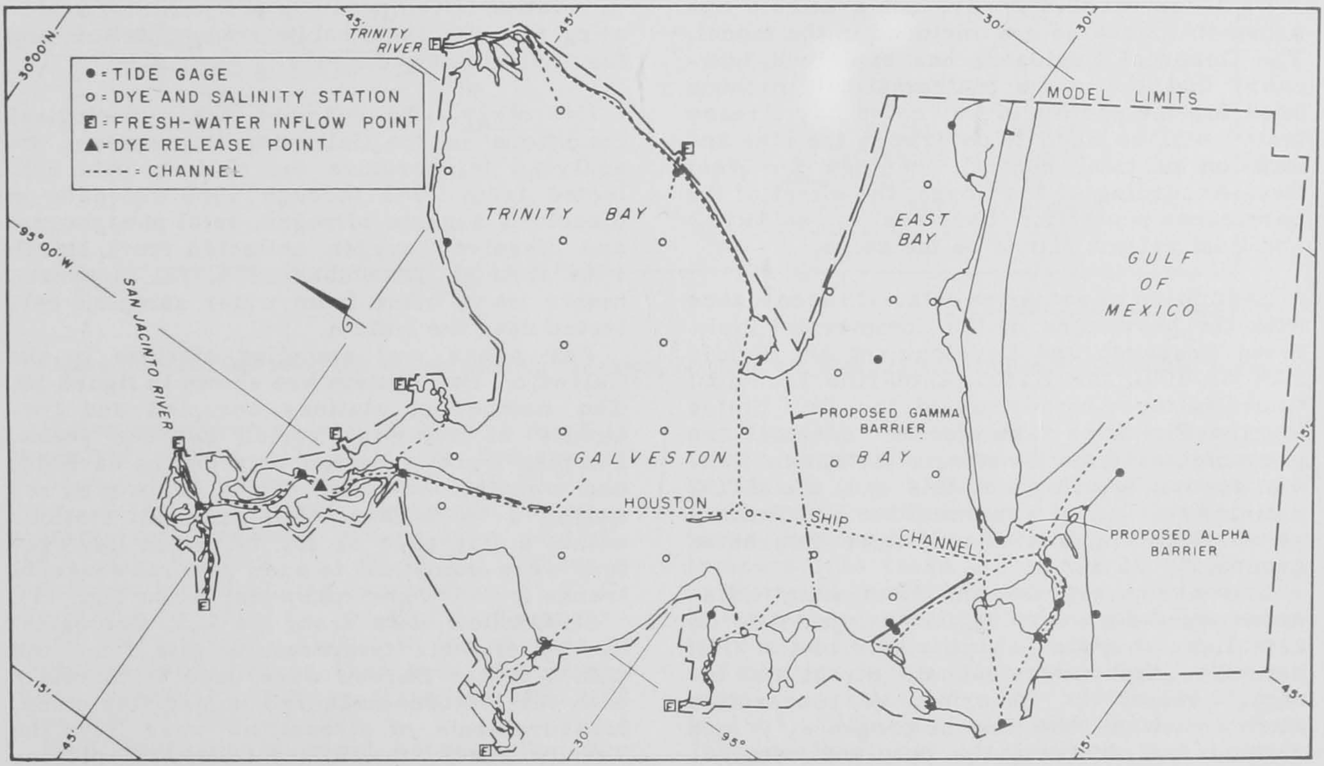

Figure 9.--Model limits and location of Alpha and Gamma barrier plans, dye and salinity stations, tidal gages, and points of fresh-water input in Galveston Bay, Tex.

Table 10.--Average annual salinity differences in parts per thousand by subbay for: the 1980 conditions and 1965 natural; Alpha barrier and 1980; and Gamma barrier and 1980

Condition simulated by model	Trinity Bay	East Bay	Lower Galveston Bay	Upper Galveston Bay
	P.p.t.	P.p.t.	P.p.t.	P.p.t.
1965 vs. 1980				
Surface	+1.2	+0.8	+1.3	+0.3
Bottom	+1.0	+0.7	+0.9	+0.4
Alpha vs. 1980				
Surface	+1.0	+0.1	-0.5	+0.7
Bottom	+1.3	+0.2	-0.1	+0.6
Gamma vs. 1980				
Surface	-0.2	-0.9	-1.2	-0.7
Bottom	+0.1	-0.9	-1.5	-0.6

contaminants in upper Galveston and Trinity Bays, particularly during low fresh-water inflow. Increased concentrations of pollutants could adversely affect the quality of habitat for estuary-dependent organisms. This observation was reported to the Corps of Engineers, and they seem confident that this condition can be corrected.

Data for West Bay are not available because this area is not included in the model. The Corps of Engineers has explained, however, that the same mathematical methods used for the portion of Galveston Bay already tested will be used to determine the size and location of tidal control openings for West Bay. According to the Corps, the effect of the hurricane protection barriers on salinities and tidal prisms should be the same.

Evaluation of estuarine data.--In accordance with the provisions of the Commercial Fisheries Research and Development Act (Public Law 88-309), the ETCC (Estuarine Technical Coordinating Committee) of the Gulf States Marine Fisheries Commission undertook the preparation of an inventory of estuarine fishery resources. To meet this end, the ETCC enlisted the aid of various State and Federal conservation agencies and other interested groups.

One way to evaluate the detrimental influences of water-development projects is to establish comparable appraisals of the Gulf estuaries that indicate their direct and indirect values to fisheries. A cooperative study, such as the one in progress, is one method for obtaining the required information. Such an inventory is possible through the use of standardized methods approved by the cooperating states for compiling results of the study.

The resultant GMEI (Gulf of Mexico Estuarine Inventory) has four parts: area description, hydrology, sedimentology, and biology. Considerable work was done this year on the area description portion for Texas in general and Galveston Bay in particular.

Galveston Bay is unique in many respects and is of considerable economic importance. The estuary, which has over 350,000 surface acres of water and about 230,000 acres of peripheral marshlands, is the largest on the Texas coast. The equitable distribution of benefits from a resource such as this is not easy. The speed with which water management comes into play will be chiefly a result of marketplace pricing in which new uses of water and waste-water treatment will have their impact.

Richard J. Hoogland, Project Leader

Ecology of Western Gulf Estuaries

Our work during the year was devoted to a detailed analysis of data collected from the Galveston Bay system since 1963. These studies included describing the hydrological conditions; determining the abundance and size of brown shrimp as related to habitat; documenting the distribution of sciaenid fishes in relation to temperature and salinity; evaluating the effects of habitat rehabilitation; and the analysis of sediments.

Hydrology.--To describe the hydrological conditions in the Galveston Bay system, we analyzed temperature and salinity data collected from 1963 through 1966 and data on dissolved organic nitrogen, total phosphorus, and dissolved oxygen collected from March 1964 through December 1966. All measurements were made from water samples collected near the bottom.

Bay areas and sampling stations in the Galveston Bay system are shown in figure 10. The number of stations occupied and frequency of sampling varied between years. Samples were collected only during daylight, and complete coverage of the study area required 2 to 3 days. Data from all stations within a Bay area or for the entire Bay system were combined to show general seasonal trends for each environmental factor (fig. 11).

Streamflow data from the U.S. Geological Survey and air temperature data from the U.S. Weather Bureau were used to correlate with the factors measured during this study. Measurements of streamflow were from the Trinity River, the major tributary entering the Galveston Bay system, and measurements of air temperature were from Galveston, Tex.

Figure 10.--The Galveston Bay system showing bay areas, habitats, and hydrological or biological sampling stations.

Water temperature ranged from a monthly mean of 10.3° C. (50.5° F.) in January or February to a mean of 31.0° C. (87.8° F.) in July. Between years, minimum average monthly temperatures ranged from 10.3° C. (50.5° F.) to 12.8° C. (55.0° F.), whereas maximum temperatures ranged from 29.2° C. (84.5° F.) to 31.0° C. (87.8° F.). Temperatures were slightly higher in the winters of 1965 and 1966 than in 1963 and 1964. Maximum temperatures were higher in 1963 and 1966 than in 1964 and 1965.

Heat exchange is rapid between the Bay water and air and an equilibrium is attained readily; this is indicated by the similarity in the seasonal trends of water and air temperatures (fig. 11). The relatively consistent differences between air and water temperatures, however, are probably not real. Water temperatures taken during the day were used to compute monthly averages, whereas air temperatures averaged over a 24-hour period were used in computing monthly values.

Salinities in the Bay system ranged from a monthly mean of 4.8 p.p.t. in 1966 to 24.0 p.p.t. in 1963. Each year salinities were lowest in January-June, but increased in the summer and reached an annual high in the fall.

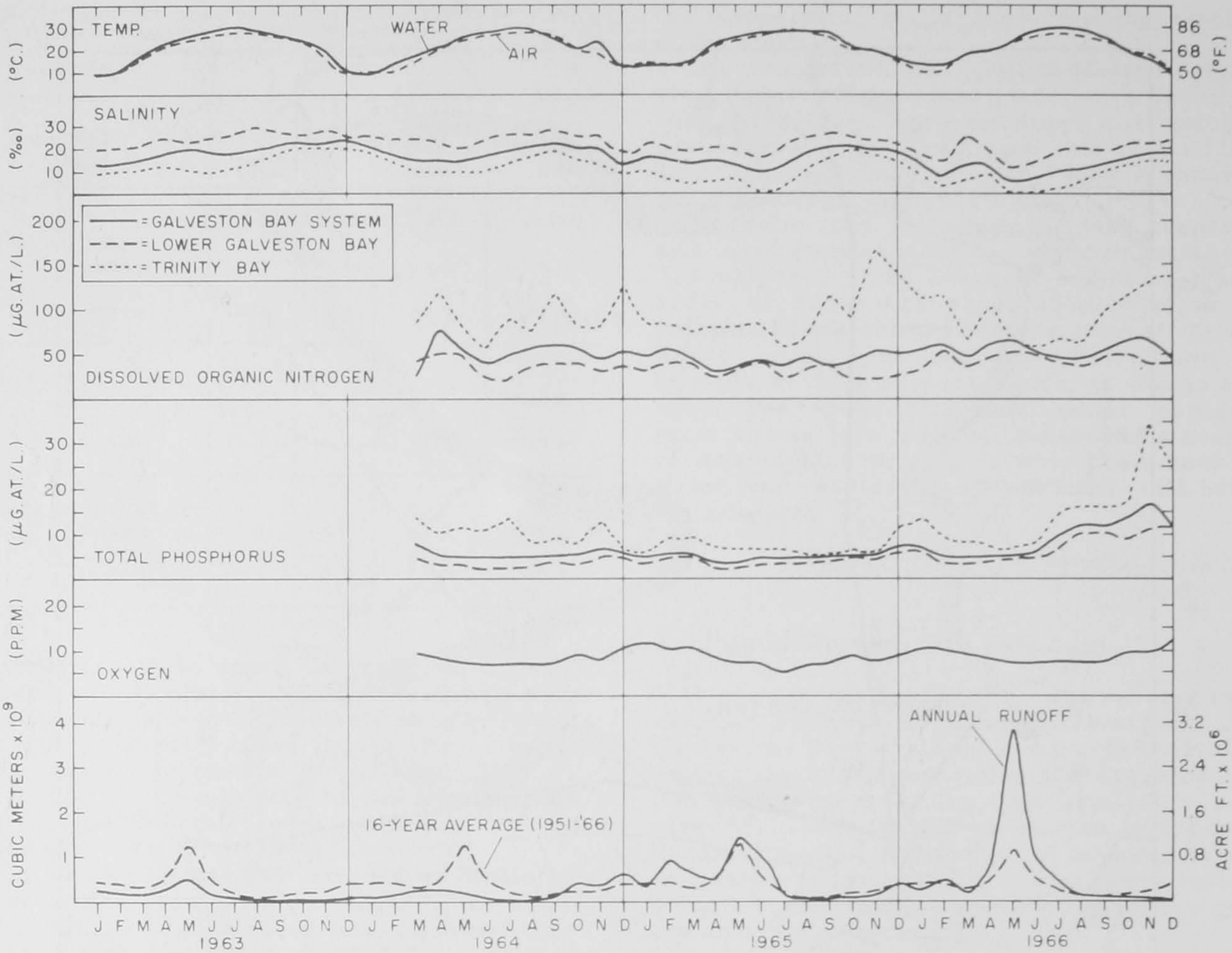

Figure 11.--Monthly mean values of air and water temperature, salinity, dissolved organic nitrogen, total phosphorus, and dissolved oxygen in Galveston Bay or selected Bay areas within the system in relation to Trinity River discharge.

Salinities were usually lowest in Trinity Bay, whereas the salinities were highest in lower Galveston Bay.

Streamflow had an important effect on salinities. Because discharge was below normal in 1963-64 and near normal in 1965, average yearly salinities tended to decrease slightly over this period; in 1966, when streamflow was considerably above average, salinities were extremely low.

Dissolved organic nitrogen ranged from a monthly average of 28.0 μg. at./l. (microgram atoms per liter) in March 1964 to 79.2 μg. at./l. in April 1964. Thereafter, monthly values generally decreased through 1964 and until early spring of 1965. In May 1965, the concentration of nitrogen increased and peaked in May and November 1966. In all seasons and years, values of nitrogen were always greater in the upper than in the lower portion of the Bay. No relation was apparent between the seasonal concentration of nitrogen and river flow.

Monthly mean values for total phosphorus ranged from 3.53 μg. at./l. in April 1965 to 17.42 μg. at./l. in November 1966. Monthly concentrations were relatively stable from March 1964 to June 1966, but increased sharply beginning in July 1966. Values continued to increase during the rest of the year, reaching an annual and a 3-year maximum in November 1966. Concentrations of phosphorus were highest in the upper Bay and lowest in the lower Bay. A relation was not apparent between the seasonal concentration of phosphorus and river flow.

Phosphorus and nitrogen were always higher in San Jacinto Bay than in lower Galveston Bay, probably because San Jacinto Bay is the first to receive water from the Houston area via the Houston Ship Channel. A large quantity of sewage and industrial and municipal water discharged into the upper reaches of the Houston Ship Channel is no doubt responsible for the high nutrient levels.

Monthly values of dissolved oxygen ranged from an average of 5.3 p.p.m. in July 1965 to 12.3 p.p.m. in December 1966. In general, concentrations of dissolved oxygen did not show distinct areal differences; values were irregularly distributed, probably in relation to biochemical processes. Fluctuations in oxygen were greatest in San Jacinto Bay where values ranged from 0.3 to 19.4 p.p.m., probably in response to varying concentrations of waste (pollutants) entering the Bay.

Monthly values of oxygen for the Bay system showed a distinct seasonal trend that was inversely related to the trend in air and water temperatures.

Abundance and size of brown shrimp in relation to habitat.--Brown shrimp were collected from 1963 to 1966 and during 3 months in 1967 at some or all of the stations shown in figure 10. Sampling frequency varied from once a month to several times a month.

The study area was arbitrarily divided into peripheral, open-water, shallow-channel (Gulf Intracoastal Waterway), and deep-channel (Houston Ship Channel) habitats; we analyzed the collected data to determine relative abundance and average size of brown shrimp in each area. The arbitrary division of the estuary is based on depth zones; table 11 gives the maximum and minimum depths for each area.

Average annual catches (numbers caught per 5-minute tow) of brown shrimp are shown by habitat in figure 12. Except for large catches in the shallow-channel zone in 1963 and 1964, catches decreased with increase in depth. In 1963 and 1964--the only years the shallow-channel habitat was studied--the catch of shrimp in that area was greater than the average catches in the other three habitats.

Yearly trends in seasonal abundance of brown shrimp are shown by habitat in figure 13. In 1963 and 1964 when shrimp were sampled in all areas, trends were generally similar except for a large catch in the

Table 11.--Maximum and minimum depths of four habitats in Galveston Bay

Habitat	Depth			
	Maximum		Minimum	
	M.	Feet	M.	Feet
Peripheral	1.2	3.9	0.6	2.0
Open-water	3.0	9.9	1.2	4.0
Shallow-channel	5.7	19.0	3.0	10.0
Deep-channel	14.5	48.0	11.5	38.0

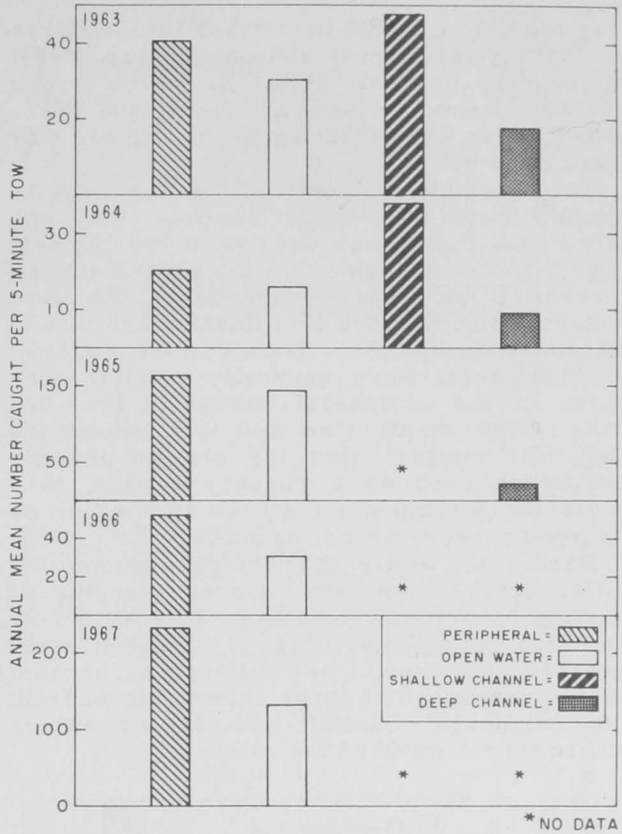

Figure 12.--Annual mean catch per unit effort of brown shrimp by habitats in the Galveston Bay system, 1963-67. (Asterisk indicates no data.)

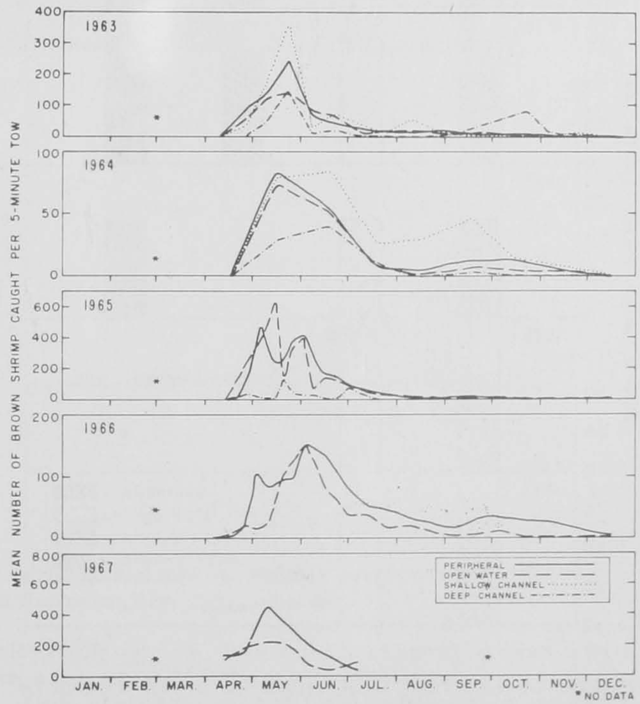

Figure 13.--Mean catch per unit effort of brown shrimp by date, habitat, and year in the Galveston Bay system, 1963-67.

Houston Ship Channel in October 1963. Catches of shrimp during peak abundance were lowest in the deep-channel habitat. Over the 5-year period, shrimp in the peripheral and open-water areas were most abundant between May 5 and June 5.

To illustrate differences in the size of shrimp from the various habitats, we combined data from each area on a yearly basis (fig. 14). It is apparent that the size of shrimp increased from the peripheral to the open water to the Houston Ship Channel habitats in all years except 1965. Shrimp in the shallow-channel area were generally smaller than those in the peripheral habitat in 1963 and 1964. This small size and high abundance (fig. 13) suggest that the shallow-channel habitat is used as a nursery ground, as a route for shrimp moving back to the Gulf or between nursery areas, or both.

During the early part of the season the differences between the average lengths of shrimp from the various habitats were nearly constant each year. As the season progressed, however, these differences became more pronounced as large shrimp moved from the peripheral habitat into deeper waters where they dominated the catches.

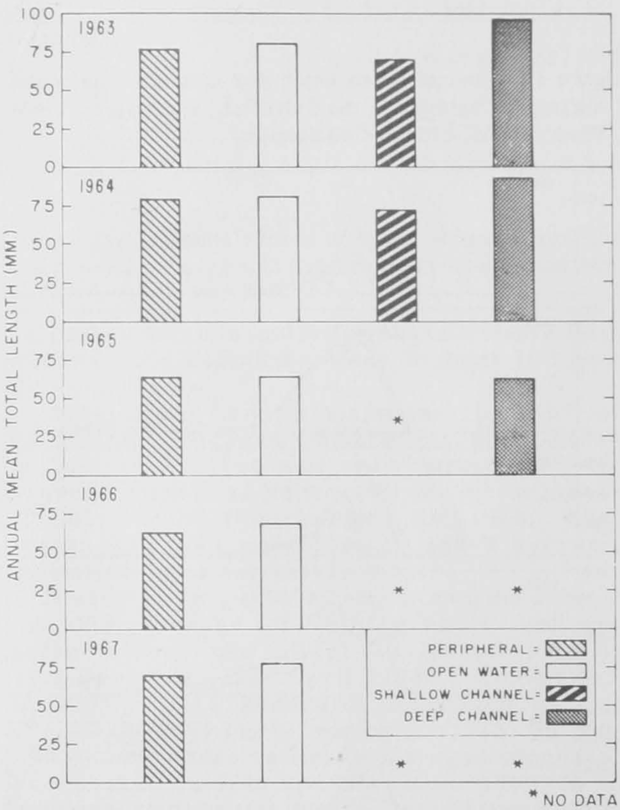

Figure 14.--Average total length of brown shrimp by habitat and year in the Galveston Bay system, 1963-67. (Asterisk indicates no data.)

Distribution of sciaenid fishes in relation to temperature and salinity.--In 1963 and 1964 biological sampling on a monthly or semimonthly basis in Galveston Bay provided data on seasonal distribution and abundance of several species of fish. Collected concurrently with these samples were measurements of temperature and salinity. This past year we analyzed these data to determine the frequency of occurrence and abundance of the four most common species of sciaenids in relation to temperature and salinity.

The four sciaenids taken most frequently in catches were the croaker, spot, sand seatrout, and the southern kingfish. Their levels of abundance differed greatly. The average number caught per 5-minute tow with a 0.6- by 3.0-m. (2- by 10-foot) trawl were croaker - 86.7, spot - 7.6, sand seatrout - 4.5, and southern kingfish - 0.2.

For each species, the frequency of occurrence (percent) and average number caught per tow were plotted against 2° C. (3.6° F.) temperature and 2 p.p.t. salinity intervals (fig. 15). Not included were temperature and salinity intervals in which less than 10 tows were made.

The entire range of temperature and salinity measured in Galveston Bay appeared generally suitable for each species, but conditions for greatest abundance varied between species. Croakers were taken frequently at all temperatures and salinities but were most abundant in temperatures from 14° C. (57.2° F.) to 29° C. (84.2° F.) and in salinities from 2 to 21 p.p.t.

Spots also were taken at all temperatures and salinities recorded in the Bay, but greatest catches were at temperatures at and above 22° C. (71.6° F.) and in salinities from 4 to 25 p.p.t. Frequency of occurrence and the abundance of spot increased generally with an increase in temperature, but decreased at salinities above 22 p.p.t.

Temperature appeared to affect the frequency of occurrence and abundance of the sand seatrout more than did salinity. This species was taken most often at temperatures of 20° C. (68.0° F.) and above, and catches were largest in waters 24° C. (75.2° F.) or higher. With the possible exception of the highest and lowest values encountered, this species did not appear to be affected by salinity.

We caught the southern kingfish most often and in greatest numbers in temperatures of 20° C. (68.0° F.) and above, and in salinities 24 p.p.t. and greater.

Habitat rehabilitation.--We used two techniques to establish an environment suitable as a nursery ground for postlarval and

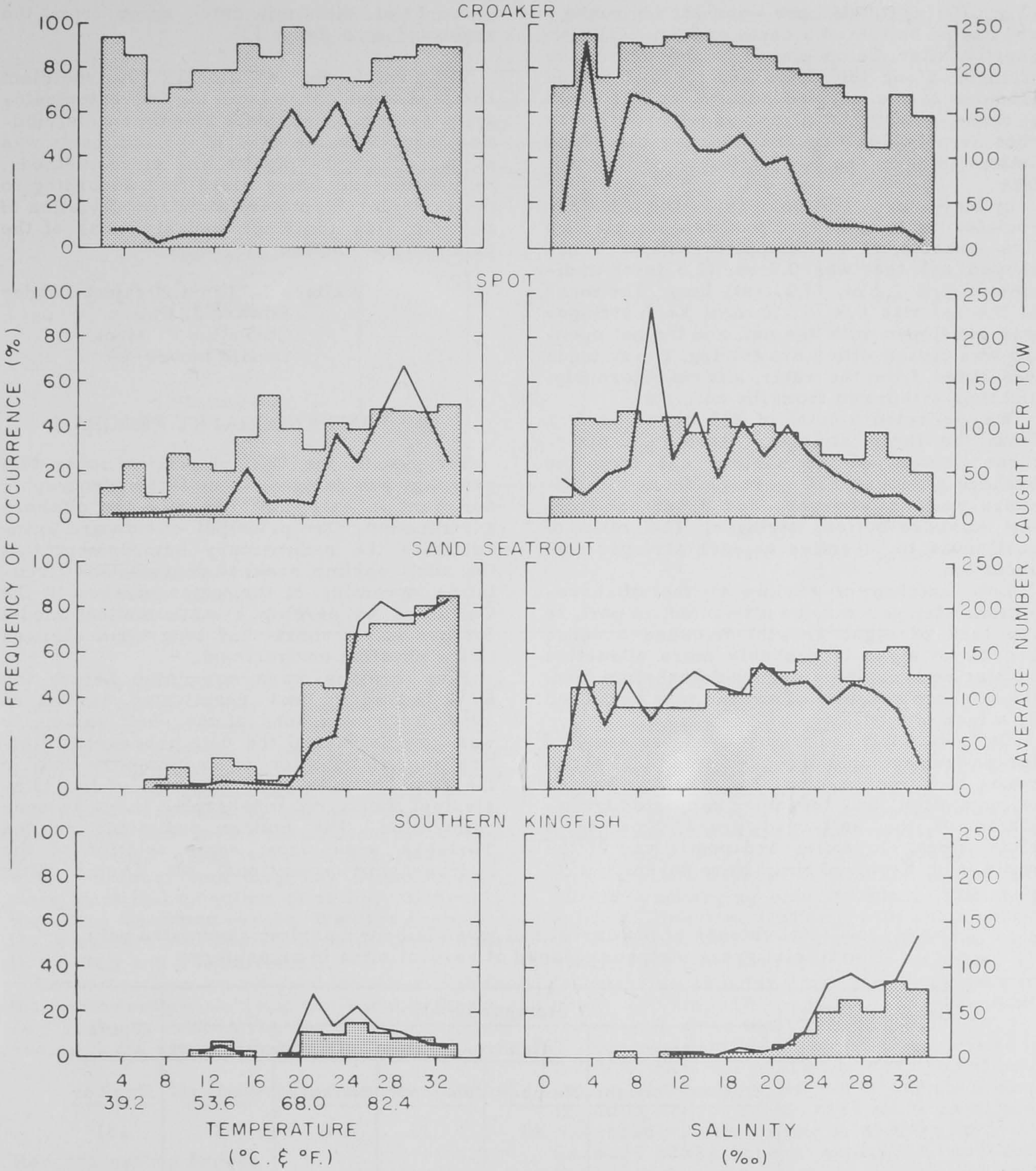

Figure 15.--Percentage frequency of occurrence of four fishes (shading) and average number caught per tow (line) in relation to salinities and temperatures in Galveston Bay, Tex., 1963-64.

juvenile shrimp. One was the placement of three stringers of an artificial grass (polypropylene ribbon) along a barren shoreline; the second was to transplant Spartina alterniflora, a natural emergent grass, in an area void of natural vegetation.

One stringer of artificial grass was placed along a shoreline, and two were placed about

15 m. (50 feet) offshore--one at the surface and one on bottom at a depth of 0.9 m. (3 feet). Shortly after being placed in the water, the stringer along the shore and the one placed offshore at the surface became covered with a dense growth of algae. Algal growth was considerably less on the stringer placed on bottom than on the two stringers at the surface.

In May, June, and July 1967, the biota associated with each stringer was sampled on five occasions; we sampled with a cone-shaped net that was 0.7 m. (2.3 feet) in diameter and 1.2 m. (3.9 feet) long. The mesh of the net was 0.9 to 1.0 mm. Each stringer was enveloped with the net, and the net opening was closed with a drawstring. The stringer was lifted from the water, shaken vigorously, and then withdrawn from the net.

We collected a total of 235 brown shrimp from the three stringers (table 12). Sixty-three percent of the shrimp was from the onshore stringer, 34 percent from the offshore-surface stringer, and 3 percent from the offshore-bottom stringer. The ratio of postlarvae to juveniles at each stringer was about 1:1.

Low catches of shrimp at the offshore-bottom stringer may be attributed, in part, to the lack of algal growth. Because a dense growth of algae is probably more attractive to marine organisms upon which shrimp feed, the offshore scarcity of shrimp may be caused by a lack of food.

Between April and August 1967, we sampled for shrimp monthly along two intertidal shore zones of a spoil mound. One zone was barren of vegetation, and the other supported transplants of the salt-cord grass, Spartina alterniflora. Juveniles and postlarvae of the white and brown shrimp were taken, but 90 percent of the total catch came from the vegetated zone (table 13).

Sediments.--An additional 700 sediment samples were taken from the Galveston estuarine system to complete a sediment distribution map. Particle size of the sediments was measured by the pipette and sieve methods. Sediments are being classified according to their median diameter, standard deviation of particle size (sorting), and skewness of the particle distribution.

Wallace L. Trent, Project Leader
Edward J. Pullen
Cornelius R. Mock
Donald Moore

GULF OCEANOGRAPHY PROGRAM

Surveys in the Gulf of Mexico under this program are designed to collect hydrographic and benthic data that describe the offshore environment. Our principal efforts are to investigate the sedimentary environment that the adult shrimp seek, to describe the circulation dynamics of the water masses in the Gulf, and to develop a mathematical model for predicting short- and long-term changes in the physical environment.

Five cruises were completed before the R/V Geronimo was deactivated in March 1968. Reconnaissance of the shelf sediments was completed and the data processed. Plotting the distribution of sedimentary data in the Dry Tortugas area and east of the Mississippi Delta on topographic maps is near completion. The bottom sediments in the Tortugas area show some relation to the hydrographic conditions; we found little

Table 12.--Total catches of postlarval and juvenile brown shrimp associated with artificial grass stringers placed at several sites in an estuary

Developmental stage	Stringer location						Total
	Onshore		Offshore-surface		Offshore-bottom		
	Number	Percent	Number	Percent	Number	Percent	Number
Postlarval	84	64	43	33	4	3	131
Juvenile	63	61	38	36	3	3	104
Total	147	-	81	-	7	-	235
Percentage of total catch	63	-	34	-	3	-	

Table 13.--Total catches of postlarval and juvenile brown and white shrimp along a barren and a rehabilitated spoil bank

Species and stage	Shore zone				
	Vegetative		Barren		Total
	Number	Percent	Number	Percent	Number
Brown shrimp					
Postlarval	85	89	10	11	95
Juvenile	27	90	3	10	30
White shrimp					
Postlarval	1	100	0	0	1
Juvenile	4	100	0	0	4
Total	117	-	13	-	130
Percentage of total catch	90	-	10	-	100

relation to the north on the southern Florida shelf. In another study, plumes of sediment-laden water (determined from space photographs) were found to extend offshore over some of the most productive shrimp fishing grounds off the Texas coast.

Although analyses of the data are still in progress, we examined the physical properties of the water along selected transects. Six water masses, including new bottom water, were identified by values of salinity, temperature, and dissolved oxygen. We also computed the surface circulation in summer and winter in the Gulf and Yucatan Strait.

Concentrations of zooplankton were high in the northwestern Gulf and the Yucatan Strait-Dry Tortugas area in regions of upwelling and eddies in the summer and winter.

John R. Grady, Acting Program Leader

Reconnaissance Survey

Bottom sediments.--Field work for the sedimentary reconnaissance of the Continental Shelf and upper slope was completed this year. The final cruise to sample the Gulf Coast shelf, including the detailed survey of the Dry Tortugas area, ended in November. At this time we collected bottom samples from the shelf and upper slope off the coasts of Mississippi, Alabama, and Florida (fig. 16).

Analyses of the physical data on the bottom sediments are complete, but we are continuing to measure the carbon and nitrogen.

West of De Soto Canyon, sediments on the shelf are principally detrital, whereas to the east the detrital component decreases until off southern Florida the sediment is essentially carbonate shell and debris. Lack of terrigenous detritus in the sediments results from the low terrain of Florida and the few rivers discharging onto the shelf. The shelf, a broad limestone platform with a thin veneer of sediment and irregular patches of algal reefs, has an average depth of 65 m. (36 fathoms) at its outer edge. It extends seaward about 200 km. (124 nautical miles) to maximum width at its most southern end.

Previous detailed surveys of sediments on the Florida shelf to 180 m. (98 fathoms) indicate a narrow zone of quartz and shell sand, including the adjacent beach sands parallel to the coast but diminishing in width to the south. Seaward of the zone of quartz sand is a carbonate facies that extends across the shelf and slope. Divisions of the carbonate sediments into zones that extend to the outer edge of the shelf are based on the abundance of shell, algal fragments, oolite, or foraminiferal material. The distribution of these sediments south of the 26th parallel can now be delineated.

Of added interest in this area are the relic beaches that consist of stained and rounded

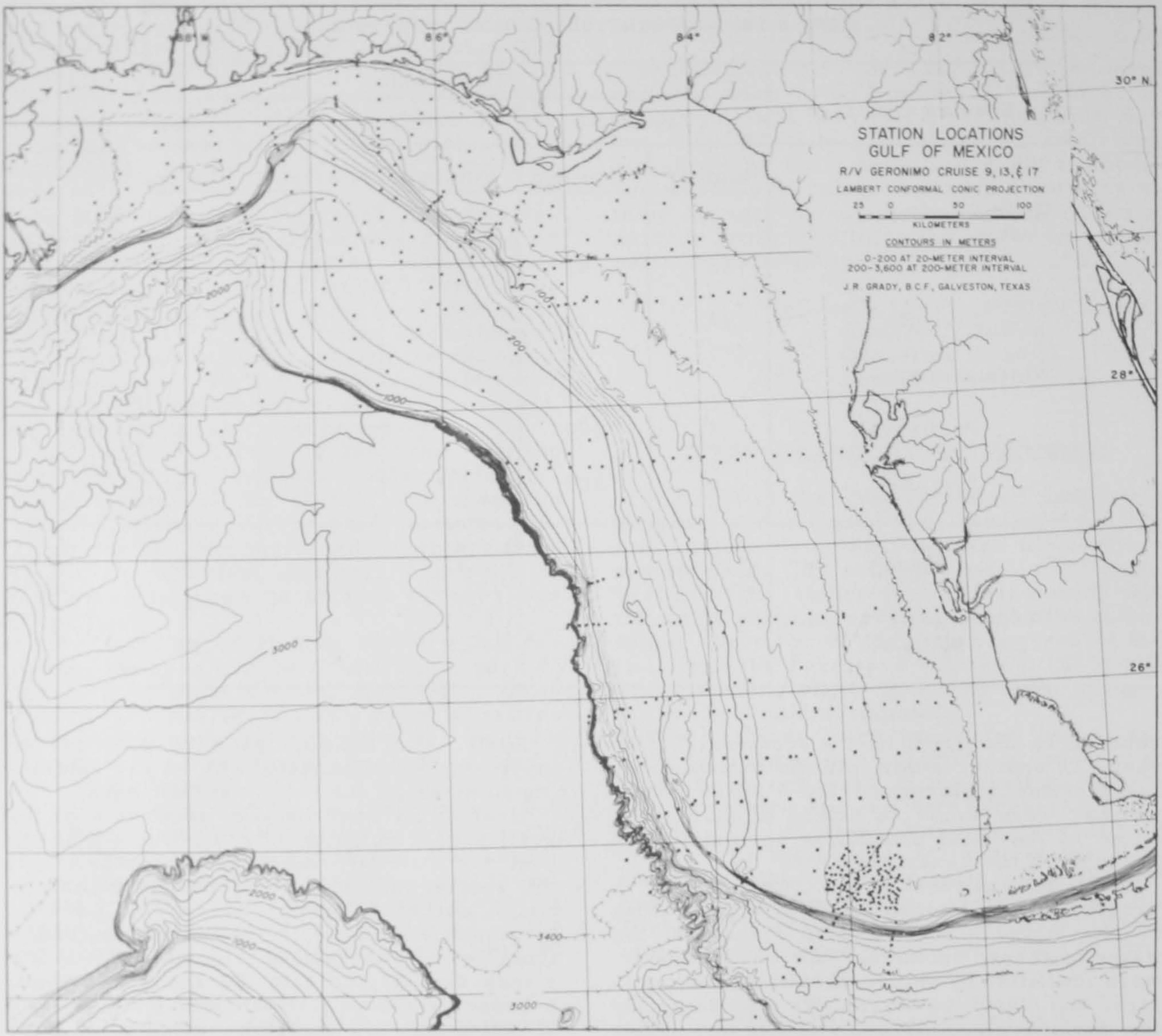

Figure 16.--Location of bottom grabs and cores taken in the Gulf of Mexico on the Continental Shelf and slope east of the Mississippi Delta.

foraminifers, mollusk shells, echinoid spines, and fragments of cemented aggregates of shells and carbonate that are spread across the shelf. The deepest of these exposures is in 320 m. of water (175 fathoms) and 80 km. (50 nautical miles) offshore.

On the shrimping grounds off Galveston, Tex., an intensive survey was started to evaluate properties of the bottom sediments that may affect shrimp abundance. Samples are collected every 1.6 km. (1 nautical mile) on profiles 5 km. (3 nautical miles) apart that extend seaward to 70 m. (38 fathoms). Of primary interest are the particle-size distribution and the organic content. The resulting data are to be compared with the distribution of adult shrimp in this area, known from the shrimp catch, and to similar data from the area of the Dry Tortugas.

Analyses of particle size of the sea floor sediments collected on the cruise to the Yucatan Strait in February were completed. These samples were taken principally on the western side of the Strait with a van Veen grab. Nearly all the sediments have a sand fraction greater than 50 percent, and a few are essentially all sand. Within the sand-size fraction, 90 percent of the distribution lay in the medium to fine grade. Color, which reflects the organic source of the sediments, varied from chalky white to buff to light brown.

A few samples from the northern and southern portions of the Strait contained stained, well-worn shells of ancient marine faunas. Some of these were foraminifers of the shallow water Archaias and Amphistegina assemblages and were similar to samples dredged on the southern Florida shelf. Fossil planktonic foraminifers of Miocene and Pliocene age were also in the bottom samples. The deepest of these exposures was 612 m. (335 fathoms).

In the surface waters, concentrations of planktonic foraminifers were higher in the areas of upwelling over the Campeche Bank and Slope than in the waters in the central part of Yucatan Strait. In the Strait, the velocity of the northward-moving current, computed from surface density data, was greater in February 1968 than in February 1967. The related upwelling also was more intense. The axis of the stream was on the west side of the Strait and paralleled the slope of the Campeche Bank between the 100- and 1,000-m. (55- and 547-fathom) depth contours.

The particle size of the bottom sediments appears related to the flow. Winnowing of the slope sediments seems clear and apparently has been a constant feature of the environment throughout the Recent Epoch.

Waters in the southern Gulf.--Data from seven stations were selected from the second hydrographic survey of the Gulf (August-October 1967) to illustrate some of the variable properties of the Gulf water masses. Because of the circulation in these waters, we chose a transect from Yucatan Strait to the western Gulf of Mexico. One of the properties examined, dissolved oxygen, though not a conservative property of sea water as are salinity and temperature, aides in tracing the water masses in the Gulf.

The most prominent characteristic of the distribution of dissolved oxygen is the oxygen minimum (fig. 17). The usual minimum in the world ocean is between 700 and 1,000 m. (383-547 fathoms). The minimum layer in the Yucatan Strait, at a depth of 700 m. (383 fathoms), had an oxygen content of 2.98 ml./l. In the western Gulf, the oxygen minimum rose to 300 m. (164 fathoms), and the content decreased to 2.64 ml./l. The minimum lies at the boundary of the overlying Subtropical Underwater and the underlying Antarctic Intermediate Water.

John R. Grady, Project Leader

Circulation Dynamics

The main activities in this project during the year were planning and conducting two oceanographic surveys in the Gulf of Mexico and then reducing the data obtained. Cruise 16 of the R/V Geronimo (August 14 to October 8, 1967) was the second of an expected series of cruises, each of which is planned to provide information on the entire Gulf of Mexico. The cruise and station plan used for the second "All-Gulf" cruise (fig. 18) is basically the plan that will be used on any succeeding "All-Gulf" operations. The 151 hydrographic stations, 298 bathythermograph casts, and 260 plankton hauls during Cruise 16 make it the most comprehensive oceanographic survey of a sea that has been conducted.

A preliminary analysis of some of the data from Cruise "All-Gulf II" indicates six distinct water masses, five of which enter the Gulf through Yucatan Strait and the sixth forms at the surface in the western Gulf. The same six water masses were present during the first "All-Gulf" survey (Cruise 12 of the R/V Geronimo, February 20 to April 1, 1967), but the one that occupies the bottom 2,000 m. (1,094 fathoms) in the Gulf was more distinct during Cruise 16 than during Cruise 12. This bottom water mass is of particular interest to us because it was not present during a survey of the Gulf by the R/V Hidalgo (Texas A&M University) in February-March 1962.

Percentages of change in the deepest water were determined for each station of our two "All-Gulf" cruises relative to the data from the survey by Texas A&M University. The distribution of these percentages indicated that the bottom 2,000 m. (1,094 fathoms) of water in the western Gulf was moving in a clockwise direction at an average speed of about 3 to 5 cm./sec. (0.06 to 0.10 knot). Although the speed is low, the volume transport is large; consequently, the energy associated with the circulation is large. The energy is such that the bottom water motion would, conceivably, impart a circulation to the surface layers that could not be overcome, or even balanced, by the prevailing winds over the western Gulf if the wind stress were in an opposing direction. The shelf waters of the Gulf, therefore, are believed to be moving in response to the deep-water circulation.

Two particularly significant questions concern the entrance of this new botton water into the Gulf:

(1) How does this bottom water enter the Gulf?--The sill depth at Yucatan Strait is about 2,100 m. (1,148 fathoms), but the new bottom water is most distinct in the Gulf near the bottom (about 3,500 m. or 1,914 fathoms). It is also present in the northwestern Caribbean in similar concentrations at about the same depth.

(2) The fact that new bottom water is entering the Gulf requires that an equal volume of bottom water leave the Gulf--how is this

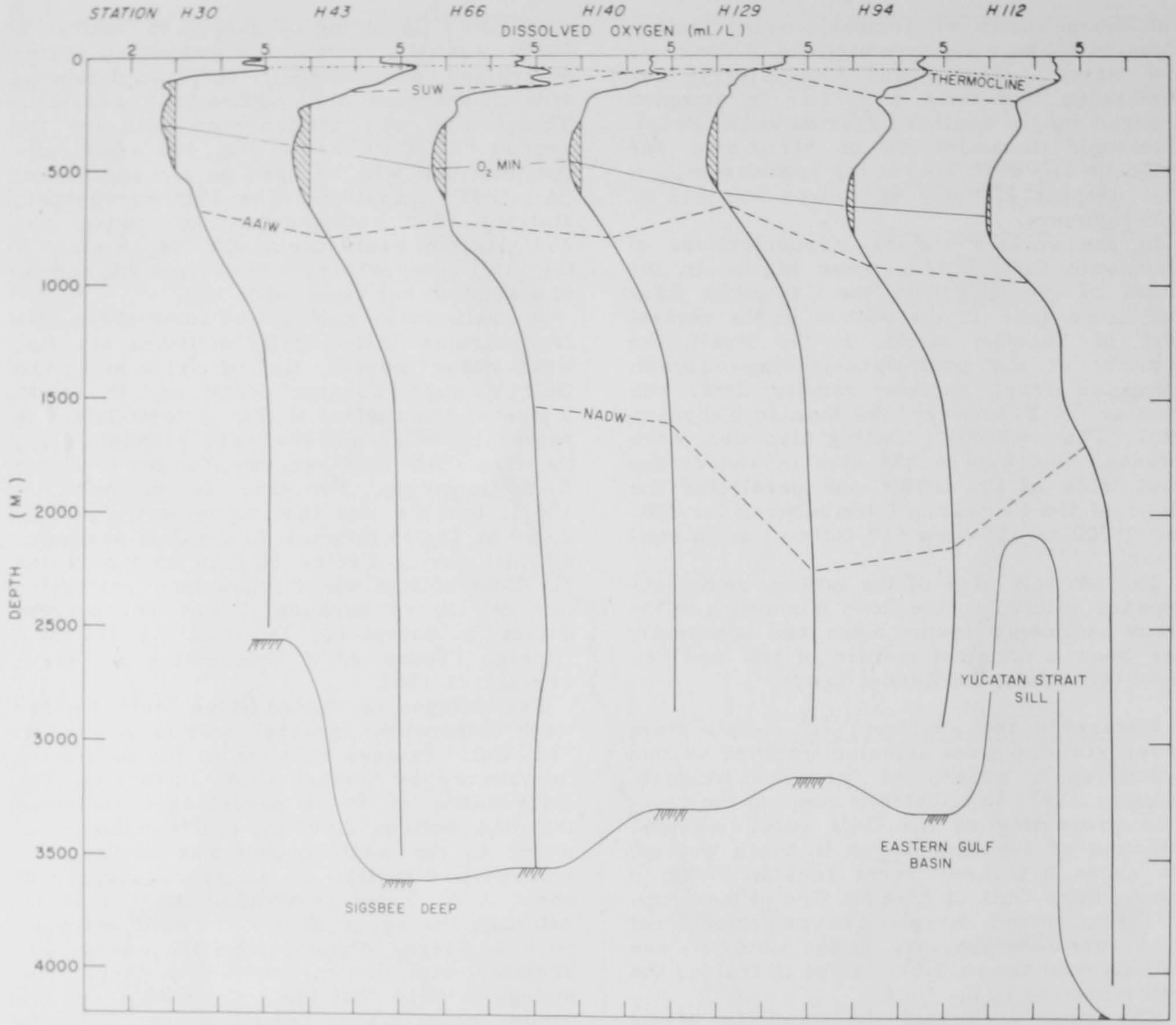

Figure 17.--Vertical profiles of dissolved oxygen in the Gulf of Mexico showing the oxygen minimum layer (horizontal solid line), the top of the thermocline (horizontal dotted line), and the cores of the water masses (horizontal dashed lines). Solid line below oxygen curves indicates depth to bottom at these stations.

effected? The upper layers of water in the Gulf enter Yucatan Strait and depart by the Florida Straits, but the sill depth of the Florida Straits is something less than 800 m. (437 fathoms).

One of the purposes of Cruise 20 of the R/V Geronimo (February 8 to March 5, 1968) to Yucatan Strait (fig. 19) was to obtain information that might give some clues to answer the two previous questions. The primary purpose of the cruise, however, was to make a preliminary hydrographic survey of Yucatan Strait before a similar operation is made as "ground truth" for the photography that will be taken during the first manned Apollo spaceflight. The preliminary cruise was made to determine if the cruise and station plan was adequate to describe the water motions in Yucatan Strait.

Treatment of the data from Cruise 20 is still in progress, but analysis of the surface data indicates that the surface currents over the Continental Slope off the eastern side of the Campeche Shelf were probably stronger during this cruise than was indicated by the data from Cruise 12 of the R/V Geronimo 1 year earlier. Upwelling on the Campeche Shelf also was more intense during the winter of 1968 than of 1967. Finally, the large cross-stream gradients of temperature, salinity, and density in this strong northward flow were absent downstream in the southwestern area of Yucatan Strait. This condition probably

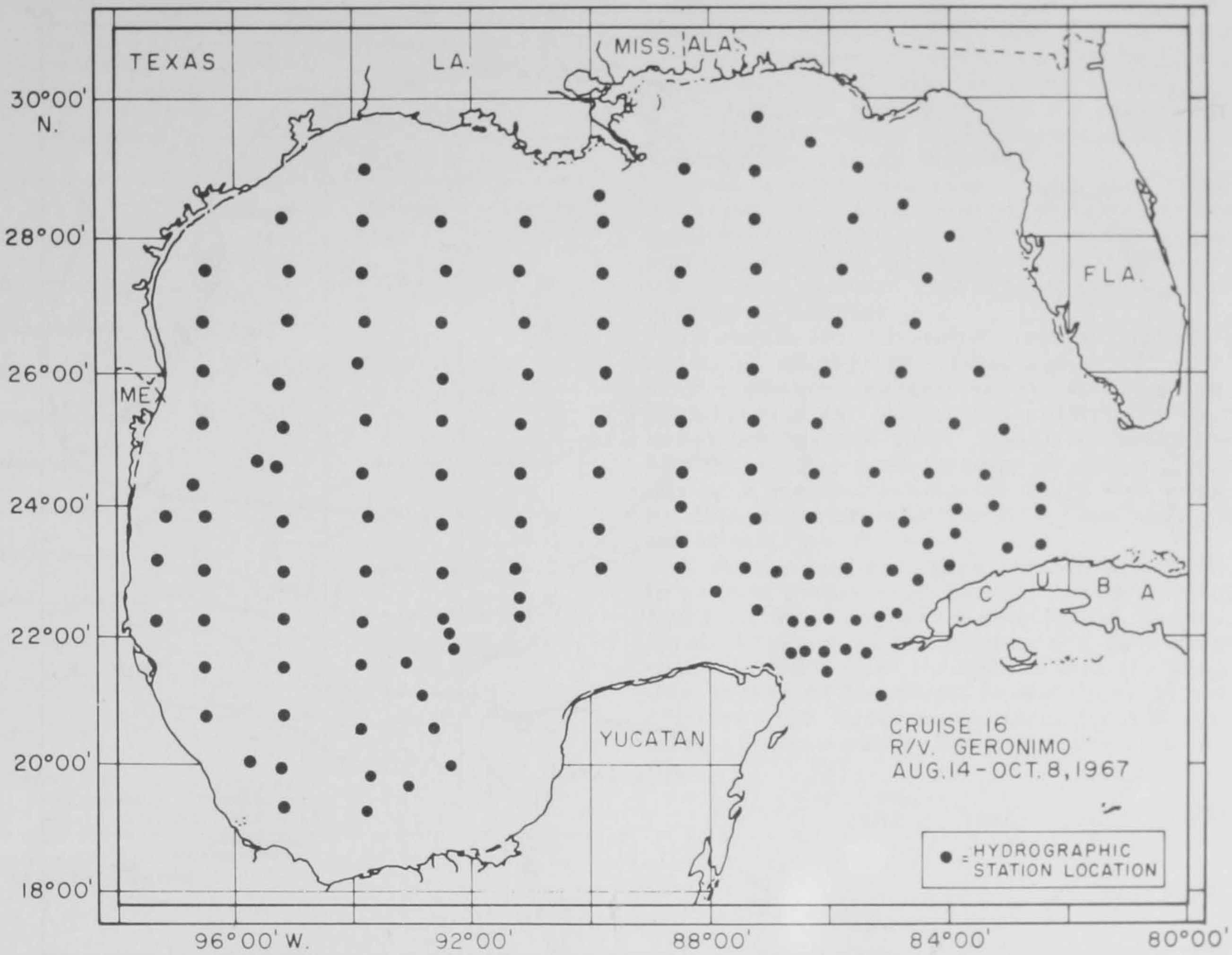

Figure 18.--Station plan for Cruise 16, "All-Gulf II" of the R/V Geronimo, August 14 to October 8, 1967.

resulted from the fact that the core of the current was in water so shallow, and that the bathymetry was of such a configuration, that upwelling, which causes the gradients, could not occur.

Toward the end of the year, a program was initiated to computerize the hydrographic data collected during Cruises 12, 16, and 20 of the R/V Geronimo.

Reed S. Armstrong, Project Leader

Biological Applications

The purposes of this project are to determine the major planktonic constituents and their distribution in the euphotic waters of the Gulf of Mexico. To accomplish this end, we collected samples of zooplankton and phytoplankton, together with physical and chemical data, during all cruises of the R/V Geronimo.

Samples of zooplankton were collected by making vertical hauls from 100 m. (55 fathoms) with metered NV-70 nets having a mesh aperture of 0.33 mm. and a mouth diameter of 70 cm. (28 inches). At the laboratory, major groups of plankters were separated from one-fourth of each sample, counted, and stored for future identification to species. Faunal groups considered were: appendicularians, amphipods, chaetognaths, copepods, euphausiids, fish larvae, gastropods, mysidaceans, natantids, ostracods, reptantids, and foraminifers.

Phytoplankton was collected by making 35-m. (19-fathom) vertical tows with nets having mesh aperture of 0.0035 mm. and a mouth diameter of 22 cm. (9 inches). Sayed El-Sayed of the Department of Oceanography at Texas A&M University is examining these samples.

Although samples of zooplankton were collected throughout the Gulf, emphasis was placed this year on the analysis of samples

Figure 19.--Station plan for Cruise 20 of the R/V Geronimo to Yucatan Strait, February 8 to March 5, 1968.

from the southeastern Gulf of Mexico-Yucatan Strait area. The percentage occurrence of major groups (table 14) in that area varied little among cruises in March 1967 (GO-12), August to October 1967 (GO-16), and February to March 1968 (GO-20). On the basis of average values for the three cruises combined, copepods accounted for 45 percent of the total catch, unidentified zooplankton 23 percent, appendicularians 11 percent, chaetognaths 6 percent, and the remaining nine groups 4 percent or less.

Major concentrations of copepods occurred over the Continental Shelf and slope off Florida Yucatan (fig. 20). Slight variations were apparent, however, between seasons. In the late winter of 1967 (GO-12) and 1968 (GO-20), the concentrations of copepods along the coast of Yucatan extended farther northward into the Gulf of Mexico than during the late-summer cruise (GO-16). In addition, a major concentration of copepods, which was not apparent in the winter cruises, was detected in the deep waters northwest of Cuba in the late summer. Catches were greater over a larger portion of the study area during the last cruise (GO-20) than during the preceding two cruises.

Charles J. Guice, Project Leader
Virginia Longley
Idia Whitfield

Space Applications

Realization that applications of space oceanography would prove of great significance to fisheries became obvious from a preliminary examination of color photographs taken on the manned Gemini spaceflights. Supported by NASA (National Aeronautics and Space Administration), a catalogue of large-

Table 14.--Percentage occurrence of major zooplankton groups in the southeastern Gulf of Mexico-Yucatan Strait area in March 1967, August-October 1967, and February-March 1968

Major groups	R/V Geronimo cruises		
	GO-12	GO-16	GO-20
	Percent	Percent	Percent
Copepoda	45	43	49
Appendicularia	7	15	10
Chaetognatha	7	5	6
Ostracoda	5	2	5
Foraminifera	2	8	1
Natantia	3	6	2
Gastropoda	1	1	2
Euphausiids	*	1	2
Amphipoda	*	*	2
Reptantia	1	*	*
Fish larva	*	*	*
Mysidacea	*	*	*
Unidentified zooplankton	29	19	21

*Less than 1 percent

scale oceanographic features, such as eddies, upwelling, convergences, divergences, and current boundaries that were photographed, was published. A similar index considering meteorological and oceanographic phenomena photographed during the unmanned Apollo 502 spaceflights is being prepared.

Space photographs taken of the Gulf coast of Texas have already produced information applicable to fishery problems, such as current directions, turbidity, plumes of sediment-laden water extending offshore, and current boundaries.

To obtain the full value from an interpretation of photographs from space that show visible features associated with the dynamic structure of the water, sea surface surveys known as "ground truth" must accompany the overflight. The first attempt at ground truth during a manned spacecraft flight was made by this program with the R/V Geronimo off the Mississippi Delta.

A survey has now been planned with NASA to provide ground truth for the coming manned Apollo orbit. The area selected is Yucatan Strait because of the intense and persistent currents that flow through it into the Gulf. Our survey of the Strait in February-March 1968 was the first sea-surface, ground-truth effort in preparation for a spacecraft overflight.

John R. Grady Project Leader

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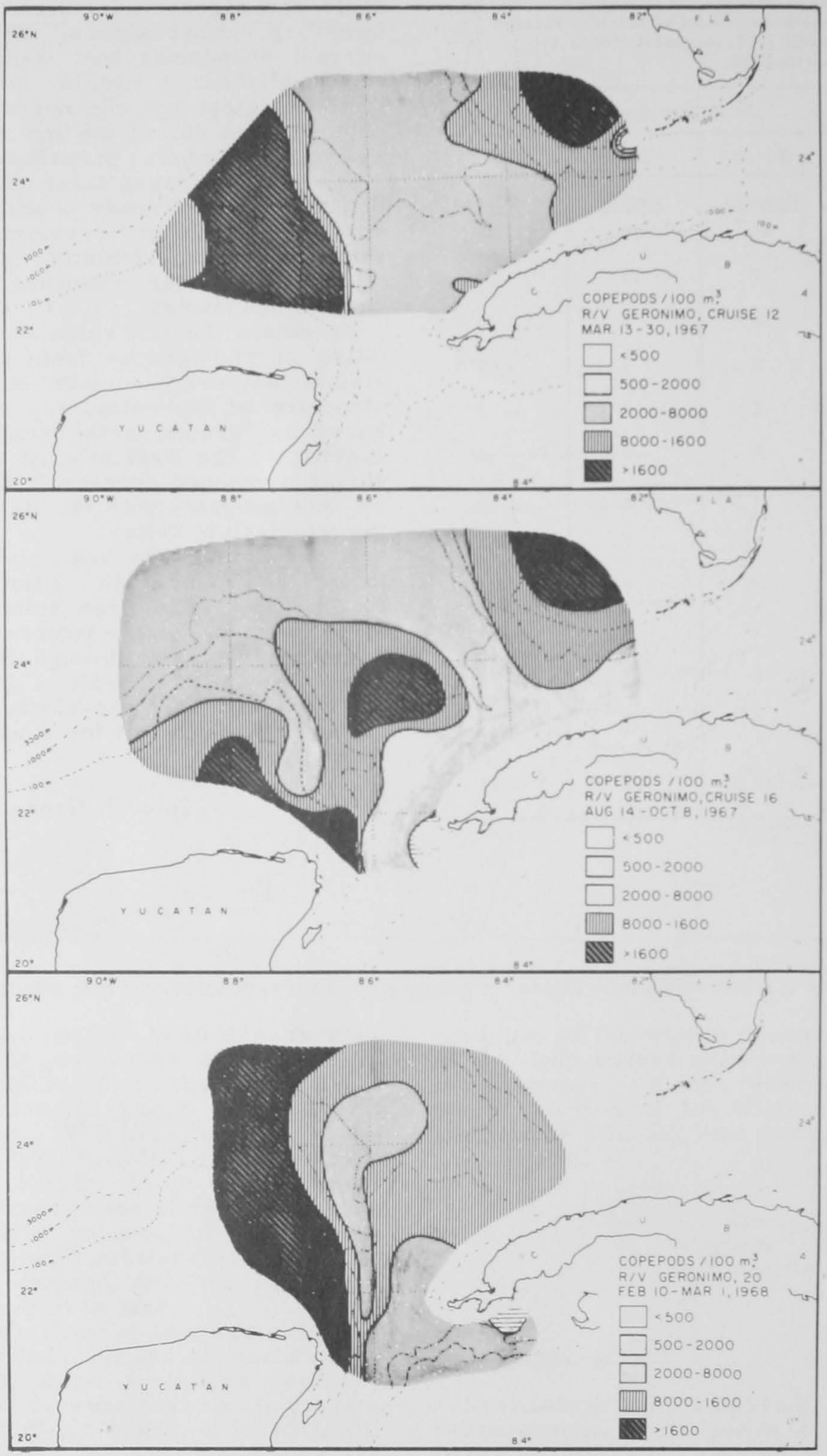

Figure 20.--The distribution of copepods in the southeastern Gulf of Mexico in March 1967 (GO-12), August to October 1967 (GO-16), and February to March 1968 (GO-20).

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