

REPORT OF THE  
BUREAU OF  
COMMERCIAL FISHERIES  
BIOLOGICAL LABORATORY  
GALVESTON, TEXAS  
FISCAL YEAR 1966



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



UNITED STATES DEPARTMENT OF THE INTERIOR

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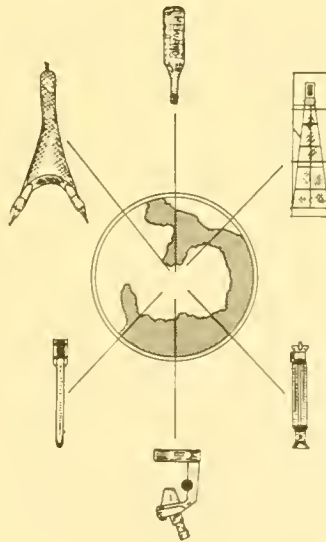
BUREAU OF COMMERCIAL FISHERIES, Harold E. Crowther, *Acting Director*

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

**Fiscal Year 1966**

Milton J. Lindner, *Director*

Robert E. Stevenson, *Assistant Director*



Contribution No. 226, Bureau of Commercial Fisheries  
Biological Laboratory, Galveston, Texas

Circular 268

Washington, D.C.  
September 1967

The Bureau of Commercial Fisheries Biological Laboratory, Galveston, Tex., and its field stations 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 Don Ce-Sar Federal Center (P.O. Box 6245), St. Petersburg Beach, Fla. 33736.

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Radiobiological Laboratory, Beaufort, N.C.  
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## CONTENTS

	Page
Report of the Director . . . . .	1
General . . . . .	1
Laboratory facilities . . . . .	2
Public relations . . . . .	2
Foreign visitors . . . . .	2
Foreign trainees . . . . .	2
Laboratory activities . . . . .	2
Publications . . . . .	2
Manuscripts in press . . . . .	3
Manuscripts submitted . . . . .	3
Shrimp biology program . . . . .	3
Larval distribution and abundance . . . . .	4
Distribution and abundance, January-September 1964 . . . . .	5
Overwintering . . . . .	5
Identification and culture of shrimp larvae . . . . .	6
Rearing of larvae . . . . .	6
Larval food cultures . . . . .	7
Cultivation of shrimp in artificial ponds . . . . .	7
Ecologically associated organisms . . . . .	8
Florida Bay ecology studies . . . . .	9
Relation of variations in abundance of juvenile pink shrimp emigrating from the Everglades National Park Estuary to the commercial catch . . . . .	11
Seasonal changes in relative abundance of postlarvae of pink shrimp entering the Everglades Estuary . . . . .	12
Shrimp dynamics program . . . . .	12
Population studies . . . . .	13
Postlarval and juvenile shrimp . . . . .	14
Postlarvae . . . . .	15
Juvenile shrimp . . . . .	15
Inshore currents . . . . .	16
Mark-recapture experiments . . . . .	16
Population dynamics of white shrimp and brown shrimp in Ver- milion Bay, La. . . . .	19
Estuarine program . . . . .	19
Ecology of western Gulf estuaries . . . . .	21
Hydrology . . . . .	21
Species diversity . . . . .	23
Relative abundance and distribution of major species . . . . .	24
Brown shrimp study . . . . .	24
Natural and altered habitats for penaeid shrimp . . . . .	26
Blue crab study . . . . .	26
Effects of engineering projects . . . . .	28
Evaluation of estuarine data . . . . .	29
Experimental biology program . . . . .	30
Behavior and ecological parasitology . . . . .	30
Metabolism of estuarine organisms . . . . .	31
Growth and survival . . . . .	32
Gulf oceanography program . . . . .	33
The air over the Gulf . . . . .	33
Waters entering the Gulf . . . . .	36
Extreme modifications of Gulf waters . . . . .	39
Library . . . . .	43



**BUREAU OF COMMERCIAL FISHERIES  
BIOLOGICAL LABORATORY, GALVESTON, TEXAS,**

**Fiscal Year 1966**

**ABSTRACT**

A progress report of the research at the Laboratory in Galveston. Emphasis is on shrimp, and the research involves the fields of biology, population dynamics, ecology, experimental biology, and oceanography.

**REPORT OF THE DIRECTOR**

**GENERAL**

The total landings of shrimp in 1965 (140 million pounds) constituted the fifth best year since 1950 for the U.S. shrimp fishery. Yet, this volume was but 40 percent of the shrimp made available to the U.S. public. For the fifth successive year, the U.S. shrimp catch was less than 50 percent of the total poundage available in our country; the remainder was imported.

This situation has been brought about by three unrelated factors. First, the population growth (152 to 194 million in 15 years); second, the increased per capita consumption of shrimp (0.79 to 1.41 pounds); and third, the lack of increase in U.S. shrimp catches. Although the catch has varied from year to year--the greatest in 1954 (158 million pounds) and the least in 1961 (91 million pounds)--there has been no general increase in the 15 years since 1950.

If a continued increase in population and per capita consumption, and stability in the shrimp catch are assumed, then the disparity between volumes of domestic and foreign shrimp will continue to grow. This disparity is not unique to shrimp. Other fisheries fail to produce the major portion of the volume available to the U.S. public. Tuna is another significant example; its domestic-to-foreign ratio in 1965 was about the same as for shrimp.

In dollar value shrimp and tuna are in the top three fisheries--shrimp made up 18 percent of the 1965 total value and tuna 10 percent. Because of the value of these fisheries, especially shrimp, any decrease of domestic and increase of foreign supply constitutes a distinct dollar drain on the U.S. economy. Any

investigations into the fishery must, therefore, be to devise methods and techniques and to provide knowledge that will decrease this economic drain.

The ultimate goals of fishery research are crop management and crop prediction. Once the management principles are known, their significant application becomes prediction. The earlier the prediction the more economic the fishery.

It is to crop management and prediction that the efforts at the Bureau of Commercial Fisheries Biological Laboratory in Galveston have pointed. Important steps have been made in the past year. Loose ends have been trimmed; dead ends have been recognized and detoured; and the three main avenues of approach to the goal of maximum shrimp production have been clearly illuminated.

The five research programs at Galveston are organized to analyze the three fundamental factors inherent to any fishery investigation: (1) life histories of the species constituting the fishery (Shrimp Biology, Experimental Biology, Estuarine Ecology); (2) the response of the species to fishing and to their environment (Shrimp Dynamics, Experimental Biology, Estuarine Ecology, Shrimp Biology); and (3) the environment, including variations and their magnitudes in time and space (Gulf Oceanography, Estuarine Ecology, Experimental Biology, Shrimp Biology). Not all of the programs were adequately funded in 1966. The production in the programs of Gulf Oceanography and Experimental Biology, owing to this lack, was not significant in comparison with the need for information. Even so, the studies in these two programs helped to clarify the state of affairs.



## LABORATORY FACILITIES

The expansion of activities in all programs required modifications of building interiors for a more efficient use of space. New interior additions included (1) a sedimentology laboratory, (2) turbine pumps for the sea-water system, (3) a walk-in freezer for specimen storage, and (4) additional laboratory space for biological analyses. A number of laboratories were redecorated and had improved lighting added, along with improved ventilating and air-conditioning systems. Most of the interior space of the buildings on the Fort Crockett site is now completely functional.

The exteriors of the Laboratory buildings continue to deteriorate and have become progressively more unsightly.

## PUBLIC RELATIONS

Nearly one thousand students, instructors, and other visitors were given Laboratory tours, field trips, or both. The students were from 12 different universities and 9 high and grade schools. By category the students ranged as follows:

University . . . . .	210
High School . . . . .	174
Elementary . . . . .	<u>389</u>
Total . . . . .	773

Other public relations activities involved consultations with foreign visitors and trainees, lectures to student and civic groups, and cooperative endeavors with universities.

### Foreign Visitors

The visitors to the Laboratory were: Francois Paraiso, Service des Pêches Cotonou (Republic of Dahomey) West Africa, and his interpreter, Pierre Fontaine, AID, Washington, D.C.; Banchong Teinsongrusmee, Fisheries Department, Ministry of Agriculture, Bangkok, Thailand; M'nakhem Ben-Yami, Fishing Gear and Methods Technologist, Israel Department of Fisheries, who traveled to various seacoast areas of the United States on a 2-month research tour, primarily to learn as much as possible about American commercial fishing methods; and Mitsutake Miyamura, President, The Shrimp Farming & Co., Ltd., Takamatsu, Japan, and two colleagues, Messrs. Kawaguchi and Tsutsumi, of Long Beach, Calif.

### Foreign Trainees

Also visiting the Laboratory were: Bertram Uboma from Nigeria, West Africa, an exchange student attending the University of Washington

in Seattle; Vincent Price from Kenya, East Africa, also attending the University of Washington on an AID scholarship under the African Scholarship Programme of American Universities; Juan Manuel de la Garza, Biologist with the I.N.I.B.P. Campeche Laboratory in Mexico; and Jesus A. Macias, Biologist with the I.N.I.B.P. Tampico Laboratory in Mexico.

## Laboratory Activities

Films describing fishery research were shown by staff members to about 275 elementary and high school students, and five staff members spoke of the Laboratory's role in fisheries before school and civic groups.

Permission was obtained from Sun Oil Company to place salinity- and temperature-recording apparatus in a marsh complex near their Caplan, Tex., station.

An agreement was entered into in March between this Laboratory and Texas A&M University, Department of Wildlife Science, College Station, Tex., to cover the use by Texas A&M University personnel of field sampling equipment and facilities in the Estuarine Program.

A member of Texas A&M University and the Zapata Oil Company used our salt-water systems for various experiments, and two other institutions were provided specimen collections.

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### SHRIMP BIOLOGY PROGRAM

Since 1962, the major portion of the research by personnel in this program has been designed to provide a better understanding of the life history of shrimp in the northwestern Gulf of Mexico. To meet the objectives of this research, cruises were made monthly to the waters over the Continental Shelf between the Mississippi River and the United States-Mexican border, and biological and hydrological observations were made at predetermined stations located in waters ranging from

about 7 to 110 m. deep. In December 1965, discontinuation of the monthly biological sampling brought to a close the synoptic survey that originated 4 years ago. Since then, we have been analyzing data and formulating studies designed to answer more specific questions regarding the life histories of the brown shrimp (Penaeus aztecus), white shrimp (P. setiferus), and pink shrimp (P. duorarum).

<sup>1</sup> Contract research.

Considerable time was spent during the past year examining data on the spawning seasons of white, brown, and pink shrimp; the seasonal distribution and abundance of *Penaeus* spp. larvae; the seasonal distribution and abundance of finfish occurring on the shrimp fishing grounds; and surface currents over the Continental Shelf of the northwestern Gulf of Mexico. Analysis of these data will contribute significantly to a better understanding of the offshore life-history phases of the commercially important shrimp and of the environment in which they live.

Apart from our offshore work, but by no means of less importance, are the accomplishments of the members of our staff engaged in rearing larval shrimp, describing their larval stages, and developing mass rearing techniques. This past year both the seabob, *Xiphopeneus krøyeri*, and the white shrimp were successfully reared from eggs spawned in the laboratory. This marks the first time that these two species have been spawned and reared to postlarval stages under laboratory conditions. Additionally, techniques were developed which should permit mass cultures of larvae to be grown for either experimental studies or stocking of enclosed brackish-water ponds for future harvesting.

To investigate the possibility of growing shrimp in enclosed ponds, we completed 1 year of study on shrimp held in ponds constructed specifically for that purpose. Brown shrimp, stocked at an average size of about 12.0 mm, total length, grew to about 130 count, heads-on, over a period of 120 days; white shrimp,

stocked inadvertently with these brown shrimp, grew to an average of 31 count, heads-on. Although inconclusive, these results suggest that the white shrimp may be more adaptive for pond culture.

Bureau of Commercial Fisheries employees at our Miami Field Station and members of the staff at the University of Miami Marine Laboratory are studying the pink shrimp in Florida waters. During the past year, shrimp movements into and out of the estuaries were observed in Florida Bay and at specific sites in the Everglades National Park. Systematic sampling gave a better understanding of those factors affecting shrimp movement and yielded data on seasonal abundance trends of post-larval shrimp entering, and juvenile shrimp leaving, the estuaries. Efforts continue to develop an abundance index from which the future offshore harvest of pink shrimp on the Tortugas fishing grounds can be predicted. In addition, Bureau employees are continuing their research to determine which types of estuarine habitats in Florida Bay the juvenile pink shrimp prefer.

Robert F. Temple, Program Leader

#### LARVAL DISTRIBUTION AND ABUNDANCE

The monthly synoptic survey in the offshore waters along the Texas and Louisiana coasts was discontinued December 1965. Sampling in these waters with Gulf-V plankton nets covered the period January 1962 to December 1965. The examination of plankton samples

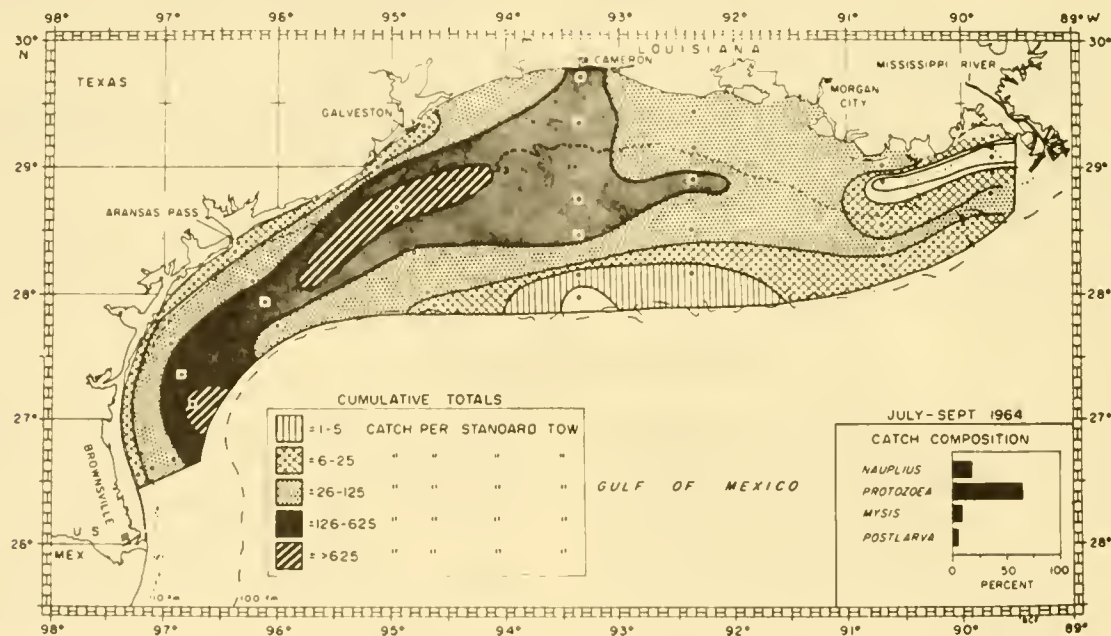


Figure 1.--Distribution of planktonic stages of *Penaeus* spp. in the northwestern Gulf of Mexico, July-September 1964. Stations occupied are shown as open circles.

collected in 1962 and 1963 has been completed, and the catch data and related hydrographic records are being transposed for automatic data processing and future analysis. In addition, about 500 plankton samples collected from January to September 1964 were examined as well as 300 plankton and bottom samples collected during overwintering studies of postlarval brown shrimp.

### Distribution and Abundance, January-September 1964

Seasonal distribution of planktonic stages of *Penaeus* spp. shrimp during the first 9 months of 1964 closely resembled that in 1962 and 1963. Between January and April, planktonic stages of *Penaeus* spp. occurred in three general areas--(1) the waters off Corpus Christi, Tex., (2) between Freeport, Tex., and Cameron, La., and (3) to the east off Morgan City, La. After April, however, distribution became more widespread, particularly shoreward of the 27-m. depth. Catches were relatively light until May but increased steadily through September. Greater concentrations of planktonic stages occurred at 27 to 46 m, than in either the 7- to 13-m. or 73- to 110-m. depth zones. In addition, young shrimp were about five times more abundant in Texas waters than in Louisiana waters (fig. 1). Catches were particularly high in the 27-m. zone south of Galveston. Typically, these waters from 27 to 46 m. deep have produced the greatest numbers of larvae each year since 1962.

As in the past, seasonal differences in catch composition were evident. Postlarval stages made up about 80 percent of the catch between January and April. In the ensuing months, however, the catch included predominantly naupliar and protozoal stages. Spawning intensity, indicated by the percentage of naupliar and protozoal stages in the catch, was low during January-April but increased slightly in May and June and sharply in August and September.

The timing of larval abundance varied with depth (fig. 2). *Penaeus* spp. larvae were abundant between June and September in 7 to 13 m. In 27 to 46 m., where most larvae were caught, a small peak in May was followed by a sharp increase in abundance during August and September. Larvae occurred in plankton hauls throughout the 9-month period in 73 to 110 m. but were most abundant during September.

### Overwintering

Four cruises were made in waters off Galveston between December 1965 and February 1966 to locate bottom concentrations of postlarval brown shrimp. Samples were collected in the water column with the Gulf-V

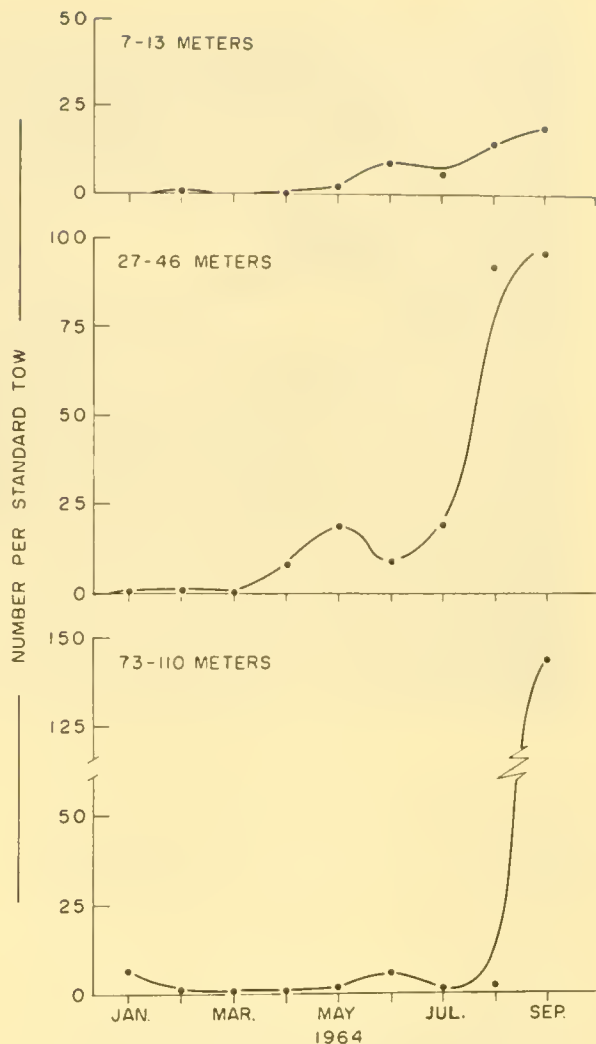


Figure 2.--Seasonal abundance of *Penaeus* spp. larvae in Texas and Louisiana waters during the first 9 months of 1964.

and Clarke-Bumpus plankton nets<sup>2</sup> and along the substrate by a newly designed bottom sled (fig. 3). Station depths ranged from 5 to 37 m. but most sampling was inside 14 m.

The major purpose of this study was to determine if postlarvae of brown shrimp leave the water column and burrow into the substrate when temperatures fall below 16°C. As expected, relatively cold water temperatures (mean, 13.4°C.) prevailed during December-February. In the initial cruises, few postlarvae were taken and most of them were on bottom rather than in the water column. In later cruises, particularly at 5-m. stations where the postlarvae appeared to be concentrated, large numbers occurred at temperatures as low as 10°C. on bottom as well

<sup>2</sup>Trade names referred to in this publication do not imply endorsement of commercial products.



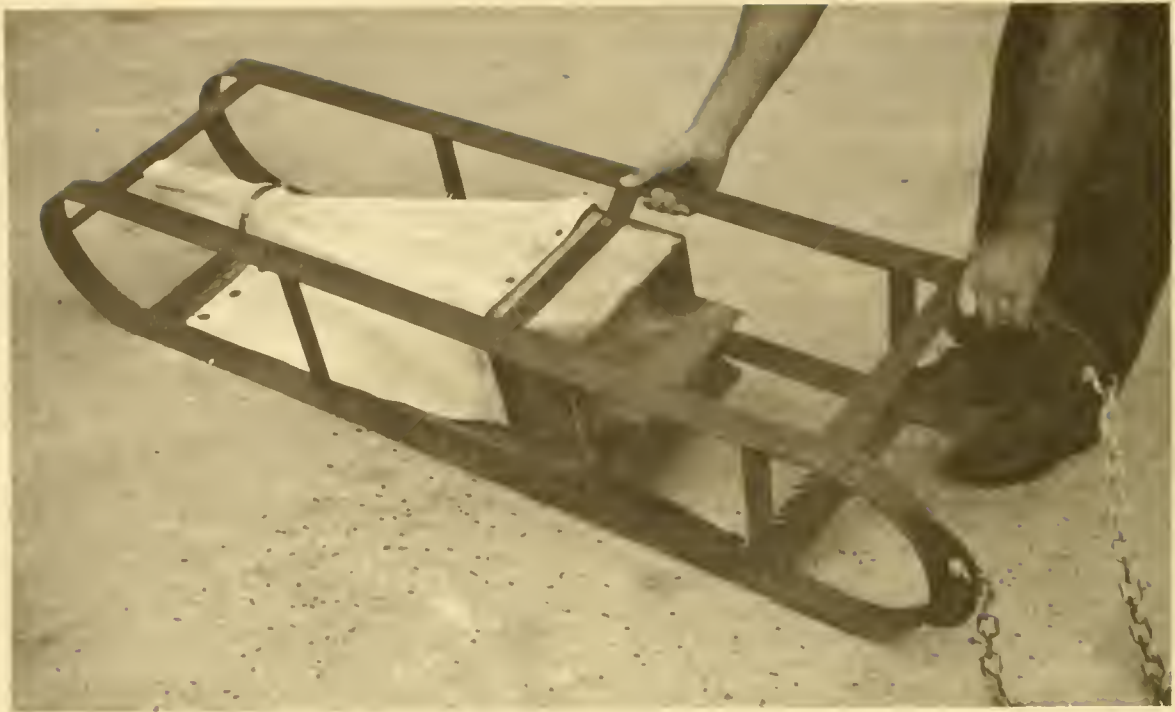


Figure 3.--Bottom sled designed to sample top 1.3 cm. of the substrate.

as in the water column. The occurrence of these postlarvae in the water column suggests that they are able to tolerate relatively low temperatures and may not have to burrow, at least in temperatures down to 10° C.

Clarence C. Fischer, Project Leader

#### IDENTIFICATION AND CULTURE OF SHRIMP LARVAE

Our efforts during the past year were concentrated on rearing larvae of the brown shrimp in large quantities. To supply food for the larval shrimp, we also spent considerable time developing a method to grow the diatom, *Skeletonema costatum*, in mass culture. Substantial progress was made in both endeavors.

#### Rearing of Larvae

Toward the end of the year, 2,889 postlarval brown shrimp were obtained from a 555-liter fiber glass tank in which shrimp had spawned. This was the first time we had been able to rear larvae through to postlarvae in a tank of this size. Mortality was high, primarily because the diatom culture did not attain sufficient density for feeding on schedule; the first protozoae were without sufficient food for a day. After the larvae started to feed, survival was good.

The water was aerated vigorously and the room was lighted constantly. The turbulence caused by the aeration seemed to keep the larvae from being trapped by surface tension, and at the same time, it kept the algae in suspension so that food had to be added only once a day. The water temperature during this experiment varied between 24° C. and 29° C. and the salinity was 22 p.p.t. (parts per thousand).

An 18.5-liter polyurethane carboy with the bottom cut out was also used as a rearing container. It was inverted, and air was bubbled up through the neck. We kept 17.4 liters of sea water in the carboy and successfully reared 1,032 postlarvae. Estimated survival was about 50 percent.

Larvae of the seabob were reared to postlarvae in mass culture. Seabob larvae given alga--*Gymnodinium splendens*, *Thalassiosira* sp., and *Exuviella* sp.--had better survival than those fed *Skeletonema* sp. Also, additions of cultures of mixed algae gave better survival of shrimp larvae than additions of their individual components. Sufficient numbers of larvae were preserved for future taxonomic studies.

In June, larvae of the white shrimp were reared from eggs to postlarvae in the laboratory for the first time. The fertile eggs were spawned by two females, neither of which had an external spermatophore attached. Because these shrimp are not supposed to have an internal sperm receptacle, we do not know how the eggs were fertilized. In eight inverted

polyurethane carboys used as culture vessels, 16,000 postlarvae were produced; 3,396 were reared in one carboy. These larvae were cultured at a temperature of 28.5° C., and salinity was maintained at 30 p.p.t. by addition of artificial sea salts to 24 p.p.t. sea water from the laboratory's recirculating sea-water system. The first postlarvae were found late on the eighth day after hatching. A series of larvae was preserved for future morphological studies.

Before the successful culture of white shrimp larvae, we made two attempts to obtain viable eggs of this species. Four pairs of shrimp were placed in each of two 555-liter tanks during the first trial. They spawned between 10:30 and 11:00 p.m. The females did not have an externally attached spermatophore, and spermatophore transfer did not take place prior to spawning. As soon as eggs were seen, spermatophores were taken from several males, opened, and the sperm placed in the tanks with the eggs. The eggs in this experiment appeared normal, but they did not develop to the point where nauplii could be distinguished within them. For the second trial, three females, without attached spermatophores, were placed in each of three tanks. Males were not placed in the tanks. Spawning occurred in only two of the tanks, again between 10:30 and 11:00 p.m. Sperm was immediately added to one tank but not the other. Eggs in both tanks developed to a point where nauplii could be seen moving inside the eggs but they did not hatch. The salinity in the tanks was 18.4 p.p.t. which might have been too low for hatching.

### Larval Food Cultures

We have been growing Skeletonema in open cultures (up to 74 liters) in filtered estuarine water and different additives. During the summer and early fall, this diatom was cultured by adding the metal chelator EDTA (Ethylenediaminetetraacetate) to the water, but beginning in October it could no longer be cultured in this manner. We have since learned that additions of commercial fertilizers, iron, and EDTA to estuarine water will support growth of Skeletonema in the late fall.

Because the quality of the water varies during the year, we have begun a series of experiments to determine which additives must be used to obtain the best growth of Skeletonema as water conditions change. Test-tube cultures are started every 4 to 6 weeks with the following additives in varying combinations: nitrate and phosphate, EDTA, iron, and a trace-metal mixture. The nitrate and phosphate, EDTA, and trace-metal combination gave the best growth in April; trace metals were not needed in May and June. Eventually, one should be able to make this determination in 3 days with only a few tubes.

In the summer of 1965, we found that Skeletonema in a rapidly growing culture used about 100 µg.at./l. (microgram atoms per liter) of nitrate per day. The nitrate-phosphate ratio was 20 to 1. KNO<sub>3</sub> and Na<sub>2</sub>PO<sub>4</sub> have been added to the cultures daily to supply these quantities.

A colorimeter is used to monitor the diatom cultures, and in the large cultures, we try to keep the density near a colorimeter unit count of 100 (about 250,000 chains per milliliter). In our last culture, two-thirds of the culture volume was drawn daily. Each culture is usually kept only 8 to 10 days.

Harry L. Cook, Project Leader

### CULTIVATION OF SHRIMP IN ARTIFICIAL PONDS

Postlarval brown shrimp for our pond studies were collected from the Galveston Pass as they migrated into the bay. These shrimp were separated from accompanying organisms and stocked in two 1/20-hectare (1/8-acre) shallow-water ponds at the rate of 9,000 postlarvae per pond. In one pond, water was exchanged continuously, and the shrimp were fed a prepared diet. In the other, we added water only to compensate for loss from evaporation and seepage, and adjusted the pond's fertility by adding inorganic fertilizer to promote plankton growth. Shrimp were taken from each pond each week, weighed, measured, and returned.

During a 95-day period (March 31, 1965, to July 4, 1965), shrimp stocked in the circulating-water pond grew steadily, attaining an average total length of 97.4 mm. and an average total weight of 6.08 g. Average daily growth was .88 mm. in length and .06 g. in weight. This study was ended prematurely by heavy mortality as a result of a dense bloom of algae accompanied by high water temperatures, poor circulation, and continuous heavy cloud cover for 2 days. On the basis of the projection of the weights of dead shrimp recovered from the banks and water's edge (dead shrimp on the bottom of the pond were not recovered), the total production of shrimp was 38 kg. per hectare (207 pounds per acre).

Shrimp in the static-water pond did not grow as well as those in the circulating pond. In 120 days, shrimp grew to an average total length of 79.6 mm. and an average total weight of 3.45 g. Shrimp growth, characterized by initial rapid gains, retardation, and finally cessation, appeared to depend on the density of plankton. Although one-half of the population was removed 1 month after growth had stopped, the remaining shrimp continued to lose weight. The addition of fertilizer, however, restimulated plankton growth, and the shrimp began to gain weight. Projection of the weights of shrimp harvested resulted in an

estimated yield of 4 kg. per hectare (22.2 pounds per acre). If shrimp that were removed from the pond had survived and grown at the same rate as those remaining, harvest estimates would be doubled, or 8 kg. per hectare (44.4 pounds per acre).

After termination of the initial study, we flushed, refilled, and restocked the circulating-water pond with one-half of the shrimp population from the static-water pond. This "transplant" was made to determine the possible growth response of stunted shrimp to feeding. Food was provided and withheld during alternate periods. This study demonstrated that growth could be accelerated or retarded at will by either supplying or withholding food, and furthermore that this response was rapid.

An interesting aspect of the pond culture arose when a few postlarvae of white shrimp were inadvertently placed in the static-water pond with the postlarvae of brown shrimp. Although data on growth of white shrimp were limited, the average lengths and weights attained in 120 days were spectacular when compared with brown shrimp (table 1). These results suggest that it may be more feasible to rear white shrimp than brown shrimp under seminatural conditions.

Table 1.--Average length and number of white and brown shrimp per kilogram after a 120-day growing period under identical conditions

Species of shrimp	Average length	Shrimp per kilogram (heads-on)
	<u>Mm.</u>	<u>Number</u>
Brown.....	79.6	59
White.....	126.5	14

Preparations were made in the spring of 1966 to rear both brown and white shrimp in mass culture from eggs spawned in the laboratory. Gravid female shrimp collected offshore so far, however, have failed to spawn in the ponds.

Ray S. Wheeler, Project Leader

### ECOLOGICALLY ASSOCIATED ORGANISMS

During the last half of 1965, we tabulated data on 30 species of fish commonly taken in experimental shrimp trawling at 7 to 110 m. along the Texas and Louisiana coasts in 1962-64. A report on the seasonal, bathymetric,

and relative abundance of each species is nearing completion.

To supplement the data on finfish in the same ecological habitat as the white, brown, and pink shrimp in the northwestern Gulf of Mexico, we began in January 1966 to study the epifauna (organisms living on the ocean floor) and infauna (organisms living in the bottom sediments) of the offshore commercial shrimping grounds. Considerable time has been spent reviewing the literature, conferring with others engaged in the same type of research, and testing various kinds of sampling gear. This preliminary work is to be followed by systematic sampling along the Texas coast to obtain quantitative and qualitative estimates of the bottom fauna.

Although our initial sampling was designed primarily for testing gear, one series of samples was obtained along a transect extending seaward off Galveston. Samples were taken at depths from 5 to 37 m. with a sled-type dredge designed to sample the top 1.3 cm. of the substrate. The analysis of these samples indicated that the greatest catch of all organisms combined per unit effort was inshore; catches decreased with increase in depth (fig. 4). Conversely, the number of species taken increased with an increase in depth. Mollusks dominated--the hauls had 20 families of snails (Gastropoda) and bivalves (Pelecypoda). To date, we have identified 48 species of snails and 38 species of bivalves, and a reference collection has been established.

To complement the investigation of bottom fauna, studies have also begun on the food habits of shrimp and the more abundant fish species. Contents of the stomachs of two species of shrimp and four species of fish taken during the winter are listed in table 2. Although data are limited, it appears that the

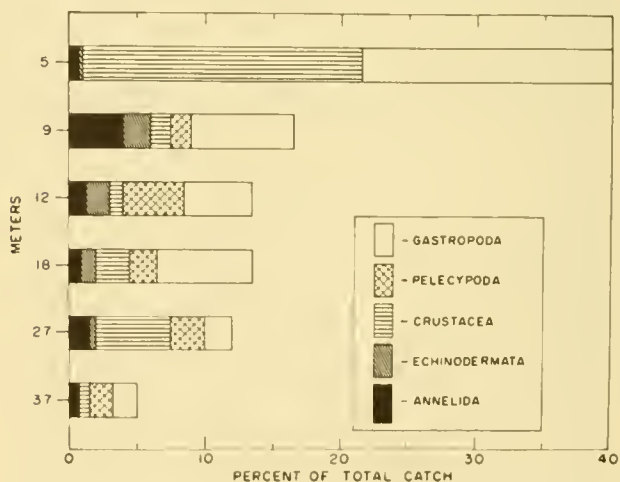


Figure 4.--Percentage occurrence by depth of bottom invertebrate groups collected off Galveston, Tex., January-February 1966.



Table 2.--Stomach contents of six species (two shrimp, four fish) collected at 7 to 46 m. on commercial shrimp grounds off Galveston and Freeport, Tex., winter 1966

Food item	White shrimp, <u>Penaeus setiferus</u>	Brown shrimp, <u>P. aztecus</u>	Atlantic croaker, <u>Micropogon undulatus</u>	Silver seatrout, <u>Cynoscion nothus</u>	Longspine porgy, <u>Stenotomus caprinus</u>	Shoal flounder, <u>Syacium gunteri</u>
Crustacea:						
Shrimp:						
Penaeid shrimp...				x		
Rock shrimp.....						x
Snapping shrimp..						x
Unidentified.....				x	x	x
Crabs.....	x	x	x	x	x	x
Amphipods.....	x	x	x	x	x	x
Mantis shrimp.....					x	
Copepods.....	x	x		x	x	
Ostracods.....	x	x			x	
Mysids.....			x			x
Cumacea.....			x	x		
Unidentified.....	x	x	x	x	x	x
Mollusks:						
Bivalves.....	x	x			x	
Snails.....	x	x			x	
Squid.....	x	x				
Polychaete worms....	x	x	x		x	x
Kinerhyncha worms....		x				
Starfish.....						x
Foraminifera.....	x	x				
Fish.....	x	x	x	x		x
Algae.....	x	x				

diets of the Atlantic croaker and silver seatrout were not as diversified as those of the other four species.

The stomach contents of the two species of shrimp were identical. We could not detect any difference in the diets of shrimp of different sizes except that squid tentacles occurred more frequently in stomachs of the larger shrimp. Major food items appear to be squid tentacles, crustacea, and sea worms.

Donald Moore, Project Leader

#### FLORIDA BAY ECOLOGY STUDIES

Personnel at the Biological Field Station in Miami, Fla., completed the first year of an ecology study on postlarval and juvenile pink shrimp in eastern Florida Bay. Systematic field observations were made at stations along the northernmost Florida Keys and in the shallow-water shrimp nursery areas (fig. 5).

One purpose of this study was to measure the abundance of postlarvae entering the nursery grounds through passes in the Florida Keys and the abundance of advanced postlarvae and juveniles on the nursery grounds. Immigrating postlarvae were sampled at various Key bridges and at Whale Harbor, Islamorada. A specially designed metal frame that simultaneously supported plankton nets at three depths was installed (fig. 6). Included as part of the submerged equipment was a Savonius Rotor Current Speed Sensor to measure current speeds when the plankton nets were in operation. Postlarval and juvenile shrimp were sampled on the nursery grounds with a unit-area suction sampler.

The abundance of immigrating postlarvae and of postlarvae and juveniles in the bays varied monthly over 9 months (fig. 7). Although these trends in abundance are similar, the shrimp appeared to be taken in the passes 1 month earlier than on the nursery grounds. An extended series of similar observations and projection of previously determined growth rates may permit tentative identification of

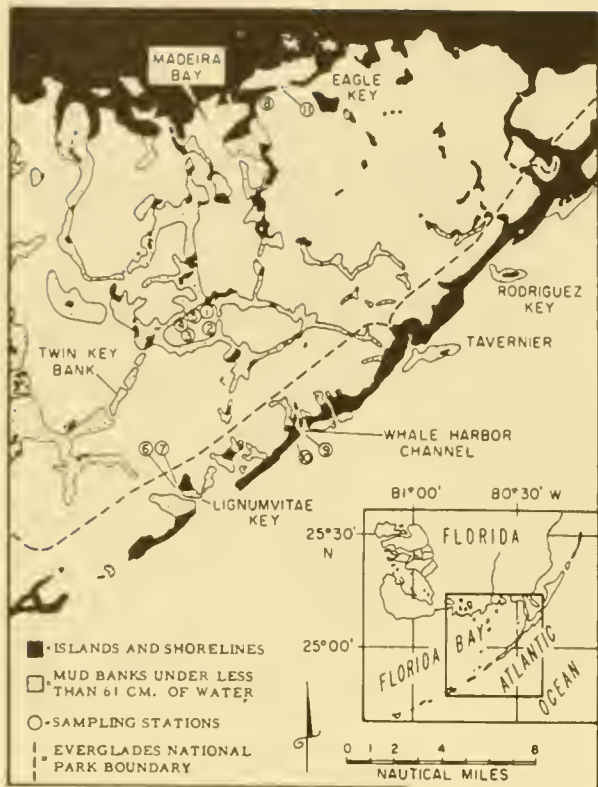


Figure 5.--Sampling stations for ecological studies in eastern Florida Bay.

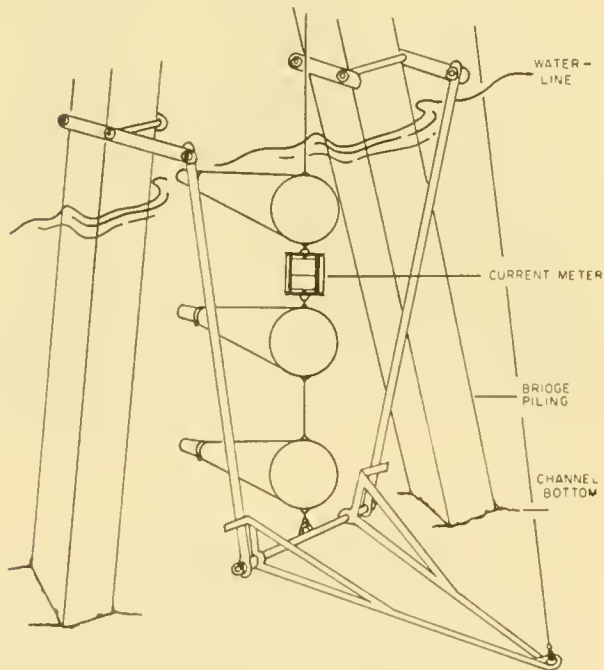


Figure 6.--Metal frame supporting plankton nets and current meter in water column.

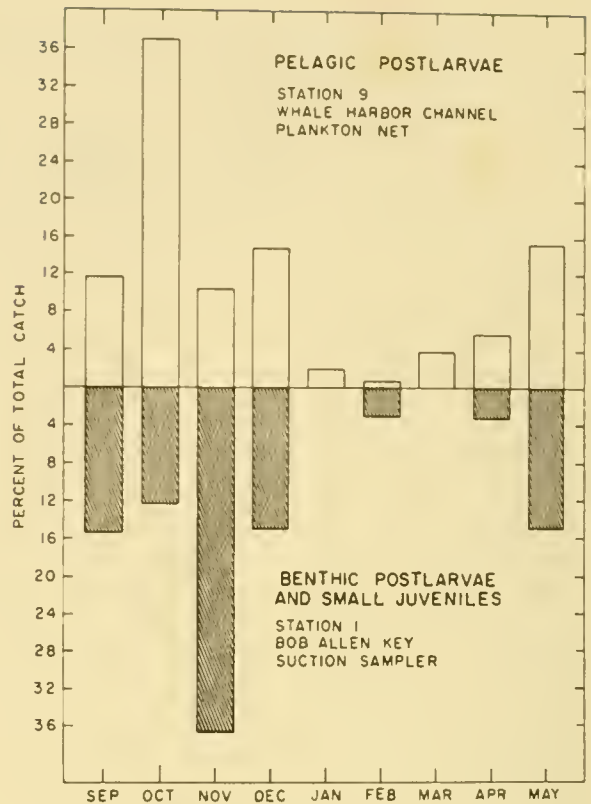


Figure 7.--Monthly abundance relation between stages of young shrimp in eastern Florida Bay.

peaks of abundance of postlarvae entering Florida Bay with abundance peaks of young adults entering the Tortugas Fishery. Success here may provide a means of predicting shrimp abundance on Tortugas 4 to 5 months in advance.

Another aim of this study is to identify and enumerate organisms, other than shrimp, taken in samples collected in the Bay so that we can describe the habitat types preferred by juvenile pink shrimp. Environmental requirements and preferences have already been defined for certain associated organisms. A thorough understanding of the shallow-water environment should reveal factors that influence the abundance of young pink shrimp.

The unit-area suction dredge took 63 genera representing 74 species of marine animals at the three regularly sampled stations in Florida Bay. Polychaetes, mollusks, and crustaceans dominated the substrate samples. Peaks of abundance of small shrimp and of associated animals appeared in August and November (fig. 8). Although we do not know which organisms are important food for

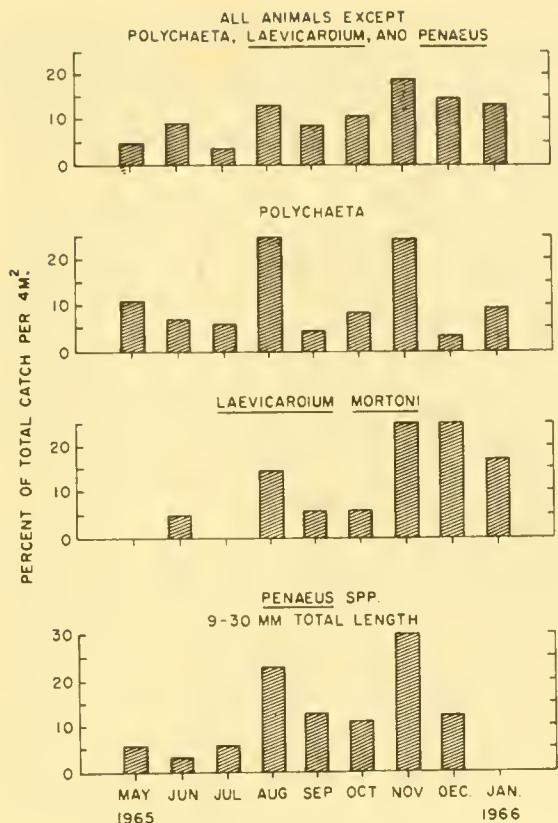


Figure 8.--Monthly abundance of *Penaeus* spp. and associated animals at station 1, Florida Bay.

juvenile pink shrimp, studies by personnel at Galveston indicate that brown shrimp definitely prefer polychaetes.

Thomas J. Costello, Project Leader  
Donald M. Allen

#### RELATION OF VARIATIONS IN ABUNDANCE OF JUVENILE PINK SHRIMP EMIGRATING FROM THE EVERGLADES NATIONAL PARK ESTUARY TO THE COMMERCIAL CATCH

This year marked the beginning of the second phase of the study of juvenile pink shrimp in Everglades National Park. Observations on the abundance of pink shrimp leaving this nursery have been increased considerably by establishing a second sampling station at Joe River.

The abundance of pink shrimp migrating out of Everglades National Park was estimated in previous years by sampling with a large channel net at a single station in Buttonwood Canal. As knowledge of the changes in abundance and the distribution of the shrimp in the ebbing currents of the canal improved, it was possible to design "wing-net" gear that provided a

reliable index of the total numbers of shrimp migrating in the canal. The use of the wing net has made it possible to maintain the continuity of observations in Buttonwood Canal with less manpower and at the same time to sample in more remote areas with comparable gear.

The second sampling station in Joe River (in the western outlet of Whitewater Bay) has improved the accuracy of abundance estimates. Wing-net sampling at this station was started on a weekly basis in October 1965.

"Conical-net" sampling was also started at the Joe River station in October. These nets provide data on the vertical and lateral distribution of the shrimp in the river in relation to moon phase, water velocity, and other factors. This sampling was suspended temporarily in late October when shrimp abundance declined and insufficient numbers were being caught to determine their distribution in the river. Sampling with conical nets was resumed in May 1966; catches indicate a high percentage of the shrimp migrate near the surface and that the largest samples are obtained by sampling in the swiftest currents. These results are similar to those for Buttonwood Canal.

We recorded a single period of high abundance of shrimp migrating out of Buttonwood Canal in 1965. A peak in June tapered off through October. At least two periods of high abundance were observed in 1963 and 1964. The level of abundance in 1965 was slightly greater than that in 1964, and the period was about 2 months shorter. The period of low abundance that started in October 1965 continued at a still lower level for a longer period (5 months) than in previous years. The abundance trend was similar in Joe River.

The relative abundance of juveniles migrating out of Buttonwood Canal and the size of commercial catches continue to have little correlation. Periods of high abundance that have occurred, however, during these years of sampling in Buttonwood Canal are consistently reflected in increased catches of the smallest commercial shrimp 1 to 2 1/2 months later; the lag depends on the size of the emigrating shrimp. Conversely, all major peaks of abundance in the commercial landings of the smallest shrimp can be related to a corresponding period of abundance in Buttonwood Canal. The peaks are only roughly comparable, but the extent of agreement with only one sampling station encourages us to believe that dependability of predictions can be improved by adding a second station.

In 1965-66, as in previous years, the smallest shrimp collected in Buttonwood Canal were taken during the period of highest abundance. Although shrimp in both Joe River and Buttonwood Canal have remained large since October 1965, the monthly mean lengths of shrimp caught in Joe River are consistently larger



than those in Buttonwood Canal. The mean carapace length of shrimp from Joe River in January 1966 was 19.6 mm.; these shrimp were the largest collected from either station.

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

Institute of Marine Science,  
University of Miami  
(Contract No. 14-17-0002-140)

## SEASONAL CHANGES IN RELATIVE ABUNDANCE OF POSTLARVAE OF PINK SHRIMP ENTERING THE EVERGLADES ESTUARY

Studies began on the abundance and seasonal distribution of postlarval pink shrimp entering the Everglades nursery area.

Two sampling stations have been established, one in Buttonwood Canal about 0.8 km. (0.5 mile) from its end at Florida Bay and one in the Little Shark River about 0.8 km. (0.5 mile) from the Gulf of Mexico. These stations represent the eastern and one of the western access routes to the Whitewater-Coot Bay system.

A 1-m. nylon plankton net with 471-micron mesh is used as the sampling gear. Surface and bottom samples are taken simultaneously from a small boat which is run against the tidal current at a constant speed. The plankton nets are equipped with Tsurumi Precision Instruments Company "TSK-Type" flowmeters to permit the calculation of the cubic meters of water strained per tow.

Observations on tidal current velocity, water temperature, salinity, and depth of water have been recorded to determine their importance in the movement of the postlarvae. Moon-phase and meteorological conditions have also been recorded to learn their effect on migration and abundance.

Sampling began at the Buttonwood Canal station in July 1965 and at the Little Shark River station in January 1966. When postlarval abundance was high, sampling was conducted in all phases of the moon; during periods of low abundance, sampling was limited to new- and full-moon phases. The abundance of shrimp in Buttonwood Canal showed a bimodal distribution that had a major peak in July-August and a minor peak in November. Abundance was relatively low in 1966 from January to the first of April; catches of postlarvae began to increase by mid-April at both stations.

A preliminary analysis of the data indicates that several factors may affect the relative abundance and movement of postlarvae: (1) the abundance of shrimp during a single tide is correlated with water velocity; (2) shrimp are most common during night flood tides; (3) the greatest numbers of shrimp are taken in bottom hauls; (4) more shrimp are caught in Buttonwood Canal than in Shark River; and (5) shrimp are most abundant during the waning moon and least at the full moon.

C. P. Idyll and Martin Roessler,  
Project Leaders

Institute of Marine Science,  
University of Miami  
(Contract No. 14-17-0002-141)

## SHRIMP DYNAMICS PROGRAM

The research responsibilities of this program include studies to determine the most appropriate means for managing shrimp fisheries and investigations of methods to predict the catch of shrimp. The program includes three projects at this Laboratory and contract research at the University of Southwestern Louisiana. Each of these activities has been in operation between 3 and 6 years and is now well established. Although progress toward our eventual aims already has been substantial, we continually find reasons to review and revise our methods. We have made several changes in the past year and contemplate others.

The organizational structure of the program was altered during the year to incorporate a former project, Commercial Catch Sampling, into another existing project entitled Population Studies. This change marks the end of studies designed to evaluate the accuracy of published data on shrimp landings and an expansion of research on how commercial fishing affects

stocks of shrimp. Conclusions drawn from the appraisal of landing data are included in the present report. Other work within the Population Studies Project, but not reviewed here, includes a detailed study of how the Tortugas pink shrimp stock and the commercial fishery interact; investigations of the selectivity of shrimp nets; and studies of seasonal changes in the size composition of shrimp off the central Texas coast.

The report for the Mark-Recapture Project centers on many recent improvements in the design of equipment for staining shrimp. Use of the new equipment makes it possible to mark large numbers of shrimp and thereby increase the reliability of resulting estimates of shrimp growth, mortality, and movements. Whereas earlier experiments had included about 3,000 marked shrimp, between 7,000 and 12,000 stained shrimp were released during the past year.

The Postlarval and Juvenile Shrimp Project has succeeded in measuring the abundance of

brown shrimp at the postlarval and juvenile stages and has demonstrated that predictions of commercial catches are possible. To date, predictions made on the basis of the abundance of postlarvae have been somewhat less reliable than those based on catches of juveniles, but the postlarval method has greater potential value because predictions can be made almost 2 months earlier. Emphasis in the past year has been placed on the improvement of the postlarval index of abundance. Continuous sampling schemes are being investigated as a means for reducing the influence of local environmental variations on catches of postlarvae. We are studying minimum temperature limits of postlarvae in the laboratory and under field conditions to determine whether periods of low temperature during the spring are lethal to postlarvae that arrive sooner than usual. To discover the fate of postlarvae that arrive later than usual, we are sampling juvenile shrimp to determine which groups actually contribute to subsequent offshore harvests.

The University of Southwestern Louisiana, which has studied seasonal variations in the abundance of postlarval shrimp since 1963, expanded its research during the past year. Laboratory investigations of several types are now underway to seek solutions to problems confronting the three projects within the Shrimp Dynamics Program.

Richard J. Berry, Program Leader

## POPULATION STUDIES

Detailed tabulations of shrimp landings from the Gulf of Mexico have been published each month since January 1956. These data are not only a source of information on the shrimp stocks and the shrimp fishery, but they can be used to learn the effects of fishing on shrimp populations. Before the tabulations can be used, however, we must know (1) the reliability of information about the size composition of the shrimp landed and (2) the accuracy of estimates of the amount of effort expended in making the catches.

To evaluate the published information, we have collected similar records and compared them with the published information. This evaluation is based on landings from the Texas ports of Galveston, Freeport, and Aransas Pass during the season of heaviest catches. Shrimp landed at these ports represent nearly 50 percent of the total catch from Texas waters.

From July through November 1965, biologists at these three ports collected detailed information on shrimp sizes and fishing effort on a strict schedule. This schedule was designed to provide an equal chance for each landing to be sampled and for a crew member from each vessel to be interviewed. Random samples of shrimp were obtained as they

moved along conveyor belts from the vessels to the shrimp houses. At least 200 shrimp were measured from each landing sampled.

To estimate the size composition of shrimp in a particular fishing area, we compared the size of shrimp in samples obtained from vessels that had fished together, even though they may have landed their catches at any of the three ports. A comparison of the size of brown shrimp sampled during July at Aransas Pass and at Freeport is shown in figure 9. Similar tests were made each month on data collected at the three ports; all differences were minor.

The size composition from published data of all shrimp landed during July from the same area sampled by our personnel is given in figure 10. The two figures illustrate an effect of the grading practices at the shrimp houses. For the published data, shrimp were collected or lumped into fewer size categories. Most of the landings which contributed to figure 10 were box graded. Box grading usually places the shrimp landed by a vessel into one or two size categories by an averaging process. The other technique, machine grading, mechanically sorts shrimp into several size categories. The latter is used primarily in Louisiana and in Brownsville, Tex. Few shrimp graded by machines were used in the above comparison. Samples taken in areas where machine grading is used indicate that this method shows more accurately the sizes of the shrimp landed than does box grading.

Another discrepancy noted between the published information and our sampling data concerned the average size of shrimp landed each month. The size group which included the greatest weight of shrimp according to the published data usually differed from that indicated by our measurements. Early in the season, when shrimp were small, the published data placed them in a larger size category than indicated by our measurements. Agreement between the reported landings and our measurements was close in midseason. Near the end of the season, when shrimp were large, the published data indicated a smaller average size than did our measurements.

Accurate information concerning the fishing time involved in making catches is as important as the size composition of landings. The ratio of catch to fishing effort is commonly used in commercial fisheries as an estimate of relative abundance. This information is obtained from interviews with the vessel crew at the end of a trip.

Estimates of the catch per hour of fishing for vessels that had fished together and landed at Freeport or Aransas Pass and the catch rate for vessels fishing in the same location, as obtained from published information, agreed well (table 3). Similar tests made for other areas showed equally close estimates.

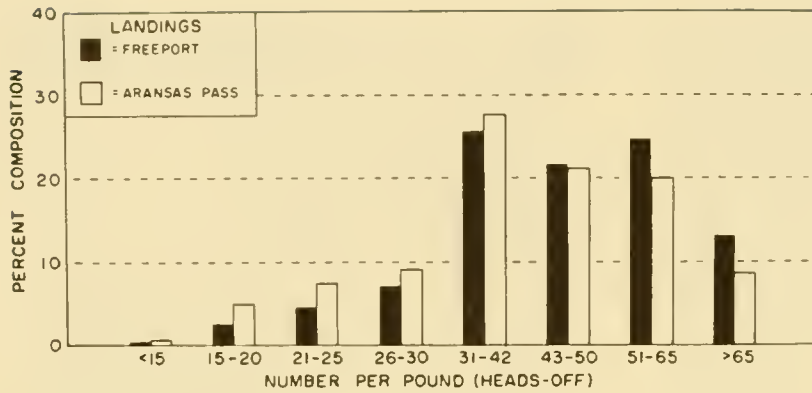


Figure 9.--Size composition of brown shrimp sampled from landings, July 1965.

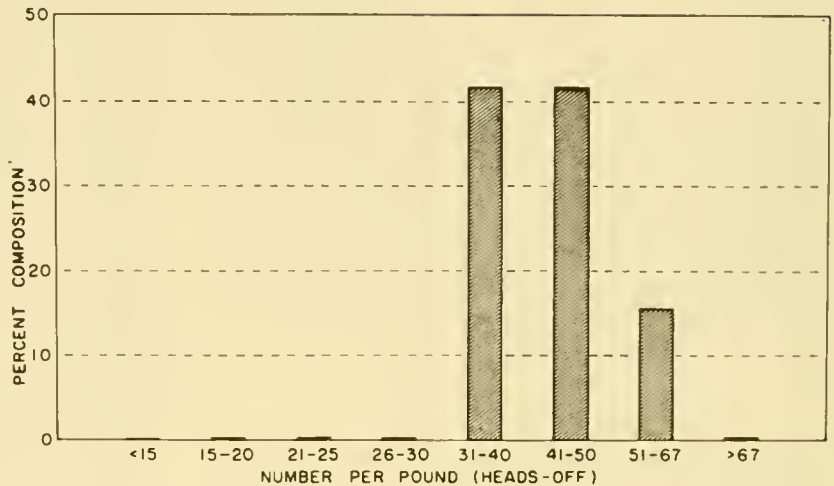


Figure 10.--Size composition of brown shrimp landings from published data, July 1965.

Table 3.--A comparison of three estimates of catch rates (kilograms per hour) for a particular fishing area

1966	Landing ports		Published data
	Freeport	Aransas Pass	
	<u>Kg.</u>	<u>Kg.</u>	<u>Kg.</u>
July.....	20.9	20.7	19.5
August.....	13.7	16.1	15.1
September..	16.8	14.3	15.6
October....	15.0	13.9	15.4
November...	12.7	12.9	12.7

Comparisons of our data with the published information suggest that the reported data on size are satisfactory for description of general trends. When more accurate information is required for estimating growth or

mortality of shrimp, we must supplement the reported size data with measurements. The published data on landings do accurately reflect catch rates of shrimp in areas where interviews with crew members are obtained.

James P. Clugston, Project Leader

#### POSTLARVAL AND JUVENILE SHRIMP

The abundance of postlarval and juvenile brown shrimp collected near Galveston, Tex., has been used for the past 6 years to estimate offshore supplies of adult brown shrimp. Our indices of abundance for the two younger stages and the monthly catch of adult brown shrimp along the Texas coast are shown in figure 11. The initial occurrence of postlarvae and the duration of their movement into Galveston Bay vary from year to year, but peak numbers ordinarily are found between mid-March and mid-April. Often August or September has a second smaller peak. The strength of the year class is correlated with



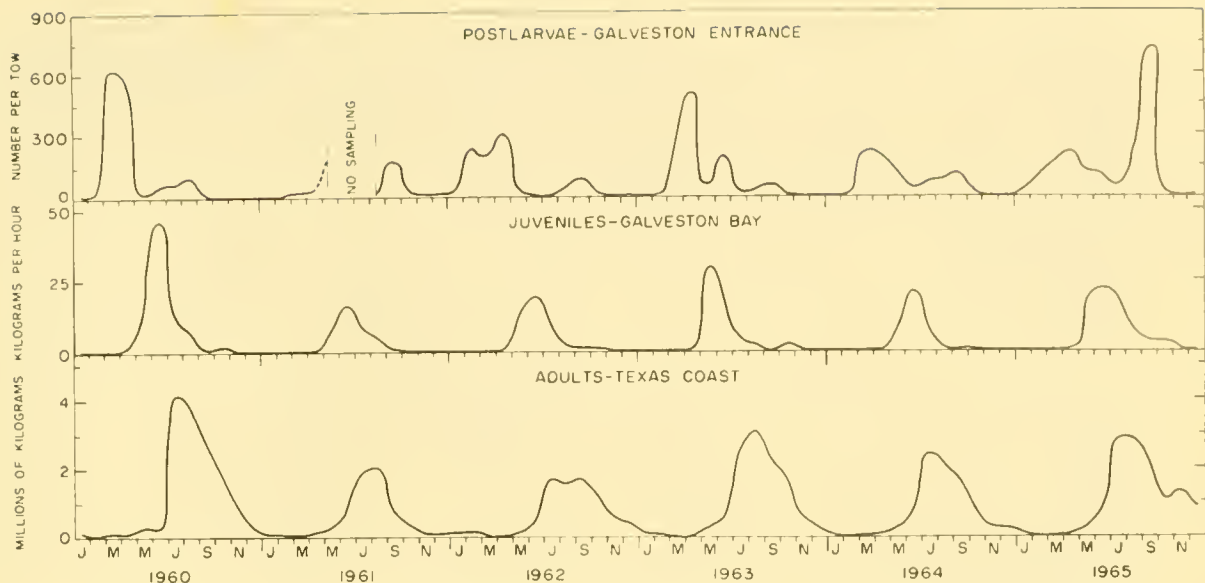


Figure 11.--Monthly indices of abundance for postlarval, juvenile, and adult brown shrimp, 1960-65.

the spring peak, and seldom can the second peak be recognized in the fall commercial fishery for brown shrimp.

It is most likely that brown shrimp postlarvae which arrive early at Galveston Entrance are killed by abrupt drops in temperature during February and March in some years. For this reason, we are cooperating with personnel of the Experimental Biology Program to determine the low temperature which is lethal to postlarval brown shrimp. This knowledge may help us refine our postlarval index by eliminating from consideration those animals killed by low temperature.

### Postlarvae

Routine sampling for postlarval shrimp at Sabine Pass, Rollover Pass, Galveston Entrance, and Aransas Pass, Tex., continued throughout the year. Weather was relatively mild during the early part of the 1965-66 winter, and a few postlarval brown shrimp came into the bays until mid-January when cold weather apparently curtailed immigration. Postlarval brown shrimp were caught again beginning in late February. The peak movement of postlarvae into Galveston Bay was between March 10 and April 15. Postlarval white shrimp were first caught at Galveston Entrance on May 27, or almost a month later than in preceding years.

An experiment was made in September to determine whether postlarvae tend to skirt the main current when they move through the tidal pass at Galveston Entrance. Results agreed with those from a similar study done in the spring of 1964, when we learned that the numbers of postlarvae decreased from the shoreline toward the channel.

### Juvenile Shrimp

We continued our weekly survey of the Galveston Bay bait-shrimp fishery, to measure the relative abundance of juvenile brown and white shrimp each year. The total catch of bait-size shrimp from Galveston Bay in 1965 was 446,700 kg. from an estimated 22,700 hours trawling effort. The catch-per-hour increased 18 percent over that of 1964. Juvenile brown shrimp remained in Galveston Bay longer and accounted for a higher percentage of the bait catch than in 1964. Table 4 summarizes statistics for the bait fishery for 1965.

Table 4.--Bait shrimp statistics for Galveston Bay, 1965

Month	Landings		Fishing effort	Average number of dealers
	White shrimp	Brown shrimp		
	<u>Kg.</u>	<u>Kg.</u>	<u>Hours</u>	
January...	5,080	--	420	16
February...	2,041	91	150	12
March....	2,586	--	525	12
April.....	1,633	91	1,110	15
May.....	2,948	21,818	1,170	69
June.....	816	78,836	3,430	83
July.....	20,503	55,793	2,950	94
August....	45,315	31,344	4,140	91
September.	41,504	15,422	3,430	76
October...	43,364	13,472	3,450	72
November..	48,399	1,678	1,560	62
December..	9,843	91	370	22
Total...	224,032	218,636	22,705	--

## Inshore Currents

Since February 1966, drift bottles and seabed drifters have been released monthly offshore from Galveston Island to define the current pattern from the shore to 14.6 m. and to determine the role of currents in transporting postlarval shrimp (fig. 12). The drift bottles released in February indicated a strong south-westerly surface current. Bottle returns from

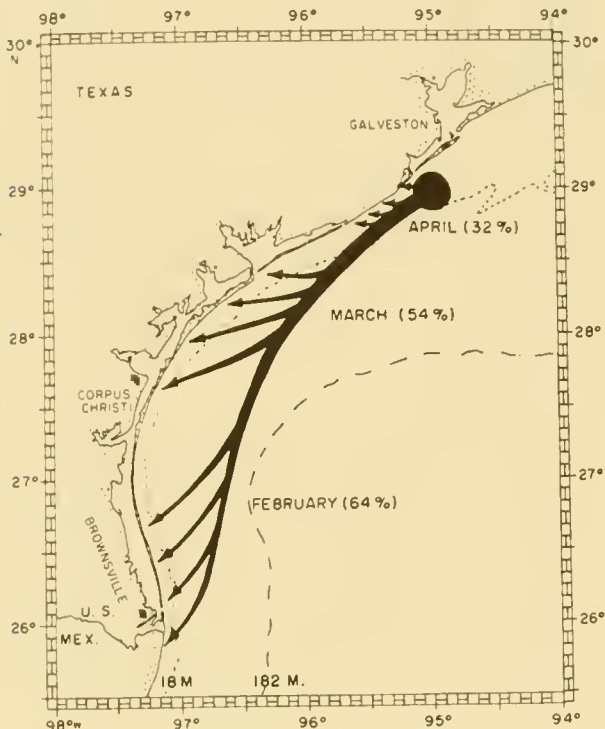


Figure 12.--Movement of drift bottles released off Galveston Island, Tex., in February, March, and April 1966. Numbers indicate the percentage of bottles recovered.

the March release showed a more shoreward current, and by April many of the bottles were recovered from the Galveston Island and Freeport areas. The onshore currents at these times coincide with the periods of peak arrival of postlarval brown shrimp at Galveston Entrance.

Kenneth N. Baxter, Project Leader

## MARK-RECAPTURE EXPERIMENTS

Mark-recapture experiments, with shrimp marked with biological stains, have been made on populations of the three commercial species in several areas of the Gulf. This method for obtaining estimates of growth and mortality of shrimp is the most direct and practical means available, but it poses many problems. The most common difficulties encountered stem either from changes in the

activities of the commercial fleet during an experiment or from the problem of releasing a sufficient number of stained shrimp in a fishing area. Although we cannot foresee how the fishery will change, we can take steps to increase the number of marked shrimp released. With this purpose in mind, we have altered some of our techniques and have begun to use new types of equipment in recent months.

A minor problem that arises during a staining experiment is the catching of large numbers of shrimp in good condition. To reduce injuries to shrimp during trawling, tows are normally limited to 10 or 15 minutes. We have also found it advisable to use 70-foot nets instead of the smaller ones used formerly.

A more serious problem involves keeping shrimp alive in holding tanks when water temperatures are above 26.5°C. We have found that mortalities are reduced greatly when the temperature is held near 24°C. A refrigeration unit with the capacity to keep water temperatures at this level in three large holding tanks has been used successfully in the past two seasons. Fresh sea water is introduced slowly into the essentially closed-water system to prevent an accumulation of wastes.

Fiber glass holding tanks have been constructed to replace the heavy wooden tanks used formerly. The new tanks (fig. 13) are divided by vertical partitions to make it possible to separate groups of shrimp and by horizontal partitions to increase the surface area on which shrimp may rest. Portable staining tables and measuring boards are attached to the holding tanks. These additions reduce to a minimum the need to move and handle shrimp during staining.

Shrimp are marked by injecting a small quantity of stain from a syringe into the shrimp's abdomen; from there the pigment is carried to the gills where it remains. An overdose of stain kills shrimp, and an underdose makes it difficult or impossible to detect a marked individual in a fisherman's catch. It is important to reduce the variation in the amount of stain injected into shrimp without increasing the time required for marking and handling. Recent use of automatic calibrating and refilling syringes has eliminated this variation of the amount of stain and has increased the number of shrimp that can be marked in a given period of time (fig. 14).

The final phase of the marking operation is the return of the shrimp back to the sea floor in a manner that will not expose them to predation. In the past, we lowered a box containing marked shrimp to the bottom where it opened in response to a weighted messenger. This type of box must be lowered with the aid of a winch and, therefore, requires that the research vessel be stopped. A new compact lightweight and disposable release box is now



Figure 13.--Fiber glass holding tanks used in shrimp staining experiments.



Figure 14.--Injecting stain into shrimp with automatic calibrating and reloading syringes. These syringes have increased the efficiency and rapidity of staining.



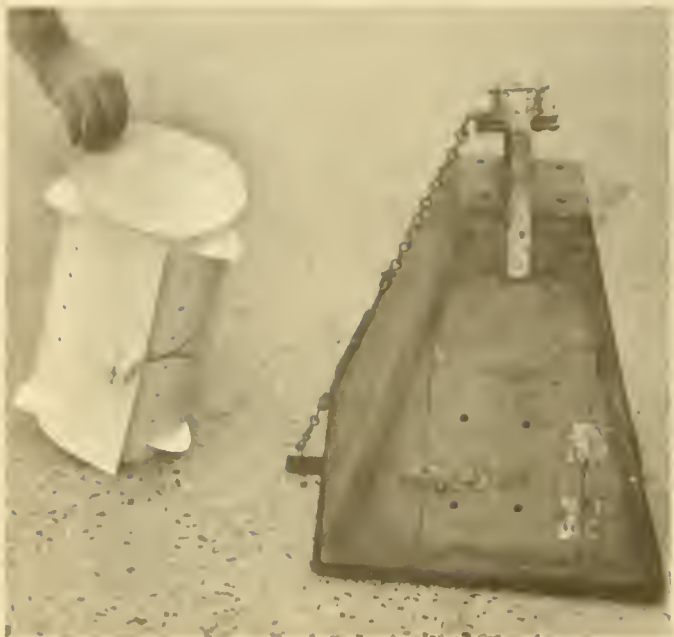


Figure 15.--Two types of containers used to transport stained shrimp to the sea floor. The disposable container now in use is on the left. When the block of salt dissolves, the container springs open.

being used. The box is dropped overboard while a vessel is underway. About 10 minutes after the box reaches the water and begins to sink, it springs open when a cube of compressed salt that holds it shut dissolves (fig. 15).

Each of the refinements of equipment required for staining shrimp has increased the efficiency of the operation, and some have

led to releases of shrimp in better condition than previously. The three most recent mark-recapture experiments have included releases of between 7,000 and 12,000 stained shrimp; whereas, former experiments were limited to much smaller numbers.

Charles E. Knight, Project Leader

## POPULATION DYNAMICS OF WHITE SHRIMP AND BROWN SHRIMP IN VERMILION BAY, LA.

Investigations of seasonal fluctuations in the abundance of postlarval shrimp in Vermilion Bay have been underway since February 1963. Information collected to date indicates a possibility for predicting the commercial abundance of white shrimp from densities of postlarvae. Attempts to relate the abundance of postlarval brown shrimp to later commercial catches have been less successful. The reverse of this situation has been found at Galveston, where predictions of brown shrimp abundance appear to be more feasible than those for white shrimp.

New short-term studies during the summer when classes are not in session were added to the schedule of contract work. Laboratory experiments were undertaken to determine the glycogen and lactic-acid content of shrimp muscle tissue, and to develop antisera that may be used to distinguish white and brown shrimp at the postlarval stage. Shrimp production in a small portion of Vermilion Bay is being studied by following changes in the size composition of brown and white shrimp.

Charles W. Caillouet, Jr., Project Leader

University of Southwestern Louisiana  
(Contract No. 14-17-0002-131)

## ESTUARINE PROGRAM

Gulf estuaries, which harbor fishery resources that contribute almost one-third of the commercial harvest from U.S. coastal waters, are being rearranged, modified, destroyed, and polluted at an alarming rate. These valuable ecosystems are natural nutrient "traps" that frequently produce more per hectare than the croplands of our midwest. Nonetheless, those planning construction have given little thought to the present and potential value except as natural features to be converted to industrial and residential sites or receptacles for sewage. The short-term gains from these modifications cannot be in the best public interest.

A major purpose of our Estuarine Program, then, is to amass the basic facts needed to document the dependency of fishery resources on estuaries, the specific type of estuarine habitat that is the most productive, and the value of such areas to our national economy in terms of their production of renewable fishery resources. When these facts are documented, the fishery resources can compete in the race to develop our coastal basins for maximum good.

During the past year we learned much about the specific types of habitat that most of the major commercially important species prefer during the estuarine phase of their development. The peripheral "edge" of an estuarine system (exemplified by bordering marshes, small stream or bayou complexes, and protected shorelines) is used more extensively by most estuary-dependent species as their primary nursery area than any other part of an estuary. Unfortunately, these valuable edges are being developed and converted to residential and industrial sites faster than other portions of an estuary (fig. 16). They are easily accessible and often privately owned.

In an effort to use our manpower resources better and obtain better basic data, we are

streamlining and mechanizing our field work and emphasizing ADP (automatic data processing) to an ever greater degree. Since most estuary-dependent animals are sensitive to temperature, we have developed and installed in the field a temperature-recording device (fig. 17) and will soon have salinity-recording instruments for our vessels and for field installation. We hope eventually to record the hydrological regime of an entire estuary with such instruments adapted for ADP.

Several special studies were started during the year, and one was completed. Our first attempt to assess the effect of modifying a natural shoreline zone by bulkheading was successful. We began a study to determine the effects of pumping hydraulic spoil over a marsh area and nearby submerged grass flats because we needed more information on this increasing type of activity (fig. 16). Our attempt to assess the population of brown shrimp in the tidal passes of the Galveston estuary as they return to the Gulf of Mexico continues in cooperation with the Shrimp Dynamics Program.

Cooperative research was expanded considerably during the year. We exchanged field data, provided technical assistance, or participated directly in field studies with several universities, private companies, State conservation and pollution control agencies, and other Federal agencies, including Bureau of Commercial Fisheries Laboratories. One of the more important of these enterprises is a cooperative study with Texas A&M University to survey the fishery resources of the lower Trinity River Delta before a reservoir is built and the area inundated.

Our review of water-development projects for the Bureau in the western Gulf area continued to require a great amount of time. Private developments in the estuaries increased by more than one-third over the previous year, and the larger Federal projects

BEFORE



AFTER



Figure 16.--Destruction of valuable estuarine marsh by spoil from hydraulic dredging for real estate development. The mound in the right background is the discharge end of the dredge line. The widespread effect upon the marsh and water areas is readily evident.

are becoming more complex as entire basins or groups of basins are being studied as units for the development of their water resources. We, unfortunately, do not have the staff to investigate properly each of the hundreds of engineering projects, both large and small, that are proposed, authorized, or

constructed each year. We did, however, complete the estuarine fishery section for the Fish and Wildlife Service report on the Bureau of Reclamation's Texas Basins Project, the most ambitious plan proposed so far for water development in the western Gulf area. We also assisted in preparing a draft





Figure 17.--Recording device measures continuously the temperature of surface and bottom waters and bottom sediments to provide information to help understand the behavior of estuarine animals.

Departmental report that included Fish and Wildlife as a full partner in the Texas Basins Project proposal.

We are now working with the Estuarine Technical Coordinating Committee of the Gulf States Marine Fisheries Commission to develop an estuarine atlas. The atlas will include an inventory of basic descriptive and biological information for each estuary along our Gulf of Mexico coastline.

Charles R. Chapman, Program Leader

## ECOLOGY OF WESTERN GULF ESTUARIES

This project, as in former years, included a wide range of activities. Routine hydrological and biological sampling was continued throughout Galveston estuary and adjacent marshes to survey the environment and abundance of major species and to provide detailed information on the estuarine phase of the brown and white shrimp.

The number of biological sampling locations was reduced in January to include sites in a nursery area complex in five of the six sub-bays of the estuary. These sites include the bordering marsh, controlling bayou system,

bay beach (surf zone), near-shore waters, and open bay. The high-salinity marshes and submerged grass flats of West Bay are to be added next year to complement the variety of habitat types being studied.

## Hydrology

Since 1963, the winter water temperatures in the Galveston estuary have been turning warmer (fig. 18). Temperatures during the spring, however, have been getting cooler, as have those in the fall. Following the normal seasonal cycle, monthly mean water temperature was highest in September 1965 (29.2° C.) and lowest in February 1966 (11.9° C.).

As in previous years, concentrations of total nitrogen and phosphate were highest in the upper bays of the estuary and declined Gulfward (fig. 19). Although seasonal trends are apparent and values are highest in winter, considerable fluctuation is evident. The extremely high levels of nitrogen and phosphate, particularly in the upper bays, are probably caused by industrial waste and domestic sewage that enter the estuary from the San Jacinto River via the upper Houston Ship Channel.

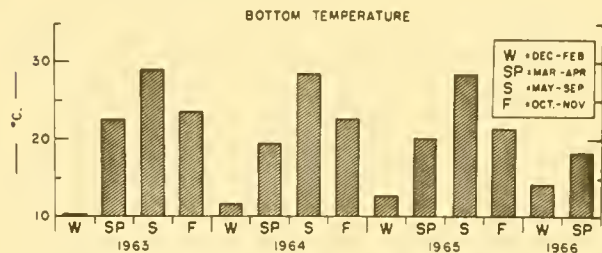


Figure 18.--Seasonal trends in water temperature in the Galveston estuary.

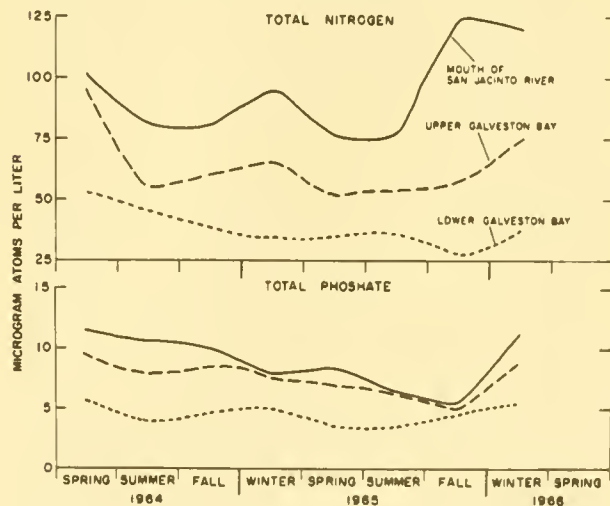


Figure 19.--Influence of pollution from the upper Houston Ship Channel (mouth of San Jacinto River) on upper and lower Galveston Bays as indicated by seasonal trends in total nitrogen and total phosphate.

Bay-water salinities were relatively low in July 1965 (average, 11.0 p.p.t.) because of large discharge from the Trinity River in May. Salinity increased thereafter and reached a seasonal high in the fall (21.5 p.p.t.). Large winter flows from the Trinity River again lowered salinity throughout the estuary in January and February 1966, but levels were higher in March and April.

A major flood of the Trinity River in late April and May 1966 then reduced salinity throughout the estuary to the lowest level in 5 years. Salinity dropped to less than 2 p.p.t. in

bays, but its effect was evident only about a month in the lower bays (fig. 22). During May and early June, however, salinity in the lower bays increased as salinity declined in the upper bays. River flow did not reach the lower bays until late June, and the maximum lowering did not occur until early July. Recovery was rapid in the lower bays.

The effect of the constriction between the upper and lower bays of the Galveston estuary is to delay the time it takes fresh water from the Trinity River to reach the Gulf. Conversely, even though Gulf salinities reached a high in

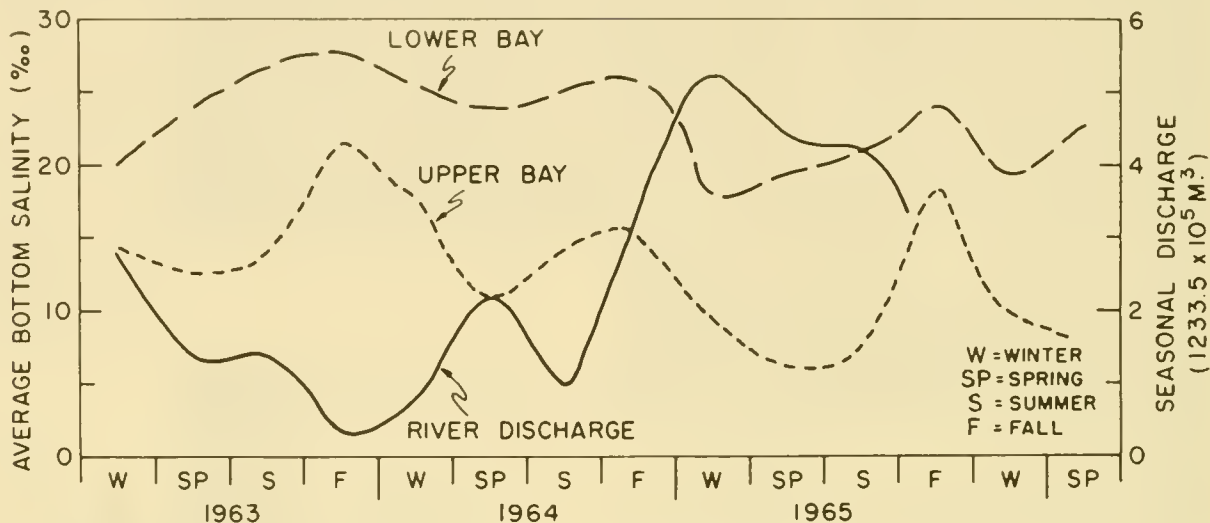


Figure 20.--Influence of seasonal trends in Trinity River discharge on salinity in the upper (Trinity) and lower (lower Galveston) bays of the Galveston estuary.

Trinity Bay; less than 6 p.p.t. in upper Galveston Bay; and less than 10 p.p.t. in lower Galveston Bay where the salinity is usually highest (20 to 30 p.p.t.). Reduced river flow in June 1966 produced a rapid increase in salinity in the lower bays of the system, but the salinity in the upper bays remained relatively low. The seasonal influence of Trinity River on bay salinities is depicted in figure 20.

An excellent opportunity to study how Trinity River influences bay salinities arose in May 1963 when almost 600 million cubic meters of fresh water was discharged. Before May, river flow was small and bay salinities were increasing. River flow was again small after May for the rest of the year (fig. 21). Salinity was depressed considerably in the upper bays, but the effect was small in the lower bays and tidal pass. The constricting effect of Smith Point, Eagle Point, and Redfish Bar in mid-Galveston Bay was strikingly evident during the summer when prevailing southerly winds tend to prevent the flow of waters Gulfward from the upper bays. In terms of time, the influence of 600 million cubic meters of fresh water in May lasted until August in the upper

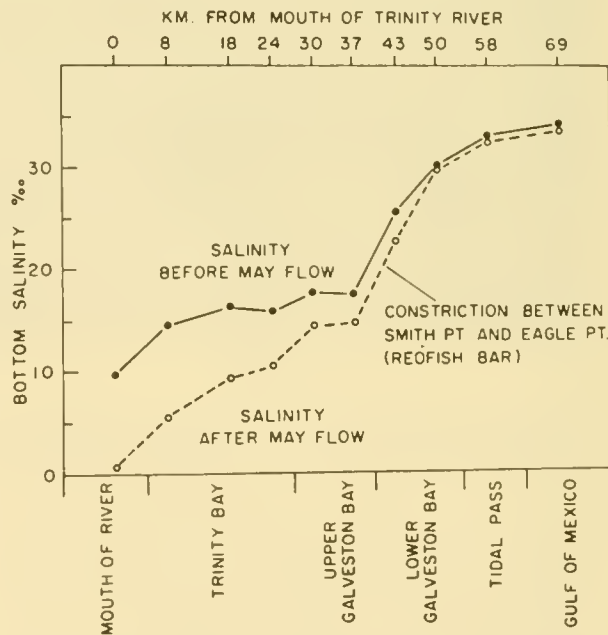


Figure 21.--Effect of May 1963 Trinity River flow ( $5.8 \times 10^8 \text{ m.}^3$ ) on salinity of Galveston estuary.

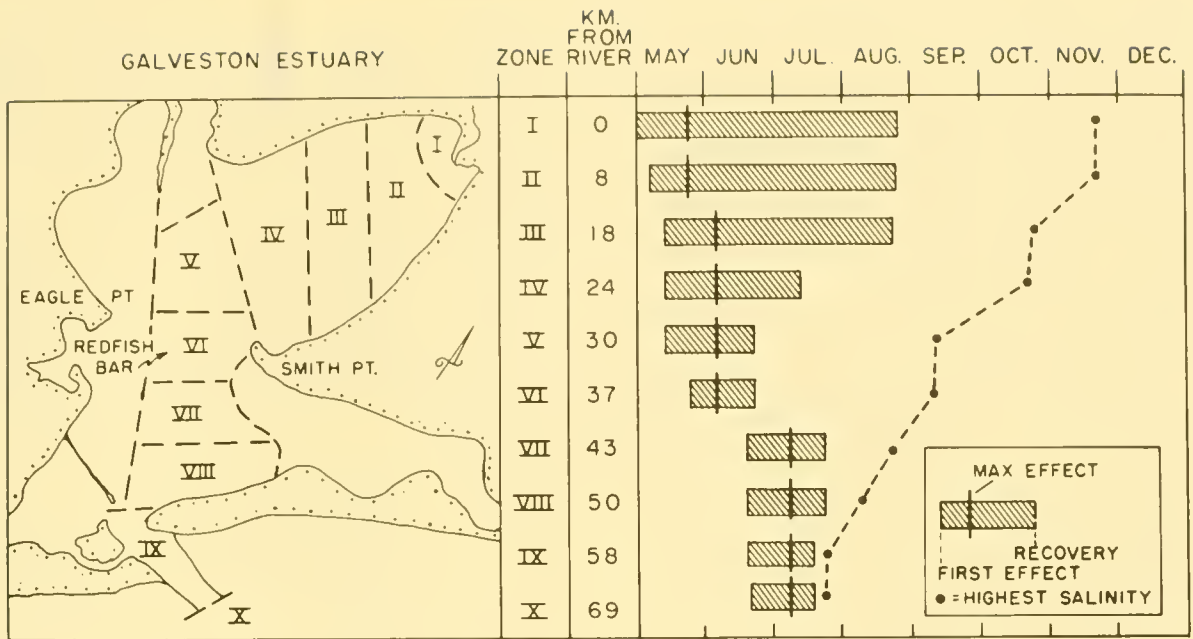


Figure 22.--Period of influence of May 1963 Trinity River flow on salinity of Galveston estuary.

July, the high did not occur in upper Trinity Bay until November.

The configuration of the Galveston estuary provides a natural "trapping" effect so that relatively small volumes of fresh water exert considerable influence for months. Should the constriction between the upper and lower bays become more severe, however, salinity in the upper bays would probably remain low for longer periods.

### Species Diversity

The Galveston estuary provides a typical example of increasing species diversity at higher salinities. Of more than 150 species of fish, crab, and shrimp collected in small trawls, 74 were caught in the higher salinities (20 to 30 p.p.t.) of lower Galveston Bay, 59 in upper Galveston Bay, and only 45 in the relatively low-salinity waters near the river mouth. Although more species were caught in waters of high salinity, the greatest numbers of individuals (all species combined) were taken in the lower salinity waters of the upper estuary. The average size of animals of each species was smaller in the upper estuary than in the lower bay. The relation of temperature to species diversity was also typical of Gulf estuaries. The collection of more species in water where temperature varied between 10° and 30° C. than at other temperatures indicates that many species may be sensitive to high temperatures in summer as well as to low temperatures in the winter (fig. 23).

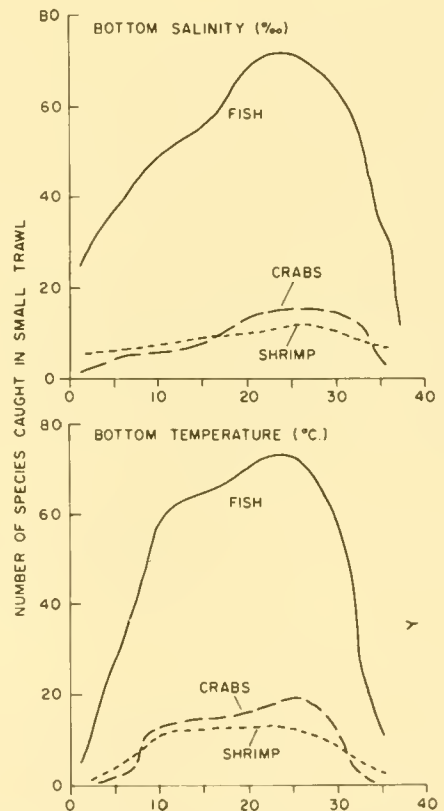


Figure 23.--Diversity of species of fish, crab, and shrimp in relation to temperature and salinity in the Galveston estuary.



## Relative Abundance and Distribution of Major Species

Since January 1963, we have assessed the relative abundance in the Galveston estuary of the species most frequently caught in a small trawl. Of the more than 150 species of fish, crab, and shrimp collected, 9 estuary-dependent species made up more than 80 percent of all animals caught for each of the past 3 years. These species are: Atlantic croaker, *Micropogon undulatus*; bay anchovy, *Anchoa mitchilli*; brown shrimp; white shrimp; spot, *Leiostomus xanthurus*; sand seatrout, *Cynoscion arenarius*; blue crab, *Callinectes sapidus*; sea catfish, *Galeichthys felis*; and large-scale menhaden, *Brevoortia patronus*. All but the bay anchovy, an abundant forage fish, are of direct commercial importance.

Annual variation in the relative abundance of these nine species is considerable. The abundance of croaker, anchovy, menhaden, sand seatrout, sea catfish, and brown and white shrimp was higher in 1965 than in 1963 or 1964. Thus, 1965 was well above average for many species. Interspecific competition and predation were probably not major controlling factors. Abundance of these same species was generally lowest in 1964. Only the blue crab and spot reached their maximum abundance in 1964.

These species demonstrated a preference for a particular part of the estuary. East Bay harbored greater numbers of croaker, sand seatrout, spot, and white and brown shrimp than any other subbay. Menhaden, sea catfish, and blue crabs were most numerous in upper Galveston Bay, whereas bay anchovies were most abundant in Trinity Bay.

Each species also demonstrated a preference for a specific type of habitat in the subbays. Considerably more menhaden, spot, croaker, blue crabs, and white and brown shrimp were caught in the peripheral waters of the estuary than elsewhere. Only the bay anchovy demonstrated a preference for the open-bay waters and the sea catfish for the near-shore waters. The sand seatrout was equally abundant in the open and peripheral waters.

In view of the rapid deterioration of our estuarine habitat, every effort should be made to conserve the natural environment of East Bay and its bordering peripheral areas.

### Brown Shrimp Study

The brown shrimp is the most valuable species taken commercially from Texas coastal waters. We have sampled the juvenile population in Galveston Bay since 1963 to estimate their relative abundance and possibly provide a rough index of the amount of shrimp that might be available to the fishery (fig. 24). The year 1963 was relatively good for brown shrimp in Texas; 1964 was poorer; and 1965

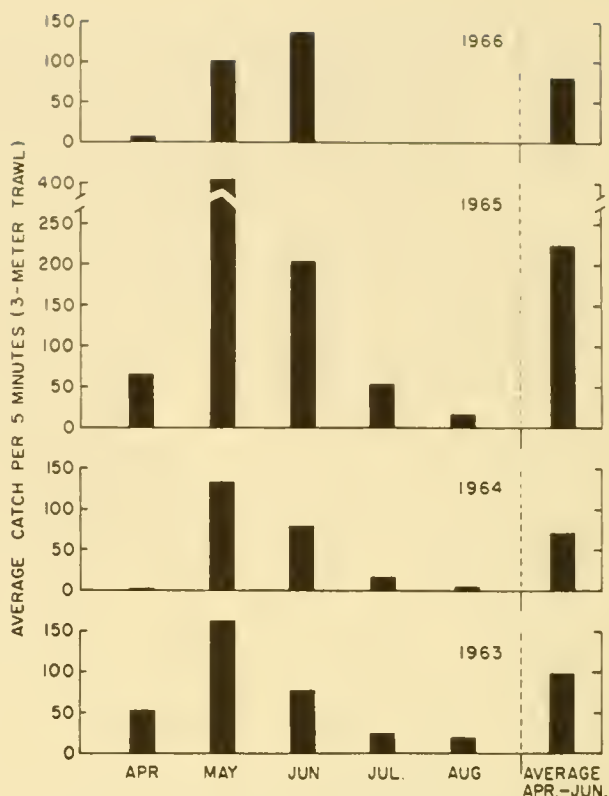


Figure 24.--Relative abundance of juvenile brown shrimp in the Galveston estuary.

was the best of the three. If we relied on numbers alone, however, 1965 should have set an alltime record for harvest because fantastic numbers of juvenile brown shrimp were present in the estuary. The 1966 crop of brown shrimp in Galveston Bay is probably greater than in 1964 but less than in 1963 or 1965.

This abundance index is at best only relative between years, and its interpretation is complicated by many factors. The time of the year when the juvenile population in the bay reaches peak abundance (as indicated by trawl sampling where only shrimp larger than 40 mm. are retained) varies between years. Furthermore, shrimp frequently leave the estuary at a different average size and at different times from year to year.

Maximum abundance of juvenile brown shrimp occurred in May 1963, 1964, and 1965, but in early June in 1966. A cool, late spring in 1966 may have retarded growth sufficiently so that they were not big enough to be captured in our trawls until later in the season.

The period of heavy emigration of brown shrimp from the estuary can start as early as mid-May or as late as early June. In 1963 and 1964, emigration was not significant until early June, whereas in 1965 large numbers of shrimp left the estuary in mid-May and

emigration continued heavy through mid-June. It also appears that an early movement of small shrimp to the Gulf started in mid-May of 1966, but peak emigration was not reached until the first week in June.

When maximum emigration from a bay starts early, average size of the shrimp is much smaller than when departure is later. The early movement of small shrimp from the estuary in 1965 might have been caused by the tremendous population density. A similar movement occurred in 1966, however, when shrimp were much less plentiful in the bay. Thus, intrapopulation competition seems unlikely as a cause of early emigration. Flood flows from Trinity River in the spring depressed bay salinities lower in 1965 and 1966 than in 1963 or 1964. The lower salinity may possibly contribute to earlier return of brown shrimp to the Gulf of Mexico.

Small brown shrimp reside in an extremely complex, constantly changing environment during their estuarine development. In the Galveston estuary, they range from the high-salinity waters of the lower bays to the nearly fresh waters of the bayous and marshes of the upper bays.

To determine whether these small shrimp might be influenced by such environmental variations, their condition (based on length-weight relation) was compared from three areas that are hydrologically different and relatively isolated from each other--East Bay, Trinity Bay, and upper Galveston Bay southwest of the Houston Ship Channel. Their condition was also compared during the period when they were very numerous in the estuary (April-June) and a later period (July-December) when the population was small.

Condition differed significantly in the shrimp collected from the three areas during both periods, but the extent of the differences was not constant and it changed with size. The smaller shrimp from Trinity Bay were in better condition than those from East Bay or upper Galveston Bay, whereas the larger shrimp from upper Galveston Bay were in the best condition. Ecological differences in the habitat evidently are reflected in the observed difference in the condition of shrimp.

Comparison of condition between the two periods did not give clear-cut results. Shrimp of all sizes from Trinity Bay were in better condition during the April-June period of greatest abundance. The condition of shrimp from upper Galveston and East Bays, however, varied between the two periods with size; some size groups were in better condition during the period of greatest abundance and other groups when the population was small. These discrepancies suggest that the environment and not the density of shrimp affected their condition.

When postlarvae enter the estuary in the spring, considerable numbers occupy the

peripheral marshes. Salinity is one of the factors that dictate the type of marsh. Near the Galveston estuary are fresh-water marshes, intermediate marshes of relatively low salinity, transition marshes, and salt marshes where salinity is high. Considerably more small brown shrimp were caught in the marshes where salinity was low than in the high-salinity marshes (fig. 25).

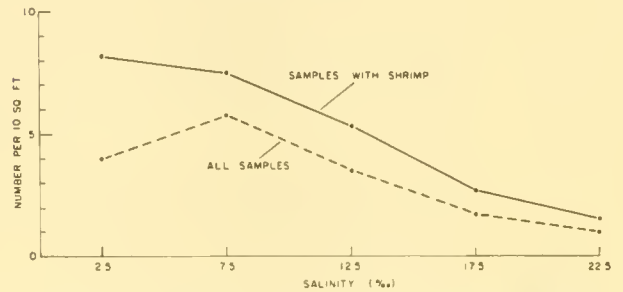


Figure 25.--Density of juvenile brown shrimp in Galveston Bay marshes in relation to salinity, 1965.

We frequently did not catch small brown shrimp in the low-salinity marsh in the early spring, however. During this spring warming period, this lack of shrimp might be explained by combined effect of salinity and temperature. When temperature is low, salinity must be higher. (See U.S. Fish and Wildlife Service Circular 230, Biological Laboratory, Galveston, Tex., fishery research for the year ending June 30, 1964, p. 67.)

We did not catch postlarval shrimp in marshes where salinity was extremely low (1.0 to 5.9 p.p.t.) until the water temperature reached 23° C., but caught them in marshes where salinity was higher (10.0 to 24.9 p.p.t.) when water temperatures reached 15° C. (fig. 26). Thus, a considerable acreage of

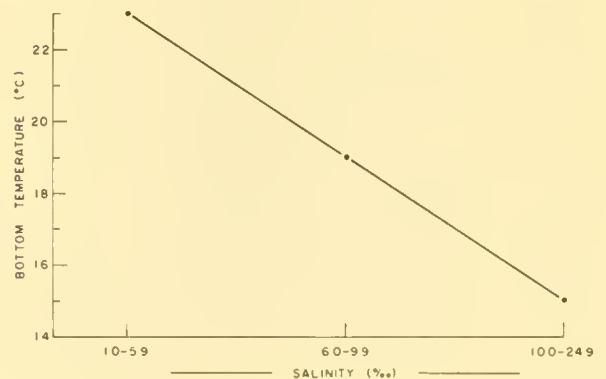


Figure 26.--First occurrence of small brown shrimp in the Galveston estuary marshes during the spring of 1965 in relation to water temperature and salinity.

marsh might not be available immediately as nursery area for brown shrimp during a late spring.

Many types of habitat are available to postlarval and juvenile brown shrimp in an estuary. Some are obviously more suitable than others. In view of the vast physical changes that are occurring to the estuaries, we must know which parts of an estuarine system are most important. Intensive sampling in the marshes and bayous, along the shoreline (surf zone), near shore, in open bays, and in dredged channels has revealed that small brown shrimp have a decided preference for one part of an estuarine system over another (fig. 27). Not unexpectedly,

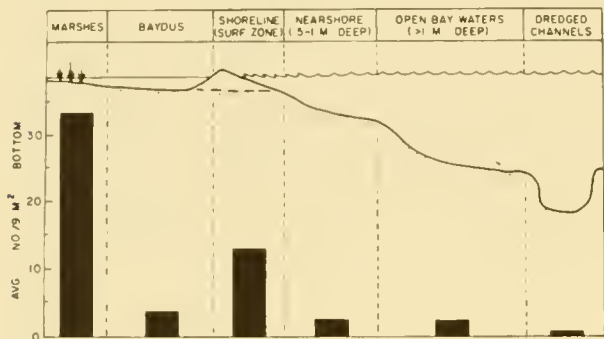


Figure 27.--Relative importance of different types of habitat in the Galveston estuary as nursery areas for juvenile brown shrimp, March-August 1965.

the edge, or marshes and bay shorelines, of the estuary harbored a denser population of shrimp than elsewhere. Dredged channels were almost barren of the smaller shrimp.

#### Natural and Altered Habitats for Penaeid Shrimp

Because bays are the nursery area for commercially important shrimp of the Gulf of Mexico, it is important to evaluate accurately the effects of man's increasing activities on the suitability of this environment for young shrimp. This study illustrates one way in which structural modification of a natural shoreline may have detrimental effects.

Two areas in Clear Lake, a part of the Galveston estuary, were selected for comparison. One area included an unaltered, vegetated shoreline, and nearby, the other

a concrete bulkhead which drastically altered a habitat formerly similar to the first (fig. 28). Both areas had similar salinity and water temperatures but differed in the amount of organics in the bottom sediments and water depth at the shoreline.

Large amounts of organic detritus were present along the natural shoreline in a narrow band adjacent to the vegetation. The bulkheaded shoreline contained little organic detritus and no vegetation, and was deeper. Intensive sampling over a 10-month period along the shorelines and at 15.2 m. and 30.5 m. from the shorelines of each area (equal sampling effort in each area) disclosed that 76 percent of all postlarvae and 64 percent of all juvenile brown shrimp were in the natural, unaltered area. Even more striking, 98 percent of all postlarvae and 87 percent of all juvenile white shrimp were caught at the unaltered area.

Comparison of catches from the shoreline and from stations 15.2 and 30.5 m. from shore for both altered and unaltered areas proved that the natural, unaltered shoreline zone adjacent to the vegetation was by far the preferred habitat for brown and white shrimp of all sizes.

Obviously, bulkheading a natural productive shoreline practically destroys its suitability as a nursery area for young shrimp.

#### Blue Crab Study

Specimens for our study of the life history of the blue crab in the Galveston estuary were obtained from routinely collected trawl samples. Hydrological measurements were obtained concurrently with the trawl samples. Crabs were weighed and measured, and sex was determined. The resulting data were analyzed for length-weight, length-frequency, and size-salinity relations for both sexes.

Male crabs were heavier at equal lengths (carapace widths) than the females. Crabs at equal lengths caught in the lower high-salinity bays near the Gulf were in better condition (heavier) than those caught in the upper, low-salinity bays. Smaller crabs were concentrated in low-salinity areas, whereas the larger crabs were caught most frequently in the areas of higher salinity.

The upper low-salinity bays of the Galveston estuary, together with their contiguous marshes and bayou systems, are nursery areas for the juvenile crabs, whereas the





NATURAL VEGETATED SHORELINE



BULKHEADED SHORELINE

Figure 28.--A valuable nursery area for small shrimp destroyed by bulkheading. This is a typical example of man's increasing encroachment on our estuarine areas.

lower more saline bays nearer the Gulf harbor the adults (fig. 29).

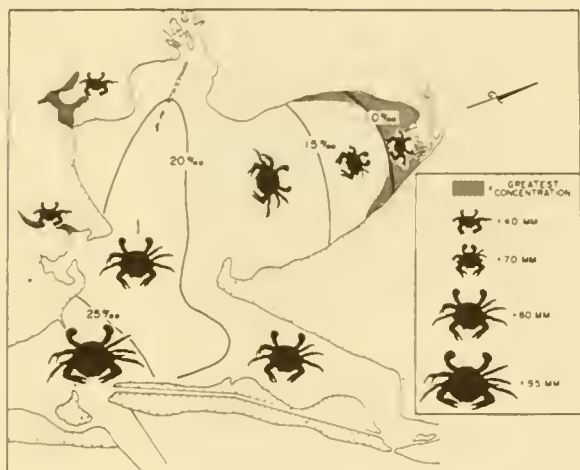


Figure 29.--Average size (carapace width) of blue crabs in relation to salinity in the Galveston estuary.

Charles R. Chapman, Acting Project Leader  
Wallace L. Trent  
Cornelius R. Mock  
Edward J. Pullen  
Robert D. Ringo

## EFFECTS OF ENGINEERING PROJECTS

The development of water resources for maximum use is being accelerated, largely in response to increased Federal participation. The need for the Federal Government to enter this field to provide irrigation, flood control, navigation, hydroelectric power, municipal water supply, and other functions was recognized many years ago. Such Federal agencies as the Corps of Engineers, Bureau of Reclamation, and the Soil Conservation Service have carried out and continue to initiate water-development programs. State governments, municipalities, and private organizations also are active in this field.

The value of estuaries as nursery and feeding grounds for many commercially important species of fish and crustaceans is well known to biologists but usually not to the planners and developers. Because more than 90 percent of the fish taken in the Gulf of Mexico are in some way dependent upon estuaries, the need to review and evaluate water use and development projects and to devise appropriate measures for protecting, rehabilitating, and improving the estuarine nursery areas is clearly evident.

Laboratory personnel are cooperating and assisting the Division of River Basin Studies of the Bureau of Sport Fisheries and Wildlife to evaluate effects of engineering projects on commercial fisheries in Texas. We also help

formulate specific recommendations for project modifications that will ensure the least damage to and, when possible, improve the value of estuarine fishery resources. It can be demonstrated, occasionally, that the adverse effects from construction projects on the fishery resources clearly overbalance the benefits to other interests.

Recognizing the above problems, project personnel during the past year and under the present system of coordination with the Division of River Basin Studies reviewed and appraised the plans for 435 private projects that could potentially affect estuarine fishery resources. Sections of 57 Bureau of Sport Fisheries and Wildlife draft reports pertaining to construction projects were also reviewed. The number of projects and reports reviewed increased more than one-third in the last year.

During the latter half of fiscal year 1966, considerable effort was devoted to coordination of studies on the Corps of Engineers Texas Coast Hurricane Protection Project. The proposed plans would provide for a combination of seawalls, levees, and tide-control structures along the Texas coast to provide hurricane protection. The hurricane study covers five areas as follows: Galveston Area, Corpus Christi Area, Matagorda Bay Area, Sabine Lake Area, and the Laguna Madre Area.

The location of the seawall for the Galveston Bay Area has not been decided, but the following four alignments between High Island and Freeport are being studied: Plan A--the seawall would be 305 m. offshore in the Gulf of Mexico; Plan B--the seawall would be constructed on the Gulf beaches; Plan C--the seawall would follow the existing highways on Bolivar Peninsula, Galveston Island, and Follets Island; and Plan D--the seawall would follow the existing Gulf Intracoastal Waterway alignment. Each alternative would include a surge-control structure in San Luis, Bolivar, and Rollover Passes (fig. 30).

A fifth and different alignment is also being considered in the event Plans A through D cannot be justified economically. This plan would include a surge-control structure and levee across the bay between Smith and Eagle Points that would divide upper and lower Galveston Bays. The levee or seawall would extend along the north shore of East and West Bays. The separation of the marshes bordering East and West Bays from the bay proper poses a real problem. This plan jeopardizes both fish and wildlife habitats, including two wildlife refuges. The loss of this much marsh could be disastrous to the fishery resources of Galveston Bay. A solution must be found.

The Corps of Engineers has constructed two scale models of the Galveston Bay system, each having their particular functions and capabilities. One, a small-scale surge model covering the area between High Island and

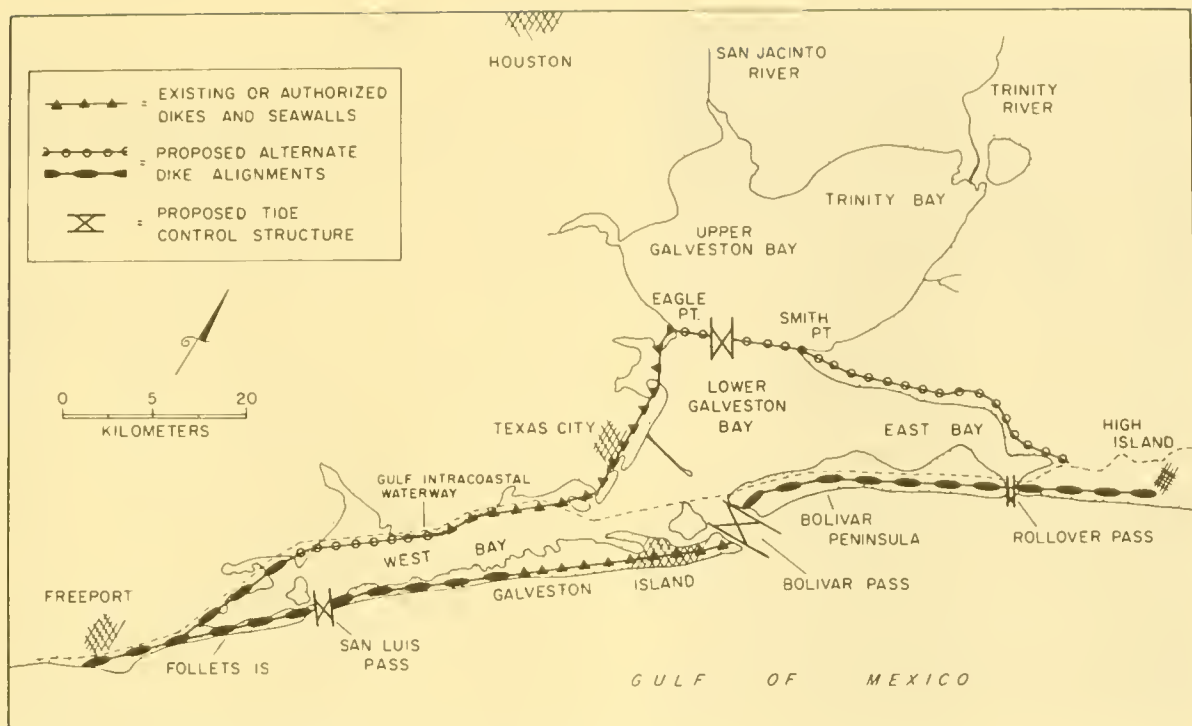


Figure 30.--Proposed alignments for dikes and water-control structures to prevent hurricane flooding in the Galveston Bay area.

Freeport from the Gulf of Mexico to the 6-m. contour inland, will be used to test storm-surge penetration. This model cannot be used to study changes in hydrology as indicated by salinity. The larger Houston Ship Channel model, however, can be used for more detailed studies but does not include West Bay or the extreme upper end of East Bay. It will be necessary, therefore, to use both models to test the effect of the particular plan to be selected.

Several meetings have been held with the Corps of Engineers to discuss their proposed plans and to develop a program for model testing. We believe that a suitable series of tests has been developed that will satisfy our requirements as well as those of the Corps of Engineers.

Project personnel are also assisting in a research project to study the impact of bulk-heading and hydraulic dredging on the estuarine environment and its biota.

Richard J. Hoogland, Project Leader

### EVALUATION OF ESTUARINE DATA

The Estuarine Technical Coordinating Committee of the Gulf States Marine Fisheries Commission has undertaken to coordinate the development and completion of an estuarine atlas for the States that border the Gulf of

Mexico. The atlas will include an inventory of basic descriptive and biological information. The Committee has enlisted the aid of the Fish and Wildlife Service and the conservation agencies of Alabama, Florida, Louisiana, Mississippi, and Texas. Funds are available to the States for this work from the new Commercial Fisheries Research and Development Act (Public Law 88-309).

The need for this inventory is emphasized by the accelerated competition for estuarine areas between fisheries on one hand and industrial, real estate, and commercial developments on the other. The best way to offset these detrimental influences is to develop realistic appraisals of the Gulf estuaries that show their direct and indirect values to the fisheries. A cooperative study like the one being planned is a logical way to obtain the required information. Standardization of the methods of collecting and compiling the data should give comparable results for each State. Consequently, information from the study can be combined into a larger volume for the entire U.S. shoreline on the Gulf of Mexico.

The inventory has been divided into four parts: (1) Area Description, (2) Biology, (3) Hydrology, and (4) Sedimentology. Preliminary working outlines have been prepared for the Area Description and Hydrology sections and are being reviewed by the respective States.

Richard A. Diener, Project Leader



## EXPERIMENTAL BIOLOGY PROGRAM

We need to determine which natural conditions are biologically important to shrimp in the offshore spawning grounds, the inshore nursery grounds, and the offshore fishing grounds. Studies of growth, survival, metabolism, and behavior of shrimp under known conditions can provide valuable leads to a clearer understanding of the environmental requirements of these decapod crustaceans.

David V. Aldrich, Program Leader

### BEHAVIOR AND ECOLOGICAL PARASITOLOGY

Observations under laboratory-controlled conditions have provided new information on behavioral responses to low temperature in the two species of shrimp commercially most important in the northwestern Gulf of Mexico. Postlarval brown shrimp (8 to 12 mm. long) burrowed when water temperatures were experimentally lowered to 12°-16.5° C. (fig. 31) if the substrate was sufficiently soft and the rate of temperature change was not too rapid. (Changes of 1° C. per 5 or more minutes induced burrowing.) Postlarval white shrimp collected with the postlarval brown shrimp did not burrow under our experimental conditions.

The absence of the burrowing response to low temperature in white shrimp led us to consider known seasonal aspects of these species' natural histories. The season at which postlarvae of the two species reach the

bays differ markedly. The white shrimp arrives at Galveston Bay when water temperatures are consistently warm (about 24° to 32° C.), whereas most brown shrimp appear in March or April when the bay is not only cool (average, 15° to 24° C.) but also subject to drastic temperature reductions (often to 13° C.) by atmospheric cold fronts. The ability to burrow in response to low temperature may have special survival significance for brown shrimp during this period of its natural history. Burrowing can attenuate temperature changes to which the animal is exposed and protect it from predatory attack when temperatures are low enough to slow avoidance or escape movements. On the other hand, a burrowing response to low temperature would have no obvious adaptive significance for postlarval white shrimp because the seasonal characteristics of this species' life cycle are such that most postlarvae do not encounter cold temperatures in the northwestern Gulf of Mexico.

Results in the laboratory further revealed that most brown shrimp postlarvae that have burrowed in response to low temperature leave their burrows as the temperature increases to 18°-21.5° C. (fig. 31). Field data of other workers in the Texas-Louisiana area (K. N. Baxter, L. T. St. Amant, and their respective coworkers) indicate that the major influx of postlarval brown shrimp is in the early spring when water temperatures have reached this range. This suggests the possibility that postlarval brown shrimp are burrowed part of the winter before entering the bays in early spring.

The fact that soft substrate is required for successful burrowing indicates that physical characteristics of natural substrates may be an important determinant of the survival of postlarval brown shrimp at late-winter or early-spring water temperatures.

Observations of postlarval brown shrimp during previous growth and survival studies suggested that temperature influences the behavior of these animals. The shrimp seemed most active at warm temperatures (25° to 32° C.), somewhat less active at 18° C., and immobile at 11° C. A behavioral study was carried out, therefore, on a group of 50 postlarvae exposed to known temperatures in the laboratory. The number of animals swimming was visually determined with the aid of low levels of red light. No substrate was added to the floor of the 45-liter glass aquarium. The data clearly substantiate the previous findings and indicate a marked direct effect of temperature on activity (fig. 32).

To gain information on shrimp ecology through studies of their parasites, we have continued to examine shrimp from several Texas bays. Latest results indicate that incidence of metacercariae of the trematode,

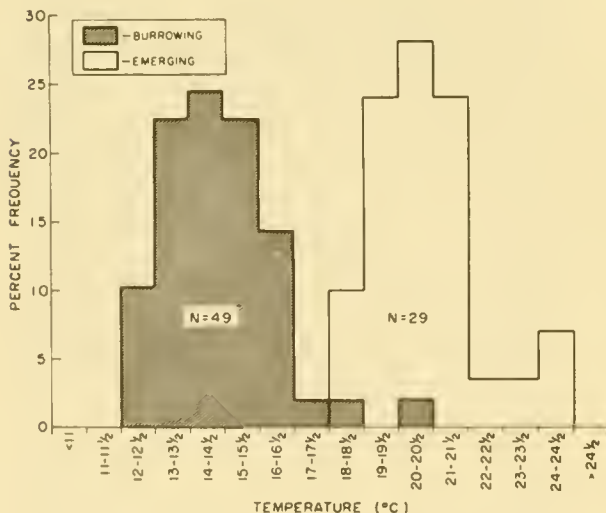


Figure 31.--Frequency distribution of burrowing and emerging of postlarval brown shrimp at various temperatures.



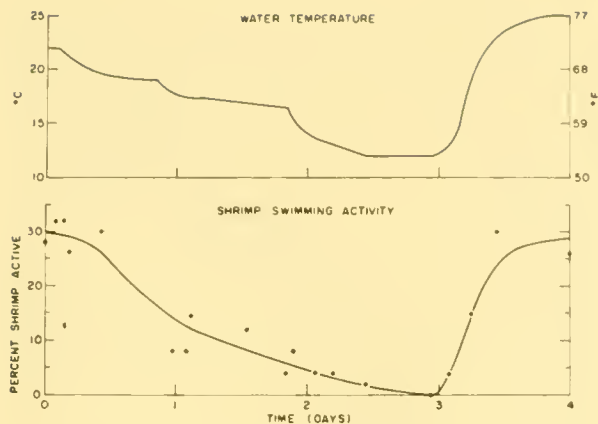


Figure 32.--Temperature and swimming activity of postlarval brown shrimp.

*Opecoeloides fimbriatus*, in shrimp varies widely from bay to bay. Further work of this type is necessary to determine whether shrimp are "tagged" with natural parasites. Such information may provide biological methods useful for tracing movements of shrimp from their estuarine nursery areas to the fishery offshore.

David V. Aldrich, Project Leader

### METABOLISM OF ESTUARINE ORGANISMS

Like the other projects in this program, the metabolism project is concerned with how physical factors affect the behavior of shrimp. We, therefore, deal with effects that are not readily visible within the organisms. We now are investigating how salinity and temperature affect the oxygen requirements of postlarval shrimp.

The amount of oxygen that an animal requires varies with the temperature, the amount of food it eats, the work it must do to maintain itself in its environment, and its size. A smaller animal, for example, uses more oxygen per unit of body weight than does a larger one. We are extending the study begun on larger animals to postlarval shrimp of various sizes to find the amount of oxygen they require. Only brown shrimp from 12 to 25 mm. long have been tested in the Warburg apparatus (fig. 33). Although the containers have a 15-ml. capacity, only 3 ml. of fluid are used. Even in such small volumes, individual postlarvae have survived for 48 hours in water of salinity of 25 p.p.t. at 25°C. Oxygen consumption decreases, however, when animals are tested on a second day.

To compare our present results with those obtained earlier from large shrimp, we are



Figure 33.--Technician preparing Warburg apparatus.

determining wet and dry weights. Determinations from 20 postlarvae gave body-water percentages of 70 to 80 percent (mean, 76.5 percent).

We have chosen 25°C. and about 25 p.p.t. salinity as standard conditions under which to measure oxygen uptake since both white and brown shrimp grow well in this combination. The smallest animals (12 mm.) use more than twice as much oxygen per unit weight as the 25-mm. animals. The temperature also affects the oxygen requirement. Animals at 25°C. use twice as much oxygen as animals at 15°C. regardless of size.

The amount of oxygen used may be affected also by changes in the salinity. We have shown previously that postlarval brown shrimp can grow at a salinity of 2 p.p.t. if they are acclimated for 60 to 72 hours. Similarly, they survive this salinity for 24 hours if they are acclimated for 12 hours. Both of two postlarvae placed directly in 2-p.p.t. water from 23 p.p.t. died, however, within 4 hours, and 5 of 17 postlarvae put directly into 5-p.p.t. water lived less than 3 hours. In contrast, all of 17 animals placed in water of 38 to 44 p.p.t. were able to survive the experimental period of 3 to 4 hours. Brown shrimp apparently are more sensitive to a decrease in salinity than to an increase. These studies are continuing as part of a study on the effect of salinity on oxygen consumption in shrimp.

In a second type of study we have attempted to find a chemical test that distinguishes

between species of commercial shrimp. We chose to investigate the use of paper chromatography of the free amino acids. These compounds, the building blocks of body tissue, are found free in the tissue fluid and can be extracted with alcohol. Individual amino acids in the extract are identified by color reactions with certain chemicals and by the distance they move in certain solvents. If some amino acids were present in one species but not in the others, these compounds could be used to identify the species of shrimp.

We examined extracts of the tail muscle of brown, white, and pink shrimp. The patterns of the free amino acids showed no significant differences between the species. Furthermore, the amino-acid pattern of individuals within a species did not change within a size range of 12 to 150 mm. All three species had very large amounts of free amino acids.

Zoula P. Zein-Eldin, Project Leader

### GROWTH AND SURVIVAL

Experiments during the past year tested the effects both of temperature and of container size on growth of postlarval shrimp. Experiments were made also with three species of laboratory-hatched postlarvae.

Postlarval white shrimp were collected from the surf. These animals were held at nine temperatures from 15° to 35° C. at 2.5° C. intervals for 28 days to observe the effect on growth. Growth in white shrimp generally increased as temperature increased, except at the upper extreme (fig. 34). At the highest temperature (35° C.) growth rate was depressed. The animals were larger at temperatures between 25° and 32.5° C. Survival at all temperatures except the two extremes was 70 percent or better.

A comparison of survival of brown and white shrimp is shown in figure 35. At low temperature (15° C.) brown shrimp survived better than white shrimp. From 17.5° C. to about 25° C., survival of the two was similar. Above 25° C. white shrimp survived much better than brown shrimp. These data seem logical in view of the natural seasonal habits of postlarval shrimp. Brown shrimp postlarvae ordinarily arrive in the estuaries much earlier in the year than those of white shrimp. Consequently, the brown shrimp are normally subjected to much cooler water.

In past growth experiments we have found a wide final size range of animals in a given aquarium. We do not know if this variation was caused by crowding, container size, food,

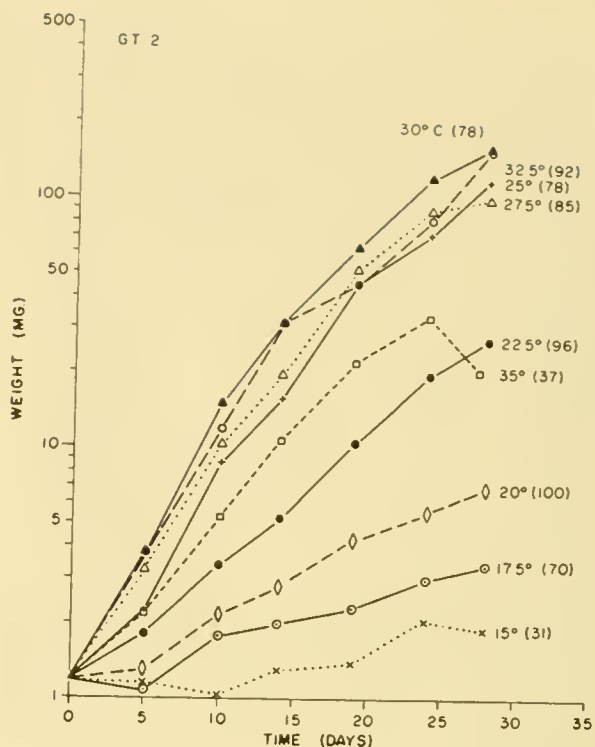


Figure 34.--Mean increase in weight of white shrimp postlarvae exposed to different temperatures (C.) for 1 month. Figures in parentheses indicate percentage survival.

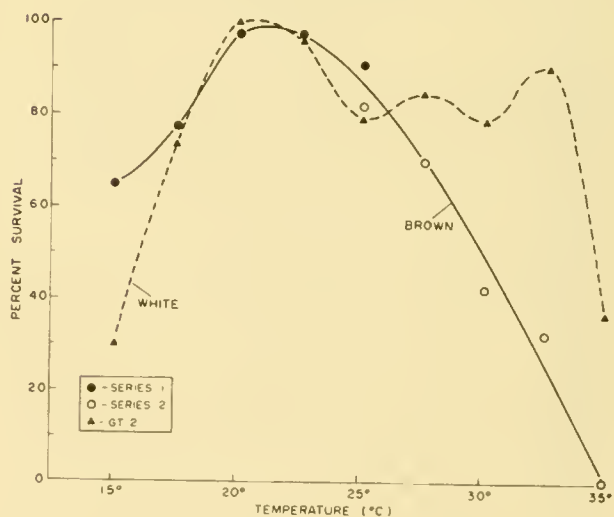


Figure 35.--Percentage survival of postlarval brown shrimp (series 1 and 2) and postlarval white shrimp (GT-2) held at various temperatures for 1 month.

or some inherent character difference. An experiment tested two of these factors--crowding and container size. For test containers we used beakers of three sizes--1, 2, and 4 liters. Four population densities were tested at each capacity--1, 5, 10, and 20 shrimp. The experimental period was 28 days at a temperature of 26° C. and salinity of 23 p.p.t. At the end of 28 days all animals were weighed and measured. Population size had little effect on growth for a given volume of water. Growth increased, however, as beaker size increased, except for beakers with one animal. Best growth was in the 4-liter beaker with five animals. These shrimp had an average growth rate of 1.11 mm. per day during the 28-day test period.

In the past we have grown shrimp in either 4- or 45-liter aquaria. We suspected that growth rate of postlarval shrimp reared in the two sizes of aquaria was different even when the number of animals per volume of water was the same. To test this possibility, we held postlarval brown shrimp from the same population in the two tanks for 1 month at 25° C. and 31° C. Animals in the large tanks were obviously larger within 2 weeks at both temperatures. At the end of the experiment, shrimp in both sizes of aquaria at the higher temperature and in the large aquarium at the lower temperature were roughly the same size. Animals in the small aquaria at the lower temperature were considerably smaller than any of the

others. In view of these ambiguous results we need to repeat the experiment.

A number of laboratory-hatched postlarval pink shrimp, brown shrimp, and seabobs were supplied by the Larval Shrimp Identification and Culture Project. Growth rates of these laboratory-reared shrimp during 28 days at constant temperatures were very similar to that of natural animals collected from the surf.

At the request of the Shrimp Dynamics Program, we tested the survival of postlarval brown shrimp exposed to low temperatures. This information is needed as a guide in field sampling for abundance of postlarvae arriving in the nursery area after the coldest part of winter. Two studies were made covering the same temperature range (2° to 8° C.). Postlarval shrimp in the first experiment were collected from 11° C. water and exposed up to 72 hours to these temperatures (a control group was kept at 18° C.). Shrimp in the second study were collected from 21° C. water. No postlarvae in either experiment survived 24 hours of exposure to 2° C.

Survival was lower at both 4° and 6° C. in the second experiment than at 5° C. in the first. This difference may be the effect of natural acclimation of the first group of shrimp to cooler water prior to study in the laboratory. Survival at 8° and 18° C. was almost 100 percent for 72 hours in both experiments.

George W. Griffith, Project Leader

## GULF OCEANOGRAPHY PROGRAM

A program was initiated in 1965 to describe the oceanographic environment of the Gulf of Mexico. The funds provided were modest but sufficient to allow some compilation of historical data. The purposes of the program are to: (1) define the water masses and subunits, and their variations; (2) enumerate those atmospheric and oceanographic factors that produce variations and modifications of the waters; (3) determine the range of the variations and modifications in time and space; and (4) combine these evaluations into practical techniques of forecasting oceanographic conditions in the fishing waters of the Gulf of Mexico.

### THE AIR OVER THE GULF

An examination of the atmospheric climate over the Gulf was begun to learn the long-period, ocean-atmosphere response. Although

significant water-temperature data are not yet available from the Gulf and Caribbean Sea, a degree of correlation can be realized through data from the North Atlantic Ocean. This study is coordinated with a program at the Seewetteramt, Deutscher Wetterdienst (German Weather Service), in Hamburg, Germany, whereby detailed evaluations are made of the water temperatures and their anomalies in the North Atlantic Ocean. The North Atlantic ocean-atmospheric link is becoming clearer, but the links in the Caribbean, Gulf, and between these areas and the Atlantic are extremely ill defined.

A distinct cooling trend in the northern Gulf began in 1958. This "deterioration" continued through 1964, and during these 6 years mean annual temperatures were as much as 2.5° C. below normal (at Mobile in 1958; at New Orleans in 1964). This cool period is the longest experienced in the northern Gulf since 1906 when a 9-year "cold spell" ended.



The Caribbean climate warmed at the same time that the Gulf coast cooled (fig. 36). This condition was not unusual, for the mean annual temperatures in Puerto Rico have been "mirror images" of those in New Orleans since 1900 (the year of first records on the

is apparently in the transition zone between the climates of the northern Gulf and northern Caribbean.

The cool annual temperatures have resulted mainly from colder-than-usual winters. In February 1958, for example, the month when

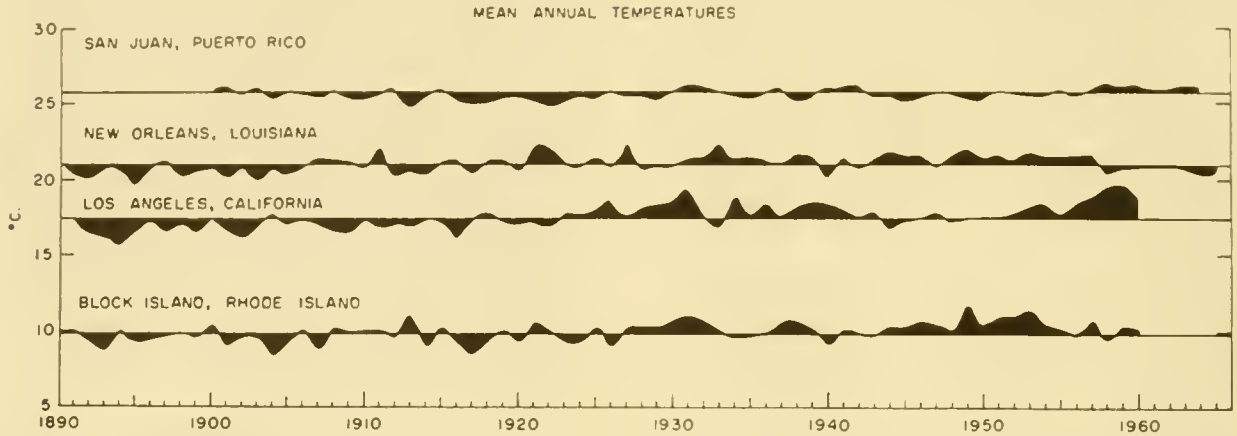


Figure 36.--Annual mean temperatures at representative Atlantic and Pacific stations. Gross correlations north of Puerto Rico are noteworthy.

island). The climatic regimes of the Gulf and Caribbean are clearly different. Consequently, the details of the climates must be learned, for the Gulf waters come under the influence of the atmosphere in both the Caribbean and the Gulf regions.

The cool air extended to Key West in 1958 and 1960, but, in other years since 1958, the mean annual temperature there has been warmer than normal. In Tampa, 483 km. north of Key West, the annual temperatures followed those of Key West from 1958 through 1961. But Tampa has continued to have cold years through 1965 (fig. 37). Thus, Key West

the 6-year decline began, the mean temperatures along the Gulf coast were 10° C. below normal (Mobile; fig. 38). The cold air was introduced over the Gulf of Mexico when an unusually strong and persistent anticyclone was situated over the western United States. The prevailing winds, which in the warm February of 1956 blew from the south and east across balmy waters (fig. 39), in February 1958 were strong and from the north (fig. 40).

The cooler air has corresponded with cooler waters in the western Atlantic Ocean since 1960 and, thus, cooler waters in the Gulf. (This problem is under investigation by marine

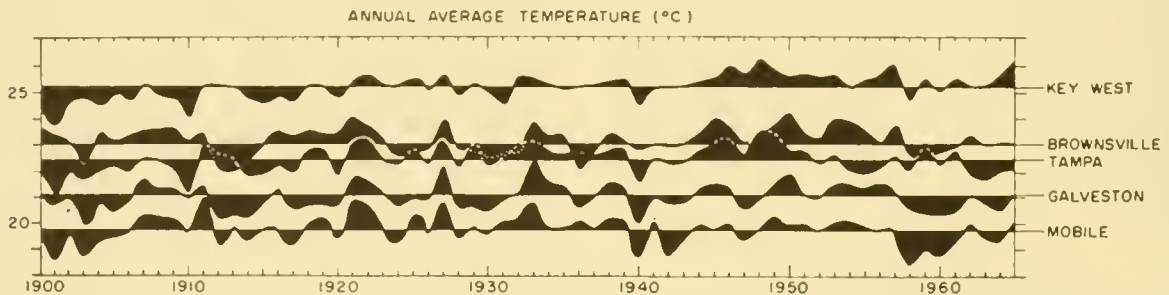


Figure 37.--The annual average air temperatures for major stations near the Gulf of Mexico, 1900-65. Note the "cold year" throughout the Gulf region in 1958; the continuing sequence of "cold years" in the northern Gulf, as at Galveston; and the "warming tendency" at Key West and Brownsville.

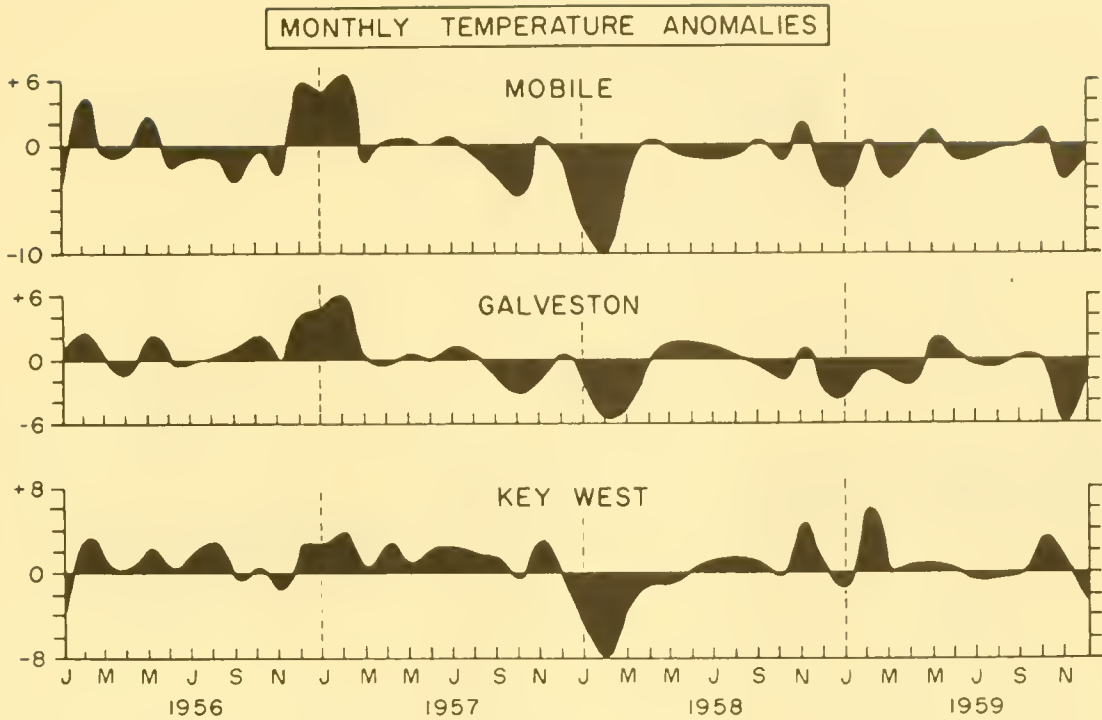


Figure 38.--Monthly temperature anomalies at Mobile, Ala., Galveston, Tex., and Key West, Fla., 1956-59. Note the "warm winter" in 1956-57; the "cold winter" of 1957-58; and the differences between Key West and the northern Gulf in the winter of 1958-59. Anomaly, in  $^{\circ}\text{C}$ . on left.

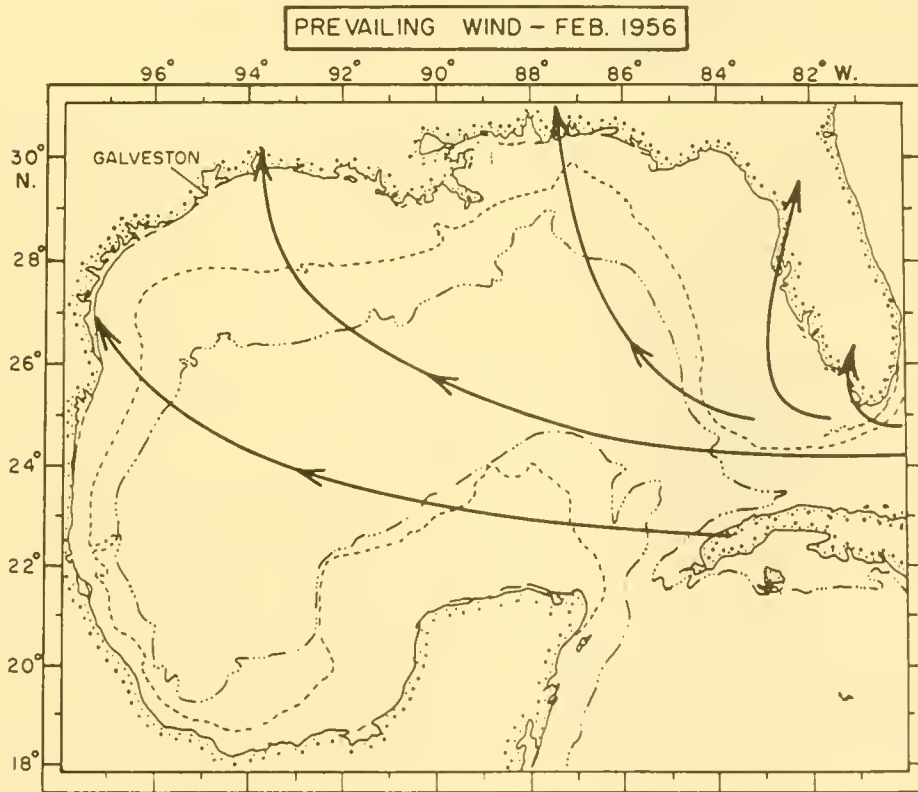


Figure 39.--The prevailing winds over the Gulf of Mexico in February 1956.

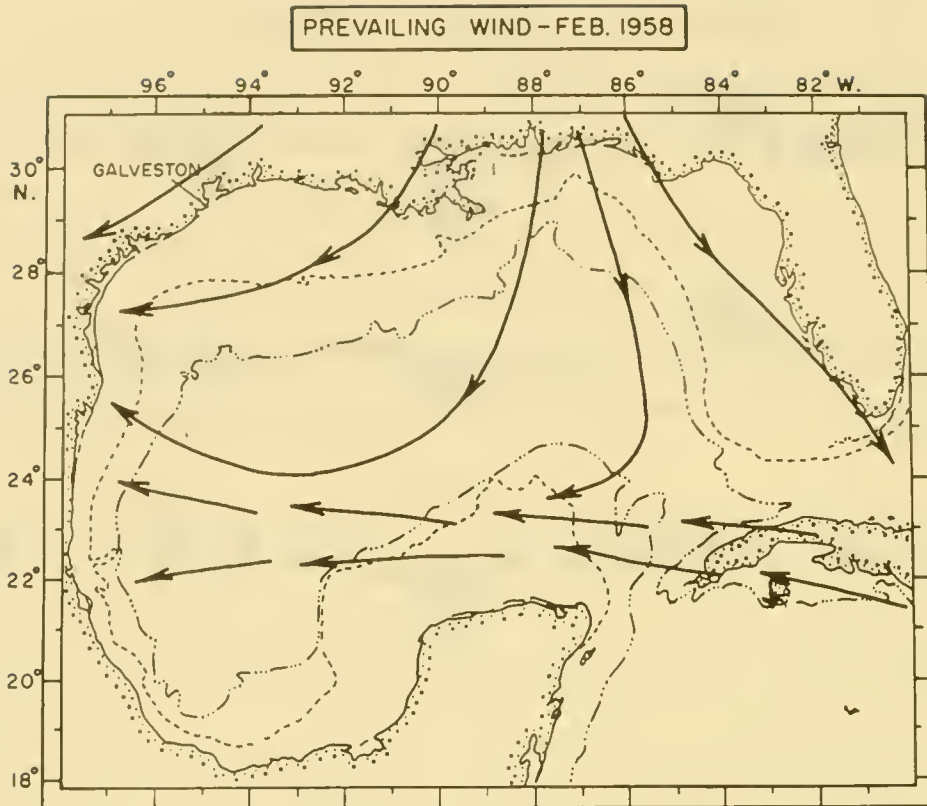


Figure 40.--The prevailing winds over the Gulf of Mexico in February 1958. Note the converging winds in the southern Gulf.

climatologists of the Seewetteramt, Deutscher Wetterdienst.) The sea-atmosphere coupling of the Caribbean-Gulf-Atlantic system is not yet clear. There is, however, an apparent correspondence with variations in the intensity of the Bermuda High Pressure System.

#### WATERS ENTERING THE GULF

The waters which bathe the shrimping grounds of the Gulf and which make up the significant water mass to depths of 200 m., originate in the Atlantic Ocean to the east of the Virgin Islands (near 20° N. and 60° W.). The water, called SUW (Subtropical Underwater), comes into the Caribbean Sea over the Antilles Ridge and through the Windward Passage between Cuba and Hispaniola. During its residence in the Caribbean Sea, SUW is mixed with warmer and less-saline waters. Thus it enters the Gulf of Mexico through the Yucatán Channel with a salinity of 36.7 p.p.t. and temperature of 22° C. (fig. 41).

SUW comprises the upper water mass carried in the Yucatán-Florida-Gulf Stream system. The main axis of this current swings abruptly to the east after passing through the Yucatán Channel, so that the main volume of SUW is directed into the Florida Straits, not into the Gulf of Mexico. In a sense, the circulation in the Gulf is a backwater of the mainstream. As a consequence, the introduction of SUW into the Gulf varies from time to time. The range and characteristics of the variations have yet to be defined.

An examination of the spread of SUW through the Gulf of Mexico is possible from data collected from the R/V *Hidalgo*, Texas A&M University, in February and March 1962. (This was the only cruise ever made which covered the entire Gulf during one period of time.) The main axis of SUW in the Gulf was more or less east-west after the water penetrated north of the Yucatán Shelf (fig. 42). The salinity and temperature decreased away from the axis (fig. 41) and from the area of concentration in the southeastern Gulf. The depth





to SUW also decreased on either side of the main axis of the water (fig. 43).

Even though there have been no other "all-Gulf" cruises, analyses of data from parts of the Gulf during February and March

vicissitudes and biologic constituents is clear.

As the SUW spreads through the Gulf, it is (1) mixed and (2) modified by reactions between the sea and the atmosphere. The salinity and temperature are changed--

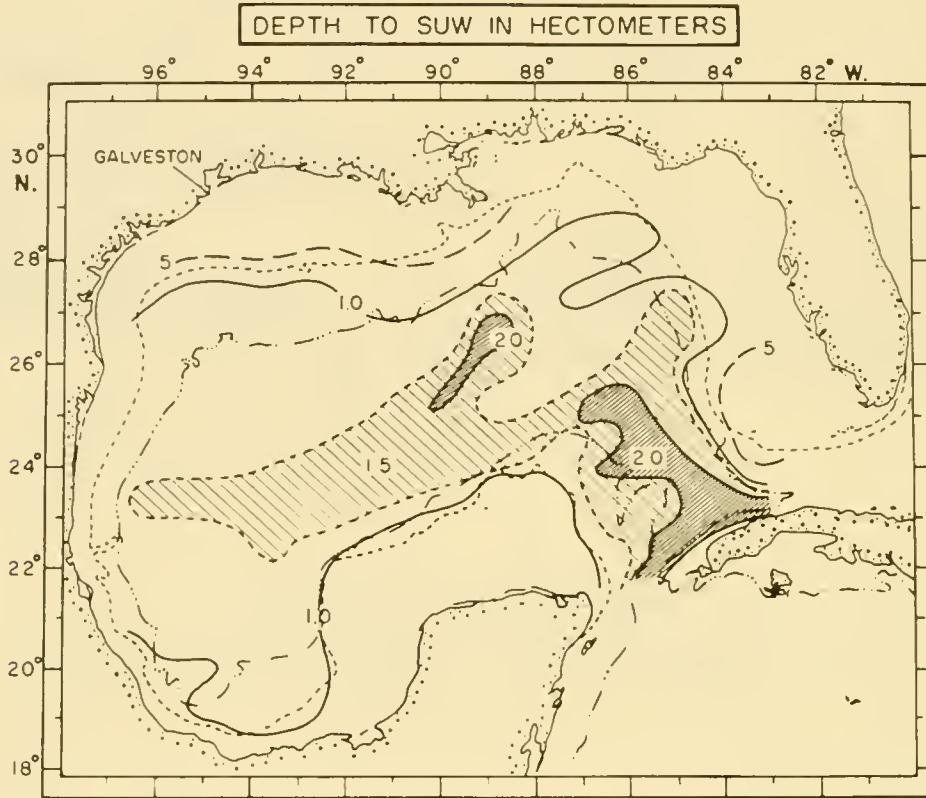


Figure 43.--The depth to the SUW in the Gulf of Mexico in February and March 1962 in hundreds of meters (hectometers).

of other years are sufficient to indicate that the distribution of SUW in the late winter of 1962 does not depict a "steady-state" condition. For example, no SUW was north of lat. 25° N. in the northwestern Gulf in 1964.

Data from the central and eastern Gulf taken in fall, spring, and summer are being evaluated. It seems that the distribution of SUW changes dramatically, both in position and in time. Because this water mass is the habitat for the major fish populations in the Gulf of Mexico, the significance in learning its

manner and extent depending on which of the two processes dominates during the period under consideration. A further change in the surface and near-surface waters is in the nutrient content. Surface waters entering the Gulf are notoriously devoid of inorganic nutrients. Inorganic phosphate is a good indicator. Waters to depths of 10's of meters frequently have none. The addition of this inorganic nutrient to the waters of the Gulf in the late winter of 1962 was an evident change--easily noted (fig. 44).

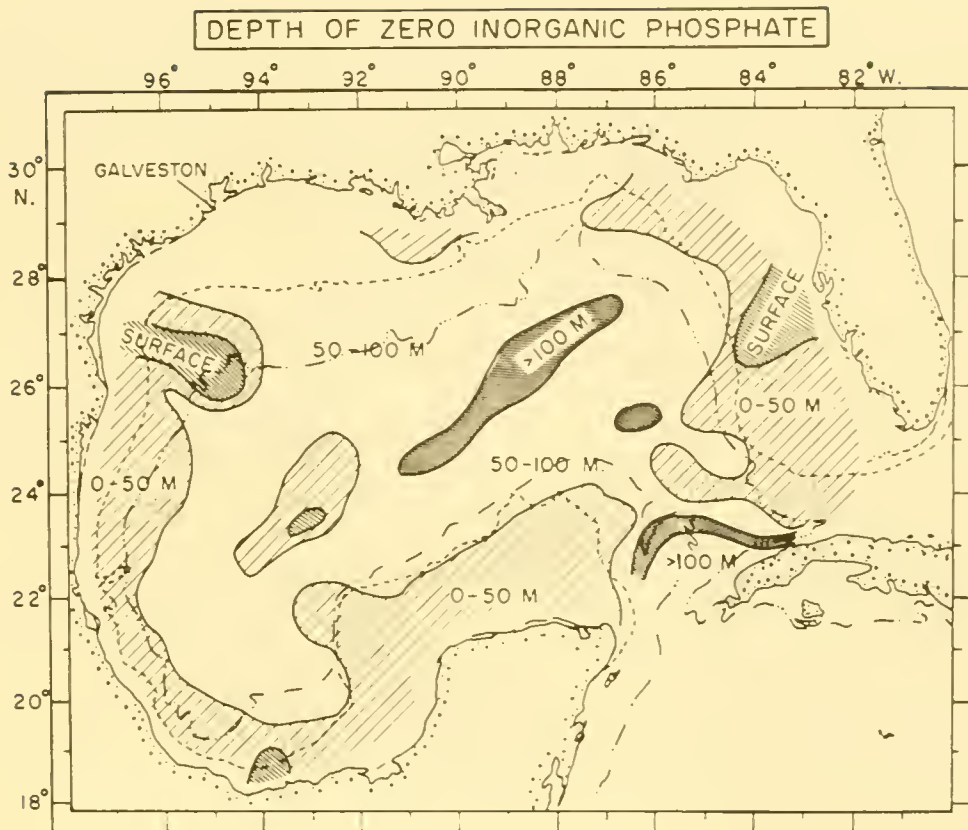


Figure 44.--The thickness of the surface waters of the Gulf of Mexico, February and March 1962, in which inorganic phosphate was "zero." Water entering through the Yucatán channel had no  $\text{PO}_4\text{-P}$  ( $\mu\text{g. at./l.}$ ) from the surface to a depth greater than 100 m. Only around the periphery of the Gulf was there measurable  $\text{PO}_4\text{-P}$  in the top 50 m. of the water column.

### EXTREME MODIFICATIONS OF GULF WATERS

Hurricane Betsy entered the Gulf of Mexico on September 8, 1965, after crossing the southern tip of Florida. The storm followed a northwesterly path and crossed the coast to the west of New Orleans, La., in the late hours of September 9. Hurricane-velocity winds extended 130 km. from the center and wind speeds of 190 km./hr. were measured near the "eye." The average forward speed of the storm as it crossed the Gulf of Mexico was 24 km./hr.

The R/V Alaminos, Texas A&M University, cruised along the edge of the Continental Shelf and occupied a series of bathythermograph stations on August 23-24, 1965. Immediately following the storm on September 12-13, the Alaminos again cruised the same track. Ten days later, September 20-22, the Bureau

of Commercial Fisheries M/V Gus III occupied stations made earlier by the Alaminos (fig. 45). From the data collected on these cruises, analyses can be made of the water structure before and immediately after the hurricane, and an insight gained of the rate at which waters affected by a violent storm may return to normal, seasonal conditions.

In August, the waters near the Mississippi Delta had a surface brackish layer spread over waters of normal salinity. The top of the thermocline was bounded by the 28° C. and 29° C. isotherms and began at depths of 20 to 30 m. The thermocline was nearly horizontal in an east-west direction, and the net water motion was parallel to the coast (fig. 46).

The temperature structure shortly after the passing of Hurricane Betsy was considerably different from that in August. The



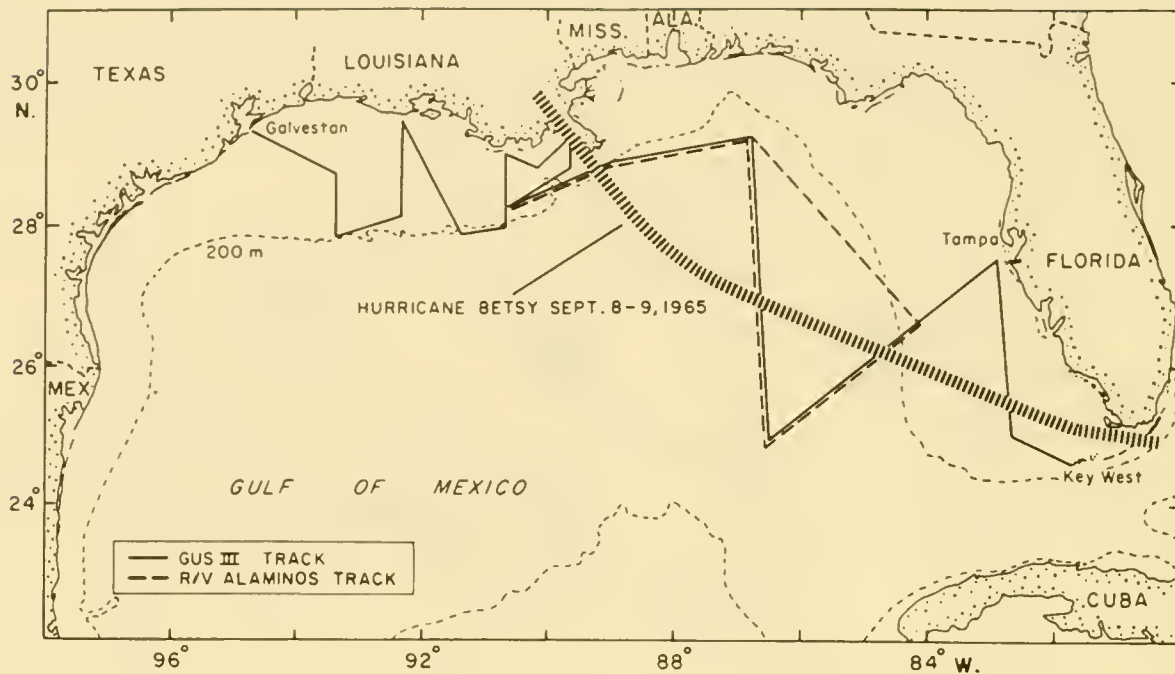


Figure 45.--Tracks of the M/V Gus III of the Bureau of Commercial Fisheries, Galveston, and the R/V Alaminos of the Texas A&M University, on cruises after Hurricane Betsy in September 1965.

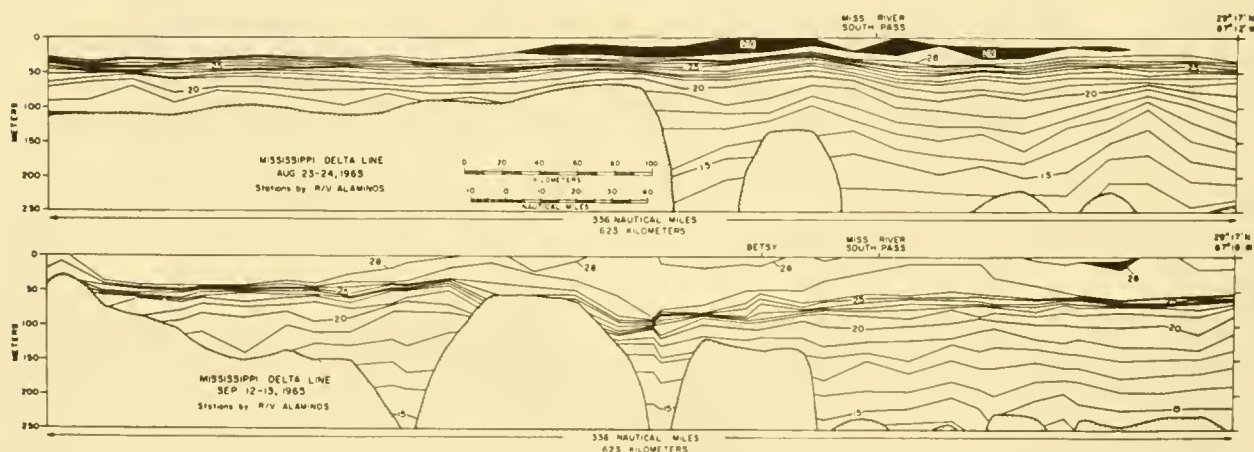


Figure 46.--Temperature profiles along the east-west line seaward from the Mississippi Delta. The "blacked-in" portions indicate strong temperature inversions and represent surface layers of brackish water from the Mississippi River. Hurricane Betsy crossed these waters on September 9, 1965.

thermocline was deeper in all waters than it was in August; the depth of the top varied from 40 to 90 m. The greatest depths to the thermocline were in the waters which lay under the eye of the storm. The isotherm marking the top of the thermocline differed

from the August condition; it was lower by 2° to 3° C. along much of the section, and differed from one place to another along a transect across the path of the hurricane (fig. 47). Beneath and for about 130 km. to the east and west of the eye's path, the top

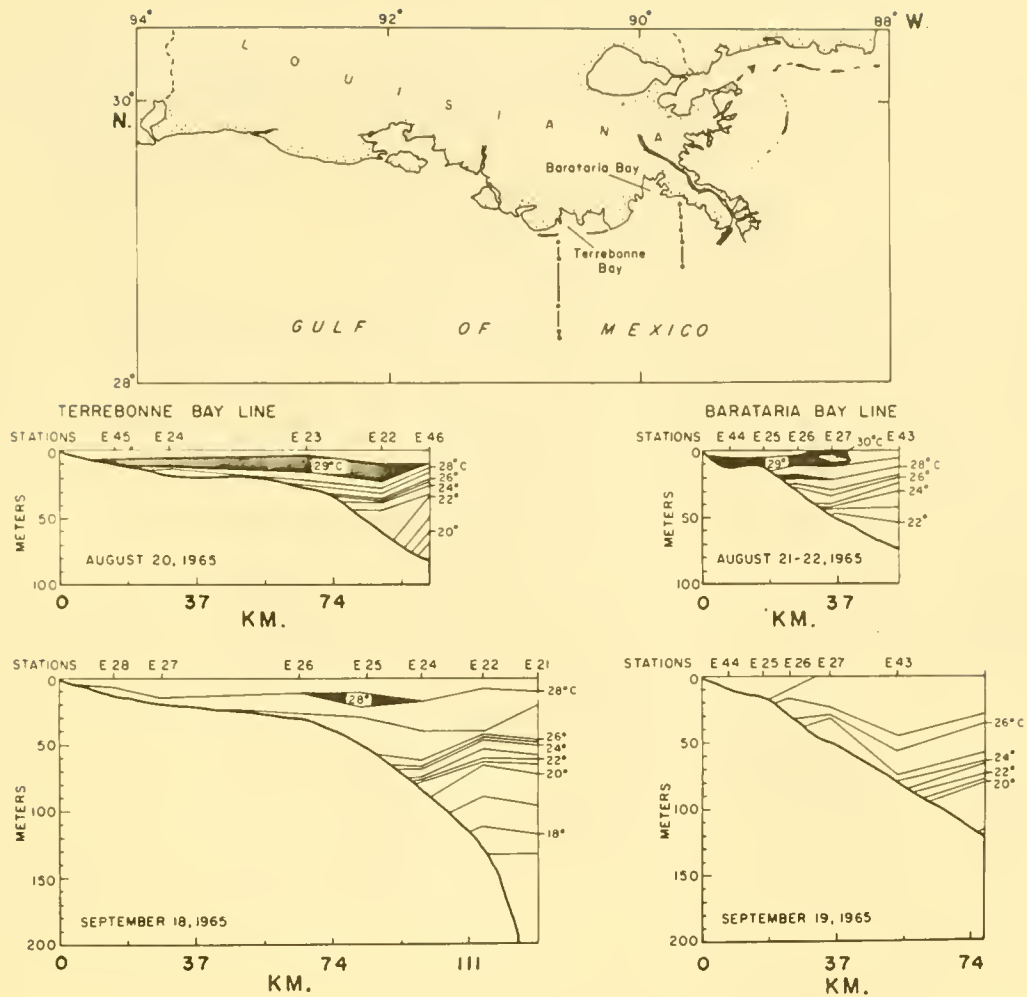


Figure 47.--Station lines occupied aboard the M/V Gus III before and after Hurricane Betsy. The hurricane eye crossed the coast over Barataria Bay. Note the subsidence of the thermocline after the hurricane and the wedge of warm water against the shore.

of the thermocline was bounded by the 26° C. isotherm. Beyond 130 km., the isotherm at the top of the thermocline was either 27° C. or 28° C., but in all areas it was at least 1° C. less than in August. Little indication of brackish water appeared above the thermocline.

Ten days after Hurricane Betsy had crossed the northern shelf of the Gulf of Mexico, the depth to the thermocline beneath and to the east of the path of the storm lay at depths between 40 and 50 m. To the west of the path, the top of the thermocline was between 20 and 50 m. In all waters except those immediately beneath the path of the storm, the top of the thermocline was bounded by the 27° C. isotherm. Beneath the eye's path,

26° C. continued to mark the top. Brackish water had returned to the surface layers and was evident to the west of the mouth of the Mississippi River (fig. 48; note layers with temperature inversion).

Clearly, the hurricane profoundly modified the waters over the northern shelf of the Gulf. The typical surface waters next to shore were removed and replaced by waters with oceanic characteristics. The influence of the hurricane extended to the greatest depths of the Continental Shelf (75 m.) so that water temperatures on the shelf floor were as much as 6° C. warmer after the storm than before (fig. 49). Upwelling in the upper 30 m. of the water column was evident at distances of about 90 km. either side of the

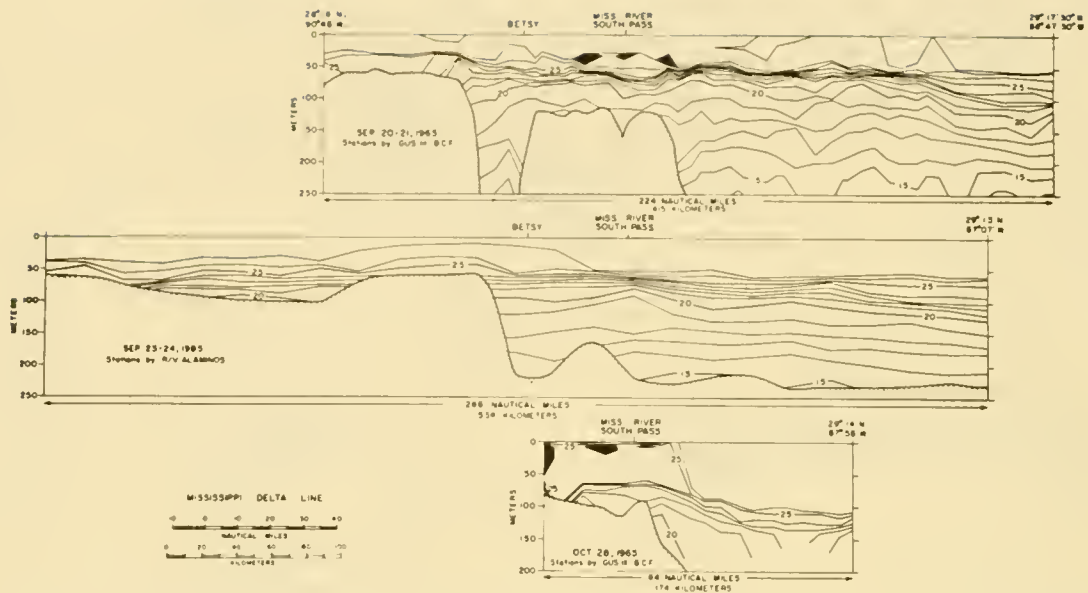


Figure 48.--Temperature profiles seaward from the Mississippi Delta from data gathered from the M/V Gus III and R/V Alaminos.

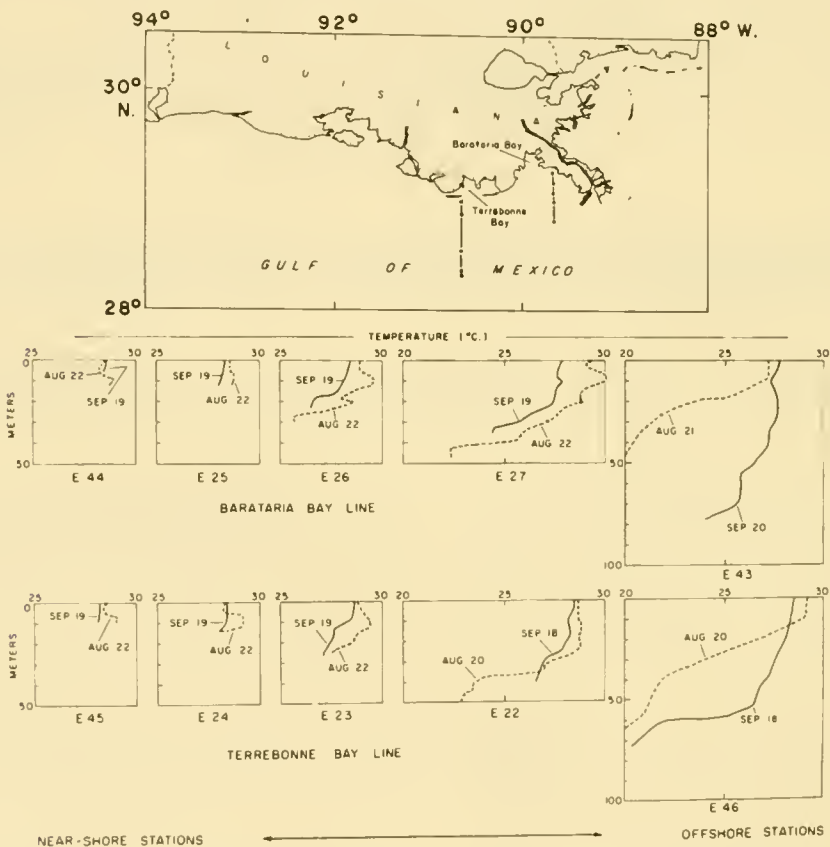


Figure 49.--Temperature traces of the waters off the Mississippi Delta before and after Hurricane Betsy. The "downwelling" of warm surface waters is noted in depths greater than 50 m.



path of the hurricane eye. A 50-m.-thick layer of isothermal water lay on the surface at distances of about 150 km. either side of the path. A strong divergence developed seaward of the Mississippi Delta. Surface currents flowed to the east and west on respective

sides of the delta. Although modified to some degree, these latter features were still present 10 days after the storm had passed over the northern shelf.

Robert E. Stevenson, Program Leader

### LIBRARY

More than 600 volumes of books and journals, and 2,200 reprints and miscellaneous publications were added to the library collection during fiscal year 1966. Additions included microform and reprint editions of selected out-of-print publications and a number of translations. Additional shelving and equipment have been acquired to accommodate the expanding collection.

The use of library services and the library resources increased markedly during the year. In addition to current activities, special projects have included (1) revision of the subject index for reprints received before the current listing to consolidate them with the subject catalog in use; (2) compilation of an author index for certain series of Service publications; and (3) preparation of a selected subject index for the Laboratory supply of reprints. Duplicate and surplus publications were forwarded to other laboratories upon request. The weekly list of current acquisitions was continued for distribution to the staff and to selected laboratories.

The librarian has continued to assist other laboratory libraries in Region 2 in methods and procedures.

Table 5.--Statistical summary of library collection, 1965-66

Items	On hand 1965	Additions 1966	On hand 1966
	<u>Number</u>	<u>Number</u>	<u>Number</u>
Books.....	2,600	237	2,837
Journals (bound)...	583	102	685
Journals (unbound).	1,590	233	1,823
Reprints.....	3,252	384	3,636
Institutional.....	11,280	1,622	12,902
Other.....	1,401	117	1,518
Total items.....	20,706	2,695	23,401

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