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Report of the National Marine Fisheries Service Gulf Coastal Fisheries Center, Fiscal Years 1970 and 1971

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Report of the National Marine Fisheries Service Gulf Coastal Fisheries Center, Fiscal Years 1970 and 1971

Abstract

Progress is reported at the National Marine Fisheries Service Gulf Coastal Fisheries Center (formerly the Biological Laboratory, Galveston, Texas). Emphasis is placed on shrimp, and the research involves the fields of mariculture, population dynamics, ecology, and oceanography.

Introduction

During the period covered by this report, research at the National Marine Fisheries Service Gulf Coastal Fisheries Laboratory (then the Biological Laboratory, Galveston, Texas) underwent a marked change in direction. In fiscal year 1970, studies were carried out under five programs: Shrimp Culture, Shrimp Dynamics, Estuarine Ecology, Estuarine Studies, and Gulf Oceanography. The following year, our studies were redirected and research was conducted on Artificial Propagation-Shrimp and Effects of Biological, Chemical, and Physical Environments with major emphasis on the former. This report, therefore, covers discontinued and recently initiated studies.

Shrimp Culture

Research during the last two years was directed toward solving three serious problems facing the emerging shrimp culture industry. These problems are: (1) the nutritional requirements of shrimp are unknown and consequently suitable diets cannot be formulated; (2) reliable, economical larval culture methods have not been developed; and (3) none of the three commercial species in the Gulf will mature in captivity.

ALGAL AND NATURAL FOOD CULTURE

Feeding and experimental diets research was largely concerned with the food requirements of penaeid shrimp at different life stages. Our primary task was the provision of algae on a large scale as food for larval shrimp.

Unialgal cultures of *Skeletonema, Thalassiosira, Cyclotella, Isochrysis, Dunaliella,* and *Monochrysis* were grown in 20- to 75-ml culture tubes and 1- to 8- liter carboys. These cultures were reared in commercial salt mixtures prepared in Galveston tap water.

Salinity optima of the three diatom species were determined in dilutions of Instant Ocean[2] salt. *Thalassiosira* required salinities of 28‰ to 34‰, *Skeletonema* 26‰ to 34‰, while *Cyclotella* seemed to grow best at salinities less than 26‰. The sources of iron routinely used as an added nutrient may have influenced the salinity preference of the organisms.

Mass cultures of algae were produced to provide food for larval penaeids produced in our hatchery experiments. The small-scale procedures developed previously were adapted to cultures as large as 300 liters. Densities between 4 and 8 million cells/ml of *Skeletonema* were produced after a period of 4 days.

During fiscal year 1971, we altered the method of mass culturing algae so that we are now able to supply food organisms of approximately the same age and condition at all times during an experiment. This change amounted to inoculating fresh tanks daily and harvesting the entire tank during the exponential growth phase. This is in contrast to the usual method of inoculating all culture tanks at one time, harvesting some from each tank, and bringing

[1] Contribution No. 327, National Marine Fisheries Service Gulf Coastal Fisheries Center, Galveston, TX 77550.

[2] Reference to trade names in this publication does not imply endorsement of commercial products.

the volume back up with fresh culture medium.

A new method of sterilizing algal culture tanks with ultraviolet light is being used routinely (Fig. 1). It is apparently an effective means of eliminating bacteria and algal contaminants from the tanks between uses.

The possibility of utilizing rotifers as a food or a food supplement with brine shrimp (*Artemia*) was tested for larval brown shrimp. Preliminary results indicate that mixed cultures (*Dunaliella*-rotifer-*Artemia*) produce the greatest gain in total length (tip of rostrum to tip of telson) over a 40-day period.

A search for a chemical method of distinguishing laboratory-reared shrimp has led to studies involving flat-sheet and disc electrophoresis. These studies have revealed distinct differences between protein patterns of laboratory-reared and wild brown postlarval shrimp. Analyses have been based on individual specimens ranging in total length from 4.5 to 12 mm and on composite samples of up to several hundred specimens of the same size. As far as we have been able to determine, the patterns characterizing the two sources of shrimp are consistent and are not affected by the animal's diet.

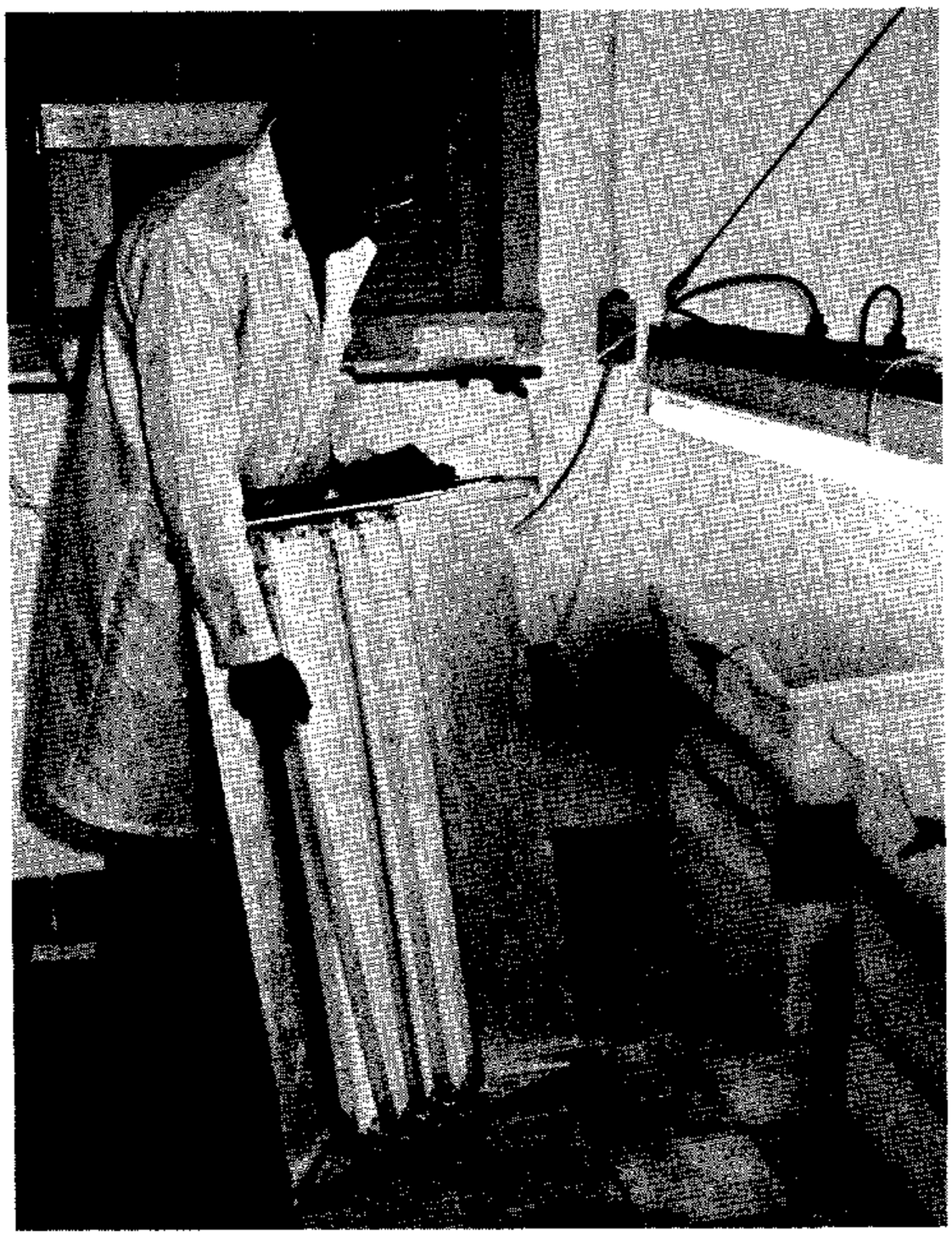

Figure 1. — Ultraviolet tank sterilizer which is placed on top of empty tanks when in use.

FOOD AND EXPERIMENTAL ENVIRONMENTS

A goal implicit in the artificial propagation and culture of any organism is the production of a standard high quality animal. Our recent goal has been to define the quality of the animals presently produced by our hatchery facilities, and to determine the effects on this standard of various modifications in the diet of both larval and postlarval brown shrimp.

Of primary interest was the testing of artificial salt solutions as a defined medium for use in our future experiments. To date, only one artificial salt made up in distilled water has been tested. No organic compounds were added to the water except in the food provided. Laboratory-hatched brown shrimp postlarvae were used as experimental animals. Postlarvae in the artificial salt solution grew slower than did animals in water from our seawater system. Furthermore, animals in the artificial medium showed increased rates of cannibalism, general sluggishness, and certain gross pathological conditions not noted in the animals in the natural waters. Individuals frequently had difficulty in completing a molt, or if they did molt, their exoskeletons did not harden. We are, therefore, continuing studies to define a medium adequate for the growth of postlarval and juvenile penaeids.

Variations between groups of laboratory-spawned and hatched shrimp were notable in differences in survival between larval stages, in growth rates of postlarvae fed a standard diet of naupliar brine shrimp, and in response to selected environmental conditions. For example, two groups of postlarvae—one hatched in October and a second in December — responded differently to changes of salinity or temperature. Differences in growth are equally notable, both within aquaria groups and between groups. In Figure 2 examples are presented of the best average growth, typical growth, and the poorest average growth observed among hatchery shrimp fed a diet of *Skeletonema* during protozoeal stages, followed by naupliar *Artemia* during mysis and postlarval stages. Even in the curve of best growth, ranges at each point are large — 13-55 mm in the final observation.

Larvae were also fed diatoms which were frozen slowly, or freeze-dried alone or in the presence of

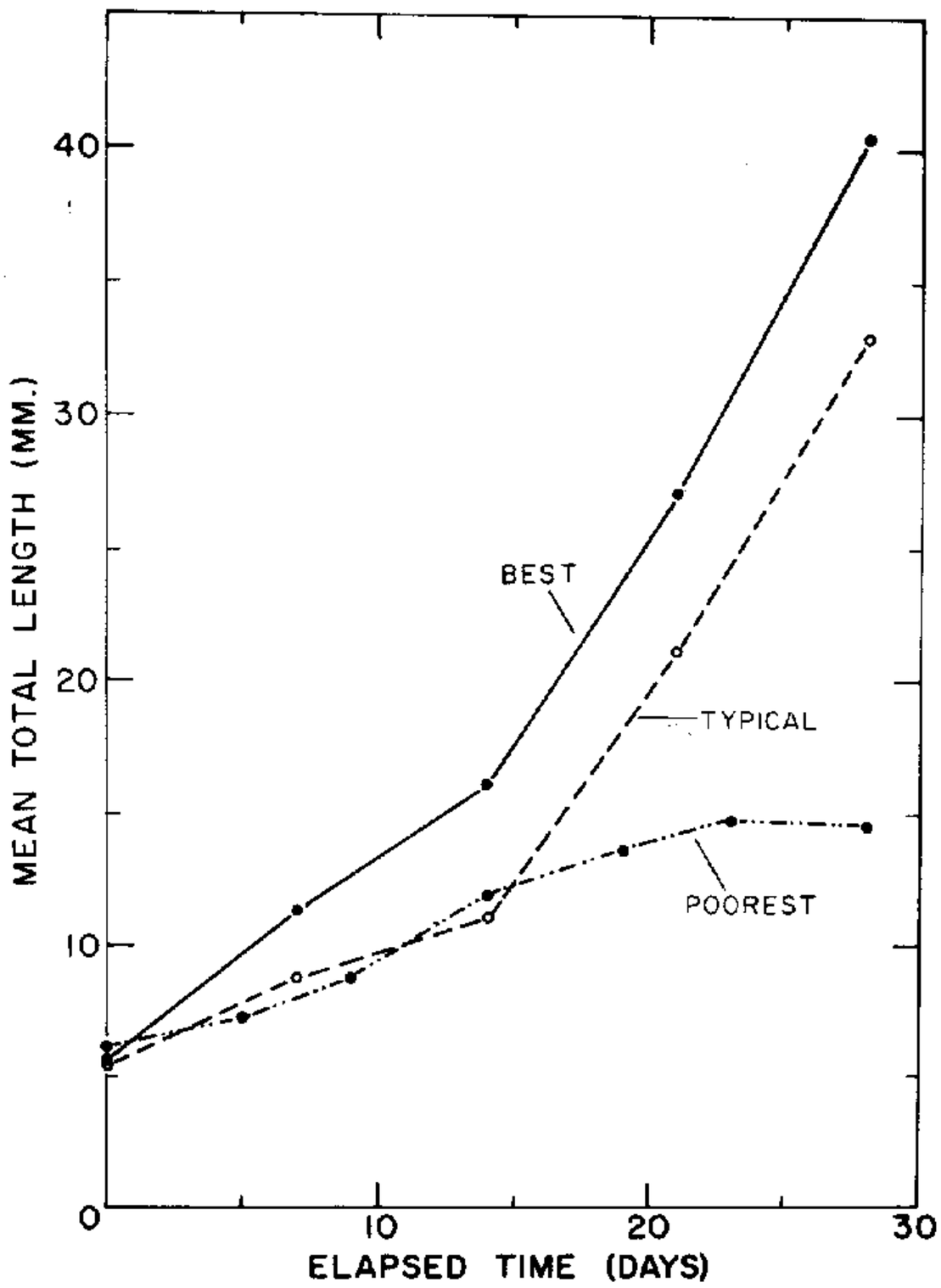

Figure 2. — Growth curves of hatchery-reared *Penaeus aztecus* fed *Artemia* and held at 29°C. Each point is a mean of 10 observations.

protectants. The use of such techniques would considerably reduce the task of synchronously producing large quantities of live diatoms to feed thousands of protozoeal shrimp. Results, reported at the meeting of the National Shellfisheries Institute by Ausbon Brown, Jr., suggest that frozen or freeze-dried diatoms may well supplement the live foods. Protectants, including glycerol, are not harmful to the shrimp, as evidenced by survival and growth of larvae and postlarvae.

A series of tests in conjunction with Dr. Samuel Meyers of Louisiana State University suggest that penaeid shrimp more than 40 mm total length may be satisfactorily fed a prepared diet. On one formulation, biomass increased six times during a 6-week period in a filtered 203-liter aquarium. Further testing of this and similar foods in a flow-through system is now in progress.

As consultants to the Lunar Receiving Laboratory of NASA (National Aeronautics and Space Administration), we provided brown and pink shrimp for tests of lunar samples returned by Apollo 11, 12, and 14. Regular visits were made to the NASA facility to determine the status of the shrimp and to participate in the meetings of the Invertebrate Consultant Group at the close of each mission. Shrimp and *Planaria* exposed to lunar material in the Lunar Receiving Laboratory were sectioned, stained, and examined by Dr. Sparks to determine any pathological effects of their exposure.

MATURATION AND SPAWNING

One phase of our work has dealt primarily with the problem of inducing young female penaeid shrimp (*Penaeus setiferus, P. aztecus,* and *P. duorarum*) to grow and attain sexual maturity. Adult pond-reared male brown shrimp that had reached maturity in early May remained potent throughout the summer. Although mating occurred in the ponds, female shrimp failed to show signs of advanced ovarian development.

Because of our interest in the quality of water in which we hold shrimp, water samples from the ponds, the indoor tanks, and from the Gulf were analyzed at regular intervals to determine total phosphate, nitrate, ammonia, calcium, pH, alkalinity, and salinity. Using the Gulf water as a standard, we adjusted the quality of the water in our ponds and indoor tanks to maintain a certain range of environmental conditions in each. Water quality in our ponds was adjusted by: (1) the evaporation of water and/or the addition of salt to raise the salinity; (2) the addition or exchange of water from the adjacent lagoon, the Gulf, and/or ponds; (3) the addition of sodium hydroxide to raise the pH level; (4) bubbling air through the water; and (5) the circulation of water through biological filters. In our indoor tanks where conditions could be controlled more precisely, the pH was held at 8.1, the temperature was maintained at 25°C, and the salinity at 36‰ to correspond with conditions off the Texas and Louisiana coasts in areas where spawning occurs.

Pond-reared shrimp were fed a commercial trout food that produced more rapid growth in shrimp than other commercial feeds tested.

Shrimp kept in indoor tanks were fed a prepared diet containing carbohydrates, animal and plant proteins, and oils blended with vitamins and minerals all bound with gelatin or carboxymethyl cellulose.

Laboratory-reared pink shrimp that were stocked as postlarvae in mid-September attained an average

total length of 84 mm before growth ceased in mid-December. Survival through the winter was 18%. Growth resumed in late March, and by mid-May when shrimp had obtained an average length of 104 mm, most males appeared to be sexually mature and actively mating. Although most females had copulated by mid-June, their ovaries did not develop.

White shrimp averaging 130 mm in length were stocked at a density of about two shrimp per square meter of bottom surface in each of three ponds early in March. We examined these shrimp regularly for growth and sexual development. Although virtually all of the males attained sexual maturity by mid-June, there was no evidence that mating had occurred in the ponds and the females remained immature.

Adult white and brown shrimp were kept in several large indoor tanks to study requirements for maturation. The bottoms of the tanks were covered with 5.1 cm of beach sand. To maintain suitable water quality, we recirculated the water through two biological filters and replaced one-fourth of the water each week. Shrimp were stocked at an approximate density of one per 0.43 m^2 of bottom. Several groups held over a 6-month period survived, but their gonads failed to develop, molting was infrequent, and their exoskeletons became soft and rough. These shrimp, when transferred to ponds, however, resumed growth and their exoskeletons became smooth and firm. Upon being transferred to ponds, the males became sexually mature.

POSTLARVAL CULTURE

Work began on the development of techniques for mass culture of young penaeid shrimp for use in experiments to evaluate stocking. Shrimp in their late mysis and early postlarval stages of development were reared in dense cultures in large tanks to sizes up to 30 mm in length. In conjunction with this work, a series of experiments was conducted comparing the effects of temperature, salinity, stocking densities, surface area, and filtration of water upon growth and survival of the shrimp. Rearing tanks of three sizes (1,850, 8,880, and 33,486 liters), were used and *Artemia* were fed in all experiments.

Essentially we found that:

1. Of the nine combinations of salinity and temperture tested, young shrimp grew and survived best at 32° C and 30‰.

2. Although shrimp survive and grow slightly better at the lower stocking densities (densities tested were 13.5, 27, and 54 shrimp per liter of water), the costs of temperature and salinity control, maintaining the food level in rearing tanks, and the construction of rearing tanks may favor some waste by rearing at higher densities.

3. Survival of shrimp was significantly better in bare tanks than in tanks in which polyethylene strips were suspended to increase the surface area.

4. Survival of shrimp was slightly better in water that had been aerated and filtered through crushed oyster shell and bone charcoal than in water being aerated only. However, growth of shrimp was slightly more rapid in unfiltered but aerated water.

5. Shrimp growth was more rapid in outdoor tanks in which, in addition to *Artemia*, an algal growth can be maintained for food.

HATCHERY ENGINEERING AND LARVAL PHYSIOLOGY

Our major effort was directed toward making the methods of larval culture of shrimp more efficient and economical. In addition, the hatchery served as a training facility for a large number of persons interested in learning our techniques for hatching and rearing larval shrimp. During the 2 years, a total of 2,923,000 penaeid shrimp were reared to the postlarval stage. Of these, 2,332,000 were used in our own research and 591,000 were given to 13 different groups involved in shrimp research.

To culture economically relatively large numbers of penaeid shrimp to the postlarval stage for pond stocking, it was necessary to develop new procedures and to design new equipment. For example, electrical pumps were previously used throughout the operation to transport diatoms and to recirculate water in rearing tanks. Because electricity is expensive and its use around water is dangerous, electrical pumps have been replaced by air-lift pumps, and all filter systems are operated by compressed air.

To control population densities in the rearing tanks, we found it necessary to spawn females individually instead of in groups. Consequently, each female was placed in a separate spawning container, an inverted 19-liter carboy with the bottom removed. This gave us an opportunity to observe each spawn, count the number of eggs, and concentrate them in the rearing tanks at predetermined densities.

Figure 3. — Apparatus used to feed algal concentrates continuously to the larval shrimp.

Samples from each spawning were placed in an incubator; if the eggs were viable, they hatched within 32 hr. At this time the samples were preserved and the numbers of eggs that hatched were determined. Aliquot counts made throughout the rearing experiment enabled us to calculate numbers of larvae and survival rates. Numbers of shrimp in each rearing tank were estimated at least three times during each experiment. The method for enumerating the organisms varied with stage of development. When the shrimp were egg nauplii and nauplii I, they were counted with an electronic counter. Samples of larvae of the older stages were photographed with a Polaroid camera, and counts were made from the photographs using a dissecting microscope.

Population densities of shrimp larvae up to 530 per liter of water have been used in a 2,270-liter tank. Survival through the protozoeal stages is good at this density, but as the shrimp become older and

reach the mysis stage, crowding results in poor survival.

One factor determining the success or failure of shrimp culture is the cost of foods necessary to rear large quantities of larval shrimp. Our approach is to rear the food separately from the larvae and to feed only that amount of food, whether it be a diatom, flagellate, *Artemia*, or other cultured organism, necessary to maintain that population. By monitoring densities of food organisms regularly, we determine grazing rates. Diatoms and flagellates were counted with a hemocytometer and *Artemia* sp. were counted with a mechanical counter. The amount of food to be fed was determined by: (1) number of larvae present, (2) stage of larval development, (3) general condition of the larvae (such as the presence of food in the gut, the presence of fecal chains, and the color of the larvae), and (4) the item being used as food.

Previously, live diatom cultures were added directly to the shrimp larval rearing tanks, but this resulted in two problems:

1. Algal cultures did not always "peak" exactly when food was needed.
2. The media in which the diatoms were grown were slightly toxic to larval shrimp.

Consequently, it was decided to separate the algae from their culture media, and to test methods of preserving the concentrated algae. Separation with a centrifuge has proven successful, be it a table model, a continuous centrifuge, or a large cream separator. Refrigeration has been used successfully to preserve the concentrate for periods of a few hours, and freezing is a suitable method of holding algae for several months.

We have reared shrimp successfully through the larval stages feeding algal concentrates treated in the following ways:

1. Algal concentrates fed fresh.
2. Concentrates refrigerated 4 to 10 hr prior to feeding.
3. Concentrates frozen prior to feeding.

Each type of concentrate has been fed successfully using a metering pump to supply food continuously to the shrimp culture tanks (Fig. 3). Both single species and mixed algal concentrates were fed with this pump.

A series of rearing experiments (from egg to postlarvae) were performed to determine levels of feeding and larval densities for maximum survival of brown shrimp (*P. aztecus*). Survival and feeding levels from several experiments can be observed in Tables 1 and 2. In experiment I, development to the postlarval stage was rapid and survival was good. In experiments II and III, algae were fed during the mysis stages as well as during protozoeal stages. Obviously, interactions occur between larval density, feeding rates, rates of growth, and survival, but insufficient data are available to define these interactions at present.

Estuarine Ecology

Studies designed to evaluate the changes created by housing development operations in estuarine areas were completed. New studies were initiated to evaluate the effects of seeding or stocking wild, estuarine shrimp populations with laboratory-reared shrimp.

Table 1.--Numbers of larval brown shrimp surviving at different stages of development (data for a single tank from each experiment).

Experiment number	Tank capacity	Stage				Survival
		Nauplii I	Protozoea I	Mysis I	Postlarvae	
	Liters	Number				Percent
I	950	242,000	218,000		200,000	82
II	1,800	462,000		468,000	1/	
III	1,900	84,000	84,000	60,000	1/	

1/ Shrimp used in separate experiment.

Table 2.--Feeding levels maintained at different larval stages of brown shrimp (for experiments summarized in Table 1).

Experiment number	Organisms fed[1]	Protozoeal stages			Mysis stages			Postlarval stages
		I	II	III	I	II	III	
I[2]	Skeletonema costatum	250,000	350,000	450,000				
	Artemia sp.				3	3	3	3
II[3]	Skeletonema costatum	200,000	200,000	250,000	300,000	300,000		
	Cyclotella nana		175,000	250,000	250,000	250,000		
	Artemia sp.				2	6		
III[4]	Skeletonema costatum	250,000	250,000	200,000	100,000	150,000		
	Dunaliella sp.		15,000	20,000	20,000	90,000		
	Artemia sp.				3	8		

1/ Feeding levels are expressed in numbers of cells per milliliter for algae and number of animals per milliliter for Artemia.

2/ Fresh cultures were fed with their media directly to the shrimp in the rearing tanks.

3/ Fresh cultures were concentrated daily and fed to larval shrimp.

4/ Cultures were concentrated and frozen before being fed.

COMPARISON OF NATURAL AND ALTERED MARSH AREAS

Estuaries along the United States coastline are being altered extensively by Federal, State, and private institutions. The major physical modification in these areas has been the dredging of some areas for ship channels and the filling of others for building sites.

Presently, large areas of shallow bay and marsh along the Texas coast are being developed for waterfront housing sites. This type of alteration involves dredging, bulkheading, and filling. Alteration for housing sites will probably become the greatest threat to the existence of natural marsh and bay areas unless the demand for this property decreases or the present method of altering bay areas is changed. Major changes include: (1) reduction in acreage of natural shore zone and marsh vegetation, (2) changes in marsh drainage patterns and nutrient inputs, and (3) changes in water depth and substrates. The effects of these environmental changes on the productivity of estuarine organisms are poorly understood.

The objectives of our studies during fiscal year 1970 were to compare the following between natural and altered areas: (1) selected hydrographic variables and (2) the relative abundance of benthic macro-invertebrates, fishes, and commercially important crustaceans.

Study area and methods

The study area, located in West Bay, Tex., included a natural marsh (four sampling stations), an open bay area (one station), and an area that was similar to the natural marsh (five stations) before it was altered by channelization, bulkheading, and filling. The developed area, which included about 45 ha of emergent marsh vegetation, intertidal mud flats, and subtidal area prior to alteration, was reduced to about 32 ha of subtidal water area by dredging and filling. The water volume (mean low tide level) was increased from about 184,000 to 395,000 kl.

Hydrographic measurements, fish, and crustacean samples were taken the same day (between 10:00 a.m. and 2:00 p.m., CST) and night (between 10:00 p.m. and 2:00 a.m., CST) at 2-week intervals from March 25 to October 21, 1969, at the 10 stations. Water samples for determining hydrographic parameters were taken 30 cm above the bottom. Fishes

and decapod crustaceans were taken in a trawl that had a mouth opening of 0.6 by 3 m and a stretched mesh of 28 mm in the body and 2.5 mm in the cod end. The trawl was towed over a distance of 200 m at a speed of about 2 knots at each station.

Benthic macro-invertebrates were sampled at 2-week intervals over the same study period at six stations — two in the canals, three in the natural area, and one in the open bay. Cores of the substrate were taken with a metal cylinder 14 cm long and 9.6 cm in diameter. The number and volume of macro-invertebrates were determined in each sample.

Eight hydrographic factors were compared during the study. Average temperature, salinity, pH, and total alkalinity differed only slightly between areas (Fig. 4). Average dissolved organic nitrogen was highest in the marsh, possibly due to cattle which graze in this area. Values of total phosphorus were highest, and fluctuated over the greatest range, in the canal. Average turbidity values of bottom waters (Jackson turbidity unit — JTU) were highest in the bay, but the highest values were measured in the canal. Based on surface water samples, however, turbidities were over twice as high in the marsh and bay when compared with those in the canals. Average values of dissolved oxygen were highest in the bay, intermediate in the marsh, and lowest in the canals. During the summer, oxygen dropped to critically low levels of less than 0.2 ml/liter at the three stations in the canal area farthest from the bay. The annual combined average for these stations was 3.17 as compared to 4.39 ml/liter for canal stations nearer the bay.

Benthic macro-invertebrates

Four phyla of invertebrates characterized the animals caught during the benthic survey. Polychaetes of the family Capitellidae were dominant organisms observed and comprised 66% of the number and 44% of the volume of animals caught. Crustaceans belonging to the families Ampeliscidae and Corophiidae were second in number (25%) but lowest in volume (4%). Third in abundance (3%) but second in volume (41%) were molluscs, mostly belonging to the genera *Tellina, Tegelus,* and *Mulinia.*

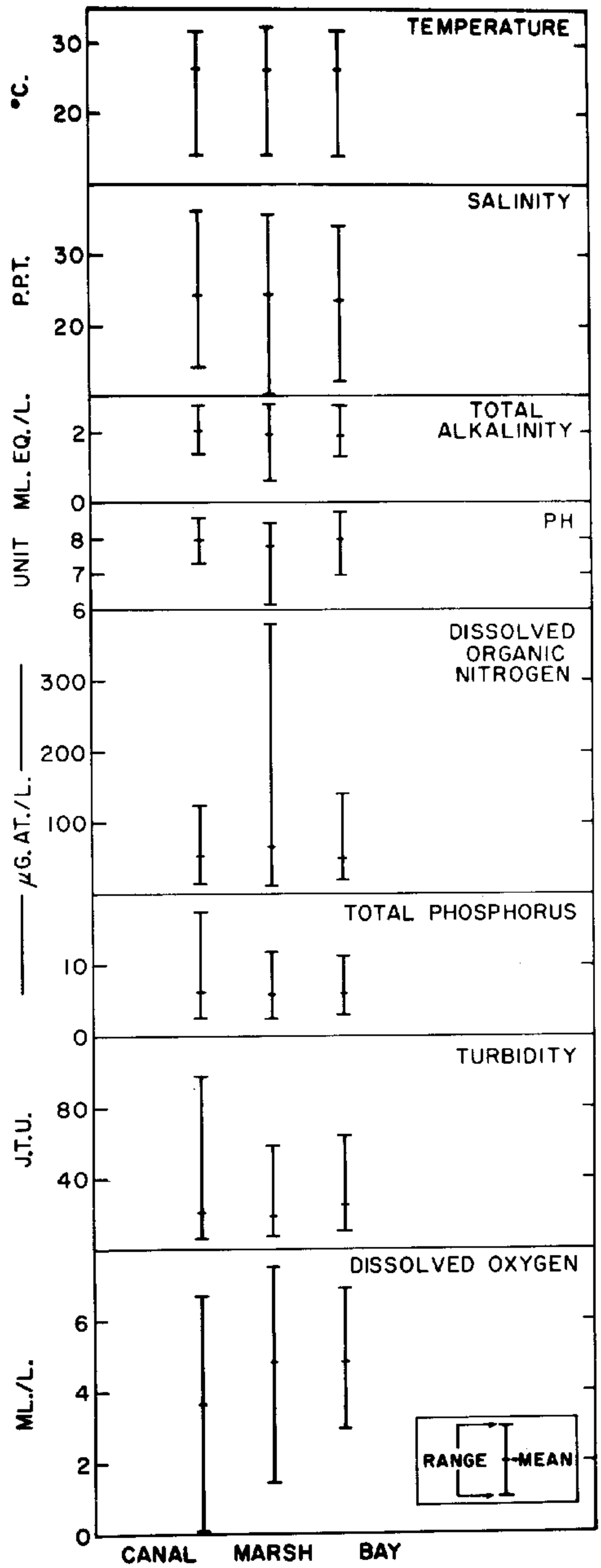

Figure 4. — Range and mean values of hydrographic variables measured at canal, marsh, and bay stations.

The percent volume of molluscan biomass available as a food source for prey species was much lower, however, because the organisms were not decalcified before their volumes were determined. Nemerteans were lowest in number (1%) and third in volume (11%) caught.

Fishes and commercially important crustaceans

Sixty-four species and 240,575 individuals of finfish and decapod crustaceans were taken with the trawl. Of the 64 species, 54 occurred in the marsh, 52 in the canals, and 44 in the bay. In terms of numbers of animals caught when all species were combined, the marsh was the most productive area, and the canals the second most productive. The average number of animals caught per tow in the marsh, canals, and bay was 951, 659, and 412, respectively.

The 10 species greatest in abundance represented 96% of the total number of specimens caught (Fig. 5). Of the six most abundant species (89% of the total catch), brown shrimp (*Penaeus aztecus*), white shrimp (*P. setiferus*), spot (*Leiostomus xanthurus*), largescale menhaden (*Brevoortia patronus*), and Atlantic croaker (*Micropogon undulatus*) are commercially valuable, and the bay anchovy (*Anchoa mitchilli*) is important as food for commercial and sport fish species. The first three species were most abundant in the marsh and the last three were most abundant in the canals.

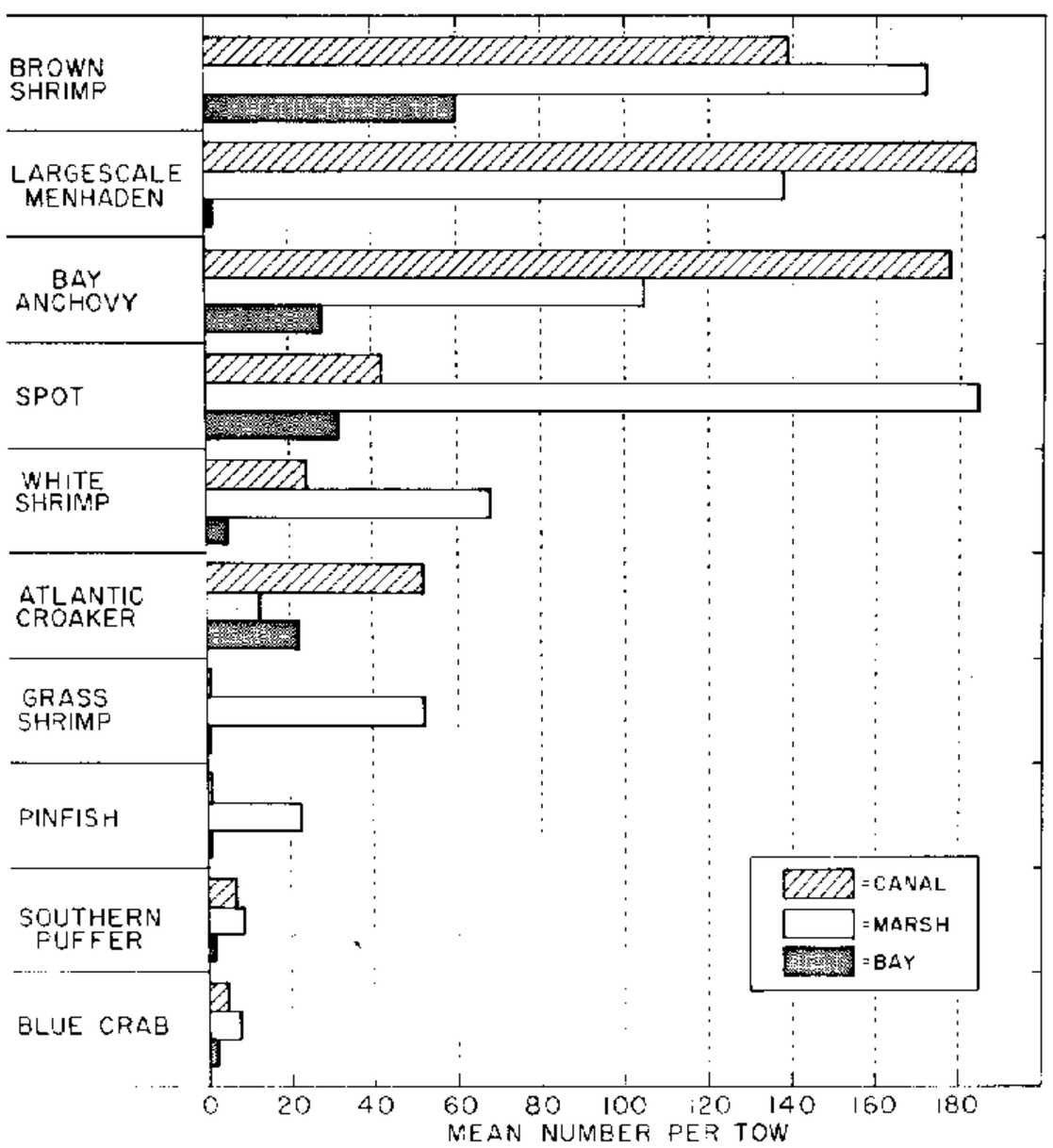

Figure 5. — Comparisons of mean number of fishes and crustaceans per tow between canal, marsh, and bay habitats.

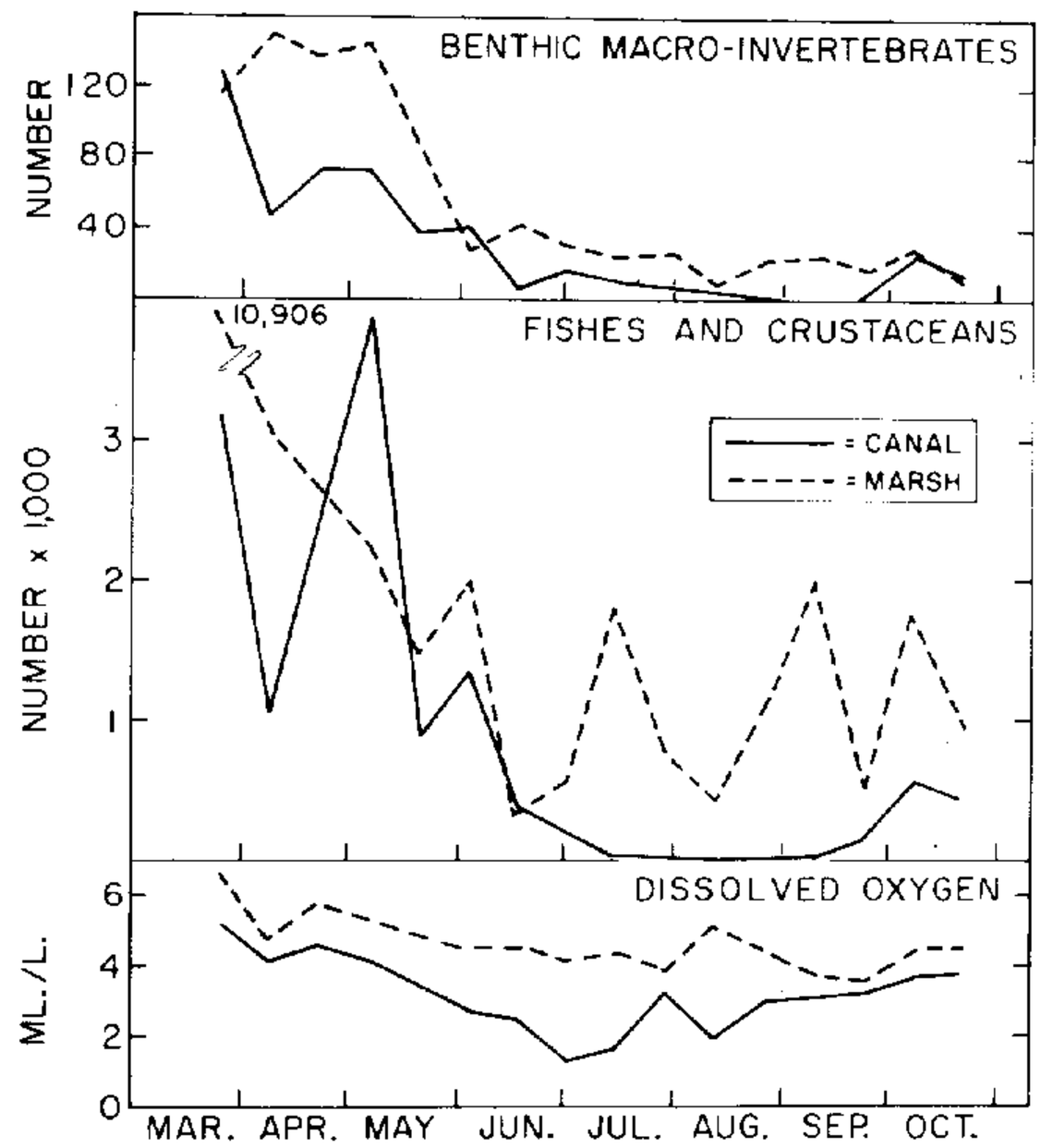

Figure 6. — Seasonal relations between abundance of benthic macro-invertebrates, abundance of fishes and crustaceans, and levels of dissolved oxygen at the canal and marsh stations farthest from the bay.

Seasonal relations

Seasonal relations between levels of dissolved oxygen, abundance of benthic organisms, fishes, and crustaceans at station 1 in the canal and 6 in the marsh (canal and marsh stations farthest from the bay) are shown in Figure 6. Oxygen levels were even more critical at station 1 than the figure indicates because: (1) the data were not taken during the most critical time of day (about 6:00 a.m.) and (2) in our regular schedule we did not happen to sample during times of heavy plankton blooms. Other observations revealed, however, that heavy plankton blooms, resulting in near zero oxygen levels and fish kills, occurred at least four times at station 1 during June-August. Low to zero standing crops of benthic organisms, fishes, and crustaceans at station 1 during June-September were probably directly or indirectly caused by low oxygen levels. Furthermore, stations 2 and 3 in the area of the

development farthest from the bay had low oxygen levels during the summer and a smaller-than-average standing crop of fishes and crustaceans. Poor water circulation in parts of the development canals is implicated as causing conditions favorable for high populations of phytoplankters.

POSTLARVAL SHRIMP SEEDING

In evaluating the stocking of postlarval penaeid shrimp as a means of increasing wild populations, it is necessary to determine for stocked animals (1) survival and growth, (2) resident time in the nursery area, and (3) the effect of artificial stocking on the density of naturally recruited stocks. Initial efforts to gain the desired information involved the release of hatchery-reared and wild postlarval brown shrimp into small natural estuarine bayous. Postlarval shrimp populations in the bayous were sampled at predetermined intervals before and after stocking in an effort to measure resultant changes in population density and to follow the movement of stocked animals. A small-scale effort to observe growth and survival of wild and hatchery postlarvae in cages accompanied the seeding experiments.

Two shallow marsh bayous (average depth = 0.6 m at mean low tide) opening into West Galveston Bay were used in this study. Hatchery postlarvae were released twice in bayou I (15.4 ha), and wild postlarvae collected in the Galveston Tidal Pass were stocked once in bayou II (16.3 ha).

From March 1 through April 1, 1971, postlarval shrimp samples were collected twice weekly at three stations in each of the bayous. On March 15, 158,000 hatchery-reared brown shrimp postlarvae (7-9 mm in total length) were released in the inner end (the end farthest from the bay) of bayou I. Samples were then collected in bayou I at 3-hr intervals for 24 hr.

Numbers of postlarval brown shrimp increased about 15% in samples collected during the 24 hr following the release. Examination of the sizes of captured animals, however, revealed that the increase was not attributable to stocking because only 5 of the 6,049 postlarvae caught in this time interval were within the size range of those released. Assuming that all five of the 7- to 9-mm postlarvae captured were stocked animals, they account for an increase of 0.62 postlarvae per collection, whereas the measured increase was about 100 per collection. The five captured postlarvae assumed to be stocked animals were all taken in the immediate release area, thus giving no evidence of movement.

Failure to recapture significant numbers of hatchery postlarvae suggested either that the 158,000 released animals did not make a measurable contribution to the natural population or that they did not survive.

On March 29, 145,000 wild postlarval brown shrimp were released in the inner end of bayou II. Both the resident and the seeded population were dominantly 12-mm animals.

Numbers of postlarvae increased 75% in samples taken 24 hr after stocking. Assuming 100% efficiency of the sampling gear, we calculated that the total postlarval population of bayou II increased from 314,000 to 549,000 at 24 hr after seeding. By 72 hr after stocking, the population had decreased to its pre-seeding level. Unfortunately, the portion of the population increase directly attributable to seeding could not be determined with certainty because the resident and seeded animals were essentially the same size and could not be separated by length data.

Catch increases at 24 hr after seeding were about equal at all locations sampled in bayou II. These increases, however, could not definitely be linked to the movement of stocked postlarvae because of the inability to distinguish resident from stocked animals.

On May 3, 1971, about 300,000 hatchery-reared postlarval brown shrimp (size range 8-20 mm total length, mode = 13 mm) were marked with a green stain and released in the inner end of bayou I. Preliminary samples of wild postlarvae in the study area were collected on April 26 and 29 and again immediately before the release on May 3. Intensive sampling was carried out at 3-hr intervals for 24 hr after the release of the marked postlarvae. Additional samples were collected on May 6 and the experiment was terminated after sampling on May 10.

As was expected, the rapidly fading mark used in this experiment was of limited value. A 28% mark retention for 24 hr was observed for caged postlarvae. The useful life of the mark was further reduced by the necessity to mark large numbers of postlarvae as long as 7 hr before their release.

Nineteen marked postlarvae were recovered within 12 hr after seeding. All were recovered at the station immediately adjacent to the release area. Numbers of shrimp recovered in four successive collections at 3-hr intervals were eight, six,

four, and one. No marked animals were recovered at 12 hr.

Numbers of 8- to 20-mm postlarvae doubled in samples taken 3 hr in bayou I after seeding, then generally decreased during the remainder of the intensive sampling period. The relative increases measured at each station coupled with the pattern of mark recoveries, however, demonstrate that the increased numbers do not accurately indicate the effectiveness of seeding. Captures at the outer two stations (stations nearest the bay) increased by factors of 2 and 4, but included no recaptures of marked animals. At the inner station, captures increased by a factor of 1.2 and were entirely accounted for by mark recoveries.

Numbers of postlarvae in regular samples taken in bayou I 3 days after seeding averaged 3 times the pre-seeding level. Most of the increase was at the outer station where a six-fold increase occurred. By this time, however, the mark had disappeared, and it became impossible to determine what part of the increase, if any, resulted from seeding. Seven days after stocking, postlarval numbers attained their pre-seeding level.

Observations of marked and unmarked hatchery postlarvae and endemic postlarvae placed in cages in bayou I accompanied the seeding study. Three sets of cages were used. One set was removed and its contents examined at the end of 1, 3, and 7 days. Survival rates over 1 day for unmarked hatchery postlarvae, marked hatchery postlarvae, and endemic postlarvae were 84%, 98%, and 100%, respectively. Survival rates over 3 days were 90%, 94%, and 100%. At 7 days, the survival rates were 84%, 70%, and 28%. Growth of hatchery postlarvae caged in bayou II averaged about 3 mm in 7 days.

EQUIPMENT FOR CAPTURING WILD POSTLARVAL SHRIMP

A collecting system was developed for capturing, sorting, and keeping alive large numbers of postlarval penaeid shrimp as they immigrate through tidal passes. The collecting equipment (Fig. 7) was designed for use on a 12.2-m vessel while anchored in tidal currents.

The equipment was effective in capturing large numbers of postlarvae. It was fished on 20 days between March 17 and June 2, 1971. The average number of postlarval brown shrimp, *P. aztecus*, caught per cruise ranged from 0 to 105,000. The

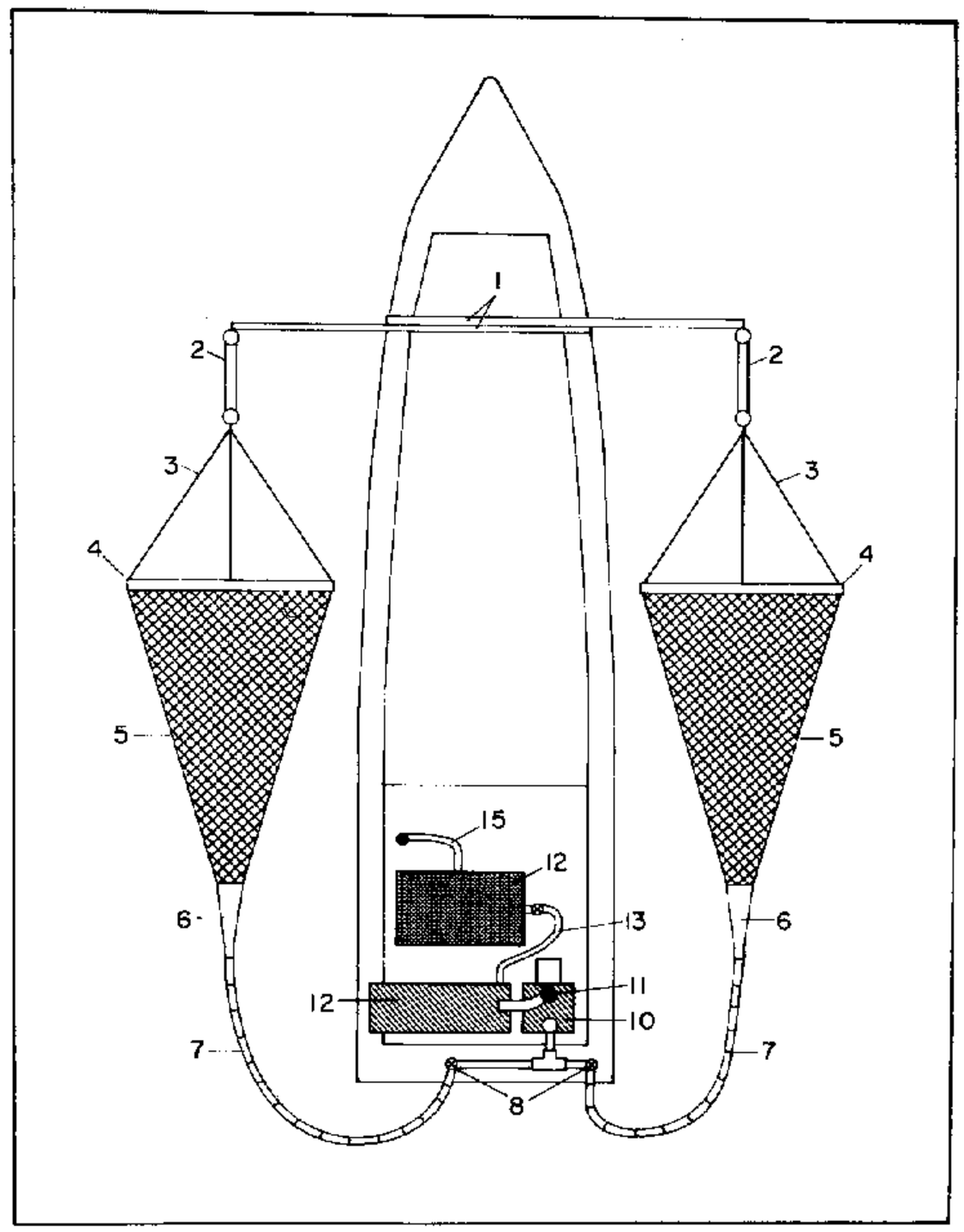

Figure 7. — Schematic drawing of collecting system: 1—telescoping outriggers, 2—double blocks, 3—cable bridles, 4—metal frames and trash screens, 5—fine mesh nets, 6—collecting funnels, 7—suction hose, 8—screw valves, 9—pump intake, 10—solids handling pump, 11—pump discharge, 12—sorting box, 13—drain line and valve, 14—holding tank, and 15—drain line and valve for holding tank.

total estimated catch during the 20 cruises (58.4 hr of fishing) was 421,290 postlarvae, or 7,214 per hour.

Postlarval mortalities associated with the pump were negligible (< 1%). The remaining postlarvae appeared healthy and in good condition. During the sampling, cutlassfish, *Trichiurus lepturus*, sea catfish, *Galeichthys felis*, croaker, *Micropogon undulatus*, menhaden, *Brevoortia patronus*, and anchovy, *Anchoa mitchilli*, were passed through the pump with low mortality.

The sorting box used in the system was effective in removing all trash > 3 mm in diameter and about 95% of the larval fishes. The numbers of postlarvae retained in the trash constituted 10% of the total caught. Larval stages of the blue crab, *Callinectes sapidus*, however, were not sorted out. A light-trap is presently being tested in an attempt to remove these animals from the holding tank.

The system, which is efficient and inexpensive, has the potential for wide application either as a

sampling, or as a collecting, device for egg and larval stages of marine fishes and crustaceans. Large numbers of larval anchovy, *A. mitchilli*, menhaden, *B. patronus*, croaker, *M. undulatus*, and blue crab, *C. sapidus*, along with many more unidentified larval forms, were passed through the pump with low mortality.

Population Monitoring

Emphasis of shrimp population studies has shifted gradually from adult stocks in offshore waters to earlier life history stages in estuaries as various phases of research were finished.

New methods of marking young stages of shrimp were needed and considerable effort has been directed toward their development.

Activities continued in several other research areas, including predictions of shrimp abundance, and research regarding microsporidia infection of shrimp collected from the bait shrimp fishery of Galveston Bay.

POPULATION DYNAMICS

During fiscal year 1970, two mark-recapture experiments were conducted to fill gaps in existing knowledge concerning growth rates and movements of brown shrimp. In June and July, a total of 28,079 juvenile shrimp were tagged and released near the entrance to Galveston Bay. Only 1% of these were returned by commercial fishermen, suggesting a relatively high rate of tag-induced mortality. Most recaptures were made in heavily fished waters about 56 km southwest of the release area.

In November, 6,514 large adult brown shrimp were tagged and released in 36-m depths off Freeport, Tex. These shrimp, sexually mature adults (average total length 169 mm) and at least 8 to 12 months old, were marked with a cut-down version of the Petersen disc tag. Pins used to secure the discs were coated with an antibiotic mixture to retard infection. Nine percent have been recaptured, several, males and females, are at least 24 to 30 months old. These data show that brown shrimp live at least twice as long as previously believed. Returns as late as mid-June 1971 indicate the probability of more recoveries and a further extension of the known life span of brown shrimp. These data also will provide valuable information on winter growth rates.

Because our present methods of marking tend to cause mortality among shrimp of less than 80 mm total length, we continued to search for new techniques for marking smaller shrimp. One method that shows promise is mass-marking with sprayed pigments. Extensive laboratory tests were made to evaluate the possibility of embedding granular pigments in or under the exoskeleton of shrimp. The fluorescent spray-marking material is a granular fluorescent pigment 250μ to 297μ in diameter. It is applied with an air-blast gun similar to those used with paint spraying equipment. In laboratory experiments, fluorescent pigments sprayed under air pressures of about 240 lb per in^2 provided marks that could be identified for more than 3 months in some shrimp. More commonly, however, some of the pigment was lost when shrimp molted, indicating that the mark will be most useful for short-term, mark-recapture experiments such as those designed to estimate population size. Advantages of this technique are that large numbers of shrimp can be marked quickly, inexpensively, and without excessive mortality (Fig. 8).

The spray-marking technique was field-tested in May when 8,000 small brown shrimp (40 to 110 mm total length) were marked and released in a 36-ha marsh pond. Recoveries during the following 5 days indicated that the marked animals dispersed throughout the pond and that there was no appreciable loss of pigment from marked individuals. Further, the ratio of marked to nonmarked shrimp in catches remained reasonably stable, meaning that the technique may be suitable for obtaining rapid estimates of shrimp population size in ponds.

Laboratory tests also were conducted to evaluate the feasibility of marking small shrimp with color-coded wire tags measuring 1 mm in length. The wire tag is inserted into the shrimp through a needle. After insertion it is magnetized and can be detected when the marked animal is passed close to a metal detector head. The entire tagging and detecting apparatus was developed primarily for use in salmon studies but has since been used to mark other aquatic animals. Extensive laboratory studies with the wire tag have been completed and indicate that the tag can be placed directly into the hepatopancreas organ within the cephalothorax with little mortality among animals over 50 mm total length. Tags can be inserted and detected rapidly with commercially available equipment.

Before our field work began, brown shrimp were marked with wire-coded tags, sprayed fluorescent

Figure 8. — Spray-marking shrimp with fluorescent pigments.

pigment, and injected fluorescent pigment-petrolatum mixture and placed in three small ponds with known population sizes. Total lengths ranged between 40 and 120 mm. Subsequent sampling indicated that all three methods would be reliable for short-term mark-recapture studies designed to estimate population size. The wire tag, however, may be the most reliable mark when extended periods between marking and recapture are desired for estimating survival and growth rates of young shrimp in estuarine areas.

In 1970 and early 1971, much of our work was directed toward evaluating juvenile shrimp populations in small estuaries along the Texas coast with most emphasis on population size and survival rates.

Our study areas ranged in size from 3 to 30 surface ha and had restricted openings to bayous or open bays. Restricted openings are necessary so that block nets can be set to eliminate essentially all immigration and emigration, thus providing a stable population for estimating population size during a 3- or 4-day study period. The studies involved marking, releasing and recapturing shrimp in the enclosures described.

Preliminary evaluations of data collected to date for juvenile brown shrimp populations along the Texas coast indicate that the population size of animals 40 mm and larger may range between 9,880 and 19,760 per ha. The population size of animals in this length range will vary, of course, depending upon the percentage of the population that is 40 mm and larger during the period of study. We believe our fishing gear is adequately sampling shrimp as small as 20 mm.

Since many of our study areas are shallow and quite inaccessible, we designed and built a portable barge which can be moved to the study area when powered by an outboard motor. Disassembled, the barge can be transported on a trailer between study areas. The barge provides a stable 4.8 m by 4.8 m work platform needed for extended periods of field work in the shallow marsh. Except for the plywood deck, all parts of the barge are aluminum. Essentially it consists of three pontoons bolted together with U-beams and a plywood deck bolted on top. One outside pontoon with its connecting beams and plywood deck can be disconnected, placed on top of the remaining barge section, and the entire barge can then be loaded on a 3-m wide trailer for highway transportation. When completely disassembled, any single part of the barge can be handled conveniently by two men. The assembled barge was

designed to have a 23-cm draft when loaded with 1,589 kg.

PREDICTIONS OF SHRIMP ABUNDANCE

In fiscal year 1970, research designed to provide measures of shrimp abundance was concentrated on postlarval shrimp immigrations at the entrance to Galveston Bay and juvenile shrimp abundance within the bay. Postlarval brown shrimp entered Galveston Bay later than usual in the spring apparently because of comparatively low water temperatures. Average April air temperatures at Galveston were the lowest recorded in 39 years and evidently accounted for the slow growth of juveniles that year. High catches of brown shrimp by bait shrimp fishermen in late May and early June, however, indicated a good shrimp season offshore later in the summer.

Postlarval brown shrimp entered the Galveston Bay system in above average numbers in fiscal year 1971. Catch per unit of effort from the bait shrimp fishery in May and June was also higher than in the preceding year. Accordingly, our pre-

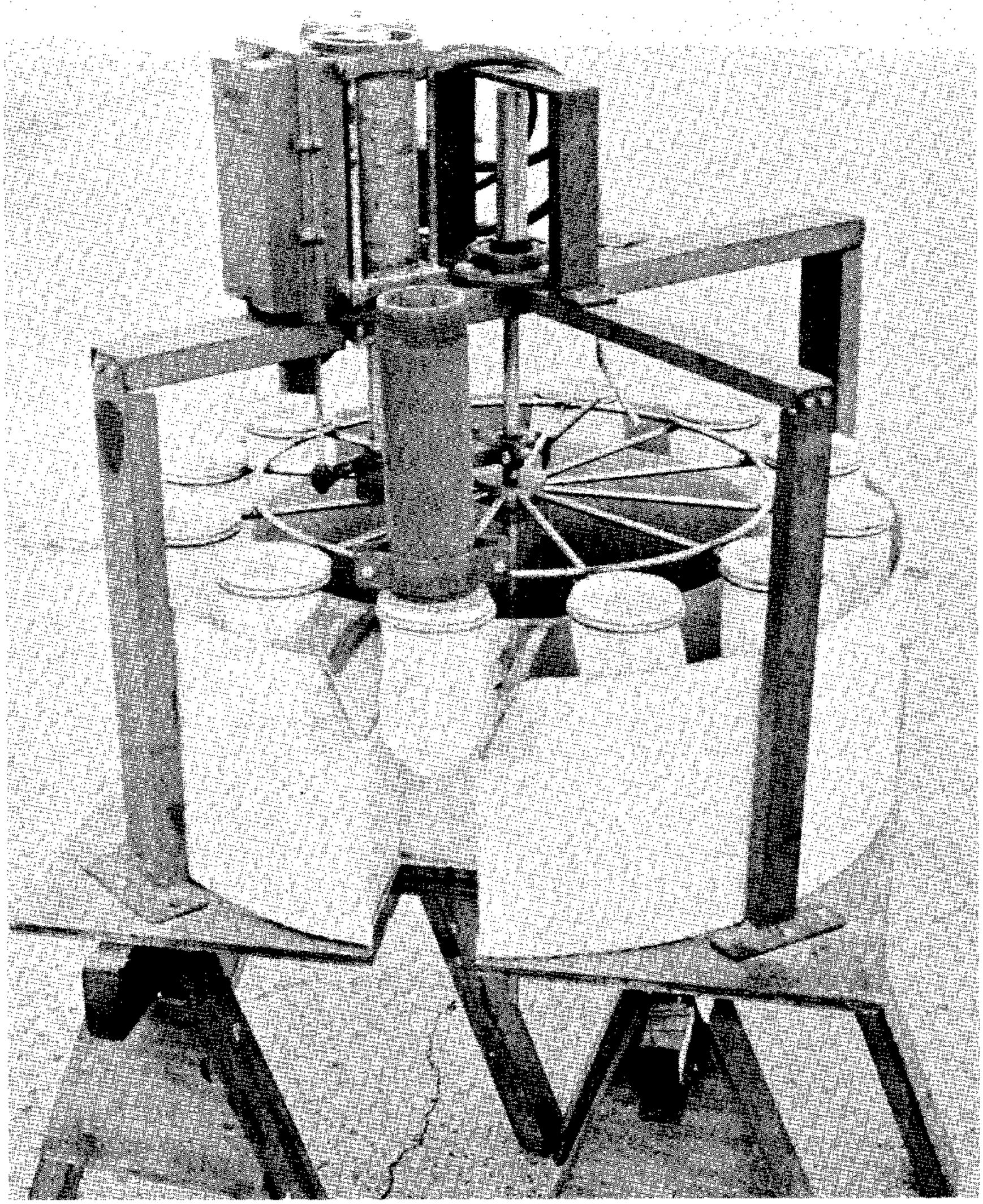

Figure 9. — Automatic turntable for receiving and preserving postlarvae collected by the automatic pump.

diction was for an above-average offshore shrimp season. This information was disseminated to the industry on request in a series of preseason shrimp information releases.

A second automatic plankton pump was installed at the entrance to Galveston Bay on the opposite side of the tidal pass from the first unit to provide continuous samples of immigrating postlarval brown and white shrimp. Water depth at the original location is 5 m compared to 3 m at the second location. To determine the optimum level in the water column for the pump intake, a vertical distribution study of postlarval brown shrimp was conducted. Five nets were fished 0.3 m apart from surface to bottom during flood tide. Thirty-three percent of the 12,611 postlarval brown shrimp taken were caught in the top net just under the surface. This contrasts with the depth distribution of postlarvae at the first pump location where most were caught at a depth of 3 m.

A new system for receiving and preserving postlarvae collected by the automatic pump was tested near the end of the fiscal year. This system (Fig. 9), designed to keep individual samples separate, consists of a 0.9-m-diameter fiber glass tank containing a Formalin bath solution. Mounted over the tank on stainless steel rods are twelve 0.1-m rings which hold individual collecting nets. A 0.2-m section of the tank is cut away to allow water to pass through the nets during a pump cycle. After each pumping cycle, the nets are lifted, rotated, and lowered into a preservative solution while the next net is positioned over the opening to receive the succeeding sample.

Weekly surveys of the Galveston bait-shrimp fishery were conducted to measure the relative abundance of juvenile brown and white shrimp. Total bait shrimp catch exceeded 450,000 kg in 1969 and 1970 and was valued at more than $2.5 million for the biennium. Catch-per-unit-of-effort estimates for the 2 years were 27 and 28 kg of shrimp per hour of fishing. Bait shrimp fishermen had excellent catches of shrimp through the last two winters because large numbers of juvenile and subadult white shrimp remained in the deep channels of the bay through the winter.

Research regarding microsporidia infection of shrimp collected from the bait shrimp fishery of Galveston Bay was completed. *Pleistophora* sp. (Microsporidia: Nosematidae), a new parasite for brown and white shrimp, was discovered and described. A second malady that caused appreciable loss to bait shrimp fishermen and dealers, muscle necrosis or "tail-rot," was reported.

Environmental Research

In Fiscal Year 1971 our efforts were redirected from investigations of the sediments and waters in the Gulf of Mexico to an investigation of the hydrographic and atmospheric environments of natural estuarine areas available for stocking hatchery-reared postlarval shrimp.

RECONNAISSANCE SURVEY

Objectives of this study were to determine the characteristics of the sediments on the northern Continental Shelf of the Gulf of Mexico, with particular emphasis on the major shrimping grounds, and to provide information on the oxygen and nutrient content of the overlying waters.

Bottom sediments on the Continental Shelf

Over 1,500 sediment samples were collected on a reconnaissance basis over the shelf and on an intensive scale in the vicinity of the Dry Tortugas and Galveston fishing grounds. Although most samples were taken with a van Veen grab, a few were taken in deep water with a coring tube.

The sediments were analyzed by standard sedimentological techniques, and the particle size, sediment types (i.e., gravel, sand, silt, and clay), and statistical measures (i.e., median diameter, sorting, skewness and kurtosis) were computed. Chemical analyses included determination of calcium carbonate, total carbon, organic carbon, and nitrogen content. These parameters are now tabulated and plotted.

One of the first requirements in the study of the distribution of surface sediments was to determine the bottom topography in sufficient detail to be of aid in the interpretation of data. On completion of charts of the Continental Shelf and the southern Florida Shelf, a new map of the Dry Tortugas shrimping grounds was prepared. The chart, based on U.S. Coast and Geodetic Survey soundings, is contoured at 1-fathom intervals on a mercator projection at a scale of 1:40,000.

The distribution of sediment types on the shelf from the Rio Grande River to the Dry Tortugas is shown in Figure 10. Properties varied widely on the shelf but a distinct difference was apparent

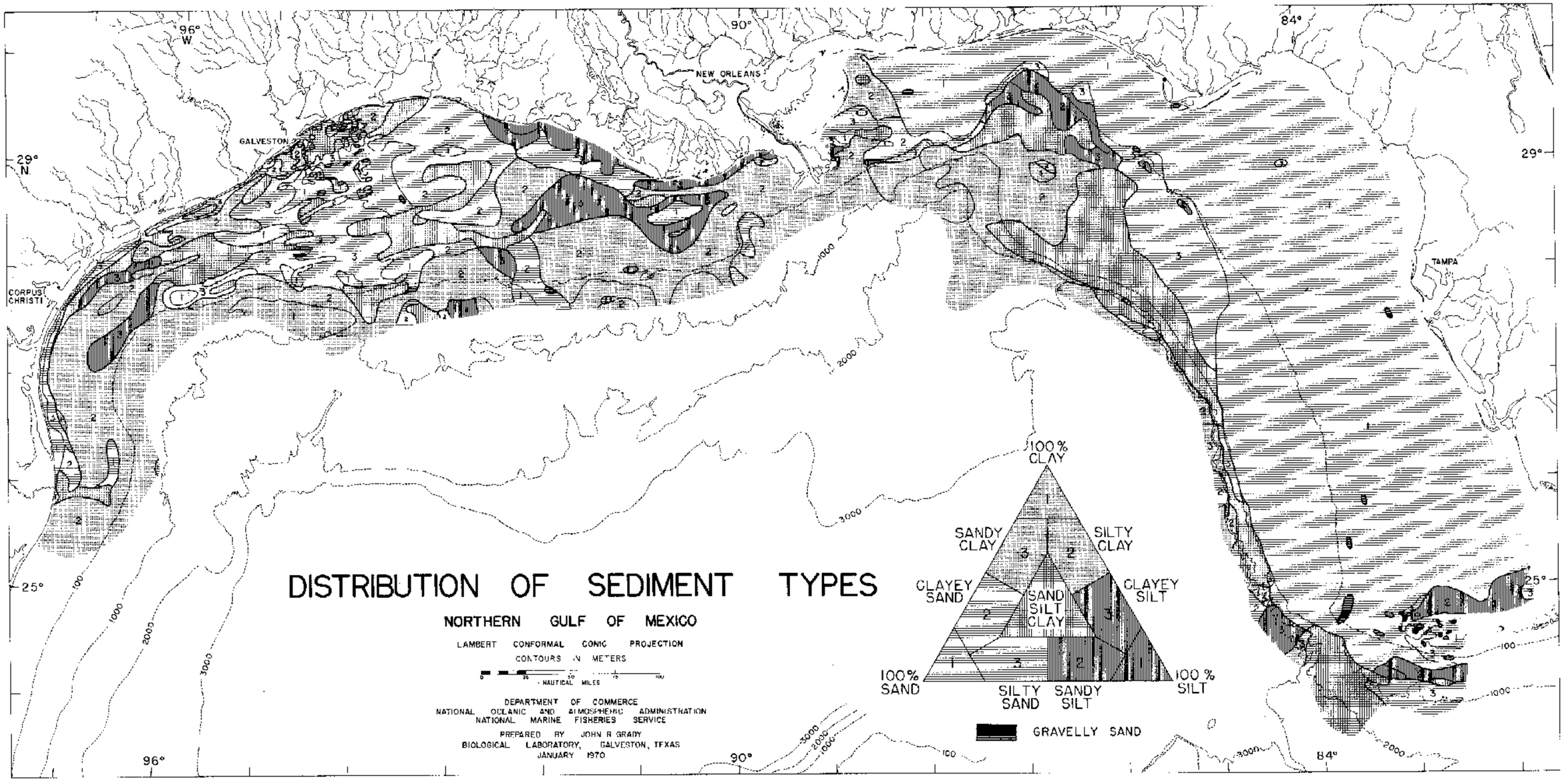

Figure 10. — Distribution of sediment types on the northern Continental Shelf of the Gulf of Mexico.

Table 3.--Averages of sediment properties for the eastern and western[1/] portions of the northern Continental Shelf of the Gulf of Mexico.

Sediment properties	Western shelf	Eastern shelf	Total shelf
Textural class[2/]			
	- - - - - - -	Percent	- - - - - - - - - -
Gravelly sand	0.19	0.28	0.23
Sand	37.42	82.02	59.72
Sand-silt-clay	16.02	0.23	8.12
Silt	14.41	2.39	8.40
Clay	29.69	1.48	15.58
Area excluded[3/]	2.23	13.57	7.90
Chemical properties			
Carbonate	6.30	55.04	30.67
Nitrogen	0.070	0.037	0.053
Organic carbon	0.526	0.254	0.390
Total carbon	1.294	6.887	4.09
Statistical measure			
	- - - - - -	Millimeters	- - - - - - - - -
Median diameter	0.033	0.384	0.208
Sorting	0.144	0.401	0.272
Skewness	0.370	0.375	0.372

1/ Division of shelf placed near the Mississippi-Alabama boundary.

2/ Sediment classification is based on textural classes after Shepard (1954), J. Sediment. Petrology, 24(5): 151-158.

3/ Area inshore from which no data were available.

between the average values on the eastern shelf and those on the western shelf. The averages of the sedimentary parameters for the eastern and western shelf are presented in Table 3. The division of the shelf into two parts was based principally on the marked change in average particle size in the area off the Petite Bois Island near the Mississippi-Alabama boundary, rather than off the Mississippi Delta. Other parameters measured showed an equally sharp change in this area.

The most abundant type of surface sediment exposed is sand (2.000- to 0.062-mm diameter) which covers more than 62% of the shelf. Over 82% of the sand is on the eastern shelf. Predominance of sand size particles on the eastern shelf is due principally to the abundance of biogenic carbonate which approaches 100% in the southern Florida area. On the western shelf the average is slightly greater than 6%, and the average particle size is about one-tenth that of the eastern shelf; the content of organic matter is approximately double. Higher organic carbon content is associated with finer particle sizes.

The sedimentary data from the Dry Tortugas grounds were referred to statistical divisions of the grounds which are essentially based on depth zones within which the shrimp catch is averaged. On the shrimping grounds, which are characterized by a hard limestone substrate overlain by a thin veneer of organic-derived sediments, are carbonate sand-size particles constituting 78% of the surface sediment. Of this, 35% is a fine to very fine sand and the remaining sediment is principally a very coarse silt. Off the grounds the sediments are generally coarser. Distribution of grain size on the grounds is influenced by sediment source and the currents. In contrast, the area off Galveston has a relatively smooth dipping detrital bottom with finer sediment

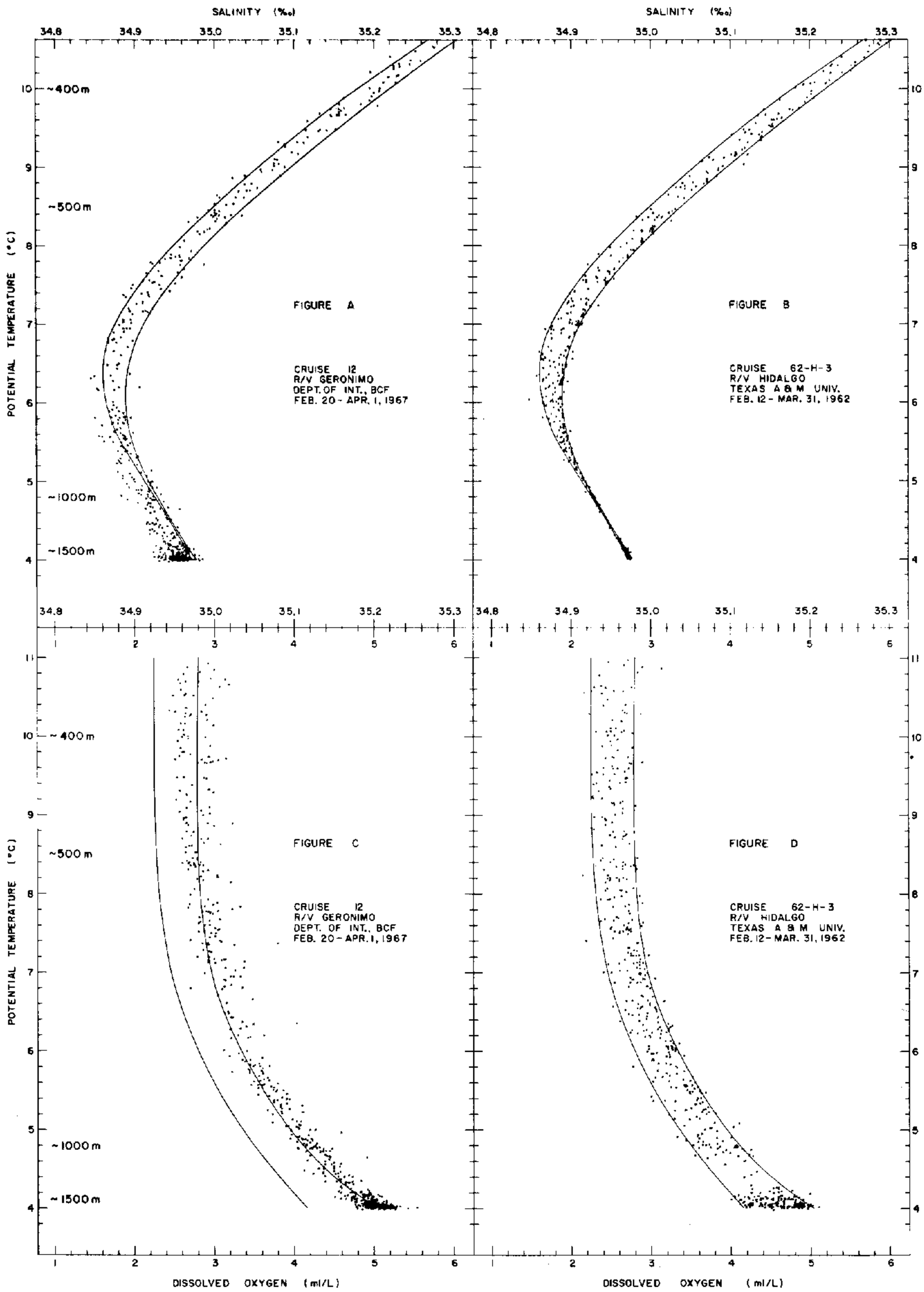

Figure 11. — Water mass structure at the time of cruise 62-H-3 of the RV *Hidalgo* and cruise 12 of the RV *Geronimo* in the Gulf of Mexico.

types and a wider range of organic content.

North of the Dry Tortugas grounds the average value of the total carbon content at similar depth intervals was low and increased slightly as depth increased. On the Tortugas grounds, the average percentages of organic carbon are notably higher and increase seaward as much as threefold compared to the shelf area north of the grounds. This increase appears coincident with finer grained sediments occurring north off the Dry Tortugas and suggests that a relation between the higher catches and finer sediment types with higher organic content may exist. On the Galveston grounds, the distributions of sediment types and organic matter are less uniform over the statistical squares within which the landings have been averaged. Additional sediment samples west of the Galveston grounds in the areas of high shrimp harvest may clear this relationship.

Dissolved oxygen in the Gulf waters

The presence of new, deep and bottom water in the Gulf of Mexico was reported previously by this program when data collected during the cruises of the RV *Geronimo* during 1967 were compared with data acquired on the cruise made by the RV *Hidalgo* of Texas A&M University in 1962. Based on the distribution of salinity, it was found that during the 5-year period between the cruises, the deep and bottom water changed to the extent that the deepest four-fifths of the water column was replaced while the near-surface waters apparently remained essentially unchanged. A study of the dissolved oxygen and phosphate-phosphorus content confirmed the appearance of the new water. A comparison of salinity and dissolved oxygen from our stations in the Gulf with the stations from the cruise of the RV *Hildalgo* shows a decrease in the salinity and an increase in the dissolved oxygen since 1962 (Fig. 11). In the figure, the envelopes enclosing the values of salinity and dissolved oxygen were fitted to the RV *Hidalgo* data and then overlain on our data distribution. A decrease in the phosphate-phosphorus concentration occurred and corresponded to the increase in dissolved oxygen.

CIRCULATION DYNAMICS

Our main effort was the computation of currents and the examination of the circulation and transport of the water masses in the Gulf with particular attention to the current entering the Gulf through the Yucatan Strait. The inflow from the Caribbean through the Yucatan Strait appears to control the distribution of currents and water properties in the Gulf.

Hydrographic conditions prevailing in the Yucatan Strait during the winter of 1968 are presented in Figure 12. Surface currents reached a maximum of almost 200 cm per sec toward the western side of the Strait. This northward current extended to the bottom and brought water into the Gulf at a rate of 30 million m^3 per sec. Intense upwelling, which brought water from a depth of 200 m near the center of the Strait to the surface, accompanied the movement of the current. The upwelling is well defined in the temperature section by water as much as 7.5 Celsius degrees cooler than in the center of the Strait at the same depth. Dissolved phosphate was almost absent to about a 200-m depth in the center of the Strait, but the upwelling brought water of higher nutrient content into the euphotic zone over the western shelf, thus explaining the high plankton counts found in the area.

Adjacent to the northerly current is a southward moving counter current. This deep-water counter current transported water out of the Gulf at a rate of more than 4 million m^3 per sec. In the summer of 1967 (cruise 16, RV *Geronimo*) the deep-water exchange appeared to double in magnitude. The upper-water (less than 1,000 m) flow in the Yucatan Strait seemed to undergo considerably less variability. This apparent seasonal shift in the deep-water flow must have distinct effects on the flow throughout the Gulf.

The upper waters entering the Gulf through the Yucatan Strait moved northward into the eastern Gulf, looped clockwise, and exited the Gulf through the Straits of Florida. Figure 13 depicts conditions encountered along a section across the Straits of Florida during cruise 3 of the RV *Oregon II* in October 1968. The sill depth is at about 800 m which is some 440 km east of this section. Generally, waters below this depth cannot leave the Gulf through this passage.

About 28 million m^3 per sec of water were transported eastward between the four stations shown in Figure 13 with a maximum current speed of 150 cm per sec at the surface. The effect of the sill depth is apparent since the eastward transport below about 900-m depth appeared balanced by a westward moving counter current on the southern side. Therefore, all deep-water exchange for the

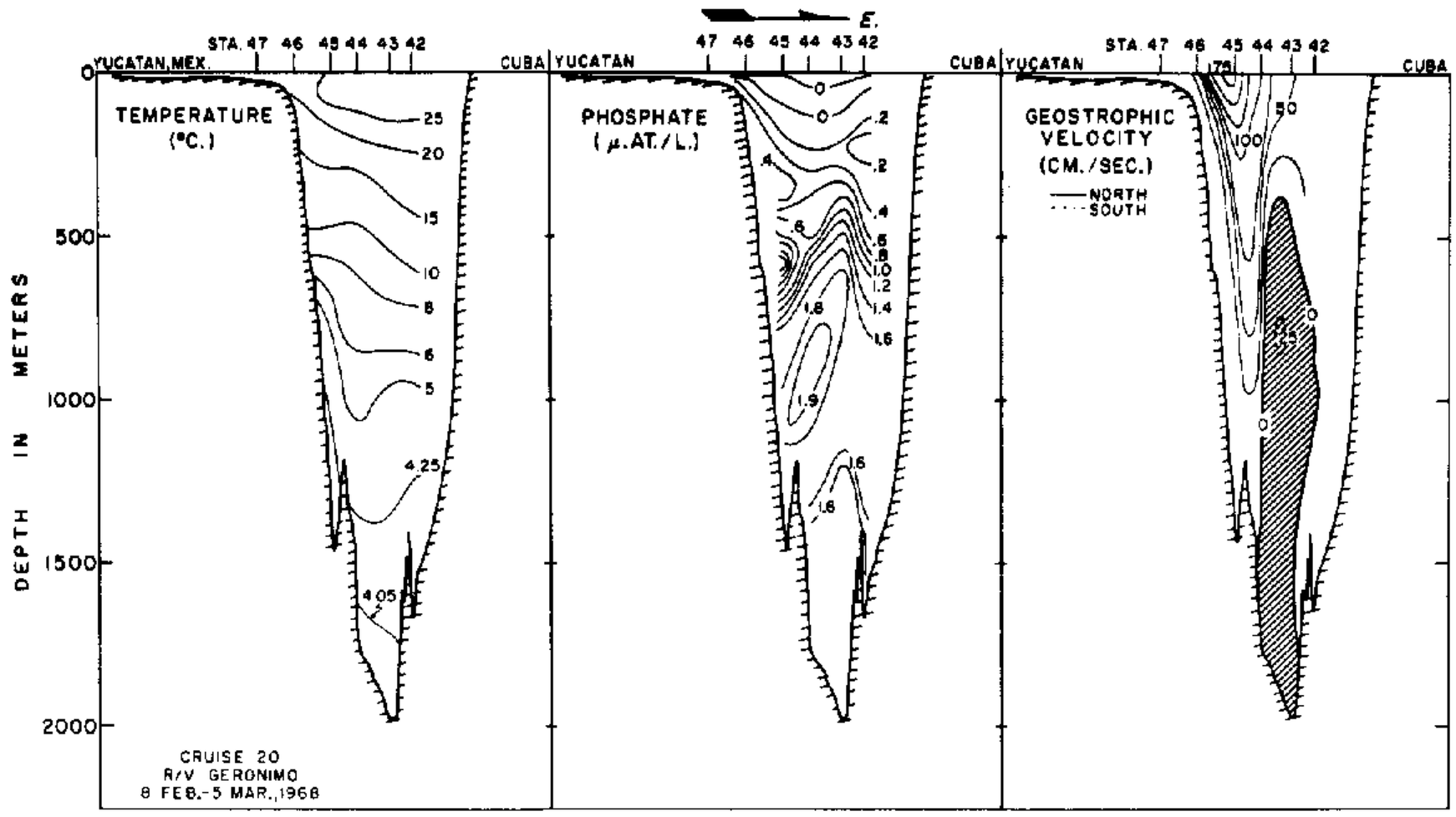

Figure 12. — Temperature, phosphate, and velocity section across the Yucatan Strait, cruise 20, RV *Geronimo*.

Gulf must be effected in the Yucatan Strait.

Upwelling occurs along the Florida Shelf as a result of the strong easterly current. The upwelling is evident in the temperature section of Figure 13. The isotherms are warped by upwelling to about the same degree as in the Yucatan Strait section. Also, the effect of upwelling on the distribution of dissolved phosphate is similar to conditions in the Yucatan Strait and accounts for the high productivity around the Florida Keys.

BENTHIC INVESTIGATIONS

This project was recently established to investigate the estuarine environment and processes that affect it. Our area of interest is the sediment-water interface which will be the principal habitat of the postlarval shrimp. A pilot study of enclosed areas was started to develop techniques and a model for research in the shallow-water estuaries.

Preliminary work was done on an area selected for experimental seeding located south of Houma, La. More detailed studies of the hydrographic structure of the water and sediment properties were made on small ponds, one constructed for raising postlarval shrimp and one naturally enclosed pond. Measurements of salinity, temperature, phosphate, silicate, Eh, pH, and dissolved oxygen of the water, and particle size, types, carbonate, total carbon, organic matter, pH, and Eh of the surface bottom sediments were taken. Reduction and analyses of the data are in progress.

During the summer, evaporation and rainfall were the two principal factors causing severe and almost continuous changes in the properties of the ponds. In the natural ponds, the sequence appeared cyclic over the short study period, producing considerable change in salinity, dissolved oxygen, nutrients, and some surface sediment properties.

Within all ponds, areal variations of organic matter and Eh were large, and in the natural ponds Eh showed some correlation with depth. Eh-pH diagrams were found useful in determining where and to what extent the substrate environment exceeded the limits of conditions expected in shallow-water estuaries. Although determination of the oxidation-reduction potentials in reduced sediments has many problems in the field, the use of pH and Eh for delimiting subenvironments in the estuarine areas appears to be promising.

Effects of Physical, Chemical, and Biological Environments

At mean high water, the estuaries of Texas cover approximately 607,000 ha, and their peripheral marshes cover an additional 445,000 ha. The Texas estuarine and marsh complex may be compared to the combined total areas of the states of Rhode Island and Delaware.

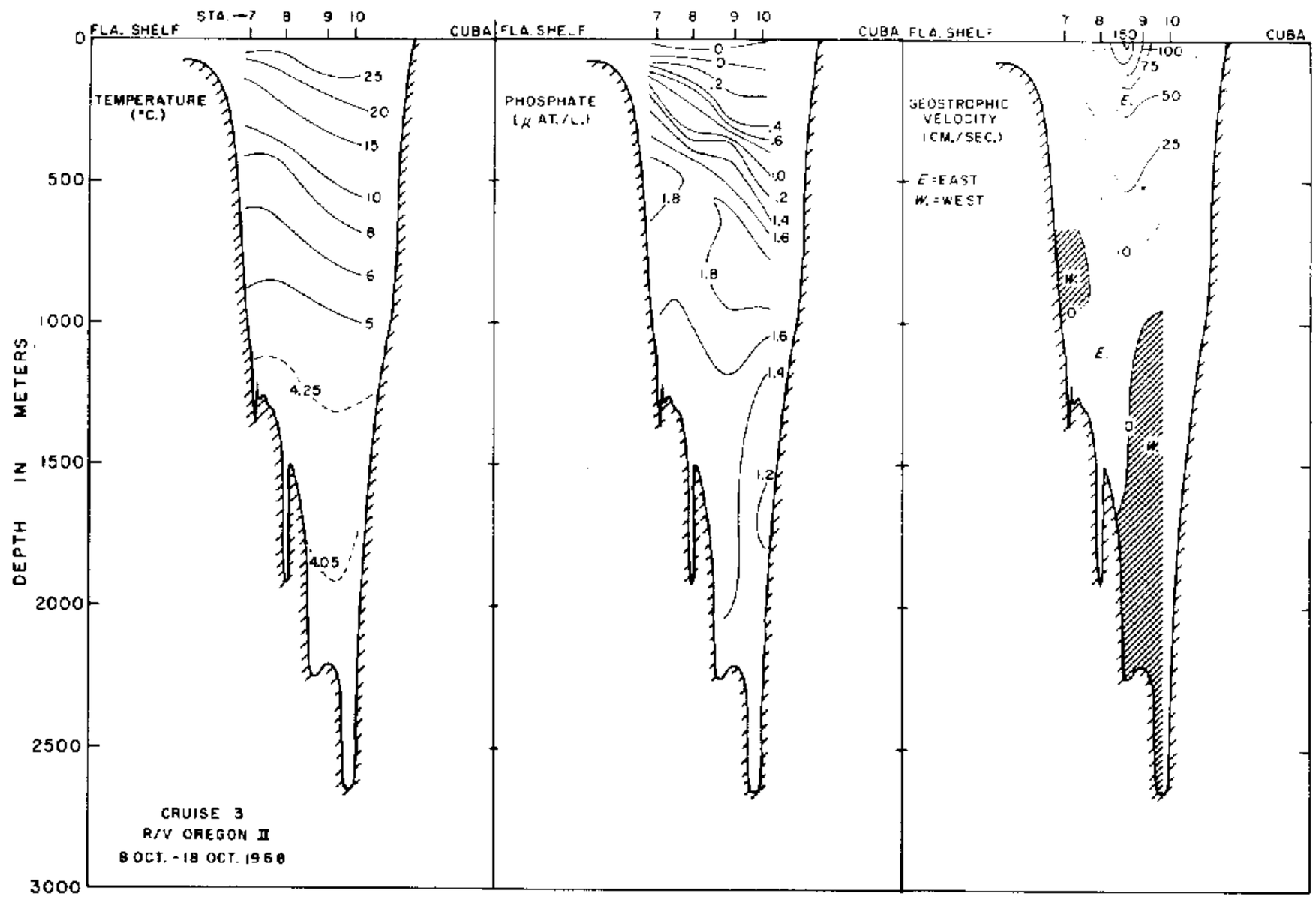

Figure 13. — Temperature, phosphate, and velocity section across the Straits of Florida, cruise 3, RV *Oregon II*.

The estuaries contribute significantly to the marine fishery in Texas. In 1968, about 148 million pounds of finfish and shellfish were harvested with a dockside value of nearly $50 million. Approximately 98% of these totals by weight and nearly 99% of the value consisted of estuarine-dependent species. As indicated, the commercial fishery values are readily assessable; however, it is difficult to affix a value upon the marine sport fisheries or upon the vital nutrients or total productivity contributed by the estuarine zone.

In Texas more than 9.8 million people live in the coastal or river basins draining into the estuaries, and about 3 million live in the 18 counties contiguous to the estuaries. By the year 2020, more than 6 million people are expected to be residing in these 18 counties.

The increased population and associated economic development will amplify the stress upon the coastal zone from the resulting water resource development projects. In the drainage basins, these projects will assume the form of new reservoirs, water diversion systems, irrigation, and navigation channels. Within the estuaries and their adjacent marshes, the environment will continue to be altered by extension of navigation channels as well as enlargement of existing channels, hurricane flood protection projects, mineral producing facilities, and dredging and filling projects for domestic and industrial purposes. Pollution from domestic, industrial, and agricultural sources is presently a serious problem in many of the Texas estuaries and is expected to worsen in the future.

The BSFW (Bureau of Sport Fisheries and Wildlife) functions as the lead agency for coordinating the Federal and State fish and wildlife agencies' evaluation of Federally planned and Federally authorized water-development projects. We therefore submit our evaluations and recommendations concerning marine fisheries to that agency (BSFW) which in turn compiles the final evaluation report.

This program aids in monitoring the welfare of the estuarine fishery habitat in the western Gulf of Mexico by conducting short-term investigations and evaluations in connection with Federally planned and Federally authorized water-development projects. Table 4 lists the number, type, and general location of applications for private construction projects reviewed during the past 2 fiscal years. Program personnel contributed to and reviewed drafts of 117 fish and wildlife reports on private and Federal projects prepared by the BSFW.

Table 4.--Number, type, and location of proposed private construction projects in the coastal areas of the northwestern Gulf of Mexico that were reviewed during fiscal years 1970-71.

Location	Mineral development		Navigation channels (primary purpose)	Bulkheading, fill, or shoreline work	Other[1/]	Renewals[2/]	Total
	Requiring dredging for access	Not requiring dredging for access					
	Number						
Sabine Lake and vicinity	0	1	1	2	3	7	14
Galveston Bay and vicinity	10	15	14	19	24	24	106
Matagorda Bay and vicinity	16	27	8	3	11	19	84
San Antonio Bay and vicinity	12	3	2	0	3	10	31
Aransas-Copano Bay and vicinity	17	16	3	10	5	20	70
Corpus Christi-Nueces Bay and vicinity	9	11	5	6	10	35	76
Laguna Madre and vicinity	19	3	5	2	6	29	64
Gulf of Mexico	0	80	0	1	53	55	146
Rivers and streams and isolated water areas not connected to above estuaries	1	0	23	71	68	38	245
Total	84	156	63	114	182	237	836

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

2/ Extensions of time (mostly mineral development).

In the past year we reviewed and commented upon 18 Environmental Impact Statements prepared by the Corps of Engineers or the Bureau of Reclamation for projects proposed by them. These impact statements are a new requirement under the recently enacted National Environmental Policy Act of 1969. The NMFS reviews are independent of those by the BSFW. Plans for some of the projects are now being reconsidered by the proponents as a result of our comments.

During the last half year, we have also been reviewing and submitting comments upon the proposed placement of spoil dredged during the maintenance of the more than 640-km-long Gulf Intracoastal Waterway (Texas sector) and many other navigation channels including the approximately 80-km-long Houston Ship Channel and 40-km-long Matagorda Ship Channel. Resulting from some discussions by the BSFW and us with the Galveston District, Corps of Engineers, the latter has generally agreed to construct containment levees around spoil dumping sites beside marshes or emergent lands. Spoil deposit areas in open water will be leveed after they become emergent at their farthest designated distance from the waterway. The Corps of Engineers has also agreed to reopen and maintain several passages critical to water circulation that are being filled by spoil-bank erosion.

Another example of habitat preservation by Program personnel in coordination with the BSFW is illustrated by the following case of a private project requiring Federal authorization.

A resort housing development corporation proposed to dredge a channel 30.3 m wide and approximately 26,400 m long to a depth of 2.1 m below mean sea level. The development corporation planned to begin the channel at a point near the head of Mentzell Bayou and extend it approximately 1.6 km into West Bay (Fig. 14). The material dredged from the bayou was to be placed on property owned by the applicant including the tidal marshes. The spoil from the part of the channel in West Bay was to be placed in mounds on the westerly side of the channel with openings 212.1 m

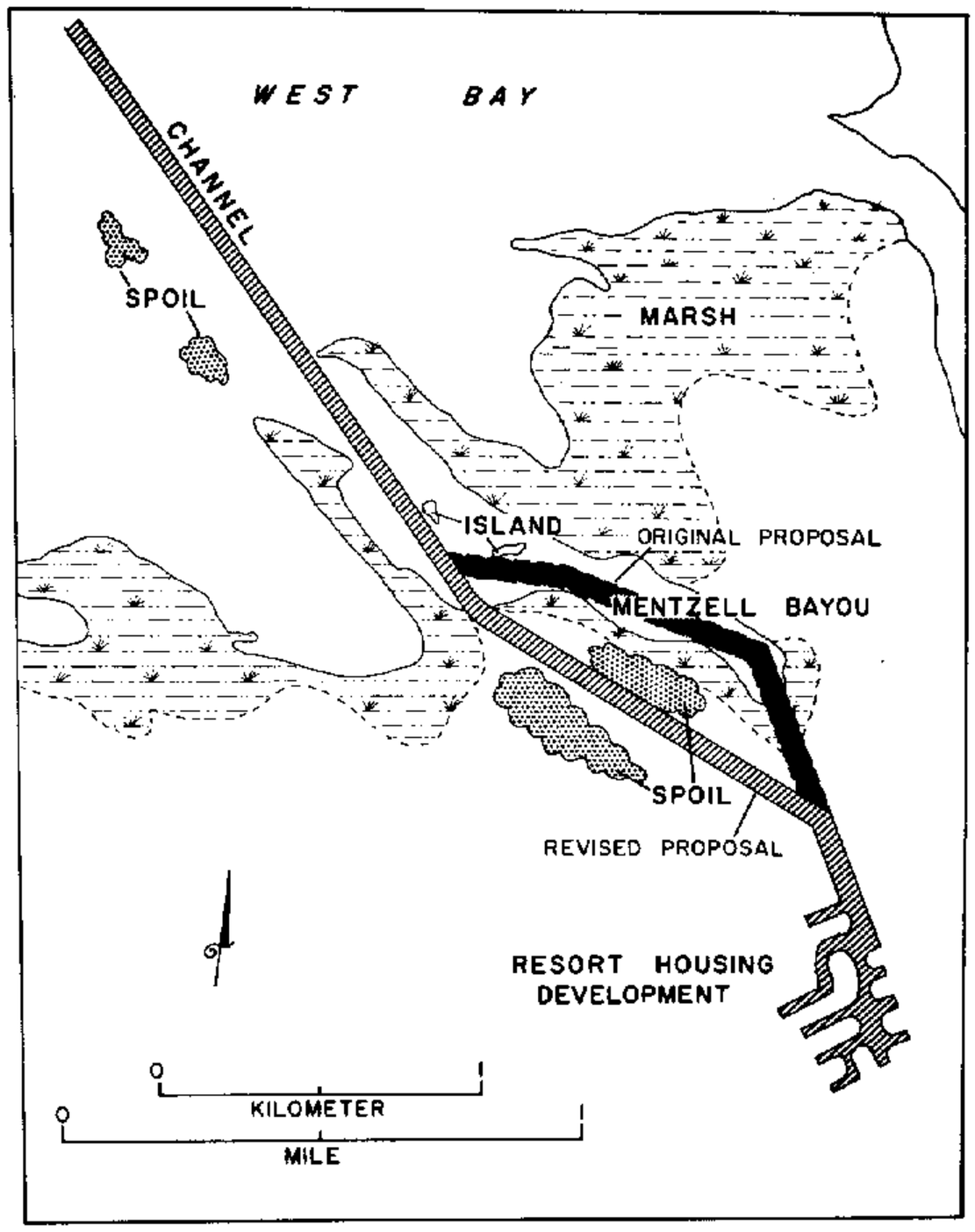

Figure 14. — In West Galveston Bay, Tex., a prime estuarine nursery area for fishes and crustaceans that was preserved when a housing development and most of the associated excavation were relocated to land above the mean high-tide line.

long between ends of the mounds. The channel was to fork in Mentzell Bayou with the western leg leading into an area presently being developed and the eastern leg providing access to an area that would be developed in the future.

A field survey of the proposed project area showed that all of Mentzell Bayou was less than 1.2 m deep and was characterized by a band of tidal marsh, some submerged aquatic vegetation, and extensive beds of attached algae. Several small but producing oyster reefs were also present.

It was determined that the proposed alignment of the channel would traverse marsh and water areas containing excellent fishery habitat. Of particular concern were the possible effects on shrimp and fish nursery areas and oyster resources. Siltation, turbidity, and physical displacement of habitat associated with project construction would detrimentally affect these resources if operations were not conducted with adequate safeguards.

In informal meetings with development officials prior to their submission for a Corps of Engineers permit, we proposed a new westerly alignment that would divert the channel away from the shallow upper reaches of the bayou, thus avoiding the tidal marshes, and the channel would follow higher elevations as far as possible before entering West Bay. Resultant spoil material from the land-cut channel would be placed and retained above the mean high tide line to prevent its reentry to the bayou and tidal marshes.

We also recommended that the spoil from dredging in the open water of West Bay, where the littoral drift of bay waters is generally westerly, be placed in mounds on the west side of the channel and at least 303.3 m from the low-water shoreline. The developer was receptive to our recommendations which were generally reflected in his permit application to the Corps.

If fishery resources dependent upon the estuaries are to be preserved or even improved in some cases, a basis is needed for evaluating the detrimental influences of water-resource-development projects upon the estuaries. One way of achieving this goal is to develop comparable appraisals of the Texas estuaries that accurately describe present conditions and indicate direct and indirect value to marine fisheries. An inventory of Texas estuaries, such as one currently being completed by this Program, is one method of compiling such information. This inventory is further enhanced through paralleling efforts of other Gulf states using standardized methods developed by representatives of the individual states for compiling results of the study.

In addition to serving the interests of conservation agencies, the resultant Gulf of Mexico Estuarine Inventory-Texas will be of value to other groups as well. For example, legislators and government officials at local State and Federal levels could refer to the publication in formulating coastal zone management laws and policies relative to the Texas estuaries.

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