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Since 1959, the NMFS laboratory in Galveston has conducted pioneering shrimp research: today its primary emphasis in on culture and population dynamics.

Shrimp Research at the Galveston Laboratory of the Gulf Coastal Fisheries Center

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Shrimp are today the most valuable marine species harvested from U.S. coastal waters by commercial fishermen. Of the yearly total landings, which amounted to an estimated 234.1 million pounds (heads-off) valued at $190.6 million in 1972, approximately 61 percent by volume or 87 percent by value was harvested from waters of the Gulf of Mexico. Three species of shrimp belonging to the family Penaeidae comprise the bulk of the landings from Gulf waters. They are the white (*Penaeus setiferus*), brown (*P. aztecus*), and pink (*P. duorarum*) shrimp.

Shrimp have not always been the most sought after marine organisms by Gulf of Mexico fishermen. Over the years, oysters, mullet, and red snapper at one time or another dominated commercial landings in the expanding Gulf fishing industry. However, with the construction of larger vessels and the replacement of shrimp seines and net by the otter trawl around 1915, the shrimping industry underwent considerable expansion.

The growth of this already expanding industry was increased even more in the years that followed as new concentrations of shrimp were discovered in the Gulf. Large numbers of white shrimp were discovered off Louisiana in 1936, and concentrations of brown shrimp were found off Texas in 1947. Continued exploration revealed brown shrimp in waters off Alabama, Louisiana, and Mississippi, and in 1949 pink shrimp were discovered in high concentrations on the Tortugas grounds off the southern tip of Florida. Only one year later—1950—large numbers of brown and white shrimp were discovered on the Campeche grounds in the southwestern Gulf.

Paralleling the growth of the shrimp fishery in the Gulf of Mexico was Federal involvement in biological research. As early as 1929 a small laboratory was established at Offatts Bayou in Galveston, Texas, for the principal purpose of studying marine fisheries and particularly the ecology of oysters. Little time passed, however, before the emphasis was shifted to shrimp, and an investigation of the South Atlantic and Gulf of Mexico shrimp fishery was initiated. Headquartered in Louisiana and Georgia, research on white shrimp was carried on at several locations.

In 1950, the Galveston Laboratory (Figure 1) was established, and a cooperative study with Texas A&M University was begun on the fisheries and oceanography of the Gulf of Mexico. Several years later emphasis was placed on "red tides" that resulted in massive fish kills throughout the Gulf, and it was not until 1959 that shrimp research was reemphasized. Since that time extensive studies have been undertaken on shrimp population dynamics, life histories, and physiology and behavior with the sole purpose of promoting efficient management and utilization of this valuable natural resource. General highlights of the research completed at the Galveston Laboratory during the 1960's are as follows.

SHRIMP POPULATION DYNAMICS STUDIES

One of the primary thrusts of these studies has been mark-recapture experiments designed to provide information on shrimp movement, growth, and mortality. This information is essential to those individuals responsible for managing this natural resource. To conduct these studies, NMFS biologists caught shrimp on the fishing grounds, measured and grouped them according to length, and marked or tagged them by techniques developed in the laboratory. The shrimp were then released on the fishing grounds, and those subsequently recaptured by fishermen were returned to the biologists with information on time and place of capture. A reward was paid for the return of each shrimp.

From studies of this type, biologists have been able to determine movements of the pink shrimp in waters west of Florida (Figure 2), white shrimp along the coast of Louisiana (Figure 3), and brown shrimp along the Texas coast. Estimates of mortality and growth have also been determined, but results are highly variable, not only between species but also within a species (Table 1). Causes for the variation bebetween mortality estimates are not known, but one of several factors that are highly suspect has been the types of tags or marks used and their effects on the shrimp. Consequently, tag improvement has been a continual process throughout the years.

A second major thrust has been the development and refinement of techniques to predict the abundance of brown shrimp in offshore Texas waters (Figure 4). This work, initiated in the early 1960's, consisted of developing abundance indices of young shrimp as they enter Galveston Bay and also juvenile shrimp that enter the bait fish fishery. Analyses of this information re-

Figure 1.—The NMFS Gulf Coastal Fisheries Center Galveston Laboratory has been the focal point for biological research on shrimp stocks in the Gulf of Mexico since 1959.

vealed that the abundance indices for postlarvae and juveniles reflected the size of the offshore harvest 2 to 4 months before the shrimp moved offshore. Of considerable value to the shrimping industry, this information is now made available to interested parties as it is being collected in the form of an informational bulletin.

LIFE HISTORY STUDIES

Prior to 1960 much of the research on the life history of shrimp dealt with either juvenile shrimp in estuarine waters or adult shrimp on the offshore fishing grounds. Little was known about the distribution and abundance of the newly hatched shrimp, called larvae, in offshore waters. Consequently, early life history studies received a considerable amount of attention in the 1960's.

This work entailed systematic sampling of waters off Florida and in the northwestern Gulf of Mexico with fine mesh nets. Use of fine mesh nets was essential, for the newly hatched shrimp are microscopic, free floating, and part of the plankton. The work in Florida waters was conducted under a Bureau of Commercial Fisheries contract with the University of Miami and that in the northwestern Gulf by personnel at the Galveston Laboratory. Time-consuming and arduous, this task resulted in biologists determining the seasonal abundance and distribution of newly

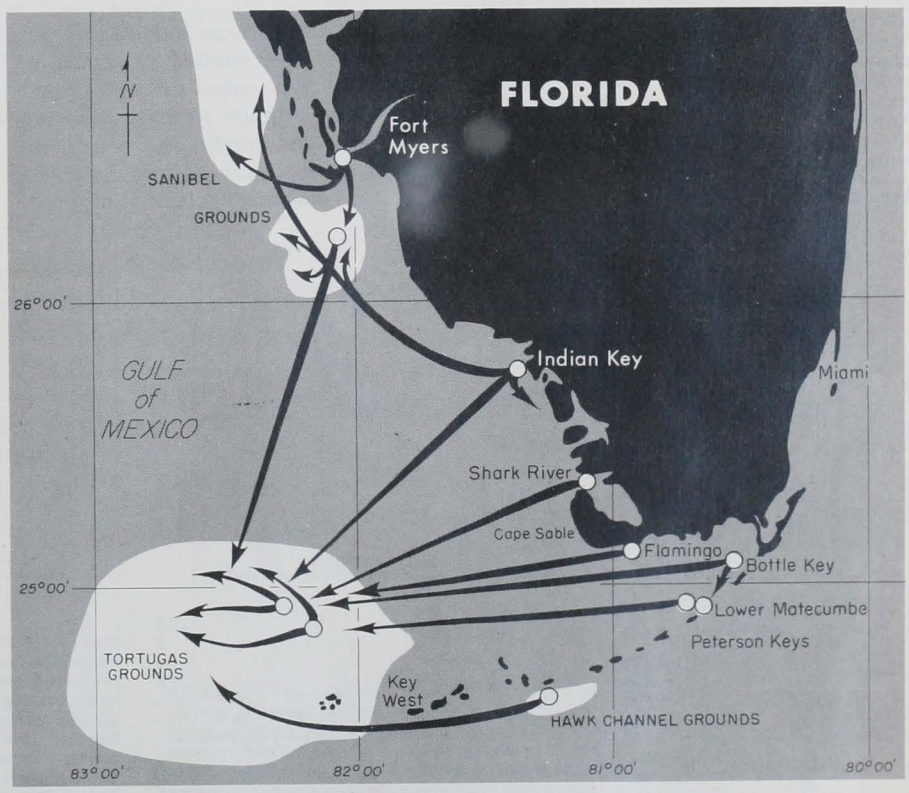

Figure 2.—The movement of pink shrimp in the waters of south Florida was documented by NMFS biologists between 1958 and 1963. Juvenile shrimp migrated as much as 150 nautical miles to the fishing grounds. The open circles show the site of the release of the marked shrimp, the arrows the possible migration routes to the recovery areas, and the tips of the arrows the point of recovery of the marked shrimp. On the east coast of Florida, all marked shrimp were found near the release site only. (Adapted from Figure 2, Costello and Allen, 1966.)

Table 1.—Weekly instantaneous rates of fishing (F), natural (M), and total mortality (Z), and growth (K) from mark-recapture studies of *Penaeus* off the southern United States (Modified from Berry, 1969).

Shrimp	F	M	Z	K	Reference
Pink (*P. duorarum*)	0.96	0.55	0.76,1.51	0.07	Kutkuhn (1966)
Pink (*P. duorarum*)	0.16-0.23	0.02-0.06	0.22-0.27	0.04-0.06	Berry (1967)
Pink (*P. duorarum*)	0.03,0.07	0.08,0.11	0.11,0.18	—	Costello and Allen (1968)
White (*P. setiferus*)	—	—	0.46	0.12	Klima (1964)
White (*P. setiferus*)	0.06-0.19	0.08	0.14-0.27	0.09[1]	Klima and Benigno (1965)
Brown (*P. aztecus*)	0.06	0.21	0.27	—	Klima (1964)

[1]Estimate of K not included in published material.

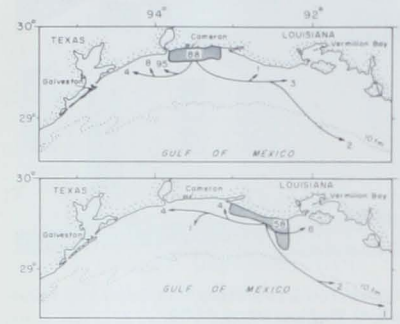

Figure 3.—Marked white shrimp released off the coast of Louisiana on September 2, 1962 moved laterally along the coast and into deeper areas. The last recovery was in March 1963. The top figure shows the movements of white shrimp released off Cameron; most of the recoveries (88) were in the Cameron area or nearby, but two shrimp moved east to south of Vermillion Bay. Of the shrimp released near Vermillion Bay (bottom figure), again most were recaptured near the point of release, but a few moved several miles away. (Adapted from Klima, 1964, Figure 3.)

hatched shrimp in the respective areas (Figures 5 and 6).

Complementing this effort were hydrographic studies designed to increase the biologist's knowledge of the environment in which the young shrimp spend the first few weeks of their life. Water temperatures were measured throughout the entire water column by bathythermographs, and salinities were recorded at preselected depths from water samples collected with Nansen bottles.

In addition, surface and bottom water currents were studied by depositing drift bottles and seabed drifters, respectively, in an attempt to learn how currents might or might not affect the movement of young shrimp from the offshore spawning grounds into the estuarine nursery areas. In southwestern Florida waters, for example, it was hypothesized from results obtained that the movement of young pink shrimp might be south off the Tortugas spawning grounds into the Florida Straits and then up the east coast and into the nursery grounds around the Florida Keys (Figure 7).

Another study closely related to life history research was an intensive examination of sediment types over the continental shelf. Samples of bottom sediments were collected systematically from an area bounded by the U.S.-Mexico border on the west and Key West, Florida, on the east. Analyses of these data revealed a marked difference between sediments in the eastern and western Gulf, and the distribution of pink shrimp in Florida waters appeared related to sediments with high organic matter (Grady, 1971).

PHYSIOLOGICAL AND BEHAVIORAL STUDIES

To complement observations made in field studies, extensive research was undertaken in the laboratory under controlled conditions to determine the physiological requirements of shrimp. Such information, although basic in nature, was of considerable value in understanding the behavior of wild shrimp.

By carefully controlled studies, biologists at the Galveston Laboratory learned that each of the three species—white, brown, and pink—responded differently to environmental factors such as salinity and temperature. In general, white shrimp preferred lower salinities, brown shrimp intermediate, and pink shrimp the higher salinities. Furthermore, it was discovered that the young of each species, i.e., postlarvae and juveniles, could tolerate a much wider range of salinities than could the older

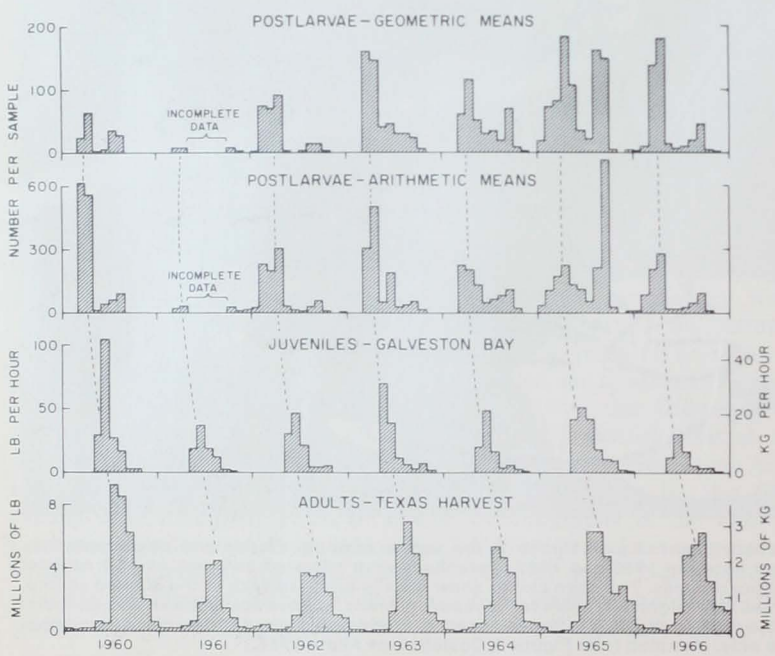

Figure 4.—The size of the brown shrimp crop harvested yearly off the Texas coast can be predicted from abundance indices of postlarvae entering Galveston Bay as well as from indices of juvenile shrimp taken in the bait fishery. This figure shows the abundance of brown shrimp at the postlarval, juvenile, and adult stages by month, 1960-66. Predictions based on postlarval indices are available to the shrimp industry 4 to 6 weeks sooner than those from the catches of juvenile shrimp. The dotted lines indicate this, by showing the time elapsing between the appearance of peak postlarval catches and high catches of adult stages. (Berry and Baxter, 1969, Figure 13.)

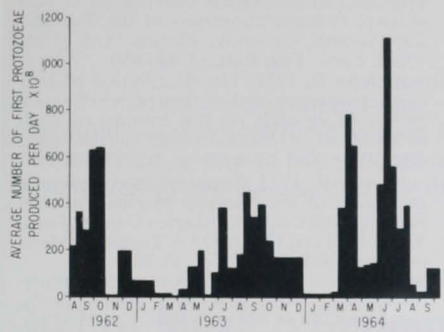

Figure 5.—Towing fine mesh nets from research vessels, personnel at the Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, determined the seasonal abundance of larval (protozoeal) pink shrimp in south Florida waters. This work was completed under a Bureau of Commercial Fisheries contract negotiated through the Galveston Laboratory. At this early stage in their life history, shrimp exist in astronomical numbers. The authors estimate that the annual production on these grounds of first protozoae is on the order of 8,700 billion of the tiny creatures. (From Munro, Jones, and Dimitriou, 1968, Figure 2.)

shrimp. Salinity tolerance apparently decreased with an increase in age!

Laboratory experiments also revealed the effect temperature has on the growth of shrimp. The growth rate of both brown and white shrimp increased rapidly between 15° and 20°C, but at higher temperatures differences were noted between species. Between 20° and 25°C the growth of brown shrimp postlarvae decreased somewhat and stopped at 35°C. White shrimp, however, continued to grow rapidly, at least in temperatures as high as 32°C. This information, applied to field observations of adult shrimp, may explain why white shrimp remain in nearshore Gulf waters in the summer months during periods of high water temperature whereas brown shrimp move offshore to cooler waters.

Differences also were noted between brown and white shrimp at low water temperatures. It was clearly documented that brown shrimp postlarvae could tolerate lower temperatures than could white shrimp postlarvae. Furthermore, it was demonstrated that at 11°C, temperatures of nearshore Gulf waters during the winter, postlarvae of the brown shrimp could survive for at least 1 month yet grow very little. Lower temperatures, initiating a protective response, caused brown shrimp young to bury in the sediments. This survival at low temperatures and the burying response suggest the capability of brown shrimp spawned in fall to overwinter in nearshore waters of the Gulf before entering the estuaries in the spring.

TODAY'S RESEARCH

Over the past 4 years, research programs at the Galveston Laboratory have undergone considerable consolidation and streamlining. Today there are two major investigations, one dealing with shrimp aquaculture (see Neal, "Progress Toward Shrimp Farming in the United States," in this number) and the second with shrimp population dynamics (see Caillouet and Baxter, "Gulf of Mexico Shrimp Resource Research," in this number).

The aquaculture research actually had its origin with the early life history studies. Larval shrimp collected in fine mesh nets could not be identified. Consequently, biologists undertook the task of raising shrimp from known parents in small numbers for descriptive purposes only. As a result of this early work, interest was kindled in the possibilities of shrimp farming and today extensive studies are underway to determine the feasibility of shrimp aquaculture in the United States.

Growth of the shrimp fishing industry, although most rapid in the 1930's and 1940's, has not stopped. Within the past 10 years there has been a gradual shift to larger, more powerful shrimp trawlers capable of towing two 70-foot trawls rather than two 40-foot trawls as

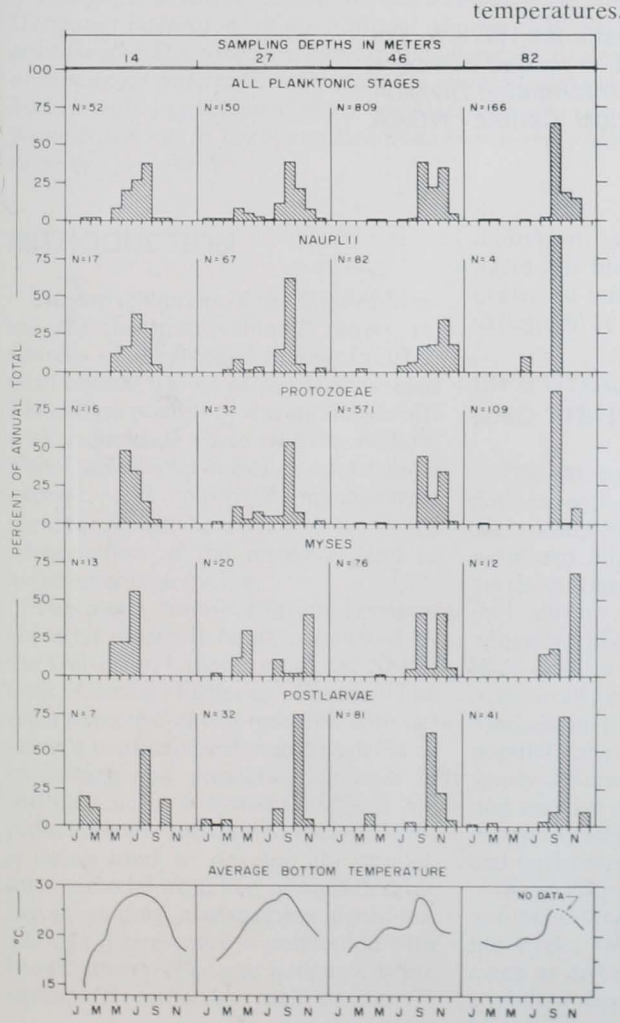

Figure 6.—The seasonal abundance trends of young or larval shrimp *(Penaeus* spp.) as related to depths and water temperatures were determined by intensive sampling of waters off the Texas coast. In general, peak abundance was attained at a progressively later time in the year with an increase in water depth. In addition, observed increases in abundance and increases in temperature of bottom waters at each depth were closely parallel, suggesting a possible direct relation. (From Temple and Fischer, 1967, Figure 4.)

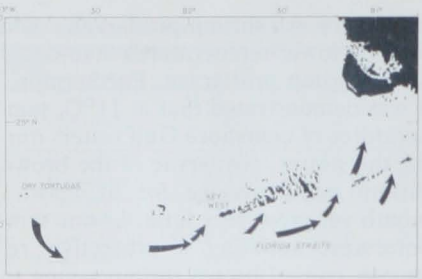

Figure 7.—Studying young or larval pink shrimp in the waters off southwestern Florida, personnel at the University of Miami, on the basis of estimates of shrimp abundance and measurements of the ocean currents, hypothesized that the young shrimp, found most plentifully near the Dry Tortugas, entered the nursery areas of south Florida waters by an indirect route (black arrows). (Adapted from Munro, Jones, and Dimitriou, 1968, Figure 10.)

in the past. Clearly the unit of effort has changed, and its effect on the shrimp populations must be clearly understood if the stocks are to be managed properly. As a result, shrimp population dynamic research, i.e., studies on shrimp fishing and natural mortality, movement, and growth, have been reinitiated at the Galveston Laboratory.

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