THE BIOLOGY OF THE SPOT, Leiostomus xanthurus Lacepede, AND ATLANTIC CROAKER, Micropogon undulatus (Linnaeus), IN TWO GULF OF MEXICO NURSERY AREAS

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ABSTRACT

The distribution of spot and Atlantic croaker in the vicinity of Lake Borgne, Louisiana and Galveston Bay, Texas was determined in relation to temperature, salinity, and certain hydrographic features. Geographic variations in spawning, growth rates, distribution and food habits were evaluated. Length-weight relationships were compared between the two areas, and in Galveston Bay, condition of fish was studied in relation to size of fish, habitat, season, temperature, and salinity.

Based on the appearance of postlarvae, the spawning period for spot was of short duration, extending from December through January in the vicinity of Lake Borgne, and from January through March off Galveston Bay. Growth of young-of-the-year differed in the two areas and within successive year classes in Galveston Bay. Young spot utilized these areas as nursery habitat from postlarvae through late juvenile stages and generally migrated back to the Gulf by August before reaching a total length of 80 mm. They were usually concentrated in shallow waters less than 1.2 m deep which received run-off directly from marshes or tidal flats. The bottom in these areas was soft mud containing large quantities of detritus. These waters probably offered a greater food supply

than was available in other areas as well as protection from predators. Spot were year-round inhabitants of both study areas and were collected in temperatures ranging from 1.2 to 35.5 C. Young were well adapted to temperatures in the 6 to 20 C range, but fish approaching 1 year or older were noticeably absent at temperatures below 10 C. The appearance of postlarvae each spring followed shortly after the spring temperature rise and suggested that this temperature rise may have triggered immigration from the Gulf. Spot exhibited a broad salinity tolerance. They were collected in abundance in salinities ranging from 1.2 to 34.8°/$_{oo}$ and it was concluded that salinity per se had little effect on their distribution. The diet of spot differed in the two areas and indicated, since spot are not selective feeders, a variation in available food. Spot in the Lake Borgne area grew at a faster rate than those in Galveston Bay. This difference in growth may have resulted from differences in available food in the two areas. The magnitude of the condition factors (K and K_b) for spot in Galveston Bay increased with increasing size of fish, and K_b increased with increasing temperature. Spot were in better condition during the period from March through August than at other times of the year. Condition also varied between nursery areas within the Bay.

Based on the appearance of postlarvae, the spawning period for croaker extended from October or November through April or June in Louisiana and Texas waters. Young-of-the-year in the Lake Borgne area grew at a faster rate than those in Galveston Bay. Growth also varied between successive years in Galveston Bay. Young croaker utilized these study areas as nursery habitat from postlarvae through late juvenile stages and generally migrated back to the Gulf by July before reaching a total length of 80 or 90 mm. They were usually concentrated in shallow waters less than 1.2 m deep and in close proximity to a source of fresh or brackish water which generally flowed through marshes, deltas or over tidal flats before entering the bay. The bottom in these areas was generally soft mud, containing large quantities of detritus. The young fish probably preferred these areas because they afforded a greater food supply and protection from predators. Croaker were year-round inhabitants of both study areas and were collected in temperatures ranging from 0.4 to 35.5 C. Young were well adapted to temperatures in the 6 to 20 C range, but fish approaching 1 year or older were noticeably absent in temperatures below 10 C. The variation of temperature with size of fish roughly described a sigmoid curve in both study areas. Croaker exhibited a broad salinity tolerance. They were collected in abundance in salinities ranging from 0.2 to 35.1°/oo and it was concluded that salinity *per se* had little effect on their distribution. There was close

correlation in the diet of young croaker in the two study areas, but little correlation in the diet of intermediate size fish. Since croaker are not selective feeders, these findings were interpreted to reflect availability of food and indicated that food items available to young fish were essentially the same, whereas those available to the intermediate size differed significantly. Differences in available food may account for the differences in growth rates observed in the two areas. The magnitude of the condition factors (K and K_b) for croaker in Galveston Bay increased with increasing size of fish and increasing salinity. Both condition factors were higher during the cooler months, January through April and November and December, than at other times of the year.

Spot and croaker were found to be in direct competition for food in both study areas. The degree to which this competition affects the abundance of these species is not known. In the Lake Borgne area, spot were more abundant than croakers in subarea III, abundance was about equal in subarea II, and croaker were more abundant than spot in subarea I. The number and biomass of croaker in Galveston Bay far exceeded that of spot throughout the system. It was not possible to detect the factors responsible for these differences, but availability of food must surely have been involved.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to personnel of the Bureau of Commercial Fisheries, Galveston, Texas and to those in the Departments of Oceanography and Wildlife Science of Texas A&M University who assisted him in collecting, processing, and tabulating the data used in this study. Most especially he is indebted to Messrs. Royce Jurries, Cornelius Mock, Fred Murray, Jack Pullen, and Gilbert Zamora and Mrs. Genevieve Adams.

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INTRODUCTION

The spot, Leiostomus xanthurus Lacépède, and the Atlantic croaker, Micropogon undulatus (Linnaeus) are two of the more abundant fish species inhabiting the coastal waters of the Gulf of Mexico. Because of their abundance they undoubtedly play an important role in the trophic dynamics of their habitat. They have been grouped together for study because they have similar seasonal distributions and life histories. They are bottom dwellers who range from the New England coast south to the Yucatan Peninsula to depths of over 100 fathoms. Both species spawn during the winter and early spring at sea in close access to the nursery areas. The young move directly into bays and lagoons using these shallow, nutrient-rich waters during postlarval and juvenile development. The adults reside primarily at sea.

Considerable information relating to seasonal abundance, length frequency distribution, size at maturity and range of occurrence at temperatures and salinities has been collected for these species from both the Atlantic and Gulf coasts. Most data are included in general surveys of the habits of a wide variety of fishes found in a particular region. The most comprehensive study of this type is that of Gunter (1945) on the middle Texas coast.

Citations follow the style of Transactions of the American Fisheries Society.

Additional information of a similar type has been presented for both species on the Mexico coast by Darnell (1962); on the Texas coast by Baldauf (1953, 1954), Reid (1955A, 1955B, 1956, 1957), Breuer (1957), Chambers and Sparks (1959), Simmons and Hoese (1959), Arnold, Wheeler, and Baxter (1960), Hoese (1960) Breuer (1962), and Parker (1965); on the Louisiana and Mississippi coasts by Gunter (1938), Christmas, Gunter, and Whatley (1960), El-Sayed (1961) and Rounsefell (1964); on the Florida coast by Dawson (1953), Ingle and Dawson (1953), Reid (1954), Kilby (1955), and Springer and Woodburn (1960); and on the Virginia coast by Raney and Massmann (1953), and Massmann (1954).

Other papers deal with more specific aspects of the biology of these fishes. The development and life history of both the spot and Atlantic croaker have been studied on the Atlantic coast by Welsh and Breder (1923), in Chesapeake Bay by Hildebrand and Schroeder (1928), in Texas in Pearson (1929) and at Beaufort, North Carolina by Hildebrand and Cable (1930). Wallace (1940) described the sexual development of the Atlantic croaker. Roelofs (1954) examined the food of young spot and Atlantic croaker from North Carolina. Suttkus (1955) studied the seasonal movements and growth of the Atlantic croaker along the east Louisiana coast. Townsend (1956) studied general aspects of the biology of the spot in Alligator Harbor, Florida. Haven (1957) commented on the distribution, growth and availability of juvenile croaker in Virginia. Pacheco (1957) noted the length and age composition of spot in lower

Chesapeake Bay. Darnell (1958) conducted a study of the food habits of both the spot and Atlantic croaker in Lake Pontchartrain, Louisiana. Dawson (1958) studied the biology and life history of the spot in South Carolina. Massmann and Pacheco (1960) noted the disappearance of young Atlantic croaker from presumably polluted waters of the York River, Virginia. Sundararaj (1960) reported on the age and growth of spot in Lake Pontchartrain, Louisiana. Dawson (1965) presented the length-weight relationships of the spot and Atlantic croaker from the Louisiana and Mississippi coasts. Dovel (1968) discussed the possible influence of predation by striped bass on the population size of Atlantic croaker in Chesapeake Bay. Avault et al. (1969) studied the growth, survival, food habits, and sexual development of Atlantic croaker in brackish water ponds in Louisiana. Hansen (1970) studied the food, growth, migration, reproduction and abundance of Atlantic croakers near Pensacola, Florida. Diener and Inglis (personal communication) studied the food habits of the spot and Atlantic croaker in Clear Lake, Texas, on Galveston Bay.

Much, however, remains to be known of the requirements of these fishes, particularly within the estuaries. It has been established in the foregoing studies that the young of both species are abundant throughout all bay systems of the Gulf and lower Atlantic coasts, ranging even into the fresh waters of the river deltas. The factors regulating distribution within the estuaries, however, are not clearly understood. Two typical estuaries which

support large populations of both species are the Lake Borgne area, Louisiana and Galveston Bay, Texas. The purpose of this paper is to present the findings of rather extensive trawl and hydrological surveys in these two areas as they pertain to the spot and Atlantic croaker.

The Lake Borgne area was surveyed from July, 1959 through March, 1961 by the Department of Oceanography, Texas A&M University through a contract by the Texas A&M Research Foundation with the U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries. This study was the result of a U. S. Army Corps of Engineers project to construct a navigational channel (Mississippi River Gulf-Outlet Canal) from the industrial area of New Orleans to the Gulf of Mexico. The channel, which is now completed, transects valuable fish and wildlife habitat in the eastern Mississippi River Delta. In order to determine the effects of this channel on both the fish and wildlife resources and the hydrology of the area, the Fish and Wildlife Service decided to conduct a survey of the area before and after construction of the channel. The data for this paper were collected before construction of the channel. El-Sayed (1961) and Rounsefell (1964) both discuss various aspects of the preconstruction survey and the information presented here is intended to add to their findings.

Galveston Bay was surveyed from January, 1963 through December, 1965 by the U. S. Fish and Wildlife Service, Bureau of Commercial

Fisheries. The intent of their study was to provide rather detailed information on the relative abundance and distribution of bottom fauna.

A marsh area adjacent to West Galveston Bay was surveyed from September, 1967 through November, 1969 by the Department of Wildlife Science, Texas A&M University. This study was intended to identify the macro-fauna inhabiting the marsh and the factors affecting their distribution to help evaluate changes resulting from water management for mariculture. Data from this survey were used to determine the extent to which spot and Atlantic croaker utilize the saline marshes.

The author participated in all three projects. The data pertaining to the spot and Atlantic croaker were made available to him through the courtesy of the Bureau of Commercial Fisheries at Galveston, Texas, and the Department of Wildlife Science, Texas A&M University.

The objectives of this study are to (1) determine the distribution of spot and Atlantic croaker in the Lake Borgne area, Louisiana and Galveston Bay, Texas, (2) determine the extent to which distribution was related to temperature, salinity and certain hydrographic features of the areas, (3) evaluate geographic variations in distribution by comparing findings in the two areas, (4) compare the food habits of these species in the two areas by comparing the findings of Darnell (1958) from Lake Pontchartrain, Louisiana with those of Diener and Inglis (personal communication)

from Clear Lake, Texas, and (5) determine the length-weight relationships of these fishes and examine factors affecting their condition based on data collected in Galveston Bay in 1963.

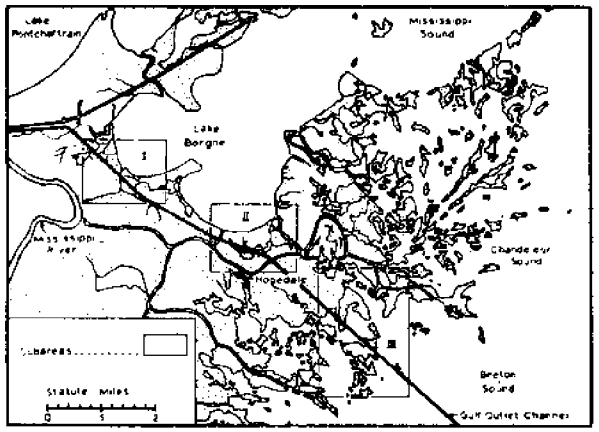
DESCRIPTION OF THE AREAS

Lake Borgne Area

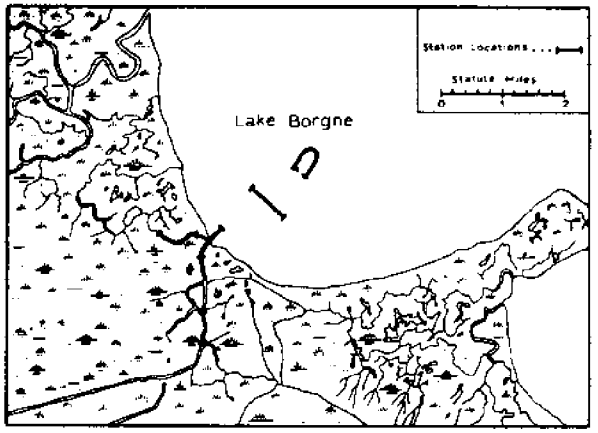
This study area (Figure 1A) was located in Saint Bernard Parish on the southeastern Louisiana coast and encompassed an estuary spreading from the brackish waters of Lake Borgne to the predominantly marine environment of Breton Sound. Fresh water was supplied to this area directly from the Pearl River which discharged into the northeastern end of Lake Borgne and indirectly from the Mississippi River which emptied in the Gulf just to the south. The region consisted primarily of coastal marshes, bayous, lakes and sounds. The waters were highly turbid, shallow (rarely exceeding 3 m in depth) and the bottoms relatively flat.

Based on the presumed salinity gradient of the area, three subareas, or complexes, were selected for study. Subarea I (Figure 1B) was presumably characterized by waters of low salinity, subarea II (Figure 1C) by waters of moderate salinity, and subarea III (Figure 1D) by waters of high salinity.

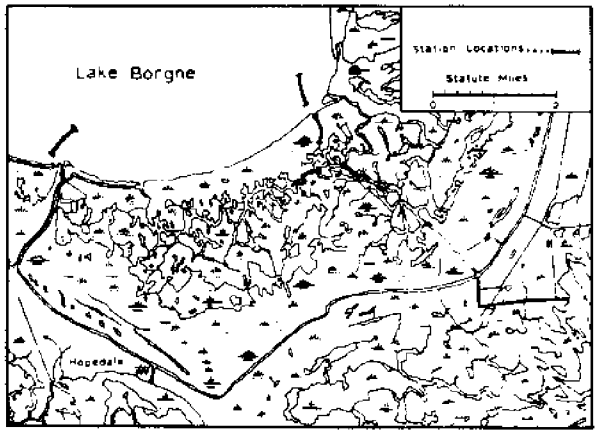
This area lay just south of the city of New Orleans and was relatively undisturbed by man. Prior to construction of the Mississippi River Gulf-Outlet Canal, the area was influenced little by the discharge of industrial wastes and domestic sewage from New Orleans. However, it was anticipated that this influence would increase with a navigational canal leading directly to the city. In addition, it was anticipated that the canal would also have an



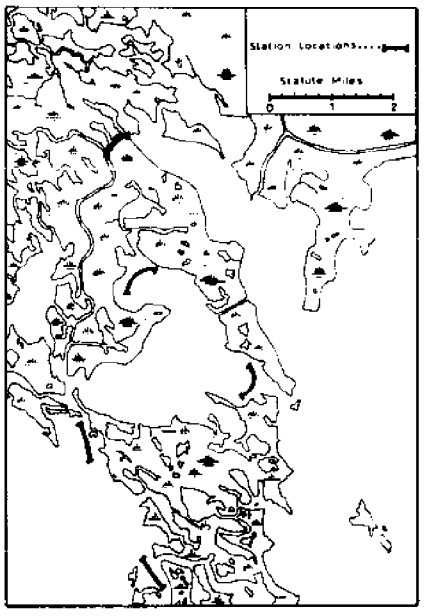
A. Lake Borgne Area



B. Subarea I



C. Subarea II



D. Subarea III

Figure 1. The Lake Borgne, Louisiana study area with the location of sampling stations.

effect on the salinity--probably allowing a salt water wedge to penetrate along the bottom of the canal well into the area.

Galveston Bay System

This study area (Figure 2), located on the upper Texas coast, included about 997 km^2 of the Galveston Bay System in addition to a small portion of the Gulf of Mexico just outside the Galveston jetties. A jettied natural pass (Bolivar Roads) and a small, man-made channel (Rollover Pass) provided access to the Gulf. Most of the fresh water was supplied by the Trinity and San Jacinto Rivers. Of the four major bays within the system--Trinity, Galveston, East and West Bays--only the first three were included within the Bureau of Commercial Fisheries survey. Their descriptions are followed by a description of the West Bay marsh surveyed by the Department of Wildlife Science of Texas A&M University.

Galveston Bay

This was the largest bay within the system. Its waters covered about 997 km^2 and ranged in depth up to 4.9 m (excluding dredged channels). The Houston Ship Channel (12.8 m in depth) extended the length of this bay and provided passage to the City of Houston for ocean-going vessels. Because of its size and because its name is synonymous with that of the system, this bay has been subdivided into upper and lower portions and will be considered accordingly hereafter.

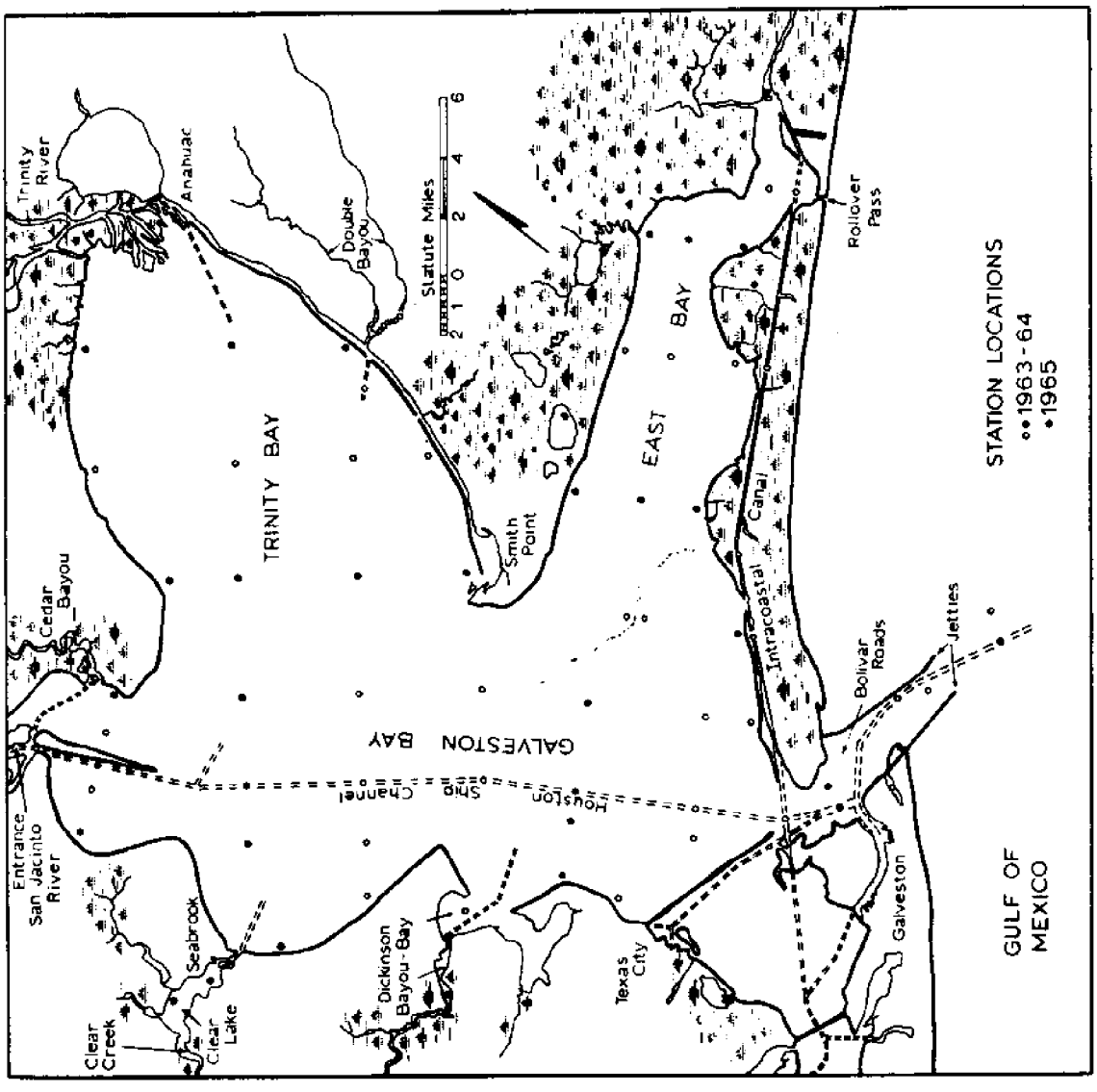


Figure 2. The Galveston Bay, Texas study area with the location of sampling stations.

Upper Galveston Bay covered approximately 250 km^2 and was located in the upper northwest quadrant of the system. The San Jacinto River entered the system at the head of this bay, as did two major streams—Clear Creek and Cedar Bayou. A marsh complex extended along much of the shoreline in the Clear Creek-Clear Lake area and also along the Cedar Bayou shore. The shoreline was heavily populated and highly industrialized. Large volumes of industrial wastes and domestic sewage were continually discharged into these waters and have been informally attributed as the cause of extensive fish kills and mass plankton blooms which occurred commonly during the warmer months. The lower and central portions of this bay have been dredged extensively for mud shell.

Lower Galveston Bay covered about 241 km^2 and was located in the southwest quadrant of the system. Bolivar Roads, which served as a passageway for Galveston and Houston ocean-going shipping, connected it with the Gulf. Dickinson Bayou provided the only direct source of fresh water. A marsh complex extended along the shore of Dickinson Bayou and Bay. This shoreline was also heavily populated and highly industrialized. Pollutants, however, did not build to the high levels found in Upper Galveston Bay, probably because tidal currents provided an effective flushing action. The upper and central portions of this bay have been dredged extensively for mud shell.

Trinity Bay

The waters of this bay covered about 360 km^2 and ranged in depth up to 3.0 m. Fresh water was supplied by the Trinity River and a number of small bayous. A marsh complex encompassed much of the Trinity River delta and also covered a portion of the southeastern shore. A barge canal with a spoil bank separating it from the bay proper extended along the eastern shore from Smith Point to Anahuac. This canal has not been in use for a number of years and has filled with silt to a depth of no more than 1.2 m. Although the shoreline was sparsely populated, an immense oil field had been developed in the bay proper and new wells were continually being drilled. The lower and central portions of this bay have been dredged extensively for mud shell.

East Bay

This bay was located in the southeast quadrant of the system and was a typical coastal lagoon. Its waters covered approximately 132 km^2 and had a maximum depth of 1.2 m. An extensive marsh complex extended along almost the entire shoreline. A number of small, brackish-water bayous flowed from this marsh into the bay. Additional brackish water was supplied to East Bay through the Gulf Intracoastal Waterway which drained much of the marsh area to the northeast. Rollover Pass connected East Bay with the Gulf but the flow, according to Reid (1957), was insignificant compared with that of Bolivar Roads and probably affected only the very

eastern end of the bay. A large, partially exposed oyster reef extended across the mouth of the bay and further reduced tidal currents in the upper bay. The shoreline was sparsely populated and it, as well as the bay proper, had not been appreciably disturbed by man's exploitation of estuarine resources. Shell dredging had been restricted primarily to the mouth of the bay, west of the exposed oyster reef.

West Galveston Bay Marsh

This area constituted a segment of marsh which covered some 121 km^2 on the shore of West Galveston Bay in Brazoria County (Figure 3). The area to which this survey was directed was a flooded basin lying between Hayes Ridge and the Intracoastal Canal spoil bank. It consisted of flooded grasslands surrounding a number of stagnant and tidewater ponds. These ponds seldom exceeded 0.6 m in depth. The highest elevations on Hayes Ridge and the Intracoastal Canal spoil bank were 1.8 and 3.6 m, respectively.

A small bayou carried tidewater into the marsh from Oyster Lake. It narrowed to a shallow ditch of not more than 0.6 m in depth near the location of station A. Its flow was further restricted by vegetation so that no measurable daily tidal fluctuation occurred in Hayes Ridge Lake. All tidewaters, including the lakes and ponds connected by this bayou as well as the bayou on which station B was located were bordered by a natural levee (which reached a height of not more than 0.7 m above mean sea level) that

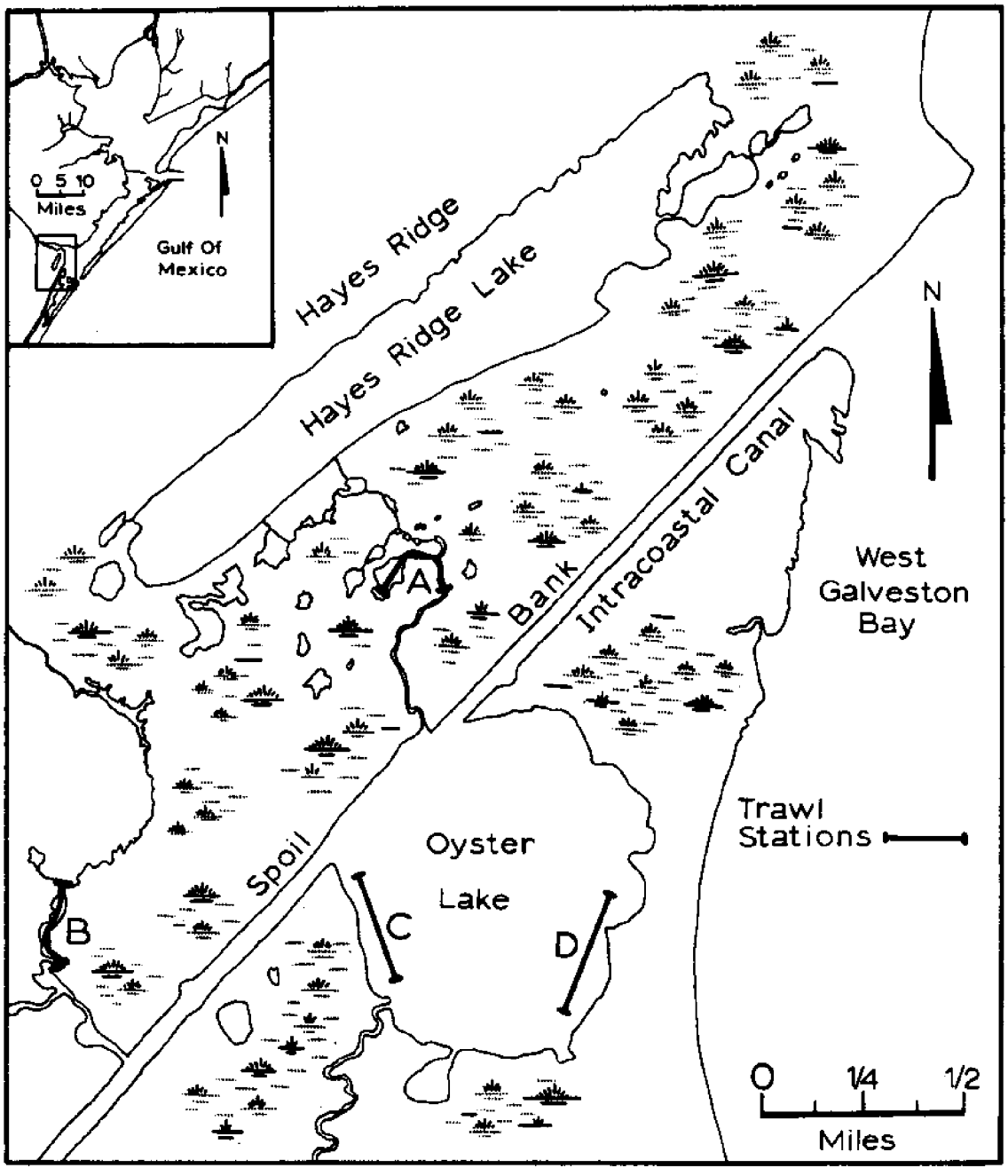


Figure 3. The West Galveston Bay marsh study area with the location of trawl stations.

also restricted tidal flow into the marsh. The flooded marsh behind this levee will be subsequently referred to as the inter-tidal zone.. The bayou on which station B was located drained approximately 40 km^2 to the west of Hayes Ridge and served as a major channel to the Intracoastal Canal for run-off from local rainfall.

METHODS

Lake Borgne Area

Beginning in July, 1959 samples were taken at five stations in each subarea (Figure 1B, 1C, 1D, Page 8). In subareas I and II, two stations were established in an open lake, one in a bayou entrance to an open lake, and two in a bayou. In subarea III, four stations were established in open lakes and one in a bayou. At each station, temperature and salinity were measured and an otter trawl was fished for 10 minutes. The trawl measured 4.9 m between the boards and had 3.8 cm stretched mesh in the body and 3.2 cm stretched mesh in the cod end. Stations were visited once every 10 days through August, 1960 and twice each month thereafter. All stations were generally visited within a 3-day period.

Trawl samples were stored in 10% formalin and returned to Texas A&M University for processing. Spot and Atlantic croaker in each sample were removed, counted, and measured to the nearest mm of total length (tip of the snout to the end of the longest caudal fin ray). In instances where the caudal fin of a specimen was damaged, the length was not taken, but these individuals were included in the total count of the sample.

Temperature was measured with a Celsius thermometer from bucket samples of surface water. Salinity was measured at the bottom with a portable battery-operated conductivity meter. The accuracy of this meter was checked periodically against salinity

determinations by Knudsen's titration method.

Galveston Bay System

Beginning in January, 1963 samples were taken at 65 stations (Figure 2, Page 10) located to monitor the marginal areas of the system (lakes, bayous, marshes, and the Intracoastal Canal), the shores (waters of the bay proper where depth was less than 1.2 m), the open bay, the Houston Ship Channel, the Bolivar Roads Tidal Pass, and the Gulf outside the pass. At each station, bottom temperature and salinity were measured and an otter trawl was fished for 5 minutes. The trawl measured 3.0 m between the boards and had 3.5 cm stretched mesh in the body and 2.5 cm stretched mesh in the cod end. Stations were visited twice each month through February, 1964 and once each month thereafter. The number of stations was reduced to 33 in January, 1965. All stations were generally visited within a 3-day period.

Trawl samples were placed in plastic bags containing 10% ethyl alcohol, stored in ice, and returned to the Bureau of Commercial Fisheries Laboratory at Galveston for processing. The spot and Atlantic croaker in each sample were counted and each specimen was weighed to the nearest 0.1 gram on a Mettler balance (Type K-7, precision ± 0.5 gram). The total weight of each species in a sample was also recorded. Where a large number were present in a sample, a subsample was taken from which the individuals were counted and weighed. The ratio of subsample weight to sample weight

equated the subsample to the sample. These weight measurements constituted the biomass of fish collected at a particular station. On randomly selected fish collected during 1963, both total length and weight were measured. These observations were used to determine the length-weight relationships from which weight was converted to length. In the ensuing presentation, total length was used as the size criterion so that these data could be compared with those from the Lake Borgne area.

Bottom temperature and salinity were measured with a portable battery-operated conductivity meter (precision ± 0.5 C and ± 0.3°/oo). A modification of Knudsen's method of salinity determination (Marvin, Zein-Eldin, May, and Lansford, 1960) was used to check the accuracy of the meter. On occasions when the meter was inoperative, water samples were obtained with a Kemmerer water sampler from which temperature was measured with a Celsius thermometer and salinity by Knudsen's method (modified).

In the West Bay marsh, specimens were collected primarily with an otter trawl of the same dimensions as that used by the Bureau of Commercial Fisheries. Trawls were made once every 2 weeks from October 29, 1967 through October 15, 1968 at two stations in the marsh (A and B in Figure 3, Page 14) and two stations in Oyster Lake (C and D in Figure 3, Page 14). Stations A and B were intended to monitor the deepest marsh penetration of normal tidewaters and stations C and D were intended to represent open bay waters just outside the marsh. At each station, bottom temperature was measured

with a Celsius thermometer, bottom salinity with an A/O optical density instrument, and the trawl was towed behind an airboat for 3 minutes. On occasion, specimens were also collected with cast nets, small seines and rotenone. Specimens were preserved in 10% formalin and returned to Texas A&M University for processing. Spot and Atlantic croaker in each sample were counted and each specimen was measured to the nearest mm total length.

HYDROLOGY

Lake Borgne Area

Temperature

Water temperature in the area varied from a low of 5.2 C in February, 1960 to a high of 34.9 C in July, 1960. No appreciable differences in temperature between subareas were observed. In order to depict the seasonal pattern, the monthly mean temperatures for the entire area are presented in Figure 4.

Salinity

The salinity variation between subareas (Figure 4) was not as distinct as had been initially presumed. Salinities in subarea III, although considerably higher than in the other subareas, were not generally high enough to typify a high saline environment. Salinities in subarea II were slightly higher than in subarea I, but both typified low saline environments. Salinity varied from 0.5 to 6.2°/oo in subarea I, from 0.2 to 15.8°/oo in subarea II, and from 2.2 to 25.4°/oo in subarea III.

No seasonal salinity pattern was evident. Rounsefell (1964) discussed some of the factors regulating salinity and presented the average isohalines of the area (Figure 5) based on 24 months of observations spanning the period of this study. He found that waters from Lake Borgne, circulating through the bayous and canals, exerted the major influence throughout the area. Salinity levels

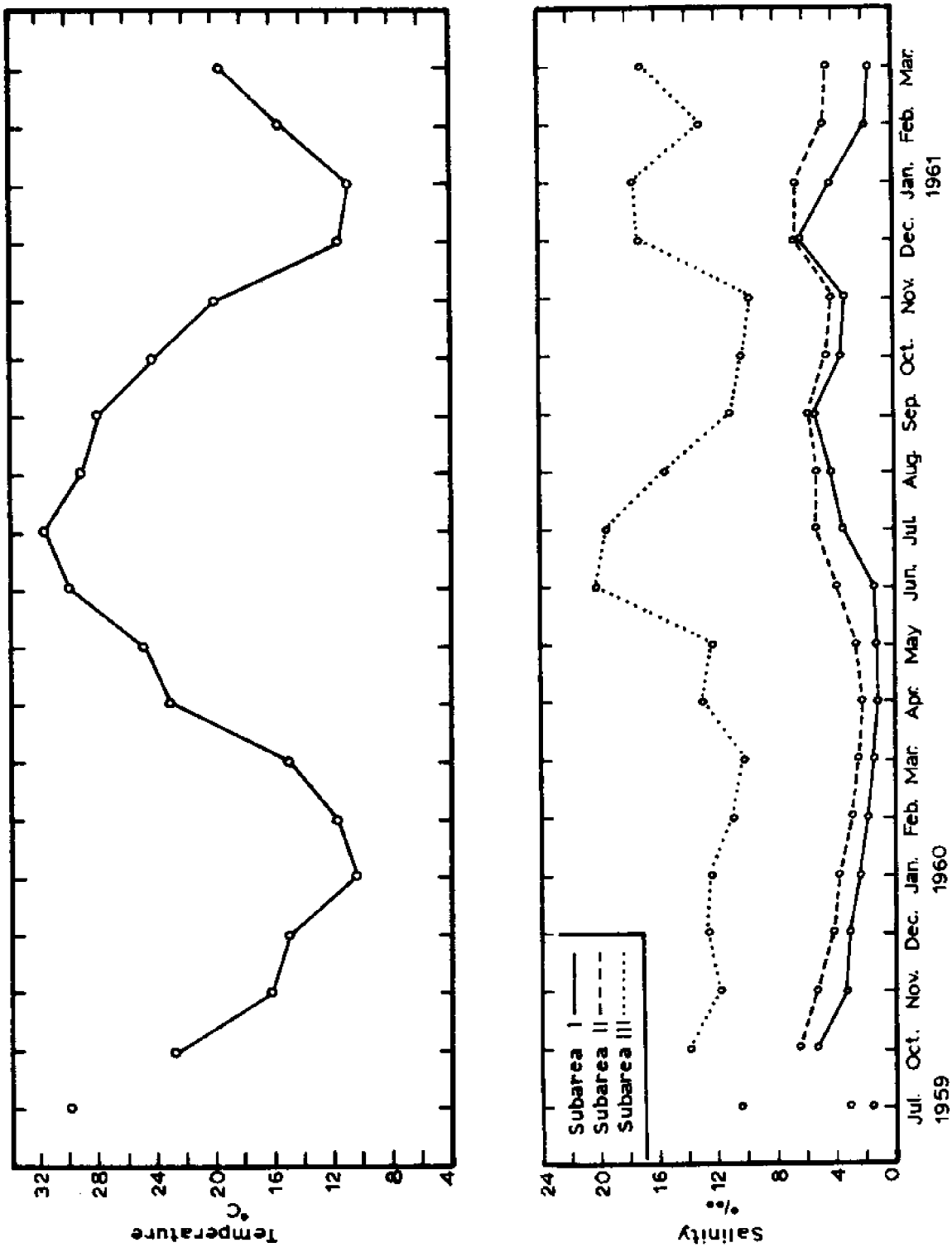


Figure 4. Monthly mean temperatures and salinities in the Lake Borgne area during the period from July, 1959 through March, 1961.

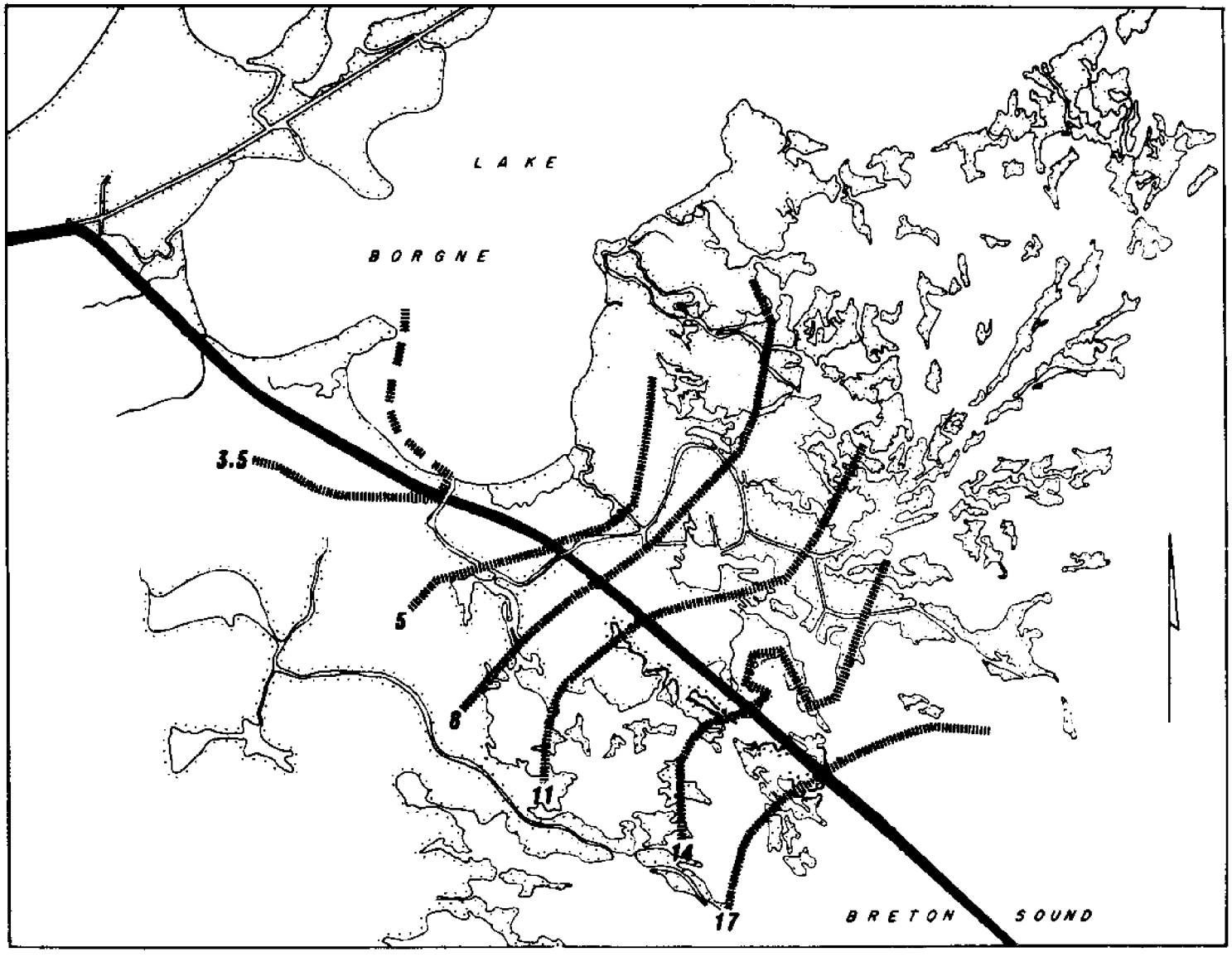


Figure 5. Isohalines in the Lake Borgne area based on averages compiled over the period from April, 1959 through March, 1961 (Reprinted from Rounsefell, 1964).

in Lake Borgne were controlled, in turn, primarily by fresh water from the Pearl River, modified by wind direction and velocity. Salinity levels in Breton Sound were regulated primarily by fresh water from the Mississippi River which suppressed the salinity of sea water circulating into the area from the Gulf.

Galveston Bay

Temperature

Water temperature varied from a low of 0.4 C in January, 1963 to a high of 34.0 C in July, 1963. Both extremes occurred in the marshes of East Bay at the shallowest station. Temperature fluctuations were usually greatest in the shallow waters. In order to depict the seasonal pattern, monthly mean temperatures are presented in Figure 6. The seasonal temperature fluctuations in the West Bay marsh did not add additionally to these data.

Salinity

Salinity in this system varied from a low of $0.2^{o}/oo$ near the mouth of the Trinity River to a high of $36.6^{o}/oo$ at the mouth of the jetties. Salinity was lowered primarily by fresh water from the Trinity River (7.1×10^{9} m^{3} per year[1]) and to a lesser degree by fresh water from the San Jacinto River (1.6×10^{9} m^{3} per year[1]). No consistent seasonal salinity pattern was evident. From the

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[1]U. S. Army Corps of Engineers Hydrographic Survey

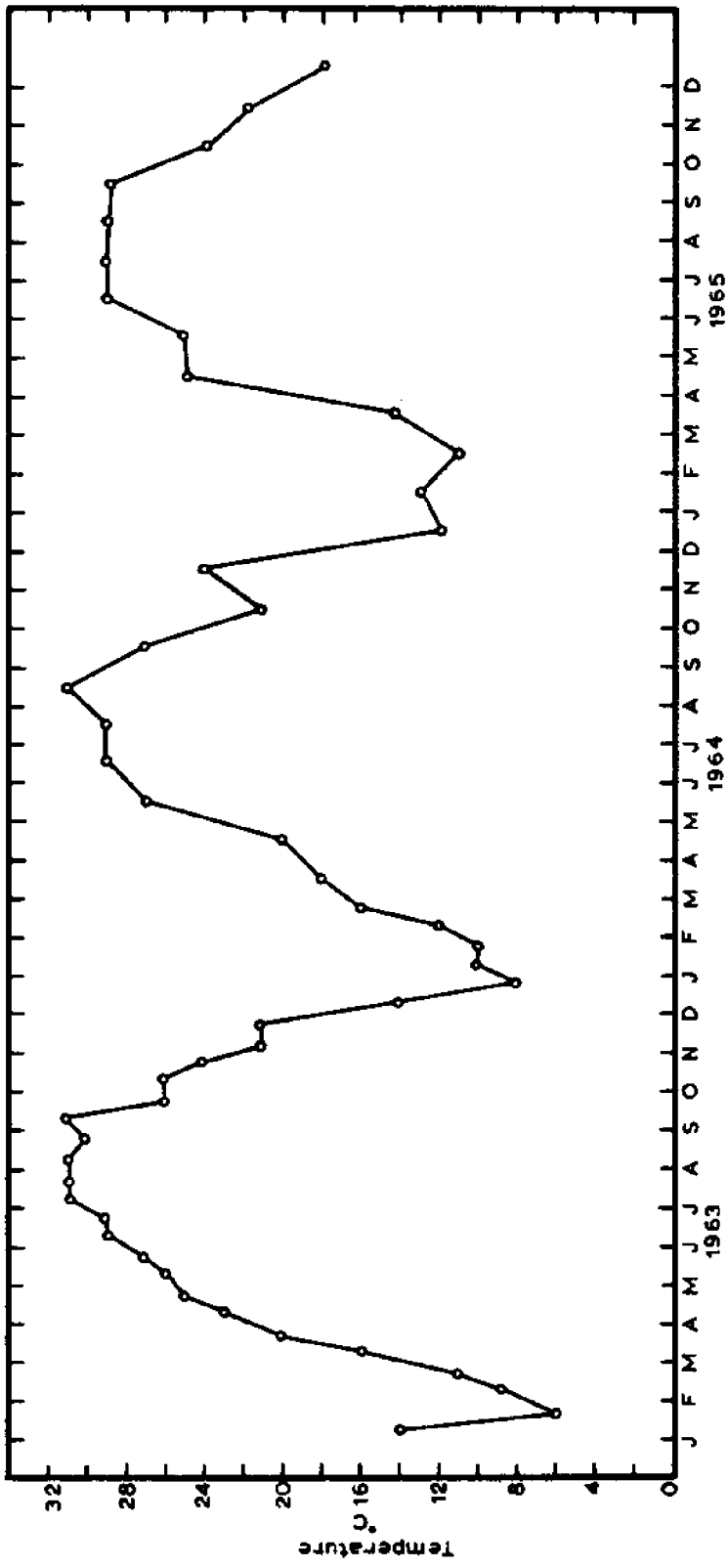

Figure 6. Monthly mean temperatures in Galveston Bay during the period from January, 1963 through December, 1965.

configuration of the mean isohalines compiled from salinities taken over the duration of the survey (Figure 7), four regions could be distinguished, based on a low to high salinity gradient. They were: Trinity Bay whose fresh water source was the Trinity River; Upper Galveston Bay which received fresh water from the San Jacinto River, Clear Creek and Cedar Bayou; Dickinson Bay which received fresh water from Dickinson Bayou; and East Bay which received fresh water drainage from nearby marshes and from the Intracoastal Canal which drained a large marsh complex to the east.

At times, considerable variation was noted between surface and bottom salinities. The most obvious of these occurred in the Houston Ship Channel and in Trinity Bay. In the Houston Ship Channel (12.8 m deep), a wedge of high salinity water was always present on the bottom. The position of the terminus of this wedge appeared to be dependent upon the interaction between the tidal cycle and fresh water from the San Jacinto River. At times, this wedge penetrated from the Gulf up the channel as far as the northeastern end of Upper Galveston Bay. Fresh water from the Trinity River generally extended from the mouth of the river variable distances into Trinity Bay and sometimes beyond, depending on volume of river flow. A rather poorly defined salinity wedge resulted and its position appeared to be dependent on both volume of river flow, tidal cycle, and wind direction and speed.

Saline conditions generally prevailed in the West Bay marsh. Fresh-water flooding from local rainfall was common, but salt

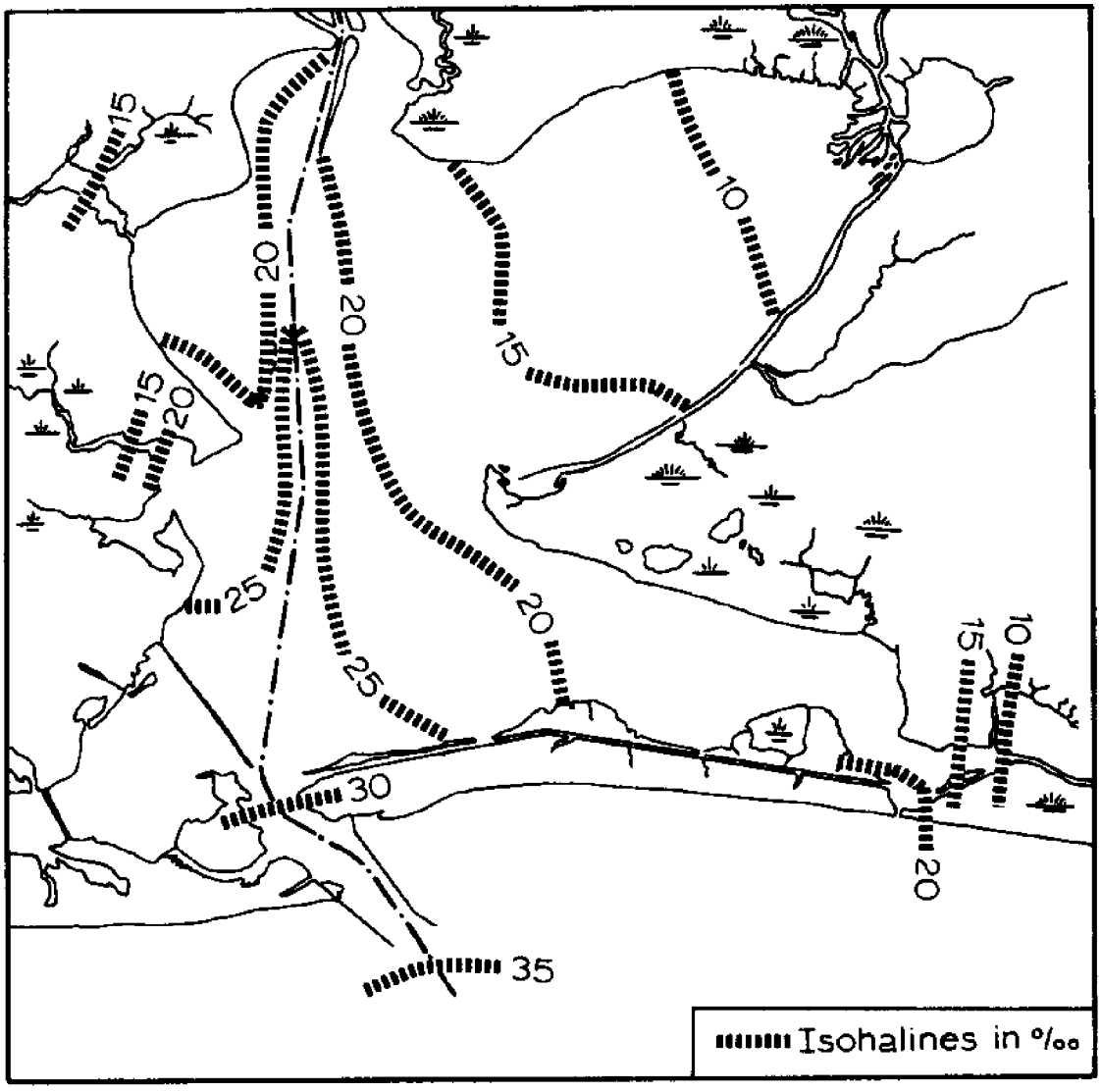

Figure 7. Isohalines in Galveston Bay based on averages of bottom salinities compiled over the period from January, 1963 through December, 1965.

leached from the bottom sediments coupled with subsequent tidal floods readily re-established saline conditions. Salinities ranged from those characteristic of fresh water to 24°/oo in tide waters and from fresh water to 42°/oo in marsh ponds. No consistent salinity gradient was evident.

BIOLOGY OF THE SPOT

Life History

The life history of the spot has been rather well defined. Smith (1907) stated that North Carolina spot spawn in the salt-water sounds and inlets. Pearson (1929) concluded that Texas spot spawn at sea, probably just outside the beachline and presumably near the passes and channel entrances to the estuaries and lagoons. Hildebrand and Cable (1930), Townsend (1956), and Simmons (1957) support the belief that spot do not spawn within the beachline and Dawson (1958) postulated that spawning along the eastern Atlantic coast occurs over the deeper bottoms and at some distance offshore. Spawning occurs during the winter, usually, according to Dawson (1958), reaching its peak during the period from December to February. Shortly after hatching, the young enter the estuaries and lagoons which they utilize as nursery areas. Postlarvae[3] have been reported in the bays as early as November (Hildebrand and Cable, 1930) and December (Pearson, 1929; Simmons, 1957) and as late as April (Welsh and Breder, 1923; Gunter, 1945). The peak influx, however, occurs during the period from January through April. Dawson (1958) believed that the young fish probably remain in the inshore nursery grounds, with local changes in distribution, until the end of their second summer. Those with developing gonads then,

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[3]Postlarvae were considered to be fish with a total length less than 30 mm.

he presumed, began a gradual movement back to sea to spawn. The ultimate fate of spawned-out fish is unknown.

Immigration and Growth

Spot were present in both areas throughout the study periods. A total of 6,778 were collected in the Lake Borgne area, and 16,516 in Galveston Bay. The monthly catches for 10 mm size classes from each area are presented in Tables 1 and 2 respectively.

The monthly length-frequency distributions for spot from the Lake Borgne area are presented in Figure 8. Those fish collected in July, 1959 represented an age-class which probably entered the area as postlarvae during the previous late winter or early spring. A few of this group remained in the area until April, 1960, but it was not possible to predict their growth rate because of the limited numbers collected and the discontinuation of sampling during August and September. Postlarvae were first collected in February, 1960 and this age-class remained in the area through the end of the survey period in March, 1961. According to Dawson's (1958) estimated time of peak spawning, these young spot were probably 1 or 2 months old when they first appeared. Growth of this age-class was evident from February through November. Spot undoubtedly continued to grow after November, 1960 and the apparent leveling off of the growth rate resulted because larger fish either left the area or were able to elude the trawl. The growth rate (based on a linear regression of monthly mean lengths of age-class-0

Table 1. Monthly catch of spot by size classes from the Lake Borgne area.

Total Length mm	1959 July	Oct.	Nov.	Dec.	1960 Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1961 Jan.	Feb.	Mar.	Total
10						92	4													96
20						21	26	2												49
30							20	16	7			2						1		46
40							5	78	64	49										196
50							3	190	303	119	4	1							5	625
60								183	712	133	70	1							11	1110
70	5						1	63	892	478	169	22								1630
80	14							15	285	285	265	111		1		1				977
90	12		2	1				3	65	136	140	146	32	3	1	6	1			548
100	11	1	14	8		1			16	25	35	89	80	30	14	52	1	1	2	380
110		13	33	15		1						21	34	62	72	61	11	12	26	361
120	1	34	27	11	1	3	1					3	10	19	76	35	14	10	52	297
130		37	22	12	1		1	5					2	5	11	27	13	5	35	176
140		9	7	5	1		1	2	3						3	7	3	1	8	50
150			2	2	1									1	1	2	3		7	19
160			2	2			1						2		2	2	3		2	16
170			1	2													2		3	8
180				2														1		3
190				1																1
200																				
Total	43	94	110	61	4	118	63	557	2347	1225	683	396	160	121	180	193	51	31	151	6588

Table 2. Monthly catch of spot by size classes from Galveston Bay.

1963

Total Length mm	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
10				2									2
20				327									327
30		1		335	303	22			2				663
40				16	33	5							54
50				100	434	146	142	5	1	1			829
60	1		1	91	540	374	447	151	32	11	2		1650
70	4	7	1	4	172	232	350	230	124	24	5	134	1287
80	7	21	1		56	112	200	170	41	28	13	87	736
90	27	30	13	1	11	67	121	121	47	26	16	65	545
100	50	22	31	5	1	11	37	42	28	17	15	24	283
110	24	21	40	4	5		6	16	15	13	8	13	165
120	15	4	40	6	8		5	3	3	15	8	18	125
130	7	1	19	6	7		1	2	4	3	3	21	74
140	3		6	11	10	2				5	4	8	49
150	2	1	1	1	12			1		1	1	2	22
160		1		1	8				1	1		1	13
170	1				1	1	1	1					5
180		1						2					3
190					2			2	1				5
200													
210				1				2	1				4
Total	141	110	153	911	1603	972	1310	748	300	145	75	373	6841

1964

Total Length mm	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
10			49								1		50
20			66	212	2								280
30			3	507	848	40	23	4				2	1427
40				5	63		3						71
50				14	378	335	49	21	6	2			805
60				15	1022	523	183	40	48	18	2		1851
70	1				233	292	297	93	91	19	19	6	1051
80	2	2			87	180	250	165	86	57	12	7	848
90	6	7	2		1	45	103	181	84	57	16	9	511
100	10	11	5		1	35	59	89	55	37	36	21	359
110	10	18	7			2	26	43	24	14	31	21	196
120	13	20	19	2			5	3	8	7	22	21	120
130	1	11	12	2	1		1	3	1		6	16	54
140		9	7	3	1		1		1		7	7	36
150	2	3	2	2	4						3	6	22
160	1			1	1							1	4
170			2		1								3
180								3				1	4
190			1										1
200													
210													
Total	46	81	175	763	2643	1452	1000	645	404	211	155	118	7693

1965

Total Length mm	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
10													
20				1									1
30				4	26								30
40				1	12								13
50				4	211	57							272
60				5	212	308	95						620
70					32	74	119	7	6				238
80	1				18	109	24	98	51	9			310
90	6	4			1	24	15	7	20	16		1	94
100	17	18	44			6	2	22	21	24	1	4	159
110	12	31	36	1			1	10	4	11	1	1	108
120	3	18	5	1	3			4	3	4	3	1	45
130	3	26	2		2					3			36
140	1	6	3	3	5	1				6		1	26
150	1	8	1	1	5			1		1			18
160	1	1		1	1					1			5
170		1										1	2
180					2	3							5
190					1								1
200													
210													
Total	45	113	91	22	531	582	256	149	105	75	5	9	1983

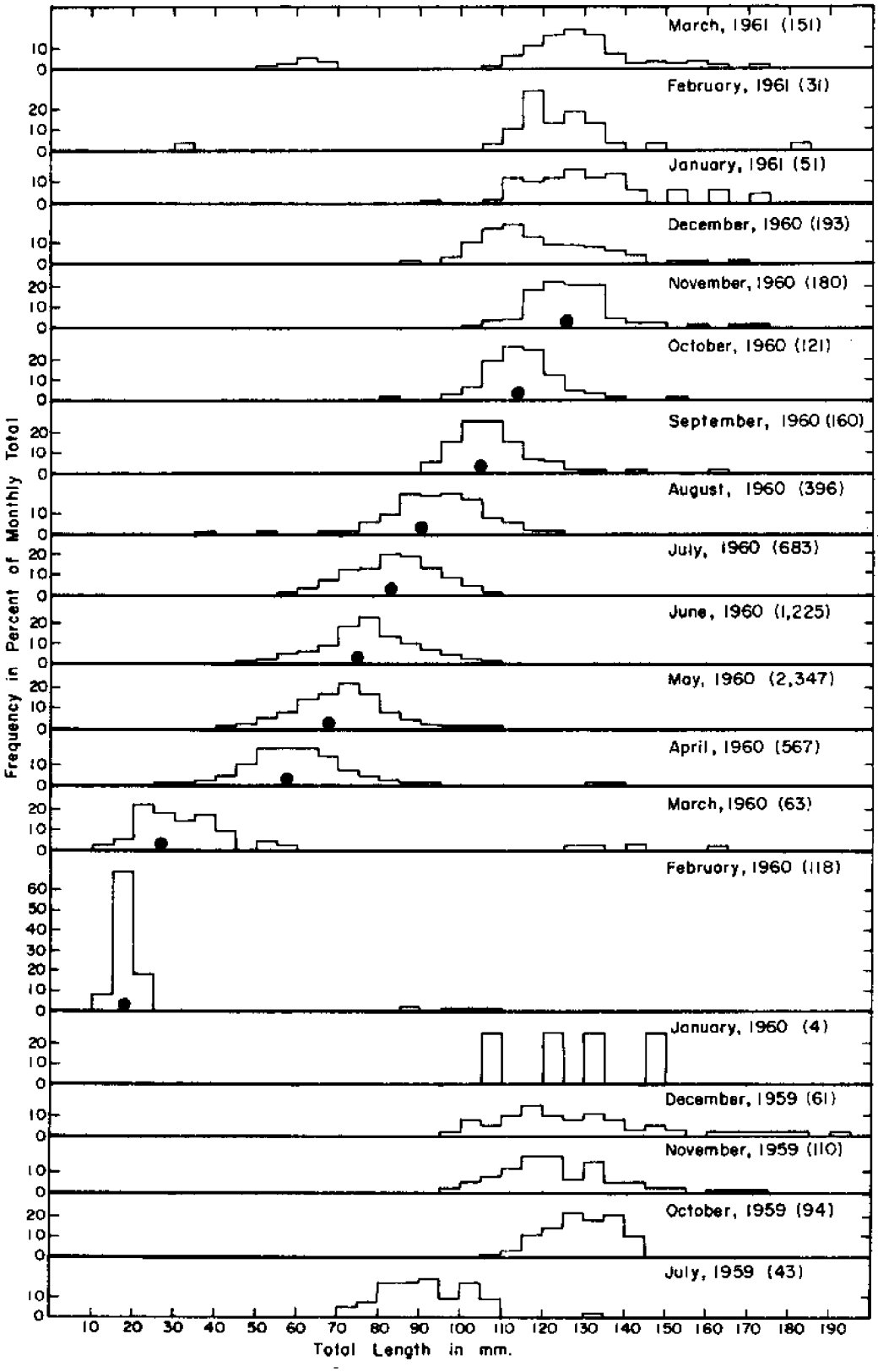


Figure 8. Monthly length-frequency distributions of spot from the Lake Borgne area. Dots denote monthly mean lengths used in computing the growth rate of age-class-0 fish.

fishes) and age prediction equation, along with other pertinent statistical information are presented in Table 3. A small number of fish, ranging in size from 30 to 60 mm, appeared in August, 1960 catches and may have been evidence of a secondary spawn which possibly occurred during March or April. Additional numbers of these "secondary spawners" were caught at progressively larger sizes in October, December, and January. No reference to second spwanings has previously been reported. Postlarvae appeared again in February, 1961, but in fewer numbers than in 1960. Catches at this time were not adequate to warrant growth analysis. Based on the appearance of postlarvae, spawning was of short duration and probably extended from December through January.

According to the monthly length-frequency distributions for spot from Galveston Bay (Figure 9), those fish collected from January through March, 1963, represented an age-class which probably entered the bay during the previous spring. A few of this group remained in the area until September, 1963, but numbers were not adequate to allow a regression analysis of their growth. Postlarvae appeared in Galveston Bay between 1 and 2 months later than in the Lake Borgne area. They were first collected in April, 1963, and members of this age-class were present in the area as late as April, 1964. The arrival of a new age-class was evidenced by the appearance of postlarvae again in March, 1964. Members of this age-group were collected as late as June, 1965. Catches again revealed the appearance of postlarvae in April, 1965, and this

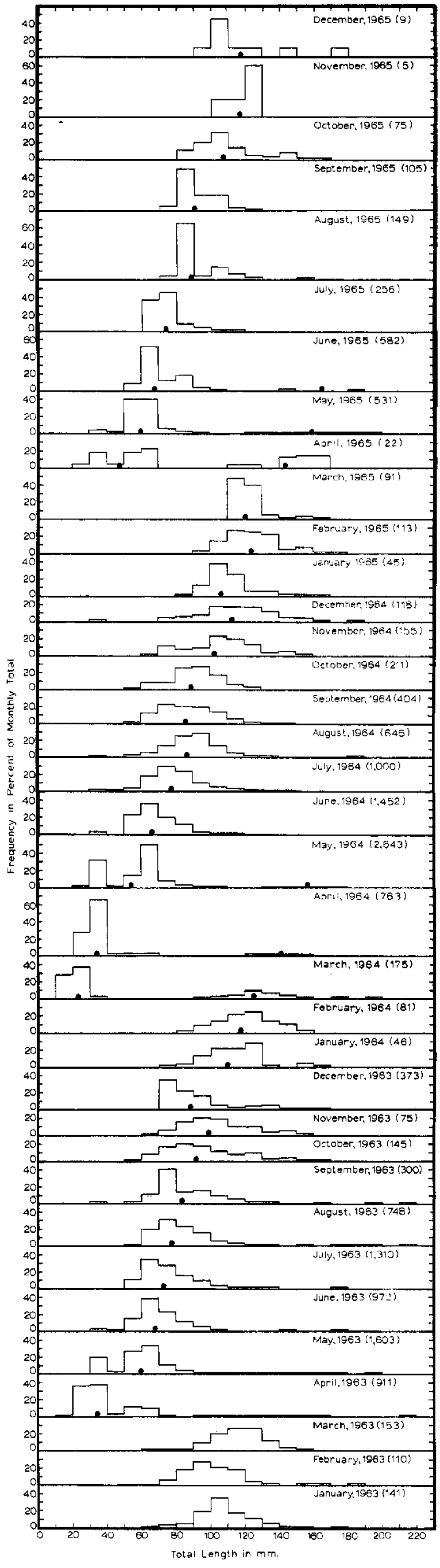
Table 3. Age prediction equations, growth rates and pertinent statistical computations for growth data of spot from the Lake Borgne area and Galveston Bay.

Area	Age Prediction Equation	Σx^2	Σy^2	Σxy	$s^2_{y \cdot x}$	b	n	Test Criterion	d.f.
Lake Borgne									
1. Feb. 1960-Nov. 1960	Y = -0.802 + 0.087X	82.500	10,567.075	915.200	51.807	11.093	10	t = 2.928**	36
Galveston Bay								v = 2.111*	9,8
2. Apr. 1963-May 1964	Y = -3.934 + 0.124X	227.506	14,208.301	1,759.838	49.612	7.735	14	t = 0.978	26
3. Mar. 1964-Jun. 1965	Y = -1.838 + 0.111X	340.000	25,924.708	2,883.215	105.351	8.480	16	v = 1.883*	8,13
4. Apr. 1965-Dec. 1965	Y = -3.811 + 0.107X	60.000	5,100.191	547.740	14.267	9.129	9	v = 0.961	8,15
5. Groups 2 and 3 Combined	Y = -2.723 + 0.116X	567.506	40,133.009	4,643.053	76.638	8.182	30		

Y = age in months
X = mm total length

x = age in months
y = mm total length
b = growth rate in mm total length per month
* denotes significance at the .05 level
**denotes significance at the .01 level

Figure 9. Monthly length-frequency distributions of spot from Galveston Bay. Dots denote monthly mean lengths used in computing growth rates of age-class-0 fish.


December, 1965 (9)
November, 1965 (5)
October, 1965 (75)
September, 1965 (105)
August, 1965 (149)
July, 1965 (256)
June, 1965 (582)
May, 1965 (531)
April, 1965 (22)
March, 1965 (91)
February, 1965 (113)
January 1965 (45)
December, 1964 (118)
November, 1964 (155)
October, 1964 (211)
September, 1964 (404)
August, 1964 (645)
July, 1964 (1,000)
June, 1964 (1,452)
May, 1964 (2,643)
April, 1964 (763)
March, 1964 (175)
February, 1964 (81)
January, 1964 (46)
December, 1963 (373)
November, 1963 (75)
October, 1963 (145)
September, 1963 (300)
August, 1963 (748)
July, 1963 (1,310)
June, 1963 (972)
May, 1963 (1,603)
April, 1963 (911)
March, 1963 (153)
February, 1963 (110)
January, 1963 (141)
Frequency in Percent of Monthly Total
0 20 40 60 80 100 120 140 160 180 200 220
Total Length in mm.

age-class remained in the bay until sampling was terminated in December. Based on the appearance of postlarvae in Galveston Bay, spawning probably began in January and extended through February or March. The spawning period here occurred between 1 and 2 months later than in the Lake Borgne area but this difference could be due to the technique used in estimating time of spawning. The time of appearance of postlarvae would be dependent on, among other factors, time of spawning and distance from spawning grounds to nursery area. Hildebrand and Cable (1930) found evidence of spawning as early as November in Chesapeake Bay and Pearson (1929) indicated that spawning took place from December through late March in Texas.

The growth rate (based on a linear regression of monthly mean lengths of age-class-0 fishes) and age prediction equation for each age-class are presented along with other pertinent statistical information in Table 3 (Page 34). A comparison of the growth of age-classes in the Lake Borgne area and Galveston Bay was accomplished by comparing growth rates (b values in Table 3). A test for homogeniety of variances ($s^2_{y \cdot x}$) between groups to be compared is required to determine the applicable statistical method. If homogeniety of variances is established, the standard t-test applies (the formula is given below), but if variances are heterogeneous, growth rates must be compared using a test criterion proposed by Pearson and Hartley (1958) which considers two variances which must be separately estimated. This criterion is denoted by the symbol v and its formula is given below.

$$t = \frac{b_1 - b_2}{\sqrt{\frac{[(n_1 - 2)\, s^2_{y \cdot x_1} + (n_2 - 2)\, s^2_{y \cdot x_2}]\,[1/\Sigma x_1^2 + 1/\Sigma x_2^2]}{n_1 + n_2 - 4}}} \qquad d.f. = n_1 + n_2 - 4$$

$$v = \frac{b_1 - b_2}{\sqrt{s^2_{y \cdot x_1}/\Sigma x_1^2 + s^2_{y \cdot x_2}/\Sigma x_2^2}} \qquad d.f. = n_1 - 2,\ n_2 - 2$$

Variances were compared using the standard F-test and growth rates were compared accordingly. The results of the comparisons of growth rates are presented in Table 3 (Page 34).

In Galveston Bay, spot in group 4 grew at a significantly greater rate than those in groups 2 and 3. There was no significant difference in growth between groups 2 and 3 and these were combined and compared, along with group 4, to the growth rate of spot from the Lake Borgne area. Both comparisons revealed a significantly greater growth rate in the Lake Borgne area. These findings indicate a significant year to year and geographical variation in growth. The geographical variation is clearly evident from the data in Table 4. Here the growth rates at various localities along the Atlantic and Gulf coasts have been compiled based on length-frequency, scale, and otolith estimates. For 1-year-old fish, growth estimates ranged from 7.5 mm per month in New Jersey (Welsh and Breder, 1923) to 16.3 mm per month in Chesapeake Bay (Pacheco, 1957), and for 2-year-old fish, from 2.9 mm per month in Chesapeake Bay (Pacheco, 1957) to 8.6 mm per month in New Jersey (Welsh and Breder, 1923). The differences in

Table 4. The age-length relationship of spot as indicated by past studies on the Atlantic and Gulf coasts and this investigation. All measurements represent total length in mm. Numbers in parentheses represent monthly growth rates. (Reprinted partially from Dawson, 1958.)

Author	Method	Area	Total length in millimeters at age: 1 year	2 years	3 years	Other
Hildebrand and Schroeder (1928)	Length-frequency	Chesapeake Bay	127.0 (10.5)			
Pearson (1929)	Length-frequency	Texas	130-140 (11.3) median 130	190-210 (5.4) median 200		
Welsh and Breder (1923)	Scales	New Jersey	80-100 (7.5) median 90	165-220 (8.6) median 193	240-290 (6.0) median 265	300 (1.9) at 4.5 years
Welsh and Breder (1923)	Length-frequency	Fernandina, Florida	140 (11.7)			
Hildebrand and Cable (1930)	Length-frequency	Beaufort, N. C.	140 (11.7)			190-200 (12.6) in 16 to 17 months
Townsend (1956)	Scales and Length-frequency	Alligator Harbor, Florida	119-161 (11.8) median 140	187-230* (5.7) median 209		76-113 (15.8) at 6 months 131-181 (9.8) at 16 months
Pacheco (1957)	Scales	Chesapeake Bay	167-224 (16.3) mean 196	196-269 (4.2) mean 246		
Dawson (1958)	Length-frequency	South Carolina	144-162 (12.8) median 153	205-218 (4.9) median 212		
Sundararaj (1960)	Scales	Lake Pontchartrain, Louisiana	143.8 (12.0)	200.1 (4.7)	223.2 (1.9)	
	Otoliths		153.3 (12.8)	212.0 (4.9)	225.1 (1.1)	
	Length-frequency		142.0 (11.8)			
Hellier (1962)	Length-frequency	Upper Laguna Madre	125 (10.4)			
This Investigation	Length-frequency	Lake Borgne, Louisiana	133.1 (11.1)			
		Galveston Bay				
		1963-64	92.8 (7.7)			
		1964-65	101.8 (8.5)			
		1965	109.5 (9.1)			

* beginning of third year

growth between localities did not reflect any distinct pattern, however, and I concluded that these geographical variations probably represented a combination of inaccuracies and differences in the techniques used to estimate growth and year to year variations resulting from local environmental differences. Environmental differences most likely constituted variations in temperature and available food. To what extent conditions varied between the Lake Borgne area and Galveston Bay to produce higher growth rates in Louisiana is not known.

Averaging the monthly growth rate estimates included in Table 4 (Page 39), spot grew at a rate of 11.1 mm per month during their first year and attained a length of 133.2 mm; 5.5 mm per month during their second year and attained a length of 210.3 mm; and 3.0 mm per month during their third year while attaining a length of 237.7 mm. Welsh and Breder (1923) estimated, based on scale studies, that some of their spot reached an age of 4.5 years. From their observations, I estimated that these fish grew an average of 1.9 mm per month during the last 18 months and attained a length of 300 mm. It is doubtful that spot in Louisiana and Texas waters attain a length much greater than the 238 mm average typical of 3-year-old fish. The largest spot collected from the Lake Borgne area measured 194 mm total length and the largest from Galveston Bay measured 219 mm. Spot collected from Galveston Bay in trammel nets by personnel of the Department of Wildlife Science, Texas A&M

University did not exceed 180 mm total length (personal communication). In discussing the general absence of large spot from Gulf waters, Gunter (1950A) noted only 15 among 1,264 spot (about 1.2%) over a total length of 255 mm from the Gulf of Mexico. Dawson (1958), in summarizing the works of Hildebrand and Schroeder (1928), Hildebrand and Cable (1930), and his own observations, stated that of 27,227 spot collected in the three studies only ten (about 0.04%) had attained a total length greater than 255 mm.

Seasonal Abundance

In the Lake Borgne area spot were caught in greatest numbers from April through August, 1960 (Figure 10). Catches increased rapidly after March, 1960 and were highest in May. The decline in numbers during June, July, and August was probably the result of an exodus of spot back to the Gulf. These relative abundance figures are somewhat misleading due to the selectivity of the trawl on various sizes of fish. Postlarvae are small enough to pass through the net mesh and fish older than 1 year are frequently able to elude the trawl. Postlarvae were more abundant than any other size group and were present in the area during both February and March when catches were relatively low. The rapid increase in catch during April and May resulted when these young fish grew to a catchable size, and very likely depicts a time-lag record of the earlier rate of influx of postlarvae. The rapid decline in catch from May through August, however, cannot

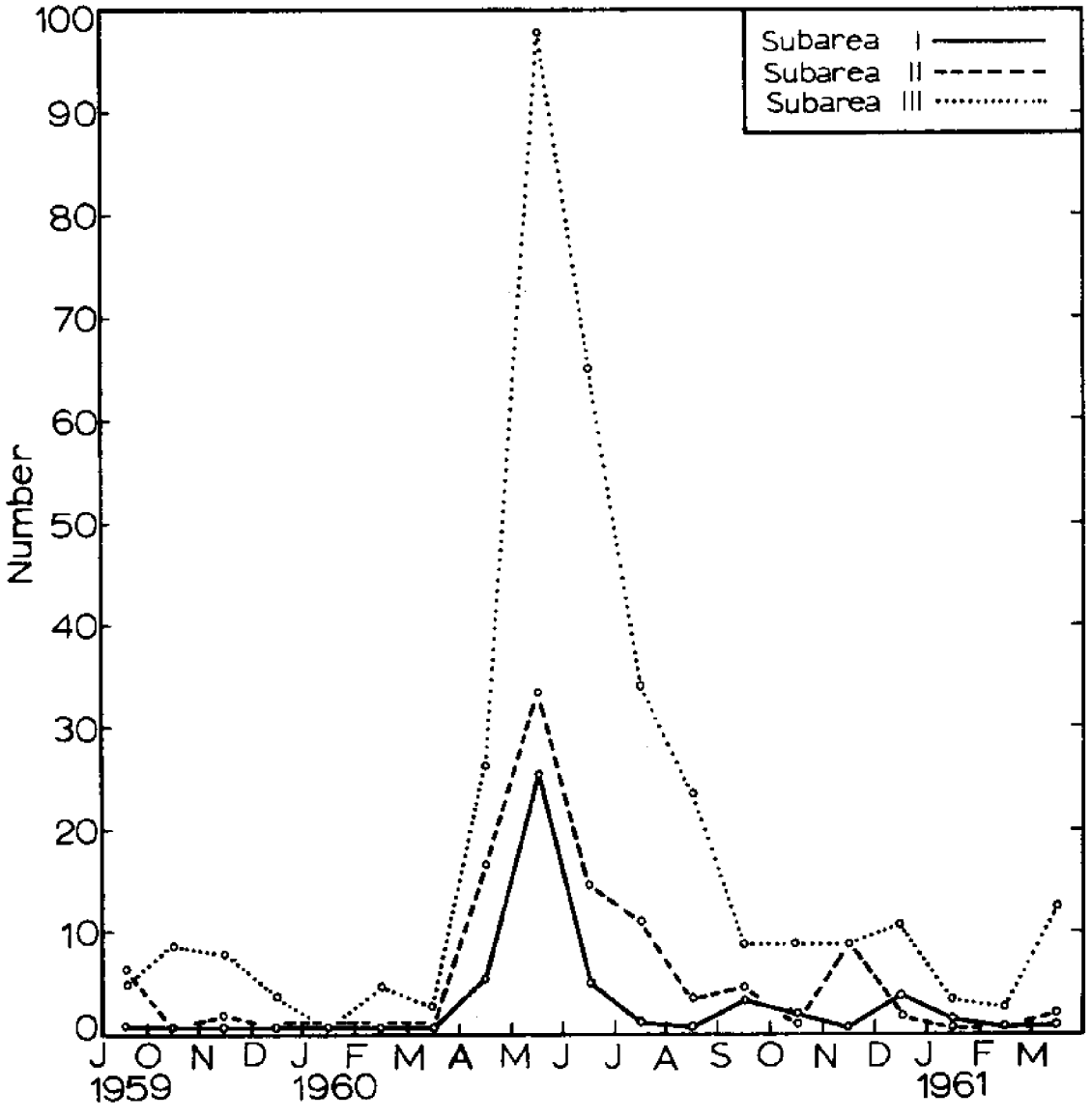


Figure 10. Relative abundance of spot from the Lake Borgne area by subareas during the period from July, 1959 through March, 1961 in terms of monthly mean catch-per-tow.

reasonably be attributed to gear selectivity resulting from growth beyond a catchable size or to mortality. The greatest decline in catches occurred during May and June. Growth over this period amounted to only about 23 mm and does not appear to be enough increase in size to account for the drastic reduction in catches. Mortality, either by predation or other causes, could not be estimated, but does not, in my opinion, provide a suitable explanation for the rapid decrease in numbers. The decline in catch from May through August was most likely evidence of mass movement of spot out of the survey area and into the Gulf. This mass exodus probably began when spot averaged between 70 and 80 mm total length (Figure 9, Page 36).

In Galveston Bay, spot were also caught in greatest numbers during the period from April through August in each year (Figure 11) and the highest monthly catch was taken in May. Catches in 1963 were erratic with no well-defined peak, whereas distinct peak catches were observed in 1964 and 1965. Fluctuations in relative abundance followed much the same pattern as in the Lake Borgne area. The rapid increase in catch during April and May of each year was indicative of the earlier rate of influx of postlarvae. The decline in catches after May of each year was probably the result of a mass exodus of spot back to the Gulf which began when spot were slightly smaller (60-70 mm total length, according to Figure 9, Page 36) than in the Lake Borgne area.

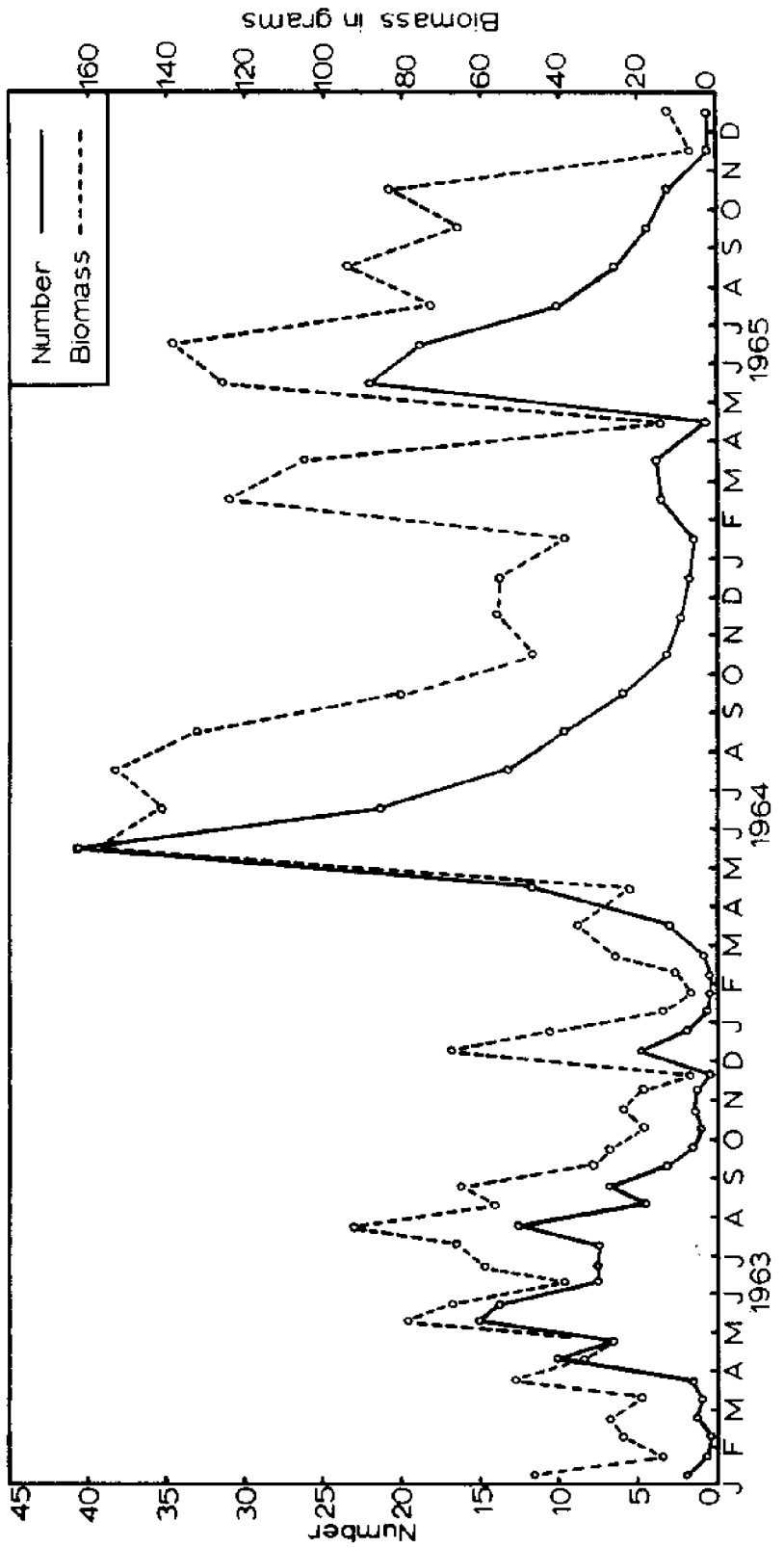


Figure 11. Relative abundance and biomass of spot from Galveston Bay during the period from January, 1963 through December, 1965 in terms of mean catch-per-tow by sampling period.

Fluctuations in relative biomass followed much the same pattern as fluctuations in numbers in 1963 (Figure 11, Page 44), except that the highest relative biomass was observed in late July. In 1964, catches indicated an increase in relative biomass from March through May which coincided with an increase in numbers, but biomass remained high during June, July, and August while numbers declined rapidly. Biomass and numbers were relatively low from October, 1964 through January, 1965. Biomass, however, increased significantly in February and remained high in March while numbers increased only slightly. This peak in biomass was the result of a slight increase in the number of larger fish and was presumed to be indicative of sampling error rather than an influx of spot from the Gulf. In May, biomass again increased with the immigration of postlarvae and reached its peak in June. Although catches indicated an erratic decline through November, the bay supported a large biomass of spot from May through October.

It would appear that both relative numbers and biomass in 1963 were lower than in 1964 and 1965, however, comparisons of equivalent monthly mean catches revealed no significant differences. The variation between station catches within months was large in every instance and undoubtedly obscured any difference between monthly means which may have existed. These comparisons demonstrated the difficulty in detecting differences in mean catches obtained by trawls except when those differences are extremely large. Parker (1970) was able to detect differences in numbers of brown

shrimp (Penaeus aztecus) in 1963 and 1964, based on the same trawl catches from which these spot were taken. Although the variability between catches was equally high for shrimp, the greatest difference in mean-catch-per-tow at peak abundance amounted to 140 brown shrimp as opposed to a difference of only 26 spot.

Contrary to my findings, Hildebrand and Cable (1930) stated that commercial catches of spot at Beaufort, North Carolina were small during the summer, and Dawson (1958) observed a notable reduction in his South Carolina catches from April through October. Dawson attributed this anomalous situation to a modification of the schooling behavior of late spring and summer spot with the result that trawls fail to adequately sample a dispersed population. The studies of Gunter (1938) in Louisiana, and Reid (1955A, 1955B, 1956, 1957) in East Galveston Bay, Texas have shown, as do my data, that spot were abundant inshore in these areas during the spring and summer.

My findings do not support Dawson's (1958) contention that spot remain in the inshore nursery grounds, with local changes in their distribution, until the end of their second summer. Rather, it is likely that spot move offshore after a short 8 or 9 month stay in the inshore nursery grounds and probably mature and spawn in the Gulf at the end of their second year. Fish with ripe or developing gonads have been reported over the total length range from 177 (Pearson, 1929) to 214 mm (Hildebrand and Schroeder, 1928).

According to my growth estimates, some age-class-0 fish may reach this size range by the end of their first year, but most do not.

Areal Abundance

The seasonal variation in catch of spot from the Lake Borgne area is presented by subareas in Figure 10 (Page 42). A comparison of monthly mean catches between subareas revealed that numbers in subarea III were significantly higher than in subareas I and II during the period from March through August, 1960 and again in March, 1961. No significant differences in catch could be detected between subareas I and II. The analysis of variance for catch comparisons which yielded significant differences and the probability levels by which these differences were declared are presented in Table 5. If the areas under the relative abundance lines in Figure 10 (Page 42) are considered as measures of relative density, subarea III carried about six times the density of subarea I and three times the density of subarea II. Catches in subareas I, II, and III yielded 680, 1,340, and 4,578 fish respectively.

The areal distribution of spot in Galveston Bay in terms of numbers and biomass is presented in Figure 12. The quantitative divisions of both numbers and biomass were based on what appeared to be major delineations in distribution. There was little difference between the distribution patterns of numbers and biomass,

Table 5. Analysis of variance of the comparison between subareal monthly means and the significant distinction between these means based on the results of Duncan's New Multiple Range Test.

May, 1960 - Analysis of Variance

Sources of Variation	d.f.	SS	MS	F
Among Subareas	2	47,646.0	23,823.0	8.083**
Within Subareas	42	123,786.3	2,947.3	
Total	44	171,432.3		

Results of Duncan's Test

Subarea	I	II	III	
Mean Catch	25.7	33.0	98.1	.01 Confidence Level

June, 1960 - Analysis of Variance

Sources of Variation	d.f.	SS	MS	F
Among Subareas	2	32,153.6	16,076.8	4.942*
Within Subareas	42	136,622.7	3,252.9	
Total	44	164,776.3		

Results of Duncan's Test

Subarea	I	II	III	
Mean Catch	5.0	12.1	14.9	.05 Confidence Level
				.01 Confidence Level

July, 1960 - Analysis of Variance

Sources of Variation	d.f.	SS	MS	F
Among Subareas	2	8,667.9	4,334.0	7.338**
Within Subareas	42	24,805.9	590.6	
Total	44	33,473.8		

Results of Duncan's Test

Subarea	I	II	III	
Mean Catch	0.7	11.0	33.9	.05 Confidence Level
				.01 Confidence Level

August, 1960 - Analysis of Variance

Sources of Variation	d.f.	SS	MS	F
Among Subareas	2	4,846.0	2,423.0	5.797**
Within Subareas	42	17,554.4	418.0	
Total	44	22,400.4		

Results of Duncan's Test

Subarea	I	II	III	
Mean Catch	0.1	3.1	23.5	.05 Confidence Level
				.01 Confidence Level

March, 1961 - Analysis of Variance

Sources of Variation	d.f.	SS	MS	F
Among Subareas	2	777.5	387.2	3.861*
Within Subareas	27	2,707.7	100.3	
Total	29	3,485.2		

Results of Duncan's Test

Subarea	I	II	III	
Mean Catch	0.8	1.7	12.0	.05 Confidence Level

* denotes significance at the .05 confidence level
** denotes significance at the .01 confidence level

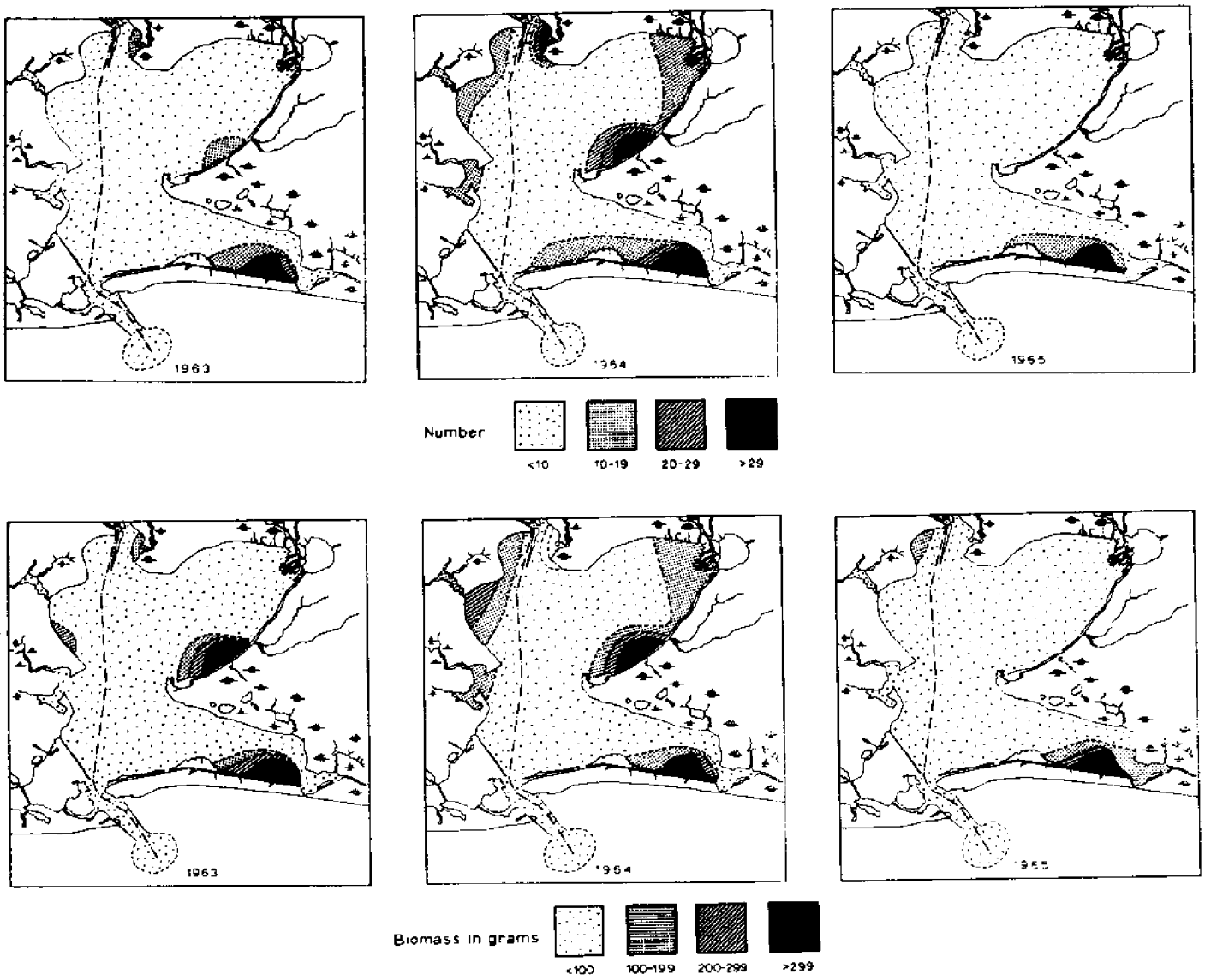


Figure 12. Areal distribution of numbers and biomass of spot in Galveston Bay based on annual mean catch-per-tow by station.

indicating that all size classes were distributed in essentially the same manner. This was further substantiated by plotting the areal distribution of individual 10 mm size classes.

In 1963, spot were concentrated in and adjacent to a major marsh area in East Bay, at the mouth of two bayous and corresponding openings in the levee bordering the abandoned Anahuac channel and adjacent marshes, and at the mouth of Cedar Bayou which also drains a marsh complex. The pattern was expanded in 1964 to include, additionally, the lower shore of East Bay, the mouth of the Trinity River, Clear Lake and the western shore of Upper Galveston Bay, and the Dickinson Bay-Moses Lake area. Only the East Bay marsh area and adjacent shore appeared to carry large concentrations of spot in 1965.

The large concentrations of spot were always observed in shallow waters less than 1.2 m deep which received run-off directly from marshes or tidal flats. The bottom in these areas was soft mud containing large quantities of detritus. The north shore of East Bay did not carry high numbers of spot although large marshes lie just inland. The flow through the bayous connecting these marshes with the bay, however, was restricted by weirs or dams. Based on numbers, 90% of the spot caught in Galveston Bay were taken in the areas shaded by numbers of 10->29 on the 1964 map in Figure 12 (Page 49). These areas and their adjacent marshes appeared to constitute the major nursery habitat for spot in Galveston Bay. Most

likely young spot prefer these areas because they afford a greater food supply and protection from predators. Reid (1955B) found that his trawl and seine catches from East Bay yielded highest numbers of spot in the upper area of the bay in waters where the bottom was thick, loose mud. He also noted that spot were least abundant along the north shore. Dawson (1958) found young spot in South Carolina most abundant in the river division which was characterized by marsh and mud bottom. He also observed that juvenile spot frequented the shallow creeks and marshes in South Carolina. He noted, however, that little was known concerning the depth distribution over the remainder of the inshore area. He found that few spot were taken at depths less than 4.3 m at times of extremely low temperature and during the remainder of the year no consistent trends in size or abundance were evident in a comparison of shallow (3.0-5.5 m) and deep (6.7-9.1 m) station data. Very few spot were caught in waters this deep in Galveston Bay or the Lake Borgne area.

The extent to which spot penetrate and utilize the marshes was examined in more detail in the West Bay marsh. Monthly station catches, based on 3-minute trawls taken twice monthly, are presented in Table 6 from the time postlarvae first appeared in March, 1968 through the period of peak abundance. A dense growth of filamentous algae throughout the tidewater areas, coupled with low tides restricted trawling efforts after May. Catches at stations A and B (the tidewater marsh stations in Figure 3, Page 14) accounted

Table 6. Monthly catch of young spot by station in the West Galveston Bay marsh.

Month	Station				
	Marsh		Oyster Lake		
	A	B	C	D	Total
March, 1968	0	0	1	5	6
April	167	412	5	7	591
May	185	233	29	39	486
Total	352	645	35	51	1,083

for 92% of the spot collected. Unquestionably, the tidewaters bordering the fringe of the marsh along with the adjacent shallow bay waters constitute prime nursery habitat for this species, and it is likely that these fish penetrate as deeply as possible into the tidewater marshes. Trent (1969) compared the abundance of spot in West Galveston Bay in natural marshes and marshes which had been channeled and bulkheaded for resort developments. He found that spot were much more abundant and of a slightly larger size in the natural marshes. Here spot concentrated at stations bordered by vegetation and were caught in greatest numbers at stations fartherest from the bay. Numbers in the altered area and in the open bay were considerably lower.

The presence of spot in marsh waters of the intertidal zone was observed on several occasions in the West Bay marsh. Although the data were not quantitative, conclusions could be made concerning the suitability of these waters as habitat. Spot, along with other marine species, were able to enter the marsh during abnormally high tides. After waters had receded following a tidal flood, many dead spot were observed scattered over the marsh vegetation. Many more were trapped in ponds, but conditions were seldom favorable for their return to the bay and depended upon another tidal flood within a relatively short period of time. These trapped fish usually died as a result of freshwater flooding, low temperatures during the winter, or drought conditions during the summer. Gunter (1950B) speculated

on a similar fate for marine species, including spot, in saline marsh ponds on the Aransas Wildlife Refuge in Texas.

Distribution Related to Temperature

The effects of temperature on the distribution and survival of spot have been considered by a number of authors. Hildebrand and Cable (1930) reported that spot became very scarce in the inshore waters around Beaufort, North Carolina during extended cold spells. Pearson (1929) and Townsend (1956) have indicated that availability of spot declines with low temperatures. Pacheco (1957) stated that Chesapeake Bay spot usually leave the Bay when water temperature drops below 10 C. Dawson (1958) noted that South Carolina spot were comparatively abundant in inshore waters at temperatures of 11 C and he collected some spot in temperatures as low as 6 C. He attributed the high abundance at low temperatures, at least in part, to freedom from extended periods of low temperatures. Gunter (1945) took Texas spot over a temperature range from 8.1 to 32.0 C and Dawson (1958) found South Carolina spot at temperatures as high as 36.7 C.

No references were found concerning the tolerance of this species to high temperatures, but several have been noted on lethal low temperatures. Hildebrand and Cable (1930) found spot numb and drifting ashore at Beaufort, North Carolina after a 6-day cold spell when water temperatures ranged from 5 to 9 C. They stated that 5 C

was probably close to the lethal limit for 1-year-old fish, but suggested that young-of-the-year were less sensitive to cold. Gunter and Hildebrand (1951) reported stunned and dead spot lining the shore of Aransas Pass harbor following a 6-day period when air temperatures ranged between -7.8 and -3.9 C. Spot have been reported killed by cold in Bears Bluff ponds at water temperatures of 4.5 C (Lunz, 1951) and 1.1 C (Lunz, 1958). Dawson (1958) noted no evidence of cold-killed spot in natural waters of the region over the same period which the latter of Lunz's observations covered. He concluded, based on a summary of previous literature, that the lethal minimum temperature for spot is in the 4.0 to 5.0 C range and probably fluctuates with the size of the fish. Schwartz (1964) in reporting on aquarium held spot from Chesapeake Bay found that young can tolerate slightly lower temperatures (2.2 C) than adults (3.3 - 4.4 C) and for longer periods of time.

As was noted previously, spot were year-round inhabitants of both study areas. In the Lake Borgne area they were collected at temperatures ranging from 5.2 to 34.9 C and in Galveston Bay from 1.2 to 35.5 C. The extremes in Lake Borgne were observed in the shallow open waters and the extremes in Galveston Bay were both observed in the shallow marshes of East Bay. No mortalities due to either extreme were observed.

The relative abundance of spot in the Lake Borgne area (Table 7) was highest at temperatures between 26 and 35 C, and lowest at

Table 7. Relative abundance of spot in the Lake Borgne area as related to temperature.

Temperature °C	Number Of Tows	Number Caught	Mean Catch Per Tow
<6	1	3	3.00
6-10	31	147	4.74
11-15	95	85	0.89
16-20	95	419	4.41
21-25	77	891	11.57
26-30	193	3,328	17.24
31-35	67	1,173	17.51
Total	559	6,046	10.82

temperatures between 11 and 15 C. These figures are weighted in favor of the size fish most easily caught by the trawl (50-110 mm) and should not be interpreted to represent a temperature preference for all sizes. Statistical comparisons of these catch data were not made because equivalent sampling was not conducted within each temperature class. Postlarvae spot entered the area during the colder period of the year (February and March) and were obviously both abundant and well adapted to temperatures in the 6 to 20 C range, whereas fish approaching 1 year of age or older were usually absent at temperatures below 10 C.

The monthly mean temperatures at which spot were collected in the Lake Borgne area are presented in relation to the overall area monthly mean temperatures in Figure 13A. During the period from October, 1959 through April, 1960, spot were present at mean temperatures higher than the corresponding area mean temperatures in each month except December (the pattern was reversed here). The only other noteworthy differences between these means occurred in June, 1960, and February, 1961, when the areal mean was lower than the distributional mean, and in December, 1960, when the means were again reversed. Since temperatures within the area were essentially homogenous at any given time the differences in these means during the period from October, 1959 through January, 1960, could have resulted from a periodic influx of spot from the Gulf into subarea III. The fish present in the area at this time were

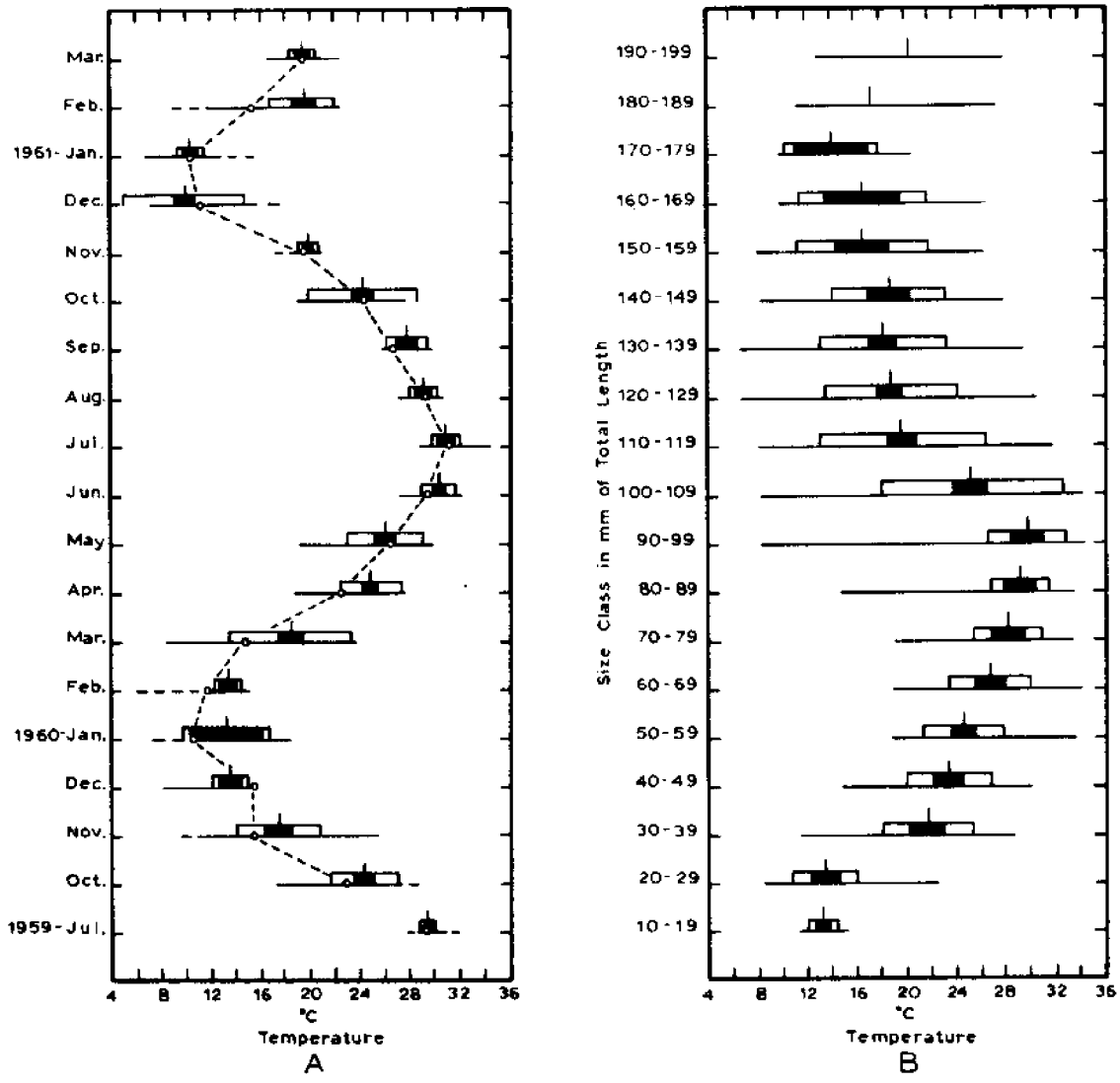


Figure 13. A - Monthly mean, $s_{\bar{x}}$, 2σ of the mean and range of temperatures at which spot were collected in the Lake Borgne area superimposed monthly mean areal temperatures.

B - Mean, $s_{\bar{x}}$, 2σ of the mean and range of temperatures at which spot were collected in the Lake Borgne area computed by 10 mm size classes.

large enough to travel considerable distances (they ranged in size from 90 to 199 mm) and could have been attracted into the area during periods when the waters were warm and subsequently retreated to the Gulf during cold periods. The reversal of the pattern in December, however, casts some doubt on this hypothesis and alternately suggests that the distribution was relatively random and the differences, which are not particularly large, were the result of sampling error. Although the number of large spot declined from 61 in December, 1959 to 4 in January, 1960 and remained low thereafter (Table 1, Page 30), it is doubtful that the corresponding drop in temperature shown in Figure 13A was the causative factor. A similar drop in temperature occurred in December, 1960, but numbers increased from 180 in November to 193 in December and continued high throughout the winter. The differences in means in June and December, 1960, probably resulted from sampling error. In January and February, 1960, spot were absent at temperatures on the lower end of the monthly range, but were present at similar temperatures during the following winter. Catches from February through April, 1960, and February, 1961, were composed of young spot which were found at monthly mean temperatures higher than the corresponding areal means. These were the periods during which immigration occurred and temperatures were rising. The differences in means probably reflected the results of a more active immigration during periods when temperatures were at the upper end of the monthly range. Dawson (1958) concluded that the seasonal abundance of postlarvae in inshore waters was regulated by temper-

ature. The appearance of postlarvae in my catches at the end of each winter occurred shortly after temperatures began to rise. The initial temperature increase may be the factor which stimulated the onshore immigration of postlarvae.

Mean temperatures and temperature ranges for 10 mm size classes are presented in Figure 13B (Page 58). Young-of-the-year were found in temperatures as low as 8C, and early growth was associated with a gradual increase in temperature. Temperature means increased from 12 C for 10-19 mm fish up to 30 C for 90-99 mm fish. For fish 100-179 mm, growth coincided with a decline in temperatures from 30 to 14 C. Beyond 179 mm, observations were not adequate for reliable predictions. Young spot were able to grow rapidly at temperatures between 14 and 32 C and were distributed, for any given size, over a comparatively narrow range (approximately 15 C) until they reached 79 mm. The broadest range (26 C) was observed for fish between 90 and 109 mm. Fish in this size range were common in the area over a longer period than other groups. The temperature range for larger sizes was comparatively narrow probably because sampling was restricted to only a portion of the area in which these fish reside.

The relative abundance of spot in Galveston Bay (Table 8) was highest during each year at temperatures between 26 and 35 C and abundance was generally low at temperatures below 20 C. These figures are, to some degree, misleading because they are directly dependent upon both seasonal abundance and size of fish and sampling

Table 8. Relative abundance of spot in Galveston Bay as related to temperature.

Year	Temperature °C	Number Of Tows	Number Caught	Mean Catch Per Tow
1963	<6	22	8	0.36
	6-10	137	134	0.98
	11-15	215	520	2.42
	16-20	106	71	0.67
	21-25	313	756	2.42
	26-30	505	3,308	6.55
	31-35	194	1,895	9.77
	Total	1,492	6,692	4.49
1964	<6	5	0	0.00
	6-10	71	25	0.35
	11-15	202	174	0.86
	16-20	153	337	2.20
	21-25	156	1,550	9.94
	26-30	263	5,269	20.03
	31-35	32	369	11.53
	Total	882	7,724	8.76
1965	<6	1	11	11.00
	6-10	18	1	0.06
	11-15	166	232	1.40
	16-20	226	31	0.14
	21-25	246	84	0.34
	26-30	392	867	2.21
	31-35	23	746	32.43
	Total	1,072	1,972	1.84

was not equivalent for either parameter. For this reason, statistical comparisons of relative abundance by temperature classes was not attempted. As in the Lake Borgne area, postlarvae entered the Bay during the colder periods (temperatures below 20 C) and were obviously well adapted to the low temperatures which occurred during the winter. Fish approaching 1 year of age or older were noticeably absent during these periods. Findings in both study areas suggested that large spot were not as well adapted to low temperatures as were postlarvae and young juveniles. Hildebrand and Cable (1930) contended that young-of-the-year were less sensitive than older fish to cold.

Monthly mean temperatures at which spot were collected in Galveston Bay are presented in relation to the overall monthly areal temperature means in Figure 14. In 30 of the 36 months covered by the survey, the mean temperature at which spot were collected was higher than the overall area temperature mean. This should be expected considering that spot were found concentrated in the nearshore waters adjacent to marshes. These shallow waters are warmer than the deeper waters except for short periods in the winter during and a few days following passage of a cold front. As in the Lake Borgne area, postlarvae appeared each year in Galveston Bay shortly after temperatures began to rise, but the time lag was somewhat greater. This relation can best be seen by cross-referencing Figures 9 (Page 36) and 14 (Page 63). In 1963, temperatures began to increase after February with increasing size up to about 140 mm. Spot

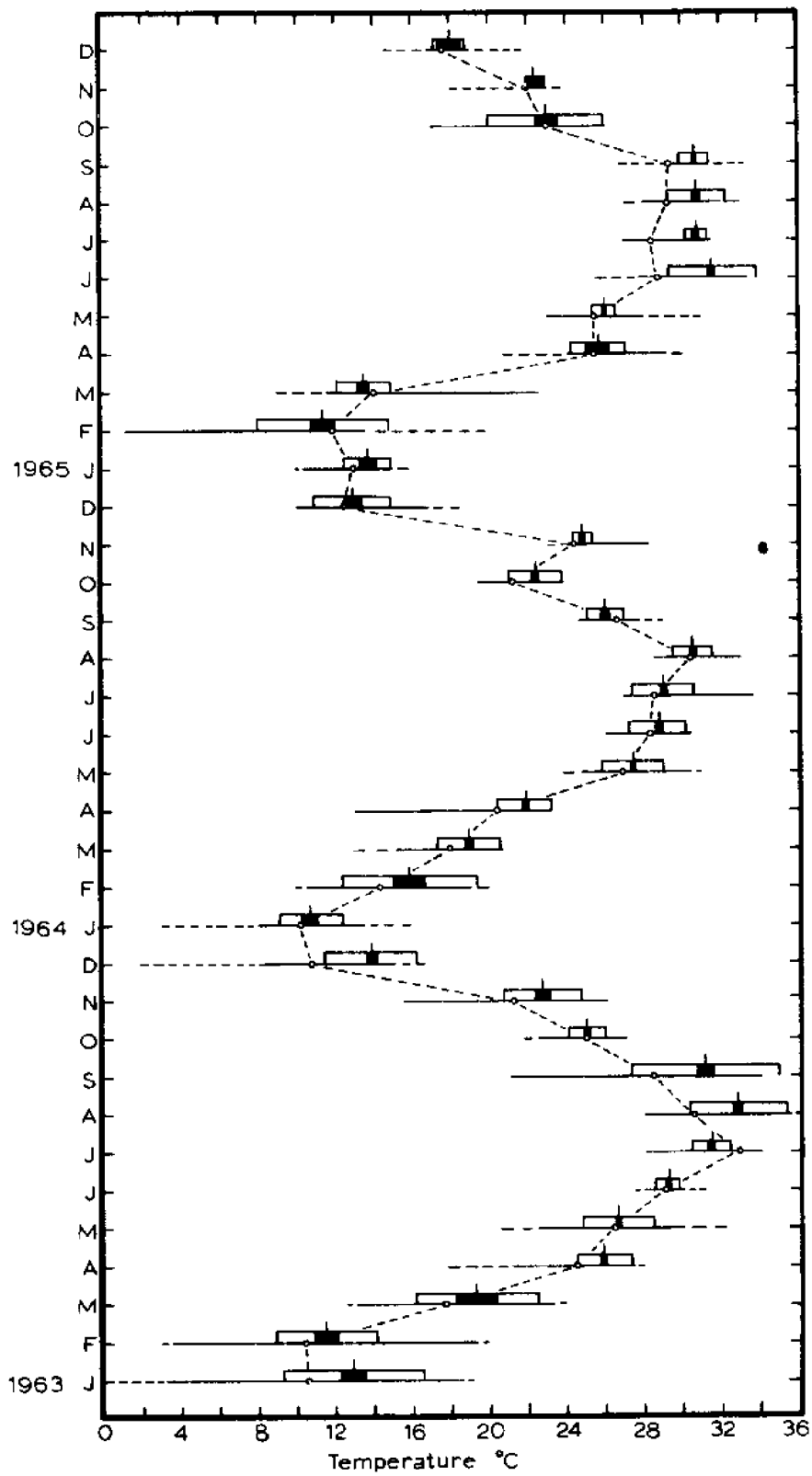


Figure 14. Monthly mean, $s_{\bar{x}}$, 2σ of the mean and range of temperatures at which spot were collected in Galveston Bay superimposed on the monthly mean areal temperatures.

but postlarvae did not appear in quantity until April. They were generally of a larger size (20-39 mm) than those caught in the Lake Borgne area (10-29 mm), but could possibly have been present at a smaller size as early as March and eluded the trawl. Temperatures increased after January in 1964, but postlarvae (predominantly 10-29 mm) were not caught until March. In 1965, temperatures did not increase appreciably until after March and a limited number of postlarvae appeared in April.

According to the mean temperatures, and temperature ranges, for 10 mm size classes in Figure 15, young spot grew up under differing temperature conditions in succeeding years. Postlarvae less than 20 mm in length were found at temperatures as low as 10 C, but overall they were collected at means of 26 C, 19 C and 26 C in the three successive years. In 1963, fish from 10-69 mm were found at mean temperatures ranging erratically between 22 and 29 C. For spot between 70 and 139 mm, mean temperatures declined with increasing size from 29 to 20 C and for spot between 140 and 149 mm mean temperatures increased with increasing size from 20 to 28 C. The pattern in 1964 was similar to that described for the Lake Borgne area with the principle exception that the smallest spot (10-19 mm) were found at a mean temperature of almost 19 C. Although somewhat more erratic, the pattern in 1965 was similar to that in 1963. Overall the trend was toward an increase in temperature with increasing size up to about 80 or 90 mm followed by a decline in temperature

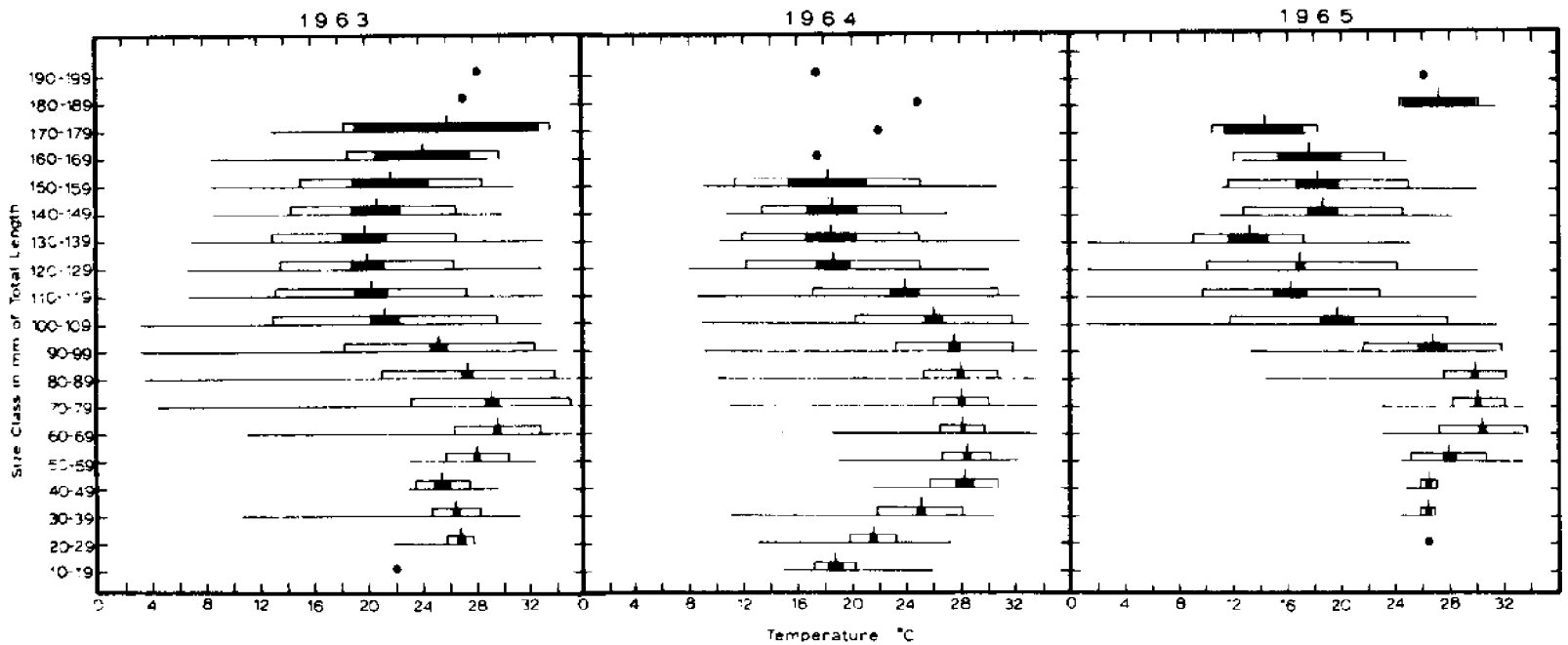


Figure 15. Mean, $s_{\bar{x}}$, 2σ of the mean and range of temperatures at which spot were collected in Galveston Bay computed by 10 mm size classes.

with increasing size up to about 140 mm. Spot between 10 and 69 mm were usually found over a comparatively narrow temperature range and spot between 70 and 139 mm were usually found over the widest range. Spot 140 mm or larger were found over a comparatively narrow range but records were incomplete because sampling did not extend into their offshore habitat.

Distribution Related to Salinity

Observations by various authors indicate that the spot is euryhaline throughout its North American range. Specimens have been found in salinities less than 1 (Gunter, 1945; Raney and Massmann, 1953; Massmann, 1954; El-Sayed, 1961; Rounsefell, 1964) and up to 60°/oo (Simmons, 1957). Reid (1955B) found spot in East Bay, Texas in greatest abundance in the upper area of the bay where low salinities prevailed. The work of Kilby (1955) and Simmons (1957) implied a salinity oriented distribution and Kilby noted that in marsh areas habitat may have greater influence than salinity on the distribution of young spot. Dawson (1958) found few spot in fresh and brackish waters but noted that available data indicated that juvenile and young spot may show preference for low salinity waters in South Carolina. He found spot under 152 mm total length most abundant in the rivers, and those under 76 mm most common at low salinity stations. He noted little variation in mean salinities between stations (24.4-32.0°/oo) and suggested that the low salinity preference may have

reflected the influence of other environmental factors such as bottom type and food availability.

The nature of the life history of the spot requires an adaptability at the postlarval and juvenile stage, not only to a comparatively wide salinity range, but also to relatively rapid salinity changes. It has been shown that the abundance of spot in both study areas was decidedly seasonal and to some extent temperature oriented. The high concentrations observed in subarea III of the Lake Borgne area and the dispersion toward the marshes in Galveston Bay suggest that other factors also play an important role in the distribution of this species. The interaction of these factors with a parameter such as salinity, which is stabilized by neither time nor area, makes evaluating the effects of salinity on distribution difficult. Because of the inability to measure the interaction of these factors quantatively, statistical analyses of the field data relating to salinity did not appear relevant, however, some inferences could be made.

In the Lake Borgne area spot were found in salinities ranging from 1.2 to 25.4°/oo. According to the mean-catch-per-tow values in Table 9, spot were caught in greatest abundance at salinities between 21 and 25°/oo and abundance declined with decreasing salinity. These figures, however, do not necessarily represent salinity preference because equivalent sampling was not conducted within each salinity class. The areal salinity pattern varied with time, therefore, relative abundance was weighted in favor of the salinities

Table 9. Relative abundance of spot in the Lake Borgne area as related to salinity.

Salinity °/oo	Number Of Tows	Number Caught	Mean Catch Per Tow
<6	323	1,940	6.01
6-10	100	812	8.12
11-15	68	1,318	19.38
16-20	46	1,432	31.13
21-25	16	723	45.19
Total	553	6,225	11.26

prevailing during the period when seasonal abundance was highest. A comparison between areal and distributional salinity means (Figure 16A) revealed that these fish were caught at mean salinities higher than the corresponding area mean in every month except July, 1959. The differences between the means can be attributed to greater abundance of spot in subarea III where salinities were highest and do not necessarily reflect a salinity preference. The most revealing evidence relating salinity to the distribution of spot was obtained by examining the salinities at individual stations where spot were caught in abundance. I considered spot to be abundant at a particular station when the catch per 10-minute tow exceeded 100 fish. During the survey period, 15 tows (Table 10) caught more than 100 fish. The corresponding salinities ranged between 1.2 and 21.8°/oo or over almost the entire range of salinities observed in the area. All but two of these tows were made in subarea III in salinities ranging between 9.5 and 21.8°/oo The presence of spot in abundance throughout a wide range of salinities does not indicate salinity preference and suggests that salinity per se within the range observed here may not be a factor affecting distribution.

The mean salinities and salinity ranges for 10 mm size classes of spot from the Lake Borgne area are presented in Figure 16B. Mean salinities declined with increasing size from 13°/oo for 10-19 mm fish to 5°/oo for 40-49 mm fish, then increased with increasing size to 16°/oo for 90-99 mm fish and declined with increasing size to

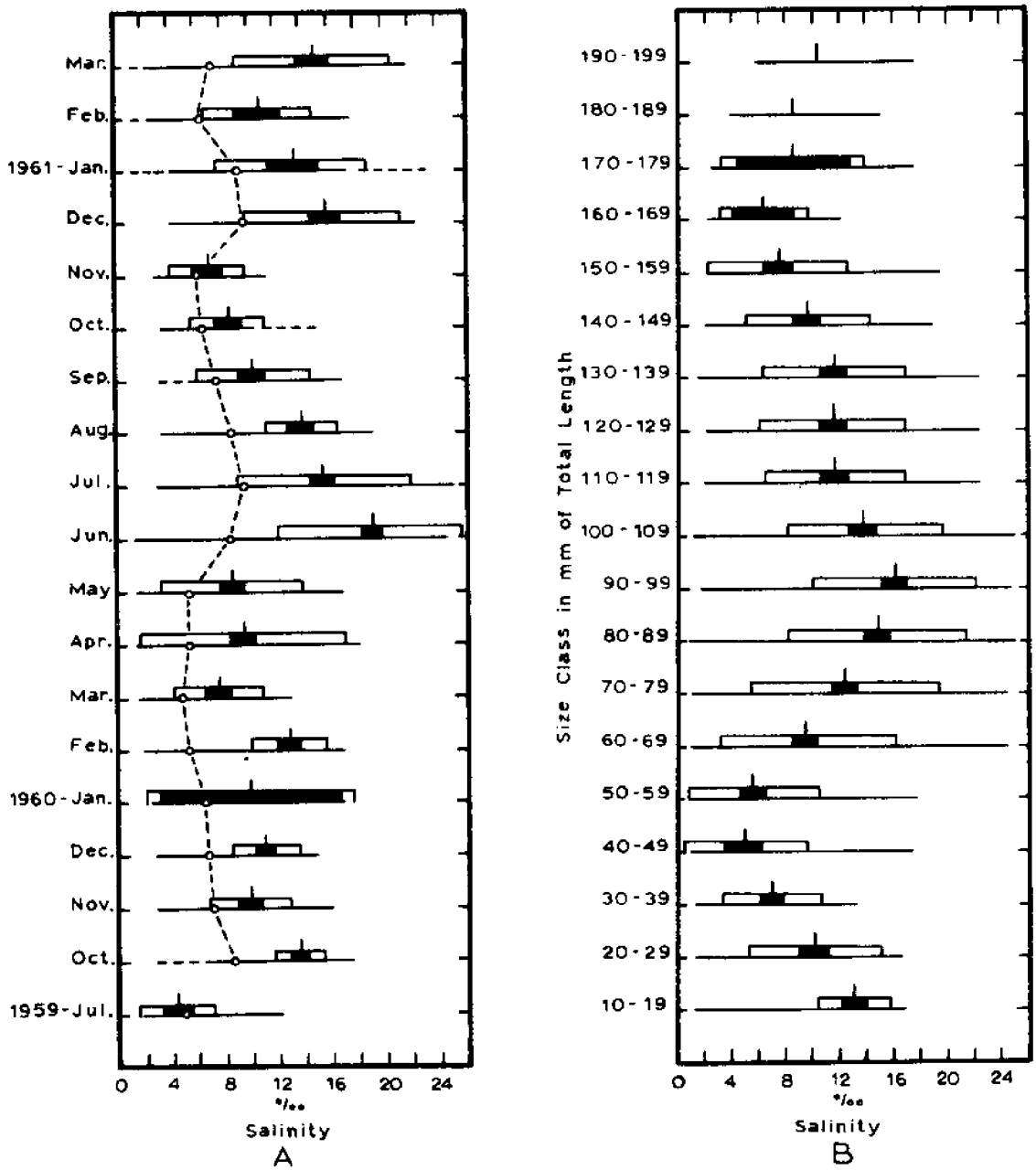


Figure 16. A - Monthly mean, $s_{\bar{x}}$, 2σ of the mean and range of salinities at which spot were collected in the Lake Borgne area superimposed on the monthly mean areal salinities.

B - Mean, $s_{\bar{x}}$, 2σ of the mean and range of salinities at which spot were collected in the Lake Borgne area computed by 10 mm size classes.

Table 10. Salinity classes in which an abundance of spot were caught (more than 100 fish per 10-minute tow) in the Lake Borgne area and the number of tows made in each class.

Salinity °/oo	Number Of Tows
<6	2
6-10	1
11-15	4
16-20	5
21-25	3
Total	15

6°/oo for 160-169 mm fish. The data for spot larger than 169 mm were not adequate for reliable predictions. The salinity range was comparatively narrow for spot smaller than 60 mm and averaged only about 15°/oo. Fish from 60-109 mm were observed over a range of about 25°/oo, whereas larger spot were found over a range which narrowed with increasing size. The salinity range for any given size group was most likely dependent upon the numbers collected and the length of time that particular group was found in the area.

Spot were found in Galveston Bay in salinities ranging from 0.4 to 36.4°/oo. In contrast to the Lake Borgne area the monthly mean salinity at which they were collected was lower than the monthly baywide mean salinity (Figure 17) 23 of the 36 months of the survey period. According to the mean-catch-per-tow values in Table 11, they were most abundant in 1963 at salinities from 16 to 20°/oo and also present in high numbers at salinities from 6 to 10 and 21 to 25°/oo. In 1964, catches were highest at salinities between 6 and 10°/oo and relatively high at salinities between 11 and 20°/oo. Abundance was highest in 1965 at salinities between 11 and 15°/oo and comparatively high at salinities from 6 to 20°/oo. In each year relative abundance was lowest at salinities between 26 and 35°/oo. These figures, however, do not necessarily denote a salinity preference because equivalent sampling was not conducted within each salinity class. In each year the salinities where abundance was high were those which prevailed in the primary nursery areas

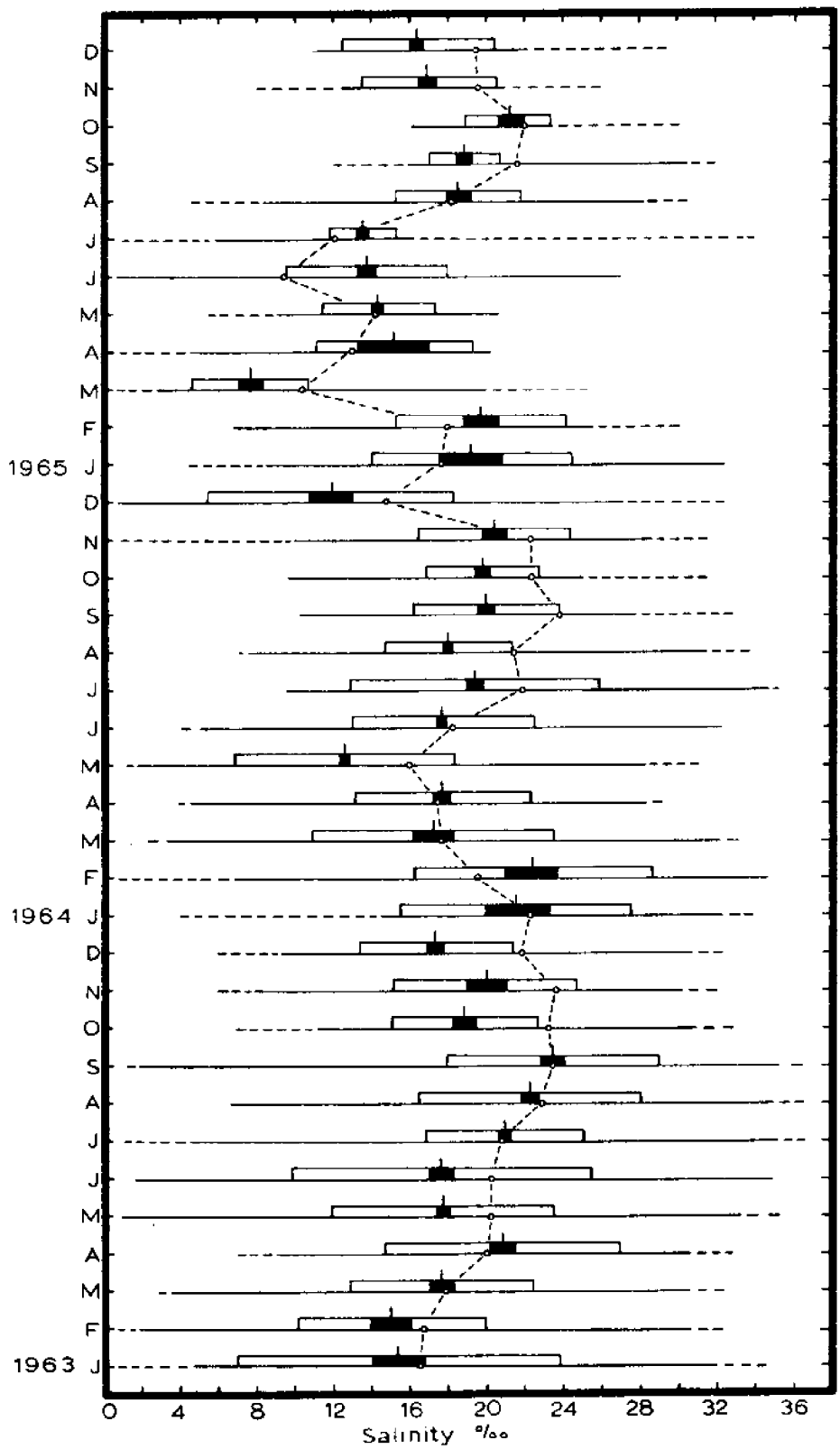


Figure 17. Monthly mean, $s_{\bar{x}}$, 2σ of the mean and range of salinities at which spot were collected in Galveston Bay superimposed on the monthly mean areal salinities.

Table 11. Relative abundance of spot in Galveston Bay as related to salinity.

Year	Salinity °/oo	Number Of Tows	Number Caught	Mean Catch Per Tow
1963	<6	25	118	4.72
	6-10	98	607	6.19
	11-15	210	614	2.92
	16-20	365	2,383	6.53
	21-25	397	2,300	5.79
	26-30	232	486	2.09
	31-35	183	108	0.59
	Total	1,510	6,616	4.38
1964	<6	28	127	4.54
	6-10	49	1,212	24.73
	11-15	140	1,329	9.49
	16-20	245	3,498	14.28
	21-25	218	1,223	5.61
	26-30	110	201	1.83
	31-35	72	138	1.92
	Total	862	7,728	8.97
1965	<6	35	30	0.86
	6-10	44	227	5.16
	11-15	77	696	9.04
	16-20	125	853	6.82
	21-25	92	130	1.41
	26-30	24	9	0.38
	31-35	8	6	0.75
	Total	405	1,951	4.82

(see Figure 12, Page 49) in Trinity and East Bays during the period of peak abundance. This suggests that factors other than, or in addition to, salinity were important in regulating distribution. Again, the most revealing findings concerning the effect of salinity per se on the distribution of spot become apparent when considering the salinities at individual stations where spot were abundant. I considered spot to be abundant in Galveston Bay when the catch per 5-minute tow at a particular station exceeded 50 fish. Although catch-per-tow values are probably not related in the two study areas, I chose an abundance figure half that shown for the Lake Borgne area based on the duration of the trawl effort. During the 3-year survey, 73 tows (Table 12) caught more than 50 fish. The salinities at stations where these tows were made ranged from 4.9 and 34.8°/oo or over most of the observed salinity range. These findings confirm those previously obtained from the Lake Borgne area and indicate that spot are distributed in abundance over a broad range of salinities in the nursery areas. Presumeably, other previously mentioned factors are more important than salinity per se in the distribution of spot in these nursery areas.

The mean salinities and salinity ranges for 10 mm size classes of spot from Galveston Bay are presented in Figure 18. With few noteworthy exceptions there was little variation between salinity means for different size classes in 1963 and 1965. The distribution of means in 1964 very closely resembled the pattern described for

Table 12. Salinity classes in which an abundance of spot were caught (more than 50 fish per 5-minute tow) in Galveston Bay and the number of tows made in each class.

Salinity °/oo	Number Of Tows
<6	1
6-10	9
11-15	13
16-20	32
21-25	14
26-30	2
31-35	2
>35	0
Total	73

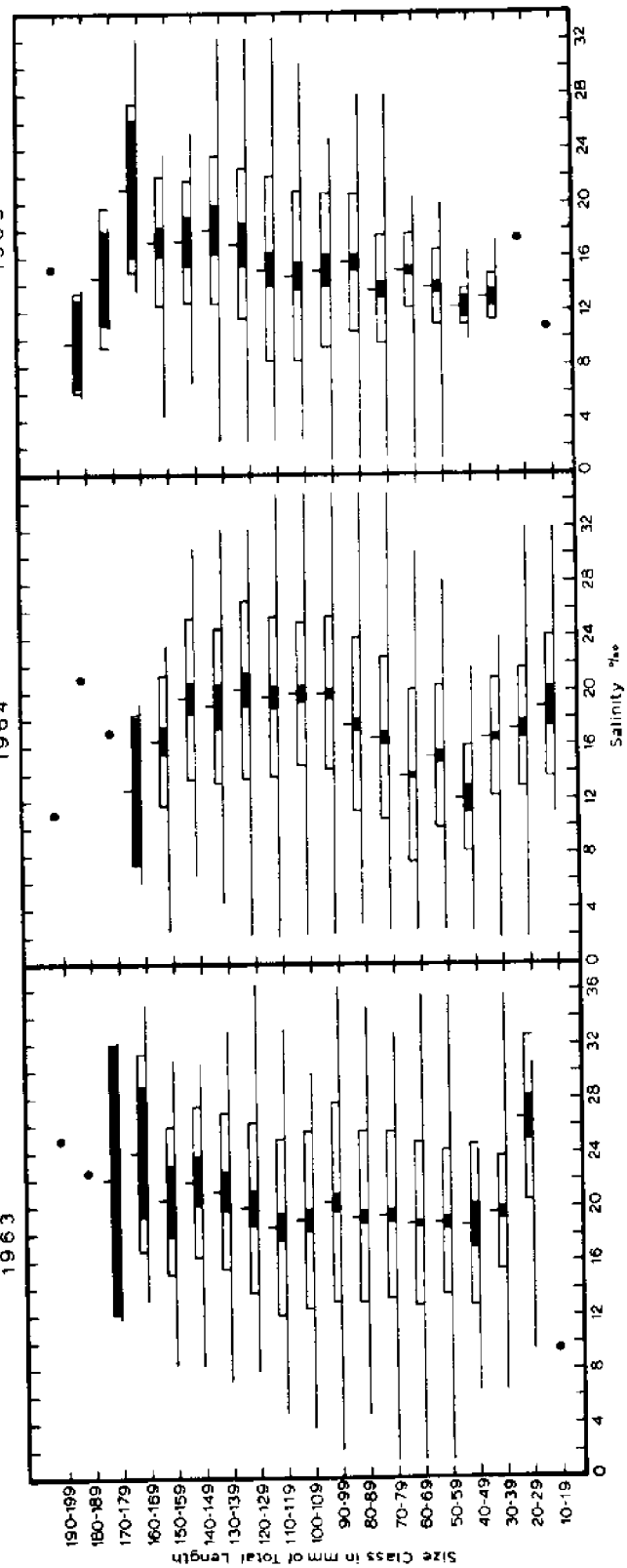


Figure 18. Mean, $\bar{x}$, 2σ of the mean and range of salinities at which spot were collected in Galveston Bay computed by 10 mm size classes.

the Lake Borgne area except that there was less variability between the means. Overall, there appeared to be no meaningful change in the salinity distribution of spot for different size classes in Galveston Bay. In the Galveston Bay study, almost the entire nursery area for spot was monitored and it is likely that the information obtained here provides a clearer picture of the distribution of the young fish. For this reason, I am inclined to conclude that the variation in salinity means for different size classes in the Lake Borgne area was a chance occurrence indicative of conditions prevailing for a time in one nursery area (subarea III).

Food Habits

Roelofs (1954) found that spot, feeding in laboratory aquaria, scooped the surface of the bottom catching whatever material was available and used the dense straining basket formed by the gill rakers to sort out the food items. This form of feeding does not suggest a high degree of selectivity and, in terms of comparisons of food items between localities, implies that available food probably dictates the diet of spot. Dawson (1958) has adequately reviewed the diet of spot and indicated that this fish takes a wide variety of plant and animal material. Overall, there was a general preference for small planktonic and demersal crustaceans as well as annelids. Townsend (1956) observed that young spot in Florida fed mainly on copepods, whereas older fish were less selective,

taking annelids and fish among other things. Reid (1955B) enticed spot in East Bay, Texas to take baited shrimp and fish, but believed they were not adapted to catching shrimp in their natural habitat. Dawson (1958) argued that this may apply to larger shrimp, but contends that numbers of postlarval shrimp are taken by spot.

The food of the spot has been investigated by Darnell (1958) in Lake Pontchartrain which adjoins the Lake Borgne area and by Diener and Inglis (personal communication) in Clear Lake which adjoins Galveston Bay. Both lakes occupied similar positions in their respective areas. They were located near large municipal and industrial centers and their waters were shallow and had relatively low salinity. The food items listed in these two studies included, with few exceptions, the entire array of items reported previously and constituted the most detailed assemblages yet available.

Darnell (1958) noted, in summarizing the observations of Linton (1904), Smith (1907), Welsh and Breder (1923), Hildebrand and Schroeder (1928), Hildebrand and Cable (1930), Gunter (1945), Roelofs (1954) and Reid (1954, 1955B), that the feeding habits of spot change with size. As a rule, young spot feed just above the bottom on zooplankton and micro-crustaceans. As they grow, they begin to feed more upon bottom surface animals, and as they approach maturity they dig more deeply into the bottom, taking a greater quantity of burrowing forms. His data was separated into three size classes <100, 100-149, and 150-203 mm, which, as I interpreted his discussion

represented groupings based on these differing feeding habits. Diener and Inglis, on the other hand, separated their data by 10 mm size groups and, according to Darnell's criteria, include an adequate number of observations in only one group, that composed of spot <100 mm total length.

The food items reported from the two areas were compared for this size group using Spearman's coefficient of rank correlation (r_s). Twenty different items were reported between the two areas. These items were ranked (Table 13) according to their frequency of occurrence. Rank 1 was assigned to the item occurring with the greatest frequency. Ties were given the mean rank. In cases where an item occurred in only one area it was ranked accordingly there and given the highest rank in the other area. The correlation coefficient, r_s, was then computed from the formula:

$$r_s = 1 - \frac{6\Sigma d^2}{(n-1)n(n+1)}$$

where d was the difference between the corresponding ranks of each food item.

Applying the procedure to the date of Table 13

$$r_s = 1 - \frac{6(828)}{(19)\ (20)\ (21)}$$

$$= 0.3774$$

Table 13. Food items of spot from Lake Pontchartrain, Louisiana and Clear Lake, Texas ranked according to frequency of occurrence.

Food Items	Lake Pontchartrain	Clear Lake	d
Rotifera	11	19	-8.0
Ostracoda	5	3	2.0
Copepoda	3	1	2.0
Mysid shrimp	14.5	8.5	6.0
Decapoda	19	15	4.0
Isopoda	7	16	-9.0
Amphipoda	7	8.5	-1.5
Cirripedia	19	12	7.0
Insecta	10	11	-1.0
Arachnida	14.5	19	-4.5
Annelida	14.5	13	1.5
Gastropoda	4	17	-13.0
Pelecypoda	1.5	10	-8.5
Hydroids	14.5	19	-4.5
Foraminifera	9	4	5.0
Vertebrata (fish)	19	14	5.0
Algae	14.5	7	7.5
Vascular plants	14.5	2	12.5
Detritus	1.5	6	-4.5
Mud and sand	7	5	2.0
No. Specimens Examined	22	457	$\Sigma d = 0$
No. With Food	18	397	$\Sigma d^2 = 828.00$
Size Range in mm	40.0.99.0	18.0-99.0	n = 20

The following student's t was used to test the significance of this correlation coefficient.

$$t = r_s \sqrt{n-2/1-r_s^2} \qquad d.f. = n - 2$$

$$= 0.3774 \sqrt{18/1-(0.3774)^2}$$

$$= 1.7294 \qquad d.f. = 18$$

This t is nonsignificant indicating that there is little correlation between food items taken by spot <100 mm total length in the two areas. Because spot are not selective feeders, this lack of correlation reflects a degree of variability in available foods in the two areas. Pelecypods, detritus, and copepods predominated in that order in the digestive tracts of the fish from Lake Pontchartrain, whereas, copepods, vascular plants, and ostracods predominated in that order in the tracts of fish from Clear Lake. Gastropods and vascular plants accounted for the greatest differences between areas with the former occurring more frequently in Clear Lake. These dietary differences may explain the difference in growth rates observed in the two study areas.

Length-Weight Relationship and Condition

Data on the relationship between lengths and weights of fish are important tools in the study of fish biology. The analyses of length-weight data have usually been directed toward two objectives.

First, to describe the regression of length on weight so that one may be converted to the other, and second, to measure the variation in weight for length of individual fish or relevant groups of individuals as indications of, among others, fatness, general "well-being", gonad development, and suitability of environment. The term "length-weight relationship" is applied to the first category and the term "condition" is generally reserved for length-weight analyses of the second category. Applications of length-weight relationships and condition factors for fish have been discussed by numerous authors including Carlander (1950), LeCren (1951), and Lagler (1956).

The length-weight relationship of most fish can be described by the exponential function:

$$W = aL^b$$

where W = weight, L = length, a is a constant and b is an exponent usually lying between 2.5 and 4.0 (Hile, 1936; Martin, 1949).

In order to deal with length-weight data in terms of regression, some means of linear transformation is necessary. If the log of length is plotted against the log of weight, this relationship becomes linear and can be dealt with using simple linear regression statistics. Rewriting the above equation in terms of this log transformation, an equation in the linear form Y = a + bX is obtained.

$$\begin{aligned} W &= aL^b \\ \log W &= \log (aL^b) \\ \log W &= \log a + b \log L \end{aligned}$$

Log $\underline{a}$ represents the point at which the regression line intercepts the log W axis and $\underline{b}$ represents the slope of the line. The length-weight relationship in this form can be used to compare the condition of different groups of fish provided fish within the groups span a wide size range and the groups do not differ significantly in size. The procedure involves first, the computation of the length-weight relationship for each group; second, a test of homogeniety of $\underline{b}$ between groups (if the values of $\underline{b}$ differ significantly, further analyses will have little relevance); and third, a comparison of the log $\underline{a}$ values. When it can be shown that $\underline{b}$ is homogeneous for different groups of fish, the values of $\underline{a}$ for each group represent a direct measure of their condition relative to each other (LeCren, 1951).

Individual variations of fish or variations between groups spanning a small size range are usually analyzed by means of a condition factor. The condition factor most typically used by fishery researchers is computed by the formula:

$$K = \frac{W \times 10^5}{L^3}$$

This equation is based on the ideal form of a fish where, in the length-weight formula $W = aL^b$, $\underline{b} = 3$, and the cube law is obeyed. When $\underline{b} \neq 3$, as is frequently the case, K computed by this formula changes with length (LeCren, 1951). The effect of length on K, however, can be eliminated by computing a condition factor based

on the empirical length-weight relationship. The condition factor in this case is called the relative condition factor (proposed by LeCren, 1951) and is calculated from the formula:

$$K_b = \frac{W}{aL^b}$$

which in practics is calculated from the formula:

$$K_b = \frac{W}{\hat{W}}$$

Where $\hat{W}$ is the antilog of W in the length-weight equation. The difference between K and K_b is that the former is measuring the deviation of an individual from a hypothetical "ideal fish" while the latter is measuring the deviation of an individual from the average weight for length. The choice of which condition factor to use must be based to some extent on which of these two comparisons is more relevant. Hile (1936) contends that a condition factor calculated from an empirical formula (K_b) fails to measure any change in form associated with change in length. LeCren (1951) notes that change in form or condition associated with length is accurately described by the value of the exponent b. With the relative condition factor, he argues, it is possible to distinguish between and measure separately the influences on condition of factors not associated with length; whereas these are not readily separated when the ordinary factor (K) is used. Lagler (1956), in reviewing

these arguments, acknowledged the validity of LeCren's proposal within populations in which the length-weight relationship does not vary too erratically with year, season, etc. but noted difficulty when comparing indices based on different regressions and favored the use of K in spite of its limitations.

Dawson (1958) described the length-weight relationship of spot from South Carolina (Table 14) and fitted his equation to the average length and weight at 5 mm length-frequency intervals. Except for those classes represented by a few fish at the extremes of the size range, he noted a close correspondence between empirical and calculated weights with a maximum difference of 9.2 grams at 200 mm and a mean absolute deviation for all classes represented by 10 or more fish of 1.5 grams. He also described (Dawson, 1965) the length-weight relationship of spot from the Mississippi and Louisiana coasts (Table 14). Using his standard length-total length conversion equation (Dawson, 1958) he compared these length-weight relationships and concluded that, within the observed length ranges, weight per unit length was approximately the same in the two areas. From the calculated curves, he observed that, although Gulf spot were somewhat heavier per unit length on the Mississippi and Louisiana coasts, such differences were within the statistical error of the methods employed.

The length-weight data for spot from Galveston Bay (bay-wide) were computed from observations on individual fish and are presented in Table 14. There appeared to be close agreement in the length-

Table 14. Length-weight data for spot from South Carolina (Dawson, 1958), the Mississippi and Louisiana coasts (Dawson, 1965) and Galveston Bay, Texas.

Location	n	Length Range in mm	log a	b	Σx^2	Σxy	Σy^2	$s^2_{y.x}$	r
South Carolina (Dawson, 1958)	4,297	45-205*	-4.54396	2.95831					
Miss.-La. coasts (Dawson, 1965)	944	50-175	-5.03588	3.07255					
Galveston Bay, Texas (bay-wide)	902	40-185	-5.00626	3.05832	14.83209	45.36125	140.58820	0.00206	0.993
Trinity Bay, Texas	169	40-170	-4.79182	2.94603	3.41464	10.05965	30.05578	0.00251	0.993
East Bay, Texas	258	40-185	-4.93269	3.01367	3.87710	11.68430	35.63514	0.00165	0.994

* standard length, remaining measurements are total length

r denotes correlation between observed and predicted weights

weight relationships for fish from the Mississippi-Louisiana coast and Galveston Bay (bay-wide). It was not possible to compare these regression lines statistically, but the differences in slope and elevation do not appear to be large enough to suggest statistical significance.

Certain areas of Galveston Bay have been shown to be prime nursery habitat for spot and in two of these areas -- Trinity and East Bays--sufficient length-weight measurements were taken to allow a comparison of the condition of spot between the two habitats by means of the length-weight regressions. The computations for these groups are presented in Table 14 (Page 87). A comparison of the variances ($s^2_{y \cdot x}$) revealed that they differed significantly and the comparison of slopes was made using Pearson and Hartley's (1958) test criterion v, (the formula is given on page 46) which considers a comparison with variances that must be separately estimated. Computing v from the data in Table 14 (Page 86):

$$v = \frac{3.01367 - 2.94603}{\sqrt{0.00251/3.41464 + 0.00165/3.87710}} = 1.985^{*}, \text{ d. f. } = 167, 256$$

This v is significant at the .05 level, indicating a significant difference in the slopes of the lines and implying that the condition of spot in the two areas varied with size. The extent of the variability (Figure 19) was not great.

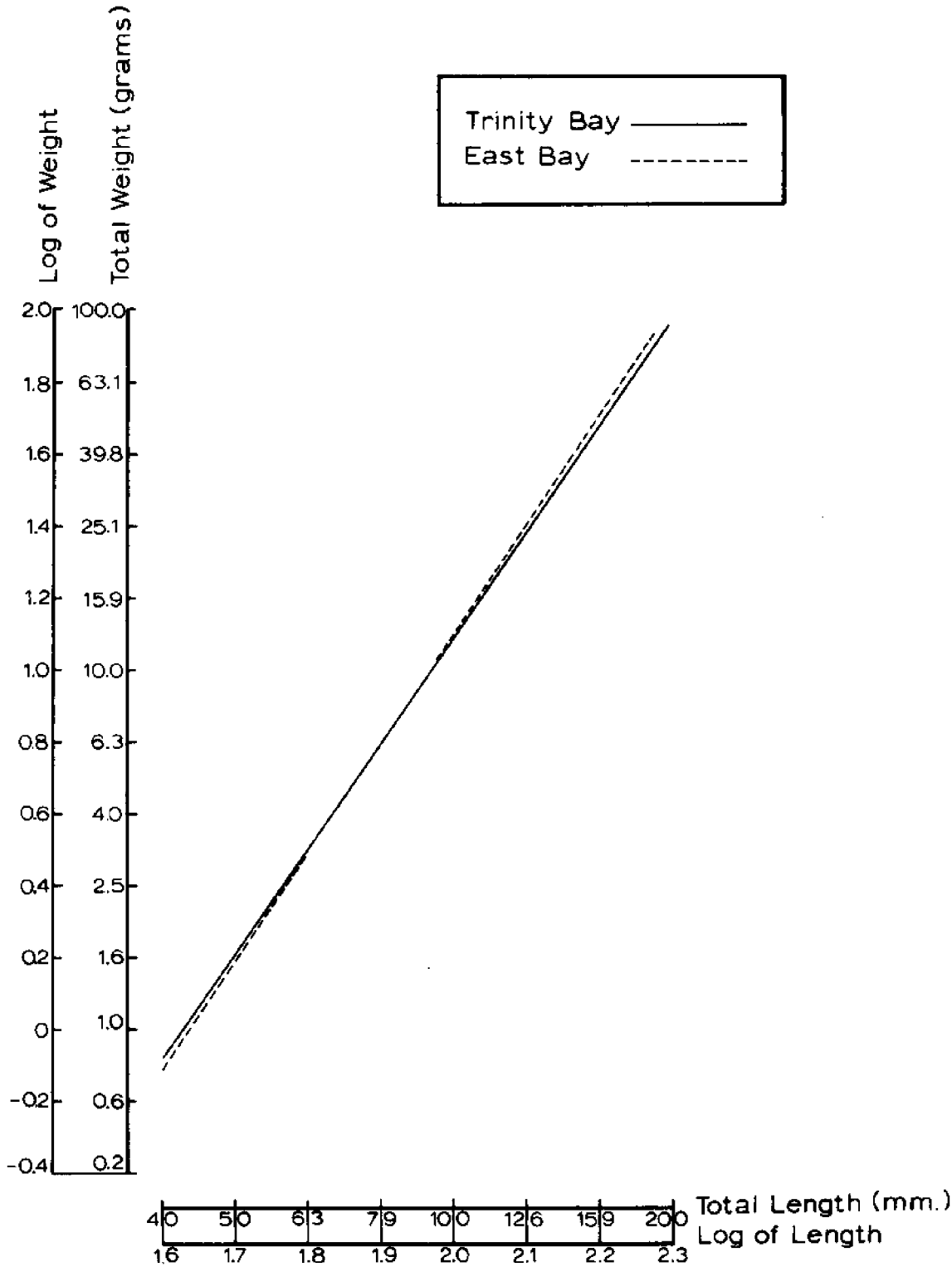


Figure 19. Length-weight relationship of spot from Trinity and East Galveston Bays.

Small spot were in better condition in East Bay, but as size increased this difference shifted, and for the larger spot favored the Trinity Bay fish. At 40 mm, East Bay spot weighed 0.42 grams more than those from Trinity Bay, but at 170 mm, the Trinity Bay fish were heavier by 1.43 grams. The fish in the two areas were immature, of essentially the same size and age class, and were collected during the same time of year. The cause of variation between the length-weight relationships is not known, but could represent size specific environmental differences in the form of nutritional variability.

Further efforts to analyze the condition of spot in Galveston Bay involved an evaluation of changes in condition with size, over time, and with temperature and salinity. Although it has already been shown that condition differed significantly between two nursery areas within Galveston Bay, these analyses were computed based on spot collected throughout the bay (bay-wide in Table 14, Page 87) because of the limited number of observations at a given time within individual nursery areas.

If condition changes with size, $b \neq 3$, and the "cube-law" does not apply. The following t-test was used to determine the validity of the "cube-law" for spot.

$$t = \frac{b - 3}{\sqrt{s^2_{y \cdot x}/\Sigma x^2}} \quad \text{d.f.} = n - 2$$

$$= \frac{3.05832 - 3}{\sqrt{0.00206/14.83209}} = 4.947^{**}, \text{ d.f.} = 900$$

This t-value was significant at the .01 level indicating that $\underline{b}$ was greater than 3, and implying, according to LeCren's interpretation, that condition increased with increasing size. Presumably, K_b is the more applicable condition factor for examining changes in condition over time and due to temperature and salinity. However, because there is not consistent agreement as to the relevancy of the two indices under given circumstances, both K and K_b were computed in the ensuing analyses.

An analysis of the variation of condition over time was accomplished by comparing monthly condition factors. The analysis of variance for these comparisons along with the monthly mean condition factors are presented in Table 15. The F-tests revealed that both K and K_b differed significantly over time. A modification of Duncan's method (Kramer, 1956) was used to distinguish between means. The resulting differences and the confidence level at which these differences were declared are also presented in Table 15. According to Spearman's coefficient of rank correlation there was good agreement between K and K_b. Condition was highest during the month of May and, with the exception of July, was com-

Table 15. Analyses of monthly mean K and K_b for spot from Galveston Bay.

Analysis of Variance for K					Analysis of Variance for K_b			
Sources of Variation	d.f.	SS	MS	F	d.f.	SS	MS	F
Among Months	11	1.54895	0.14081	7.50923**	11	1.13116	0.10283	9.45129**
Within Months	891	16.70813	0.01875		891	9.69065	0.01088	
Total	902	18.25709			902	10.82181		

Month	n	Mean K	Confidence Level .05	Confidence Level .01	Mean K_b	Confidence Level .05	Confidence Level .01	Rank K	Rank K_b
Jan.	126	1.30727			1.00526			6	6
Feb.	102	1.25463			0.96676			10	10
Mar.	70	1.33935			1.02545			2	3
Apr.	74	1.31602			1.03408			4	2
May	153	1.34189			1.04807			1	1
June	103	1.30848			1.02515			5	4
July	72	1.28645			1.00306			8	7
Aug.	32	1.32370			1.01832			3	5
Sept.	64	1.25553			0.97303			9	9
Oct.	48	1.28993			0.98602			7	8
Nov.	27	1.18179			0.91496			12	11
Dec.	31	1.18688			0.91396			11	12

r_s = 0.9545
t = 10.123**
d.f. = 10

**denotes significance at the .01 level

paratively high throughout the period from March through August. Condition was lowest during the winter months of November and December and comparatively low during September, October, January, February and July. The sum of the rankings for K and K_b during the period from March through August were 23 and 22, respectively and for the remaining months, 55 and 56, respectively.

The effect of temperature and salinity on the condition of spot was determined through a multiple regression of these parameters on both K and K_b. The analyses of variance, the t-values used to test the partial regression coefficients and the regression equations are presented in Table 16. The F-test for Samples in the analysis of variance was significant at the .01 level for both K and K_b. Since samples were taken over the entire year and throughout the system, both areal and seasonal factors are confounded within this source of variation. Little information was gained from this test, but, by partitioning this source of variation, the error term for regression was reduced and the precision of the ensuing F-test for regression was improved. The F-test for regression in the analysis for K was nonsignificant and in the analysis for K_b was significant at the .05 level. A test of the partial regression coefficients in the K_b analysis indicated that the effect due to temperature was significant at the .05 level and the effect due to salinity was nonsignificant. It was therefore concluded that K was not significantly affected by temperature or salinity and that K_b increased with increasing temperature but was not affected by

Table 16. Multiple regression analyses of temperature and salinity on the condition of spot from Galveston Bay.

	Analysis of Variance for K				Analysis of Variance for K_b			
Sources of Variation	d.f.	SS	MS	F	d.f.	SS	MS	F
Samples	202	10.2678	0.0508	4.7925**	202	6.1756	0.0306	4.8571**
Due to Regression	2	0.1147	0.0574	1.1299	2	0.1908	0.0954	3.1906*
Deviations from Regression	200	10.1531	0.0508		200	5.9848	0.0299	
Fish within Samples	658	6.9835	0.0106		658	4.1715	0.0063	
Total	860	17.2513			860	10.3468		
	$K = 1.25172 + 0.00131X_1 + 0.00056X_2$				$K_b = 0.95861 + 0.00193X_1 + 0.00002X_2$			
	t for $b_1 = 1.2695$ d.f. = 200				t for $b_1 = 2.4445*$ d.f. = 200			
	t for $b_2 = 0.4689$				t for $b_2 = 0.0215$			

X_1 = Temperature ^{o}C

X_2 = Salinity $^{o}/oo$

*, **, denote significance at the .05 and .01 levels, respectively

salinity.

These findings indicate that changes in the condition of spot are associated with habitat, size, season and temperature. Few, if any, of the fish included in this study were large enough to be considered sexually mature, and it is unlikely that gonad development was responsible for the observed changes in condition. I assumed, therefore, that changes in condition represented both changes in body form associated with growth and fatness associated with suitability of the environment.

Dawson (1958), in summarizing condition data for spot from South Carolina, noted a well-defined seasonal variation in monthly mean K (based on standard length) from a winter low of 2.20-2.24 to an August high of 2.60 and concluded that, although gonad development may account for some of the variation, seasonal variation in condition is not restricted to fish approaching sexual maturity. Hildebrand and Schroeder (1928), in discussing the Chesapeake Bay fishery, stated that April spot (152 to 178 mm total length) were not in prime condition and had no marketable value. Pacheco (1957) stated that summer spot were in relatively poor condition, whereas marketable fish were in prime condition during the August-October period. His preferences pertain, primarily, to sexually mature fish. Dawson (1958) commented that, although Pacheco gave no measures of condition, his remarks were largely substantiated by observed seasonal fluctuations in the condition coefficients of South Carolina spot. He also noted that

condition coefficients of pond reared spot at Bears Bluff Laboratories were significantly higher than those of "wild" fish taken during the same month.

BIOLOGY OF THE ATLANTIC CROAKER

Life History

The life cycle of this species is similar to that of the spot with the exception that spawning begins slightly earlier and extends over a longer period. Although Welsh and Breder (1923) stated that spawning took place in the estuaries, Pearson (1929) found that in Texas adults spawn at sea, probably near the passes and channel entrances to the estuaries and lagoons. According to the observations of Pearson (1929), Hildebrand and Cable (1930), Gunter (1945), Suttkus (1955), and Springer and Woodburn (1960), the spawning season extends from September through March. Suttkus (1955), extrapolating his length frequency data, concluded that the bulk of spawning occurred from October through January. Upon hatching, the young move directly into the bays and lagoons which they utilize as nursery grounds. Postlarvae[4] have been reported in these waters as early as October in Texas (Pearson, 1929) and as late as April in Louisiana (El-Sayed, 1961). The peak influx, however, usually occurs during November or December. Hildebrand and Shroeder (1928), Wallace (1940) and Suttkus (1955) noted

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[4]Postlarvae were considered to be fish with a total length less than 30 mm.

that young-of-the-year return to the sea with the onset of cold weather and Wallace found that 1-year-old fish return to the inshore waters in the spring and remain until they approach maturity in late summer. Pearson (1929) and Gunter (1945) concluded that croaker spawn at the end of their second year, whereas Wallace (1940) found that males mature at 2 years of age and females during their third year. The fate of spawned out fish is unknown.

Immigration and Growth

Atlantic croaker were present in both areas throughout the study periods. A total of 4,620 were collected in the Lake Borgne area, and 189,606 from Galveston Bay. The monthly catches for 10 mm size classes from each area are presented in Tables 17 and 18, respectively.

The monthly length-frequency distributions for croaker from the Lake Borgne area are presented in Figure 20. Those fish collected in July, 1959 represented an age-class which probably entered the area as postlarvae during the previous fall or early winter. A few of this group remained in the area as late as July, 1960, but their growth rate was not computed. Postlarvae were first collected in November, 1959 and members of this age-class remained in the area through the end of the survey period in March, 1961. According to Suttkus' (1955) estimated time of peak spawning, these young fish were probably no more than 1-month old when they

Table 17 Monthly catch of Atlantic croaker by size classes from the Lake Borgne area.

Total Length mm	1959 July	Oct.	Nov.	Dec.	1960 Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	1961 Jan.	Feb.	Mar.	Total
10			42	6	27	24	9	1							21	52	77	38	5	302
20			19	29	31	63	26	3							5	6	35	47	65	329
30			2	23	16	41	36	41							4	23	12	24	121	343
40				9	27	51	63	38	22							22	25	30	92	379
50				3	16	43	79	69	101	8						9	17	36	70	451
60	1				6	29	93	115	189	43							13	27	79	595
70	7				3	7	40	147	235	102	6					1	1	12	63	624
80	21				1	3	15	105	254	89	39						1	3	35	566
90	27				2	2	1	47	178	51	81	6					1		6	402
100	10							15	64	50	43	22							2	206
110	1			2				2	24	23	23	20	15							110
120		1	2	11				1	7	12	16	19	8							77
130		1	5	18	1	3	1	1	1	9	5	16	4	1		1				67
140		8	3	17	2	2	3	3	4	1	2	6	3	1	2	10	1		4	72
150			1	4	2	2			4	2		1	1	5	2	7	3	2	8	44
160		1	2					1	3		2			2	6	7	2	2	4	32
170				2					1		2	1		1	1	1			1	10
180							1		1							1			1	4
190												1			2	1				4
200	1								1							1				3
Total	68	11	76	124	134	270	367	589	1089	390	219	92	31	10	43	142	188	221	556	4620

Table 18 Monthly catch of Atlantic croaker by size classes from Galveston Bay.

1963

Total Length mm	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
10	987	1291	3191	490	11	9				1	30	158	6168
20	641	985	3712	1708	27				1	2	42	195	7313
30	626	1053	6195	4843	254		3			3	94	199	13270
40	605	717	7526	9895	4810	98	7			4	139	138	23939
50	153	151	1812	4911	6166	837	39				52	68	14189
60	58	52	589	3196	5840	2660	310	10	2		7	25	12749
70	3	9	297	1781	3402	2422	940	101	16	3	2	15	8991
80	2	8	95	953	2025	1904	1184	226	25	9	5	2	6438
90	1	1	16	503	877	941	998	288	47	20	2	4	3698
100	1	1		149	320	247	449	292	89	35	7	9	1599
110	1		1	35	121	39	182	254	58	39	22	13	765
120	5	18	3	2	62	30	100	143	47	44	54	25	533
130	13	44	11	3	27	10	18	23	29	27	32	36	273
140	22	55	32	2	1	5	3	7	16	12	36	39	230
150	17	35	38	7			4	3	4	4	27	31	170
160	4	12	23	33	1		1		4	2	19	20	119
170	4	2	15	11	15	4	2	1	1	1	5	8	69
180	2	2	18	6	9	1	3	5	2		2	1	51
190		1	2	5	1	2			1			1	13
200	3	1	1	1	1		2	2					11
210				1			2	3		2	2		10
220								1					1
230			1		1	2		2				1	7
240													
250			1	1									2
Total	3148	4438	23579	28536	23971	9211	4247	1361	342	208	579	988	100608

1966

Total Length mm	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
10	184	634	1109	134							30	131	2222
20	168	696	2095	220							65	125	3369
30	171	1058	1750	1430	162						197	209	4977
40	128	1471	2664	5496	2686	67					329	330	13171
50	47	337	1720	2798	4545	559	24				116	168	10314
60	24	125	897	1956	3966	1947	183	4			16	122	9240
70	5	63	347	1107	2280	2470	425	58	3		8	12	6778
80		8	288	708	1277	1717	1113	285	49	16	1	7	5469
90	2	10	292	203	759	926	1129	284	236	91	8	14	3952
100	1	2	2	60	195	371	839	235	281	148	12	8	2154
110	6	1	1	15	112	77	281	205	220	194	18	13	1141
120	11	6	1	2	31	34	59	99	122	189	15	18	587
130	11	6	4	2	3	8	24	16	65	142	12	18	331
140	7	15	51	27	26	6	10	4	56	86	30	37	355
150	10	10	15	3		4	2	7	6	49	6	18	130
160	6	1	11	15	19	8		1	2	10	1	12	86
170	2	3	4	10	2	1		1		6	1	15	45
180	3	2	1	7	1	4	6	3		1	1	9	38
190		1	3	2		2	1	4	1		1		15
200		1		2	2	1	16	7				1	30
210						2	2	1		4			9
220						1		1		1			3
230													
240													
250						1		1					2
Total	784	4450	11255	14197	16066	8204	4116	1216	1061	937	867	1267	64418

1965

Total Length mm	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
10	131	271	87	33				2			11	26	561
20	143	245	307	188							7	13	903
30	297	391	545	801	16						16	28	2094
40	353	638	2000	2202	281	5	1				17	40	5537
50	88	321	1424	1386	1117	63	10				2	39	4450
60	63	154	477	1057	1322	484	52	1				37	3647
70	30	110	159	655	651	1054	228	9	1			3	2900
80	4	46	40	257	444	703	313	92	17	1			1917
90	6	37	102	79	318	257	140	124	38	12	3	1	1117
100	4	5	12	21	236	140	62	59	40	16	10	17	622
110		4	1	18	53	19	31	21	33	24	25	32	261
120			2	7	40	13	4	1	24	24	12	31	158
130	11	2		1	5	14	2	1	9	13	9	32	99
140	9	18	4		6	4	1	1	4	7	6	27	87
150	12	8	17		17	1	4		1	3	1	2	66
160	33	17	9	1	3		1		1			2	67
170	10	16	3	2	3							1	35
180	1	6	1	1	3						1		13
190	2	2		1	1		5		1				12
200			1		10			1					12
210		2	1	1				1					5
220					10								10
230			1				1						2
240					1								1
250		2				2							4
Total	1197	2295	5193	6711	4537	2759	855	313	169	100	120	331	24580

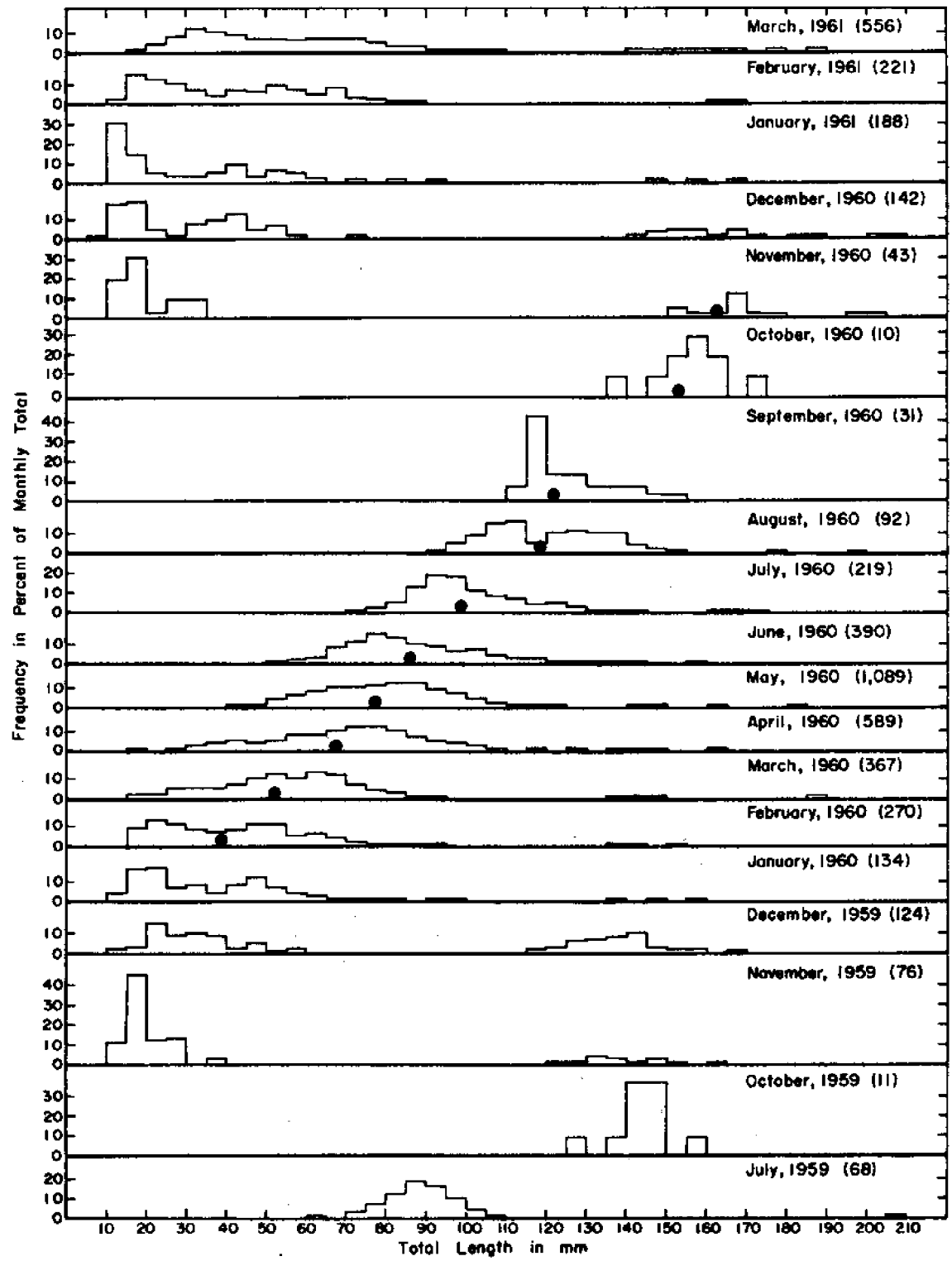


Figure 20. Monthly length-frequency distributions of Atlantic croaker from the Lake Borgne area. Dots denote monthly mean lengths used in computing the growth rate of age-class-0 fish.

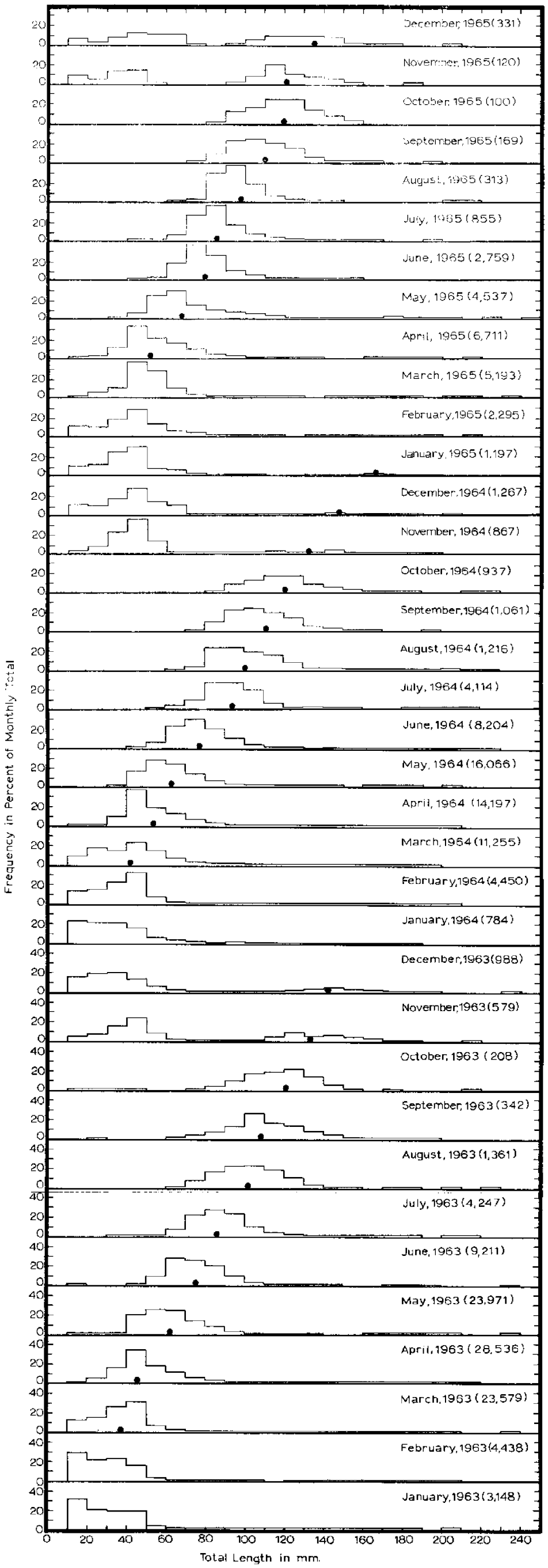
first appeared. Growth of this age-class was evident from November, 1959 through November, 1960. The apparent leveling off of the growth rate thereafter must have resulted because larger fish either left the area or were able to elude the trawl. During the first few months after postlarvae appeared, the growth rate was slightly distorted by the immigration of new postlarvae into the area. For this reason growth computations covered only the period from February through November, 1960. The growth rate (based on a linear regression of monthly mean lengths of age-class-0 fishes) along with the age prediction equation and other pertinent statistical information are presented in Table 19. Postlarvae again appeared in the area in November, 1960, but sampling was terminated before adequate data to measure the growth rate of the new year-class were collected. The period over which postlarvae were present during a given sequence approximated 6 months and is probably indicative of the period over which spawning occurred.

According to the monthly length-frequency distributions for croaker from Galveston Bay (Figure 21) those fish collected from January through December, 1960 represented an age-class which probably began entering the bay the previous fall. The growth rate of this group was computed, based on monthly mean lengths of fish taken from March through December, 1960. Immigration of young-of-the-year was evidenced by the appearance of postlarvae in September, 1960. The growth rate for this group was computed,

Table 19. Age prediction equations, growth rates and pertinent statistical computations for growth data of Atlantic croaker from the Lake Borgne area and Galveston Bay.

Area	Age Prediction Equation	Σx^2	Σy^2	Σxy	$s^2_{y.x}$	b	n	Test Criterion	d.f.
Lake Borgne									
1. Feb. 1960-Nov. 1960	Y = -1.535 + 0.072X	82.500	15,474.409	1,120.250	32.847	13.579	10	V = 2.567*	8,19
Galveston Bay								V = 4.727**	8,7
2. Mar. 1963-Dec. 1963	Y = -2.250 + 0.084X	82.500	11,478.724	968.500	13.640	11.739	10	t = 0.281	17
3. Mar. 1964-Jan. 1965	Y = -2.359 + 0.083X	110.000	15,762.609	1,313.100	9.753	11.937	11	t = 2.101	15
4. Apr. 1965-Dec. 1965	Y = -4.563 + 0.099X	60.000	6,027.540	597.4	11.345	9.957	9	t = 2.686*	16
5. Groups 2 and 3 Combined	Y = -2.361 + 0.084X	192.500	27,241.333	2,281.600	10.460	11.852	21		
	Y = age in months	x = age in months							
	X = mm total length	y = mm total length							
		b = growth rate in mm total length per month							
		* denotes significance at the .05 level							
		** denotes significance at the .01 level							

Figure 21. Monthly length-frequency distributions of Atlantic croaker from Galveston Bay. Dots denote monthly mean lengths used in computing growth rates of age-class-0 fish.


December, 1965 (331)
November, 1965 (120)
October, 1965 (100)
September, 1965 (169)
August, 1965 (313)
July, 1965 (855)
June, 1965 (2,759)
May, 1965 (4,537)
April, 1965 (6,711)
March, 1965 (5,193)
February, 1965 (2,295)
January, 1965 (1,197)
December, 1964 (1,267)
November, 1964 (867)
October, 1964 (937)
September, 1964 (1,061)
August, 1964 (1,216)
July, 1964 (4,114)
June, 1964 (8,204)
May, 1964 (16,066)
April, 1964 (14,197)
March, 1964 (11,255)
February, 1964 (4,450)
January, 1964 (784)
December, 1963 (988)
November, 1963 (579)
October, 1963 (208)
September, 1963 (342)
August, 1963 (1,361)
July, 1963 (4,247)
June, 1963 (9,211)
May, 1963 (23,971)
April, 1963 (28,536)
March, 1963 (23,579)
February, 1963 (4,438)
January, 1963 (3,148)
Frequency in Percent of Monthly Total
Total Length in mm.

based on monthly mean lengths of fish taken from March, 1964 through January, 1965. Young-of-the-year again appeared in the bay in November, 1964 and their growth rate was computed based on monthly mean lengths of fish taken from April through December, 1965. Growth rates for each age-class along with an age prediction equation and other pertinent statistical information are presented in Table 19 (Page 103).

For the age-class which was present in the area in January, 1963, immigration of postlarvae continued until June but terminated after April for later age-classes and for croaker from the Lake Borgne area. The period over which postlarvae were present during a complete sequence varied from 8 months during 1963-64 to 6 months during 1964-65 and is probably indicative of the year-to-year variability in the duration of spawning. Hildebrand and Cable (1930) found postlarvae in their catches in Beaufort, North Caroline over a 9-month period from September through the following May. According to previous studies, the time at which spawning is initiated and the duration of the spawning period vary from year to year and geographically. Spawning probably begins in August in Chesapeake Bay and Northward (Hildebrand and Schroeder, 1928), in September at Beaufort, North Carolina (Hildebrand and Cable, 1930), and usually in October or November in Louisiana and Texas (Pearson, 1929; Suttkus, 1955; and this study); and probably ends in December or January in Chesapeake Bay and northward, in

April at Beaufort, North Carolina and between April and June in Louisiana and Texas.

The growth rates of croaker in the Lake Borgne area and Galveston Bay were compared using the statistical tests employed previously for spot. The results are presented in Table 19 (Page 103). There was essentially no difference in the growth rates in groups 2 and 3 from Galveston Bay. These rates were higher than that for group 4 but only the difference between groups 3 and 4 could be declared significant. To simplify testing, data for groups 2 and 3 were combined and the resulting growth rate (group 5) along with that for group 4 were compared with the growth rate for croaker from the Lake Borgne area. In both instances, the growth rate was significantly higher in the Lake Borgne area. These findings indicate a significant year-to-year and geographical variation in growth.

The growth rates at various localities along the Atlantic and Gulf coasts have been compiled (Table 20), based on length-frequency estimates, and clearly reflect geographical variation. For 1-year-old fish, growth estimates ranged from 9.0 mm per month at Pensacola, Florida (Hansen, 1970) to 15.0 mm per month at Pamlico Sound, North Carolina (Higgins and Pearson, 1927) and for 2-year-old fish from 5.0 mm per month in Texas (Pearson, 1929) to 5.8 mm per month in New Jersey (Welsh and Breder, 1923). Welsh and Breder (1923) and Pearson (1929) estimated the growth of croaker during their third year at 3.8 and 3.3 mm per month, respectively. No distinct geographical

Table 20. The age-length relationship of the Atlantic croaker as indicated by past studies on the Atlantic and Gulf coasts and this investigation. All measurements represent total length in mm. Numbers in parentheses represent monthly growth rates.

Author	Method	Area	Total Length in mm at Age: 1 year	2 years	3 years
Welsh and Breder (1923)	Length-frequency	New Jersey	150 (12.5)	220 (5.8)	265 (3.8)
Higgins and Pearson (1927)	Length-frequency	Pamlico Sound, N. C.	180 (15.0)	240 (5.0)	
Pearson (1929)	Length-frequency	Texas	180 (15.0)	240 (5.0)	280 (3.3)
Hildebrand and Cable (1930)	Length-frequency	Beaufort, N. C.	143.4 (12.0)		
Suttkus (1955)	Length-frequency	Louisiana	145.0 (12.1)		
Hansen (1970)	Length-frequency	Pensacola, Florida			
		1964	108.0 (9.0)		
		1965	129.6 (10.8)		
This Investigation	Length-frequency	Lake Borgne	162.9 (13.6)		
		Galveston Bay			
		1963-64	140.9 (11.7)		
		1964-65	143.2 (11.9)		
		1965	119.5 (9.9)		

pattern was evident, however, and I concluded that these variations probably represented a combination of gear selectivity, inaccuracies in the techniques used to estimate growth, and year-to-year fluctuations resulting from local environmental differences. These suggested environmental differences most likely constitute variations in temperature and food. To what extent conditions varied between the Lake Borgne area and Galveston Bay to produce the higher growth rates in the Lake Borgne area is not known.

Averaging the estimates included in Table 20 (Page 108), croaker grew at a rate of 12.1 mm per month during their first year and attained a length of 145.6 mm; 5.3 mm per month during their second year and attained a length of 208.8 mm; and 3.6 mm per month during their third year and attained a length of 251.4 mm.

Authors in several localities have reported differences in the age at which croaker spawn. Welsh and Breder (1923) concluded that maturity was reached in New Jersey waters at 3 or 4 years while Pearson (1929) and Gunter (1945) reasoned that croaker in Texas spawn at the end of their second year. Wallace (1940) examined gonads of almost 1,000 croaker of various ages from Chesapeake Bay and the ocean and found that 45% of the males reached maturity at the end of their second year and that all spawned in subsequent years. The smallest mature male was 240 mm total length. No females gave indications of ripening at 2 years. The smallest female observed was 275 mm total length. He also concluded that

most of the spawning was over by the end of November. Avault, et al. (1969) found that both male and female pond-reared croaker in Louisiana were sexually mature when approximately 1-year old. They observed while handling these fish that both eggs and sperm flowed freely. According to Hansen (1970), both male and female croaker in the Pensacola estuary had developing gonads in the fall of their first year.

The means by which postlarvae enter the estuaries and disperse is not fully understood. Pearson (1929) observed that young croaker at Aransas and Corpus Christi Passes came into the bays from the Gulf on incoming tidal currents. On the ebb tide, he noticed these young fish massed in schools and attempting to enter the passes by hugging the sides of the channels, apparently, to take advantage of the slower currents. He found young croaker throughout the bays and observed that some remained in the Gulf, but he did not attempt to explain the means by which these fish dispersed in the nursery areas. Wallace (1940) concluded that larval croaker were carried into and up Chesapeake Bay by deep channel currents of more saline water. Presumably these young fish then disperse to other localities as they become free-swimming.

Seasonal Abundance

In the Lake Borgne area, croaker were caught in greatest numbers from March through June, 1960 (Figure 22). Catches in-

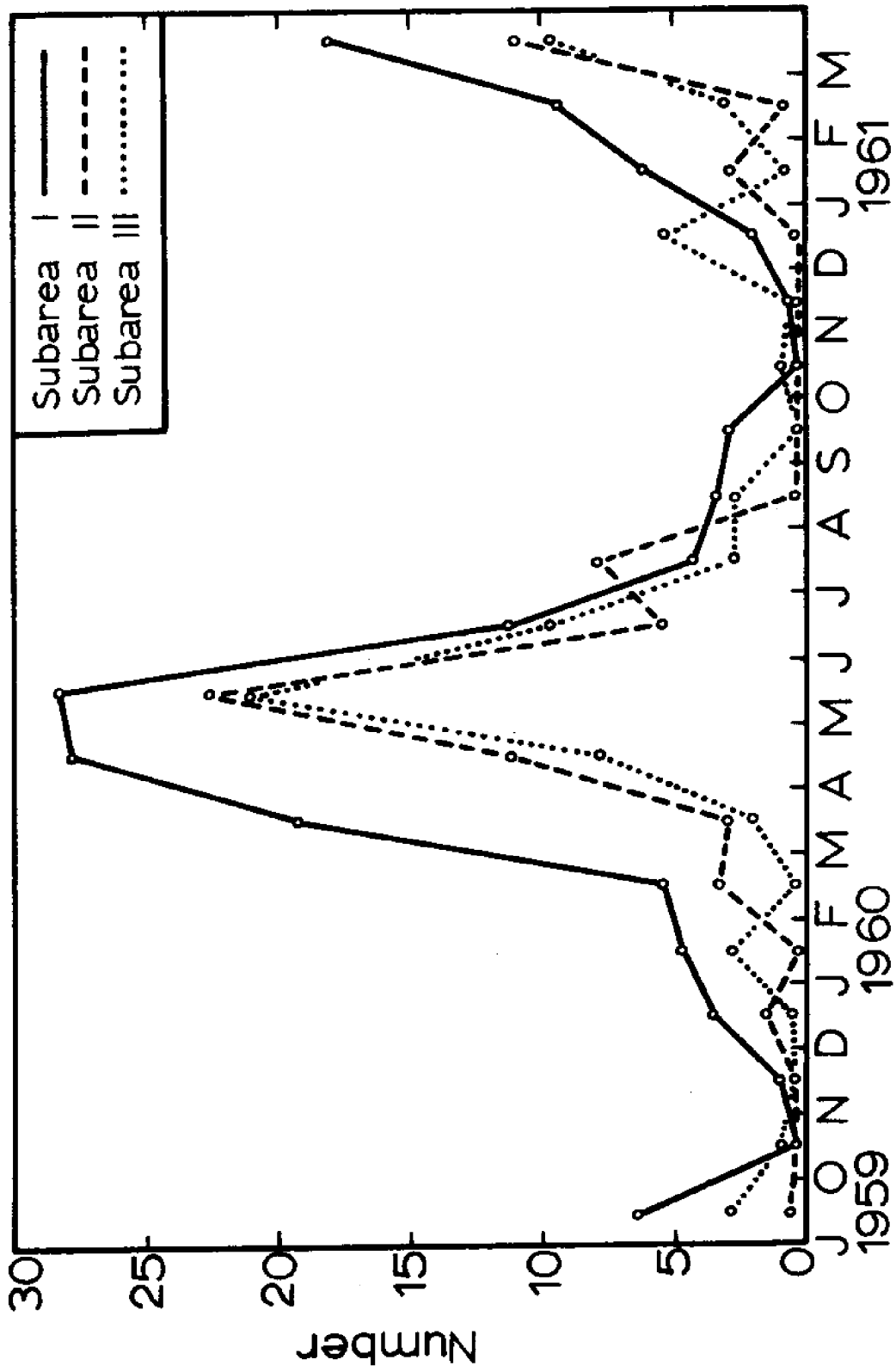


Figure 22. Relative abundance of Atlantic croaker from the Lake Borgne area by subareas during the period from July, 1959 through March, 1961 in terms of monthly mean catch-per-tow.

creased rapidly after February, 1960 and were highest in May. The significant decline in numbers during June and July was probably the result of an exodus of croaker back to the Gulf. These relative abundance figures are somewhat misleading due to the selectivity of the trawl on various sizes of fish. Postlarvae, 1- and 2-months old, are small enough to pass through the net and fish older than 1 year are frequently able to elude the trawl. Postlarvae were more abundant than any other size group and were present in the area in November and December, 1959 and January and February, 1960 when catches were relatively low. The rapid increase in catch during March, April and May resulted when these young fish grew to a catchable size, and very likely depicts a time-lag record of the earlier rate of influx of postlarvae. The rapid decline in catches during June and July, however, cannot reasonably be attributed to gear selectivity resulting from growth beyond a catchable size or to mortality. The greatest decline in catches occurred during May and June. Growth over this period amounted to only about 27 mm and does appear to be enough increase in size to account for the drastic reduction in catches. Mortality, either by predation or other causes, could not be estimated, but does not, in my opinion, provide a suitable explanation for the rapid decrease in numbers. The decline in catch after May was most likely evidence of mass movement of croaker out of the survey area and into the Gulf. Hansen (1970) stated that monthly

changes in abundance were caused primarily by migration and to a lesser extent by mortalities. This presumed seaward emigration began when croaker averaged about 85 mm total length (see Figure 20, Page 101). In 1961, catches began increasing in January but sampling was terminated before peak abundance was reached.

In Galveston Bay, croaker were caught in greatest numbers during the period from March through June in each year (Figure 23) and the highest monthly catch was taken in April, 1963, May, 1964, and March, 1965. Fluctuations in relative abundance followed much the same pattern as in the Lake Borgne area. The rapid increase in catch during each year was indicative of the earlier rate of influx of postlarvae. Judging from the slopes of the lines, mass immigration of postlarvae occurred over a much longer period in 1963 and 1964 than in 1965. The rapid decline in catches during each year was probably the result of an exodus of croaker back to the Gulf. Seaward emigration began after April, 1963, after May, 1964, and after April, 1965. When emigration began, croaker averaged about 60 mm in 1963, 75 mm in 1964, and 80 mm in 1965 (see Figure 21, Page 105). These were smaller than the first emigrants from the Lake Borgne area.

Galveston Bay supported a sizable biomass of croaker from April through August in 1963 and 1964 and from February through June in 1965. Relative biomass was highest in late April, 1963 and in May, 1964 and 1965. The decline in relative biomass lagged behind

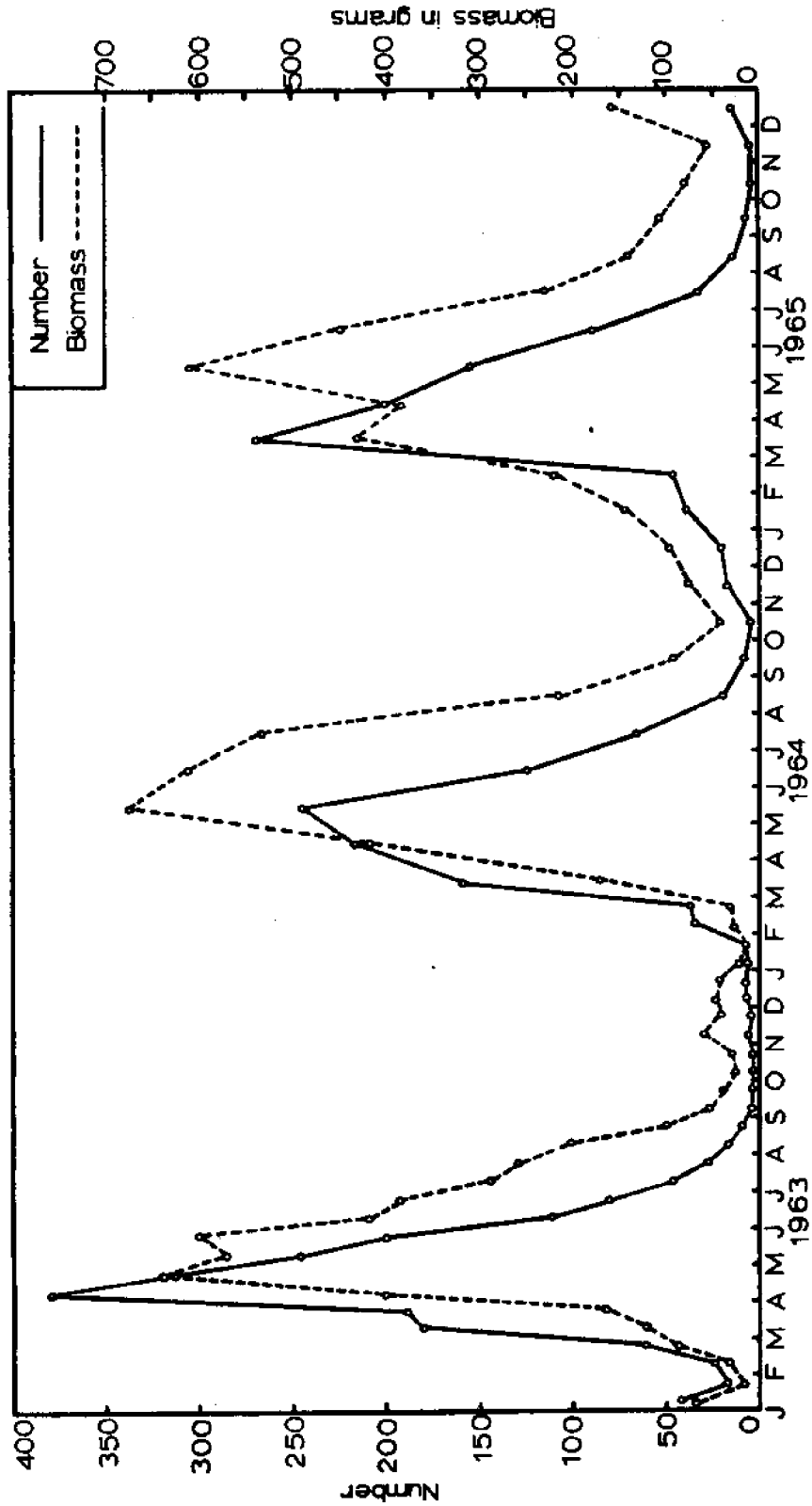


Figure 23. Relative abundance and biomass of Atlantic croaker from Galveston Bay during the period from January, 1963 through December, 1965 in terms of mean catch-per-tow by sampling period.

the decline in numbers by almost a month in 1963 and almost 2 months in 1964 and 1965.

It would appear that relative numbers were higher in 1963 than in 1964 or 1965, however, a comparison of equivalent monthly means revealed no significant differences. The variation between station catches within months was considerably large in every instance and undoubtedly obscured any difference between monthly means which may have existed.

Hildebrand and Schroeder (1928) found that croaker were common in Chesapeake Bay during the summer and that they became scarce in late September or October with the arrival of cool weather. They concluded that this fish leaves the bay upon the approach of winter. Wallace (1940) stated that croaker were strictly summer visitors to inshore waters and migrate to warmer offshore waters with the approach of cold weather. Immature fish, he found, remained in Chesapeake Bay until driven out by adverse temperatures, whereas mature fish began to leave earlier in preparation for spawning. For these mature fish, he predicted a seaward spawning migration extending from July through November, with males beginning the journey before females. His tagging experiments revealed that immature croaker stayed locally until late in the fall, long after the mature fish had completed their spawning migrations. Suttkus (1955) noted a similar migration of immature croaker from Lake Pontchartrain during September, October and November. He observed that the drop

in water temperature was directly correlated with this movement of fishes out of the lake and was possibly the controlling factor. He also commented that some individuals spend the entire first year and a half in the lake. Hansen (1970) stated that the migration of Atlantic croaker out of the Pensacola estuary begins in late summer and ends before November. The decline in catches which I observed during May, June and July in the Lake Borgne area and Galveston Bay indicate, to the contrary, that the majority of immature young-of-the-year migrate offshore during warm weather. Some remain and continue to grow in the inshore waters throughout the winter but their numbers are comparatively few.

Areal Abundance

The seasonal variation in catch of spot from the Lake Borgne area is presented by subareas in Figure 22 (Page 111). A comparison of monthly mean catches between subareas indicated that numbers in subarea I were significantly higher than in subareas II and III only during March and April, 1960. No significant differences in catch could be detected between subareas II and III. The analysis of variance for catch comparisons which yielded significant differences and the probability levels by which these differences were declared are presented in Table 21. If the areas under the relative abundance lines in Figure 22 (Page 111) are considered as measures of relative density, subarea I carried about twice the density of subareas II and III. Catches in subareas I, II, and III yielded 1,815, 914, and 933 fish respectively.

Table 21. Analysis of variance of comparisons of subareal monthly mean catches of Atlantic croaker from the Lake Borgne area and the significant distinction between these means based on the results of a modification of Duncan's New Multiple Range Test (Kramer, 1956).

March, 1960 - Analysis of Variance

Sources of Variation	d.f.	SS	MS	F
Among Subareas	2	2,133.8	1,066.9	11.068**
Within Subareas	34	3,277.4	96.4	
Total	36	5,411.2		

Results of Duncan's Test

Subarea	I	II	III	
Mean Catch	19.18	2.92	2.29	.05 Confidence Level
				.01 Confidence Level

April, 1960 - Analysis of Variance

Sources of Variation	d.f.	SS	MS	F
Among Subareas	2	2,772.3	1,386.2	5.376**
Within Subareas	35	9,024.9	257.9	
Total	37	11,797.2		

Results of Duncan's Test

Subarea	I	II	III	
Mean Catch	27.83	11.21	7.92	.05 Confidence Level
				.01 Confidence Level

** denotes significance at the .01 confidence level

The areal distribution of croaker in Galveston Bay in terms of numbers and biomass is presented in Figure 24. The quantitative divisions of both numbers and biomass were based on what appeared to be major delineations in distribution. There was little difference between the distribution patterns of numbers and biomass, indicating that all size classes were distributed in essentially the same manner. This was further substantiated by plotting the areal distribution of individual 10 mm size classes.

In 1963 croaker were concentrated in greatest numbers in Trinity Bay near the mouth of the Trinity River, in Upper Galveston Bay at the entrance to the Houston Ship Channel, in the upper end of East Bay, and in the Dickinson Bay-Moses Lake area. High concentrations in 1964 were observed near the mouth of the Trinity River, in Clear Lake, and in the upper end of East Bay. This pattern was expanded in 1965 to include the mouth of Cedar Bayou, the western portion of Upper Galveston Bay, and the Dickinson Bay-Moses Lake area. The distribution of biomass extended into the open waters to a greater degree than numbers and would appear to indicate a dispersion of larger fish towards the open waters. To some extent, fish larger than 100 mm were more evenly distributed throughout the bay, but judging from the seasonal distribution pattern these were fish which I presumed were migrating back to the Gulf. The bulk of catches included fish smaller than 80 mm and for these, distribution remained essentially unchanged throughout the size range.

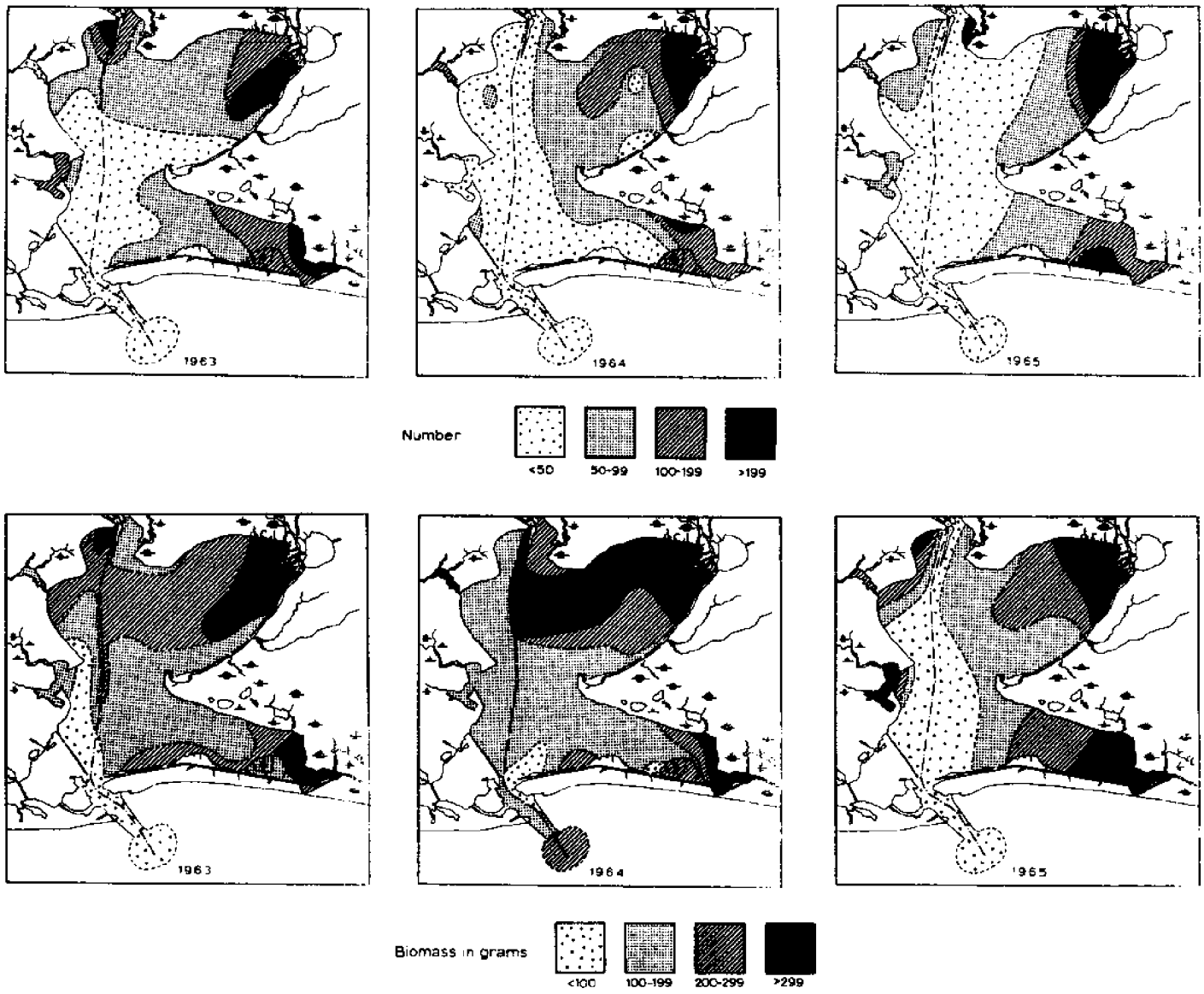


Figure 24. Areal distribution of numbers and biomass of Atlantic croaker in Galveston Bay based on annula mean catch-per-tow by station.

The large concentrations of croaker were always observed in shallow waters less than 1.2 m deep and in close proximity to a source of fresh or brackish water which generally flowed through marshes or tidal flats before entering the bay. The bottom in these areas was generally soft mud containing large quantities of detritus. The deeper bay waters, and especially those in Lower Galveston Bay, yielded the fewest fish and I concluded that these waters did not provide nursery habitat for the Atlantic croaker. Catches were also extremely low in the Houston Ship Channel. Based on numbers, 80% of the croaker caught in Galveston Bay were taken in the areas shaded in Figure 25. These constitute the primary nursery areas for this species in Galveston Bay. Most likely young croaker prefer these areas because they afford a greater food supply and protection from predators. Reid (1955B) found that his trawl and seine catches from East Bay yielded highest numbers of croaker in the upper area of the bay in waters where the bottom was thick, loose mud. In discussing the ecological requirements of these fish, he commented that cover, to man's eye at least, was non-existent and that the population mass was maintained by sheer force of numbers. I observed, however, in reflecting on my field notes, that the waters in which croaker were commonly found were generally turbid and I considered turbidity a form of cover or protection from predators.

Wallace (1940) noted that larval croaker were found during

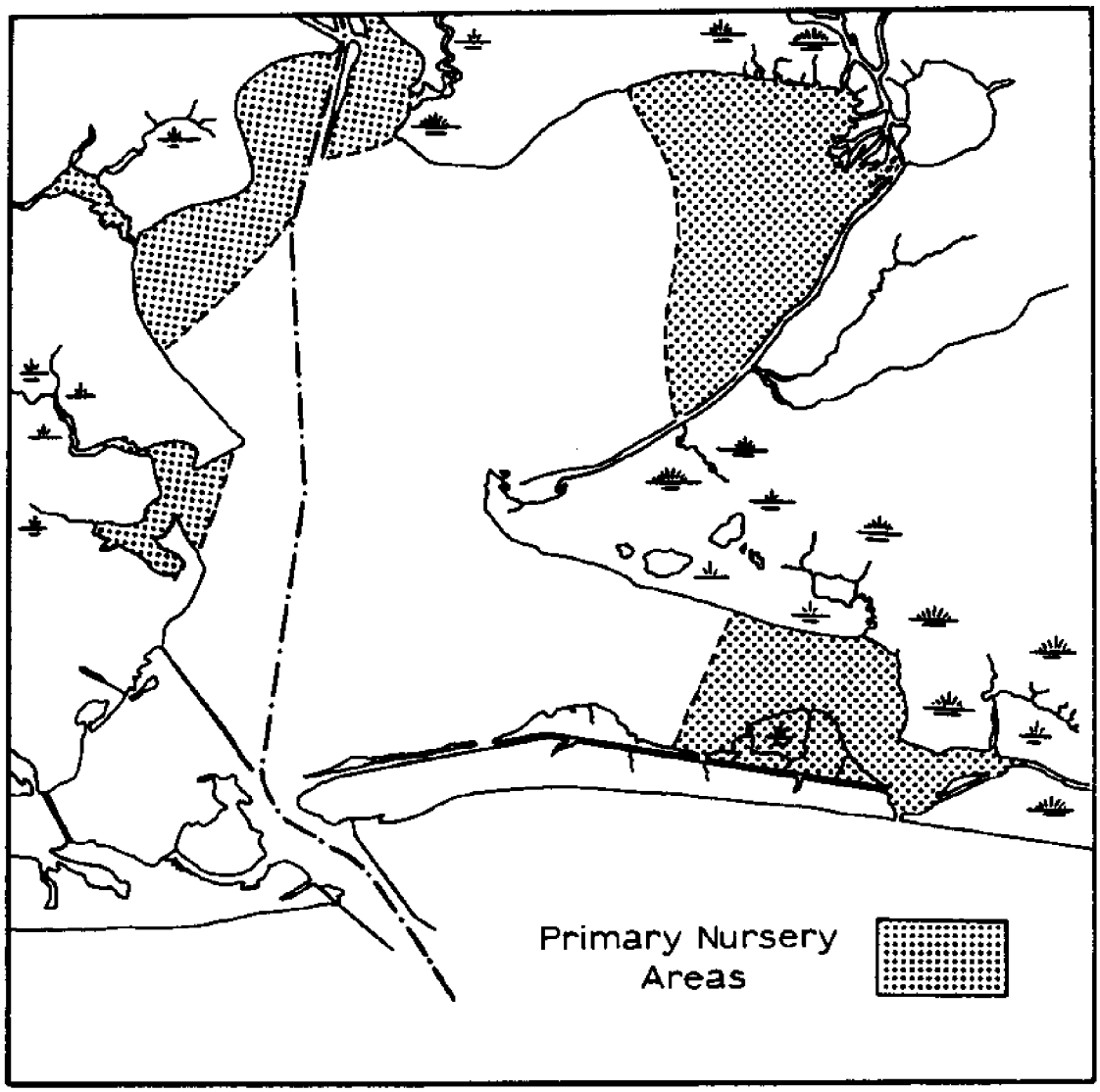


Figure 25. Primary nursery areas for the Atlantic croaker in Galveston Bay.

the winter months only in deep channel waters of Chesapeake Bay and that they were much smaller and more numberous at the mouth of the bay than those found in the upper parts of the bay. According to Suttkus (1955), croaker in Lake Pontchartrain were trawled in greater numbers from the deep channels than from the shallow flats. He also noted that specimens taken from the north shore averaged larger than those taken from the south shore and speculated that young croaker group after they enter the lake, remaining in more or less discrete populations throughout the spring and summer. Haven (1957) found that small croaker in Chesapeake Bay estuary were usually more abundant upriver and there was a gradual increase in average length toward the bay. He also noted that O-age-group croaker were most abundant in the relatively deep waters of the river channels and seldom moved in close to the shore line.

The extent to which croaker penetrate and utilize the marshes was examined in more detail in the West Bay marsh. Monthly station catches, based on 3-minute trawls taken twice monthly, are presented in Table 22 from the time postlarvae first appeared in November, 1967 through the period of peak abundance. A dense growth of filamentous algae throughout the tidewater areas, coupled with low tides, restricted trawling efforts after May. According to these catches, croaker were most abundant in January and numbers declined thereafter. During the time that abundance declined, croaker were averaging 50 to 70 mm total length which was typical

Table 22. Monthly catch of young Atlantic croaker by station in the West Galveston Bay marsh.

Month	Stations				
	Marsh		Oyster Lake		
	A	B	C	D	Total
Nov., 1967	8	7	0	7	22
Dec.	6	3	11	13	33
Jan., 1968	3	577	89	160	829
Feb.	145	353	0	30	528
Mar.	0	74	211	63	348
Apr.	47	158	0	0	205
May	9	50	0	0	59
Total	218	1,222	311	273	2,024

of the size of gulfward migrants in Galveston Bay, and I assumed that this decline in abundance was the result of croaker leaving the area on their gulfward migration. Catches were highest at station B and reflected the ability of croaker to penetrate deeply into the marsh. This station was located in a tidewater marsh lake at the mouth of a brackish water bayou. Station A was also located in a tidewater marsh lake, but this lake was not in close proximity to a fresh or brackish water bayou. A narrow ditch connected the lake with other saline marsh ponds, but the flow here was restricted such that daily tidal fluctuations were not measurable in the inland ponds. Catches at station A were low and comparable with those in Oyster Lake. Bottom sediments at both marsh stations consisted of soft mud with a high silt content, whereas sand predominated in the sediments in Oyster Lake. A considerable amount of organic debris was consistently present in the sediments at station B. Whatever the attractant, tidewaters in the vicinity of fresh or brackish water bayous or rivers provide prime nursery habitat for the Atlantic croaker.

Trent (1969) compared the abundance of croaker in West Galveston Bay in natural marshes and marshes which had been channeled and bulkheaded for resort developments. He found that croaker were abundant at four of five stations in the altered area and one of five stations in the natural marsh. The natural marsh station was located at the upper end of a long, narrow marsh lake more like

the habitat I observed in Oyster Lake. He speculated that differences in bottom composition in the altered area explained the higher numbers there, contending that croaker preferred areas with a soft bottom. He found no difference in size of croaker in the altered and natural areas and no difference in day-night catches.

The presence of croaker in marsh waters of the intertidal zone was observed on several occasions in the West Bay marsh and, although the data were not quantitative, conclusions could be made concerning the suitability of these waters as habitat. Croaker, along with other marine species, were able to enter the marsh during abnormally high tides. After waters had receded following a tidal flood, many dead croaker were observed scattered over the marsh vegetation. Many more were trapped in ponds, but conditions were seldom favorable for their return to the bay and depended upon another tidal flood within a relatively short period of time. These trapped fish usually died as a result of freshwater flooding, low temperatures during the winter, or drought conditions during the summer. Gunter (1950B) speculated on a similar fate for marine species, including croaker, in saline marsh ponds on the Aransas Wildlife Refuge in Texas.

Distribution Related to Temperature

The effects of temperature on the distribution and survival of croaker has been considered by a number of authors. Hildebrand and

Schroeder (1928) reported croaker in Chesapeake Bay moved to the deeper waters of the channels with the onset of cool weather in September and October and eventually left the bay with the approach of winter. Hildebrand and Cable (1930) noted the absence of croaker over 1 year of age in shallow waters during the winter at Beaufort, North Carolina and concluded that the winter home for large or adult croaker was offshore at depths greater than 1.8 m. Wallace (1940) stated that croaker from Chesapeake Bay were strictly summer visitors to inshore waters and migrated to warmer offshore waters with the approach of winter. Suttkus (1955) noted a similar migration of immature croaker from Lake Pontchartrain during September, October and November. He observed that the drop in water temperature was directly correlated with this movement of fishes out of the lake and was possibly the controlling factor.

No references were found concerning the tolerance of this species to high temperatures but several have been noted on lethal low temperatures. Hildebrand and Cable (1930) found croaker, 178 to 254 mm total length numb and drifting ashore at Beaufort, North Carolina after a 6-day cold spell when water temperatures ranged from 5 to 9 C. They noticed no mortality among smaller fish (fry) and, in fact, repeatedly took large numbers in very active condition during similar cold snaps. They concluded that young croaker are less sensitive to low temperatures than older fish. Gunter and Hildebrand (1951) reported stunned and dead croaker lining

the shore of Aransas Pass harbor following a 6-day period when air temperatures ranged between -7.8 and -3.9 C. In summarizing observations made during killing freezes in Texas in 1940, 1941, 1947, 1949, and 1951, they noted that when damaging cold waves are preceded by other freezes their destructive effect is lessened. Some fish escape to deep water if the onset of the cold weather is slow and they contended that the rate of decline in temperature following a cold snap is a factor influencing mortality. Schwartz (1964) reported the deaths of an adult and two young aquarium-held croaker taken from Chesapeake Bay at temperatures of 3.3, 0.6 and 0.0 C respectively.

As was noted previously, croaker were year-round inhabitants of both study areas. In the Lake Borgne area they were collected at temperatures ranging from 5.2 to 34.9 C and in Galveston Bay from 0.4 to 35.5 C. The extremes in the Lake Borgne area were observed in the shallow open waters and the extremes in Galveston Bay were both observed in the shallow marshes of East Bay. No mortalities due to either extreme were observed.

The relative abundance of croaker in the Lake Borgne area (Table 23) was highest at temperatures between 21 and 25 C and was also high at temperatures between 6 and 10 C. Relative abundance was lowest at temperatures <6 C. These catch figures are weighted in favor of the size fish most easily caught by the trawl (50-110 mm) and should not be interpreted to represent temperature preference

Table 23. Relative abundance of Atlantic croaker in the Lake Borgne area as related to temperature.

Temperature °C	Number of Tows	Number Caught	Mean Catch Per Tow
<6	1	2	2.00
6-10	31	249	8.03
11-15	95	250	2.63
16-20	95	499	5.25
21-25	77	723	9.39
26-30	193	1,066	5.52
31-35	67	336	5.01
Total	559	3,123	5.59

for all sizes. Postlarvae croaker entered the area during the colder period of the year (November through March) and were obviously both abundant and well adapted to temperatures in the 6 to 20 C range, whereas, fish approaching 1 year of age or older were noticeably absent at temperatures below 10 C.

The monthly mean temperatures at which croaker were collected in the Lake Borgne area are presented in relation to the overall area monthly mean temperatures in Figure 26A. In most months, croaker appeared to be rather evenly distributed over the range of available temperatures. In December, 1959 and March, April, May September and December, 1960, they were collected at mean temperatures lower than the area mean temperatures and in July, 1959 and February, 1961 they were collected at a mean temperature higher than the area mean temperatures. These differences do not appear to represent any pattern and were assumed to be the result of sampling error. In January, February and December, 1960, croaker were absent at temperatures below 8 C but were present at similar temperatures in December, 1959 and January, 1961.

Mean temperatures and temperature ranges for 10 mm size classes are presented in Figure 26B. For fish between 10 and 119 mm, mean temperatures increased gradually with increasing size from 12.8 C for 10-19 mm fish to 28.4 C for 110-119 mm fish. This should be expected since postlarvae entered the area during the colder period of the year and grew in gradually warming waters. These findings

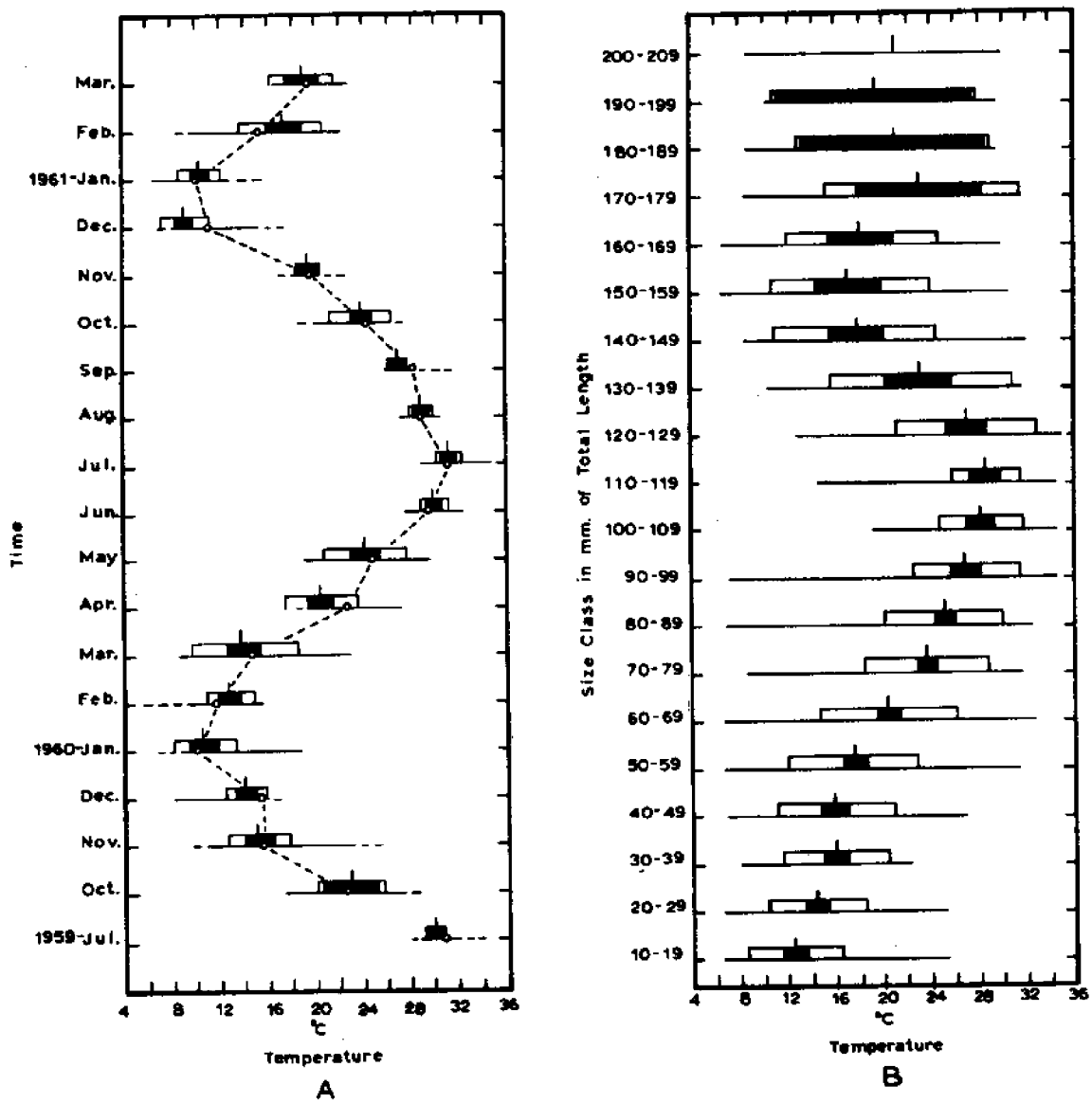


Figure 26. A - Monthly mean, $s_{\bar{x}}$, 2σ of the mean and range of temperatures at which Atlantic croaker were collected in the Lake Borgne area superimposed on the monthly areal mean temperatures.

B - Mean, $s_{\bar{x}}$, 2σ of the mean and range of temperatures at which Atlantic croaker were collected in the Lake Borgne area computed by 10 mm size classes.

indicate that croaker grow well at temperatures between 12.8 and 28.4 C. Temperatures over which growth takes place probably range both lower and higher than these figures but the data were not collected in a manner to yield definite limits. For fish between 120 and 159 mm, mean temperatures declined with increasing size. Above 160 mm data were not adequate to allow reliable predictions. Croaker larger than 120 mm represent those few fish which winter over in the nursery areas. The temperature range was comparatively narrow for small croaker, but as size increased the range broadened and was greatest for 90-99 mm fish.

The relative abundance of croaker in Galveston Bay (Table 24) was highest in 1963 at temperatures between 16 and 20 C, in 1964 at temperatures between 26 and 30 C, and in 1965 at temperatures between 31 and 35 C, whereas, abundance was lowest in each year at temperatures between 6 and 10 C. These catch figures, like those from the Lake Borgne area are weighted in favor of the size fish most easily caught by the trawl (50-110 mm) and should not be interpreted to represent the temperature preference for all sizes. Postlarvae croaker were abundant in the bay during the winter and appeared to be well adapted to temperatures in the 6 to 20 C range, whereas fish approaching 1 year of age or older were noticeably absent at temperatures below 10 C. Findings in both study areas indicated that large croaker may not be as well adapted to low temperatures as are postlarvae and young juveniles and

Table 24. Relative abundance of Atlantic croaker in Galveston Bay as related to temperature.

Year	Temperature °C	Number of Tows	Number Caught	Mean Catch Per Tow
1963	<6	22	538	24.45
	6-10	137	2,100	15.33
	11-15	215	8,769	40.79
	16-20	106	13,902	131.15
	21-25	313	36,453	116.46
	26-30	505	54,598	108.11
	31-35	194	5,060	26.08
	Total	1,492	121,420	81.38
1964	<6	5	83	16.60
	6-10	71	393	5.54
	11-15	202	5,312	26.30
	16-20	153	18,183	11.85
	21-25	156	8,646	55.42
	26-30	263	28,325	107.70
	31-35	32	886	27.69
	Total	882	61,828	70.10
1965	<6	2	45	22.50
	6-10	18	88	4.89
	11-15	166	10,967	66.07
	16-20	226	1,475	6.53
	21-25	246	4,580	18.62
	26-30	392	9,830	25.08
	31-35	23	747	32.48
	Total	1,072	27,732	25.87

agrees with Hildebrand and Cable's (1930) contention that young-of-the-year are less sensitive to cold.

Monthly mean temperatures at which croaker were collected in Galveston Bay are presented in relation to the overall area monthly mean temperatures in Figure 27. As in the Lake Borgne area, croaker appeared to be rather evenly distributed over the monthly temperature ranges. In the first winter of sampling, (January and February, 1963) they were collected at mean temperatures slightly higher than the areal mean temperatures, in the second winter (December, 1963 and January, 1964) at mean temperatures slightly lower than the areal mean temperatures and in the third winter (December, 1964 through February, 1965) at mean temperatures almost identical with the areal mean temperatures. Since there was little difference in the areal means during these successive winters it seems likely that these observed differences were the result of sampling error.

Mean temperatures and temperature ranges for 10 mm size classes are presented in Figure 28. The pattern of variation in means was similar to that described for croaker in the Lake Borgne area. Mean temperatures increased with increasing size in 1963 from 16 C for 10-19 mm fish to 28 C for 110-119 mm fish; in 1964 from 17 C for 10-19 mm fish to 28 C for 110-119 mm fish; and in 1965 from 14 C for 10-19 mm fish to 26 C for 100-109 mm fish. Mean temperatures declined with increasing size in 1963 from 28 C for

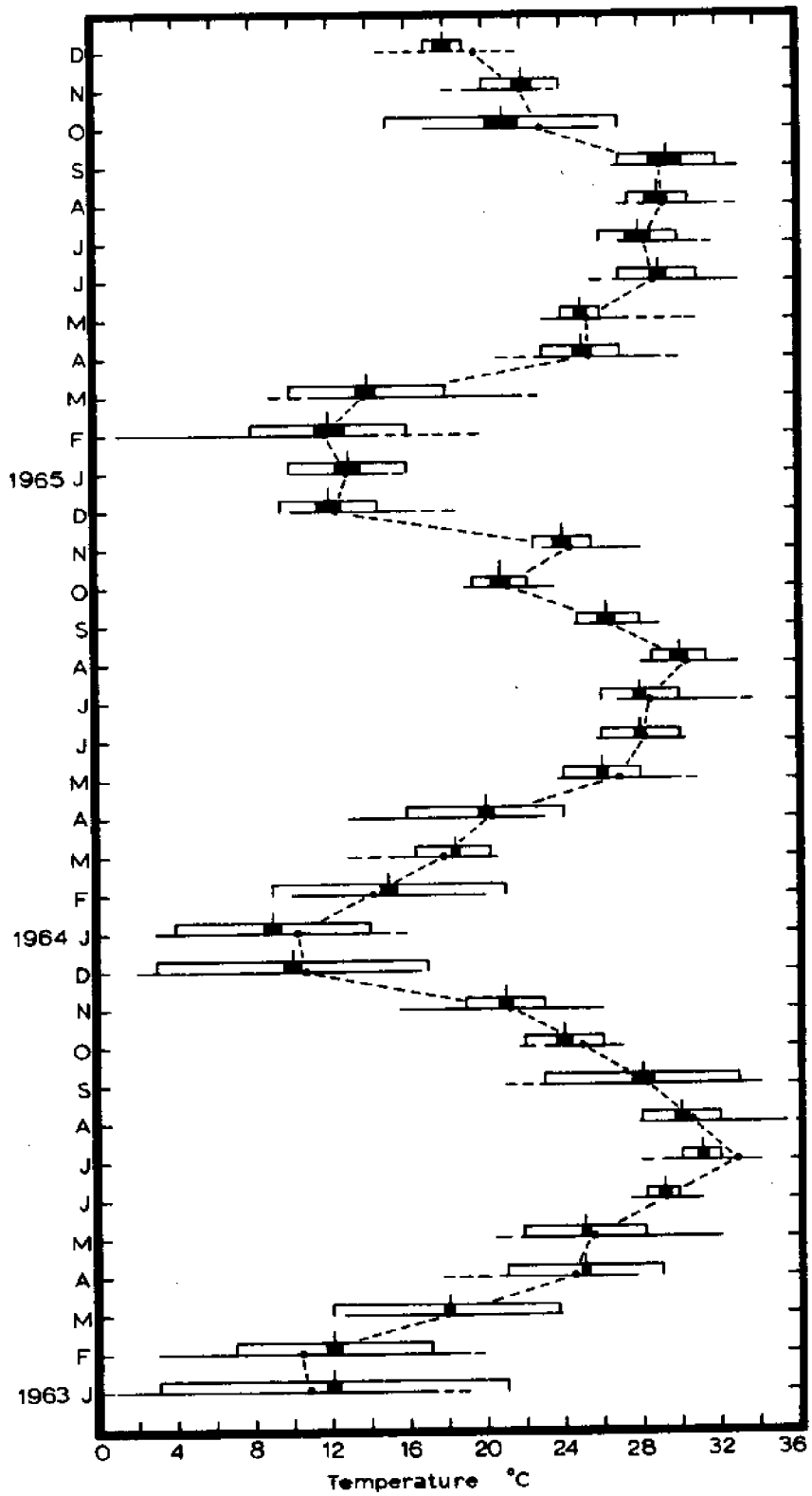


Figure 27. Monthly mean, $s_{\bar{x}}$, 2σ of the mean and range of temperatures at which Atlantic croaker were collected in Galveston Bay superimposed on the monthly mean areal temperatures.

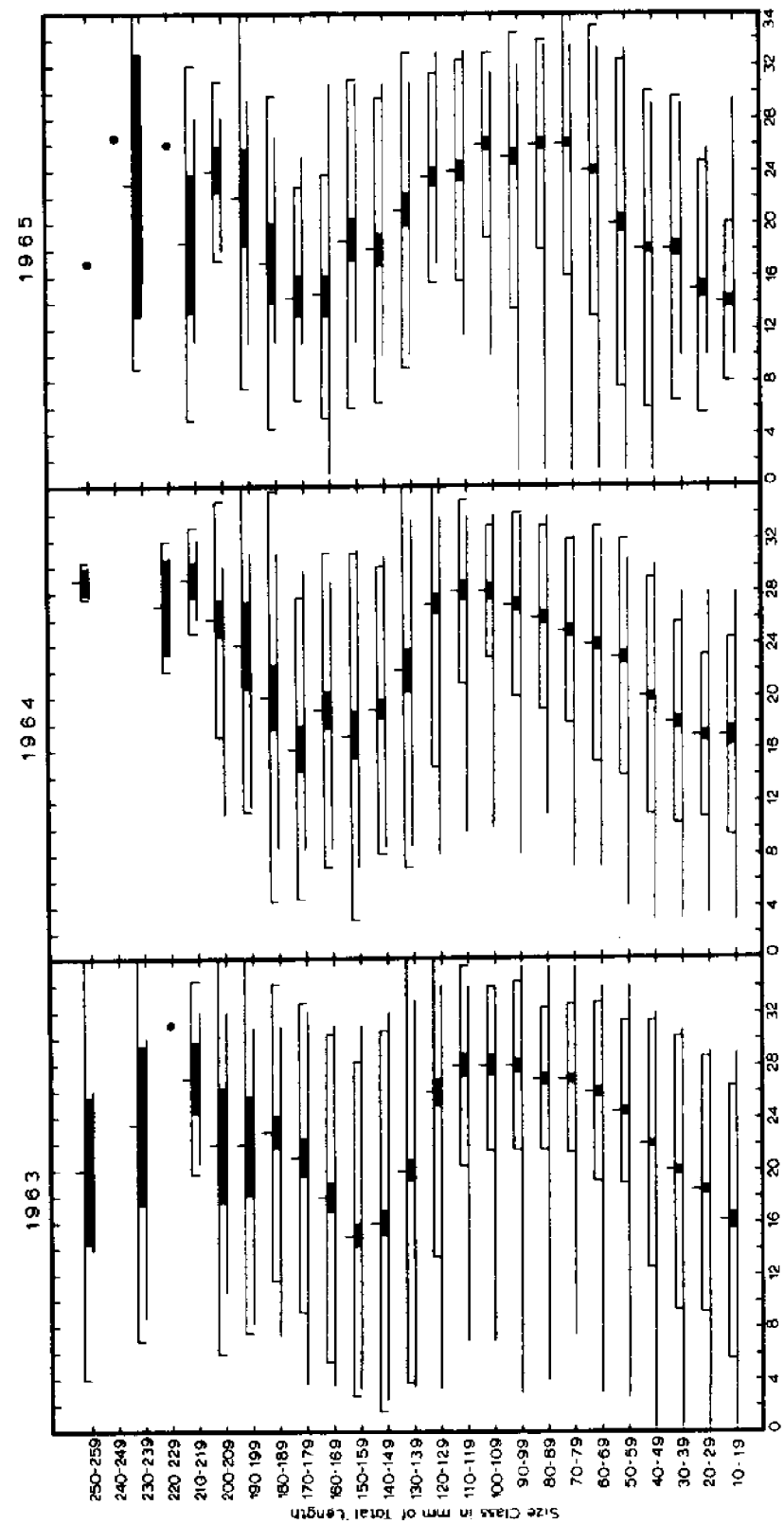


Figure 28. Mean, $\bar{x}$, 2σ of the mean and range of temperatures at which Atlantic croaker were collected in the Galveston Bay area computed by 10 mm size classes.

110-119 mm fish to 15 C for 150-159 mm fish; in 1964 from 28 C for 110-119 mm fish to 16 C for 170-179 mm fish; and in 1965 from 26 C for 100-109 mm fish to 14 C for 170-179 mm. At larger sizes, observations were generally not adequate for reliable predictions. The variation of temperature with size described a more or less sigmoid pattern in each year in Galveston Bay and also in the Lake Borgne area. The pattern was the result of the seasonal distribution of croaker by size. The extent to which growth at various sizes is dependent upon this pattern is not known, but if size is not a factor here, then croaker can grow over a wide range of temperatures (probably between 6 and 32 C), making them an attractive species, at least from a temperature standpoint, for commercial culture. As was noted in the Lake Borgne area, the temperature range over which croaker were collected did not appear to vary greatly with size and I concluded that all size classes were equally suited to a broad range of temperatures spanning approximately 26-30 C.

Distribution Related to Salinity

Observations by various authors indicate that croaker are euryhaline throughout their North American range. Specimens have been found in salinities less than 1 (Gunter, 1945; Haven, 1957; El-Sayed, 1961; Rounsefell, 1964) and up to 75°/oo (Simmons, 1957). Wallace (1940) noted that small croaker were carried into and up Chesapeake Bay by currents of more saline water that occur

in the deep channel which extends nearly the entire length of the bay. Reid (1955B) found croaker in East Bay, Texas concentrated in greatest numbers in the upper areas of the bay where the lowest salinities prevailed. Massmann and Pacheco (1960) observed larvae concentrated in waters of low salinity in Chesapeake Bay and Dovel (1968) noted further that, in this bay, the young congregated in waters of low salinity during the fall and early winter, but apparently moved to warmer, more saline waters during January.

The nature of the life history of the Atlantic croaker requires that postlarvae and juveniles be adaptive, not only to a comparatively broad salinity range, but also to relatively rapid salinity changes. The abundance of croaker in both study areas was decidedly seasonal, and to some extent, temperature oriented. The high concentrations observed in subarea I of the Lake Borgne area and the dispersion toward the marginal regions of Galveston Bay indicates that other factors likely play an important role in the distribution of this species. The interaction of these factors with a parameter such as salinity, which is stabilized by neither time nor area, makes evaluating the effects of salinity on distribution difficult. Because of the inability to measure the interaction of these factors quantatively, statistical analyses of the field data relating to salinity did not appear relevant; however, some inferences could be made.

In the Lake Borgne area croaker were found in salinities

ranging from 0.5 to 25.4°/oo. According to the mean-catch-per-tow values in Table 25, croaker were abundant at salinities between 21 and 25°/oo and below 6°/oo. These figures, however, do not necessarily represent salinity preference because equivalent sampling was not conducted within each salinity class. The areal salinity pattern varied with time, therefore relative abundance was weighted in favor of the salinities prevailing during the period when seasonal abundance was highest. A comparison between areal and distributional salinity means (Figure 29A) revealed that these fish were caught at mean salinities lower than the corresponding areal means 12 out of the 19 months covered in the study period. The differences between the means can generally be attributed to greater abundance of croaker in subarea I were salinities were lowest and could reflect habitat preference not necessarily dependent upon salinity. Croaker were not as abundant as spot in the Lake Borgne area and catches never exceeded 100 per 10-minute tow. For this reason, I did not attempt to evaluate salinity tolerance on the basis of abundance in individual catches as was done with the spot data.

The mean salinities and salinity range for 10 mm size classes of croaker from the Lake Borgne area are presented in Figure 29B. Mean salinities declined gradually with increasing size for fish from 10-69 mm, increased with increasing size for fish from 60-129 mm and declined rather rapidly with increasing size for fish from

Table 25. Relative abundance of Atlantic croaker in the Lake Borgne area as related to salinity.

Salinity °/oo	Number of Tows	Number Caught	Mean Catch Per Tow
<6	323	2,302	7.13
6-10	100	246	2.46
11-15	68	316	0.22
16-20	46	166	0.28
21-25	16	121	7.56
Total	553	3,151	5.70

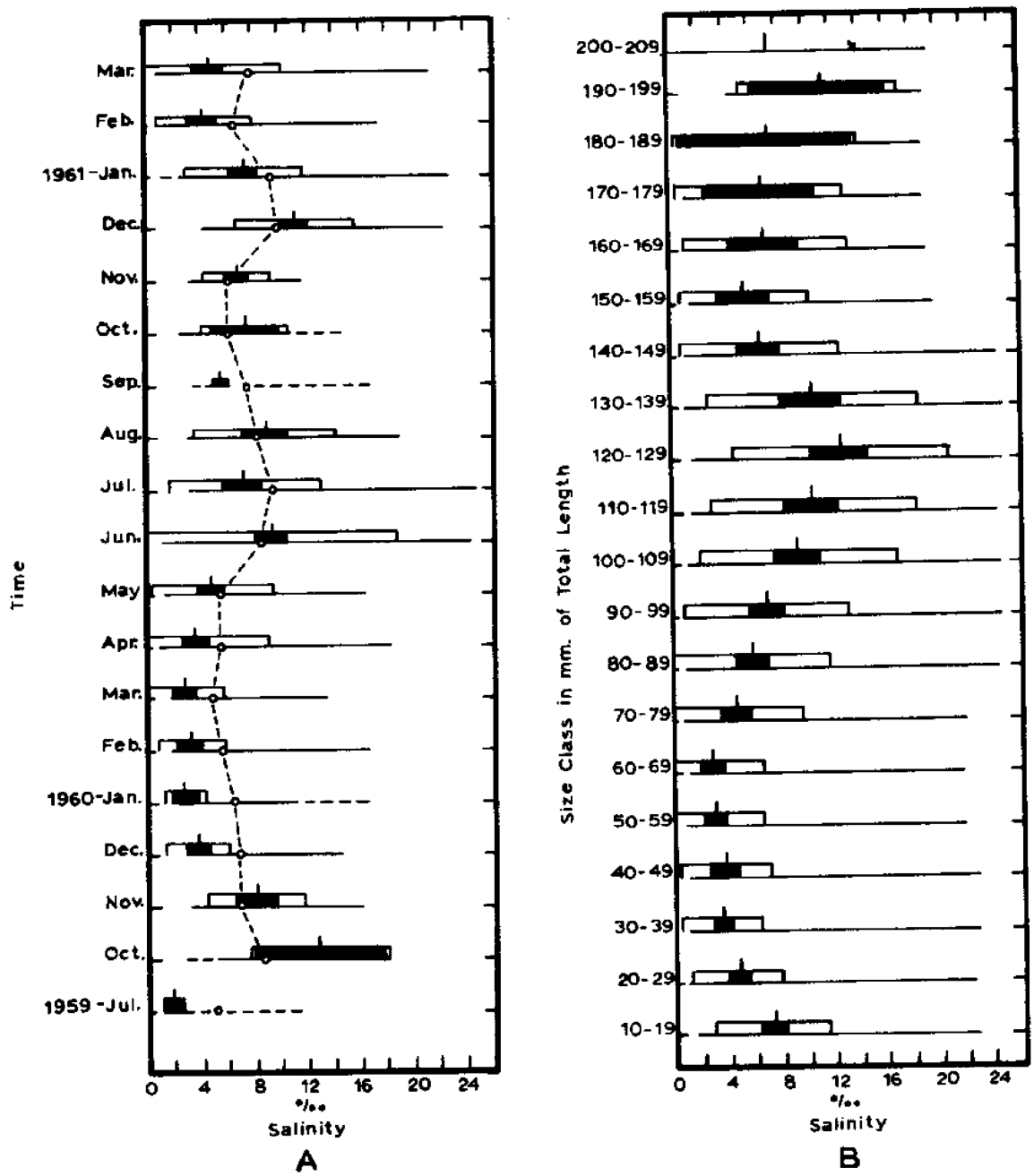


Figure 29. A - Monthly mean, $s_{\bar{x}}$, 2σ of the mean and range of salinities at which Atlantic croaker were collected in the Lake Borgne area superimposed on the monthly mean areal salinities.

B - Mean, $s_{\bar{x}}$, 2σ of the mean and range of salinities at which Atlantic croaker were collected in the Lake Borgne area computed by 10 mm size classes.

120-159 mm. The data for larger croaker were not adequate for reliable predictions. The average salinity range for 10-79 mm croaker was 23°/oo; and for 80-209 mm fish, 24°/oo. The salinity range for any given size group was most likely dependent upon the numbers collected and the length of time that particular group was represented in the area. The smaller fish were distributed more abundantly in the lower salinities but as size increased, abundance shifted toward the center of the salinity range and was almost exactly centered for 120-129 mm fish. Fish 130 mm or larger were, to varying degrees, more abundant in the lower salinities.

Croaker were found in Galveston Bay in salinities ranging from 0.2 to 36.4°/oo. The monthly mean salinity at which they were collected was lower than the monthly bay-wide salinity (Figure 30) during 33 of the 36 months of the survey period. They were, however, consistently found over a rather broad salinity range. According to the mean-catch-per-tow values in Table 26, they were most abundant in 1963 and 1965 at salinities from 6 to 10°/oo and in 1964 at salinities <6°/oo. These findings do not, however, necessarily imply a salinity preference since equivalent sampling was not conducted within each salinity class. Over the 3-year period, more than 75% of these fish were taken at salinities below 20°/oo. On the other hand, salinities in the primary nursery areas during the periods of peak abundance seldom exceeded 20°/oo and were generally much lower in the vicinity of the bayous and rivers

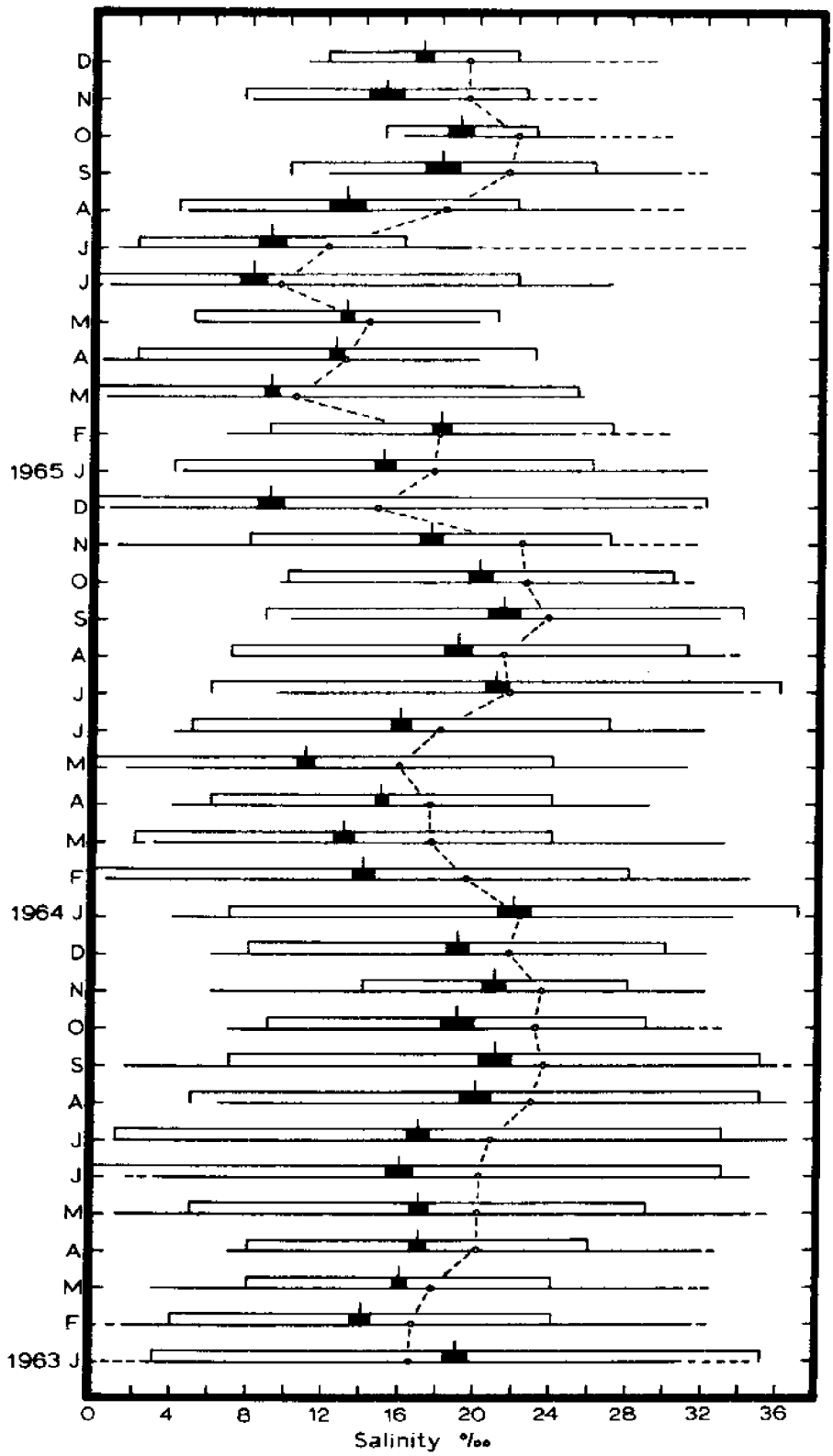


Figure 30. Monthly mean, $s_{\bar{x}}$, 2σ of the mean and range of salinities at which Atlantic croaker were collected in Galveston Bay superimposed on the monthly mean areal salinities.

Table 26. Relative abundance of Atlantic croaker in Galveston Bay as related to salinity.

Year	Salinity °/oo	Number of Tows	Number Caught	Mean Catch Per Tow
1963	<6	25	1,777	7.08
	6-10	98	16,784	171.27
	11-15	210	21,767	103.65
	16-20	365	49,021	134.30
	21-25	397	26,740	67.36
	26-30	232	6,085	26.23
	31-35	183	2,857	15.61
	Total	1,510	125,031	82.80
1964	<6	28	6,587	235.25
	6-10	49	7,291	148.80
	11-15	140	20,360	145.43
	16-20	245	16,180	66.04
	21-25	218	7,907	36.27
	26-30	110	2,463	22.39
	31-35	72	1,070	14.86
	Total	862	61,858	71.76
1965	<6	35	2,991	85.46
	6-10	44	5,711	129.80
	11-15	77	6,781	88.06
	16-20	125	11,062	88.50
	21-25	92	1,055	11.47
	26-30	24	237	9.88
	31-35	8	9	1.13
	Total	405	27,846	68.76

where croaker frequently congregated. None of these tabulations specifically relate abundance to salinity. The most revealing evidence can be seen by examining the salinities at individual stations where croaker were caught in abundance. As with the spot in Galveston Bay, I considered croaker to be abundant when the catch-per-5-minute-tow exceeded 50 fish. During the 3-year survey, 466 tows (Table 27) caught more than 50 fish. The corresponding salinities ranged between 0.2 and 35.1°/oo. This constituted the entire range of salinities observed between the Gulf of Mexico and the mouth of the Trinity River. In 370 of these tows, the catch exceeded 100 fish-per-tow and the salinity where these catches were made spanned the same range. These findings indicate that croaker are able to adjust to a broad range of salinities in the nursery areas with no apparent ill effects. Presumably, other previously mentioned factors are more important than salinity *per se* in the distribution of croaker in the nursery areas.

The mean salinities and salinity ranges for ten mm size classes of croaker from Galveston Bay are presented in Figure 31. The pattern of means is similar to that described for croaker from the Lake Borgne area except that the means were generally more centrally located in the range.

Food Habits

Roelofs (1954) found that croaker, feeding in laboratory

Table 27. Salinity classes in which an abundance of croaker were caught (more than 50 fish per 5-minute tow) in Galveston Bay and the number of tows made in each class.

Salinity °/oo	Number of Tows
<6	34
6-10	65
11-15	109
16-20	115
21-25	73
26-30	45
31-35	25
>35	0
Total	466

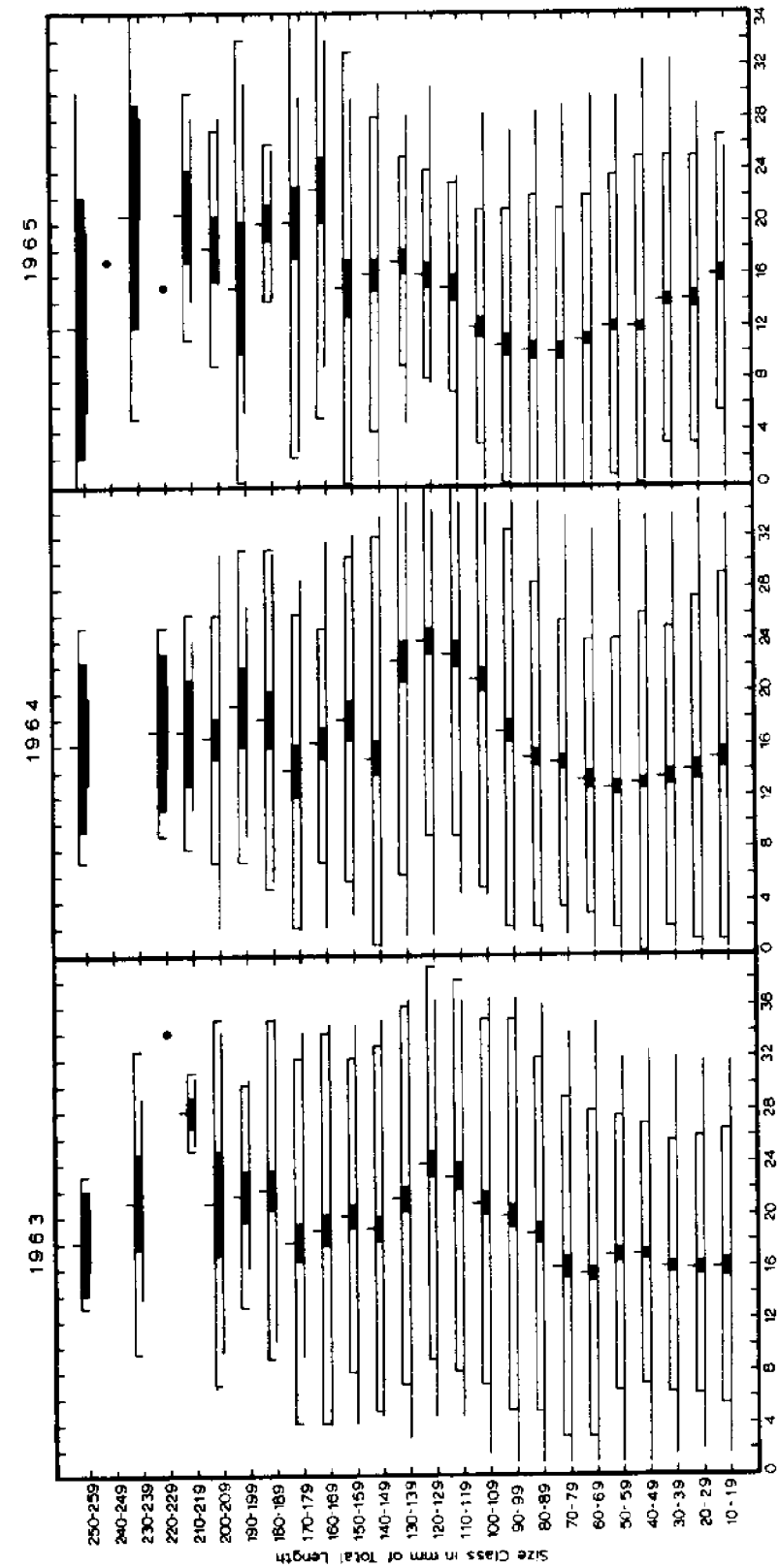


Figure 31. Mean, $\bar{s}$, $\bar{x}$, 2σ of the mean and range of salinities at which Atlantic croaker were collected in Galveston Bay computed by 10 mm size classes.

aquaria, dived deeply into the bottom with some force, digging as they fed, and were thus able to obtain subsurface material. Food items were sorted from debris with the gill rakers. This form of feeding does not suggest a high degree of selectivity and, in terms of comparisons of food items between localities, implies that available food probably dictates the diet of croakers. He observed that annelids comprised about 90% (volume) of the diet of juvenile croaker in North Carolina waters. Reid (1955B) reported molluscs (primarily Macoma mithcilli) in 61% of the stomachs of East Bay, Texas croaker. Avault et al. (1969) found that fish and palaemonid shrimp were the chief items in the diet of pond-reared croaker in Louisiana.

The food of the Atlantic croaker has been investigated by Darnell (1958) in Lake Pontchartrain which adjoins the Lake Borgne area and by Diener and Inglis (personal communication) in Clear Lake which adjoins Galveston Bay. Both lakes occupy similar positions in their respective areas. They are located near large municipal and industrial centers and their waters are shallow and have relatively low salinity. The food items listed in these two studies include, with few exceptions, the entire array of items reported previously and constitute the most detailed assemblages yet available.

As with the spot, Darnell (1958) concluded, in summarizing the works of Linton (1904), Smith (1907), Welsh and Breder (1923),

Hildebrand and Schroeder (1928), Pearson (1929), Hildebrand and Cable (1930), Gunter (1945), Roelofs (1954), Reid (1955B), and Reid, Inglis and Hoese (1956), that the feeding habits of the Atlantic croaker change with size. He found that from young to adult they pass through a succession of 4 overlapping, but distinctly recognizable food stages. They specialize successively upon (1) zooplankton, (2) micro-benthos, (3) detritus, and (4) larger animals, the latter group including burrowers, crawlers and swimmers. He distinguished three size classes, attributing the first two food stages to the young fishes (11.5-74 mm), the detritus stage to the intermediate size fishes (75-150 mm), and the larger animal stage to the largest fishes (150-325 mm). His data is presented in 24 mm size classes, but the above groups are readily distinguished. Diener and Inglis, on the other hand, presented their data in 10 mm size classes and the scope of their observations cover only Darnell's young and intermediate size croaker. In order to allow a comparison of these data, the following modifications were made. Young croaker from Clear Lake included fish ranging from 10-69 mm and were compared with young croaker from Lake Pontchartrain ranging in size from 10-74 mm. Intermediate size croaker from Clear Lake included fish ranging from 70-119 mm and were compared with croaker from Lake Pontchartrain ranging in size from 75-124 mm. These size groups do not correspond exactly to those proposed by Darnell but are as close as possible with the available data.

The food items reported from the two areas were compared for each group using Spearman's coefficient of rank correlation (r_s).

For the young croaker, 22 different food items were reported and they are ranked according to their frequency of occurrence in Table 28. Applying the rank correlation procedure (see Page 78):

$$r_s = 0.0614$$

$$t = 3.3663^{**} \quad d.f. = 20$$

This t is significant at the .01 confidence level, indicating that there was a rather close correlation between food items taken by these croaker in the two areas. Because croaker are not selective feeders, this high degree of correlation indicates that many of the food items listed were common in both areas. Copepods, mysid shrimp, and amphipods, along with organic matter and detritus were ranked relatively high in both areas. However, insects, which were comparatively frequent in the stomachs of Lake Pontchartrain croaker, ranked low in the Clear Lake fishes, while vascular plants and annelids ranked high in the croaker's diet in Clear Lake and comparatively low in Lake Pontchartrain.

For the intermediate size croaker 21 different food items were reported and they are ranked as before in Table 28. Applying the rank correlation procedure:

$$r_s = 0.3078$$

$$t = 1.4101 \quad d.f. = 19$$

This t is nonsignificant, indicating that overall there is little

Table 28. Food items of Atlantic croaker from Lake Pontchartrain, Louisiana and Clear Lake, Texas ranked according to frequency of occurrence.

	Young			Intermediate		
Food Item	Lake Pontchartrain	Clear Lake	d	Lake Pontchartrain	Clear Lake	d
Bryozoa	17	22	5.0			
Branchiopoda	17	17	0			
Ostracoda	8	9	1.0	12	8	-4.0
Copepoda	2	1	-1.0	6.5	3	-3.5
Mysid shrimp	5	2	-3.0	4.5	2	-2.5
Palaemonid shrimp	17	14	-3.0	14	10.5	-3.5
Penaeid shrimp	17	19.5	2.5	18.5	14.5	-4.0
Shrimp (unid.)	17	15	-2.0	18.5	14.5	-4.0
Crabs	17	16	-1.0	10	10.5	0.5
Isopoda	6.5	10.5	4.0	8	18	10.0
Amphipoda	4	5	1.0	4.5	16	11.5
Cirripedia	17	21	4.0	18.5	18	-0.5
Stomatopoda	17	19.5	2.5			
Insecta	3	13	10.0	1.5	13	11.5
Arachnida				18.5	20	1.5
Annelida	17	6	-11.0	6.5	7	0.5
Mollusca	9	18	9.0	3	18	15.0
Sponges				14	21	7.0
Foraminifera	10	10.5	0.5	18.5	12	-6.5
Vertebrata (fish)	11	4	-7.0	9	5	-4.0
Algae	17	12	-5.0	14	9	-5.0
Vascular plants	17	3	-14.0	11	1	-10.0
Detritus	1	7	6.0	1.5	4	2.5
Mud and sand	6.5	8	1.5	18.5	6	-12.5
No. Specimens Examined	63	1,866	$\Sigma d = 0$	44	475	$\Sigma d = 0$
No. With Food	61	1,671	$\Sigma d^2 = 706.00$	38	460	$\Sigma d^2 = 1066.00$
Size Range in mm	10-74	10-69	$n = 2$	75-124	70-110	$n = 21$

correlation between food items taken by these croaker in the two areas. This lack of correlation reflects a degree of variability in available foods in the two areas. Copepods and mysid shrimp along with organic matter and detritus again rated comparatively high in both areas. However, mulluscs, insects, amphipods and isopods occurred with much greater frequency in the diet of Lake Pontchartrain croaker while mud and sand, along with vascular plants, were found more frequently in the stomachs of Clear Lake croaker.

Length-Weight Relationship and Condition

The methods employed in the analyses of length-weight and condition data for spot are also applicable for the Atlantic croaker. The length-weight relationship for croaker from the Mississippi and Louisiana coasts has been described by Dawson (1965) and for croaker from brackish water ponds in Louisiana by Avault et al. (1969). Their results along with mine for croaker from Galveston Bay are included in Table 29. Avault et al., noted close agreement between theirs and Dawson's values. A comparison of their length-weight regression line with Dawson's and mine (Figure 32) revealed, however, that croaker were in much better condition in the brackish water ponds than "wild" fish taken from either the Mississippi-Louisiana coasts or Galveston Bay. At 200 mm, pond-reared croaker weighed 17.12 grams more than those from the Mississippi-Louisiana coast and 24.15 grams more than those from Galveston Bay.

Table 29. Length-weight data for Atlantic croaker from the Mississippi and Louisiana coasts (Dawson, 1965), brackish water ponds in Louisiana (Avault, et al., 1969) and Galveston Bay, Texas.

Location	n	Length Range in mm	log a	b	Σx^2	Σxy	Σy^2	$s^2_{y \cdot x}$	r
Miss.-La. coasts (Dawson, 1965)	1,123	50-200	-5.28476	3.14750					
Louisiana ponds (Avault, et al., 1969)	362	165-264	-5.2498	3.1652					
Galveston Bay (bay-wide)	2,645	40-198	-5.21366	3.10173	81.12870	251.63931	790.14343	0.00364	0.994
Trinity Bay	702	40-198	-5.16924	3.07785	23.46873	72.23316	224.38291	0.00294	0.995
East Bay	743	40-186	-5.17749	3.07937	21.18305	65.23056	204.20514	0.00450	0.992

r denotes correlation between observed and predicted weights

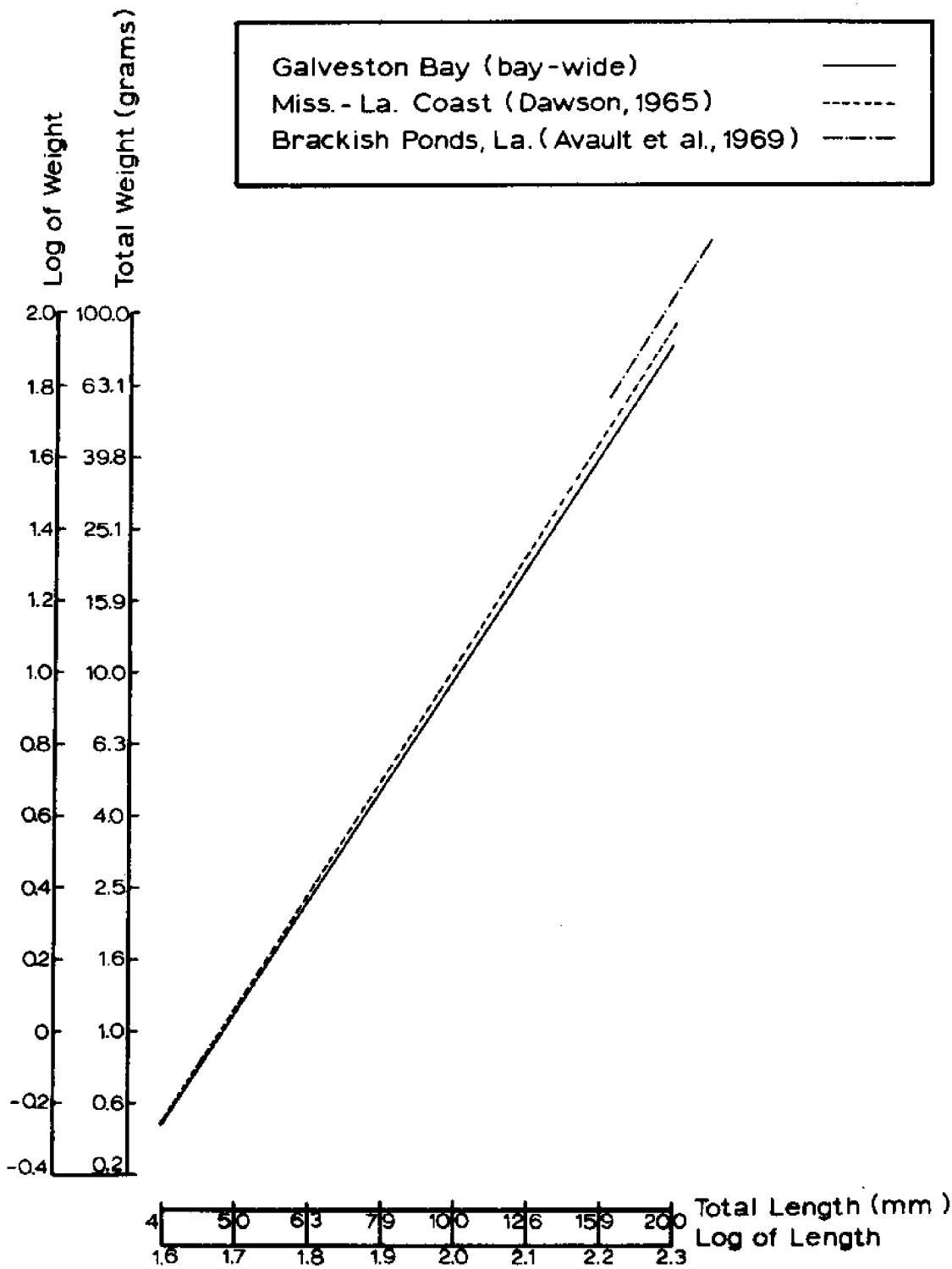


Figure 32. Length-weight relationship of Atlantic croaker from Galveston Bay, the Mississippi-Louisiana coast, and brackish ponds in Louisiana.

These differences may be explained, in part, by the differences in size range and the sexual condition of these fish. Avault's croaker, both male and female, were sexually mature and ready to spawn, whereas those observed by Dawson and myself were mostly immature. Mississippi-Louisiana croaker were in better condition than those from Galveston Bay and the difference increased with increasing size, reflecting a difference in the slopes of the length-weight regression lines. At 50 mm, Mississippi-Louisiana croaker were only 0.02 grams heavier than those from Galveston Bay, but at 200 mm the difference amounted to 7.03 grams. Since the size range and the stage of sexual maturity were essentially the same for these groups, the difference in condition probably reflects environmental differences in the form of nutritional variability.

Certain areas of Galveston Bay have been shown to be prime nursery habitat for croaker and in two of these areas--Trinity and East Bays--sufficient length-weight measurements were taken to allow a comparison of the condition of these fish between the two habitats by means of the length-weight regressions. The computations for these groups are presented in Table 29,(Page 150). A comparison of the variances ($s^2_{y \cdot x}$) indicated that they differed significantly and the comparison of slopes was made using Pearson and Hartley's (1958) test criterion $\underline{v}$ (see formula on page 38) which considers a comparison with variances which must be separately estimated.

$$v = \frac{3.07937 - 3.07785}{\sqrt{\frac{0.00294}{23.46873} + \frac{0.00450}{21.18305}}} = 0.083, \text{ d.f.} = 700, 741$$

The difference between the slopes of the lines was not significant and a comparison of the elevation of the lines (log $\underline{a}$ values) was warranted. This comparison was accomplished using another of Pearson and Hartley's (1958) test criterion v which considers a comparison with variances that must be separately estimated.

$$v = \frac{\bar{d}_a}{\sqrt{s^2_{\bar{d}_a}}}$$

where $\bar{d}_a$ is the difference in the log W intercepts and computed from the formula:

$$\bar{d}_a = \overline{\log W_1} - \overline{\log W_2} - b_p(\overline{\log L_1} - \overline{\log L_2})$$

and $s^2_{\bar{d}_a}$ is the variance of that difference and computed from the formula:

$$s^2_{\bar{d}_a} = \frac{s^2_{y \cdot x_1}}{n_1} + \frac{s^2_{y \cdot x_2}}{n_2} + \frac{(\overline{\log L_1} - \overline{\log L_2})^2 \, (\Sigma x_1^2 s^2_{y \cdot x_1} + \Sigma x_2^2 s^2_{y \cdot x_2})}{(\Sigma x_1^2 + \Sigma x_2^2)^2}$$

For my data

$$v = 0.083, \text{ d.f.} = 1,441$$

This $\underline{v}$ is nonsignificant, indicating that the difference between the elevation of the lines was also not significant. Therefore, I concluded that there was no measurable difference in the condition of croaker in Trinity and East Bays.

Further efforts to analyze the condition of croaker in Galveston Bay involved an evaluation of changes in condition with size, through time, and with temperature and salinity. These analyses were computed based on croaker collected throughout the bay (bay-wide in Table 29, Page 181).

If condition changes with size, $\underline{b} \neq 3$, and the "cube-law" does not apply. The following t-test was used to determine the validity of the "cube-law" for croaker.

$$t = \frac{3.10173 - 3}{\sqrt{0.00364/81.12870}} = 15.161^{**}, \text{ d.f.} = 2,643$$

This was significant at the .01 level, indicating that $\underline{b}$ was greater than 3, and implying, according to LeCren's interpretation, that condition increased with increasing size. Presumably, K_b is the more applicable condition factor for examining changes in condition over time and due to temperature and salinity. However, because there is not consistent agreement as to the relevancy of the two indices under given circumstances, both K and K_b were computed in the ensuing analyses.

An analysis of the variation of condition over time was accomplished by comparing monthly condition factors. The analysis of variance for these comparisons along with the monthly condition factors are presented in Table 30. The F-test indicated that both K and K_b differed significantly over time. A modification of Duncan's Test (Kramer, 1956) was used to distinguish between

Table 30. Analyses of monthly mean K and K_b for Atlantic croaker from Galveston Bay.

Analysis of Variance for K					Analysis of Variance for K_b			
Sources of Variation	d.f.	SS	MS	F	d.f.	SS	MS	F
Among Months	11	2.32044	0.21095	12.24318**	11	3.35032	0.30456	17.31438**
Within Months	2,633	45.37212	0.01723		2,633	46.30763	0.01759	
Total	2,644	47.69256			2,644	49.65795		

Month	n	Mean K	Confidence Level .05	Confidence Level .01	Mean K_b	Confidence Level .05	Confidence Level .01	Rank K	Rank K_b
Jan.	122	0.96899			1.02391			8	4
Feb.	196	0.95283			1.01140			9	6
Mar.	220	0.99097			1.04659			4	2
Apr.	443	0.99717			1.06518			3	1
May	496	0.94285			1.00371			10	7
June	346	0.91466			0.95521			12	12
July	264	0.94241			0.96993			11	11
Aug.	158	0.99879			1.01680			2	5
Sept.	143	0.98379			0.99433			5	9
Oct.	79	0.96992			0.97518			7	10
Nov.	118	0.97307			0.99764			6	8
Dec.	59	1.02190			1.03713			1	3

$r_s = 0.7063$
$t = 3.155$**
d.f. = 10

** denotes significance at the .01 level

means. The resulting differences and the confidence level at which these differences were declared are also presented in Table 30 (Page 187). According to Spearman's coefficient of rank correlation, there was good agreement between K and K_b, but enough difference in ranking existed to warrant a discussion of each index separately. Considering K, condition was high in March, April, August and December and low in May, June, and July. The highest factor was measured in December and the lowest in June, but the pattern of variability does not distinctly reflect seasonality. The pattern of variability of K_b, however, is seasonal to a degree. For this index, condition was high in January, March, April and December and low in June, July and October. The highest value was recorded in April and the lowest in June. Condition was generally higher during the cooler months than during the warmer months. The sum of the K_b rankings for the cooler months, January through April and November and December, equaled only 24, whereas the sum of the rankings for the warmer months, May through October, equaled 54. For K, the sum of the rankings equaled 31 and 47 respectively for the same months.

The relationship between temperature and salinity and the condition of croaker was determined through a multiple regression of these parameters on both K and K_b. The analyses of variance, t-values used to test the partial regression coefficients, and the regression equations are presented in Table 31. The F-test for

Table 31. Multiple regression analyses of temperature and salinity on the condition of Atlantic croaker from Galveston Bay.

	Analysis of Variance for K				Analysis of Variance for K_b			
Sources of Variation	d.f.	SS	MS	F	d.f.	SS	MS	F
Samples	372	22.0828	0.0594	5.2566**	372	22.1089	0.0594	4.8689**
Due to Regression	2	0.1487	0.0744	1.2546	2	0.2142	0.1071	1.8091
Deviations from Regression	370	21.9341	0.0593		370	21.8947	0.0592	
Fish within Samples	2238	25.2397	0.0113		2238	27.2675	0.0122	
Total	2610	47.3225			2610	49.3764		
	$K = 0.95697 - 0.00012X_1 + 0.00024X_2$				$K_b = 0.99047 + 0.00010X_1 + 0.00028X_2$			
	t for b_1 = 1.7326 d.f. = 370				t for b_1 = 1.4210 d.f. = 370			
	t for b_2 = 3.3429**				t for b_2 = 3.7899**			

X_1 = Temperature ^{o}C

X_2 = Salinity $^{o}/oo$

** denotes significance at the .01 level

Samples in the analysis of variance were significant at the .01 level for both K and K_b. Since samples were taken over the entire year and throughout the system, both areal and seasonal factors are confounded within this source of variation. Little information was gained from this test, but, by partitioning this source of variation, the error term for regression was reduced and the precision of the ensuing F-test for regression was improved. The F-test for regression in the analysis for K and K_b was nonsignificant. A test of the partial regression coefficients for both K and K_b indicated, however, that the effect due to salinity was significant at the .05 level and the effect due to temperature was nonsignificant. It was therefore concluded that both K and K_b increased with increasing salinity but were not significantly affected by temperature.

These findings indicate that the condition of croaker varies with size, season, and salinity. Few, if any, of the fish included in this study were large enough to be considered sexually mature and it is unlikely that gonad development was responsible for these changes. I assumed, therefore, that changes in condition represented both changes in body form associated with growth and fatness associated with suitability of the environment. Suitability of the environment is very likely dependent to a considerable degree on quality of available food.

Avault et al. (1969) measured the condition of pond-reared

croaker and presumably used the formula for K in his computations. Based on 362 fish ranging in total length from 165 to 264 mm, they found an overall condition factor of 1.36. This is much higher than K values computed for croaker from Galveston Bay. The difference can probably be attributed to sexual maturity since all of his fish were extruding eggs or sperm when measured.

COMPARISON BETWEEN SPECIES

The similarities in the life histories of the spot and Atlantic croaker have been discussed previously and need not be elaborated on here. In order to evaluate the degree of competition between these species, however, additional reference should be made to the overlap in seasonal and areal abundance as well as the similarities in the food habits.

Although young croaker usually arrive in the nursery areas earlier than spot, there is considerable mingling between post-larvae and juveniles of both species from February through the end of the year. According to my trawl catches, young spot and croaker were abundant in both study areas during the period from April through July. Logically, competition in the nursery areas involves competition for food and can be evaluated by comparing the feeding habits of these species as well as the food items taken in the two study areas.

As Roelofs (1954) pointed out in his laboratory experiments, spot scoop the surface of the bottom, whereas croaker dive deeply into the bottom for the subsurface animals. He also noted that the gill structure of the spot forms a more dense straining basket than that of the croaker, allowing the spot to retain a greater portion of the smaller food items. Aside from these differences, Darnell (1958) found that adults of these species appeared to be

in keen competition for food. He did not, however, investigate competition between the immature fish--the size group which abounds in the estuaries. Therefore, the food items of immature spot and Atlantic croaker reported by Darnell (1958) from Lake Pontchartrain, Louisiana and Diener and Inglis (personal communication) from Clear Lake, Texas were compared. For these comparisons, young and intermediate size fish were combined.

In Lake Pontchartrain, 19 different food items were reported between the species and they are ranked according to their frequency of occurrence in Table 32. Applying the rank correlation procedure (see Page 78):

$$r_s = 0.5487$$

$$t = 2.7061^{*} \quad d.f. = 17$$

This t is significant at the .05 confidence level, indicating that these species are taking essentially the same foods. The most common items were detritus, ostracods, copepods, and molluscs.

In Clear Lake, 19 food items were also reported between the species and they are ranked as before in Table 32. Applying the rank correlation procedure:

$$r_s = 0.6193$$

$$t = 3.2521^{**} \quad d.f. = 17$$

This t is significant at the .01 confidence level, indicating a high degree of correlation between food items. Here the most common food items were copepods and vascular plants.

Table 32. Food items of spot and Atlantic croaker in Lake Pontchartrain, Louisiana and Clear Lake, Texas ranked according to frequency of occurrence.

	Lake Pontchartrain			Clear Lake		
Food Item	Spot	Croaker	d	Spot	Croaker	d
Rotifera	10	18	8.0			
Bryzoa				18	19	1.0
Branchiopoda		11.5		18	15.5	-2.5
Ostracoda	4	2	7.5	3	10	7.0
Copepoda	3	5	-1.0	1	2	1.0
Mysid shrimp	13.5	11.5	-8.5	8.5	1	-7.5
Decapoda	18	6	-6.5	15	9	-6.0
Isopoda	6	4	0	16	13	-3.0
Amphipoda	6		-2.0	8.5	6	-2.5
Cirripedia				18	18	0
Stomatopoda				12	17	5.0
Insecta	9	3	-6.0	11	14	3.0
Arachnida	13.5	18	4.5			
Annelida	13.5	8	-5.5	13	8	-5.0
Mollusca	1	7	6.0	10	15.5	5.5
Sponges	18	15.5	-2.5			
Hydroids	13.5	18	4.5			
Foraminifera	8	14	6.0	4	11	7.0
Vertebrata (fish)	18	9.5	-8.5	14	4	-10.0
Algae	13.5	15.5	2.0	7	12	5.0
Vascular plants	13.5	13	-0.5	2	3	1.0
Detritus	2	1	-1.0	6	5	-1.0
Mud and sand	6	9.5	3.5	5	7	2.0
No. Specimens Examined			$\Sigma d = 0$			$\Sigma d = 0$
No. With Food			$\Sigma d^2 = 514.50$			$\Sigma d^2 = 434.00$
Size Range in mm	40-99	10-124	n = 19	18-99	10-119	n = 19

These findings indicate a significant competition for food between species in both areas. Roelofs (1954) laboratory observations indicated that neither species was particularly selective. Rather, they obtained a mouthful of bottom material and sifted out whatever food was present.

The degree to which competition for food affects the abundance of these species is not known, but there was a noticeable difference in relative abundance between these species in the two study areas. In the Lake Borgne area, spot were more abundant than croaker in subarea III, whereas abundance was about equal in subarea II and croaker predominated in subarea I. In Galveston Bay, croaker were caught in far greater numbers and biomass than spot throughout the system. Based on abundance, the Lake Borgne area appeared, overall, about equally suited for both spot and croaker, but Galveston Bay was decidedly better habitat for croaker. If was not possible to detect the factors responsible for this difference, but availability of food must surely be involved.

SUMMARY

1. Spot spawn at sea, probably just outside the beachline and presumably in close access to the nursery areas. Based on the appearance of postlarvae, spawning in the vicinity of the Lake Borgne area was of short duration and probably extended from December through January, whereas spawning off Galveston Bay occurred later and was of slightly longer duration, extending from January through March.
2. Young-of-the-year spot grew at a rate of 11.1 mm total length per month in the Lake Borgne area and at 7.7, 8.5, and 9.1 mm total length per month in three successive years in Galveston Bay. Statistical tests indicated that the growth rate in the Lake Borgne area was significantly greater than that during each year in Galveston Bay and that growth during the first year in Galveston Bay was significantly less than during the third year. Geographical and year-to-year variability in growth probably resulted from temperature and nutritional differences which occurred locally in the nursery areas.
3. Seasonally, spot were caught in greatest numbers in both study areas during the period from April through August. Considering that postlarvae entered these areas approximately 3 to 4 months earlier, spot utilize the nursery areas for 8 or 9 months, then return to the Gulf. Gulfward emigration began in the Lake Borgne area when these fish reached 70 to 80 mm total

length and in Galveston Bay when they reached 60 to 70 mm total length.

4. The principle habitat for spot in the Lake Borgne area was subarea III. According to relative abundance, subarea III carried about six times the numbers of subarea I and three times the numbers of subarea II. In Galveston Bay, spot were concentrated in shallow waters less than 1.2 m deep which received runoff directly from marshes or tidal flats. The bottom in these areas was soft mud containing large quantities of detritus. The young fish probably preferred these areas because they afforded a greater food supply and protection from predators, and they remained there with little redistribution until they began their gulfward emigration. Marsh waters of the intertidal zone were seldom favorable habitat for spot for more than a few months.
5. Spot were year-round inhabitants of both study areas. They were collected at temperatures ranging from 5.2 to 34.9 C in the Lake Borgne area and from 1.2 to 35.5 C in Galveston Bay. No mortalities could be attributed to temperature extremes. Postlarvae and young juveniles were well adapted to temperatures from 6 to 20 C and fish approaching 1 year or older were noticeably absent at temperatures below 10 C. Postlarvae appeared in catches each spring shortly after temperatures began to rise, suggesting that the temperature rise may have triggered immigration from the Gulf.

6. Spot exhibited a broad salinity tolerance in both study areas. They were collected at salinities ranging from 1.2 to 24.0°/oo in the Lake Borgne area and from 0.4 to 36.4°/oo in Galveston Bay. They were distributed in abundance in salinities ranging from 1.2 to 34.8°/oo, indicating that, within broad limits, salinity *per se* has little effect on the distribution of this species. Fish of all sizes appeared to be about equally distributed over the salinity range in both areas.
7. A comparison of food items of spot in the two study areas revealed little correlation and it was concluded that, since spot are not selective feeders, there was a significant variation in available food. Pelecypods, detritus, and copepods predominated in that order in the stomachs of fish from the vicinity of the Lake Borgne area, whereas copepods, vascular plants, and ostracods predominated in that order in the tracts of fish from Galveston Bay.
8. The condition of spot from the Mississippi-Louisiana coast (Dawson, 1965) was compared with that of spot from Galveston Bay (bay-wide) and within Galveston Bay between fish from Trinity and East Bays. The only differences that could be declared significant were between condition of spot in Trinity and East Bays. Between these bays, the difference in condition changed with the size of fish. At 40 mm, East Bay spot weighed 0.42 grams more than those from Trinity Bay, but at 170 mm, the

Trinity Bay fish were heavier by 1.43 grams. These fish were immature, of essentially the same size, same age class, and were collected during the same time of year. The variation in condition probably resulted from differences in available food between the areas. A comparison of monthly mean condition factors revealed that spot were in better condition during the period from March through August than at other times during the year. This was the period when they were most abundant in the nursery areas. The magnitude of K_b increased with increasing temperature.

9. Atlantic croaker spawn at sea, probably just outside the beachline and presumably in close access to the nursery areas. Based on the appearance of postlarvae, spawning probably began in October or November in Louisiana and Texas waters and ended between April and June.

10. Young-of-the-year croaker grew at a rate of 13.6 mm total length per month in the Lake Borgne area and at 11.7, 11.9, and 9.9 mm total length per month in three successive years in Galveston Bay. Statistical tests indicated that the growth rate in the Lake Borgne area was significantly greater than that in Galveston Bay and that growth during the second year in Galveston Bay was significantly greater than during the third year. Geographical and year-to-year variability in growth

resulted from temperature and nutritional differences which occurred locally in the nursery areas.

11. Seasonally, croaker were caught in greatest numbers in both study areas from March through June. Considering that post-larvae entered these areas approximately 4 to 5 months earlier, croaker utilized the nursery areas for 7 or 8 months, then returned to the Gulf. Gulfward emigration began in the Lake Borgne area when croaker reached 75 to 90 mm total length and in Galveston Bay when they reached 45 mm in 1963, 65 to 80 mm in 1964, and 40 to 65 mm in 1965.

12. The principle habitat for croaker in the Lake Borgne area was subarea I. According to relative abundance, subarea I carried about twice the density of subareas II and III. In Galveston Bay, croaker were concentrated in shallow waters less than 1.2 m deep and in close proximity to a source of fresh or brackish water which generally flowed through marshes or over tidal flats before entering the bay. The bottom in these areas was generally soft mud, containing large quantities of detritus. The young fish probably preferred these areas because they afforded a greater food supply and protection from predators, and they remained there, with little redistribution, until they began their gulfward emigration. Marsh waters of the intertidal zone were seldom favorable habitat for croaker for more than a few months.

13. Croaker were year-round inhabitants of both study areas. They were collected at temperatures ranging from 5.2 to 34.9 C in Lake Borgne and from 0.4 to 35.5 C in Galveston Bay. No mortalities could be attributed to temperature extremes. Postlarvae and young juveniles were well adapted to temperatures in the 6 to 20 C range, whereas fish approaching 1 year or older were noticeably absent at temperatures below 10 C. The variation of temperature with size of fish described a more or less sigmoid curve in the Lake Borgne area as well as during each year in Galveston Bay. The pattern was the result of the seasonal distribution of croaker by size. The extent to which growth at various sizes is dependent upon this pattern is not known, but if size is not a factor, then croaker can grow at temperatures ranging between 6 and 32 C and would be,from a temperature standpoint, an attractive species for commercial culture.
14. Croaker exhibited a broad salinity tolerance in both study areas. They were collected at salinities ranging from 0.5 to 25.4°/oo in the Lake Borgne area and from 0.2 to 36.4°/oo in Galveston Bay. They were distributed in abundance in salinities ranging from 0.2 to 35.1°/oo, indicating that, within broad limits, salinity <u>per se</u> has little effect on the distribution of this species. Fish of all sizes appeared to be about equally distributed over the salinity range.
15. A comparison of food items of croaker in the two study areas

revealed a close correlation in the diet of young fish, but little correlation in the diet of intermediate size fish. Since croaker are not selective feeders, these findings were interpreted to reflect availability of food and indicated that foods available to young fish were essentially the same, whereas, those available to the intermediate size differed significantly. The young fish fed on copepods, mysid shrimp, and amphipods, along with organic matter and detritus in both areas. The intermediate size took, in addition to common items such as copepods, mysid shrimp, organic matter and detritus, large amounts of molluscs, insects, amphipods and isopods in Louisiana as opposed to mud and sand and vascular plants in Texas.

16. The condition of croaker from the Mississippi-Louisiana coast (Dawson, 1965) and brackish ponds in Louisiana (Avault et al., 1969) were compared with that of croaker from Galveston Bay (bay-wide). Croaker from the brackish ponds were in the best condition, followed by those from the Mississippi-Louisiana coast and, lastly, those from Galveston Bay. Avault's data were taken from large sexually mature fish which were ready to spawn, whereas data in the latter 2 groups was taken from fish spanning a broad size range which included no mature specimens. The difference in condition of these latter 2 groups probably reflects nutritional variability. A comparison of

monthly mean condition factors for croaker from Galveston Bay revealed that condition was generally higher during the cooler months, January through April and November and December, than at other times of the year. The magnitude of K_b increased with increasing temperature, but did not vary significantly with salinity.

17. Spot and croaker were found to be in direct competition for food in both study areas. The degree to which this competition affects the abundance of these species is not known. In the Lake Borgne area, spot were more abundant than croakers in subarea III, abundance was about equal in subarea II, and croaker were more abundant than spot in subarea I. Throughout the Galveston Bay system, numbers and biomass of croaker far exceeded that of spot. It was not possible to detect the factors responsible for these differences, but availability of food must surely be involved.

LITERATURE CITED

Arnold, E. L., Jr., R. S. Wheeler, and K. N. Baxter. 1960. Observations on fishes and other biota of East Lagoon, Galveston Island. U. S. Fish and Wildl. Serv. Spec. Scient. Rep. Fish. (344): 30 p.

Avault, J. W., Jr., W. G. Perry, Jr., and C. L. Birdsong. 1969. Growth, survival, food habits, and sexual development of croaker, Micropogon undulatus, in brackish water ponds. Proc. 23rd. Ann. Conf. S. E. Assoc. Game and Fish Comm.: 112-27.

Baldauf, R. J. 1953. Survey and study of surface and subsurface conditions in and around Beaumont, Texas. Biological survey of the Neches River in the region of Beaumont, Texas. A. and M. Col. Tex., Tex. A. and M. Res. Found. Rept. for Project No. 32. Period from Aug. 1951 to Jun. 1952: 177 p.

_____. 1954. Survey and study of surface and subsurface conditions in and around Beaumont, Texas. Biological survey of the Neches River in the region of Beaumont, Texas. A. and M. Col. Tex., Tex. A. and M. Res. Found. Rept. for Project No. 32. Period from Jul. 1952 to Apr. 1953: 184 p.

Breuer, J. P. 1957. Ecological survey of Baffin and Alazan Bays, Texas. Publs. Inst. Mar. Sci. Univ. Tex. 4(2): 134-155.

_____. 1962. An ecological survey of the Lower Laguna Madre of Texas, 1953-1959. Publs. Inst. Mar. Sci. Univ. Tex. 8: 153-183.

Carlander, K. D. 1950. Handbook of freshwater fishery biology. W. C. Brown Company, Dubuque, Iowa. 429 p.

Chambers, G. V. and A. K. Sparks. 1959. An ecological survey of the Houston Ship Channel and adjacent bays. Publs. Inst. Mar. Sci. Univ. Tex. 6: 213-250.

Christmas, J. Y., G. Gunter, and E. C. Whatley. 1960. Fishes taken in the menhaden fishery of Alabama, Mississippi and Eastern Louisiana. U. S. Fish and Wildl. Serv. Spec. Scient. Rep. Fish. (339): 10 p.

Darnell, R. M. 1958. Food habits of fishes and larger invertebrates of Lake Pontchartrain, Louisiana, an estuarine community. Publs. Inst. Mar. Sci. Univ. Tex. 5: 353-416.

_____. 1962. Fishes of the Rio Tamesi and related coastal lagoons in east-central Mexico. Publs. Inst. Mar. Sci. Univ. Tex. 8: 299-365.

Dawson, C. E., Jr. 1953. A survey of the Tampa Bay area. Fla. Bd. Conserv. Tech. Ser. (8): 39 p.

_____. 1958. A study of the biology and life history of the spot, Leiostomus xanthurus Lacepede, with special reference to South Carolina. Contr. Bears Bluff Lab. 28: 48 p.

_____. 1965. Length-weight relationships of some Gulf of Mexico fishes. Trans. Amer. Fish. Soc. 94(3): 279-280.

Dovel, W. L. 1968. Predation by striped bass as a possible influence on population size of the Atlantic croaker. Trans. Amer. Fish. Soc. 97: 313-319.

El-Sayed, S. Z. 1961. Hydrological and biological studies of the Mississippi River-Gulf Outlet Project. A. and M. Col. Tex., Tex. A. and M. Res. Found. Rept. for Project No. 236. Vol. 1: 216 p.

Gunter, G. 1938. Seasonal variations in abundance of certain estuarine and marine fishes in Louisiana with particular reference to life histories. Ecol. Monog. 8: 313-346.

_____. 1945. Studies of the marine fishes of Texas. Publs. Inst. Mar. Sci. Univ. Tex. 1(1): 190 p.

_____. 1950A. Correlation between temperature of water and size of marine fishes on the Atlantic and Gulf coasts of the United States. Copeia. 1950(4): 298-304.

_____. 1950B. Distribution and abundance of fishes on the Aransas National Wildlife Refuge, with life history notes. Publ. Inst. Mar. Sci. Univ. Tex. 1(2): 89-119.

Gunter, G. and H. H. Hildebrand. 1951. Destruction of fishes and other organisms on the south Texas Coast by the cold wave of January 28-February 3, 1951. Ecology. 32(4): 731-736.

Hansen, D. J. 1970. Food, growth, migration, reproduction, and abundance of pinfish, Lagodon rhomboides, and Atlantic croaker, Micropogon undulatus, near Pensacola, Florida, 1963-65. Fish. Bull. 68(1): 135-146.

Haven, D. S. 1957. Distribution, growth and availability of juvenile croaker, Micropogon undulatus, in Virginia. Ecology 38(2): 88-97.

Hellier, T. R., Jr. 1962. Fish production and biomass studies in relation to photosynthesis in the Laguna Madre of Texas. Publ. Inst. Mar. Sci. Univ. Tex. 8: 1-22.

Higgins, E. and J. C. Pearson. 1927. Examination of the summer fisheries of Pamlico and Core Sounds, N. C., with special reference to the destruction of undersized fish and the protection of the gray trout, Cynoscion regalis (Block and Schneider). Appendix II, Report, U. S. Commissioner of Fisheries for 1927 (1928): 29-65. Bur. Fish. Document No. 1019, Washington.

Hile, R. 1936. Age and growth of the cisco, Leucichthys artedi (Le Sueur), in the lakes of the north-eastern highlands, Wisconsin. Bull. U. S. Bur. Fish. 48: 211-317.

Hildebrand, S. F. and L. E. Cable. 1930. Development and life history of fourteen teleostean fishes at Beaufort, North Carolina. Bull. U. S. Bur. Fish. 46: 383-499.

Hildebrand, S. F. and W. C. Schroeder. 1928. The fishes of Chesapeake Bay. Bull. U. S. Bur. Fish. 43 (Part I): 1-366.

Hoese, H. D. 1958. A partially annotated checklist of the marine fishes of Texas. Publs. Inst. Mar. Sci. Univ. Tex. 5: 312-352.

_____. 1960. Biotic changes in a bay associated with the end of a drought. Limnol. Oceanogr. 5(3): 326-336.

Ingle, R. M. and C. E. Dawson, Jr. 1953. A survey of the Cedar Key area. Fla. Bd. Conserv. Tech. Ser. (9): 27 p.

Kilby, J. D. 1955. The fishes of two Gulf coastal marsh areas of Florida. Tulane Stud. Zool. 2(8): 175-247.

Kramer, C. Y. 1956. Extension of multiple range tests to group means with unequal numbers of replication. Biometrics. 12: 307-310.

Lagler, K. F. 1956. Freshwater fishery biology. W. C. Brown Company. Dubuque, Iowa. 421 pp.

LeCren, E. D. 1951. The length-weight relationship and seasonal cycle in gonad weight and condition in the perch (Perca fluviatilis). J. Animal. Ecol. 20(2): 201-219.

Linton, E. 1904. Parasites of fish of Beaufort. Bull. U. S. Bur. Fish. 24: 321-428.

Lunz, G. R. 1951. A salt water fish pond. Contr. Bears Bluff Lab. 12: 12 p.

_____. 1958. South Carolina - Fisheries Biological Research - Progress, September-December, 1957. Progress Report. Bears Bluff Lab. 34: 4 p., also Comm. Fish. Rev. 20(3): 28-29.

Martin, W. R. 1949. The mechanics of environmental control of body form in fishes. Univ. Toronto Stud. Biol. 58 (Publ. Ont. Fish. Res. Lab. 70): 1-91.

Marvin, K. T., Z. P. Zein-Eldin, B. Z. May, and L. M. Lansford. 1960. Chemical analyses of marine and estuarine waters used by the Galveston Biological Laboratory. U. S. Fish. Wildl. Ser., Spec. Sci. Rpt. - Fish. 349: 14 p.

Massmann, W. H. 1954. Marine fishes in fresh and brackish waters of Virginia rivers. Ecology. 35(1): 75-78.

Massmann, W. H., and A. L. Pacheco. 1960. Disappearance of young Atlantic croakers from the York River, Virginia. Trans. Amer. Fish. Soc. 89(2): 154-159.

Pacheco, A. L. 1957. The length and age composition of spot, Leiostomus xanthurus, in the poind net fishery of lower Chesapeake Bay. Unpubl. M. S. Thesis, Col. William and Mary: 34 p.

Parker, J. C. 1965. An annotated checklist of the fishes of the Galveston Bay System, Texas. Publs. Inst. Mar. Sci. Univ. Tex. 10: 201-220.

Parker, J. C. In Press. Distribution of juvenile brown shrimp (Penaeus aztecus Ives) in Galveston Bay, Texas, as related to certain hydrographic features and salinity. Contr. Mar. Sci. Univ. Tex. 15: 12 p.

Pearson, J. C. 1929. Natural history and conservation of the redfish and other commercial sciaenids of the Texas Coast. Bull. U. S. Bur. Fish. 44(1928): 129-214.

Pearson, E. S. and H. O. Hartley. 1958. Biometrika Tables for Statisticians. Vol. 1. Second Edition. Cambridge University Press: 96 p.

Raney, E. C. and W. H. Massmann. 1953. The fishes of the tidewater section of the Pamunkey River, Virginia. J. Wash. Acad. Sci. 43(2): 424-432.

Reid, G. K., Jr. 1954. An ecological study of the Gulf of Mexico fishes in the vicinity of Cedar Key, Florida. Bull. Mar. Sci. Gulf. Carib. 4(1): 1-94.

_____. 1955A. A summer study of the biology and ecology of East Bay, Texas. Part I. Introduction, description of area, methods, some aspects of the fish community, and the invertebrate fauna. Tex. J. Sci. 7(3): 316-343.

_____. 1955B. A summer study of the biology and ecology of East Bay, Texas. Part II. The fish fauna of East Bay, the Gulf beach, and summary. Tex. J. Sci. 7(4): 430-453.

_____. 1956. Ecological investigations in a disturbed Texas coastal estuary. Tex. J. Sci. 8(3): 296-327.

_____. 1957. Biological and hydrographic adjustment in a disturbed Gulf coast estuary. Limnol. Oceanogr. 2(3): 198-212.

Reid, G. K., A. Inglis, and H. D. Hoese. 1956. Summer foods of some fish species in East Bay, Texas. S. W. Nat. 1(3): 100-104.

Reid, G. K. and H. D. Hoese. 1958. Size distribution of fishes in a Texas estuary. Copeia. 1958(3): 225-231.

Roelofs, E. W. 1954. Food studies of young sciaenid fishes, Micropogon and Leiostomus, from North Carolina. Copeia. 1954(2): 151-153.

Rounsefell, G. A. 1964. Preconstruction study of the fisheries of the estuarine areas traversed by the Mississippi River-Gulf Outlet project. Fish. Bull. 63(2): 373-393.

Schwartz, F. J. 1964. Effects of winter water conditions on fifteen species of captive marine fishes. Amer. Mid. Nat. 71(2): 434-444.

Simmons, E. G. 1957. An ecological survey of the Upper Laguna Madre of Texas. Publs. Inst. Mar. Sci. Univ. Tex. 4(2): 156-200.

Simmons, E. G. and H. D. Hoese. 1959. Studies on the hydrography and fish migrations of Cedar Bayou Pass, a natural tidal inlet on the central Texas coast. Publs. Inst. Mar. Sci. Univ. Tex. 6: 56-80.

Smith, H. M. 1907. The fishes of North Carolina. Raleigh, N. C. Geol. Econ. Surv. II: 453 p.

Springer, V. G. and K. D. Woodburn. 1960. An ecological study of the fishes of the Tampa Bay area. Fla. Bd. Conserv. Tech. Ser. (1): 104 p.

Sundararaj, B. I. 1960. Age and growth of the spot, Leiostomus xanthurus Lacepede. Tulane Stud. Zool. 8(2): 40-62.

Suttkus, R. D. 1955. Seasonal movements and growth of the Atlantic croaker (Micropogon undulatus) along the east Louisiana coast. Proc. Gulf and Carib. Fish. Inst., 151-158.

Townsend, B. C., Jr. 1956. A study of the spot, Leiostomus xanthurus Lacepede, in Alligator Harbor, Florida. Unpubl. M. S. Thesis, Fla. St. University: 43 p.

Trent, W. L. 1969. Ecology of western Gulf estuaries. U. S. Fish and Wildl. Serv., Bur. Comm. Fish. Circ. 343: 25-31.

Wallace, D. H. 1940. Sexual development of the croaker, Micropogon undulatus, and distribution of the early stages in Chesapeake Bay. Trans. Amer. Fish. Soc. 70: 475-482.

Welsh, W. W. and C. M. Breder, Jr. 1923. Contributions to the life histories of the Sciaenidae of the eastern United States coast. Bull. U. S. Bur. Fish. 39: 141-201.