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SALINITY CHANGES AND
OYSTER DISTRIBUTION

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BARATARIA BASIN: SALINITY CHANGES AND OYSTER DISTRIBUTION

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ABSTRACT

The biology, production, and distribution of the American oyster in the Barataria basin have been correlated with environmental factors that determine spatfall, growth, reproduction, and mortality. Mortalities resulting from predation and disease are often associated with increased levels of salinity and temperature. Oysters thrive in the mixture of fresh and salt waters found in many of our estuaries; their distribution is found to be directly related to salinity. This paper explains the interrelationships that exist between salinity and other environmental parameters affecting oyster populations.

Salinity data accumulated over a twenty-year period has afforded the documentation of salinity changes in the lower Barataria basin. The trend is towards increased levels of salinity in the Barataria estuary. During the past 30 years natural oyster spatfall has been observed further and further inland, in areas that had previously been too fresh to support oyster growth. If oyster growth is displaced further northward at the present rate, the Barataria oyster fishery may suffer, as encroaching levels of pollution intrude southward into areas of current and future oyster production.

INTRODUCTION

During the past 30 years there has been an increasing concern for the protection of the various species that inhabit Louisiana's richly endowed coastal zone. This interest has prompted an investigation into the abundance and distribution of commercial and noncommercial species that exist in estuarine communities. Presently, the Coastal Zone Management team of the Center for Wetland Resources (Louisiana State University) is attempting to evaluate the interrelationships that exist between marshland inhabitants and their biophysical habitats. The Division of Oysters, Water Bottoms, and Seafoods of the Louisiana Wildlife and Fisheries Commission (LWFC) is responsible for much of the research activity and the collecting and achieving of environmental data describing these aspects of the coastal zone.

Historically, our most valuable commercial fisheries have been shrimp, menhaden, and oysters (in that order). Each of these organisms depends heavily on estuarine environmental systems such as those found in Louisiana. The productivity of such systems is predetermined by the balance of several factors that comprise the delicate estuarine framework. Recently the U.S. Environmental Protection Agency stated that "it is currently assumed that none of the major commercial species would continue to exist in commercial quantities if estuaries were not available for development" (U.S. EPA 1971). This is particularly true for the American oyster (Crassostrea virginica Gmelin), which inhabits estuarine waters during its entire life cycle. The dependence of this organism on the mixture of fresh and saline waters--coupled with its benthic development and feeding behavior--account for its extreme sensitivity to sporadic environmental fluctuations that can result in increased mortalities. Louisiana has been subject to fluctuations in production since the beginnings of the oyster industry in the latter half of the nineteenth century. Several oyster surveys conducted around the turn of the century have facilitated this investigation.

Currently the most widely used means for the quantitative assessment of commercial species is the use of catch data. However, the lack of consistent and realiable reporting of oyster landings has restricted the use of conventional methods for the inventory and analysis of the Louisiana oyster resource. Accordingly, sources other than catch data had to be utilized to construct a program that would reveal current and historical aspects of oyster production, distribution, and relationship with a dynamic and changing environment.

The approach for accumulating data was broken down into five basic tasks:

1) Survey of previous efforts to locate and quantify Louisiana oyster populations.
2) Personal interviews with qualified members of the oyster fishery to establish production estimates from private leases.
3) Consultation with LWFC (Division of Oysters, Water Bottoms, and Seafoods) to obtain lease charts and records.
4) Analysis of water quality in areas of oyster production as recorded by the Louisiana State Department of Health.
5) Evaluation of the interrelationships between oyster production and environmental factors.

The Barataria Basin was selected as a pilot study area because of the quantity and quality of available environmental data. It is a semiclosed basin that receives its freshwater input mainly from rainfall and agricultural runoff. The northern head of the basin is dominated by fresh to brackish waters while salt water environments dominate the southern seaward end. This basin is one of the major oyster producing areas in the state.

This report first discusses environmental factors affecting oyster population and the history of oyster production in the Barataria Basin. Then, in the context of information presented in these two sections, the effects on oysters of environmental changes in the Barataria Basin are presented. The reader is urged to give full attention to this final section, which documents clearly for the first time the steady northward movement of oyster producing areas in the basin due to salinity encroachment (and the accompanying problems of predation and disease from marine organisms). As oyster producing areas move northward, further problems arise from encroaching pollution levels from the north. These problems pose a real threat to oyster production in the Barataria Basin, and the introductory information on the biological requirements of oysters should be read with them in mind.

ENVIRONMENTAL FACTORS AFFECTING OYSTER POPULATIONS

Any investigation into the causes of mortality, decline in production, or changes in distribution of oysters should take into consideration many possibilities. Principal factors that produce favorable growth rates, propagation, and general welfare in an oyster community are optimal temperature, food supplies, water circulation, bottom character, and salinities. A second set of factors, which may adversely affect oyster populations, includes disease, competition, predation, turbidity and sedimentation, and pollution. The interactions of the positive and negative factors of the environment act simultaneously on an oyster community to determine its productivity (Galtsoff 1964).

Temperature

A great difference in climatic conditions exists within the geographical range of the American oyster. Temperature is one of the principal variants in benthic communities of this type. The oyster is a poikilothermic organism that has been observed in waters with temperatures ranging 34-97°F (Galtsoff 1964). The external temperature directly affects the life of the oyster by controlling gonad formation, spawning, respiration, feeding, and water transport.

Ciliary motion of the gills, which is responsible for the transport of water, is maximum at a temperature of about 77-79°F. The ciliary activity declines rapidly below 70°F and ceases completely at 41-45°F. Growth of oysters maintained at temperatures below 46°F is often referred to as hibernation (Galtsoff 1964). At temperatures above 90°F there is also a decline in ciliary movement. The effect of ciliary activity is very important to the physiology of the oyster because of the direct relation of water transport to other vital processes. In addition to respiration, the celia of bivalve gills play an important role in feeding. As the tiny, whip-like celia beat to transport water over the gill filaments, dissolved organic substances and microscopic life are trapped on the surface of the gills. These particles are transported to the mouth by continuous ciliary motion associated with water transport. Galtsoff (1964) observed that feeding does not occur below temperatures of 43-44°F.

The second set of functions that are directly related to environmental factors, primarily temperature, are gonad formation and spawning. As the temperature of the water begins to rise in late winter and spring, the sperm and egg cells develop, thickening the gonadal epithelium (Hopkins et al. 1953). Spawning of ripe gonads is triggered by a rapid rise in temperature but is not determined by a specific critical temperature, as others had originally suggested (Nelson 1931).

The number of sex cells produced during a single season varies, depending upon environmental conditions. Greater gonadal development is more likely to be found in oysters from latitudes north of the Chesapeake Bay rather than in the south Atlantic and Gulf of Mexico waters. However, in these northern populations the reproductive season is of short duration, lasting only 4 to 6 weeks. In our warmer southern waters, gonadal formation and spawning continue for several months. The peak of the spawning season for Barataria Bay oysters occurs early in May (Mackin and Wray 1950). Mackin and Wray (1949) state that oysters in the lower region of Barataria Bay are kept at near gonadal exhaustion for 6 to 8 months of the year, due to prolonged high temperature stimulation. Postreproductive degeneration of tissue and glycogen loss in these oysters is partly responsible for the shortened life span of oysters found in our southern habitat.

Indirectly, temperature is a controlling factor in that it, along with salinity, determines solubility of oxygen in water and affects the matabolism, reproduction, and behavior of associated organisms. Metabolic rates of predators, parasites, and competitors are accelerated in spring and summer months at precisely the time when oysters are most vulnerable to damage due to spawning and glycogen losses.

Mackin and Hopkins (1961) noted that seasonal mortalities of oysters were obviously correlated with temperature. However, Mackin and Wray (1950) stated that the effect of temperature is secondary as high temperature alone has little or no effect, but high temperature combined with some factor associated with high salinity, such as predation, is effective in producing lethal results.

Food

Observations of various investigators indicate that diatoms, dinoflagellates, and other groups of phytoplankton and zooplankton plus bacteria and organic detritus comprise the diet of the oyster. Selection is made primarily on the size and shape of the food particles. Jørgenson and Goldberg (1953) observed that the American oyster filters about 10 to 20 liters (2.6-5.2 gallons) of water for each milliliter of oxygen consumed. At this rate, under normal conditions at 75-77°F, an oyster may filter 1,500 liters (396 gallons) of water daily. Actual food requirements of oysters do not exceed 0.15 mg of utilizable organic matter per liter of water used (Jørgenson 1952). The organic matter of the phytoplankton found in American coastal waters has been shown to range from 0.17 to 2.8 mg per liter (Riley 1941; Riley and Gorgy 1948). Research along the coast of Louisiana conducted by M. H. Owen (1955) for LWFC indicates that "at all times and at all stations sampled there were sufficient numbers and kinds of microorganisms present in the water to support existing populations of oysters."

The abundance of plankton is critical only during the period when the oyster is actively feeding and accumulating glycogen. Conditions are ideal for the feeding of oysters when non-polluted water containing a low concentration of small diatoms and dinoflagellates runs over a bottom in nonturbulent flow (Galtsoff 1964). High concentrations of phytoplankton, such as those seen during algal blooms, are not desirable and can be harmful. Sudden development of red tide dinoflagellates, Gymnodinium breve, may cause extensive mortalities of oysters growing in water along the shores of affected areas. Consumption of the poisoned shellfish may produce lethal results in the consuming organisms. Toxic algal blooms are not common in Louisiana waters; no reports of the poisoning of shellfish exist in the recent literature.

Water Circulation

"Free exchange of water is essential for the growth, fattening and reproduction of oysters" (Galtsoff 1964). Ideally, an oyster bed is supplied with a steady, nonturbulent flow of water. The current need only be strong enough to carry away liquid and gaseous metabolic wastes and feces and to provide oxygen and food. The distribution of planktonic populations, eggs spawned within the estuary, pollutants, and any other material dissolved or suspended in water is determined by the circulation of fresh and salt water in the estuary. These waters are mixed and distributed constantly within the estuary as a result of daily winds and tidal oscillations. River flow and rainfall also effect water circulation but on a more seasonal basis (Ketchum 1951).

Tidal currents and other water movements in the northern Gulf area have been described by Marmer (1947, 1948, 1954). Tides of the Barataria Bay area are diurnal (one high and one low per day). Mean tidal levels fluctuate in a regular rhythm throughout the year; the lowest mean levels are in January and the highest in September (Marmer 1954). There is an increase in mean tidal level from August to September. This is of greatest significance in its effect on salinity levels in bays and marshes. During this same period, with low rainfall in the marsh drainage area, high evaporation rates due to summer temperatures coupled with high transpiration rates of lush summer vegetation cause a net flow of water from the Gulf into Louisiana bays and marshes. As would be expected, this has a pronounced effect on the salinity of the estuaries (Mackin and Hopkins 1961).

The velocity of currents over an oyster bed will determine the amount of sediment deposition. Natural oyster reefs are commonly located in areas free from sediment deposition or siltation. Oyster spat require hard clean surfaces for attachment. Planted shell or cultch placed in areas of relatively high current velocity tend to collect more spat than those placed in low velocity areas (Keck et al. 1973). In addition to being relatively free from the problem of siltation, these high current areas are exposed to a greater volume of water and hence a higher number of larvae will come in contact with the shell. Perkins (1952) showed that oyster larvae concentrations are high where current is fairly strong and salinity shows no stratification.

Oyster communities are most vulnerable to occasional turbulent currents of high velocities, such as those associated with hurricanes. These movements may dislodge and carry away young and adult oysters not attached firmly to some bottom feature. Oysters that are attached to the bottom are also harmed by such currents. Valve injury is incurred if sand is present to act as an abrasive material.

Bottom Character

One of the physical factors of great importance to the oyster grower is the character of the bottom. Oysters grow best on bottoms that are hardened with firm mud, rock, or shell. Oysters do not grow well on sandy or soft mud bottoms. The abrasive action of shifting sand will cause valve injury; shifting mud may cause death by suffocation.

Barrett (1971) mapped sediment type distribution in Barataria Bay and vicinity. He describes the sediment type in this area as being predominantly clayey silt. The Gulf side of the bay has a higher sand content than that of the north and central regions, which have a siltier character. Clay content in the bottoms of Barataria Bay is low.

A soft muddy bottom may be improved by planting cultch to form an artificial reef. The most common cultch materials are oyster and clam shell. These materials give the bottom an artificial but functional firmness desired for oyster culture. Louisiana oystermen prefer clam shell as a cultch material because it produces more single, rounded oysters that are desirable in the counter trade. Pollard (1973) found that "no cultch material candidate could approach clam shell for suitability as cultch, because of its abundance, low cost, and ready availability with a minimum of transportation difficulties." The limitations of the practice of planting cultch are primarily those of time and money. The current price of clam shell and oyster shell is \$5.00/yd^3. Louisiana oyster fishermen may plant cultch at densities as high as 500 yd^3/acre on relatively small plots, while the LWFC plants cultch at rates of 30-50 yd^3/acre on the seed oyster grounds or reservations. The fishermen apply cultch at higher rates because they are generally trying to build a hard reef-like bottom that will endure dredging operations from year to year.

The bays of southern Louisiana are typically hard bottomed around the periphery with the bottom increasing in softness toward the center (Mackin and Hopkins 1961). Galtsoff (1964) states that the most valuable type of bottom for oyster culture is firm and stable, composed of rocks and hard or sticky mud. Louisiana oystermen prefer a bottom type that is a mixture of coarse particles of hard mud and clay, which easily supports the weight of cultch or natural oyster growth; rocky bottoms are rare in coastal Louisiana. The reinforcement of oyster bottoms by shell is the principal practical method used on a large scale for the improvement of oyster bottoms or the establishment of new ones.

New oyster reefs may also be established naturally. This is partly due to the innate ability of oyster larvae to choose a substratum upon which to settle. As a result of this ability, soft muddy bottoms may be gradually converted by the oysters themselves into oyster reefs in a process that may require several years. The process begins with the attachment of larvae to a single shell or other hard object lying on the surface of the bottom. Other larvae attach to those that have already settled. Soon a cluster of oysters is formed. As the oysters grow, natural and artificial processes will determine mortality. Dead oyster shells drop from the cluster and provide additional surfaces for larvae attachment. The cycle begins again and the reef grows horizontally and vertically (Galtsoff 1964).

Salinity

Perhaps the single most important environmental factor affecting oyster populations is salinity (Butler 1949). The direct relation of rainfall to salinity makes surplus precipitation another important parameter to consider. Coastal Louisiana is an area of high annual rainfall, averaging 59 in/yr. In Barataria Bay, high rainfall serves to decrease salinity whereas tides drive Gulf water into the bay through the passes, increasing salinity. Thus, during periods of high rainfall there is usually a significant decrease in salinity. During periods of drought and high temperature, salinity may be expected to rise.

Oysters are euryhaline organisms, able to live in waters of a very wide range in salinity. Chanley (1957) reported that optimum salinity for growth and development of C. virginica falls between 15 and 22.5 ppt. Galtsoff (1964) found oysters inhabiting waters with a range of salinity from 5 to 40 ppt. The optimum salinity for oyster populations in the Chesapeake Bay area is from 10 to 28 ppt. The optimum salinity for natural oyster growth and survival in Louisiana is much lower, 5 to 15 ppt (Galtsoff 1964; St. Amant 1964). Oysters inhabiting waters of more northern latitudes seem to be more adapted to higher salinity levels. Lindall et al. (1972) explain these differences as being preferences exhibited by distinct ecotypes, possibly even subspecies.

Oysters are somewhat adapted to diurnal, seasonal, and annual fluctuations of salinity. The mean values of these salinities are of little significance because of the oysters' ability to isolate itself from the environment by tightly closing its valves. In this way it may survive adverse conditions, provided they do not last indefinitely (Galtsoff 1964). Direct effects of change in salinity on C. virginica are determined by two factors: the range of the fluctuations and the suddenness of changes. Barataria Bay is periodically subjected to drastic changes in salinity. During Hurricane Carmen, which passed near the Barataria coastline on September 7, 1974, the salinity at St. Mary's Point (see Fig. 1) was increased from 7 to 30 ppt within 3 hours (Maurice Lasserre, personal communication, LWFC, Baton Rouge, La.).

Several studies have attempted to relate oyster mortalities to salinity. Lowered salinities have been directly correlated with increased mortalities (Butler 1949). Marine bivalves have little power of osmo-regulation when placed in dilute seawater; they can prevent loss of salts only by closing their valves. The first physical reaction of oysters to lowered salinity is the slowing or cessation of water current through the gills. This is accompanied by partial or complete contraction of the adductor muscle. This behavior may last for several hours with no permanent injury to the oyster (Galtsoff 1964). Of course, if the exposure is prolonged, the oyster will become weakened or permanently injured and may die.

The reproductive capability of oysters is reduced by low salinity. Butler (1949) showed that gametogenesis is inhibited in oysters maintained in salinities less than 6 ppt. He attributes this failure of gonad development to variations in food availability and feeding rather than direct inhibition of sexual activity. Loosanoff (1952) found that normal gonadal development may proceed in salinities near 7.5 ppt, but oysters with ripe gonads subjected to lower salinities spawn at 5 ppt. He also noticed abnormal feeding behavior and little growth at salinities of 5 ppt or less. Davis and Calabrese (1964) related rate of growth to type of food organisms available. The type and abundance of food organisms is determined by environmental factors such as salinity.

Barataria Bay oyster fishermen usually transplant young oysters from water of low salinity into water nearer the Gulf. The increase in salinity results in an increase in the rate of growth and fattening of the oysters. In addition, the taste of the oyster is improved as the salt content is increased.

Galtsoff (1964) reported a gradual increase in ash (mineral matter) and salt content of oysters from May to September. Variations in the chemical composition of oysters follow distinct patterns related to the environment and season of the year. "The major environmental factor affecting the chemical composition is the salinity of the water" (Galtsoff 1964). Lynch and Wood (1966) showed that amino acid content of oyster adductor muscle increases proportionally with increased salinity. The increase in solids and corresponding decrease in water content is associated with an increase in glycogen content (Galtsoff 1964). These factors directly affect the commercial quality of oysters.

Continued exposure to salinities above the optimum range has an unfavorable effect on oyster populations. However, most investigators feel that the combined effects of high salinity and high temperature are much greater than the effect of either variable when taken singularly. The synergistic effects of high temperature and high salinity have been the topic of much research interest. Mackin and Wray (1950) and Owen (1955) found that excessive mortalities in the Barataria Bay region occur when there is a combination of high temperature and high salinity. These mortalities are the primary reason for low production in certain years (Owen 1955).

The influx of fresh water into an estuary is often quite beneficial. Decreased salinities have lethal effects on carnivorous gastropods, flatworms, and fungi that are highly destructive or debilitating to oysters. Brackish water constitutes a barrier through which these predators and parasites cannot penetrate and survive for extended periods. Periodic flushing restores the productivity of oyster beds by reducing these harmful organisms and introducing nutrients.

Predation

Predation is one of the more obvious environmental factors associated directly with oyster mortality. Representative flatworms, molluscs, echinoderms, crustaceans, fishes, birds, and mammals prey on oysters. Not all of these enemies are equally destructive to oyster populations; the most dangerous are those that prefer oyster meat to other types of food (Galtsoff 1964).

Every oyster fisherman questioned agreed that the most serious predators found in Louisiana waters (excluding man) are the Louisiana conch or oyster drill (Thais haemostoma) and the black drum (Pogonias cromis). The stone crab (Menippe mercenaria) was mentioned as having been a serious pest during the 1930s and 1940s. The starfish, Asterias forbesi, a highly destructive predator in Atlantic coast oyster grounds, is usually not found in Louisiana estuaries, probably because of its low tolerance to reduced salinities such as those found in Barataria Bay.

The deadliest enemy of Louisiana oysters is the conch, a carnivorous gastropod common to waters of the south Atlantic and Gulf of Mexico. The organism feeds chiefly on oysters and other molluscs by drilling a neat round hole, approximately 0.004 inches (1 mm) in diameter, through the shell. The oyster flesh is removed by means of an extensible proboscis. The conch seems to prefer small oysters to large ones. Selective destruction of young oysters may result in extinction of natural reefs (Burkenroad 1931). The conch poses a threat to the Barataria Bay oyster fishery, with normal attacks occasionally resulting in near total depletion of oysters grown in the lower bay region.

Several studies have been conducted to elucidate the biology of the Louisiana conch and its relation to the American oyster. St. Amant (1938) presents a detailed, informative dissertation concerning Thais and its effect on oyster populations. Burkenroad (1931) and Galtsoff (1964) have published brief accounts of the predacious nature of this organism.

Many years ago, before the oyster fishery became so extensive, the oystermen would set traps for the conch. These were wire baskets that were baited with clam or oyster meats.

Another method for control of this predator was the use of palmetto fronds. During breeding season, the conchs develop a tendency to climb as high as possible (below low tide mark) on structures elevated above the surrounding bottom. The eggs are fastened to these elevated objects. Because of this habit, the animals and their eggs can be trapped during the breeding period. At one time, Louisiana oyster fishermen used stakes with bunches of palmetto fronds wired to them throughout an infested area. The animals climbing up accumulated on the palmetto fronds as they deposited their eggs. The oyster fishermen pulled up the stakes periodically and shook the palmetto fronds over the bottom of their boat, removing predator and potential offspring (Gates 1910). One oyster fisherman stated that in one year he harvested as many conchs from his leases in lower Barataria Bay as he had oysters.

One of the most beneficial effects of freshets (sudden influxes of fresh water) that occur in the Louisiana estuaries is the effect they have on the conchs. The limiting factor in the distribution of the conch is considered to be salinity. The organism cannot survive prolonged exposure to salinities less than 10 ppt (Galtsoff 1964).

Schools of black drum often invade the northern waters of the Gulf of Mexico where they feed on molluscs such as the oyster. These fish possess powerful jaws and pharyngeal teeth that can crush oyster shell. Piles of crushed oyster shells are the only remains of productive oyster reefs that have been attacked by the voracious black drum.

These fish seem to be especially partial toward oysters that have been freshly transplanted or bedded. The damage to natural reefs is slight, but in areas where oysters are transplanted to saltier waters, the ravages of the drum are more frequent (Gates 1910). If a bed is accidentally disturbed by a tugboat, crewboat, or other object scraping over a reef, the drum are more likely to attack that particular bed. For this reason, once harvesting operations are begun, Louisiana oyster fishermen often continue dredging an individual lease until all the oysters are removed.

During the early years of the fishery, oyster fishermen fenced their oyster beds with galvanized wire to prevent attacks by the black drum. The use of this technique has disappeared because the fence interfered with navigation in the coastal zone. Since the days of fencing, oyster fishermen have no means for controlling this predator.

Competition and Commensalism

Oyster competitors are those organisms that live in close proximity to oysters and struggle with them for available food and space. Commensal organisms live in a related capacity to oyster populations, sharing the food gathered by their oyster host. Some commensals may become parasites or cause injury to the oysters as a result of their habits or fecundity.

The oyster is subject to several commensal and competitive relationships as the shell and body of the oyster are the natural abodes for many plants and animals that attach themselves to the shell surface or bore through it to make for themselves a well protected residence (Galtsoff 1964). The list of such species and their behavior is well documented and described by Galtsoff (1964).

The major species of this group common to Barataria Bay waters are Polydora, Cliona, and Diplothyra. Mackin and Wray (1949) refer to these three as "the shellpest triumvirate." Polydora is a genus of mudworm found in the intertidal zone of Atlantic, Pacific, and Gulf waters of the United States. P. websteri is found in Louisiana oyster shells and on the lateral inner surfaces of the valves. The worm builds a U-shaped tube in the shell that is covered by shell material (conchiolin) secreted by the oyster; the formation on the inner shell surface is usually called a blister. Hopkins surface is usually called a blister. Hopkins (1958) presents a report describing the behavior of the organism and its occurrence throughout Louisiana. Mackin and Wray (1949) feel that abnormally high populations of these worms are probably due to high organic detritus content of the waters.

Two species of boring sponge, *Cliona celata* and *Cliona truitti*, have been observed in Barataria Bay. The major difference between the two species is their distribution, which is based on different tolerances to low salinities. *C. truitti* is more tolerant of low salinities and is found in upper bay areas (Mackin and Wray 1949).

The presence of the boring sponge is revealed by small round holes on the surface of oyster shells. Heavy infestations may result in brittle valves that break under slight pressure. If the oyster has been subjected to adverse conditions, delayed deposition of conchiolin may result. In this case the sponge makes direct contact with the oyster flesh. This results in dark pustules forming directly opposite the holes in the shell (Galtsoff 1964).

Oyster shells in Louisiana are often infested with the boring clam, *Diplothyra smithii*. This species reaches about 0.5 inches in length and is found inside oyster shell material in a cavity that increases in size as the clam grows. The clam is rarely found to directly contact the oyster flesh, again because the oyster secretes conchiolin over nearly perforated areas. The presence of the boring clam is indicated by small holes in the outer surface of the valves. Infestations of boring clams are harmful to oysters because they weaken shell structure (Galtsoff 1964).

Turbidity and Sedimentation

Several factors contribute to turbidities found in bays and bayous of the Mississippi River delta depressions. Much of the autochthonous turbidity is because of materials introduced into Gulf waters by the Mississippi River. As river waters reach the Gulf, decreased velocities and flocculation precipitate most of the silt load; the remainder enters the tidal zone. A portion of these highly turbid waters ultimately reach the estuaries. Other important causes of turbidities in the estuaries are high surplus precipitation and runoff, wind agitation of inorganic debris on the water bottom, and human activity such as boat traffic and dredging. Both natural and man-induced production of turbidities is present in Barataria Bay, which always seems to have high turbidity.

The effects of turbidity on shellfish are quite complex, with beneficial and harmful aspects. Several investigators agree that low levels of turbidity do not harm either adult oysters or oyster larvae (Ingle 1952; Mackin and Hopkins 1961; Loosanoff and Davis 1963). Loosanoff and Davis (1963) suggest that suspended silts and clays may even absorb toxic pollutants and thereby allow oysters and other filter feeders to survive.

Abnormally high levels of turbidity are dangerous to estuarine communities. Prolonged excess turbidities can be detrimental to primary producers, which determine the productivity of estuarine environments. Planktonic plants are dependent upon sunlight as the energy source for photosynthesis. As the suspended solids content of the water increases, the depth of light penetration decreases. Therefore, the compensation depth (level at which rate of photosynthesis equals the rate of respiration) decreases or approaches the surface. If light penetration does not reach compensation depth, respiration may exceed productivity. In this case, the system loses energy and the biological community undergoes degradation (Brehmer 1965).

Estuarine communities are adapted to cope with turbid environments, but man-made levels of turbidity often exceed the tolerance level of such systems. Shellfish are especially vulnerable to damage by inorganic suspended solids. These filter feeding organisms remove suspended solids from the environment as water is transported across the gills. Feeding activity is inhibited by high suspended solid levels (Galtsoff 1964).

As the velocity of water containing suspended materials is decreased, the amount of deposition of the suspended matter is increased. The role of siltation in the destruction of aquatic habitats is well documented. Siltation can smother benthic forms of life. Louisiana fishermen say that oysters are suffocated by 1 to 3 inches of silt, depending upon the size of the oysters. Investigators of siltation damages to oyster leases by LWFC biologists strongly suggest that oysters may be able to cope with a slow, gradual siltation by maintaining a clear area for water intake. However, rapid siltation of several inches usually results in high mortalities.

Increased dredging activities have presented serious problems to oyster fishermen working in areas of active oil and sulfur operations. About 50 percent of oyster damage complaints registered with the LWFC involve dredging and siltation (Lindall et al. 1972). Brehmer (1965) states that "turbidity and subsequent siltation reduce the quality of estuarine waters for intended uses and degrade the system as a biological habitat." He describes turbidity and siltation as forms of pollution which have been greatly increased by man's activities.

Pollution

Brehmer (1965) defines water pollution as "the introduction into the water of any material that reduces the value or utility of the water for any intended use." The generality of such statements has made for complex social, economic, and biological points of view on the subject of pollution. The term means different things to different people, depending upon their particular interest. Public health officials are primarily concerned with the health hazards associated with pollution. The ecologist relates pollution to changes in the environments. To the oyster grower, pollutants are any materials that decrease the availability of oysters.

Detailed descriptions of all types of pollution that may affect oyster populations are beyond the scope of this paper. Basically, there are two groups of pollutants commonly found in oyster growing areas: domestic sewage and industrial or trade wastes.

The discharge of domestic sewage is one of the most ancient forms of pollution, common to all geographic areas inhabited by man. Increased population has necessitated the use of sewage treatment and organized disposal. The introduction of domestic sewage sludge directly into oyster growing waters may immediately produce lethal effects as oyster beds are smothered with the material. This type of pollution also increases the BOD (biological oxygen demand) of affected waters, reducing the amount of dissolved oxygen available to the shellfish.

The most significant problems associated with domestic sewage pollution and oyster consumption are due to the oysters' feeding behavior. These filter feeding molluscs retain and accumulate bacteria found in their aquatic environment. This characteristic makes the oyster a potential source for a concentrated number of pathogens associated with domestic waste, such as the microorganisms causing typhoid fever and hepatitis. The U.S. Department of Health, Education, and Welfare (HEW) determines the degree of contamination of oyster growing waters by the abundance of Escherichia coli, a nonpathogenic coliform bacterium found in mammalian fecal waste.

The Louisiana State Department of Health (LSDH) monitors coliform levels of all oyster growing waters along the coast. If the MPN (most probable number) of E. coli exceeds the permissible maximum of 70 per 100 ml and more than 10 percent of the samples exceed an MPN of 2 30 per 100 ml, the area is restricted and cannot be used for harvesting (HEW 1965). However, under certain specified conditions, the oysters in these areas may be transplanted to unpolluted areas where they are allowed to depurate for a period of several weeks.

The Louisiana State Health Department records temperature, pH, turbidity, salinity, total coliforms, and fecal coliforms (E. coli) at stations located in each oyster growing area of the state. This data is compiled and published in Louisiana Oyster Water Surveys, which are available through the Engineering Division of LSDH. Barataria Bay lies in sample areas designated III-A and III-B. These areas receive some sewage contamination from Mississippi River discharge that drifts northwestward and enters the bay through various passes and inlets. Other sources for contamination are settlements and camps found in Barataria Bay and along adjacent bayous and marshes.

No industrial wastes are known to be discharged directly into Louisiana oyster growing waters (LSDH 1972). However, several types of industrial pollutants enter oyster producing areas via Mississippi River discharge and various drainage systems in the basin. Common industrial pollutants flushed into growing areas include those from oil, sulfur, paper, chemical, plastics, and food industries that characterize the south Louisiana region. The type of pollutant varies with the product.

State and federal laws forbid the discharge of oil into coastal waters. Yet many of our bays and marshes are heavily polluted by oil (Galtsoff 1964). The parishes of the Barataria Basin produce almost one-half of Louisiana's oil and natural gas. Petroleum exploration and extraction activities have been among the more evident sources of industrial pollution in this area. When oil is spilled onto the surface of water, it spreads rapidly to form a thin film. In highly turbid waters such as those found in Barataria Bay, suspended particles of clay, silt, and organic detritus absorb oil, coalesce, and gradually sink to the bottom (Owen 1955). The crude oil may remain in the sediments for several weeks, retaining toxicants that impart "oily" tastes to the oysters of the affected bottom (Blumer et al. 1970).

Runoff from agricultural areas presents multiple pollution problems in oyster growing areas. In 1967, the Public Health Service of HEW published a study of pesticides in shellfish and estuarine areas of the Lower Mississippi River region and southern Barataria Bay. Oyster meats and water samples were collected during three separate time periods between January 1964 and June 1966. All of the oyster meats sampled were found to contain one or more chlorinated pesticides. The amounts of pesticide residues occurring in the oyster samples were not significant as health hazards (HEW 1967).

The Louisiana State Department of Health monitors agricultural pesticides and heavy metals in oysters and performs radiation analyses of oyster meats. The available data indicate no contamination of growing waters by radioactive materials, heavy metals, agricultural pesticides or other objectional materials (LSDH 1972).

Disease

Oysters, like most other living creatures, are subject to both noncontagious and infectious diseases. The oyster's resistance to disease is a reflection of environmental conditions that can weaken or strengthen the organism. Symptoms of disease in oysters are usually nonspecific. The more common symptoms are slow growth, failure to fatten, inhibition of gonadal development, or abnormal spawning activity. If the oyster is severely diseased the adductor muscle is weakened so that the valves do not close tightly. In the literature these oysters have been called gapers. Abnormal deposition of shell in diseased oysters is a chronic condition resulting in the formation of short and thick shells. The body of a sick oyster is often discolored (dirty green or brown), watery, and bloody with blood cells accumulating on the body surface and gills (Galtsoff 1964). This condition is not to be confused with that of a firm-bodied, healthy oyster highly pigmented in red or brown as a result of the food it has consumed. These oysters are considered top quality in the counter trade.

A number of pathogenic and nonpathogenic organisms have been associated with periodic mortalities of oysters in waters of the United States. However, widespread oyster mortalities can rarely be attributed to a single factor such as disease. In most cases, a combination of several adverse conditions, including infection, are responsible for these occurrences.

The most dangerous parasite associated with infectious oyster disease in Louisiana is a fungus called *Dermocystidum marinum* for many years (Mackin et al. 1950). Recent taxinomical advances have resulted in a reclassification of the organism as *Labyrinthomyxa marina*. During 1947 and 1948, Mackin and Wray (1949) observed that almost 100 percent of oysters in Louisiana waters, including Barataria Bay, were infected by this fungus.

The many phases of the life history of *Labyrinthomyxa* and various degrees of infection, coupled with environmental factors that affect the resistance of the oyster to disease, result in a complex collection of symptoms, including some of those previously mentioned. For the purpose of this study, it will be sufficient to mention the following information concerning the fungus and its relation to the oyster (from Owen 1955).

1) *Labyrinthomyxa marina* is a causative agent of oyster disease, which is histolytic in nature.
2) The disease is lethal to oysters under conditions of high temperature.
3) High temperature and high salinity produce optimum conditions for the spread of the organism.
4) Oyster production in Louisiana is seriously affected by the disease.
5) Infected oysters in an optimum environment usually recover from the infection, based on degree of the infection.
6) This fungus is probably the major cause of unusual, widespread mortalities of Louisiana oysters.
7) The consumption of infected oysters by humans does not, under any circumstances, produce or have any detrimental effect.

No other pathogenic organism seems to be as persistent in Louisiana waters as *Labyrinthomyxa*.

However, other pathogenic organisms do exist and have been correlated with oyster disease in coastal Louisiana. Hexamita sp. is one such organism (Mackin et al. 1952). Heavy infestation of this flagellated protozoan causes breakdown of connective tissue cells, general inflammation, and necrosis of tissues containing the dormant cyst stage of the parasite (Galtsoff 1964). Reports of the presence of Hexamita in Louisiana waters are rare, as are reports of another parasite, the oyster leech, Stylochus sp. (Owen 1955). Young oysters seem to be easily attacked by this flatworm, which has no difficulty entering the slightly opened valves of diseased oyster and spat. Stylochus is often found in Florida waters where it frequently inflicts serious damage to oyster communities, but the significance of the parasite in Louisiana is "minutely minor" (Owen 1955). Some authors feel that Stylochus is probably best classified as a predator (Galtsoff 1964), not a parasite that may cause disease (Owen 1955). The exact difference between these types of relationships is most difficult to discern.

The trematode, Bucephalus gracilescens, is an intestinal parasite of certain marine fishes. The oyster is the intermediate host of this trematode or fluke. The eggs of Bucephalus, which are liberated from the intestine of infected fishes, are ingested by the oyster as it feeds. A ciliated larvae or miracidium develops within the egg, emerges, then migrates to the gonadal tissue of the oyster where it goes through several stages of its life cycle. The growth of the organism in the oyster may become so extensive as to practically replace most of the reproductive tissue. Eventually the free living larval forms of Bucephalus develop and enter the water where they may infect the definitive host. Bucephalus does kill oysters and has been found in Louisiana waters, including lower Barataria Bay. Frequency with which Bucephalus occurs in Louisiana is very low, probably owing to its rather complicated life cycle (Owen 1955).

Owen (1955) found that practically all oysters from the major producing areas of Louisiana are infected with the wormlike sporozoans Nematopsis ostrearum. The spores and cysts of this nonpathogenic gregarine are found in the body tissues of infected oysters. Owen (1955) gives a full description of his observations of this organism in Louisiana waters during the late 1940s. He found that infected oysters were usually not harmed by most infestations of Nematopsis but suggested that heavy concentrations of the organism could be debilitating to their oyster host. Landau and Galtsoff (1951) indicate no correlation between oyster mortality and Nematopsis.

OYSTER PRODUCTION CURRENT AND HISTORICAL

Since 1880, attempts to record commercial oyster landings have been made by various state and federal agencies. The National Marine Fisheries Service of the U.S. Department of Commerce has recorded Louisiana oyster harvests on a monthly and annual basis since 1945 (Figure 1). The lowest catch was recorded in 1880 with a total of 1,189,000 pounds of meat. This figure is not surprising as the demand for oysters did not stabilize until the mid-1930s. The highest annual production was recorded in 1939 at 13,586,000 pounds. Some state fisheries management personnel believe that a greater amount of oysters were marketed in recent years than indicated by these statistics because of changed landing practices. However, they do believe that the statistics reflect accurately year to year trends.

The recorded catch or harvest of oysters cultured and taken from Louisiana waters includes only those used in canning operations. Oysters harvested for sack or counter trade, which may comprise a very large portion of total landings, are generally unreported (Lindall et al. 1972). Oysters suitable for counter stock are of uniform rounded shape and are high in salt and solid content (fattened). These oysters are cultivated most carefully and are usually served raw on the half-shell at oyster counters in restuarants. Oysters used in steam canning and packing may vary from 1 to 3 inches in size and may not have the taste or nutritional value of oysters served in the counter trade. These oysters are usually not cultured in highly saline waters that produce the quality preferred in raw, counter stock. Thus, fluctuations in sack or counter grade oyster production may never be realized, as this portion of the landings is seldom reported.

Oyster production is not recorded by specific area. Reliable production estimates are not available for Barataria Bay.

During the past 30 years, total reported oyster production has fluctuated around 9 million pounds annually. Several investigators have attempted to relate Louisiana oyster production to singular parameters such as rainfall and temperature (Owen 1955), season (Hopkins et al. 1953), salinity (Gunter 1955), and proximity to oil operations (Mackin and Hopkins 1961). For details of these studies, one should consult the individual publications.

Meaningful interpretation of catch data must consider fishing effort since fishing pressure and market demand often determine production. In 1913, there were 1,762 oyster fishermen working state and private reefs along our coast (Hart 1913). Today, oyster fishermen in Louisiana number 1,062 (Dugas 1975). These men lease oyster growing areas from LWFC annually at a price of one dollar per acre. Leases are surveyed by LWFC and marked with stakes by the oyster fishermen indicating private oyster beds.

The state manages several areas where spatfall (settlement of oyster larvae) is induced by salinities lower than those required for maximum growth, development, and reproduction in adult oysters. The more productive of these areas are located east of the Mississippi River in Plaquemines and St. Bernard parishes. These nursery grounds are opened to the public except during summer (April or May to September) when seed oysters are taken. The young oysters are transplanted to private leases, usually in areas of higher salinity. Some oyster fishermen maintain private leases in upper bay areas as an additional source of seed.

During the early days of the Louisiana oyster industry, around the time of the Civil War, seed oysters were gathered, transplanted, and harvested by the bare hands of fishermen wading in waist-deep water. During the late 1800s tongs appeared as the first tools used in oyster culture. Oyster tongs were constructed by blacksmiths and professional tong makers by hinging two rake-like tools with curved teeth that formed a basket. This enabled the fishermen to remove oysters from deeper waters. They were no longer limited to the shallows or restrained by intolerable temperatures (Vujnovich 1974). Oyster tongs are still used today but to a much less extent.

In 1905 the first pair of oyster dredges was installed on an oyster boat by Leopold Taliancich, a Yugoslavian immigrant. This method of fishing oysters is still being used today with a few modifications. Oyster dredges consist of V-shaped iron frames with ring-mesh sac-like enclosures, usually about 3 to 4 feet in length. The dredge is connected to the oyster boat or lugger by chains attached at the head of the frame. The apparatus is then dragged slowly over the oyster reef by a boat that circles at a moderate speed. The cumbersome dredges were hoisted aboard by manual winches until 1913 when two fishermen, John and Anthony Zegura, installed the first power-operated dredges. During that same decade, the oyster industry experienced a vessel transition. Sailing luggers were gradually replaced by or converted into motorized boats. By 1920, the entire sailing fleet had disappeared (Vujnovich 1974).

Since those early years (1920s) there have been few notable changes in methods or techniques for oyster culture. However, improvements in dredges and refrigeration and faster, larger boats have allowed the oyster fisherman to expand his efforts with his efficiency. Today, fishermen may travel 200 miles to bed their oysters on prime reefs.

Recently, some oyster fishermen have reported a marked decrease in yield per acre. There has actually been no significant decline or increase in cannery production. However, the amount of acreage leased for oyster growing purposes has increased almost tenfold since 1913. During that year Hart (1913) reported 17,073 acres leased to Louisiana oyster fishermen. Today, more than 140,000 acres are privately leased (Dugas 1975). Likewise, acreage leased for oyster culture in Barataria Bay has greatly increased over the past 35 years. The average size of a lease in that area has doubled since 1940 (Table 1).

It has been estimated that less than 30 percent of the acreage leased to oyster fishermen is actually used each year. This is partly explained by the fact that many oyster fishermen use productive leases every other year. They feel that this allows a planted lease to recover naturally from dredging operations. In addition, the fishermen agree that this practice helps reduce predators, especially the conch. In areas of lower salinity, where the conch is not a problem, leases may be used every year.

EFFECTS ON OYSTERS OF ENVIRONMENTAL CHANGES OCCURRING IN BARATARIA BAY

Environmental processes operating in Barataria Bay are altered continuously as a result of seasonal trends in factors such as temperature, rainfall, and salinity. These primary factors have pronounced effects upon a variety of biological processes that correspondingly fluctuate on a seasonal basis. High temperatures play an important role in seasonal oyster mortalities. However, the pattern of temperature change varies little from year to year. Rainfall, although somewhat cyclic in nature, does not seem to be significantly decreasing or increasing in southern Louisiana. The demise of oyster populations as a result of the diluting action of surplus precipitations has been observed in several upper bay areas. Yet, during the year following such high rainfall, a new growth of oysters may settle and thrive in the very same areas. Similarly, predation, competition, disease, and many other secondary factors also show seasonal trends and effects but usually show no pattern of change from one decade to the next.

Salinity is probably the most variable component of estuarine environments as it is determined by a combination of factors, primarily wind, rainfall, and river discharge. Salinity regimes in Louisiana bays and marshes are particularly interesting in that they not only seem to change seasonally but may show trends on a long term basis as well. Trends appear to be towards increased levels of salinity in most of Louisiana's coastal zone (Mackin and Hopkins 1961; Lindall et al. 1972; Pollard 1973). Symptomatic of the transition to higher salinities are a loss of seed oysters to predation associated with high salinity and an opening up of more inland areas to oystering (Lindall et al. 1972). During the past 75 years, areas formerly considered too fresh for oyster culture have become some of the prime oyster growing areas in the state. Low salinity, which had previously been associated with a great portion of oyster mortalities in the early 1900s, ceased to be mentioned and the association of mortalities with encroachment of highly saline water became more and more frequent. Saltwater intrusion seemed a feasible explanation for these phenomena, yet increasing salinity had never been demonstrated by the presence of actual salinity data supporting the thesis (Mackin and Hopkins 1961).

Barataria Bay, which is considered a typical Louisiana bay or marsh in most respects, has been the subject of much research activity during the past 30 years. Physical factors such as tides, winds, temperature, turbidity, erosion, sedimentation, and salinity have been observed during the course of several research projects conducted in this area. Concomitant with these investigations have been various biological studies of marshland or estuarine ecology. Many of these studies have been specifically concerned with oysters, shrimp, crabs, and the various species of the sport fishery.

The advantage of these interests was realized by LWFC, prompting the establishment of sampling schedules for parameters such as temperature, tide, rainfall, and salinity not only in Barataria Bay, but across the Louisiana coast. The value of this data has been realized during the last ten years as various agencies have attempted to monitor changes occurring in the endangered Louisiana marshlands. Our interest in salinity as it relates to the oyster resource has revealed several interesting possibilities.

The available salinity, Mississippi River discharge, and rainfall data have afforded us the opportunity to investigate trends in salinity regimes of Barataria Bay. A number of sampling stations are located in the Barataria Bay area, but the amount and consistency of salinity data are best at two sites: St. Mary's Point and Grande Terre (refer to Fig. 2 for locations discussed in this section). The latter is one of the barrier islands fringing Barataria Bay. Salinity at Grande Terre usually lies within the polyhaline range, 18 to 30 ppt. St. Mary's Point is one of the innermost sampling stations across the bay from Grand Terre. This station is characterized by average salinities which are found in the lower portion of the mesohaline range, 5 to 18 ppt. Salinity was sampled regularly at St. Mary's Point during the years 1945-49 and 1956 to present. Grand Terre salinity has been monitored continuously on recorders since 1961. Salinity changes at Grand Terre are highly influenced by the diluting action of Mississippi River discharge, which seasonally drifts northwestward into Barataria Bay.

River discharge, rainfall, and salinity data were subjected to intense mathematical-statistical analysis. A brief summary of the details of the analysis is given as an appendix at the end of this report. At this point it will be sufficient to present the findings of the analysis as they relate to this study:

1) Preliminary studies indicate that salinity at St. Mary's Point has increased since 1961 at a rate of 0.009 ppt per month, with little correspondence to river discharge.
2) Salinity at Grand Terre did not uniformly increase or decrease over the period 1961 to 1974. A recent drop of 0.007 ppt per month was noted to correspond with an abnormal period of rising Mississippi River discharge during the past few years. Before this period, the river showed a slight falling rate of discharge.
3) The data indicate that mean salinity at St. Mary's Point was probably about 6 ppt at the turn of the century.
4) If changes continue at the present rate, salinity at St. Mary's Point will be approximately the same as that at Grand Terre in 100 years.

The measurement of salt water intrusion gives some quantitative evidence of the rapid deterioration of our estuaries. To more fully understand the increasing salinities and rate of change we must relate the encroachment of salt water and direct physical loss of wetland habitat in coastal Louisiana to specific natural and artificial processes. The rate and quality of change may vary significantly from one part of the coastal zone to another. Changes in salinity regime of Barataria Bay are largely the result of two basic factors: land loss and changes in the flow of the Mississippi River.

Land Loss

Coastal Louisiana is rapidly losing land area to the sea. Between 1932 and 1969 the average rate of coastal erosion within the Barataria basin was 119 acres per year (B. W. Gane, personal communication, Center for Wetland Resources, Louisiana State University, Baton Rouge). During the last 600 years, the erosional forces of the sea were, to some extent, counteracted by natural land building processes in this area--specifically Mississippi River delta formation. The land building processes have been greatly reduced while the erosion rate continues and has probably accelerated in recent times due to the activities of man.

In 1971 the barrier islands Grand Terre and Grand Isle were categorized as areas of "critical erosion" by the U.S. Army Corps of Engineers, National Shoreline Study. Between 1960 and 1972, 18 percent (172 acres) of the principle Grand Terre island was lost to the sea. From 1893 to

1960, Barataria Pass, the inlet separating Grand Terre and Grand Isle, doubled in width from 1,600 to 3,500 ft. Since 1960, this pass has not changed appreciably, primarily because of the stabilizing effects of Fort Livingston, located on the western end of Grand Terre, and a stone jetty that is maintained at the eastern tip of Grand Isle.

Major erosion has occurred in Pass Abel, which was 1,200 ft in width in 1960 and 3,417 ft in 1972. Most of the erosion of this pass has occurred on its eastern side. Of the increase in width of Pass Abel of 2,217 ft between 1960 and 1972, only 758 ft were eroded from the eastern end of Grand Terre. In 1960, the eastern Grand Terre island was continuous from Pass Abel to Bay Dispute. By October of 1969, this island had been severely eroded and was reduced to only 51.7 acres; by 1972, only 30.1 acres remained. The accelerated erosion rate of this island east of Pass Abel was principally because of pipeline canals that were dredged parallel to the beach near the high tide level. The banks of these canals were rapidly eroded by waves and currents.

Quatre Bayou Pass increased from a width of 3,000 ft in 1960 to 3,542 ft in 1972. Additional measurements for the major passes connecting the Barataria Bay area with the Gulf of Mexico are shown in Table 2.

Inland land loss has also occurred at a high rate. In 1965, Hurricane Betsy, which came inland in the Barataria Bay area, totally destroyed the emerged portion of Independence Island and reduced Saturday Island to less than one 1 acre.

Land loss in the Barataria Bay area has been attributed to the following factors:

Hurricanes--Since 1831, some 23 hurricanes have struck the Barataria Bay area (U.S. Army Corps of Engineers 1972). Severe storms such as hurricanes can have immediate and drastic effects on coastal land area. Wave action and winds along with the storm surge of a hurricane erode within a few hours what may have taken hundreds of years to build up. Entire islands and sand beaches are occasionally washed away by these storms; large expanses of marsh vegetation may be uprooted and deposited on the water bottom. Hurricanes sometimes create new passes and therefore alter the hydrology of an area.

Waves--Hurricanes and lesser winds generate wave action, the most constant erosional agent in the coastal zone. In addition to beach erosion, small coastal lakes are enlarged by waves; the larger the lake becomes, the more effect waves have on its shoreline. Intense wave action tends to create circular lakes commonly found in coastal Louisiana. In the shallow Barataria Bay area, with depths averaging less than 5 ft, wave forces affect the bottom, redistributing sediments and other bottom materials.

Longshore currents--These currents are generally cyclic, building beaches during one season and eroding during another. The shoreline retreat along the Barataria coastline is approximately 16 ft/yr (Morgan and Larimore 1957). Part of the shoreline retreat can be attributed to the dislodging of beach material and transporting it away from the area by longshore currents.

Sea level rise and subsidence--The gradual rise in mean sea level during the present century (Marmer 1954), coupled with normal deltaic subsidence, has accelerated rates of marshland deterioration and bay enlargement.

Subsidence, the gradual lowering of the land with respect to sea level, is a dominant and highly significant coastal process. The rate of subsidence is determined by several interrelated processes: regional geosynclinal downwarping of the coastal zone, compaction of unconsolidated sediment, and variations (mainly rise) in sea level. Although geosynclinal downwarping is an important process when considered in terms of geological time, it is too gradual a process to be considered significant in terms of historical time spans. Sediment compaction, however, occurs contemporaneously with deposition. Therefore, the effects of subsidence due to compaction are much more apparent in the modern delta (Morgan 1972).

Loss of mangroves--One of the principal vegetation types in the Barataria area prior to 1962 was the black mangrove, Avincennia nitida. This tropical and subtropical species functions as a landbuilder and impedes erosion (Odum 1971). Mangroves are among the few emergent plants that can tolerate salinities of the open sea. They are, however, easily damaged by low temperatures. Freezing temperatures during the winters of the early 1960s killed these plants. Latest reports indicate that young mangroves are once again appearing in the Barataria Bay area.

Dredging--Before 1930 there were only a few large canals in Barataria Bay, most constructed by trappers and loggers limited to small areas. Since the 1930s the demands of the oil industry changed the system as larger channels were required to reach well sites and to transport oil and gas out of the area (Davis 1973). Today there are over 9,000 acres of marshland that have been dredged in the Barataria basin (Barrett 1970).

Channels are constructed for many purposes other than those relating to the petroleum industry. Frequently channels are created incidentally to obtain fill material to form new land in a bay or to raise the level of adjacent marshes. Channels are also dredged to drain wetlands, provide for waste disposal, transport water, obtain minerals or buried shell, and for many other reasons (Chapman 1968).

The effects of channel construction and deposition of spoil have been directly correlated with saltwater intrusion and subsequent physical loss of habitat. Chapman (1968) noted that "deep channels permit high-salinity waters from the sea to penetrate the upper reaches of an estuary and disperse throughout its area." Effects of channelization were discussed in the LWFC Biennial Report 1956-1957 as follows: "In recent times an increasing number of canals and deep water channels with their spoil levees have been cut across the marsh both laterally and vertically. This has resulted in changed direction of water flow, [and] the damming of flow by levees, and has greatly increased the velocity of salt water flow into the marsh and fresh water flow through the marshes to the sea. The net result has been drastic increases in salinity in some areas and a rapid deterioration of productive marsh and bay conditions" (St. Amant et al. 1958).

CHANGES IN MISSISSIPPI RIVER FLOW

At one time the Mississippi River occupied a course down what is now Bayou Lafourche, which borders the Barataria basin on the west. Approximately 600 years ago, the river abandoned the Lafourche course in favor of its present route to the Gulf of Mexico (U.S. Army Corps of Engineers 1971). Presently, Bayou Lafourche discharge has little or no effect upon Barataria Bay salinity. Upon reaching the Gulf, the fresh water and sediments transported in this bayou are most often carried westward by littoral currents, away from the mouth of the Barataria Basin.

Historically, the erosional forces of the sea have been checked by the land building processes--

particularly Mississippi River delta formation. Land is formed from river transported sediments that precipitate as the velocity of the river decreases upon nearing the Gulf of Mexico. A portion of the sediments are carried northwestward by offshore currents and deposited in areas such as Barataria Bay.

The river appears to be shifting its course to the Gulf once more. Within the last 50 years, the Atchafalaya River, main distributary of the Mississippi River, has increased in size, and the portion of Mississippi River discharge carried by it has increased from 10 percent to 30 percent (U.S. Army Corps of Engineers 1971). Atchafalaya Bay is the only place along the coast where major land building is taking place today. It is expected that a major delta will be formed in this area by the year 2000. Land has already appeared above the water surface in Atchafalaya Bay (Day 1975).

Changes other than natural are occurring along the Mississippi. The river has been leveed by state, federal, and private concerns down the west bank from the Arkansas River to Venice, La., about 50 miles below New Orleans. Continuous levees have been constructed on the east bank from Baton Rouge to below Pointe a la Hache, which lies about 30 miles below New Orleans. Extensive leveeing of the river has prevented natural overbank flooding, a major source of sediment input in the coastal zone.

"The construction of the Mississippi levees below New Orleans has reduced the amount of fresh water entering Breton Sound and Barataria Bay areas" (U.S. Army Corps of Engineers 1971). Leveeing not only eliminates the introduction of fresh water but also restricts subsequent nutrient and organic matter deposition.

Land loss and changes in natural river flow are directly related to the destruction of our existing wetland habitats. These are the causes of significant environmental changes occurring in Barataria Basin--specifically changes in salinity.

CHANGES IN OYSTER PRODUCTION AREAS IN BARATARIA BASIN IN PAST YEARS

The effects on oysters of increases in salinity over short-term periods have been discussed in the first portion of this paper. Gill ciliary activity, spawning, growth, and fattening of oysters are directly and immediately affected by salinity. Seasonal changes in salinity indirectly affect oyster populations by controlling predation, disease, and food supply. Saltwater intrusion does not constitute the magnitude of change in salinity required to affect seasonal factors. At the computed rate of change, salinity in north Barataria Bay is only increasing at a rate of 0.009 ppt per month. These changes are too subtle to affect oyster populations found in this area during any given year.

Twenty years or more of gradual increase in salinity is expected to have major effects on marshland inhabitants. Vegetation types have been observed to change; that is, plants less tolerant to highly saline water are redistributed to areas of lower salinity, altering processes of natural succession. The distributions of other forms of estuarine life are changed gradually as these organisms seek waters with optimum mixtures of fresh and saline components. For example, a creature that cannot survive salinities below 10 to 15 ppt is able to move into bays, marshes, and lakes that previously had salinities less than 10 ppt. Such is the case with the conch, Thais, in Barataria Bay. At one time conchs were only a problem to fishermen who transplanted oysters into the southernmost portion of the bay. In recent years of low rainfall, the effects of this predator are seen more and more frequently in middle or upper bay areas.

In attempts to trace historical oyster populations in Barataria Bay professional oyster fishermen and LWFC personnel were consulted. Historical publications concerning Louisiana oysters were also utilized, when available. Current lease charts and records were obtained from LWFC, Division of Oysters, Water Bottoms, and Seafoods. The Division does not keep lease charts on an annual basis; as individual leases are surveyed, they are plotted on a base map that is used from year to year. One old map was found showing leases of Barataria Bay in 1959. This map was compiled by the Division during the planning of the Barataria Waterway that was completed in 1963. This map is kept at the Oyster Leasing and Survey Section of the LWFC district office in New Orleans. Another lease chart was obtained from Dr. Harry Bennett (Department of Zoology, Louisiana State University, Baton Rouge), who directed a study on oyster mortalities in Barataria Bay in the mid-1940s. Dr. Bennett visited the New Orleans office of the

LWFC and obtained an oyster lease chart of the Barataria Bay area during the summer of 1947. Copies of this map are on file at the Center for Wetland Resources, Louisiana State University, Baton Rouge.

The lease information obtained for 1947, 1959, and 1975 is given in Figs. 3, 4, and 5. Ten oyster fishermen who held extensive leases in Barataria Bay during the last 30 years were questioned to determine which leases on the old charts were used for seed or transplanting.

Oysters have been cultured in Barataria Bay for more than a century. During the late 1800s, the Barataria Bay oyster fishery suffered tremendously from what appeared to be a combination of factors. Moore and Pope (1910) reported that Barataria Bay oyster beds had been "exterminated by overfishing coupled with natural causes." By 1910 the fishery had recovered somewhat with "oyster reefs located in the southern half of the bay, the northern half having never produced oysters within the recollection of the inhabitants, probably owing to its low salinity" (Moore and Pope 1910). Barataria Bay is connected to Little Lake (Fig. 2) by Bayou St. Denis and Grand Bayou. In 1898 these bayous were reported as being almost constantly fresh. At that time, Little Lake was fresh enough to harbor a continuous population of largemouth bass (Moore and Pope 1910).

The lower half of Barataria Bay remained the primary region of oyster culture in Lafourche and Jefferson parishes through the 1930s and early 1940s. By 1947, the northern half of the bay had become a reliable area for natural spatfall. The holders of the leases around St. Mary's Point (Fig. 3) stated that upper bay leases had become their most valuable private source of seed by the 1950s.

In 1959, numerous leases were charted in both upper and lower bay areas, with the most extensive oyster culture practiced around the periphery of the bay, where the bottom is firm enough to support the weight of dense oyster growth. Water bottoms were also leased in Grand Bayou and Bayou St. Denis. Lower Little Lake had begun to produce some seed oysters during years of low rainfall. A history of acreage leased for oyster culture in Little Lake is given in Table 3. This table should be used with Fig. 4 for an adequate representation of changes in oyster culture in the Little Lake-Barataria Bay complex during the 1950s and 1960s. Members of the Barataria oyster industry attribute a portion of increased leasing activity in upper bay areas to the expanding nature of the fishery, as well as changes in salinity.

During the relatively low rainfall years of the late 1960's, natural oyster growth was observed in upper Little Lake. By 1975 (Table 3), almost 4,000 acres of water bottoms had been leased in Little Lake. During years of heavy rainfall, oysters grown in Little Lake may be killed by prolonged exposure to low salinity. Such was the case in 1973 and 1975, years of unusually heavy spring rains.

Northern Barataria Bay, Grand Bayou, Bayou St. Denis, and Little Lake have become increasingly dependable areas of natural spatfall during the past 30 years. This is probably directly related to the encroachment of saline waters into the upper end of the Barataria Basin. In this respect, saltwater intrusion has been beneficial to the Barataria Bay oyster fishery, affording the fishermen much needed sources of seed. However, most effects of the gradual but steady increase in salinity are not quite so advantageous. Increased predation and disease accompany the intruding Gulf waters into prime areas of oyster culture, where reefs have been laboriously established through several years of planting seed oysters and cultch.

Furthermore, as oysters are redistributed to more inland waters, they may be found more and more frequently in areas presently polluted by domestic and industrial wastes. This problem is amplified by increased population and industrialization in the coastal zone, which serve to continually extend the zone of pollution Gulfward into the estuaries.

In essence, the oyster industry in Barataria Basin is steadily being squeezed between encroaching salinity (and the accompanying predation and disease problems) from the south and encroaching pollution from the north. Oyster production areas are being forced further inland where existence of high coliform (domestic sewage) levels may force closure of oyster harvesting. As these two forces continue, availability of areas suitable for oyster production will decline. These problems and management alternatives to help alleviate them will be discussed in a subsequent report in this series.

APPENDIX

Preliminary studies indicate that salinity at St. Mary's Point is increasing. We must put many qualifications on these findings, but the bulk of our reservations concern the extent of such a rise rather than its existence. In the following paragraphs we present some specific analyses showing this trend as well as other points of possible interest. All of the data used was supplied by LWFC.

For the purposes of our initial study we used only salinity data at St. Mary's Point and Grand Terre. The earliest available data are at St. Mary's Point and cover the years 1945-1949, with some gaps. These data were contributed to LWFC by Dr. Willis G. Hewatt. A second set of data at St. Mary's Point covers the years 1956 to the present. In both the above sets the data consist of regular sampling, with samples taken in most cases once each week. The data at Grand Terre extend from 1961 to the present and were gathered on continuous recorders. We cannot, of course, reconcile this difference in the methods of data gathering at the two sites, and the sporadic nature of the data at St. Mary's Point must place some reservations on our findings. We can, however, make two notes in this regard. First, as we will cover specifically in following paragraphs, some measure of internal consistency was apparent in the St. Mary's Point data, especially regarding long-term trends. Second, during the current year LWFC began to record salinity at both St. Mary's Point and Grand Terre with punched tape recorders taking readings every hour. Therefore, our findings here will be subject to welcomed testing and updating. We are continuing in-depth study of salinity data, and increasingly it becomes clear that these two locations offer a valuable contrast in such a study.

For the purposes of investigating the long-term trends, monthly averages were used. This was necessary for the St. Mary's Point data to have some measure of coherency. Even at this level some points are averages of only two or three samples. Furthermore, it appears that monthly means may be desirable in any case to gain comparability between different years. The processes affecting salinity are to a large extent seasonal and to a reasonable extent monthly. For instance, we can certainly say with a high degree of accuracy that we expect, in any year, to obtain significantly different readings in May and October with the extreme likelihood that the October readings will be higher. Sufficient comparability of a given month from year to year allows us to normalize the data so that all readings are comparable. We have not had time or data to vigorously demonstrate such sufficiency in this case, although we used such a normalization, and therefore attempted, whenever possible, to also apply our analysis to a "control" set of data for comparison.

The most direct method of investigating long-term trends is to simply fit a straight line varying over time to the salinity data. This technique is quite valid for the purpose of detecting either a rise or fall under certain conditions. We must first have enough data so that our line conforms to the long-term variances. We do not have these conditions in this case; we would, perhaps, if our St. Mary's Point data were complete from 1945-1974. However, the fit to the available data set is significantly influenced by the inclusion or exclusion of certain portions. Therefore, we have chosen to look at the period 1961-1974 so that similar analysis can be performed on the Grand Terre salinity data as a control. Figure 6 shows the result of such analysis. The St. Mary's Point data shows a rise of 0.009 ppt per month whereas Grand Terre exhibits a falling of 0.007 ppt per month over the same period. Due to other analysis, we do not propose that Grand Terre salinity is appreciably falling, but the above fact is at least some indication that we have not simply chosen a time period of general rise in salinity. The line depicted in Figure 5 is actually only a mean or average over time and is quite appropriate for this analysis since it can only represent a simple directed trend. We can note, as a point of interest only, that if this trend could be accepted as accurately describing the trend over a longer period, it would indicate that mean salinity at St. Mary's Point stood at approximately 6 ppt at the turn of the century.

In seeking to substantiate the existence of such trends we examined various possibilities. In either case a year or two of salinities that deviate significantly from the norm would account for these results by chance, assuming such deviation was in the right direction and in the proper half of our data set. Furthermore, the processes that affect the two locations are to some extent dissimilar, and it is possible that one of these accounts for our result. Finally, there is the possibility that the results are so small as to occur by chance in any case, or as a normal long period fluctuation.

In order to examine the possibility of unusual occurrences in the data, we computed, for each month, a mean and standard deviation over the period of years studied. We then expressed each salinity reading as a function of its deviation from the mean. This procedure reduced our data to a uniform, comparable set and singled out any unusual readings. For each month we then had a data set with a mean of zero and a standard deviation of one, and similar statements will be true for the entire set. An interesting result was thus obtained. At St. Mary's Point the largest negative fluctuation (relatively low reading) occurred in the eleventh month of the tenth year (1970) and the largest positive fluctuation (relatively high reading) occurred in the third month of the third year (1963). These values are -2.414 and 1.941, respectively, and it can be seen that not only are these values (and thus the entire range) reasonable, but the lower extreme is actually significantly greater than the upper. In fact, we may go further and examine a histogram of the values as opposed to a normal curve. In this case (Fig. 7) the largest number of readings occur in the range 0 to +0.2 with 22 readings. The next largest interval is -0.2 to -0.4 with 14 readings, followed by the interval 0.2 to 0.4 with 13 readings. These figures give considerable support to the validity of the apparent rise in salinity over the period.

The largest deviations at Grand Terre are -2.415 in the eleventh year and +2.091 in the third year. The histogram reveals a more spread pattern having 16 values in both the ranges -0.2 to -0.4 and 0.4 to 0.6 with 15 values in the range 0 to -0.2. Again, in this case, the apparent fall is not caused by the extremes but rather by the bulk of data occurring at values only slightly different from the means. In both cases, the lack of conformity to the "bell curve" illustrates our deficiency of data.

We also performed a linear fit to this adjusted data with expected results. The St. Mary's Point data showed a rise of 0.0014 units per month, while Grand Terre showed a fall of 0.0025 units per month. The units here are in terms of standard deviation of the month in which the data falls. The agreement between those and earlier figures is significant, because it is independent of the actual level of salinity.

Using the actual salinity data, the fit (or mean) can be weighed in favor of differences in the higher salinities. Therefore, we stress that the agreement rather than certain values are of importance here.

To further test the meaning of these results, we also analyzed rainfall and river discharge for the same period. Rainfall showed a rise of 0.0002 units per month, only 10 percent of the magnitude of either of the above salinity changes and illustrative of the small size of our data set, as most readings were below average while one was +3.15. This data conforms least to the bell shape as illustrated in Figure 7. River discharge showed a rise of 0.007 units per month, the largest figure of all, and somewhat skewed from the bell curve. It is quite conceivable that either the increasing river discharge or its causative forces are responsible for the fall in salinity at Grand Terre. Further efforts are being made to study the possible relationship in some detail.

Finally, when the entire set of St. Mary's Point salinity data was processed in this manner, the result was a rise rate of 0.003 units per month (a higher rate than the reduced set) with normal histogram values. The river from 1945 through 1974 showed a fall rate of 0.0005 units per month; the discrepancy between this and the earlier figures again illustrates the deficiency of data.

We wish to address a final point indicated by the above and possibly more revealing in a quantitative manner. We cannot, at this time, identify and remove all of the processes other than intrusion affecting salinity at St. Mary's Point and Grand Terre and cannot, therefore, directly measure the intrusion. However, whatever these processes are, and whatever the actual effect of intrusion, we can note that Grand Terre is essentially a coastal point whereas St. Mary's Point is across a bay from Grand Terre. We can then ask to what extent St. Mary's Point salinity is similar to that at the coastal point and what trends, if any, exist. By asking to what extent they are subject to identical influences, we can then disregard, to a certain extent, the exact nature of these influences.

To this end we formed a data set whose elements were the ratio of St. Mary's Point salinity to Grand Terre salinity. Since our earlier discerned trends were falling salinity at Grand Terre and rising salinity at St. Mary's Point, we could certainly expect the ratio to rise over the time period, as it does (0.036 percent per month). However, in automatically compiling plots of our various parameters under study we were struck by a comparison of the ratio vs. St. Mary's Point salinity and the ratio vs. Grand Terre salinity. These plots are shown in Figure 8. A distinct pattern exists in the former plot, showing that the ratio is relatively high only when salinity at St. Mary's Point is also relatively high and correspondingly low only when St. Mary's Point salinity is also low. There are no significant deviations to this relationship. However, a glance at Figure 8 reveals that low salinity at Grand Terre is not a contributor to a high ratio. The comparison is striking, as is the former figure itself. In fact, we also found a linear fit of the ratio to a combination of time and St. Mary's Point salinity. Such a doubling of independent variables would normally produce a significantly better fit in any case since it can only improve, the fitting mechanism having the ability to simply reject the new variable. The results were interesting in every respect. We found a ratio of change due to time alone of 0.049 percent per month, and to salinity alone of 0.337 percent per month, but with the dependency on salinity level decreasing by 0.0002 percent per month. The latter is a significant figure since it indicates a lessening dependency as St. Mary's Point salinity approaches that of Grand Terre. Originally the linear fit of time to ratio values had produced a starting mean of 62.1 percent and, as noted, a rate of change of 0.036 percent per month. Fitting time to ratio values computed using the above model, the comparable values were a starting mean of 62.6 percent and an identical rate of change of 0.036 percent per month. The closeness of these figures was not expected. In either case they suggest that salinity at St. Mary's Point will be approximately the same as that at Grand Terre in 100 years if the trend given by the data continues.

The above trends indicate that the rise in salinity at St. Mary's Point and the rise in the ratio of St. Mary's Point salinity to Grand Terre salinity are uniform over the period whereas the fall of salinity at Grand Terre is not. The fall in Grand Terre salinity also corresponds to a rising period of river discharge while no such correspondence was found at St. Mary's Point. Furthermore, it should be remembered that the rise at St. Mary's Point consisted largely, if not entirely, of a large number of points slightly exceeding the mean, rather than a few points glaringly exceeding mean values for the period.

Returning to Figure 6, the accumulation of results of our analyses rather than any one set of figures causes us to suggest that, while the apparent drop of salinity at Grand Terre is probably due to normal fluctuations, the upward slope of the line depicting the mean over time of St. Mary's Point salinity is very likely due to a small but persistent rise in salinity at the station. The actual amount of the rise is probably not sufficiently accurately determined by such a relatively small data set, but the data are surprisingly consistent in this one respect.

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Table 1. Acreage of Oyster Leases in Barataria Bay (by parish)

Year	Parish	Acres	Average	no. acres/lease
1975	Plaquemines	3607		
	Jefferson	4616		
		8223	Total	33.56
1968-70	Plaquemines	4839		
	Jefferson	4677		
		9516	Total	33.39
1959-60	Plaquemines	2456		
	Jefferson	3883		
		6339	Total	25.56
1948-51	Plaquemines	99		
	Jefferson	2651		
		2750	Total	21.83
1940-41	Plaquemines	0*		
	Jefferson	929		
		929	Total	15.48

*Probably classified under Jefferson Parish

Table 2. Changes in width of major passes in the Barataria Bay area (in ft)

Pass	1932	1954	1969
Barataria	2,149	2,373	3,500
Abel	212	499	1,233
Quatre Bayou	2,181	2,921	3,700

Table 3. Acreage of Oyster Leases in Little Lake (by parish).

Year	Jefferson Parish	Lafourche Parish	Total
1975	1,445	2,437	3,882
1968-70	902	942	1,844
1963	143	428	571
1961-63	301	238	539
1959-60	449	379	828
1958	378	217	595
1957	173	204	377
1955	43	0	43
1953-54	22	0	22
1951-53	2	0	2
1950	0	0	0

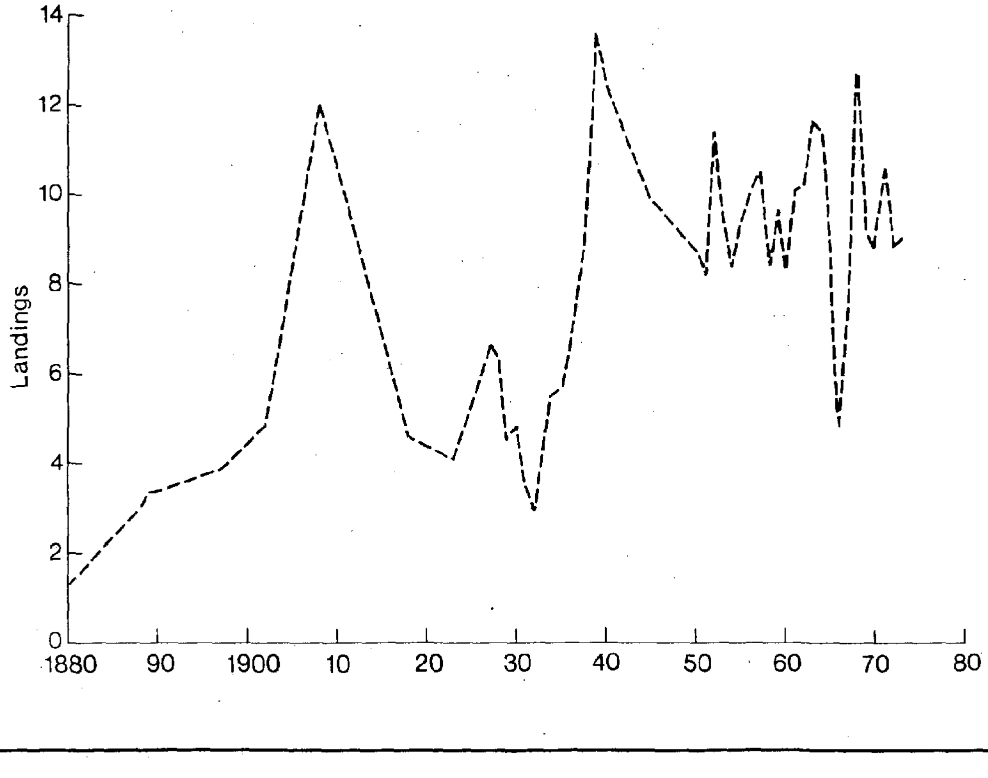

Fig. 1. Louisiana Oyster Landings (Reported), 1880-1974.

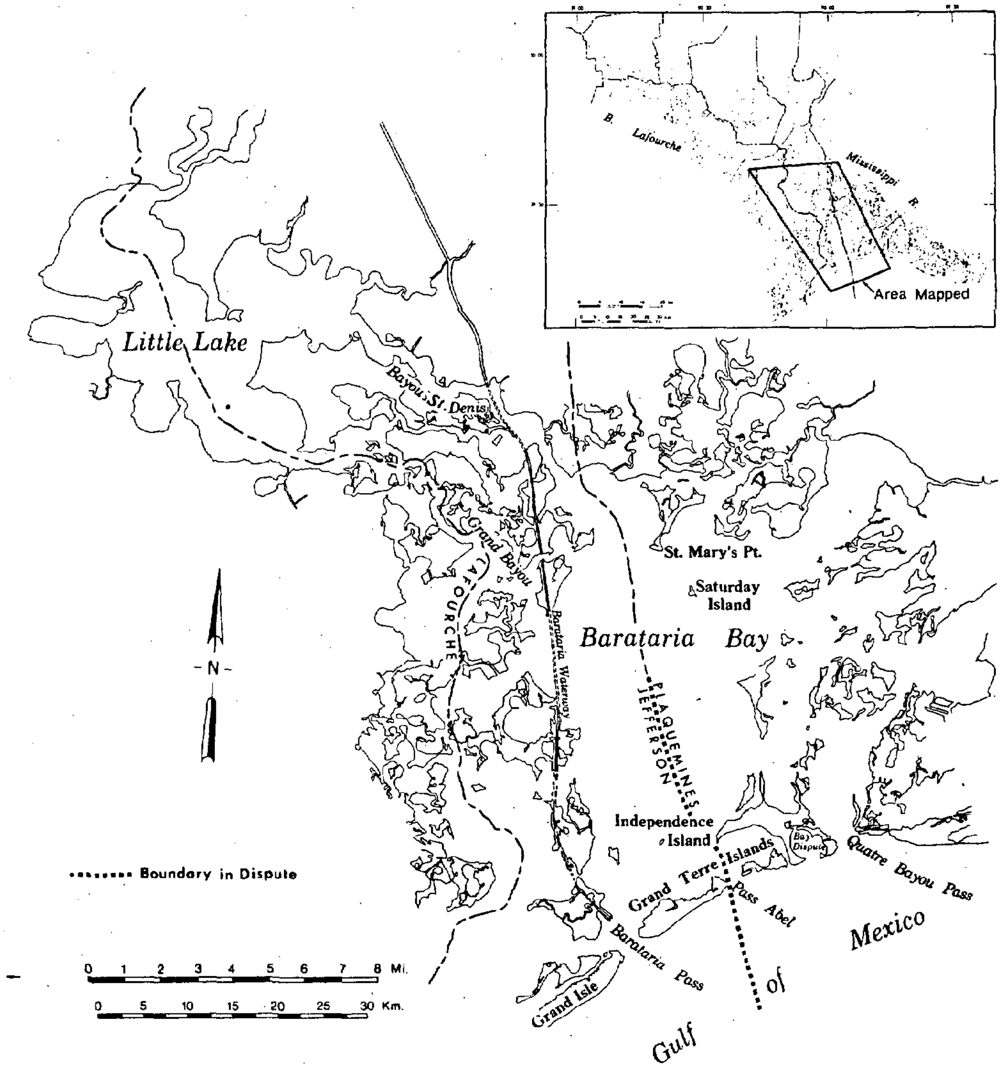

Fig. 2. Southern, gulfward portion of the Barataria Basin.

Fig. 3. Area leased for oyster culture in the Barataria Bay area in 1947. (Oyster leases shown in black.)

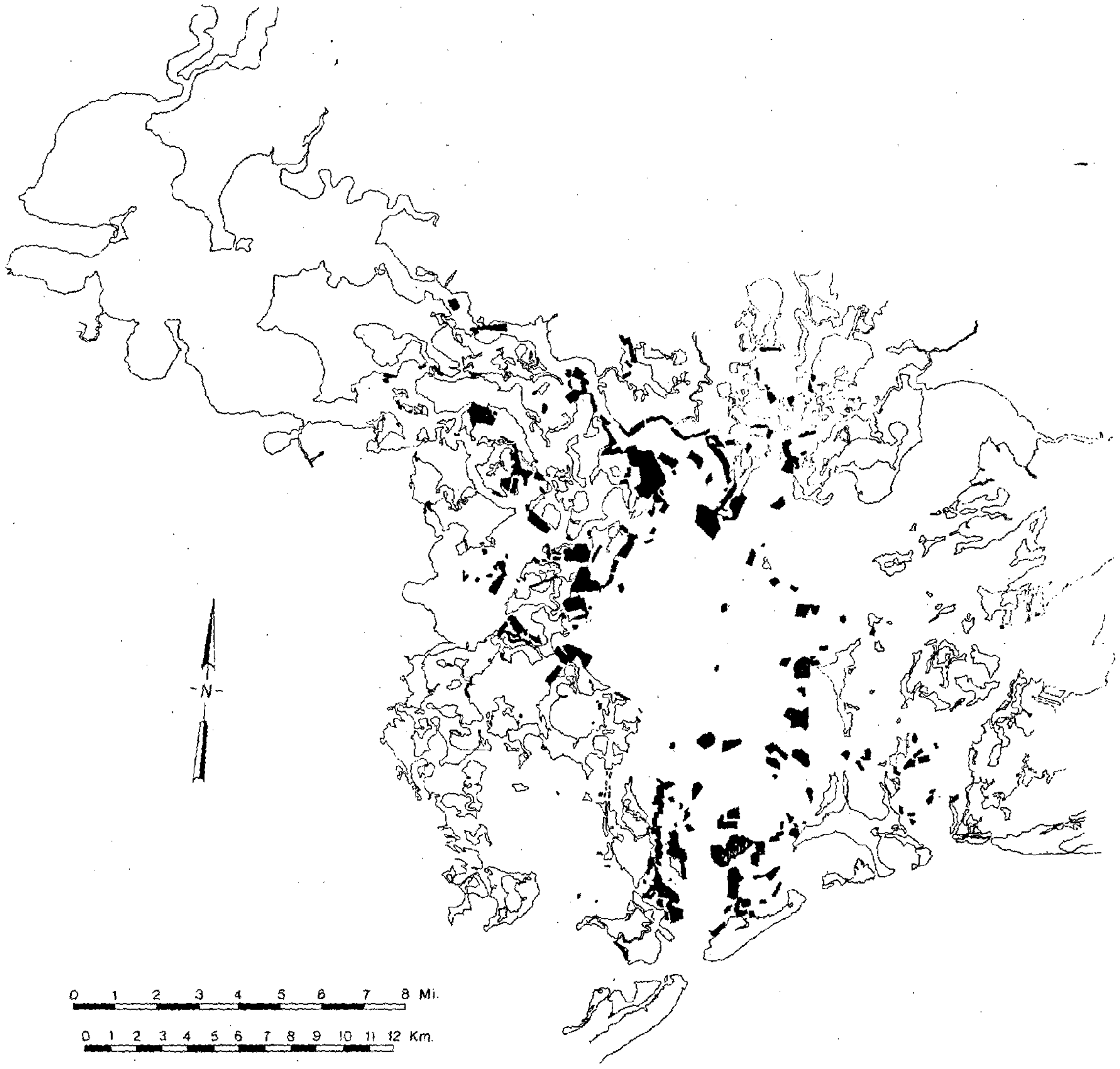

Fig. 4. Area leased for oyster culture in the Barataria Bay area in 1959.

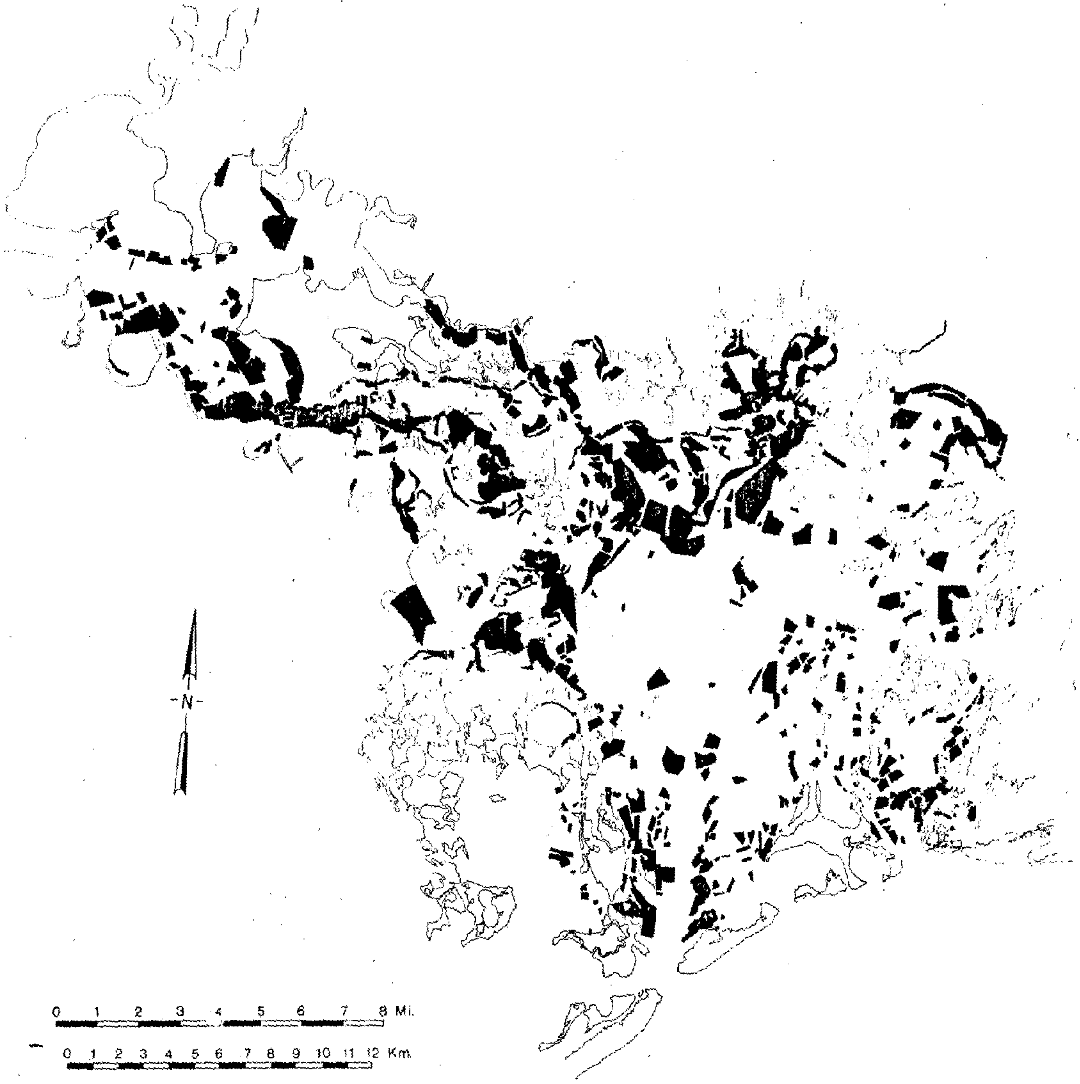

Fig. 5. Area leased for oyster culture in the Barataria Bay area in 1975.

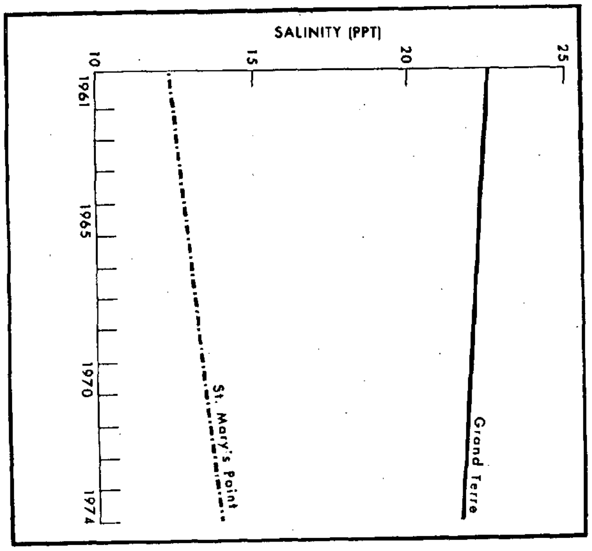

Fig. 6. Linear salinity trends 1961-1974.

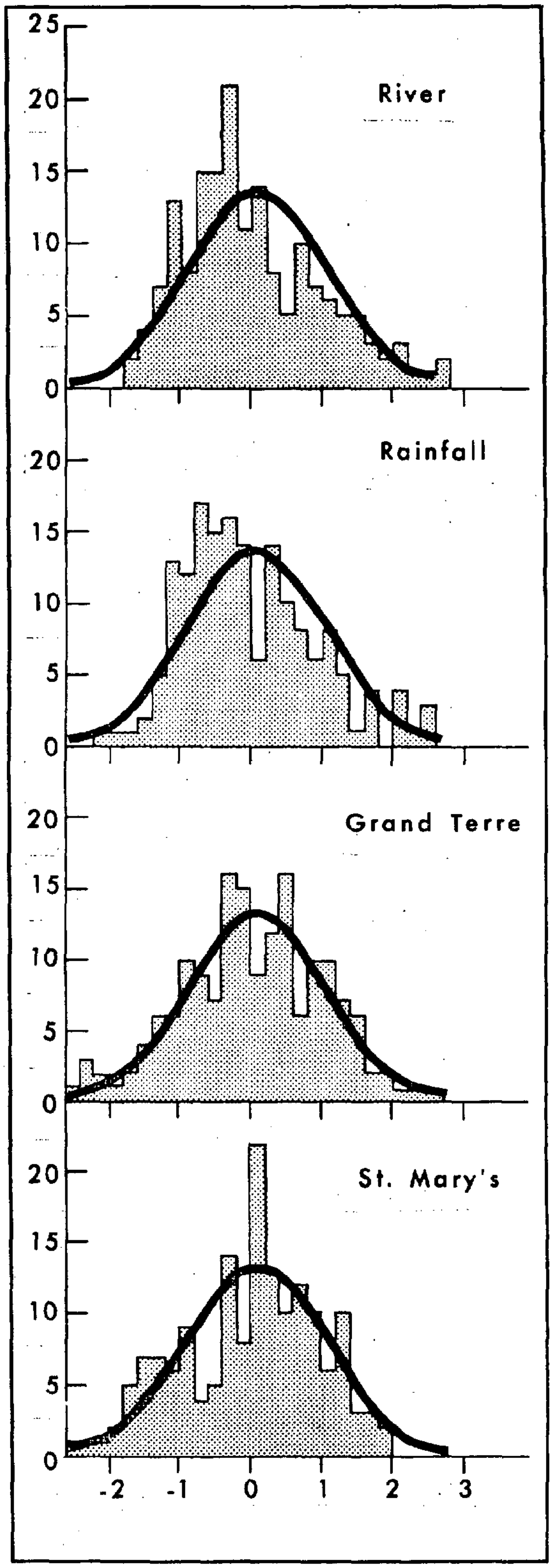

Fig. 7. Histograms of normalized data.

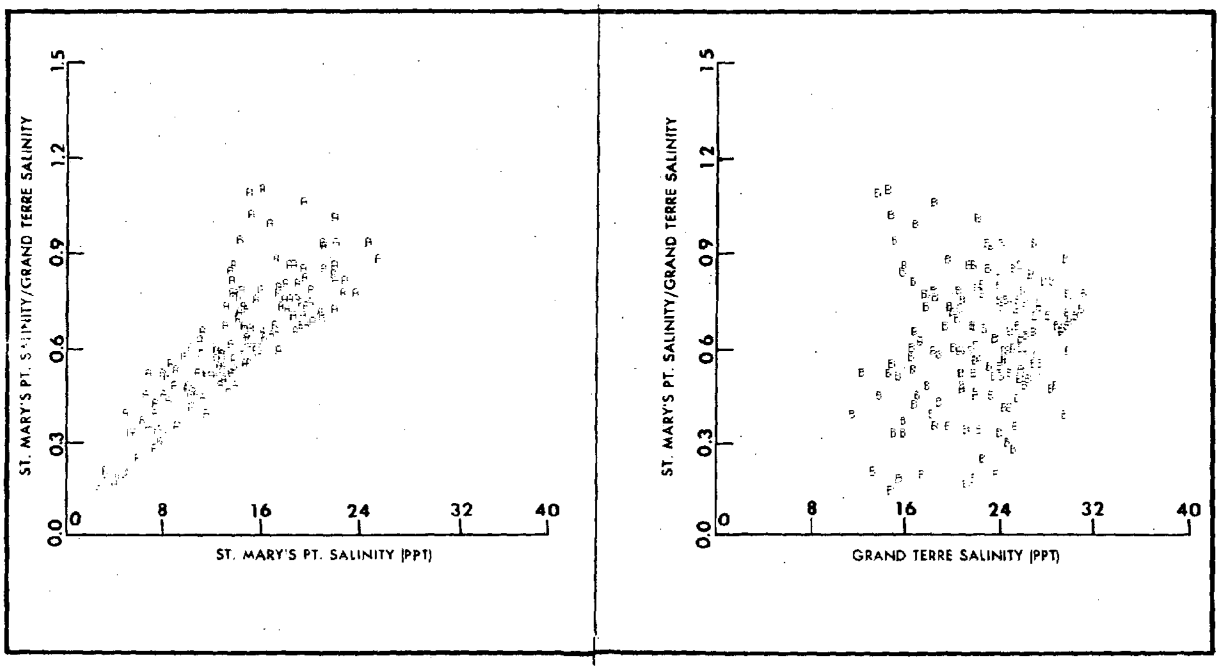

Fig. 8. Salinity vs. salinity ratio comparison.