MFR PAPER 1259

Clyde L. MacKenzie, Jr. is with the Sandy Hook Laboratory, Northeast Fisheries Center, National Marine Fisheries Service, NOAA, Highlands, NJ 07732.

Development of an Aquacultural Program for Rehabilitation of Damaged Oyster Reefs in Mississippi

CLYDE L. MacKENZIE, Jr.

ABSTRACT—A rehabilitation program was developed for damaged oyster (Crassostrea virginica) *reefs in Mississippi Sound in which new equipment will be employed to: 1) transplant oysters from polluted to clean reefs; 2) wash a mud deposit off a formerly productive reef; and 3) return buried shells to the surface of reefs for oyster spat collection. The Mississippi oyster has extremely high productive potential and ecological conditions for oysters on some reefs are normally excellent. Aspects of functional operations, economics, and sociology of the oyster industry are examined and described. After the program is completed, the oyster industry should return to its status of the 1960's when annual production averaged 160,000 barrels (640,000 bushels) of oysters.*

INTRODUCTION

Production of the oyster *(Crassostrea virginica)* from reefs in Mississippi Sound declined sharply in the early 1970's by comparison with the decade of the 1960's when annual landings averaged about 160,000 barrels[1]. In 1974-75, production was only a fraction of that level, and only 5 percent of oysters processed in Mississippi were harvested from her own reefs; the remainder came from Louisiana. The decline resulted from: 1) physical damage to reefs and, temporarily, to vessels and processing factories and shops, by Hurricane Camille in August 1969; 2) adverse salinities that were periodically too high in 1972 and too low in 1973-74; and 3) reef closures due to pollution in the 1960's (Demoran, 1972; Gunter, 1975).

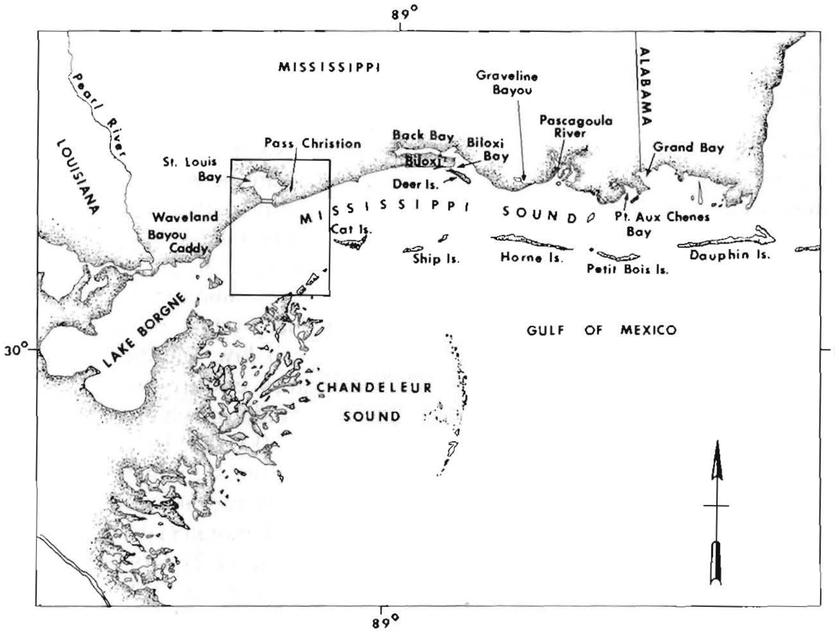
In 1975, tonging and dredging reefs off Pass Christian, the largest and most productive in the Sound, were poorly stocked and physically unsuitable for producing many oysters for the first time since the modern oyster industry began in the late 1800's. Thus, Mississippi oyster production was low in 1975-76, and undoubtedly cannot rise again to levels of the 1960's unless some reef rehabilitation measures are undertaken. If the combination of environmental circumstances that damaged the reefs does not reoccur, a single successful rehabilitation effort will probably be long lasting.

INVESTIGATION OBJECTIVES

Through an agreement with the National Marine Fisheries Service, the Mississippi Marine Conservation Commission gave me the assignment of identifying the potential of that State's oyster resources, recommending a program and, if feasible, introducing new methods to rehabilitate damaged oyster reefs to conserve the oyster resource and restore oyster production and the industry. The working program was to be simple in structure and inexpensive, but extensive in area.

During the investigative period that lasted for 5 weeks, from 5 July to 1 August, and 27-31 October 1975, information was gathered on: 1) status and needs within the oyster industry; 2) potential oyster productivity and reef ecology; 3) existing oyster stocks on reefs; and 4) constraints that limit oyster reef productivity. New aquacultural

Figure 1.—Mississippi coast showing principal areas mentioned in text, with inset showing Pass Christian area (Fig. 2).



[1]A Mississippi barrel = 4 U.S. bushels or 1.4 hectoliters.

equipment was constructed and tested. The information presented in this report was derived from the literature, from interviews with oystermen and processors, and from direct observations and testing. Scuba gear was employed extensively in evaluating conditions of reefs, oyster densities, and new aquacultural equipment.

BACKGROUND

Physical Aspects of Mississippi Sound

Mississippi Sound (Fig. 1) lies off the State's southern coast which runs in an east-west direction for about 68.8 miles (110 km). It terminates in the Louisiana marshes and Lake Borgne in the west and Alabama in the east. It is bounded offshore by an extension of the Louisiana marshes, and Cat, Ship, Horne, and Petit Bois Islands. These are from 3 to 8 miles (5 to 13 km) wide, with shallow passes between them, and they run parallel to and 8 to 12 miles (13 to 19 km) from the coast. There are also several smaller islands off Biloxi Bay and the Pascagoula River mouth. Collectively, these islands protect the Sound and coast from heavy southerly storms. They also slow intermixing of Sound water with its characteristically high nutrient levels, dense plankton blooms, and large oyster larval concentrations with less rich Gulf of Mexico water.

Thus, the Sound has a rich biota, including oysters, shrimp, and fish. Depths are mostly 9-13 feet (2.7-4 m) at mean low water; the rise and fall of tide is about 2 feet (0.6 m). Several rivers with combined drainage areas of nearly 40,000 square miles (104,000 km^2) discharge into the Sound; these, along with contributions from Lake Pontchartrain and Lake Borgne, maintain brackish waters especially at the western end of the Sound and near the coast (Christmas, 1973). The bottom consists of either mud, fine sand, or hard shell and oyster reefs.

Locations of Oyster Reefs

The largest productive oyster reefs extend off Pass Christian within 3 miles (5 km) of shore and are named the Pass Christian Tonging Reef and Pass Christian (Henderson Point) Dredging Reef (Fig. 2). There is a large reef in Biloxi Bay, small ones in Back Bay of Biloxi, two large reefs (Gautier Reef and Pascagoula Reef) in the Pascagoula River mouth, and various smaller reefs in Bayou Caddy, Waveland, St. Louis Bay, Graveline Bayou, Pt. Aux Chenes Bay, and Grand Bay (Fig. 1).

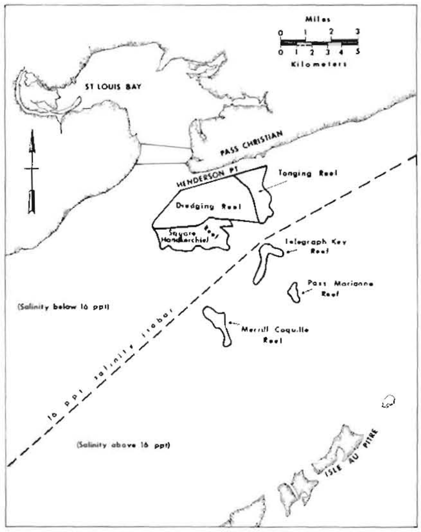


Figure 2.—Pass Christian area showing location of principal oyster reefs and usual position of 16-ppt salinity isobar.

Gunter (1975) stated that oysters were harvested from as many as 7,500 acres (3,000 hectares) during good years, and about 2,500 acres (1,000 hectares) during poor years before 1969. He also described old mud-covered reefs that had oysters hundreds of years ago, and naked reefs where oysters died when the Mississippi River was leveed south of New Orleans. The naked reefs are between 3 and 7 miles (5 and 11 km) south of Pass Christian, and are named Pass Marianne Reef, Telegraph Key Reef, and Merrill Coquille Reef, among others (Fig. 2). They produce oysters, but most inshore oysters die if low salinities caused by flood waters endure for a lengthy period, a condition which occurs about once every 10 years. Every year, they collect an oyster set which normally is killed later by predators and diseases. Gunter and Demoran (1970) stated that these reefs lie on 21-foot (6.4-m) deposits of shells about 7,000 years old at the bottom. Demoran (1966) stated that the Pass Christian reefs constitute one of the largest nearly continuous oyster reefs in the world.

Effect of Leveeing the Mississippi River

The effect of leveeing the Mississippi River and construction of the Bonnet Carre Spillway on oyster reefs in Mississippi Sound has been reviewed in various articles (Gunter, 1952, 1953, 1975). The heyday of oystering in Mississippi was from 1880-1940 when the Mississippi River had low levees or none south of New Orleans. From historical times until 1940, the Mississippi River discharged its water over a wide arc-like or triangular area, with the main flow at the mouth into the open Gulf and a lesser quantity of fresh water toward the ends of the arc into the bays of Louisiana and Mississippi Sound. This subjected the oyster reefs of Louisiana and Mississippi to a seasonal decrease in salinity during the first half of the year. Leveeing of the river funnelled water out of the river's mouth in greater volume, causing the bays and Mississippi Sound to get significantly less fresh water and nutrients. Therefore, their salinities are higher, and the original oyster zone in both Louisiana and Mississippi is significantly smaller.

In 1932, the Bonnet Carre Spillway was constructed 24 miles (39 km) above New Orleans to protect that city from floods. Whenever flood waters endanger it, the spillway is opened by the U.S. Army Corps of Engineers. The flood waters empty into Lake Pontchartrain and thence into Lake Borgne and Mississippi Sound. Most flood waters flow through Cat Island Channel into Chandeleur Sound and then into the Gulf of Mexico. Thus, the fresh water significantly affects only that part of Mississippi Sound lying west of a line from Cat Island to Pass Christian. In the 4 years of great spillway discharges since it was built, namely 1937, 1945, 1950, and 1973, nearly 100 percent of oysters in Mississippi Sound west of St. Louis Bay have been killed. East of that line to Pass Christian, mortality was about 50 percent.

The effect of the spillway has been

influenced by several factors. If the discharge is fast, fresh water impinges on reefs for only a short period with no oyster mortality. If the spillway waters come early in the spring, when condition of oysters is good and temperatures are low, mortality is lower than in summer. Spillway discharges kill most conches, disease organisms, and other pests, and also add tons of nutrients to the area. Nonetheless, the spring flood season is a critical one for Mississippi oysters. Butler (1949) reported that 50-100 percent of the oysters were killed in areas west of Pass Christian following the 1945 spillway opening during a flood.

Recently, there has been interest in Louisiana and Mississippi in a Federally controlled program to open periodically the Bonnet Carre Spillway to add some control structures south of New Orleans because of the great negative effect of the Mississippi levees. This would divert some water which empties directly into the Gulf of Mexico towards Louisiana bays and Mississippi Sound, and result in larger areas for oyster production free of conches and disease along with greater abundance of fish and bird life, especially during droughts (Etzold and Williams[2]).

Historical Oyster Landings

A glance at oyster landings from Mississippi reveals they were consistently high from the late 1800's until 1940 when they averaged about 265,000 barrels annually (Lyles, 1969). During World War II, 1941-45, the oyster reefs were unregulated and overfished making them permanently less productive (Gunter, 1975). Accordingly, oyster landings through the next two decades (through 1959) averaged only 32,000 barrels (Lyles, 1969). In 1960, landings turned sharply upward because the Mississippi Marine Conservation Commission supported a program, which, under the direction of William J. Demoran, increased productivity of several reefs through a shell and oyster seed planting program. Thus, in the 1960's, annual landings averaged 160,000 barrels, or five times greater than in the previous two decades (Lyles, 1969; Gunter and Demoran, 1971; Demoran, 1972; Christmas, 1973; and Gunter, 1975). In the 1970's landings declined sharply following the 1969 hurricane, and only 15,000 barrels were landed in 1974 following the great flood of 1973.

Effect of Channel Dredging

A large oyster reef between Biloxi and Deer Island was permanently removed when the natural existing channel was deepened in the 1960's.

Impact of Hurricanes

The hurricane season is a critical one for Mississippi oyster populations. The various hurricanes that have struck the Mississippi coast have each damaged oyster reefs and the industry. Engle (1948) reported that some oysters were killed, boats damaged or lost, and processing factories and shops damaged or destroyed. He recommended that productivity of the reefs be restored by spreading seed oysters and shells over them. Engle (1948) observed that the Square Handkerchief Reef (Fig. 2) off Pass Christian, a famous reef that once produced large quantities of oysters, contained oysters in 1974. It produced up to 1969. However, it was barren in 1975. The reef was damaged by hurricane Camille in 1969 and completely destroyed by the flood of 1973.

Hurricane Camille in August 1969 with winds of about 200 miles per hour (89 m/sec) was the most severe hurricane on record to strike the Mississippi coast. The tide level was above normal when the hurricane struck, and consequently most reefs were not severely damaged. Nevertheless, I found that the hurricane covered the Pass Christian (Henderson Point) Dredging Reef with mud, and it damaged oyster boats, factories and shops. Ford (1970) stated that it damaged some oyster reefs in Louisiana by covering them with mud and marsh grass.

Effect of Pollution

As a consequence of human population growth in southern Mississippi (Cross et al., 1974), various bays and the coastal zones within a mile of the mainland coast of the Sound have become contaminated by sewage pollution. Accordingly, the Mississippi Health Department closed several oyster reefs temporarily pending a reduction in pollution. In 1961, the reef in the Pascagoula River mouth was closed and resulted in an 80,000 barrel loss in 1962 landings. In 1967, the reef in Biloxi Bay, which had supported more than 75 tonging boats, was also closed (Demoran, 1972). During 1975, the reefs in St. Louis Bay and Graveline Bayou were closed, and those sections of oyster reefs within a mile of the Pass Christian shore had been closed already. Currently, the major oyster reefs in Mississippi Sound off Pass Christian and smaller ones to the west remain pollution-free and open for oyster harvesting. These are likely to remain open because of their distance from heavily populated zones.

Reef closures due to pollution have had economic and personal consequences. Oystermen have been the first and most severely affected, direct victims of pollution, a condition they did not create. It is a blow when a great reef that produced oysters for a number of human generations is closed. Men desire to work those reefs, in part, because they earned their livelihood from them, and, in part, for sentimental reasons because their immediate family and forebears did so. Closures have been particularly hard on elderly men who normally benefit greatly by tonging oysters with other fishermen in sheltered bayous.

PRODUCTIVITY OF OYSTERS

Some features of oyster biology were reviewed and surveyed to estimate the potential productivity of Mississippi oysters.

Spat Recruitment

Mississippi oysters have high reproductive capacity since they spawn and set prolifically over a 5- to 6-month

[2]Etzold, D. J., and D. C. Williams, Jr. 1974. Data relative to the introduction of supplemental fresh water under periodic controlled conditions for the purpose of enhancing seafood productivity in Mississippi and Louisiana estuaries. Unpubl. rep., 41 p. Mississippi-Alabama Sea Grant Consortium.

Figure 3.—A cluster of oysters consisting of spat and older year classes of oysters from a reef near Pass Christian.

period (from May to October) virtually every year (Hopkins, 1954; Demoran, 1966; Gunter and Demoran, 1971). Usually the greatest set occurs during June with a smaller wave in September (Gunter and Demoran, 1971). I observed two to four year classes of oysters (Fig. 3) on reefs from St. Louis Bay to the Pascagoula River mouth in July 1975, illustrating that setting is widespread. Annual spat recruitment has always been sufficiently intense to support significant commercial harvests of adult oysters on those reefs with favorable ecological conditions.

Growth Rate

Usually, Mississippi oysters grow to a length of more than 3 inches (76 mm) in less than 2 years (Gunter and Demoran, 1971; Maghan, 1967). Growth proceeds throughout the year as in Florida (Ingle and Dawson, 1952). My data on spat sizes on the Pass Christian tonging reef between summer and fall 1975 reveal excellent growth. In mid-July, spat averaged 0.3 inches (8.5 mm) long (range, 0.1 to 0.5 inches, 2.5 to 13 mm), and in late October, they averaged 1.2 inches (30 mm) long (range, 0.3 to 2.0 inches, 5 to 50 mm); an average increase of about 0.9 inches (23 mm) in 3.5 months.

Survival Rate

Survival of oysters until market size is high on inshore reefs during typical years when salinities are within a satisfactory range. Gunter (1953) estimated that normal survival for adult oysters is from 96 to 98 percent per month. Most oysters larger than an inch (2.5 cm) were alive on various reefs in July and October 1975.

In western Mississippi Sound oysters are susceptible to mortality from fresh water influxes, but recovery from the low-salinity condition can be rapid when rivers cease their flooding and prevailing winds are southerly (Butler and Engle, 1950). Sudden severe drops in salinity can kill oysters. For instance, in 1962 a heavy rain which resulted in virtually fresh water at the Pascagoula River mouth for a long period killed nearly 100 percent of the oysters on Pascagoula Reef (Christmas, 1973). Oysters can survive in a salinity as low as 2 ppt for about a month at low temperatures and can even survive in fresh water for a few days. The incidence of oyster mortality caused by low salinity is related to both water temperature and condition of the oyster (Gunter, 1953). However, the duration of exposure to fresh water is the most important factor in mortality (Butler, 1952).

In dry years, increased salinities over inshore reefs enable the conch to invade and prey on oysters (Gunter et al., 1974). In 1956, conches killed more than half the oysters on some Pass Christian reefs (Chapman, 1958). An adult conch can consume nearly 90 one-week old spat per day, and one adult oyster per 2 days (Butler, 1954a). Periods of high salinity coupled with high temperature may result in mass oyster mortality by the fungus *Labyrinthomyxa marina* (Mackin, 1951). Gunter et al. (1974) estimated that this fungus may be responsible for oyster mortality levels of 50-60 percent during such periods.

Hopkins (1954) stated that oysters can thrive in undiluted seawater, provided enemies are not present. However, survival of oysters to market size on offshore Pass Christian reefs where salinities are normally 20-24 ppt (Christmas, 1973) is virtually zero in normal years due to presence of conches and molluscan diseases.

I noted that crabs, probably blue crabs, which occur on all reefs regardless of salinity (Christmas and Langley, 1973), had killed many spat averaging about 1 inch (2.5 cm) on the Pass Christian reefs between July and October 1975. Under Laboratory conditions, a blue crab can consume as many as 19 spat per day (Menzel and Hopkins, 1956).

The actual extent of oyster mortality caused by each agent has never been determined. Thus, whenever oysters die on offshore Pass Christian reefs, the relative significance of each predator and disease effect is unknown, but the fact of overall death on these reefs during high salinity periods is well known.

ECOLOGY OF REEFS

The distribution and abundance of oysters in Mississippi Sound depend on several features, especially salinity, distribution of various animals, and nature of bottom substrata. There are some negative influences of the environment which suppress the productive potential of oysters. These together with other ecological features are treated in this section.

Salinity and Temperature Regimes

Salinities vary seasonally. They are lowest in March-April when normally a 16-ppt isobar lies about 1 mile (1.6 km) from, and parallels, the shore between Long Beach and Pascagoula. At Pass Christian, it swings offshore in a southwesterly direction (Fig. 2). Salinities range down to 6 ppt inside the isobar. Salinities are highest in September-October, when a 20- to 24-ppt isobar lies in about the same position that the 16-ppt isobar did earlier (Christmas and Eleuterius, 1973).

During wet years, however, when high regional rainfall coupled with drainage from the Pearl River basin coincides with flood conditions on the Mississippi River, salinities fall far below this norm (Butler, 1952). Excessive freshwater runoff can reduce salinity normally above 20 ppt in Mississippi Sound to less than 5 ppt (Butler, 1949).

Mississippi Sound has an annual mean water temperature of 72-74°F (22-23°C) with monthly averages ranging between 50°F (10°C) and 90°F (32°C) (Christmas et al., 1966).

Predators, Commensals, and Diseases

The oyster is the symbiotic center of a group of predators, commensals, and molluscan diseases on those Mississippi reefs where high salinities occur.

The most devastating predator is the conch, *Thais haemastoma*. It invades oyster reefs as pelagic larvae when salinities permit, and when its numbers are high it can destroy dense oyster stocks in a few months (Gunter and Demoran, 1971). The following description of the conch is summarized from Butler (1954a).

High densities of conches inhabit areas along the entire Gulf coast. They are generally limited to salinities greater than 15 ppt, but can tolerate lower salinities for brief periods. Reproduction occurs in summer. Growth of juveniles is rapid; they attain 1.0 inch (2.5 cm) in a month; 1.5 inches (3.8 cm) in 2 months; and 2.0 inches (5.1 cm) in 5 months with ample food. They can live several years. When conches are consuming oysters, 10 percent are killed by complete holes through their shells, and 90 percent by incomplete marginal holes; 75 percent of the latter give no evidence of attack. This latter aspect is significant because it is sometimes difficult to establish that conches actually killed oysters. McGraw and Gunter (1972) presented evidence indicating that conches utilize a paralytic secretion produced by the hyprobranchial gland in attacking oysters. Conches also consume mussels, barnacles, clams, and hydroids.

Conches have inhabited some reefs in large numbers in recent years, but they were absent in 1975. It is worthwhile to mention that empty conch shells, the remnants of those killed by low salinities, were also absent. They disappear because hermit crabs occupy and walk away with them.

Crabs and fish are also significant oyster predators (Gunter, 1953; Butler, 1954b; and Menzel and Hopkins, 1956). Blue crabs, *Callinectes sapidus*, (Hopkins, 1955; Menzel and Hopkins, 1956; Mensel and Nichy, 1958; Finucane and Campbell, 1968) and mud crabs (family Xanthidae) (Menzel and Hopkins, 1956; Menzel and Nichy, 1958; and Nichy and Menzel, 1960) are both spat predators. In this study, mud crab predation on spat 0.1-0.4 inches (2.5-10 mm) long was observed. Menzel and Hopkins (1956) also listed the black drum, *Pogonias cromis*, sheepshead, *Archosargus probatocephalus*, and skates, *Raja* sp., as oyster predators in the Gulf of Mexico.

In this study, the presence of an upright branching bryozoan near recently dead spat, 0.1-0.2 inches (2.5-5 mm) long, was observed. MacKenzie (1970a) reported a similar bryozoan which caused mortality in Connecticut and speculated that the animal releases a toxin which kills some nearby organisms.

The most common "commensals" are mussels *(Ischadium recurvum)* and barnacles *(Balanus* sp.). Table 1 lists the 1975 survey estimates of mussel and barnacle abundance on reefs. These, along with mud crabs, are the three animal types most commonly associated with oysters in Mississippi, along the U.S. Atlantic coast, and in the Gulf of St. Lawrence. Butler (1954b) listed the following common commensals of oyster reefs: algae; sponges, both boring and encrusting; hydroids; anemones; polychaete worms; other mollusks, such as jingle shells *(Anomia* sp.), slipper shells *(Crepidula* sp.), and

Table 1.—Densities and sizes of oysters and mussels, and barnacle number/oyster on various reefs in Mississippi Sound, in July 1975. Four to ten areas, each 3 square feet (0.3 square meters) in size, were sampled at each location.

Location	Oysters/ sq yd	Oyster size Range (inches)	Mussels sq yd	Mussel size range (inches)	Barnacles/ oyster
Pass Christian Tonging Reef	103 spat[1] 7 oysters[2]	0.1-1.0	15	—	25
Dredging Reef	130 spat[1] 7 oysters[2]	—	—	—	—
Biloxi Bay	7.5	0.2-4.6 (2.7 avg.)	369	0.1-1.1 (0.5 avg.)	32
Pascagoula River mouth	77	2.1-5.1 (3.0 avg.)	111	0.6-1.0 (0.8 avg.)	8

[1]Spat = 1975 year class.
[2]Oysters = 1973-74 year classes.

oysters of the genus *Ostrea;* bryozoa, both encrusting and upright; and tunicates. Their abundance is sparse in low salinities, but increases to species climax in high salinities. He believed the most significant effect of commensals on oyster productivity is to cover oysters and shells, thereby reducing oyster setting intensity. Another commensal is the boring clam *(Diplothyra smithii)* (Galtsoff, 1964).

The oyster disease *Labyrinthomyxa marina* and unidentified diseases infect and kill oysters especially when high salinities are coupled with high temperatures (Gunter et al., 1974; Gunter and Demoran, 1970, 1971).

In sum, the Mississippi oyster has an extremely high productive potential. Probably the entire bottom of Mississippi Sound would be stocked with a dense oyster population of mixed sizes if all environmental features were favorable for larval settlement and subsequent growth and survival. Oyster reef productivity is largely determined by prevailing salinities which influence survival of oysters, and distribution of predators, commensals, and molluscan diseases. On inshore Pass Christian reefs and in river mouths, bayous, and bays, oyster populations normally thrive and dominate the living community because spat setting is intense, oyster survival is high, and growth is rapid. However, on offshore Pass Christian reefs, spat setting is probably less intense due to greater abundance of commensals, and afterwards conches, crabs, and other predators, as well as microbial diseases kill the oysters. Much of the remaining area of the Sound is unsuitable for oysters because salinities are too high, and the mud and sand bottom is not a substrate on which oyster larvae can easily attach and grow.

USUAL OYSTER STOCKS ON REEFS

Before 1970, the Pass Christian Tonging Reef was so heavily stocked with oysters as a result of regular annual natural setting and growth that there was a surplus after each harvesting season had ended. Each season, the Pass Christian (Henderson Point) Dredging Reef produced a large quantity of steam-stock oysters. In recent years, however, its stocks had declined because vessels retained all oysters including spat on grit that was dredged aboard. They did so because the handling technique changed, resulting in overfishing and retention of small oysters. The crews shovelled oysters when storing them on the vessels' decks rather than piling them by hand and discarding the spat overboard. The offshore Dredging Reefs, i.e., Pass Marianne Reef, Telegraph Key, and Merrill Coquille Reef, produced quantities of oysters about every 10 years. They were productive in 1973, 1974, and 1975 due to floods and low salinities.

THE OYSTER INDUSTRY

The Mississippi oyster industry has significant sentimental and economic value to the people of southern Mississippi. It has provided a livelihood for many families, and oysters are a popular item in restaurants and retail stores in Mississippi and adjoining states.

Oystermen are among the most satisfied of workers because of a high level of personal control over their work and close ties with their product. They feel satisfied with and enjoy oystering when earnings are adequate, even though it does involve moderate physical labor. Enjoyment stems from the autonomy and freedom they have, the sense of peacefulness on the water, the satisfaction from watching animals grow, the working in harmony with nature in a healthy out-of-doors environment, and the harvesting of food for human consumption. Oystermen also have a strong personal attachment to the reefs like farmers to their land, because they provide their livelihood. Individuals experience both lean and boom periods in the years they harvest oysters.

The oyster industry normally operates with high degree of efficiency; maximum use is made of available equipment and resources, and little labor, time, and money are wasted. There is keen daily competition between oystermen within both the tonging and dredging fleets for greatest harvests and earnings; this forces the oystermen to be efficient. When one devises a new technique which increases his productivity, the others quickly copy it to increase their own. At times, oystermen take too many oysters from a reef, which results in its subsequent decline in productivity. Thus, governmental conservation regulations have to be enforced to prevent overfishing and preserve reef productivity. Oystermen want to conserve oyster resources because their livelihood is at stake, but some feel they are not consulted adequately about the best ways to apply the regulations. A status level among oystermen, based on harvests and earnings, prevails in the two oyster fleets, and it is recognized in their communities. Oystermen thrive on the fresh challenge which each new day brings of harvesting sufficient oysters both for a day's pay and for maintaining their status level.

Functional Operations

In Mississippi Sound, oysters are harvested by either tonging from skiffs (Fig. 4) or dredging from larger vessels (Fig. 5). The latter method takes the most volume. Oysters are sold to Biloxi processors (factories and shops) which either steam them open for canning, or shuck them raw and sell them chilled (Fig. 6). In the early part of this century, Biloxi was second only to Baltimore, Md., as the largest oyster processing city in the United States (Churchill, 1920).

Normally, a fleet of about 120-130 skiffs from Mississippi, Alabama, and Louisiana harvests oysters from the Pass Christian Tonging Reef. Fishermen from the latter two states move to Pass Christian for the oyster season. Besides these regulars, some part-timers work the reef during afternoons and weekends to supplement their incomes. The tongers use a 16- to 18-foot (4.9- to 5.5-m) skiff powered by an outboard motor carrying one or two persons; the second person cleans the oysters. Tongers harvest for 6-8 hours each day and usually return to shore by early afternoon.

The daily oyster harvest rate varies with the capacity of the tonger, whether

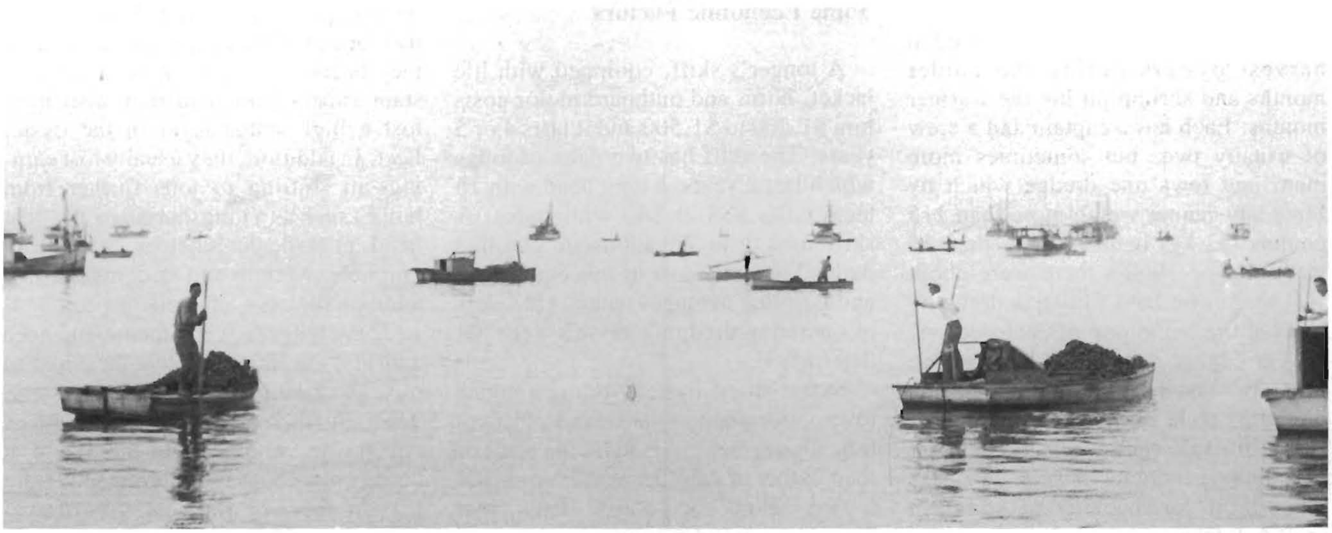


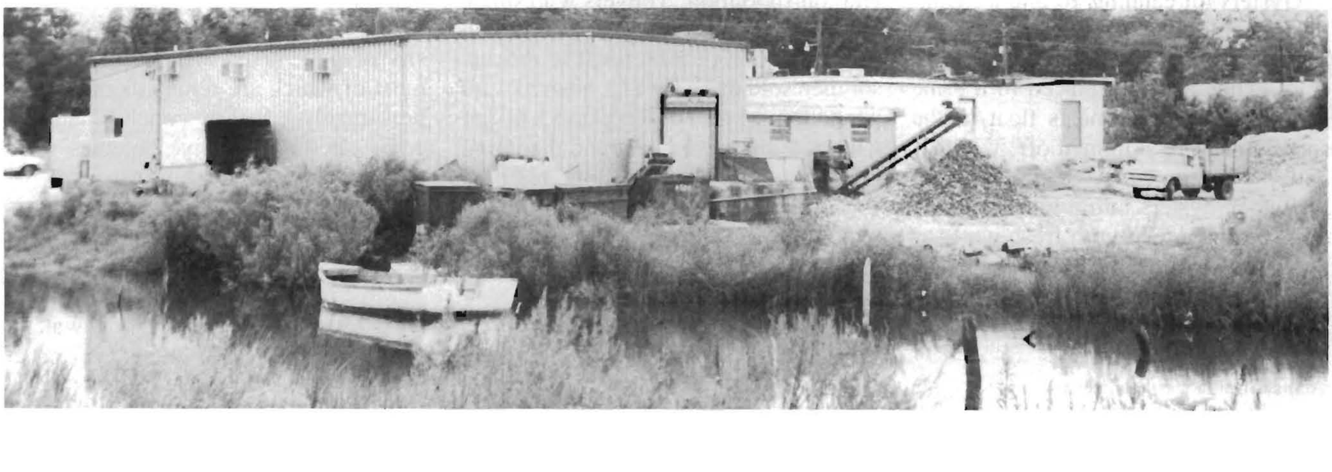
Figure 4.—Tonging oysters from reefs off Pass Christian in the 1960's.

he has a cleaner, and is harvesting for steaming or shucking. When harvesting steam-stock oysters, a skilled tonger can harvest daily 10 barrels alone, or 12 to 15 barrels if he has a cleaner. Steam-stock oysters are sold to either a freight boat anchored on the reef or a trucker ashore. When harvested for shucking, the oysters must be at least 3 inches (7.6 cm) long, and thus the harvest rate is lower. For example, a good tonger working alone can harvest daily 5 barrels, or 7 barrels with a cleaner. Some tongers shuck their own oyster to earn extra money during the off days. It takes from 45 to 60 minutes to shuck a barrel of oysters. Because of weather, a tonger can harvest oysters off Pass Christian only 3 or 4 days a week.

Dredging vessels, motor powered,

Figure 5.—These shrimp boats are converted for oystering only 1 or 2 days after the shrimp season ends.

Figure 6.—Oyster processing shop in Biloxi, Mississippi.



about 50 feet long, average (often termed "Biloxi Luggers"), are used to harvest oysters during the colder months and shrimp during the warmer months. Each has a captain and a crew of usually two, but sometimes more men, and tows one dredge which by State law cannot weigh more than 115 pounds (52 kg) or have more than 16 teeth. In the 1960's there were about 110 vessels on Pass Christian dredging reefs at the beginning of each season.

A dredging vessel can harvest two loads of oysters from Pass Christian dredging reefs and transport them to Biloxi for sale each week. Oysters for steaming are stored loosely on deck, while those for shucking are stored in sacks[3]. It takes a vessel 1 day to harvest a load of 200-300 barrels of steam-stock oysters or 75-100 sacks of raw-stock oysters from a Pass Christian reef and two additional days to run to Biloxi for off-loading and return. It can take longer in bad weather. Vessel captains make contracts or agreements with processors for selling their oysters before harvesting. Those without a contract sometimes have difficulty selling oysters, and have to hold them for a day or so before a sale can be made.

The dredging vessels harvest oysters in either Mississippi or Louisiana, depending upon where harvests and earnings are greater. During the past few years, nearly all dredging vessels have worked in Louisiana, an average 17 hours of running time from Biloxi. However, the 1975-76 season was an exception because the 1973 oyster generation on offshore Pass Christian reefs survived to market size and was available for harvest.

Oysters for canning go into a steaming machine in which they are cooked. The oysters open automatically. They are then placed in a brine solution where the meats float to the surface and are skimmed off, washed, and placed in cans. Shuckers open raw-stock oysters into a tub; later, the oysters are washed with fresh water as they pass over a series of screens. The shells are stored outside the processing plants.

[3]A Mississippi sack = ⅓ of a barrel.

Some Economic Factors

A tonger's skiff, equipped with life jacket, horn, and outboard motor costs him $1,200 to $1,500 and it lasts 4 or 5 years. The skiff has two pairs of tongs which last 2 years; a tong head with 16 teeth costs $38 or $40 with stales. A skiff uses 1 to 2 gallons of gasoline daily. The daily cost of this equipment and gasoline averages nearly $5. Costs of operating dredging vessels were not determined.

Steam-stock oysters bring a much lower price per unit than raw-stock oysters. Oystermen are paid on the basis of the number of cans of meat a harvest of oyster yields. Each barrel yields from 20 to 40 cans (4.5 ounce, drained) of oyster meat. The yield varies by month; lowest values are in fall, highest in winter (Gunter, 1942; Lee and Pepper, 1956). In 1974-75 the steam processors paid oystermen $0.20 per can for whole oysters and $0.10 per can for pieces; usually, 95 percent are whole, 5 percent are pieces. Thus, a daily harvest of 13.5 barrels by a tonger and cleaner was worth about $80; 10 barrels by a tonger alone, about $60; and 250 barrels by a dredging vessel, nearly $1,500. Processors sell canned oysters to large retail outlets. The wholesale value of 4.5-ounce cans was not determined, but 12-ounce cans sell for $0.90-$1.22 each.

Oystermen sell raw-stock oysters mostly by the sack and the remainder shucked. In 1974-75, processors paid from $5 to $6 per sack for Louisiana oysters, a sum about one-third greater than they would have to pay for Mississippi oysters because of extra handling and transportation. Tongers who shuck their own oysters sold these for about $10 per gallon (3.8 liters). The processor then sold these for $13.50 to $14.00 per gallon, a profit of $2.50 to $3.00 per gallon, since overhead and handling cost about $1.00 per gallon. He paid shuckers $3.00, plus $0.25 for social security, per gallon.

Status of Oystermen in 1975

Virtually all tongers had to find other jobs, most at some distance from their homes, since there were few oysters to be tonged in Mississippi Sound. They had faced difficult adjustments because they became hired workers under constant supervision, and may also have lost a high status level in the oyster fleet. In addition, they usually lost earnings in shifting to jobs further from home, such as a longshoreman, tugboat hand, or carpenter's helper. Some went on public welfare and in doing so, lost additional status and self-respect.

The dredgers were inconvenienced and lost earnings because they had to travel to Louisiana to harvest oysters. They sold their harvest to Biloxi, Miss., processors, which meant they were at home only about two nights and could harvest only one 150-sack load of oysters per week. When oysters are available in Mississippi, dredgers usually are at home four to five nights and can harvest two loads of 150 sacks per week. Besides loss of income, the dredgers had to purchase extra fuel to travel to Louisiana.

The oyster processors were affected because they had to purchase most of their oyster supply from Louisiana. These oysters cost $3.00 per barrel more than Mississippi oysters, and processors prefer to purchase from local fishermen and reefs for sentimental reasons.

PHYSICAL CONDITION OF REEFS AND DENSITY OF OYSTERS IN 1975

The Pass Christian reefs are composed of oyster shells. Much of the surface and underlying layers of inshore reefs consist of shells which range up to about an inch in size and are termed grit (Fig. 7). I believe that most are remnants of spat killed by blue crabs and other predators. The offshore reefs consist of grit mixed with larger shells, most of which are remnants of oysters presumably killed by conches and diseases. In 1975 no live conches were seen on any of the reefs inspected.

Pass Christian Tonging Reef (600 acres; 243 hectares)

Most of the reef is covered by only 3 feet (0.9 m) of water (mean low water), but the depth is about 9 feet (2.7 m) at its southern end. In 1975 the surface consisted of grit which covered about 94 percent of its area and some entire oyster shells, 2-4 inches (5-10 cm) long, many as boxes (shells of recently dead oysters in which the hinge remained unbroken), and a few oysters which covered the remaining 6 percent (Table 1). The boxes were remnants of oysters recently killed by low salinity and fresh water. The effects of wave action reached bottom and maintained it clean of mud and also continuously tossed the top layers of grit to a point to point distance of 6-12 inches (15-30 cm), but large shells and oysters remained stationary. Some oyster spat grew on the large shells and oysters, but none grew on the grit; any spat which had set on grit would likely be killed during windy periods, when the grit was in constant motion.

Pass Christian (Henderson Point) Dredging Reef (1,800 acres; 729 hectares)

The reef area is under 7-12 feet (2.1-3.7 m) of water (mean low water) and is composed of separate reefs, from 5 to 50 acres (from 2 to 20 hectares) in size, which total about 1,000 acres (405 hectares). Each reef has the form of a slight crown, with its center about 12 inches (30 cm) above the edges, and is surrounded by mud. The reef's surface consists of a mixture of grit and large shells. The effect of wave action does not reach bottom to disturb the mud and grit. In 1975, all reefs were covered by a viscous mud deposit as deep as 6-8 inches (14-20 cm) at their edges, thinning to about 2 inches (5 cm) in most areas, and usually absent at the central crown. The mud, spread over reefs by Hurricane Camille, prevented oyster larvae from setting and growing on the grit and shells. The bare reef crowns, from 1 to 2 acres (0.4 to 0.8 hectares) in size, contained spat attached to grit, large shells, and oysters (Table 1).

Pass Marianne, Telegraph Key and Merrill Coquille Reefs (500 acres; 202 hectares)

The reefs lie under only 2-5 feet (0.6-1.5 m) of water (mean low water). Their surfaces contain no mud deposit and are composed mostly of grit which is tossed continually by the effects of wave action. There are also quantities of large oyster shells on and under the reefs' surfaces. In 1975, the reefs were also partially stocked with adult oysters and spat which survived because of the prevailing salinities (less than 15 ppt).

Figure 7.—Oyster reefs largely consist of small oyster shells termed grit. Sizes of shells can be compared to inch and centimeter marks on ruler.

Square Handkerchief Reef (1,000 acres; 405 hectares)

This formerly productive reef was not examined.

Biloxi Bay Reef (300 acres; 121 hectares)

This reef lies on a shell deposit only about five shells deep which, in turn, lie on mud and fine sand. The shells are mostly from 3 to 6 inches (7.6 to 15 cm) long. In 1975, there was an average of 7.5 oysters per square yard (8.9 per square meter). The oysters ranged from spat to large adults and were growing in small clusters (Table 1). The oyster volume ranged between 50 and 400 barrels per acre (124 and 1,000 barrels per hectare) and totalled about 75,000 barrels.

Pascagoula River Mouth Reefs (500 acres; 202 hectares)

These reefs lie on a tightly packed shell deposit a few feet thick. In 1975, they had an average of 77 oysters per square yard (92 per square meter). The oysters ranged from spat to large adults (Table 1). Most were growing in clusters measuring several feet across. The oyster volume was estimated at 250 barrels per acre (618 barrels per hectare), and totalled about 100,000 barrels.

DEVELOPMENT OF REHABILITATION PROGRAM

The rehabilitation program was developed by identifying needs of the oyster industry, examining possibilities of relieving constraints that limit oyster reef productivity, and introducing new methods to relieve these constraints.

Identifying Needs Within Industry

To be successful, the results of a management program for the reefs must satisfy needs of both oystermen and processors. All three sectors, the tongers, dredgers, and processors, were suffering from the oyster shortage. The tongers desired to regain a valued occupation which they lost when the reefs became polluted and barren; dredgers and the processors desired rehabilitation of the Pass Christian reefs so the industry could return to the condition of the 1960's, when the reefs were well

Figure 8.—Oyster vessel, the *Conservationist*, rigged with two booms and dredges (only one is shown) with bottom doors for emptying the oysters.

stocked and earnings were adequate. This need dominated any others.

Relieving Constraints of Oyster Productivity

Every oyster reef is out of balance in that some environmental features are deficient and prevent it from supporting the oyster population which other features would be capable of supporting. Rehabilitation consists of learning the requirements of oyster populations, identifying deficient features, and strengthening them, one at a time. The basic questions are these: 1) are there enough acceptable setting surfaces on a reef for oyster larvae; 2) are features on a reef suitable for growth and survival of spat and larger oysters; and 3) is it feasible to make improvements to relieve constraints? Often a small effort, skillfully applied, produces astonishingly large results. Hopefully, only one or two physical modifications on the Pass Christian reefs would result in huge oyster population increases and fill the reefs to near capacity. This is anticipated because the productive potential of oysters is exceedingly high, and each reef had only one or two major deficiencies. Accordingly, it seemed that recovery of the reefs' oyster populations could be achieved with a simple program and with relatively small effort and expense.

In 1975, the Pass Christian tonging reef had an insufficient quantity of oysters and large shells to collect a set of spat needed to rehabilitate the oyster population; only about 6 percent of the reef's surface was covered. The reef could be immediately rehabilitated by covering it with a concentration of 200 barrels of oysters per acre (500 barrels/hectare), an ideal concentration for tonging. Once rehabilitated, the reef would be self-sustaining with spatfall. An oyster supply for transplanting is available in Biloxi Bay and the Pascagoula River mouth, which contain sufficient oysters to more than cover the reef. Although oysters in these two areas are polluted, they would cleanse themselves on the reef after a short period.

All separate reefs of the Pass Christian (Henderson Point) Dredging Reef were covered by a thin mud deposit, which prevented shells from collecting a set of spat. The reef could be easily rehabilitated by removal of the mud. Similar to the tonging reef, the dredging reef would be self-sustaining with spatfall after it has been rehabilitated.

The Pass Marianne, Telegraph Key, and Merrill Coquille dredging reefs had an insufficient quantity of oysters and shells to collect spat for completely stocking them; they contained only about one-quarter of the oyster supply they could hold. Productivity of the reef could be enhanced by the addition of more large shells.

Introduction of New Aquacultural Methods

Rehabilitation involves use of equipment which should be designed to relieve constraints on specific reefs. No two reefs are identical, and thus, each presents a different set of features which must be dealt with on its own merits. By substituting more efficient equipment for traditional gear used locally, increased productivity can usually be achieved. Often, suitable equipment has been used in another geographic area within the oyster industry and can be modified for local reef conditions.

Methods Tested in 1975

In October 1975, two types of recommended equipment were tested on reefs, and vessel operators were trained in their use.

Boom Oyster Loading System

The Mississippi Marine Conservation Commission constructed a 65-foot (23-m) steel vessel, the *Conservationist*, for transplanting oysters from polluted to clean reefs. I recommended that it be rigged for loading with two booms and dredges, that each have three-barrel capacity, and a door at their bottom to empty the oysters after it is lifted above the deck (Fig. 8). The boom oyster loading system was invented in Connecticut as a labor-saving device during World War II. A boom system of this capacity and design can load a vessel about three times as fast as a conventional roller dredge loading system that is ordinarily used on Mississippi and other Gulf Coast oyster vessels because the dredges are larger and can be handled faster. Under ideal conditions, a vessel so equipped should be able to load to capacity (400 barrels) travel 25 miles (40 km) to Pass Christian reefs, spread the transplanted stock with a water jet, and return in one 12-hour day. Thus, virtually 2 acres (0.8 hectares) of bottom would be covered daily and 400 acres (162 hectares) annually, assuming the vessel would transplant oysters about 200 days per year. This system is also less expensive than the present roller dredge because only two, rather than four, crew members besides a captain are required. In addition, each deckhand has less work because the dredges are easier to dump and no shovelling of oysters is required.

By using daily vessel costs and crew salaries, the estimated cost would be $0.50 per barrel to transplant oysters from Biloxi Bay to Pass Christian Tonging Reef. This is the cost that Engle (1948) calculated for transplanting oysters with the roller dredge loading system in the 1940's, when costs were much lower.

In October 1975, the new system had been constructed and it was tested and adjusted to perform well in Biloxi Bay. Modifications of the Connecticut prototype because of a softer bottom, included removal of the pressure plate, a shortened bag, larger rings, and larger meshed top net. These modifications aided in flushing mud out of the dredge. The dredge's tooth angle also was reduced to prevent it from digging. On a smaller reef in Biloxi Bay, the knotted net was made of smaller mesh to retain the oysters that were taken as singles, rather than in the clusters usual in this bay.

Transplanting oysters during summer is often impractical because of high mortalities from heat if oysters are held out of water overnight and spread in a different salinity. In July, I gathered 90 oysters from Biloxi Bay, trucked them to Pass Christian, and spread them around a buoy 4 hours after gathering. After 3 weeks only three oysters were dead. This test suggests that oyster transplanting during summer is safe, if oysters can be returned to water on the harvest day.

Mud Cleaning Machine

The Pass Christian (Henderson Point) Dredging Reef could be rehabilitated by towing a mud cleaning machine over it. Machines for this purpose have helped to increase oyster production in Long Island Sound (MacKenzie, 1970b) and Prince Edward Island (MacKenzie, 1975). They remove mud from the bottom quickly and inexpensively. In doing so, they also lift trapped nutrients into the water. Cleaning should be done before and at the beginning of the oysters' setting season, or March through May. I adapted them to operate on this reef. The new machine was 12 feet (8.7 m) wide and consisted of a bar with a row of 5-inch (13-cm) teeth spaced 3 inches (7.6 cm) apart and angled at 45° when towed, for loosening the mud and shells, and a pressure plate 1.5 feet (0.5 m) high, also angled at 45°, and positioned about 5 inches (12.7 cm) above the bar for scouring and lifting the mud (Fig. 9). Once lifted, most mud is carried off the reef by currents; some resettles and has to be relifted by a second cleaning. Ideally, the reef's surface would contain about 2 inches (5 cm) of clean, loose shells and grit after the cleaning is completed.

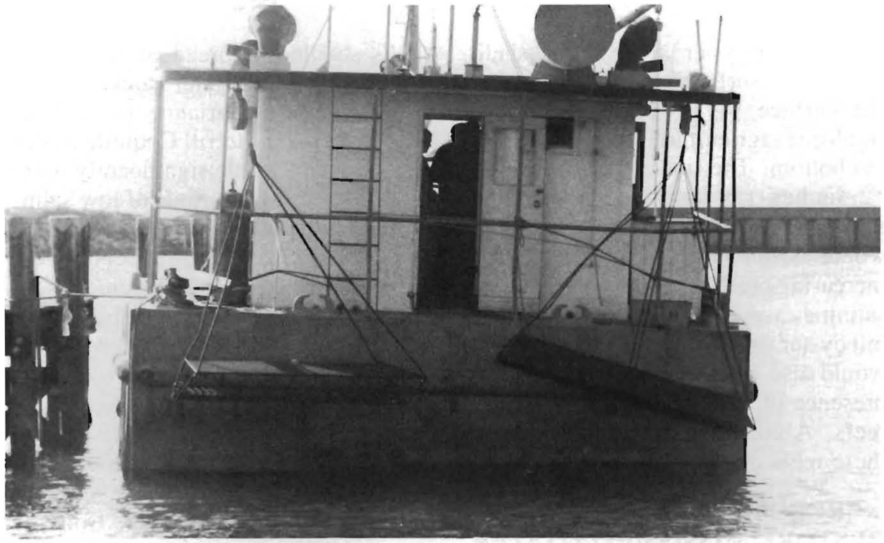


Figure 9.—Two machines for cleaning mud off oyster reefs attached to stern of motorized barge while at dock.

The Commission constructed two mud cleaning machines which were tested by towing them with an 80-foot (25-m) motorized barge over the dredging reef in late October 1975. A 4-acre (1.6-hectare) section of the reef covered by 2 inches (5 cm) of mud was buoyed. The barge then towed the machines at a speed of 3 knots. (1.5 m/sec) for 1.5 hours. A visual inspection of the reef using scuba gear revealed that between 0.5 and 1.0 inches (1.3 to 2.5 cm) of mud was removed and the shells were much looser in paths which the machines had covered once; the surface remained with a loose, thinner mud layer over the shells. Efficiency could be markedly improved by towing either two or three sets of toothed bars and plates, rather than one; with the second and third sets about 4 feet (1.2 m) behind the one in front. The number of sets would depend on the capacity of the towing vessel. The Commission's barge is large enough to pull two machines each having at least three sets of plates and bars.

I estimate that two cleaning machines, each with two or three sets of bars and plates could clean the mud off 10 acres (4 hectares) of reef bottom per 8-hour day, and as much as 400 acres (200 hectares) during March, April, and May. The machines are inexpensive to build and the daily cost of barge operation is about $150; thus the cost of rehabilitating each acre might be only $15 to $20 ($37 to $50/hectare). The lesser important deficiency of the dredging reef, spat predation by crabs, would be partially controlled as the growing oysters provided cover for the successive spat generations.

Method Recommended: Rigid-tine Cultivator

The Pass Marianne, Telegraph Key, and Merrill Coquille reefs had an insufficient density of large oyster shells as cultch for oyster larvae. Large shells under their surfaces could be raised to the surface by towing a weighted, rigid-tine agricultural cultivator over the bottom. The tines would penetrate 12 inches (30 cm) and be angled slightly forward to raise the shells. This would be an inexpensive method for increasing productivity of the reef when salinities were sufficiently low to permit oyster survival. Blue crab predation would also be partially reduced by the presence of more large oysters on the reefs. A cultivator was not tested on these reefs during this investigation.

RECOMMENDATIONS TO RESTORE MISSISSIPPI OYSTER PRODUCTION AND INDUSTRY

A series of recommendations to make maximum use of Mississippi Sound oyster reefs follows.

1) Programs which attempt to maintain water salinities at proper levels for oysters within Mississippi Sound, especially during droughts, should be supported. If proper salinities can be maintained for longer periods, oyster populations on various reefs have a greater chance of flourishing once they have been reestablished.

2) Programs by municipalities and the State to reduce pollution levels along the Mississippi coast should be enforced. Pollution abatement would be followed by reopening of productive oyster reefs in Biloxi Bay, the Pascagoula River mouth, and others. This would result in a return to oystering as a means of livelihood for many men, higher industrial earnings, greater oyster production, and elimination of a health hazard to the oyster-consuming public.

3) The Pass Christian Tonging Reef should be rehabilitated by transplanting oysters from the Biloxi Bay and Pascagoula mouth reefs by vessels equipped with a boom oyster loading system.

4) The Pass Christian (Henderson Point) Dredging Reef should be rehabilitated by cleaning off the mud deposit with cleaning machines and transplanting oysters from the Biloxi Bay and Pascagoula River mouth reefs. Once restored, a modest quantity of shells should be spread on it periodically to maintain oyster stocks.

5) The Pass Marianne Key, Telegraph Key, and Merrill Coquille oyster reefs could be made significantly more productive during periods of low salinity by returning buried large shells to the surface with a rigid-tine cultivator.

6) The Square Handkerchief Reef should be examined with scuba gear to determine its potential for producing oysters again, a diagnosis of deficient aspects made, and inexpensive equipment developed to rehabilitate it.

7) The oyster reefs in Pt. Aux Chenes Bay and Grand Bay should be rehabilitated by transplanting oysters from the Pascagoula River mouth reefs.

The Mississippi oyster reefs and industry should return to the status they had during the 1960's if this program is fulfilled. During that period, annual production averaged 160,000 barrels, with a value of about 1.5 million dollars, and more than 500 people were employed (Demoran, 1972). This is a minimum figure and higher production is well within the range of possibility.

ACKNOWLEDGMENTS

I thank Charles H. Lyles, Director, Thomas Quinn, James Williams, and Frank Daly, Mississippi Marine Conservation Commission, for support and assistance; Gordon Gunter, William Demoran, and J. Y. Christmas, Gulf Coast Research Laboratory; David Etzold, University of Southern Mississippi; and C. David Veal, Sea Grant Advisory Service, for providing assistance and information. I am grateful to a number of fishermen and processors, especially Buddy Belton, Richard Purchner, and Daniel Gullott, for providing valuable information.

The manuscript was reviewed by Jay D. Andrews, Philip Butler, James B. Engle, Gordon Gunter, Winston Menzel, and Anthony L. Pacheco to whom I am grateful for many helpful suggestions.

LITERATURE CITED

Butler, P. A. 1949. An investigation of oyster producing areas in Louisiana and Mississippi damaged by flood waters in 1945. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 8, 29 p.

__________. 1952. Effect of floodwaters on oysters in Mississippi Sound in 1950. U.S. Fish Wildl. Serv., Res. Rep. 31, 20 p.

__________. 1954a. The southern oyster drill. Proc. Natl. Shellfish. Assoc. 1953 Conv. Pap., p. 67-75.

__________. 1954b. Summary of our knowledge of the oyster in the Gulf of Mexico. *In* P. S. Galtsoff (editor), Gulf of Mexico. Its origin, waters, and marine life, p. 479-489. U.S. Fish Wildl. Serv., Fish. Bull. 55.

__________, and J. B. Engle. 1950. The 1950 opening of the Bonnet Carre Spillway: Its effect on oysters. U. S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 14, 10 p.

Chapman, C. R. 1958. Oyster drill *(Thais haemastoma)* predation in Mississippi Sound. Proc. Natl. Shellfish. Assoc. 49:87-97.

Christmas, J. Y. 1973. Phase I: Area description. *In* J. Y. Christmas (editor), Cooperative Gulf of Mexico Estuarine Inventory and Study, Mississippi, p. 1-71. Gulf Coast Res. Lab., State of Mississippi.

__________, and C. K. Eleuterius. 1973. Phase II: Hydrology. *In* J. Y. Christmas (editor), Cooperative Gulf of Mexico Estaurine Inventory and Study, Mississippi, p. 73-121. Gulf Coast Res. Lab., State of Mississippi.

__________, G. Gunter, and P. Musgrave. 1966. Studies of annual abundance of postlarval penaeid shrimp in the estuarine waters of Mississippi, as related to subsequent commercial catches. Gulf Res. Rep. 2(2): 177-212.

__________, and W. Langley. 1973. Sect. 4. Estuarine invertebrates, Mississippi. *In* J. Y. Christmas (editor), Cooperative Gulf of Mexico Estuarine Inventory and Study, Mississippi. Phase IV: Biology, p. 255-319. Gulf Coast Res. Lab., State of Mississippi.

Churchill, E. P., Jr. 1920. The oyster and the oyster industry of the Atlantic and Gulf coasts. (U.S.) Bureau of Fisheries, Report of The Commissioner of Fisheries for the fiscal year 1919. Appendix VIII (Document 890), 51 p.

Cross, R. D., R. W. Wales, and C. T. Traylor. 1974. Atlas of Mississippi. Univ. Press Miss., Jackson, 187 p.

Demoran, W. J. 1966. Homes for oysters. Miss. Game Fish. 26(3):12-13.

__________. 1972. Oyster production in the State of Mississippi for 1927 to 1972 and the State's management of the Mississippi oyster fishery. Proceedings of a public symposium on the oyster fisheries of the Gulf States, p. 16-22. Biloxi, Miss.

Engle, J. B. 1948. Investigations of the oyster reefs of Mississippi, Louisiana, and Alabama following the hurricane of September 19, 1947. U.S. Fish Wildl. Serv., Spec. Sci. Rep. 59, 70 p.

Finucane, J. H., and R. W. Campbell, II. 1968. Ecology of American oysters in Old Tampa, Bay, Florida. Q. J. Fla. Acad. Sci. 31(1):37-46.

Ford, T. 1970. Effects of Hurricane Camille on Louisiana's oyster growing areas east of the Mississippi River — Lake Borgne to California Bay and other marine fisheries industries. 13th Biennial Report 1968-69, p. 78-83. La. Wildl. Fish. Comm.

Galtsoff, P. S. 1964. The American oyster *Crassostrea virginica* Gmelin. U.S. Fish Wildl. Serv., Fish Bull. 64, 480 p.

Gunter, G. 1942. Seasonal condition of Texas oysters. Proc. Trans. Tex. Acad. Sci. 25:89-93.

__________. 1952. Historical changes in the Mississippi River and the adjacent marine environment. Publ. Inst. Mar. Sci. Univ. Tex. 2(2):119-139.

__________. 1953. The relationship of the Bonnet Carré Spillway to oyster beds in Mississippi Sound and the "Louisiana Marsh," with a report on the 1950 opening. Publ. Inst. Mar. Sci. Univ. Tex. 3:17-71.

__________. 1975. Mariculture in Mississippi: oyster management by the State. *In* B. N. Irby and D. McCaughan (editors), Guide to the marine resources of Mississippi, p. 104-114. Fox Printing Co., Hattiesburg, Miss.

__________, B. S. Ballard, and A. Venkataramiah. 1974. A review of salinity problems of organisms in United States coastal areas subject to the effects of engineering works. Gulf Res. Rep. 4(3):380-475.

__________, and W. J. Demoran. 1970. Successful management of the oyster fishery by the State of Mississippi. Proc. Symp. Mollusca. Mar. Biol. Assoc. India. Part III, p. 899-905.

__________, and __________. 1971. Mississippi

oyster culture. Am. Fish Farmer 2(5):8-12.
Hopkins, A. E. 1954. Oyster cultural experiments on the Mississippi Gulf Coast. J. Miss. Acad. Sci. 6:31-32.
Hopkins, S. H. 1955. Oyster setting on the Gulf coast. Proc. Natl. Shellfish. Assoc. 45:52-55.
Ingle, R. M., and C. E. Dawson, Jr. 1952. Growth of the American oyster, *Crassostrea virginica* (Gmelin) in Florida waters. Bull. Mar. Sci. Gulf Caribb. 2(2):393-404.
Lee, C. F., and L. Pepper. 1956. Composition of southern oysters. Commer. Fish. Rev. 18(7):1-6.
Lyles, C. H. 1969. Historical catch statistics (shellfish). U.S. Fish Wildl. Serv., Curr. Fish. Stat. 5007, 116 p.
McGraw, K. A., and G. Gunter. 1972. Observations on killing of the Virginia oyster by the gulf oyster borer, *Thais haemastoma*, with evidence for a paralytic secretion. Proc. Natl. Shellfish. Assoc. 62:95-97.
MacKenzie, C. L., Jr. 1970a. Causes of oyster spat mortality, conditions of oyster setting beds, and recommendations for oyster bed management. Proc. Natl. Shellfish. Assoc. 60:59-67.
________. 1970b. Oyster culture in Long Island Sound 1966-69. Commer. Fish. Rev. 32(1):27-40.
________. 1975. Development of a program to rehabilitate the oyster industry of Prince Edward Island. Mar. Fish. Rev. 37(3):21-35.
Mackin, J. G. 1951. Histopathology of infection of *Crassostrea virginica* (Gmelin) by *Dermocystidium marinum* Mackin, Owen, and Collier. Bull. Mar. Sci. Gulf Caribb. 1(1):72-87.
Maghan, B. W. 1967. The Mississippi oyster industry. U.S. Fish Wildl. Serv., Fish. Leafl. 607, 12 p.
Menzel, R. W., and S. H. Hopkins. 1956. Crabs as predators of oysters in Louisiana. Proc. Natl. Shellfish. Assoc. 46:177-184.
________, and F. E. Nichy. 1958. Studies of the distribution and feeding habits of some oyster predators in Alligator Harbor, Florida. Bull. Mar. Sci. Gulf Caribb. 8(2):125-145.
Nichy, F. E. and R. W. Menzel. 1960. Mortality of intertidal and subtidal oysters in Alligator Harbor, Florida. Proc. Natl. Shellfish. Assoc. 51:33-41.

MFR Paper 1259. From Marine Fisheries Review, *Vol. 39, No. 8, August 1977. Copies of this paper, in limited numbers, are available from D822, User Services Branch, Environmental Science Information Center, NOAA, Rockville, MD 20852. Copies of* Marine Fisheries Review *are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402 for $1.10 each.*