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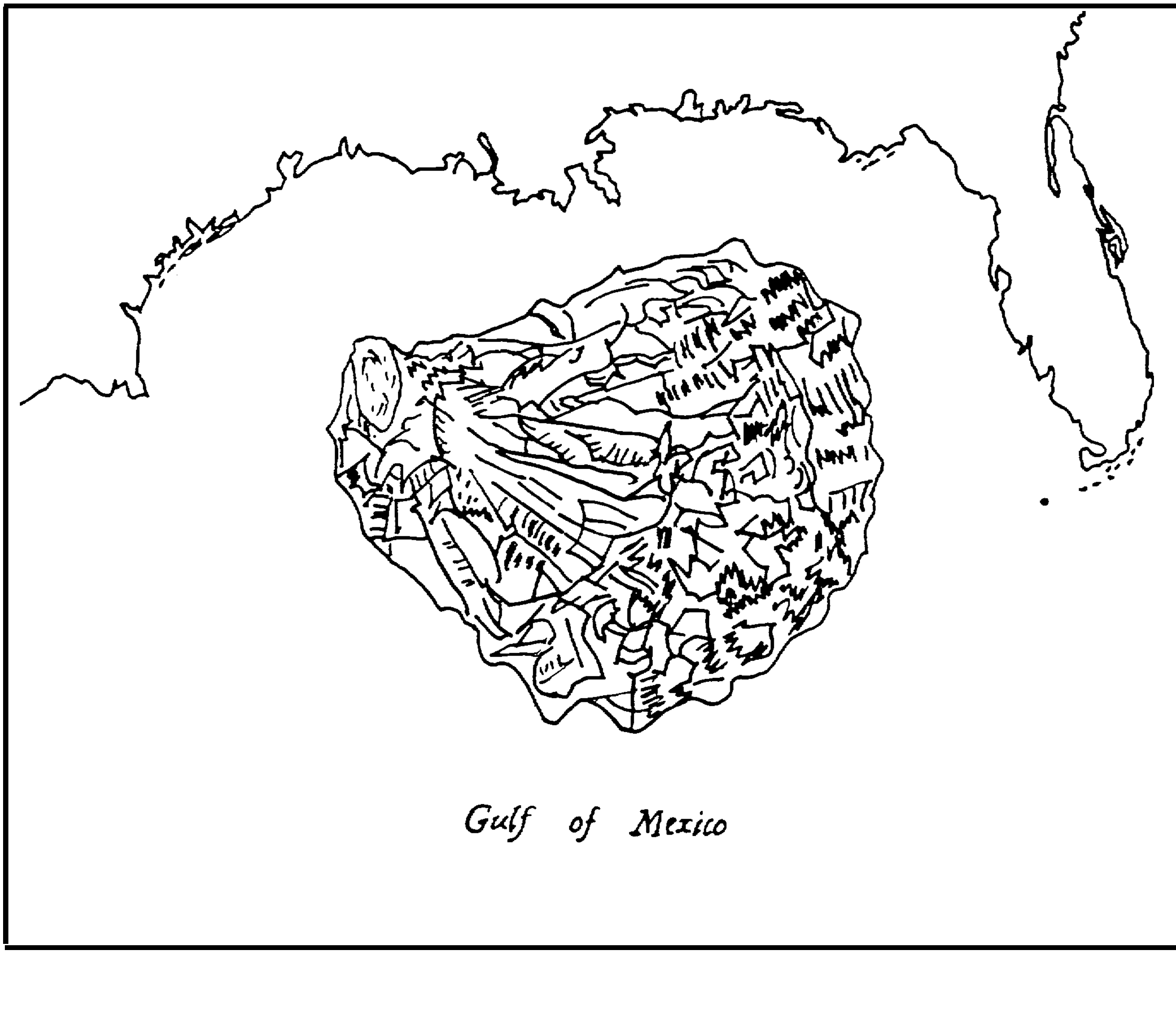
THE ECOLOGY OF OYSTER REEFS OF THE NORTHERN GULF OF MEXICO



Fish and Wildlife Service

Minerals Management Service

U.S. Department of the Interior

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THE ECOLOGY OF OYSTER REEFS OF THE NORTHERN GULF OF MEXICO: AN OPEN FILE REPORT

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PREFACE

This report generally deals with the subtidal estuarine oyster reef communities found along the northern Gulf of Mexico, with little reference to other areas of the United States. Information on oyster reefs in Louisiana dominates this report mainly because there are more oyster reefs in the waters of that Gulf State. We have attempted to gather information from all States and have tried to point out differences in environmental conditions where possible. We apologize for omissions of some of the available information, only because of space limitations.

The information in this report should provide a basic understanding of the dynamic ecosystem in which oyster reef communities are found. It is adaptable to a variety of uses, including preparing environmental assessments, providing information for coastal resource managers, and providing reading material for high school and college marine science courses. We have included two chapters (4 and 6) and two appendixes (II and III) on the exploitation and management of oyster reefs as commercially important renewable resources.

Any questions or comments about or requests for this publication should be directed to:

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CONTENTS

FIGURES

Number		Page

TABLES

CHAPTER 1. REGIONAL PHYSIOGRAPHY AND HYDROLOGY

1.1 INTRODUCTION

The gulf coast, stretching a distance of 2,483 km from the Rio Grande in Texas to Florida Bay (Figure 1), encompasses 3,193,799 ha of estuarine areas (Table 1). The physiography and geological development of the Gulf of Mexico

Table 1. Dimensions of estuarine areas of the northern Gulf of Mexico.

State	Coastline Length miles	%	Estuarine Area (MHW) acres	%
Texas	370	24	1,532,430	19
Louisiana	280	18	3,378,924[a]	43
Mississippi	70	5	500,380	6
Alabama	53	3	397,353	5
Florida	770	50	2,081,525	26
Totals	2,483		7,890,612	

[a]MLW

have been described by several authors, including Emery and Uchupi (1972). Many of these works show that ancient, buried oyster reefs played a significant role in determining the developmental history of certain areas. Both continental and marine geology along the northern gulf coast are fairly uniform (Folger 1972). The coastal zone is a low energy hydrologic regime (Gorsline 1967). Currents seldom exceed 50 cm/see, except in restricted channels, and normal tidal ranges are generally less than 0.6 m. Tidal regimes along the coast are depicted in Figure 2. Average freshwater discharge is high in the eastern gulf, but low in the western gulf. Because of sediments deposited by rivers, estuaries are generally less than 6 m in depth. Freezing water temperatures are rarely found along the gulf coast. Salinities may range from freshwater to over 100 ppt (parts per thousand).

1.2 TEXAS

Physiography and Geology

The Texas coastline, from the Rio Grande northeastward to the Sabine River, is about 595 km long. The seven major estuarine systems (Figure 3)

Figure 1. The northern Gulf of Mexico.

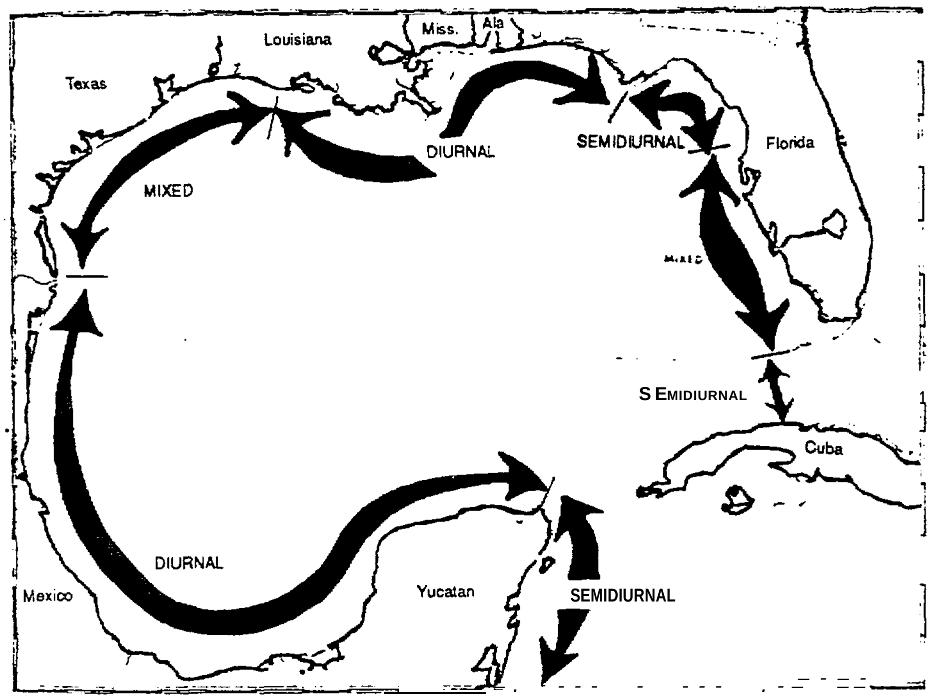


Figure 2. Gulf of Mexico tidal regimes (after Eleuterius 1975).

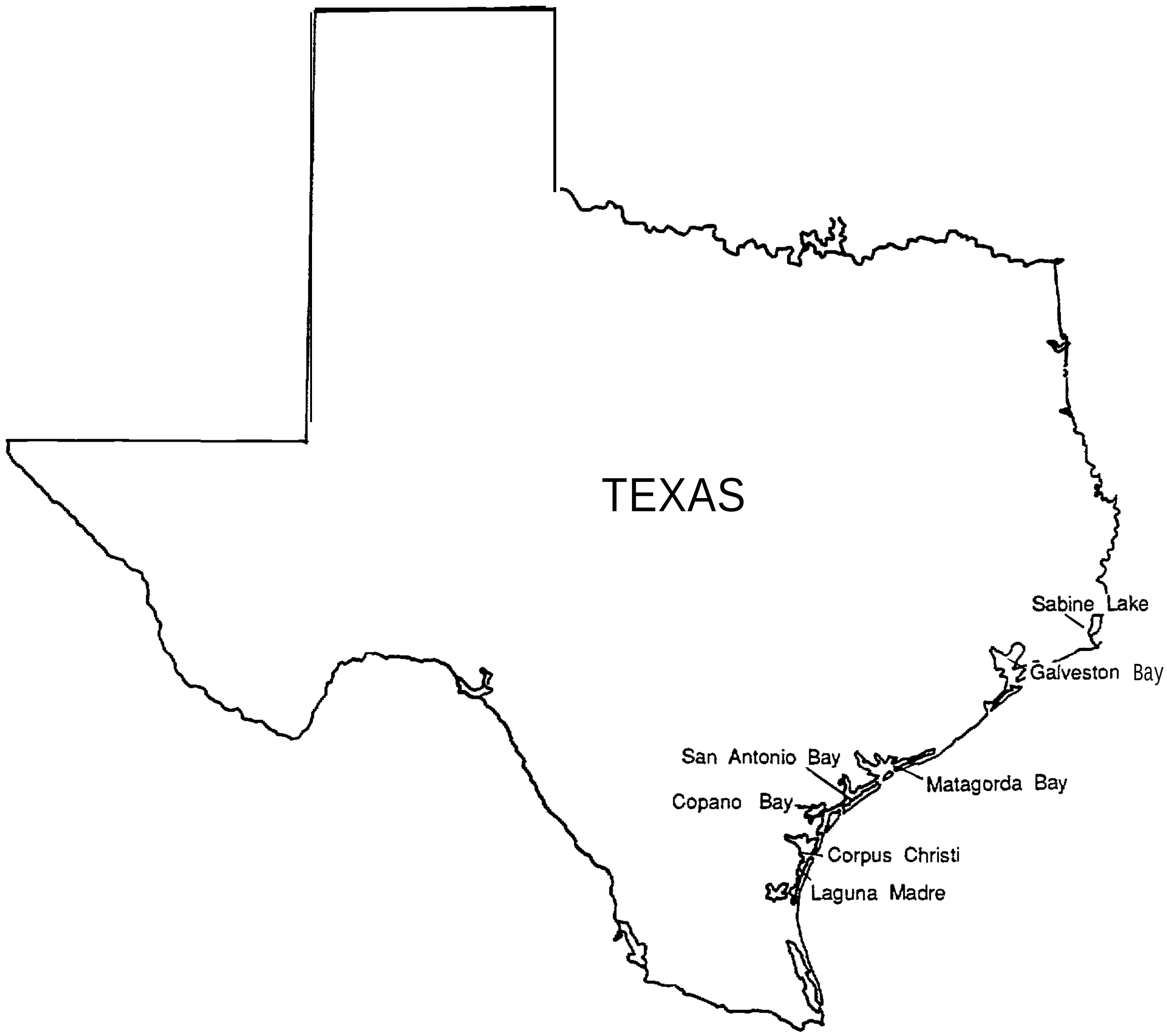


Figure 3. Texas estuarine systems.

have two basic shapes--either oval (simple) or dendritic (complex). Sabine Lake is oval, while the other estuaries are dendritic. Diener (1975) listed 55 bays and lake areas within the seven major estuarine systems. Surface areas of the major systems are listed in Table 2. The total open water area of Texas estuaries at mean high water (MHW) level is 620,634 ha. Texas estuaries are categorized geomorphologically as either coastal plain or bar-built types (Pritchard 1967). Coastal plain estuaries, composed of drowned river mouths, include Sabine Lake and Galveston, Trinity, Matagorda, Lavaca, San Antonio, Copano, Corpus Christi, and Baffin Bays. Estuaries of the Brazes, Colorado, and Rio Grande Rivers have essentially filled in. Several estuaries, including East and West Matagorda Bays, Espiritu Santo Bay, Aransas and Redfish Bays, and Laguna Madre are bar-built types, in which an offshore sand bar partially encloses a body of water. A string of barrier islands lines the Texas coast.

Table 2. Surface areas of Texas estuarine areas (Mean low water and Mean high water). Surface area does not include peripheral marsh (from Diener 1975).

Study area	Surface Area (acres) NLW	Surface Area (acres) MHW
Sabine Lake		
Sabine Lake	43,960	44,830
Sabine Pass	1,360	1,360
Galveston Bay		
East Bav	33,370	33,690
Trinity-Bay	83,310	86,240
Galveston Bay (upper)	69,890	70,080
Galveston Bay (lower)	89,380	90,390
Lake Anahuac (Turtle Bay)	4,660	4,850
Scott-San Jacinto Bay	3,230	4,310
Clear Lake	1,260	1,280
Dickinson Bay	1,520	1,540
Moses Lake (Dollar Bay)	2,130	2,140
Offats Bayou	1,180	1,200
Jones Lake	1,040	1,050
West Bay	44,390	45,420
Chocolate Bay	4,890	4,920
Bastrop-Oyster Bay	9,690	10,410
Matagorda Bay		
East Matagorda Bay	37,810	39,080
Matagorda Bay	167,570	170,130
Oyster Lake	2,450	2,570
Tres Palacios Bay	9,440	9,860

(Continued)

Table 2. (Concluded)

Study area	Surface Area (acres) MLW	MHW
Matagorda Bay		
Turtle Bay	1,280	1,760
Carancahua Bay	12,160	12,300
Salt, Redfish Lakes	920	950
Keller Bay	4,770	4,850
Lavaca Bay	39,970	40,080
Swan Lake	860	880
Lavaca River Estuary	740	760
Chocolate Bay	1,440	1,760
Powderhorn Lake	2,890	2,970
Cedar Lakes Complex	3,760	3,840
San Antonio Bay		
Espiritu Santo Bay	38,940	40,630
San Antonio Bay	76,530	77,700
Guadalupe Bay	2,070	2,090
Mission Lake	1,820	2,400
Hynes Bay	6,580	6,610
Ayers Bay	2,220	2,550
Mesquite Bay	8,080	9,220
Copano Bay		
St. Charles Bay	8,410	8,730
Mission Bay	3,760	3,760
Copano Bay	41,740	42,930
Port Bay	1,650	2,000
Mission Lake	100	100
Aransas Bay	56,220	59,200
Corpus Christi		
Redfish Bay	9,630	13,420
Corpus Christi Bay	73,820	75,560
Nueces Bay	18,470	18,550
Oso Bay	5,070	5,070
Laguna Madre		
Upper Laguna Madre	47,240	68,360
Lower Laguna Madre	175,160	329,740
South Bay-La Badilla Grande Complex	4,380	7,300
Baffin Bay	31,870	32,610
Alazan Bay	13,860	14,750
Cayo del Infernillo	700	1,630
Laguna Salada	3,230	3,530
Cayo del Grullo	4,470	8,470

The processes responsible for the geologic development of the Texas coastline have been summarized by Shew et al. (1981). In general, during the last Pleistocene glacial stage (Wisconsin), sea level was about 137 m lower than it is today, and the Texas shoreline was from 80 to 225 km seaward of the present shoreline (LeBlanc and Hodgson 1959). The broad plain was eroded by flowing rivers, forming trenches more than 30 m below the adjacent upland surface (Van Siclen 1961). It was during this period that the valley surfaces attained much of their final forms, which are preserved beneath alluvium that filled most of the valleys. Present day Texas estuaries were generally formed as a result of rising sea levels caused by melting Pleistocene. glaciers during the early Recent epoch. The lower portions of rivers were thus drowned, forming a series of estuaries. Sea level reached its present level about 5,000 years ago (LeBlanc and Hodgson 1959), and the barrier islands and peninsulas were formed. The rising sea weakened currents near river mouths, causing deposition of mud, sand, and gravel. This process continues today (Diener 1975), and the direction of estuarine development has been influenced by human activities.

A unique geological feature of the gulf coast is the manner in which a second Colorado River Delta was formed below Matagorda. Prior to 1690, a log jam developed in the Colorado River below Bay City and above Matagorda (Wadsworth 1966). As a result of the removal of logs between 1925 and 1929, the debris and sediments were carried downstream, forming a delta on the original undivided eastern arm of Matagorda Bay (Figure 4). Further changes occurred when, in 1936, a channel for handling flood discharges was cut through the delta and Matagorda peninsula to the gulf, and again in 1940, when the U.S. Army Corps of Engineers cut the Gulf Intracoastal Waterway. The spoil deposition and additional growth of the delta resulting from these projects had serious detrimental effects on an important oyster producing area in eastern Matagorda Bay (Weeks 1945).

Many attempts have been made to categorize the distribution of bottom sediments in Texas estuaries (Breuer 1957; Shenton 1957; Shepard and Rusnak 1957; Simmons 1957; Day 1959; Heffernan 1959; Stevens 1959; and Childress 1960). The results of several studies were summarized with detailed maps by Diener (1975). Sediment types in Texas estuaries are varied, with the different systems characterized as follows: Galveston Bay--silty clay; Matagorda Bay--clayey silt; San Antonio Bay--mud; Corpus Christi Bay--mud, mud and silt, or sand and mud; and Laguna Madre--silty sand or mud. The lack of uniform study methods makes it difficult to make comparison of bottom types, but some differences are evident.

Hydrology

Combined average discharges for gauged streams on the Texas coast are presented in Table 3. Diener (1975) provided data on individual stream discharges from 1951 to 1968, and Hahl and Ratzlaff (1973) provided similar data for 1969 to 1970. Streamflow to Sabine Lake and Galveston Bay accounts for over 75% of the flow to all Texas estuaries. Shew et al. (1981) discussed streamflow through each of the estuarine complexes of the Texas coast. Since

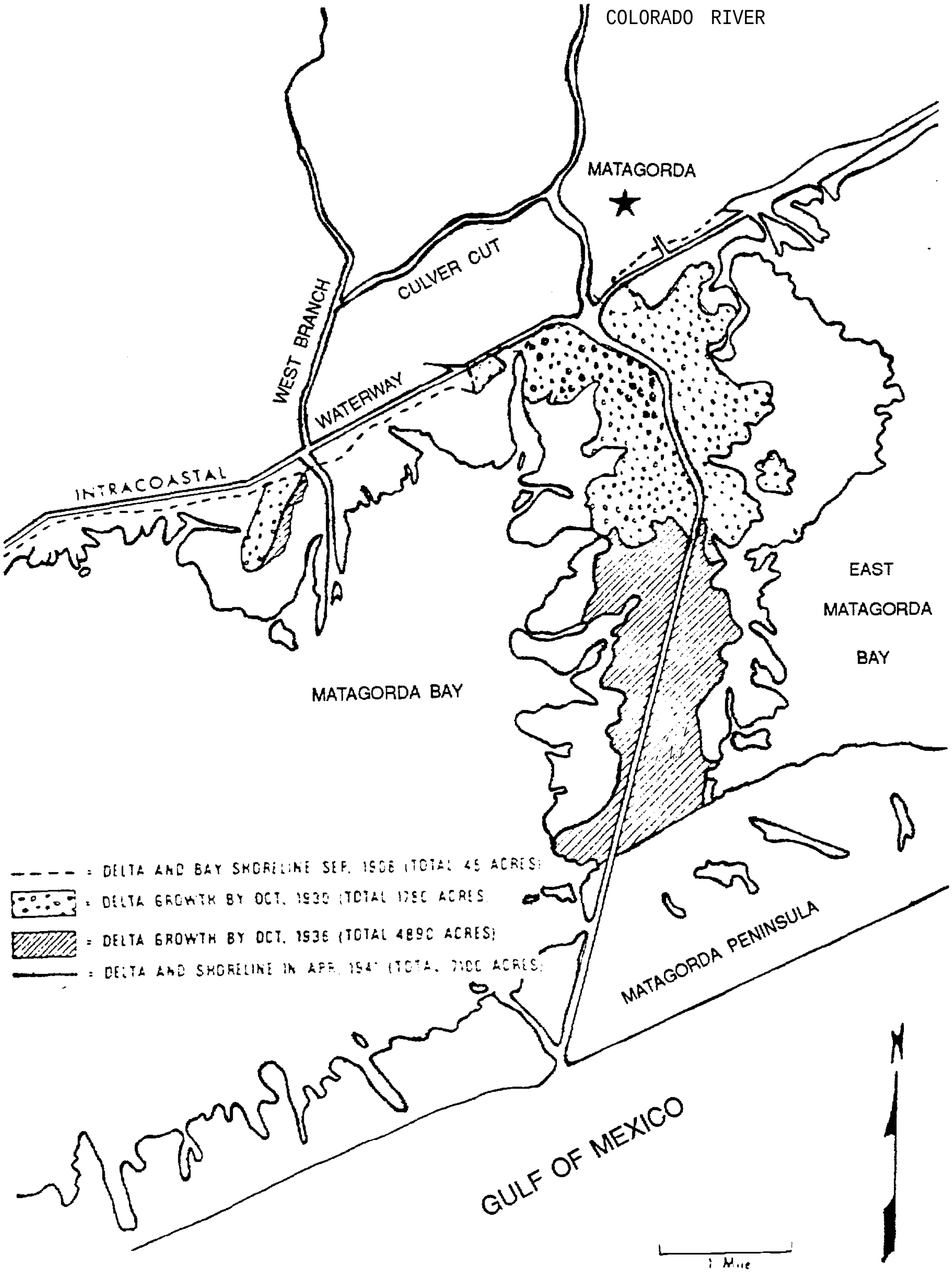


Figure 4. Successive growth stages of the modern delta of the Colorado River, September 1908 to April 1941 (after Wadsworth 1966).

Table 3. Discharge rates through Texas estuaries. From Diener (1975].

Estuarine areas	Cumulative average annual discharge (ft^3/see) Historic	1951-68
Sabine Lake	15,334	11,521
Galveston Bay	9,149	7,554
Matagorda Bay	3,085	3,078
San Antonio-Espiritu Santo Bays	2,235	2,063
Copano-Aranas Bays	182	189
Corpus Christi Bay	826	727
Laguna Madre	37	37

this area is in the transition zone between the humid southeastern United States and the arid plateau of Mexico and Texas, streamflow diversity is greater along the Texas coast than along the rest of the gulf coast. Streams of the upper Texas coast have relatively uniform seasonal flow, while streams of the central and lower coast frequently have little or no water flow (Diener 1975). The Laguna Madre has no major streams discharging into it.

Most Texas estuaries are considered to be one-layer systems, since they are relatively shallow, permitting the mixing of surface and bottom waters by tidal currents and wind-driven waves. The maxiumum depth in these estuaries is 13.4 m at MLW (lower Galveston Bay) (Diener 1975). Average tidal range is slight, from about 6 cm in Sabine Lake, San Antonio Bay, and Copano Bay to 46 cm in sections of Laguna Madre. Based upon tidal and salinity features (Emery and Stevenson 1957), Texas estuaries fall into two categories. Most are of the normal (“positive”) type, where upstream salinities are lowered by adequate river discharges and mixing (bays from Sabine Lake to Corpus Christi Bay), with salinities ranging from 5 to 25 ppt. Occasionally Corpus Christi Bay receives flood discharges from the Nueces River, causing near freshwater conditions throughout the bay. Laguna Madre falls into the hypersaline (“negative”) category--found in an arid region with poor surface runoff, limited tidal influence, and salinities generally higher than those of the adjacent ocean. Hedgpeth (1953) reported salinities above 70 ppt, with a record high of 113.9 ppt between 1946 and 1948 before the dredging of the Gulf Intracoastal Waterway in 1949.

Additional information on salinities, as well as on other aspects of water quality in Texas estuaries, was provided by Hahl and Ratzlaff (1973), Diener (1975), and Shewet al. (1981). Martinez (1975) reported that several Texas estuaries north of Corpus Christi Bay averaged 22 ‘C annually. Between 1963 and 1966, a February low of 3 ‘C and a July high of 39 “C were recorded in parts of Galveston Bay (Diener 1975). Because of the shallowness of these estuaries, thermal stratification rarely occurs.

1.3 LOUISIANA

Physiography and Geology

Louisiana's coastline, from the Sabine River eastward to the Pearl River, is about 450 km long. Virtually the entire coast consists of marshy estuarine areas. From Sabine Pass near Texas eastward to Southwest Pass in Vermilion Bay, the shoreline is relatively smooth and regular, being a region of marginal deltaic sedimentation. From the Southwest Pass to the Pearl River, the-coastline is very irregular because of its deltaic nature (Morgan and Larimore 1957). Perret et al. (1971) divided coastal Louisiana into nine estuarine study areas (Figure 5), with a total open water area of 1,367,459 ha (MLW). Dimensions of these study areas, including 29 major water bodies, are presented in Table 4. As with the other Gulf States, barrier islands occur along the coast. Louisiana's estuarine areas resulted mainly from the continual shifting of the course of the Mississippi River over the last 5,000 years. The river has followed its present course for only about 600 years. Progradation and sedimentation are presently occurring (Murray 1961). But subsidence in the coastal marshes is also taking place at the rate of 12 cm per year (Welder 1959). Barrett (1970) published an extensive listing of the dimensions of water bodies of coastal Louisiana.

The geologic development of the Louisiana coastline has been described by Fisk (1944), Murray (1961), Coleman (1966), and Frazier (1967). Late Quaternary sediments along coastal Louisiana were either deposited by former Mississippi River development or carried by littoral currents as marginal mudflats (Coleman 1966). In the last 5,000 years, the Mississippi River has shifted its course several times over nearly the entire coastline. The sediment loads deposited by it and the smaller rivers and bayous caused progradation rates of over 15 m per year in some areas. Subsequent subsidence has caused the formation of the extensive estuarine network of bays, lakes, and bayous which characterize Louisiana's coastline.

In general, sediments of Louisiana's water bottoms are similar all along the coast. Clayey silt is the most abundant sediment type in large, open water bodies where energy levels are highest, while silty clay is predominant in small semi-enclosed areas. Large water bodies with little or no openings to the gulf have less sand and coarse silt than large water bodies with larger connections to the gulf. Barrett et al. (1971) reported on an extensive study of Louisiana's coastal sediments, in which the bottom types of nearly all water bodies are described.

Hydrology

Flow rates in nearly all of the bayous along the coast are influenced by tidal fluctuations, prevailing winds, and precipitation. Many of these waterways have been modified by permanent structures (dams, weirs, locks) which affect discharge rates. The combined discharge of the Mississippi and Atchafalaya Rivers far surpasses the combined discharge of all other Louisiana waterways. Since 1900 the mean flow of the Mississippi has averaged 18,282 m^3/see, but the Atchafalaya River distributary has increased at the expense of the Mississippi since 1858. Between 1900 and 1910, the Mississippi

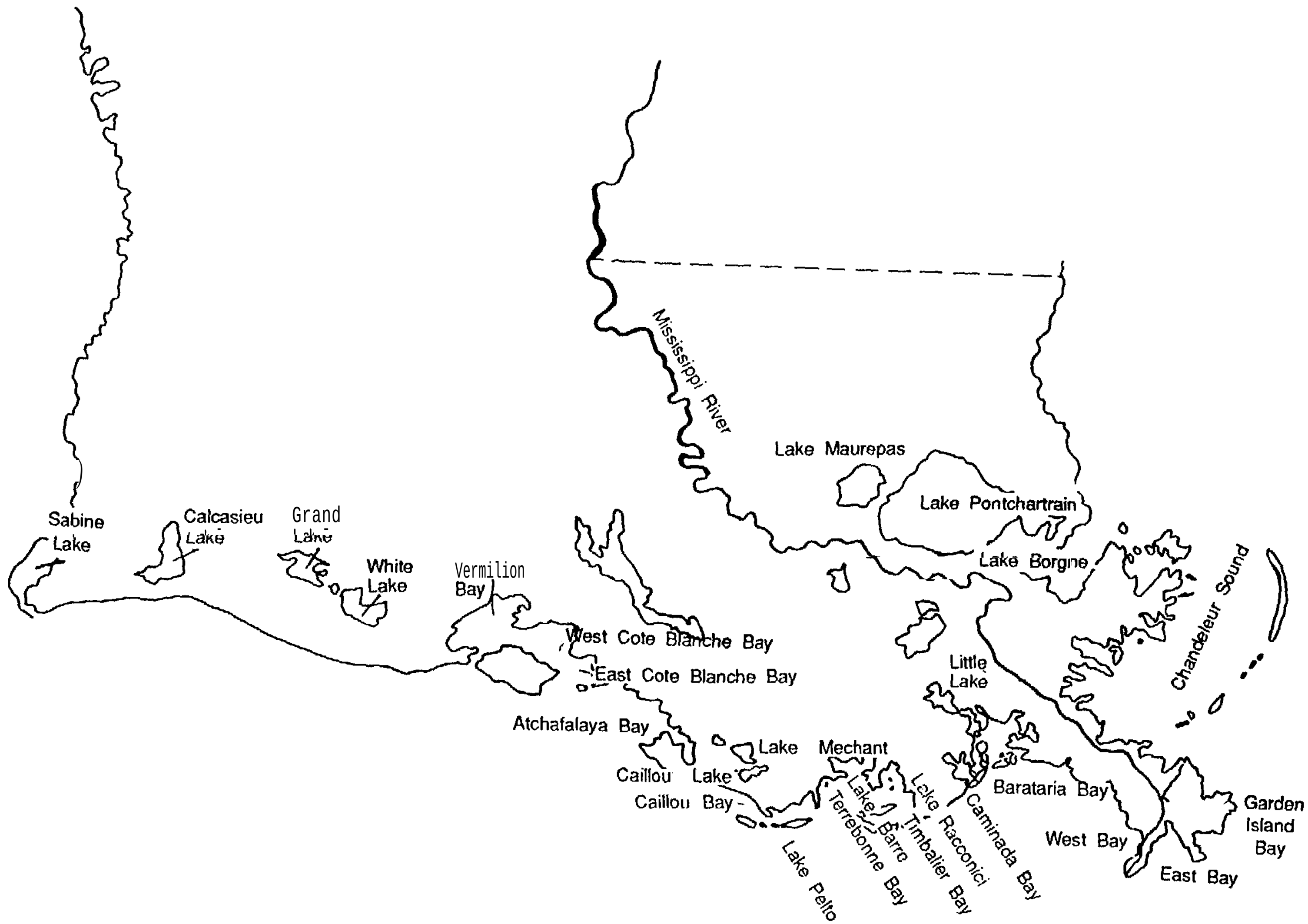


Figure 5. Louisiana estuarine systems.

Table 4. Surface areas of Louisiana estuarine areas at mean low waters (MLW). From Perret et al. (1971).

Area	hectares	acres
1	183,363	453,083
Lake Maurepas	23,550	58,191
Lake Pontchartrain	159,503	394,127
Others	310	765
2	390,252	964,299
Chandeleur Sound	233,918	578,003
Lake Borgne	69,357	171,380
Others	86,977	214,916
3	134,953	333,465
Breton Sound	79,050	195,330
Others	55,903	138,135
4	80,166	198,087
East Bay	19,505	48,195
Garden Island Bay	5,465	13,504
Mississippi River	14,157	34,982
West Bay	7,141	17,646
Others	33,898	83,760
5	95,346	235,596
Barataria Bay	17,625	43,551
Caminada Bay	5,730	14,158
Little Lake	5,216	12,888
Others	66,775	164,999
6	96,303	237,962
Lake Barre	8,599	21,247
Lake Raccourci	7,802	19,278
Terrebonne Bay	20,392	50,388
Timbalier Bay	32,260	79,713
Others	27,251	67,336
7	73,178	180,823
Caillou Bay	10,961	27,085
Caillou Lake	3,137	7,752
Four League Bay	8,257	20,402
Lake Mechant	3,397	8,395
Lake Pelto	9,969	24,633
Others	37,457	92,556

(Continued)

Table 4. (Concluded)

Area	hectares	acres
8	189,921	469,290
Atchafalaya Bay	54,505	134,679
East Cote Blanche Bay	33,312	82,314
Vermilion Bay	49,213	121,604
West Cote Blanche Bay	36,383	89,902 .
Others	16,508	40,791
9	123,967	306,319
Calcasieu Lake	17,318	42,792
Grand Lake	12,842	31,733
Sabine Lake	22,606	55,858
White Lake	20,902	51,649
Others	50,299	124,287
Totals	1,367,449	3,378,924

carried 85% of the flow, while the Atchafalaya carried 15%. From 1970 to 1978, the Atchafalaya carried 33% of the total flow. Gunter (1979) estimated that flow rates of these two rivers would be equal by the year 2038.

Bays and lakes along the coast are generally shallow, averaging 1.2-1.5 m, although depths in constricted channels in some of the larger water bodies where the currents are strong may exceed 7.6 m. Barataria Pass, connecting Barataria Bay to the gulf, has a scour hole about 58 m deep (Barrett 1971). The normal tide along the coast is diurnal, with a mean tidal level of 12-37 cm, and a range of 27-76 cm (Perret et al. 1971). Murray (1976) presented information on currents and circulation in Louisiana coastal waters.

Barrett (1971) compiled and discussed data on several aspects of water quality in Louisiana estuaries, including salinity, temperature, dissolved oxygen, turbidity, and other parameters. Salinities generally vary with seasonal changes in tides, rainfall, river discharge, and evaporation rates. Salinites are generally highest in fall and lowest during spring, ranging from sea-strength to freshwater, depending on location. Salinity wedges and stratification occur only in deep channels in bays and in rivers, and most of the estuaries are relatively homogeneous. During 1968 and 1969, annual surface water temperatures along the coast ranged from -1 to 35 ‘C.

1.4 MISSISSIPPI

Physiography and Geology

The coastline of Mississippi is relatively short compared to those of the other Gulf States--only 113 km long. The most obvious feature is Mississippi

Sound, an elongate body of water separated from the Gulf of Mexico by a series of barrier islands (Figure 6). It can thus be classified as a lagoon (Emery and Stevenson 1957; Stevenson 1968). Physiographically the Mississippi estuarine area is compound, consisting of four estuaries (Pascagoula River, Biloxi Bay, St. Louis Bay, and Pearl River) adjoining a lagoon. The Mississippi coast has been described as an alluvial coast of terraced deltaic plain (Upshaw et al. 1966). Surface areas of the four estuaries are listed in Table 5. Total wet surface area at MHW is 202,504 ha. These estuaries are all drowned river valleys, with the Pascagoula and Pearl Rivers having been filled in by deltaic depositional processes (Pritchard 1971). Biloxi Bay has not been filled to the same extent. St. Louis Bay has a relatively round shape, suggesting that it may have a different origin than the other areas.

Geologically, the present Mississippi coastline has been relatively stable for about 4,000 years (Lucas 1975). During the Pleistocene, the shoreline was as much as 193 km further south than it is today. During the end of the Wisconsin glacial stage and the Holocene, sea level rose and the shoreline advanced landward. This rise flooded the coastal areas and river valleys behind the barrier islands, forming Mississippi Sound and associated bays. These areas have been brackish for about 5,000 years (Rainwater 1964).

The bottom sediments of Mississippi Sound have been described by several authors. Rainwater (1964) stated that over the last 5,000 years, the sound has received mostly fine sediments (clay and silt) which have filled in more than one half of its original 9.1-m depth. Upshaw et al. (1966) reported that silt and clay cover most of the bottom, with sand being abundant around the margins and in inlet channels where currents and waves are strongest. Prior to this, Priddy et al. (1955) described Mississippi Sound as having mainly a mud bottom, with 80% of the area being clay-mud, 15% being silt or sandy-silt bottom (firm), and only about 5% of the area being sandy. They also referred to silt, or sandy-silt areas as "oyster bottoms," and to clay or silty-clay, muddier areas as "shrimp bottoms." Otvos (1973) described the sediment of the offshore barrier islands and interisland shoals, Mississippi Sound, major semi-enclosed embayments, and river estuaries.

Hydrology

Tides and currents in Mississippi Sound are influenced by several factors, including the drainage from its feeder streams, discharge from Mobile Bay to the east and from the Mississippi River to the west, tidal regimes of the Gulf of Mexico as modified by barrier islands, and prevailing winds. There is a generally westward current along the Mississippi coast from southwest of Pensacola, Florida (Christmas and Eleuterius 1973). About one-fourth of the river discharge into Mobile Bay is carried into Mississippi Sound. Discharge through the four estuarine systems is summarized in Table 6. The sound has an average depth of 3.0 m, diurnal tides with a predicted range of about 46 cm, and a mean tide level of 24--30 cm (Christmas 1973; Eleuterius 1975, 1976).

A salinity gradient occurs across Mississippi Sound, with average salinity above 33 ppt at the barrier islands and freshwater in the upper estuaries. Christmas et al. (1966) found drastic seasonal as well as annual

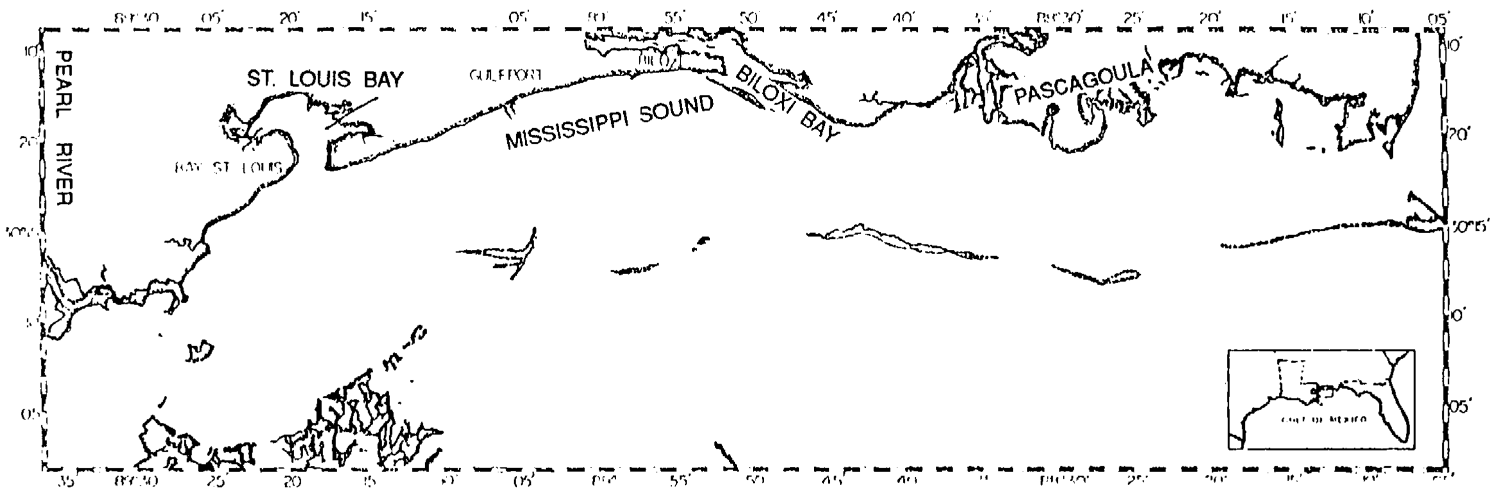


Figure 6. ssissippi estuarine systems.

Table 5. Surface areas of Mississippi estuaries (MHW). From Christmas (1973).

Area	hectares	acres
Pascagoula	53,110	131,233
Biloxi Bay	60,896	150,471
St. Louis Bay	66,163	163,486
Pearl River	22,335	55,190
Totals	202,504	500,380

Table 6. Discharge rates through Mississippi estuaries. From Christmas (1973).

Area	m^3/sec	f^3/sec
Pascagoula	430	15,200
Biloxi Bay	38	1,350
St. Louis Bay	41	1,460
Pearl River	365	12,900
Totals	874	30,910

variations and along with Engle (1948) reported that salinities tended to be lower at the western end of the sound than at the eastern end, probably as a result of discharge from the Pearl River and Lake Pontchartrain. Christmas (1973) stated that relatively sharp salinity interfaces occur in some channels, with rises in excess of 10 ppt occurring within a 1.5-m increase in depth, and that saltwater is often trapped for considerable time periods behind shallow sills at the mouths of bayous and in deep holes in the rivers. Maximum depths range from 15 m in Pearl River to 9.7 m in St. Louis Bay.

In addition to salinity gradients, vertical temperature gradients also occur in Mississippi Sound, but bottom waters are generally less than 3 °C cooler than surface waters. Gradients vary with depth, season, and location. Recorded water temperatures in the area have ranged from 3.4 to 36.5 °C (Christmas 1973).

1.5 ALABAMA

Physiography and Geology

Alabama's coastline is the shortest among the Gulf States, being only 85 km long. Crance (1971) divided the coast into five estuarine systems totaling 160,809 ha (MHW)--Mississippi Sound, Mobile Bay, Mobile Delta, Perdido Bay, and Little Lagoon. These areas include at least 11 subsystems (Table 7; Figure 7). The dominant feature is Mobile Bay. All Alabama

Table 7. Surface areas of Alabama estuarine areas (MHW). From Crance (1972).

Area	hectares	acres
Mississippi Sound	29,204	72,162
Portersville Bay, East	3,531	8,725
Grand Bay	2,788	6,890
Portersvil e Bay, West	794	1,961
Heron Bay	893	2,206
Dauphin Is' and Bay	307	758
Mobile Bay	107,031	264,470
Mobile Delta	8,225	20,323
Perdido Bay	6,990	17,271
Little Lagoon	1,047	2,587
Totals	160,810	397,353

estuaries, with the exception of Little Lagoon, are interconnected either naturally or by the Gulf Intracoastal Waterway. For the most part, the State's shoreline is marshy, but the eastern shore of Mobile Bay from Spanish Fort to Fairhope has sandy clay bluffs ranging up to 30 m above sea level. A string of freshwater and saltwater lakes is situated between the Mobile Point peninsula (a bay-mouth barrier with rows of dunes paralleling the coast), and the coast on the eastern side of Mobile Bay. Mobile Bay and the other estuarine systems are situated in the East Gulf Coastal Plain (Ryan and Goodell 1972). Alabama's estuaries are similar to those of Mississippi and western Florida in that they are drowned coastal alluvial-plain estuaries.

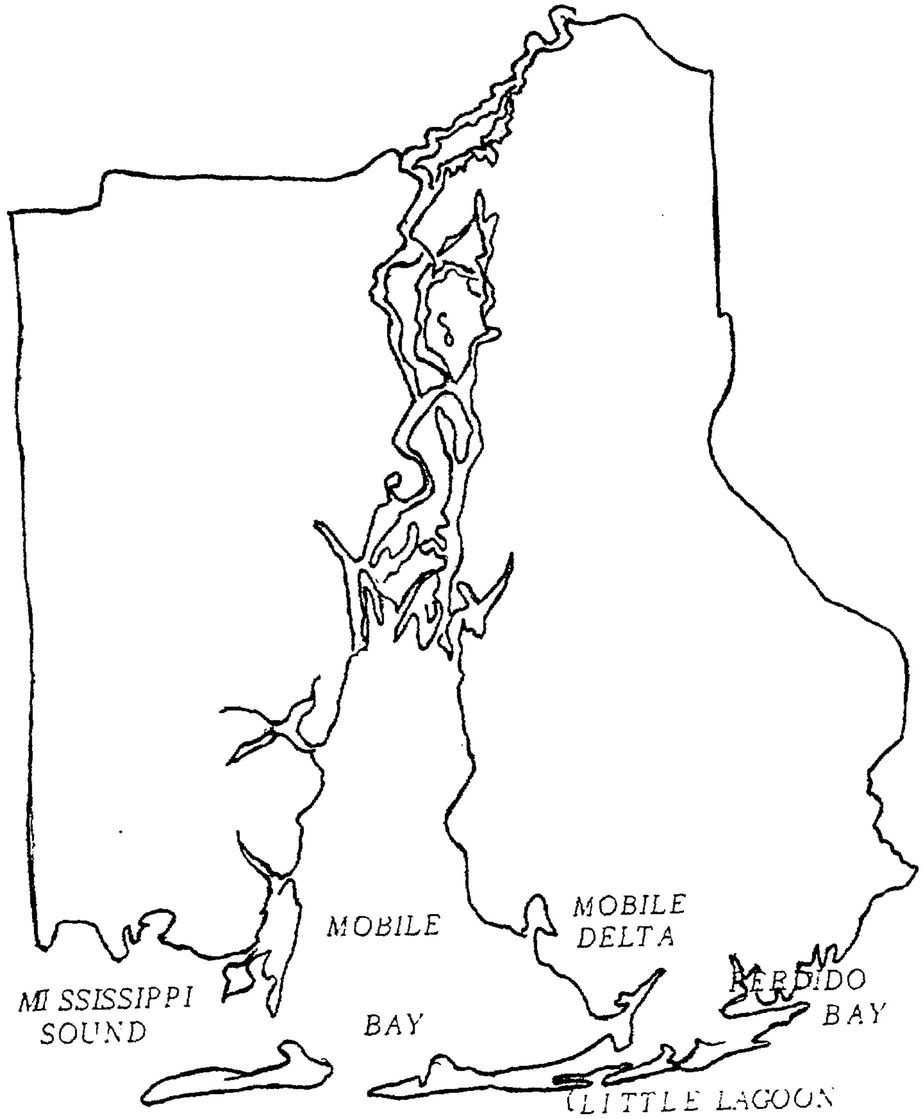


Figure 7. Alabama estuarine systems.

Crance (1971) and Ryan and Goodell (1972) presented brief discussions of the geological history of the Mobile Bay area. Evidence indicates that the coastal area of Alabama has undergone several periods of changing sea levels. In the Pleistocene, Mobile Bay was formed as a result of the drowning of the Mobile River mouth when the sea rose about 3 m during post-Wisconsin time. Marine, estuarine, and stream deposits from the Pleistocene to Holocene border Mobile Bay.

Parker (1968) reported on the sediments of Perdido Bay, and Ryan and Goodell (1972) studied the sediments of the Mobile Bay Estuary.' Although the bulk of sediments in Mobile Bay consists of silty clays and clays, the periphery of the estuary is composed of clean quartz sands. Ryan and Goodell (1972) predicted that if present rates of sedimentation persist, Mobile Bay will cease to exist within the next millennium, and the present delta will be prograded into the Gulf of Mexico.

Hydrology

The Mobile River system, which includes the Mobile, the Tombigbee-Black Warrior, and the Alabama-Coosa-Tal apoosa river systems, empties through Mobile Bay. The annual mean discharge through the bay is 1,659 m^3/sec. This accounts for nearly all of the discharge through Alabama estuaries. Crance (1971) listed diurnal tidal ranges in Little Lagoon from O to 46 cm, and in Mobile Bay from 30 to 50 cm. Mean depth of Little Lagoon is about 1.2 m, while Mobile Bay averages 3.0 m. The deepest area in Mobile Bay (13 m) occurs in the dredged ship channel. Circulation patterns within Mobile Bay are primarily controlled by the river discharge, tide, and the physical dimensions of the bay (Ryan and Goodell 1972).

Because Alabama estuaries are shallow, virtually no salinity or thermal stratification occurs. Sea-strength salinities often occur at the gulf entrance of Mobile Bay, but freshwater can be found at the upper end of the estuary. Surface temperatures in 1968 and 1969 ranged from 6.5 “C in January to 37.3 °C in July (Crance 1971).

1.6 FLORIDA

Physiography and Geology

The coastline of Florida, the longest along the gulf coast, is about 1,240 km long. McNulty et al. (1972) listed 40 estuarine areas (Table 8; Figure 8), ranging in size from 960 to 225,632 ha and totaling in 842,393 ha at MHW. Geomorphologically, Florida's estuaries are generally of three types: drowned lacustrine plain (Florida Bay); drowned limestone plateau (Florida Bay to Apalachicola Bay); or drowned alluvial plain (westward from Apalachicola Bay). Different opinions have been offered on classification of Florida estuaries, e.g., Dawson (1955) described Apalachicola Bay as being a shallow coastal plain estuary, while Kofoed and Gorsline (1963) believed the appropriate term to be “coastal lagoon.”

Table 8. Surface areas of Florida estuaries at mean high water (MHW). From McNulty et al. (1972).

Study area	Acres (MHW)
Florida Bay	557,528
Lake Ingraham	2,372
Whitewater Bay	46,532
Cape Sable to Lostmans River	24,067
Lostmans River to Mormon Key	7,395
Mormon Key to Caxambas Pass	69,824
Caxambas Pass to Gordon River	12,522
Doctors Pass to Estero Pass	14,000
Caloosahatchee River	22,926
Pine Island Sound	77,024
Charlotte Harbor	121,793
Lemon Bay	6,042
Sarasota Bay System	34,746
Tampa Bay	150,485
l-ii? lsborough Bay	28,900
Old Tampa Bay	57,834
Boca Ciega Bay	35,424
St. Joseph Sound	33,280
Baileys Bluff to Saddle Key	16,629
Saddle Key to S. Mangrove Pt.	71,530
Waccasassa Bay	52,586
Suwannee Sound	35,424
Suwannee Sound to Deadman Bay	4,320
Deadman Bay	2,698
Deadman Bay to St. Marks River	8,927
Apalachee Bay	61,322
St. George Sound	87,776
Apalachicola Bay	82,197
St. Joseph Bay	43,872
St. Andrew Sound	4,707
East Bay (St. Andrew)	18,659
St. Andrew Bay	26,209
West Bay	17,576
North Bay	6,676
Choctawhatchee Bay	86,295
Santa Rosa Sound	24,560
East Bay (Pensacola)	36,806
Escambia Bay	24,085
Pensacola Bay	40,581
Perdido Bay	25,398
Total	2,081,527

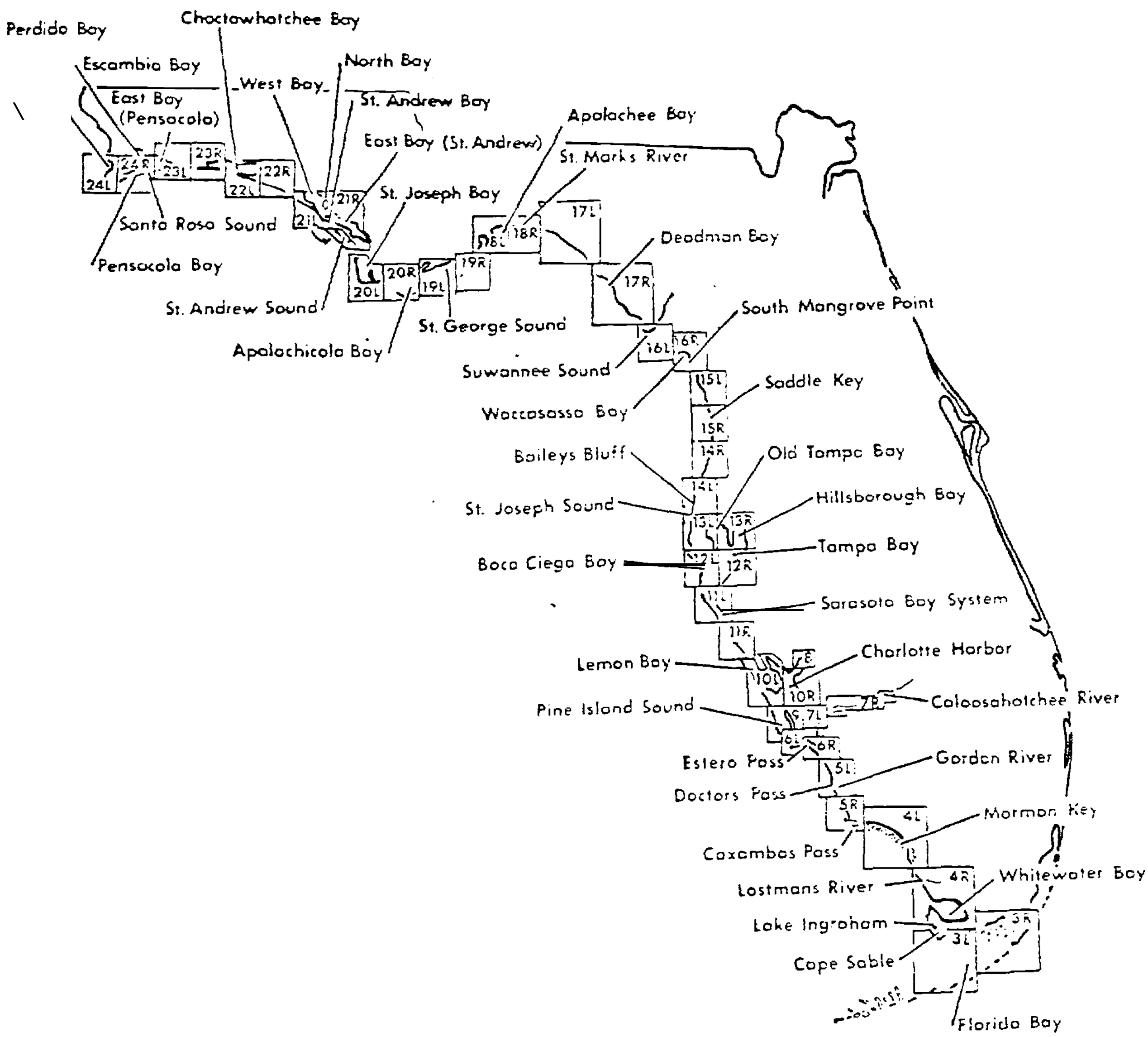


Figure 8. Florida estuarine systems (after McNulty et al. 1972).

The geological development of the Florida Peninsula has been described by Cooke (1945), Lynch (1954), Puri and Vernon (1959), and Schnable and Goodell 1968). The Florida peninsula (the above-water portion of the Floridian Plateau) consists generally of thick layers of limestone and unconsolidated sediments, resting on sandstone and volcanic rock. The Floridian Plateau originated during the mid-Triassic (Dietz and Holden 1970). About 14,000 years ago, sea level may have been 160 m below the present level (Ballard and Uchupi 1970), and began to rise due to melting polar ice caps. An average sea-level rise of 13 cm per 100 years, or about 3 m over the last 4,000 years has occurred in the Florida area (Scholl 1964). This rise produced Florida Bay, a drowned lacustrine plain, and coastal estuaries such as Tampa Bay, which is a drowned river valley (MacNeil 1950; Price 1954).

McNulty et al. (1972) pointed out that the sediments of the Florida Panhandle differ in origin and basic character from those of the peninsula. Panhandle rivers drain areas in the Appalachian Mountains, the Piedmont Plateau, and the coastal plain, while peninsular rivers drain only coastal plain areas. Panhandle sediments tend to be mainly elastic, while peninsular sediments are mainly nonelastic, predominantly carbonates and anhydrites. Some of the major estuarine systems have been studied in detail. Kofoed and Gorsline (1963) reported that the bottom sediments of Apalachicola Bay were usually silty sand, sandy silt, or silt.

McNulty et al. (1972) divided the Florida gulf coast into eight study segments for purposes of analyzing discharge characteristics (Figure 9). Mean discharges of the segments are presented in Table 9. As in the case of Texas Rivers, discharge of Florida rivers generally decreases moving from north to south. The Apalachicola, Suwannee, Choctawhatchee, and Escambia Rivers account for nearly 70% of the total runoff discharged into the gulf, with the Apalachicola River accounting for over one-third of the total. Dawson (1955), reporting on the hydrography of Apalachicola Bay, found a maximum depth of 10 m with an average of 1.5 m at mean low water. Two types of tides occur along the Florida gulf coast--mixed diurnal (daily) along with (mostly) semi-diurnal (twice daily) from Florida Bay to Apalachicola Bay and diurnal from St. Joseph Bay to Perdido Bay (Mariner 1954; Zetler and Hansen 1970). Tidal ranges in Florida are greater than along the rest of the gulf coast. From Cape Sable to the Gordon River (at Naples), the mean diurnal tide ranges about 1.3-1.4 m, while along the rest of the Florida coast, it ranges about 0.5-1.1 m. Dawson (1955) found a mean range of about 0.3 m in Apalachicola Bay.

As in Texas estuaries, salinities tend to be higher in estuaries in the southern part of the State (hypersaline or “negative” estuaries) than in the north and central areas (normal or “positive” estuaries). McNulty et al. (1972) obtained data from several sources in order to categorize salinity characteristics of Florida estuaries. Finucane and Dragovich (1959) reported salinities up to 70 ppt in parts of Florida Bay. Maximum temperatures are similar along the Florida gulf coast (33.3 ‘C), but minimum temperatures ranged from 13.9 ‘C in south Florida to 4.4 °C at Pensacola (McNulty et al. 1972).

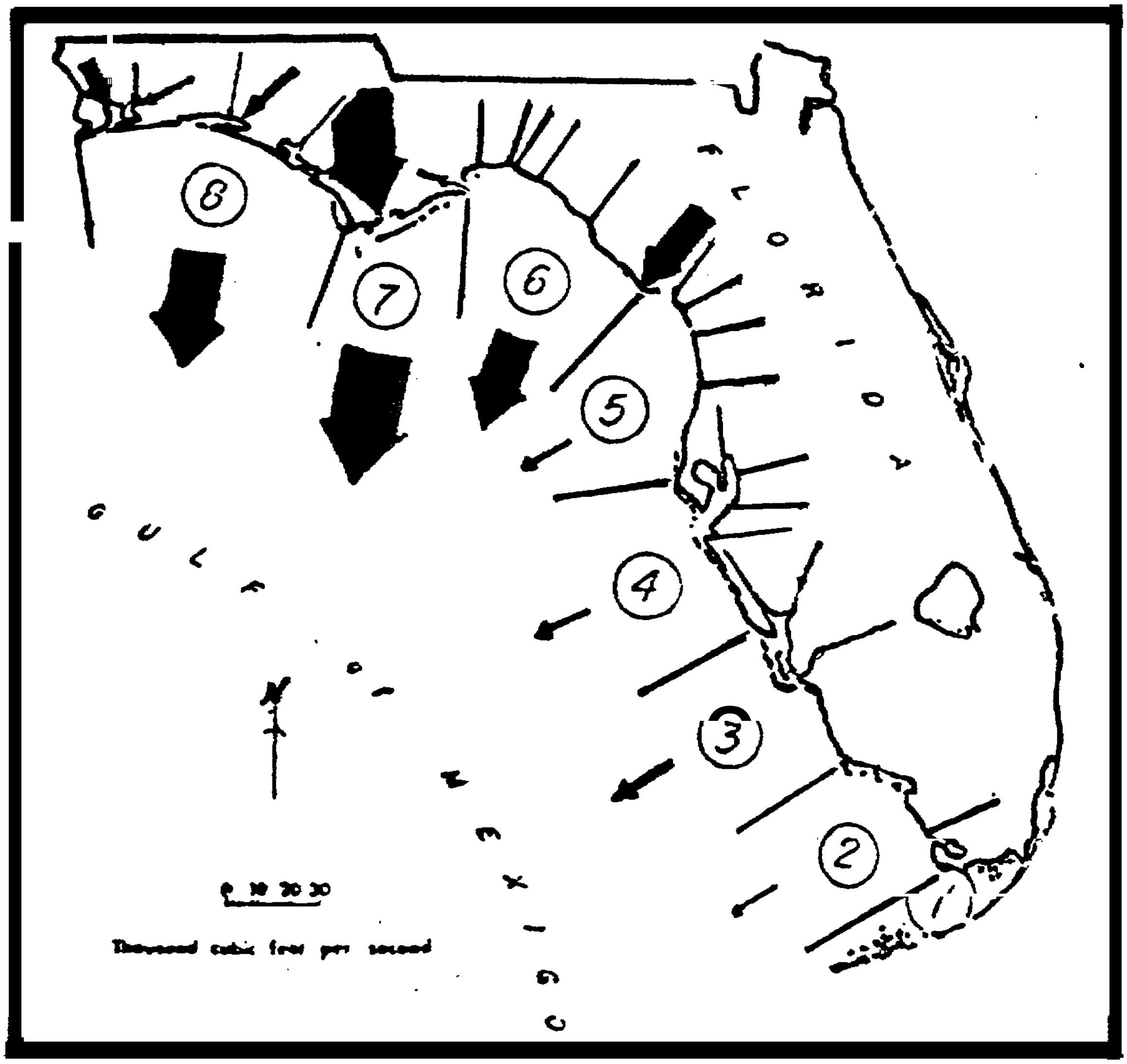


Figure 9. Relative discharge of the principal gauged streams of the Florida west coast (see Table 9) (after McNulty et al. 1972).

Table 9. Discharge rates through Florida estuaries (from McNulty et al. 1972).

Segment of coast, estuarine study area, and stream	Mean discharge ft³/sec	ft³/sec
SEGMENT 1		
Florida Bay	---	
SEGMENT 2		
Lake Ingraham:	---	
Whitewater Bay:	---	
Cape Sable to Lostmans River:		
Tamiami Canal Outlets, Miami to Monroe	906	
Barren River Canal near Everglades	99	
Subtotal, Cape Sable to Lostmans River		1,005
Lostmans River to Mormon Key:	---	
Mormon Key to Caxambas Pass:	---	
Total, Segment 2		1.005
SEGMENT 3		
Caxambas Pass to Gordon River:		
Golden Gate Canal at Naples	338	
Doctors Pass to Estero Pass	---	
Caloosahatchee River:		
Caloosahatchee Canal at Moore Haven	1,057	
Pine Island Sound:		
Subtotal, Caxambas Pass to Pine Island Sound		1,395
Charlotte Harbor:		
Peace River at Arcadia	1,267	
Joshua Creek at Nocatee	119	
Horse Creek near Arcadia	229	
Myakka River near Sarasota	264	
Warm Mineral Spring near Murdock	11	
Big Slough near Murdock	89	
Subtotal, Charlotte Harbor		1,979
Total, Segment 3		3.374
SEGMENT 4		
Lemon Bay	---	
Sarasota Bay system:		
Cow Pen Slough near Bee Ridge	54	
Phillippi Creek near Sarasota	26	
Subtotal, Sarasota Bay system		80

(Continued)

Table 9. (Continued)

Segment of coast, estuarine study area, and stream	Mean discharge ft³/sec	ft³/sec
Tampa Bay:		
Manatee River near Bradenton	109	
Little Manatee River near Wimauma	184	
Subtotal, Tampa Bay		293
Hillsborough Bay		
Alafia River at Dithia	384	
Buckhorn Spring near Riverview	11	
Sixmile Creek at Tampa	62	
Hillsborough River near Tampa	673	
Sulphur Springs at Sulphur Springs	50	
Subtotal, Hillsborough Bay		1,180
Old Tampa Bay:		
Sweetwater Creek near Sulphur Springs	9	
Rocky Creek near Sulphur Springs	43	
Alligator Creek at Safety Harbor	7	
Subtotal, Old Tampa Bay		59
Boca Ciega Bay:		
Seminole Lake outlet near Largo	15	
Subtotal, Boca Ciega Bay		15
Total, Segment 4		1.627
SEGMENT 5		
St. Joseph Sound		
Anclote River near Elfers	86	
Subtotal, St. Joseph Sound		86
Baileys Bluff to Saddle Key		
Pithlachascotee River near New Port Richey	48	
Weeki Wachee Springs at Weeki Wachee	174	
Subtotal, Baileys Bluff to Saddle Key		222
Saddle Key to South Mangrove Point:		
Chassahowitzka Springs near Chassahowitzka	81	
Homosassa Springs near Homosassa Springs	185	
Crystal River near Crystal River	785	
Withlacoochee River near Holder	1,183	
Rainbow Springs near Dunnellon	722	
Subtotal, Saddle Key to South Mangrove Point		2,956

(Continued)

Table 9. (Continued)

Segment of coast, estuarine study area, and stream	Mean discharge ft³/sec	ft³/sec
Waccasassa Bay		
Waccasassa River near Gulf Hammock	585	
Tenmile Creek at Lebanon Station	72	
Wekiva Springs near Gulf Hammock	73	
Subtotal, Waccasassa Bay		730
Total, Segment 5		3,994
SEGMENT 6		
Suwannee Sound:		
Suwannee River near Wilcox	10,740	
Fanning Spring near Wilcox	108	
Manatee Spring near Chiefland	168	
Subtotal, Suwannee Sound		11,016
Suwannee Sound to Deadman Bay	---	
Deadman Bay:	336	
Subtotal, Suwannee Sound		336
Deadman Bay to St. Marks River:		
Fenholloway River at Foley	128	
Waldo Springs near Perry	5	
Econfina River near Perry	136	
Aucilla River at Lament	407	
Subtotal, Deadman Bay to St. Marks River		676
Apalachee Bay		
St. Marks River near Newport	750	
Wacissa Springs near Wacissa	97	
Wakulla Spring near Crawfordville	283	
Ochlockonee River near Bloxham	1,698	
Telogia Creek near Bristol	216	
Subtotal, Apalachee Bay		3,044
Total, Segment 6		15,072
SEGMENT 7		
St. George Sound		
New River near Wilma	272	
Subtotal, St. George Sound		272
Apalachicola Bay		
Apalachicola River near Blountstown	25,180	

(Continued)

Table 9. (Concluded)

Segment of coast, estuarine study area, and stream	Mean discharge ft^3/sec	ft^3/sec
Chipola River near Altha	1,533	
Subtotal, Apalachicola Bay		26,713
Total, Segment 7		26.985
SEGMENT 8		
St. Joseph Bay:	---	
St. Andrew Sound:	---	
East Bay (St. Andrew):	---	
West Bay:	---	
North Bay:		
Econfina Creek near Bennett	537	
Subtotal, North Bay		537
Choctawhatchee Bay:		
Choctawhatchee River near Bruce	7,073	
Alaqua Creek near De Funiak Springs	159	
Subtotal, Choctawhatchee Bay		7,232
Santa Rosa Sound:	---	
East Bay (Pensacola):		
Yellow River at Milligan	1,151	
Shoal River near Crestview	1,092	
Backwater River near Baker	305	
Big Juniper Creek near Munson	70	
Big Coldwater Creek near Milton	532	
Pond Creek near Milton	82	
Subtotal, East Bay (Pensacola)		3,232
Escambia Bay:		
Escambia River near Century	6,102	
Pine Barren Creek near Barth	144	
Subtotal, Escambia Bay		6,246
Perdido Bay:		
Perdido River at Barrineau Park	760	
Styx River near Lox" ey, Alabama	177	
Subtotal, Perdido Bay		937
Total, Segment 8		18.184
Grand Total, Flor· da West coast		70,241

CHAPTER 2. GENERAL OYSTER BIOLOGY

2.1 INTRODUCTION

This chapter will attempt to bring together the voluminous amount of information regarding the biology of the American oyster (Crassostrea virginica) and summarize some of the basic points. We feel this treatise will be used by readers with varying backgrounds and interest, and thus some general treatment of the species is necessary. After one comprehends the broad and basic overview, a more detailed treatment can be found in Galtsoff (1964) and more specifically, the literature cited within each section. In addition, there are several bibliographies (Joyce 1972a; Breisch and Kennedy 1980) dealing with the American oyster (some authors refer to it as the eastern oyster), and more detailed and pertinent information can be obtained from the specific studies listed.

Controversy regarding the general classification of oyster species is universal; however, the most noted and abundant species occurring along the coastal Gulf of Mexico is the American oyster. A complete classification and summations for each of the classifications can be found in Appendix 1.

The American oyster is a species that is responsible for vast reef formations and has attracted the attention of researchers, gourmets, and fishermen for centuries. This species occurs along the entire east coast of North America, from the Gulf of St. Lawrence in Canada to the Yucatan in Central America. The range also includes the West Indies, and the oyster has even been reported in Brazil (Gunter 1951). Figure 10 illustrates this 8,050-km range. Crassostrea virginica prevails over this immense range because of its ability to adapt to wide ranges of temperature and salinity, as well as many other widely fluctuating environmental conditions which will be covered later.

Physiological, ecological, and biochemical data indicate that races of C. virginica from Nova Scotia and west Florida are basically similar (Menzel 1968). Menzel (1968) concluded that the two physiological races are close enough genetically to successfully hybridize under laboratory conditions. Groue and Lester (1982), in their study of genetic differences of Gulf of Mexico oysters, demonstrated the general genetic identity of the species from several collection sites; the samples indicated differences in shell morphology for the gulf region, but these can be attributed to environmental differences.

An oyster is composed of two very different parts: the edible soft body-mass and the protective shell (Figure 11). The shell (which is secreted by the mantle) is the outer covering of the oyster body and is composed primarily

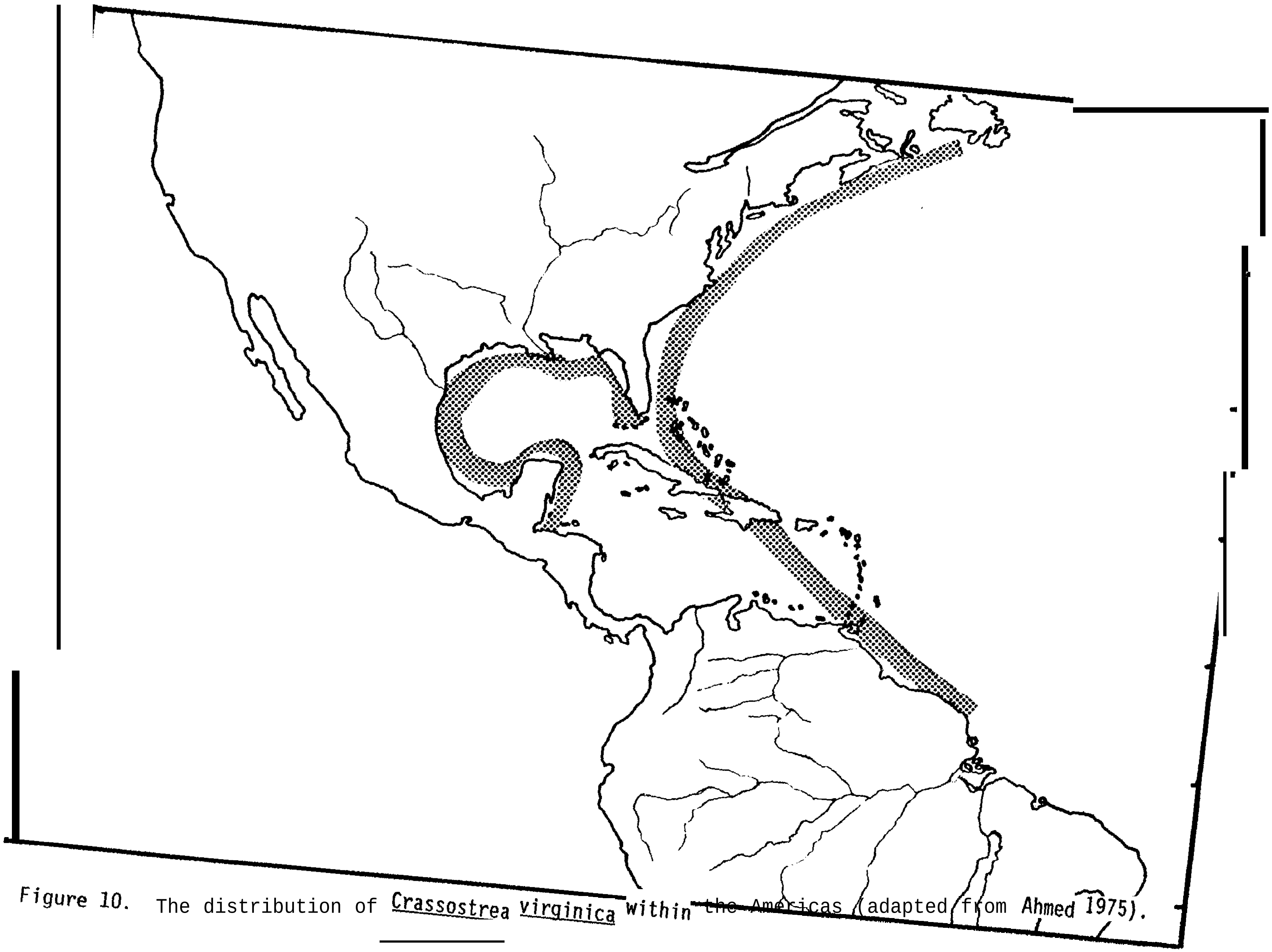


Figure 10. The distribution of *Crassostrea virginica* within the Americas (adapted from Ahmed 1975).

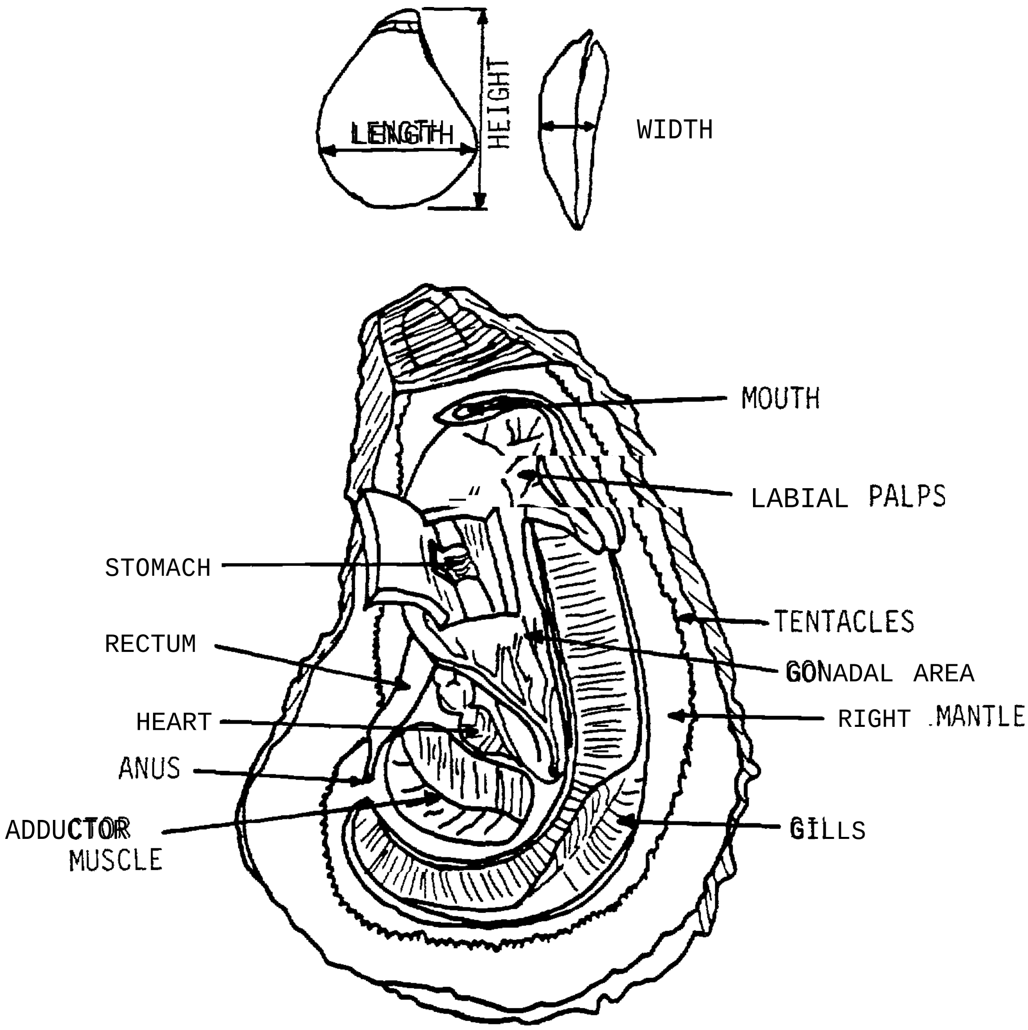


Figure 11. The general structure of *Crassostrea virginica*.

of calcium carbonate. The shell consists of five distinct layers: (1) the thin outer periostracum; (2) the median prismatic layer; (3) the inner ostracum; (4) a thin layer under the attachment of the muscular hypostracum; and (5) the inner mother-of-pearl, or nacreous layer (Figure 12).

In *C. virginica*, the shells or valves are slightly different; the lower, or left valve (Figure 11), is deep and cup-shaped and is generally the one the oyster rests on, while the upper or right valve (Figure 11) is flat and in some cases curved. The hinged area is the point of attachment with a very complex structured ligament. This ligament acts as a spring, tending to force the valves apart. The adductor muscle of the body, however, is attached to both valves and by contracting tends to pull the valves together. When the muscle contracts, it overcomes the force of the ligament and pulls the two valves together. When the muscle relaxes, the hinge ligament forces the two valves apart. The largest shell reported was 35.5 cm in height (Galtsoff 1964). Height is measured along the dorso-ventral axis of the right upper shell and is referred to as length in common usage.

There are a number of shell abnormalities which occur with regularity and are common throughout the geographic range of the American oyster. One of these is the formation of soft, white, porous material, referred to as chalky deposit. The cause and function of this material are not completely understood. There is also the formation of blisters or chambers caused by a foreign object occurring between the mantle and the inner shell layer, or by the presence of an animal, either an annelid worm (*Polydora*), the boring sponge (*Cliona*), or the burrowing clam (*Diplothyra*), all of which cause the excessive secretion of a nacrin layer because of an irritation.

When the shell of the oyster is open, millions of tiny, hair-like structures (cilia) on the gills beat back and forth, causing the circulation of water into one side of the mantle chamber and out of the other. Dissolved or suspended in the water are the necessary oxygen, mineral salts, and microscopic plankton for the oyster's life. The diatoms, dinoflagellates, and other groups of phytoplankton and zooplankton, bacteria, organic detritus, and mineral salts are taken in as the principal food. Oxygen is necessary for respiration. When the oyster closes its shells, it places an effective armor about its soft inner parts.

The feeding organs of oysters are (1) the ciliated gills that provide the circulation (with the assistance of the mantle) of water and soft particles; (2) the palps that surround the mouth and play a role in the particle-sorting process: (3) the crystalline style, a semirigid, clear rod composed of digestive enzymes that functions in the mechanical breakdown of food particles; (4) the gastric shield, against which the style rotates to select and break down particles; and (5) the stomach, a group of blind-ending tubules (diverticula) with ducts leading to the main pouch stomach.

Food particles are selected primarily according to size and shape. Jorgenson and Goldberg (1953) observed that the American oyster filters about 10 to 20 liters of water for each milliliter of oxygen consumed. At this rate, under normal conditions, an oyster has the capacity to filter

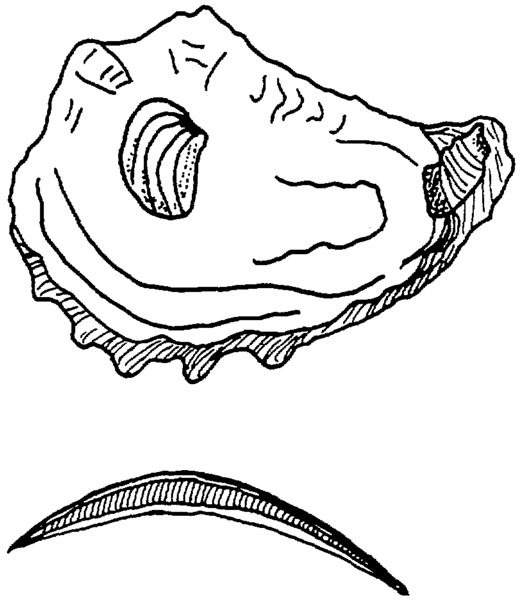


Figure 12. Shell structure of *Crassostrea virginica*.

approximately 1,500 liters of water daily. Actual food requirements of oysters do not exceed 0.15 mg of utilizable organic matter per liter of water used (Jorgenson 1952).

The oyster "breathes" (respires), much like a fish, by a simple exchange of gasses within the water medium. Many small, thin-walled blood vessels are in the gills and mantles. The water flowing outside of these blood vessels gives up some of its dissolved oxygen and takes on carbon dioxide. While the blood flows within the vessels of the gills and mantles, it receives oxygen and rids itself of carbon dioxide. The colorless blood of the oyster is pumped through all parts of the body by the animal's small three-chambered heart. In addition to its respiratory function in bringing oxygen from the gills to the tissues and in ridding the tissues of carbon dioxide by way of the gills, the blood serves in many other ways, two of which may be noted: it distributes the products of digestion to all parts of the body and brings metabolic wastes to the renal bodies for disposal. It is interesting to note that the blood of the oyster is chemically very closely related to seawater. The concentrations of salts in the blood change as the water around the oyster changes, yet the proportions of the salts remain the same.

The American oyster is dioecious (with separate sexes), but once a year some members of a given local population change their gender from male to female (protandry) or from female to male (protogyny). Oysters develop functional gonads at a young age (2 to 3 months) and small size (less than 1 cm in height). In the gulf, they usually tend to develop as males during their first season, with subsequent protandric change in following seasons (Menzel 1955). A small percentage of any given population (1%) functions as true hermaphrodites (Kennedy and Battle 1963), a pattern that seems to hold for some other species in the genus Crassostrea. Some preliminary evidence indicates that populations of oysters under certain kinds of stress tend to develop a higher proportion of males than females, but this remains to be conclusively demonstrated (Amemiya 1936; Loosanoff and Nomejko 1955; Kennedy and Battle 1963; Bahr and Hillman 1967).

After oyster gonads reach maturity in a local population, a temperature (or salinity) shock triggers the emission of sperm from one or more males. Ogle (1979) reported that in Mississippi, January and February were the only months within which no sexually developed oysters were found. Setting occurs from April through December in Florida (Finucane and Campbell 1968), Louisiana (Dugas 1977), and Texas (Hofstetter 1977), depending on water temperatures. The major spatfall peaks generally occur from May through August. These appear to be correlated to an annual rise and associated decline in water temperatures.

The emission of sperm from male oysters occurs via the exhalant chamber of the mantle. A chemical constituent of the sperm stimulates the females in the area to release their eggs, resulting in a spawning chain reaction that can sweep rapidly through a dense population, turning the water in a nonturbid area white. Females expel eggs through the inhalent rather than the exhalent chamber. This process involves a contraction in portions of the mantle margins to reduce the size of the exhalent openings. Eggs then pass through the gill filaments (against the normal feeding current) and accumulate near the inhalent chamber. Rapid and repeated contractions of the adductor muscle then forcefully eject the eggs a considerable distance. The latter mechanism is also used to expel unwanted particulate material (pseudofeces) from the mantle cavity.

Fertilization occurs in the water column via chance encounters of eggs and sperm, and larval development begins (Figure 13). These free-living larvae function as zooplankters (meroplankton) in the water column and probably are significant as a food source for planktivores in local areas.

After passing through the blastula and gastrula stages, the young oyster develops into a trochophore larva characterized by a band of locomotory cilia called the prototroch (velure). As development continues, the larval oyster secretes a pair of shells. This first shelled larval stage is also called the straight-hinged (veliger) stage.

The straight-hinged stage is succeeded by the umbo stage. During the latter part of this stage, the larval oyster develops a foot and a byssus gland with which it will eventually attach itself to the substratum. With the development of the foot, the larva becomes known as a pediveliger. During the latter part of the pediveliger stage, the larval oyster develops a pair of darkly pigmented eyes and becomes an eyed pediveliger. The presence of the eyes indicates that the free-swimming oyster is ready to attach and metamorphose into the adult form.

Depending on water temperature and food availability, the larval life stage of C. virginica will last approximately 10-20 days. Some larvae, however, will remain planktonic for up to 2 months during cooler periods or in the absence of sufficient food.

Feeding activities in larval oysters are generally well understood, particularly as a result of the development of commercial hatcheries. In the artificial conditions of an oyster hatchery, mixed cultures of various small algae produce adequate nutrition for the growing oysters. It is important to emphasize the value of mixed cultures since the diet of oyster larvae in the natural state is certainly not a pure culture and probably includes bacteria and small detrital particles as well as algae and protozoans. Since the diet and food requirements will vary seasonally due to food variability and spawning, the volume and consistency of the oyster meat will vary accordingly. In general, there is a peaking of the condition index (an indication of physiological health) in the late winter and early spring.

Several environmental factors influence the settlement of larval oysters, including the physico-chemical and biological factors discussed by Hidu and Haskins (1971). They maintained that light, salinity, temperature, and current velocity all affect “prospective” spat (newly settled oysters). Thorson (1964) proposed that the settling response of marine invertebrates is often cued by light. For example, oyster larvae tend to be photonegative in response to a temperature increase. Late settling oyster larvae also tend to be more demersally distributed than earlier larvae, possibly because of their heavier shells.

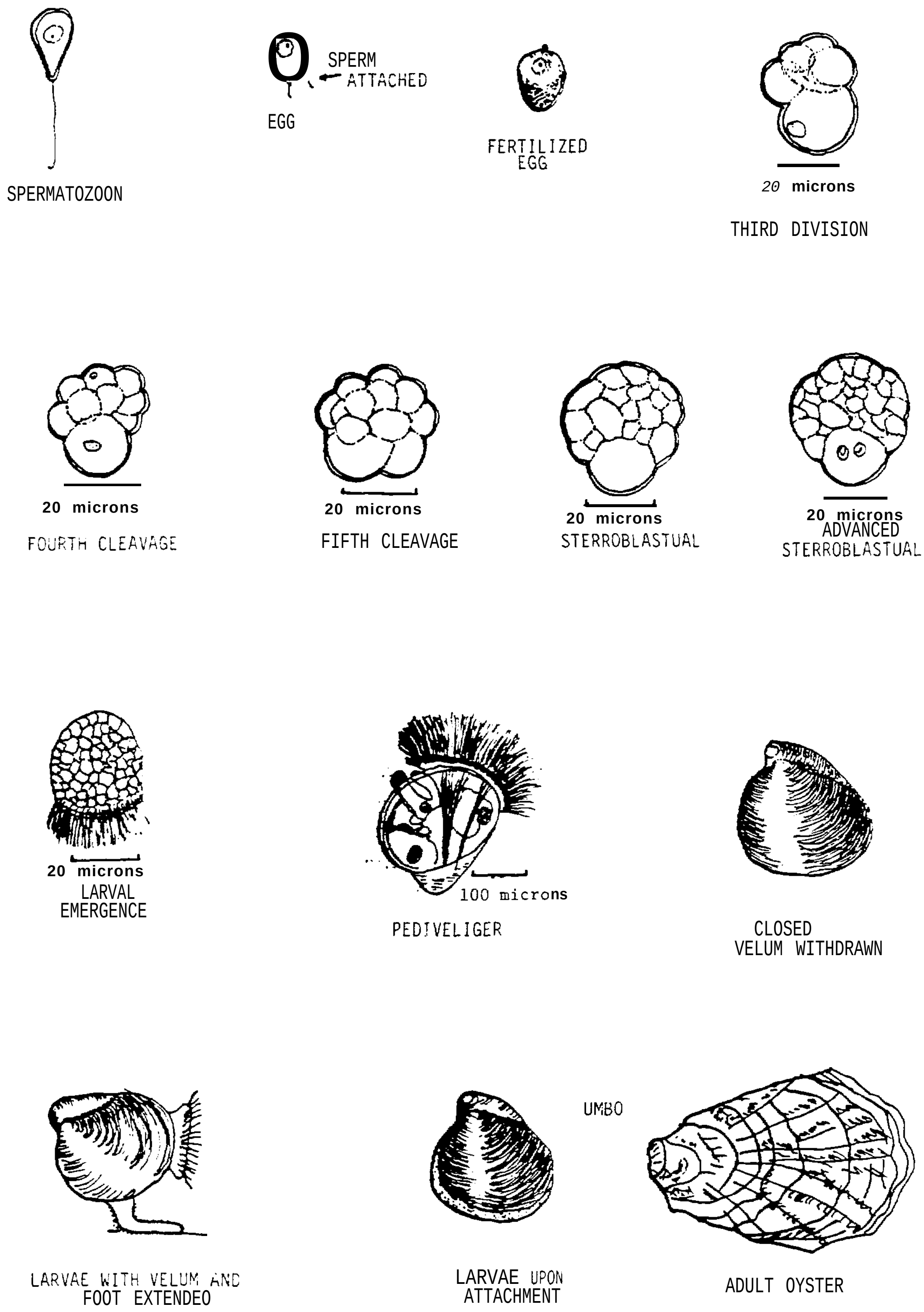


Figure 13. Larval stages of *Crassostrea virginica*.

The biological cues to oyster larval setting are related to the fact that oyster larvae are gregarious and apparently respond to a waterborne pheromone or metabolize released by oysters that have already metamorphosed (Hidu and Haskins 1971). Larvae also seem to respond positively to a protein on the surface of oyster shells. The gregarious tendency is important to a reef-building organism such as the oyster which requires settlement in proximity for successful fertilization.

2.2 ENVIRONMENTAL FACTORS AFFECTING OYSTER BIOLOGY

Any investigation into the causes of 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 optima? temperature, food supplies, water circulation, bottom character, and salinities. Additional factors affecting the oyster population include disease, competition, predation, turbidity, sedimentation, and pollution. The interactions of the positive and negative factors of the environment act simultaneously on an oyster community to determine its productivity.

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 (cold-blooded) organism that has been observed in waters with temperatures ranging from 1 to 36 "C (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 24-26 °C The ciliary activity declines rapidly below 20.5 °C and ceases completely at 5-7 °C (Galtsoff 1964). At temperatures above 32 °C 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.

Gonadal formation (gametogenesis) and spawning are also directly related to environmental factors, primarily temperature. As the temperature of the water begins to rise in late winter and spring, the sperm and egg cells develop, thickening the gonadal epitheliums (Hopkins et al. 1953). Spawning of ripe gonads is triggered by a rapid rise or fall in temperature and has not as of yet been associated with a specific critical temperature.

Indirectly, temperature is a controlling factor in that it, along with salinity, determines volubility of oxygen in water and affects the metabolism, 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.

Salinity

Butler (1949) and many others have suggested that the single most important environmental factor affecting oyster populations is salinity. The direct relation of rainfall to salinity makes excessive precipitation another important parameter to consider. The high annual rainfall of the Gulf of Mexico serves to decrease salinity, whereas tides drive gulf water into the bay through the passes, increasing the salinity. Thus, during the periods of high rainfall there is usually a significant decrease in salinity. During the periods of drought and high temperature, salinities usually rise.

Oysters are euryhaline organisms, able to live in waters of a wide range in salinity. Galtsoff (1964) found oysters inhabiting waters with a range of salinity from 5 to 40 ppt. The optimum salinity for natural oyster growth and survival is 5 to 15 ppt. (Galtsoff 1964; St. Amant 1964). Dugas (1977) and Eleuterius (1977) reported that areas containing average salinities ranging from 10 to 16 ppt support the maximum oyster production in Louisiana and Mississippi, respectively. Oysters from more northern latitudes seem to be more adapted to higher salinity levels. Lindall et al. (1972) explained these differences as being preferences exhibited by distinct ecotypes, possibly even subspecies.

Oysters have for the most part adapted to diurnal, seasonal, and annual fluctuations of salinity. The mean values of these salinities are of little significance because of the oyster's 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. During Hurricane Carmen, which passed near the Barataria Bay, Louisiana, coastline on 7 September 1974, the salinity at St. Mary's Point increased from 7 to 30 ppt within a 3-hour period (Louisiana Department of Wildlife and Fisheries--Hydrological Section Records).

Several studies have attempted to relate oyster mortalities to salinity. Lowered salinities have been directly correlated with increases in mortalities (Butler 1949). Marine bivalves have weak osmotic regulation capabilities when placed in diluted seawater and 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, followed by partial or complete contraction of the adductor muscle. This may continue for several hours with no permanent injury to the oyster (Galtsoff 1964), but if the exposure is prolonged, the oyster will become weakened or permanently injured and may die.

The Gulf of Mexico estuarine complex with its tremendous drainage system has experienced several mass oyster mortalities associated with freshwater influx. May (1968) reported oyster mortalities in Mobile Bay, Alabama, and Hoffstetter (1977) reported mortalities in Galveston Bay, Texas, associated with excessive freshwater influx. Dugas and Perret (1975) reported mortalities in Louisiana, as have other authors, but they also associated high temperatures and increased metabolic activities with the mortalities. On-the other hand, the influx of freshwater into an estuary is often quite beneficial. Decreased salinities have lethal effects on predacious gastropod and flatworms, as well as pathogenic protozoans that are highly destructive or debilitating to oysters. Brackish water constitutes a barrier through which these predators and parasites cannot penetrate nor survive in for extended periods. Periodic freshwater flushing restores the productivity of oyster beds by reducing these harmful organisms and introducing nutrients. Meeter et a?. (1979) indicated that commercial oyster harvest in the Apalachicola Estuary in Florida showed a strong correlation to annual river flow.

In addition, there is the effect of salinity on the oyster larvae. Several authors have reported the lack of spat fall in salinities below 10 ppt. This attributed in most cases to oyster larvae mortalities in these salinities, possibly due to lack of food.

The reproductive capability of oysters is reduced by low salinity. Butler (1949) showed that gametogenesis is inhibited in oysters maintained in salinities of less than 6 ppt. He attributed 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 at salinities near 7.5 ppt, but oysters with ripe gonads subjected to lower salinities spawn at 5.0 ppt. Loosanoff (1952) 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 are determined by environmental factors such as salinity.

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).

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 (1949) and Owen (1955) found that excessive mortalities in the Barataria Bay region in Louisiana occur when there is a combination of high temperature and high salinity.

Water Circulation

Free exchange of water is essential for the growth, fattening and reproduction of oysters (Galtsoff 1964). The ideal flow of water for an oyster bed is steady and nonturbulent. The current only has to 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 dissolved or suspended materials in water is determined by the circulation of freshwater and saltwater in the estuary.

These waters are mixed and distributed constantly within the estuary as a result of daily winds and tidal oscillations. Riverflow and rainfall also affect water circulation but on a more seasonal basis.

Mean tidal levels fluctuate in a fairly consistent rhythm throughout the year; however, the lowest mean levels for the entire gulf coast occur in January and the highest in September (Mariner 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 from lush summer vegetation cause a net flow of water from the gulf bays and marshes.

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. Cultch material (clam and oyster shells) is generally placed in relatively high current velocity areas to attract spatfall (Keck et al. 1973). In addition to being relatively free from the problem of siltation, these high current areas are exposed to greater volume of water and hence more larvae will come in contact with the shells. Perkins (1952) showed that oyster larvae concentrations are high where current is fairly strong and salinity shows no stratification. Hidu and Haskins (1971) and Tabony (1972) both suggested, however, that in some cases oyster larvae associated with high velocity flow will in some cases settle out in eddies formed within these currents.

Oyster communities are most vulnerable to occasional turbulent currents of high velocities such as those associated with hurricanes. Hurricanes are a common occurrence over the warm waters of the Gulf of Mexico. The resulting turbulent currents may dislodge and carry away young and adult oysters not attached firmly to some bottom features. Valve injury is incurred if sand is present to act as an abrasive material. In addition, these currents also deposit large amounts of silt and sediments on the reef community.

Bottom Character

Oyster communities are generally either associated with a large reef formation or they are spread out on the water bottom. The character of the bottom is a physical factor of great importance. Oysters grow best on bottoms that are hardened with firm mud or shell; they do not grow well on sandy or soft mud bottoms. The abrasive action of shifting sand will cause valve injury, and shifting mud may cause death by suffocation. Oyster reefs are discussed in the next chapter.

CHAPTER 3. OYSTER REEF STRUCTURE AND ASSOCIATED COMMUNITIES

3.1 DESCRIPTION OF OYSTER REEFS

Oyster reefs are one of the most distinctive features of most estuaries along the northern Gulf of Mexico. They are usually found near the mouths of estuaries in zones of low to moderate wave action, but may also occur in small estuarine streams and bayous, in either intertidal or subtidal areas of varying salinities. Although most of the oyster reefs along the gulf coast occur in waters less than 3 m in depth, highly productive reefs are often found in stream channels at depths over 4.5 m. Due to the narrow tidal range (0.6 m), gulf coast reefs tend to be subtidal rather than intertidal. Because of their location, oyster reefs often play a significant role in modifying estuarine current patterns and sedimentation rates. Often called oyster banks, oyster bars, or oyster beds, these reefs may range from less than one square meter to several hundred hectares. The large reefs are generally found in areas of relatively fast moving currents, rich in nutrients, flowing over firm muddy bottoms. In shallow coastal waters, reefs may occur as islands, often exposed to the atmosphere at low tide. Reefs may occur either as elongated islands or peninsulas oriented across the main current flow, or they may develop parallel to the direction of the current. In addition to the effects of currents, reef formation is affected by substrate type and salinity regimes.

By the term “natural reef,” most authors mean large areas in large bodies of water. Puffer and Emerson (1953) refer to a reef as “an accumulation of oyster shells which form banks or beds. The upper portion of the bed may be composed of either living or dead individuals, and is elevated at least in part, above the bottom sediments. The surface affords a hard substrate upon which organisms dwell.” Moore (1899) suggested that a natural oyster reef be defined as “an area of not less than 500 square yards (4,500 ft^2; 0.1 acre; 418 m^2; 0.04 hectares) of the bottom of any body of water upon which oysters are found or have been found within a term of 5 years in quantities which would warrant taking them for profit by means of tongs.” The latter definition would thus include oyster accumulations resulting from activities of oyster fishermen in their culture methods, wherein they may spread cultch and/or seed material over areas with suitable substrates and salinity patterns. For our purposes, we will discuss the ecology of oyster reefs in general, irrespective of age, size, or origin.

3.2 OYSTER REEF ECOLOGY--A DYNAMIC ECOSYSTEM

A study of oyster reef ecology is concerned with how different species populations, each with its particular biological needs and attributes, share their habitat with the dominant species, Crassostrea virginica. Reef organisms form an association--a recognizable assemblage of species which occur together because of similar biotic processes or needs. Some of the species may be biologically interdependent through symbiotic (beneficial or harmful interaction of the species involved) relationships.

According to Reid and Wood (1976), symbiosis may occur as mutualism, competition, amensalism, commensalism, or parasitism. Mutualistic species benefit one another. Due to competition, the population growth of both species may be partially restricted. In amensalism, one species adversely affects another but receives no benefit itself or remains unaffected itself (e.g., algal byproducts which restrict growth of another species). In commensalism, one species benefits and the other is not harmed or benefited. The parasitic relationship benefits one species at the expense of the other, possibly causing death of the host.

An oyster reef is an easily identifiable community, composed (under any given set of environmental conditions) of populations of characteristic species (Reid and Wood 1976). It is interesting to note that when the community concept was established by Mobius (1883) over 100 years ago, an oyster bank was used as an example. Mobius coined the term biocoenosis, stating that an oyster bed is "... a community of living beings, a collection of species, and a massing of individuals, which find here everything necessary for their growth and continuance, such as suitable soil, sufficient food, the requisite percentage of salt, and a temperature favorable to their development . ..."

Over the years, many authors have reported on the community structure and population dynamics of oyster reefs along the northern Gulf of Mexico. Some of the most notable works include Hofstetter's (1977) study of public oyster reefs in Galveston Bay, Texas; studies by Mackin and Hopkins (1961) and by Dugas (1977) in Louisiana; a study by Ogle (1979) on Mississippi oyster reefs; May's (1971) account of Alabama reefs; and the studies in Apalachicola Bay, Florida by Pearse and Wharton (1938) and by Menzel et al. (1966). In their comprehensive study, Pearse and Wharton (1938) listed 139 different species of organisms associated with oyster reefs. Several of the organisms which they listed were not actually collected along with oysters, but were only seen in the vicinity of oyster reefs. For example, they reported that "pompano often leaped near the boat over the oyster bars." It would be difficult to conclude from this observation that pompano are actually a part of the community structure of oyster reefs. Menzel et al. (1966) reported 48 different organisms collected from oyster reefs in the same area. In Louisiana, Mackin and Hopkins (1961) collected 18 different organisms associated with oyster reefs in higher salinity areas, 25 euryhaline species, and 4 stenohaline organisms (a total of 47 reef-associated species).

Table 10 provides a list of organisms associated with oyster reefs in the northern gulf, including some which are known to be closely associated with oyster reefs but are rarely collected in oyster samples (e.g., black drum). The list should not be considered complete, as it includes mainly macroinvertebrates and vertebrates. Microbes, plants, and many microinvertebrates are not included. A moderate effort was made to determine which species names have been changed since publication of the original reports--e.g., Callinectes

Table 10. List of organisms associated with oyster reefs along the coast of the Northern Gulf of Mexico (CM= Commensal; CP = Competitor; PA = Parasite; PR = Predator).

Scientific name	Common name	Role	Source, Location
PROTOZOA			
Ancistrocoma pelseneeri	Ciliate	PA	LA1l
Hexamita sp.	Flagellate	PA	TX9,LA21
Nematopsis ostrearum Prytherch	Gregarine sporozoan	PA	TX9,LA20,FL17
Nematopsis prytherchi	Gregarine sporozoan	PA	TX9
Nematopsis sp.	Gregarine sporozoan	PA	TX9
Perkinsus marinus	Dermo	PA	TX9,LA20,MS15,AL1,FL6,14,20
PORIFERA			
Clione celata Grant	Boring sponge	CM/CP	LA21
Clione truitti	Boring sponge	CM/CP	LA12,21
Clione vastifica Hancock	Boring sponge	CM/CP	LA5,FL14,17
Haliclona sp.	Encrusting sponge	CM	LA12
CNIDARIA			
Aiptasiomorpha texaensis Carlgren & Hedgpeth	Sea anemone	CM	LA12
Astrangia astreiformis Milne-Edwards & Haime	Stony star coral	CM	LA12
Astrangia danae Milne-Edwards & Haime	Stony coral	CM	FL17
Astrangia sp.	Coral	CM	FL14
Paranthus rapiformis (Lesueur)	Sea anemone	CM	FL17
BRYOZOA			
Bugula neritina (Linnaeus)	Treelike moss animal	CM	LA12
Membranipora sp.	Encrusting bryozoan	CM	LA5,12,FL14
Schizoporella unicornis	Bryozoan	CM	LA5
NEMERTEA			
Cerabratulus lacteus (Verrill)	Large ribbon worm	CM	LA2
PLATYHELMINTHES			
Acanthoparyphium spinulosum (Johnston)	Trematode	PA	TX10
Acerotisa pellucida	Polyclad	CM	FL17

(Continued)

Table 10. (Continued)

Scientific name	Common name	Role	Source, Location
PLATYHELMINTHES			
Bucephalus cuculus (McCrady)	Trematode	PA	FL14
Bucephalus graciliescens	Trematode	PA	LA20, FL17
Bucephalus sp.	Trematode	PA	TX9
Eustylochus meridianalis Pearse	Polyclad	PR	FL17
Hoplopleura thaisana	Polyclad	CM	FL17
Oculoplana whartoni Pearse	Polyclad	CM	FL17
Proctoeces (maculates?)	Trematode	PA	AL,MS,FL22
Prosthiostomum lobatum Pearse	Polyclad	CM	FL17
Stylochus ellipticus (Girard)	Oyster leech	PA/PR	LA12
Stylochus floridanus Pearse	Oyster leech	PA/PR	FL17
Stylochus frontalis Verrill	Oyster leech	PA/PR	FL17
Stylochus inimicus	Oyster leech	PA/PR	FL14
Stylochus Sp.	Oyster leech	PA/PR	FL6,17
Tylocephalum sp.	Cestode	PA	MS,FL3
ANNELLIDA			
Autotylus n. sp.	Syllid worm	CM/PR	FL17
Euphole globosa Winternitz		?	FL17
Hydroides (Eupomatus) dianthus (Verrill)	Calcareous tube worm	CM	LA2,12
Hydroides (Eupomatus) floridanus (Bush)	Calcareous tube worm	CM	LA2
Hydroides (Eupomatus) uncinatus (Phil.)	Calcareous tube worm	CM	FL17
Eusyllis sp.	Syllid worm	CM/PR	FL17
Glycera sp.	Bloodworm	CM	FL17
Harmothoe aculeata Andrews	Scale worm	CM	FL17
Lepidametria commensalis Webster	Scale worm	CM	FL17
Marphysa acicularum Webster	Eunicid worm	?	FL17
Nereis (Neanthes) succinea (Frey & Leuckart)	Nereid worm	PR	LA5,12,FL14
Nereis limbata Ehlers	Nereid worm	PR	FL17
Nereis pelagica occidentals Hartman	Reddish clam worm	PR	LA12,FL17
Pyllodoce n. sp.	Phyllodocid worm	?	FL17

(Continued)

Table 10. (Continued)

Scientific name	Common name	Role	Source, Location
ANNELLIDA (Continued)			
Podarke obscura Verrill	Hesionsid worm	CM/PR	FL17
Polydora websteri Hartman	Mud worm	CM/PR	LA5,12,21,FL14
Polydora sp.	Mud worm	CM/PR	FL17
Sabella sp.	Sabellid tube worm	CM/CP	FL14
Spiochetopterus oculatus Webster	Chaetopterid tube worm	CM	LA12
Streblosoma verrilli Treadwell	Terebellid tube worm	CM	FL17
ECHIURIDA			
Thalassema mellita Corm.	Echiurid worm	CM	FL17
MOLLUSCA (Cl. Polyplacophora)			
Acanthochites spiculosa Rue	Chiton	CM	FL17
Ischnochiton (Ischnoplax) papillosa	Chiton	CM	TX19
MOLLUSCA (Cl. Gastropoda)			
Anachis avara Say	Greedy dove shell	CM	LA12
Anachis avara ostreicola Melv.	Dove shell	CM	FL17
Anachis avara semiplicata	Dove shell	CM	TX19
Anachis obesa (Adams)	Fat dove shell	CM	TX19,LA12,FL14
Busycon perversum	Left-handed whelk	PR	FL6
Cerithiopsis greeni (Adams)		?	FL14
Cerithium floridanum Morch		?	FL17
Corambella barätariae Harry	Barataria nudibranch	CM	LA12
Corambella sp	Small nudibranch	CM	LA2
Crepidula fornicata Linnaeus	Common Atlantic slipper shell	CM/CP	LA5,FL17
Crepidula plana Say	Eastern white slipper shell	CM/CP	TX19,FL14,17
Diodora alternata Say	Limpet	CM/CP	FL17
Epitonium sp.		?	FL14
Eupleura caudata sulcidentata Dan		?	FL17
Kurtziella sp.		?	FL14
Mangelia sp.		?	TX15,19

(Continued)

Table 10. (Continued)

Scientific name	Common name	Role	Source, Location
MOLLUSCA (Cl. Gastropoda) (Continued)			
Melongena corona Gmelin	Crown conch	PR	FL6,14
Mitrella lunata (Say)		?	TX19,FL14,17
Nassarius vibex (Say)	Common eastern nassa	CM	LA12
Neritina reclivata Say	Brackish water snail	CM	LA12
Odostomia impressa Say	Snail	PA/PR	LA12,FL14,17
Odostomia (Menestho) trifida Totten	Snail	PA/PR	TX19,LA12
Polinices duplicates (Say)	Lobed moon shell	CM	LA5,FL17
Seila adamsii H.C. Lea		?	TX19,FL14,17
Thais haemostoma Conrad	Oyster drill	PR	LA2,5,21,FL6,14,17
Triphora nigrocinta (Adams)		?	FL14
Turbonilla sp.		?	FL17
MOLLUSCA (Cl. Pelecypoda)			
Abra aequalis Say		CM	FL14
Anadara transversal Say		CM	FL14,17
Anemia simplex Orbigney		CM	FL14
Atrina rigida Dillwyn		CM	FL17
Brachidontes exustus Linnaeus	Hooked mussel	CM	TX15,19,FL14,17
Brachidontes recurvus (Rafinesque)	Hooked mussel	CM	LA5,12,FL14,17
Chama macerophylla Gmelin		CM	FL17
Chione cancellata Linnaeus		CM	FL14
Congeria leucopheata Conrad	River mussel	CM	LA2,12
Corbula blattiana C.B. Adams		CM	FL17
Corbula sp.		CM	FL14
Diplothyra (Martesia) smithii (Tryon)	Boring clam	CM/CP	TX15,19,LA2,5,12,21,MS4,FL14
Lima hians Gmelin	Mussel	CM	FL17
Lithophaga bisulcata D'Orbigney	Date shell borer	CM/CP	FL17
Lucina amiantus Dan		CM	LA2
Martesia cuniformis Say	Pholid borer	CM/CP	FL17
Mercenaria (Venus) mercenaria	Quahog	CM/CP	FL17
Mercenaria sp.	Quahog	CM/CP	LA12

(Continued)

Table 10. (Continued)

Scientific name	Common name	Role	Source, Location
MOLLUSCA (Cl. Pelecypoda)			
Mulinia lateralis (Say)	Little surf clam	CM/CP	FL14
Mytilus edulis	Blue mussel	CM/CP	LA5
Noetia ponderosa Say		?	FL14,17
Ostrea eques-tris Say	Horse oyster	CP	FL14,17
Pinctada radiata Leach	Clam	CM/CP	FL17
Rangia cuneata Gray	Marsh clam	CM/CP	LA12
Semele bellastraita Conrad		?	FL14
Semele proficua Pult		?	FL17
Trachycardium muricatum Linnaeus		?	FL14,17
Volsella aborescens Dillwyn		?	LA2
ARTHROPODA			
Balanus eburneus Gould	Acorn barnacle	CM/CP	LA5,12,FL14,17
Balanus improvises Darwin	Barnacle	CM/CP	LA12,FL17
Callinectes sapidus Rathbun	Blue crab	PR	LA5,12,FL6,14,17
Callinectes similis (danae) Williams	Little blue crab	PR	LA12
Caprella acutifrons Latreille	Amphipod	CM	FL17
Caprella linearis Linnaeus	Amphipod	CM	FL17
Clibanarius vittatus (Bose)	Striped hermit crab	CM/PR	LA12,FL8,14
Corophium lacustre Vanhoffen	Mud tube amphipod	CM	LA12
Corophium louisianum Shoemaker	Mud tube amphipod	CM	LA12
Crangon armillatus (Milne-Edwards)	Pistol shrimp	CM	LA12,FL18
Crangon heterochaelis (Say)	Snapping shrimp	CM	LA12
Erichsonella attenuata (Harger)	Isopod	CM	FL17
Erichsonella filiformis (Say)	Isopod	CM	FL17
Eurypanopeus depressus (Smith)	Mud crab	CM/PR	LA2,12,AL13,FL17
Eurypanopeus dissimilis Benedict & Rathbun	Mud crab	CM/PR	FL17
Exosphaeroma faxoni Richardson	Isopod	CM	FL17
Hepatus epitheliticus Linnaeus	Callapid crab	CM/PR	FL17
Hapatus pudibundus (princeps) (Herbst)	Callapid crab	CM/PR	LA2
Hexapanopeus augustifrons (Benedict & Rathbun)	Mud crab	CM/PR	FL17

(Continued)

Table 10. (Continued)

Scientific name	Common name	Role	Source, Location
ARTHROPODA (Continued)			
Leptochelia dubia (kr)	Isopod	CM	FL17
Melita nitida Smith	Amphipod	CM	FL17
Menippe mercenaria Say	Stone crab	PR	LA12,21,AL13,FL6,14
Metoporaphis calcarata (Say)	Crab	CM/PR	LA2
Neopanope packardi (Kingsley)	Mud crab	CM/PR	F L14
Neopanope texana Stimpson	Mud crab	CM/PR	LA5,FL14
Pagurus annulipes (Stimpson)	Small hermit crab	CM/PR	LA2
Paguristes puncticeps Milne-Edwards	Large hermit crab	CM/PR	FL17
Palaemonetes carolinus Stimpson	Grass shrimp	CM	FL17
Palaemonetes intermedius Holthius	Grass shrimp	CM	LA12
Palaemonetes pugio Holthius	Grass shrimp	CM	LA12
Palaemonetes vulgaris (Say)	Grass shrimp	CM	LA12,FL17
Panopeus herbstii Milne-Edwards	Herbst's mud crab	CM/PR	LA2,12,AL13,FL17
Panopeus occidentals Saussere	Mud crab	CM/PR	LA2
Pelia mutica (Gibbes)	Spider crab	CM	LA2
Petrolisthes armatus (Gibbes)	Flat crab	CM	LA5,FL14,17
Pinnotheres moseri Rathbun	Small crab	CM	FL17
Pinnotheres ostreum Say	Small crab	CM	FL17
Rithropanopeus harrissii (Gould)	Mud crab	CM/PR	LA2
Synalpheus minus (Say)		?	FL14
ECHINODERMATA			
Ophiophragmus (Amphiodia) limbata (Grube)	Brittle star	CM	LA2
Hemipholis elongatus (Say)	Brittle star	CM	LA2,FL17
Psolus tuberculosis Theel	Sea cucumber	CM	LA2
CHORDATA			
Molgula manhattensis (DeKay)	Tunicate	CM/CP	LA2 ,12
Molgula occidentals Traustedt	Tunicate	CM/CP	FL17
Archosargus probatocephalus (Walbaum)	Sheepshead	CM/PR	LA7,MS16
Chasmodes saburrae Jordan & Gilbert	Florida blenny	CM	FL18

(Continued)

Table 10. (Concluded)

Scientific name	Common name	Role	Source, Location
CHORDATA (Continued)			
Gobiesox strumosus Cope	Skilletfish	CM	LA12,FL17
Gobiesox virgatulus Goode & Bean	?	?	LA2
Gonionellus hastatus Girard	Sharptail goby	CM	LA2
Gobiosoma bosci (Lacepede)	Naked goby	CM	LA12,FL17
Hypleurochilus geminatus (Wood)	Crested blenny	CM	F L14
Hypsoblennius hentzi (LeSueur)	Feather blenny	CM	FL14,17
Hypsoblennius ionthas (Jordan & Gilbert)	Freckled blenny	CM	LA12
Opsanus beta (Goode & Bean)	Gulf toadfish	CM/PR	LA12,FL14
Opsanus pardus (Goode & Bean)	Leopard toadfish	CM/PR	LA2
Opsanus tau (Linnaeus)	Oyster toadfish	CM/PR	LA2,FL17
Pogonias cromis (Linnaeus)	Black drum	CM/PR	LA2,7,21,MS16,FL17

Sources;

1. Beckert et al. 1972.
2. Behre 1950.
3. Cake 1977.
4. Chestnut 1981.
5. Dugas 1977.
6. Finucane and Campbell 1968.
7. Fontenot and Rogillio 1970.
8. Hazlett 1981.
9. Hofstetter 1977.
10. Little et al. 1966.
11. Mackin and Hopkins 1961.
12. Mackin and Hopkins 1961.
13. May 1974.
14. Menzel et al. 1966.
15. Ogle and Flurry 1980.
16. Overstreet and Heard 1982.
17. Pearse and Wharton 1938.
18. Peters 1981.
19. Puffer and Emerson 1953.
20. Quick and Mackin 1971.
21. Van Sickle et al. 1976.
22. Winstead and Couch 1981.

Locations:

AL Alabama
FL Florida
LA Louisiana
MS Mississippi
TX Texas

danae Smith (Mackin and Hopkins 1961), is now C. similis Williams (Felder 1973). Although there may be some duplication (because the same species was reported under different names, or organisms were accounted for by genera only) in Table 10, we have listed 170 different organisms as reported by the original authors. Some of these were listed as a result of a single specimen found many years ago. The list includes 6 protozoans, 4 sponges, 5 coelenterates, 3 bryozoans, 1 ribbon worm, 16 flatworms, 3 echinoderms, 20 annelid worms, 1 echiurid worm, 57 molluscs (2 chitons, 27 gastropod, 28 bivalves), 39 arthropods, and 15 chordates (13 fishes).

Table 10 also indicates the possible relationships of each organism to the oysters of the reef community. In many cases the original authors did not indicate the role of certain organisms, so we have attempted to provide our own estimate of their community relationships. Parasites and predators are discussed in Chapter 5. The list indicates the distribution of these organisms only within the state waters in which the original authors found them. This, of course, does not mean that they are restricted to these waters. For example, Table 10 lists 2 references from Louisiana and 3 from Texas for the blue crab, Callinectes sapidus, but it is common knowledge that this species occurs along the entire northern gulf coast. Likewise, Ostrea equestris is reported only from Florida waters, but we feel that it may be present in other States where salinities are high enough. For some of the lesser known species, more research must be conducted to determine their complete distribution.

Population Densities

Nearly all studies on subtidal oyster reef ecology have been qualitative rather than quantitative due to difficulties in obtaining representative samples. Bahr and Lanier (1981) reported on populations of intertidal oysters and reef-associated organisms. Because they are periodically exposed to view, intertidal reefs lend themselves to quantitative studies. Population studies on subtidal oyster reefs are usually conducted as a result of some natural or cultural disturbance of commercially important oyster reefs, or as a management tool to determine standing crops of oyster reefs in order to predict harvest potential.

In recent years, we have attempted to quantify oyster populations in Louisiana waters by using square-meter sampling procedures. This is accomplished by first locating oyster reef areas by feeling the water bottoms with a long pole, and then tossing a metal frame measuring 1 m^2 into the water. A diver, using SCUBA gear, then removes the material contained within the frame. From 3 to 12 such samples are taken in each area. More than three samples are necessary when the number of oysters collected per meter varies greatly. In highly productive areas, densities may be greater than 100 oysters/m^2 (all sizes included), but will be much less in most areas. Wherever reefs are commercially harvested, the number of oysters/m^2 will usually not vary greatly, since the oysters are spread by dredging, tonging, planting, and associated activities (culling, etc).

Population densities have been determined for relatively few other reef-associated species--mainly parasites and predators. As in the case of oyster-density investigations, most studies on population dynamics are conducted in order to determine possible reasons for excessive mortalities. Populations of several organisms are discussed in Chapter 5.

3.3 TROPHIC RELATIONSHIPS AND ENERGY BUDGET

The community structure and energy budget of intertidal oyster reefs have previously been described by Bahr and Lanier (1981). Subtidal oyster reefs are major components of estuarine ecosystems along the northern gulf. Oysters are interdependent on the activities of many organisms which are not directly associated with the reefs. Specific organisms in the estuarine food web are either packagers, regulators, or regenerators. Packagers (e.g., Spartina, benthic algae, periphyton, phytoplankton, killifish, shrimp, fiddler crabs, juvenile fish, marsh snails, mussels, and oysters) concentrate organic material into forms available for convenient transfer to higher trophic levels. Oysters as filter feeders utilize small particles of organic matter and become "packages" of energy that can be used as food sources by other organisms such as snails, crabs, fishes, and humans. Packagers may be either heterotrophs or autotrophs, and together they make up a large portion of the reef biomass. Most of the macroinvertebrates in the reef community occupy this niche. Regulators (e.g., mature fish, porpoises, pelicans, herons, comb jellies, oyster drills, raccoons, and humans) are organisms with generalized feeding habits which can regulate community populations by feeding on the most abundant food sources. The black drum and oyster drills, for example, can sometimes virtually destroy commercially important oyster accumulations as well as regulate the populations of other reef-associated organisms such as mussels which are attached to the oysters. Some species, such as comb jellies, can affect population levels by ingesting the free-floating gametes and larval forms of reef organisms such as oysters and mussels. Regenerators (e.g., bacteria, yeasts, molds, meiofauna, and protozoa) are involved with the decomposition of organic materials, causing energy to be recycled within the estuarine community. The decomposes act upon dead members of the reef community, as well as upon feces and metabolic wastes of the reef organisms, returning nutrients to the ecosystem.

Community structure and trophic relationships in an oyster reef community will vary depending on salinity and temperature, as well as other factors. Parker (1975) characterized oyster reefs as having the following energy levels: high radiant (light, temperature), intermediate kinetic (waves, currents), and high chemical (salinity). Low salinity reefs are generally low in species diversity, with high populations and a very high biomass, while high salinity reefs possess intermediate species diversity, intermediate populations levels, and an intermediate biomass (Figure 14). Temperature mainly affects population levels of reef organisms by triggering reproductive cycles, but also affects growth rates by influencing enzyme activity which regulates digestion and feeding activities. A third major factor in determining community structure is substrate type. Oyster populations, along with reef-associated species, are much greater on hard clay bottoms than on soft mud bottoms. Other factors include availability of food, predation, and competition of other species.

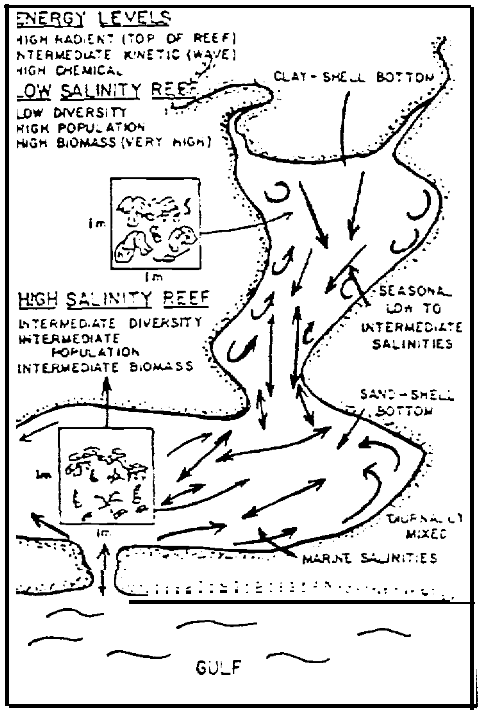


Figure 14. Diagrammatic representation of the mollusk (oyster or mussel) or serpulid reef ecosystem with typical environmental and faunal characteristics. (Adapted from Parker 1975).

Organisms in the oyster reef community often play more than one role. For example, we have listed (see Table 10) Balanus eburneus (acorn barnacle) as being both commensal and competitor, and Neopanope texana (mud crab) as being both commensal and predator. Barnacles generally use oyster shells for attachment, causing no great harm, fulfilling the role of a commensal. On the other hand, being filter feeders, they compete with oysters for food particles suspended in the water column. Mud crabs usually find protection from larger predators among oyster shells (commensal role), but will feed upon oyster spat as well as many other reef dwellers (predator role). Mud crabs also serve as hosts for several parasites, thus adding to the complexity of the trophic relationships and community structure of oyster reefs.

Day et al. (1973) described the community structure and carbon budget of a salt marsh and shallow bay estuarine system in Louisiana which would probably be fairly typical of many oyster producing areas along the northern gulf. A diagram of the food web and energy flow relationships of the ecosystem is presented in Figure 15, with a more detailed summary of the carbon flow in the water column portion presented in Figure 16. About one third of the energy input to the estuarine ecosystem originates from marsh detritus. De La Cruz (1973) stated that all marshes, regardless of geographic location, produce about the same amount of organic material annually and supply the same biomass of detritus to estuarine food chains. Detritus may be used directly by some organisms (e.g., bacteria, oysters, and fiddler crabs), but catabolic products are more often utilized by primary producers (e.g., phytoplankton), which can then be used by oysters and other species. The most important single source of energy for oysters is probably phytoplankton, principally diatoms, but resuspended benthic diatoms, other microalgae, and detritus may also contribute a significant portion. Mulkana (1970) concluded that oysters derive the major part of their food from nannoplankton. Day et al. (1973) summarized energy flow of oysters both on the reefs and over the whole water area (Figure 17). Total input from the ecosystem was estimated to be 3,509 grams of organic matter per square meter of oysterbed per year, with additional 33 grams input by the culture activities of oyster fishermen, with pseudofeces production amounting to 1,445 grams of organic matter per square meter, and feces production of 981 grams of organic matter per square meter. Ryther (1969) estimated the annual yield of shellfish to average no more meat weight than 150 kg/ha/yr, but that when specific areas of high shellfish production are considered, yields of 5,000 kg/ha/yr are possible, using conventional culture methods.

3.4 POPULATION STRUCTURE OF OYSTER REEFS

Data on age structure of a species population can reveal much about the growth state of that population. If individuals of all sizes (or ages) are present in roughly equal proportion, then the birth, growth, and death rates are probably in balance, indicating a healthy, stable condition. A high proportion of either young or old individuals may suggest an abnormality in the reproductive cycle, usually caused by abnormal environmental conditions, or it may simply reflect the ordinary survival pattern characteristic of the species being studied. In the case of an oyster reef that is commercially exploited, older (larger) oysters may exist in very low numbers, since they

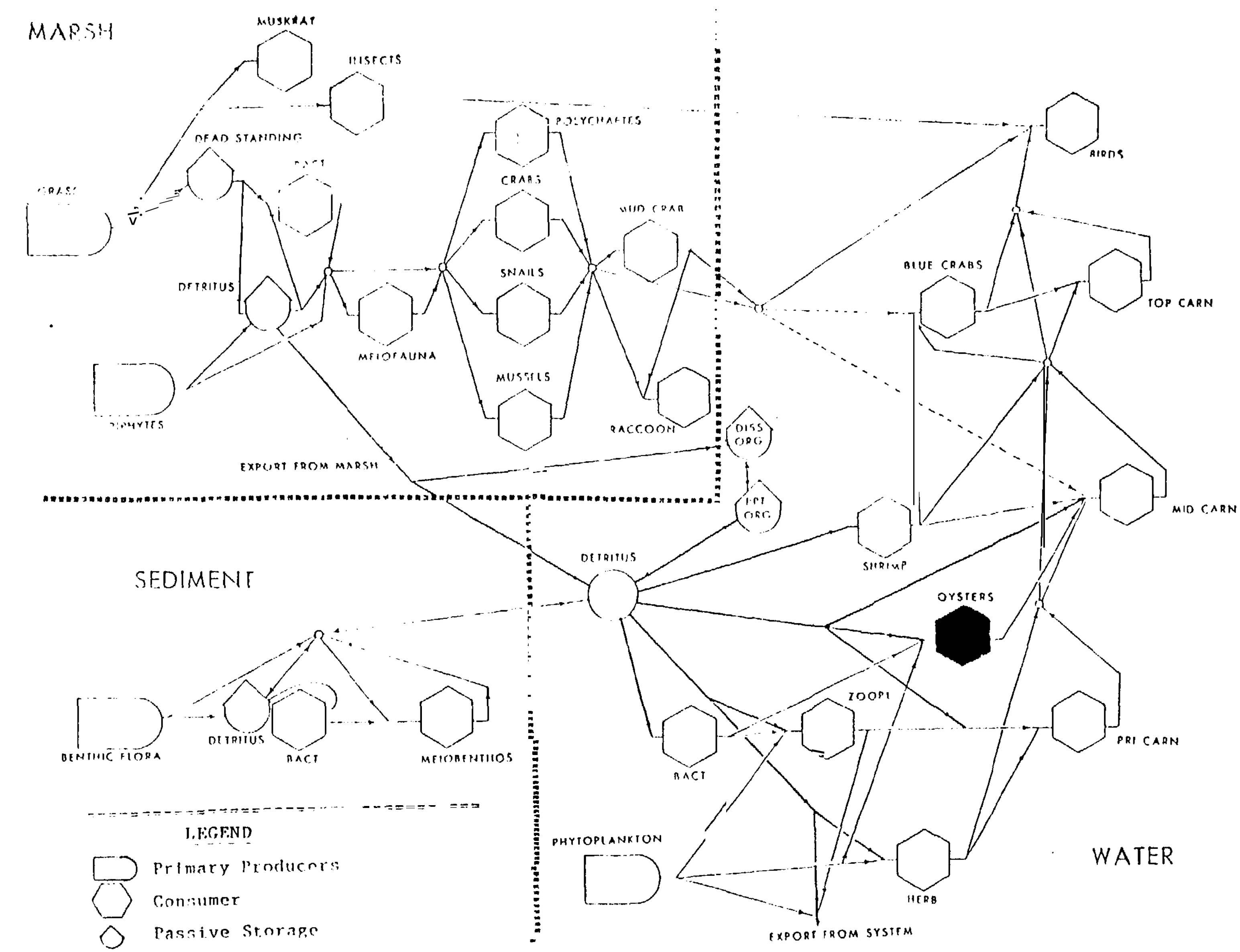


Figure 15. Diagram of marsh-estuary system showing components and pathways. Heavy lines indicate flow of detritus (adapted from Day et al. 1973).

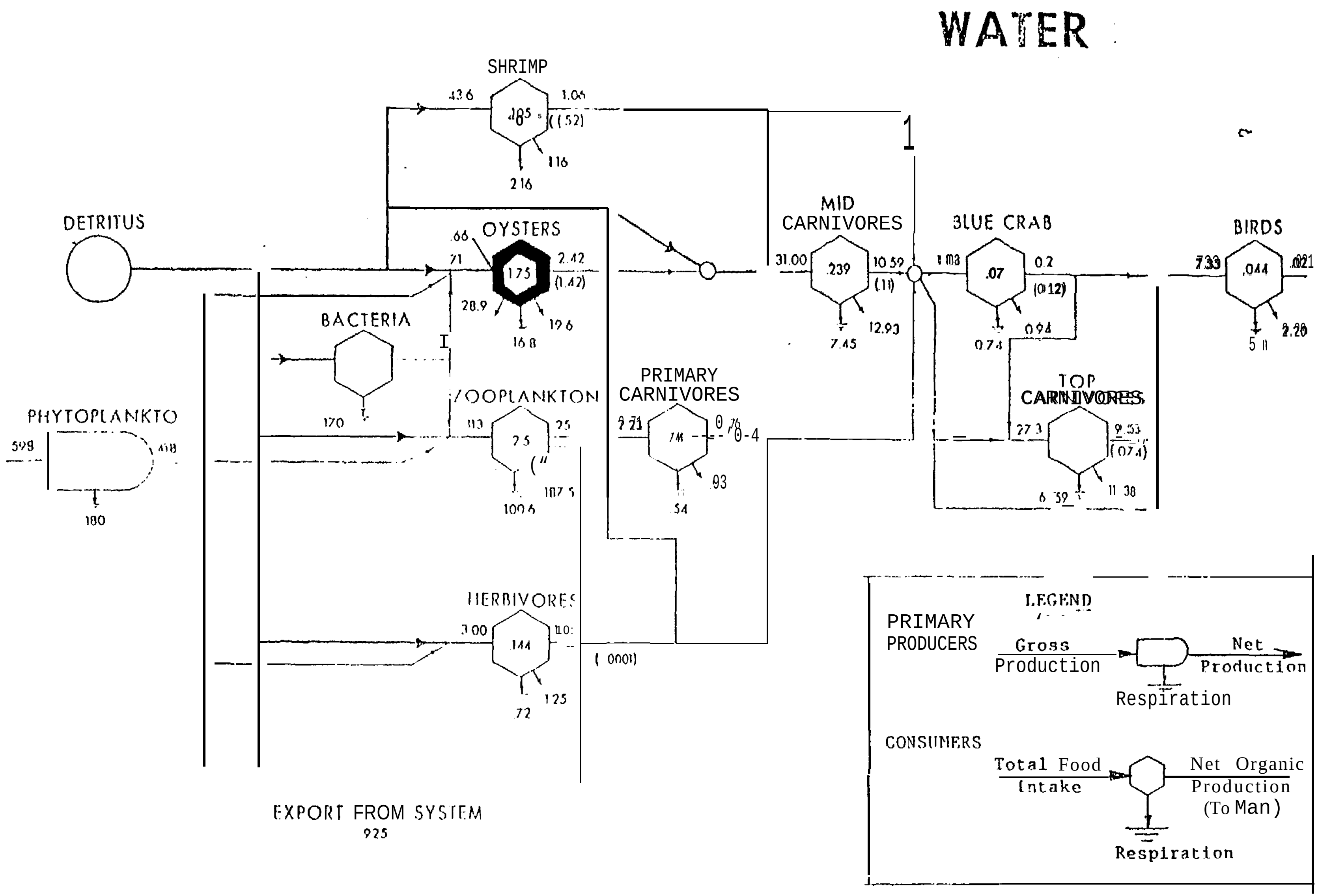


Figure 16. Summary of carbon flow in estuarine water column. Units are grams of organic matter/m^2/yr.

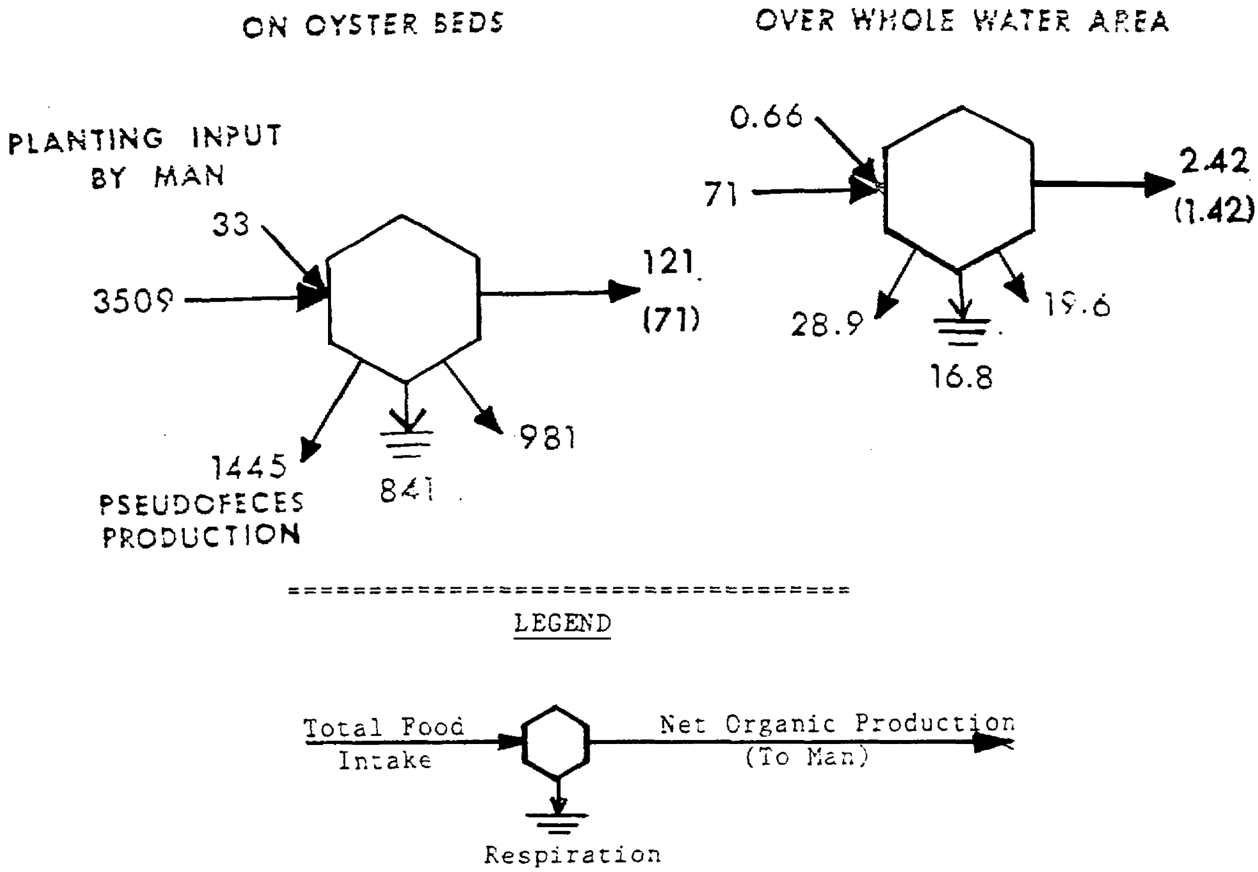
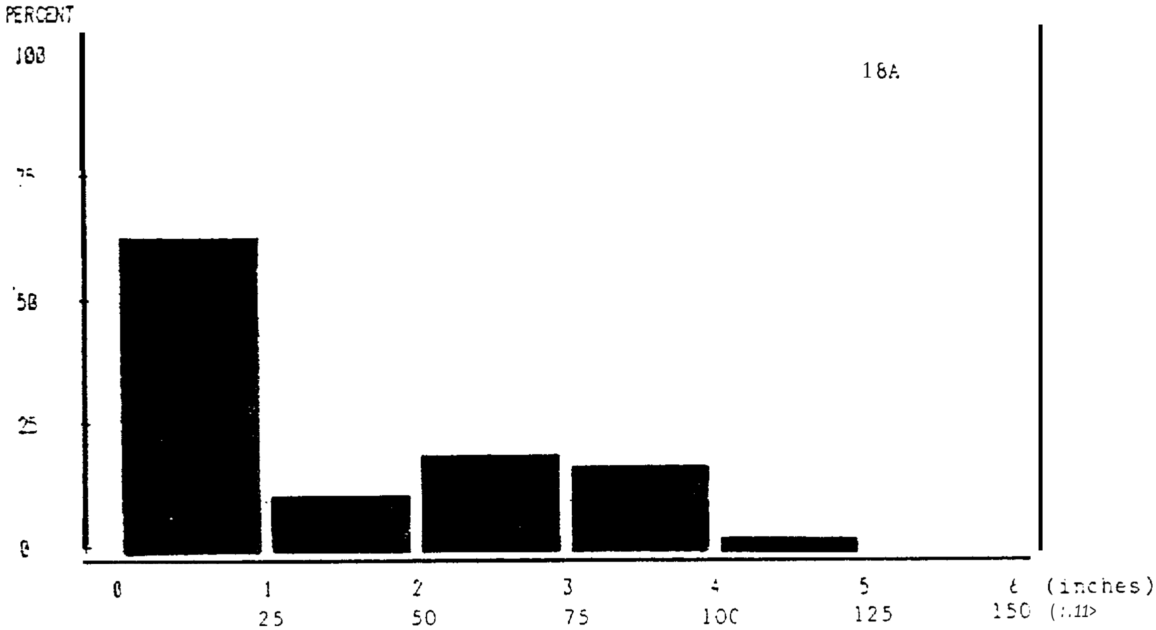


Figure 17. Energy flow of oyster biomass in estuarine system, in grams of organic matter/m^2/yr (adapted from Day et al. 1973).

are the ones being harvested. Figure 18 illustrates the differences in relative frequency of different size groups found on private oyster leases in Louisiana. Figure 18A illustrates size frequency in an area of natural reproduction, while Figure 186 represents an area of very little natural reproduction, where seed oysters (up to 75 mm) were planted by an oyster fisherman. Note that in the naturally reproductive area, well over 50% of the oysters are less than 25 mm (1 inch), while in the planted area, very few oysters are less than 50 mm (2 inches).

Several authors (Menzel et al. 1966, Dugas 1977, Hofstetter 1977, Ogle 1979) have presented detailed information on size frequencies of oysters under different environmental conditions. An example is presented in Figure 19. Note the small number of dead individuals. We have determined that, under normal conditions and in the absence of serious parasitic infections, predatory attacks, or other disturbances (freshwater, heavy sedimentation, etc.), the number of dead oysters on a reef at any given time is usually less than 10%.



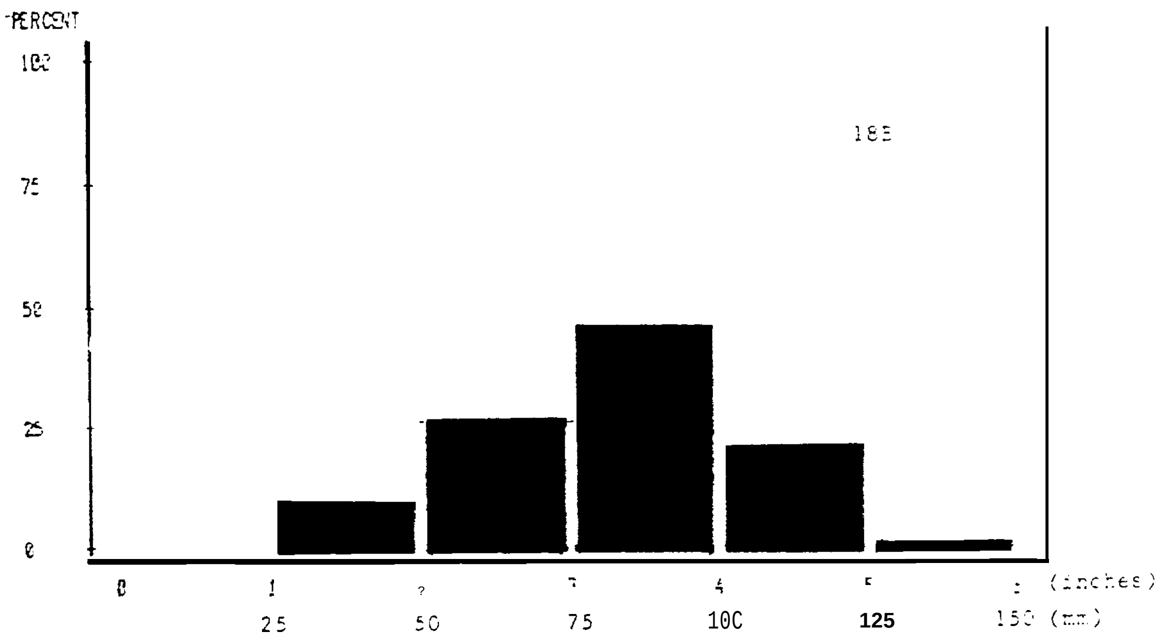


Figure 18. Size frequency distribution of oysters on reefs in Louisiana. A. Reef in an area of natural reproduction. B. Reef in an area of low natural reproduction; seed oysters planted by an oyster fisherman.

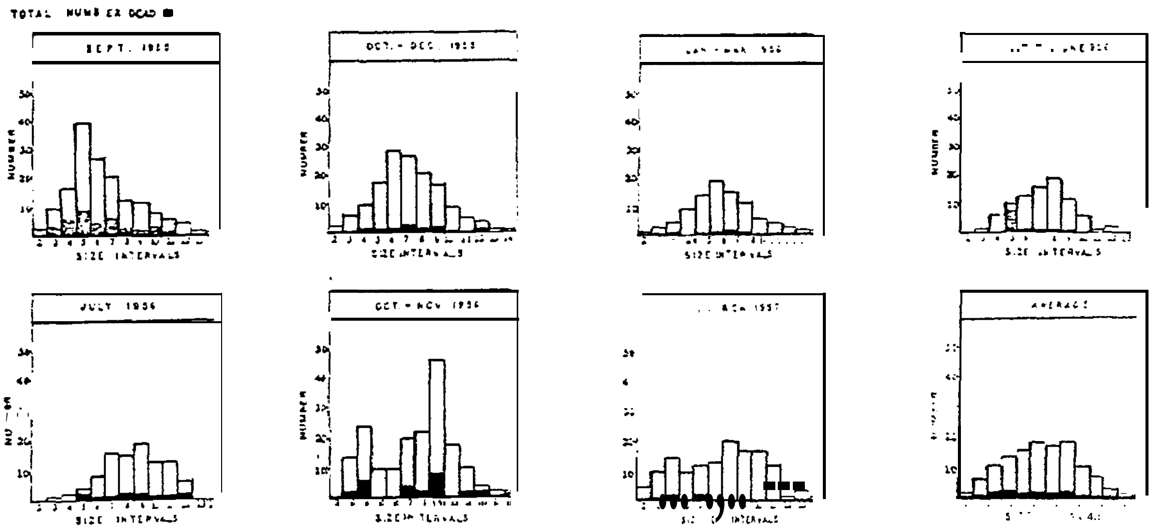


Figure 19. Seasonal average total number of Crassostrea and number dead per square meter in each 10-mm size group (adapted from Menzel et al. 1966).

CHAPTER 4. MAJOR OYSTER REEF AREAS AND COMMERCIAL EXPLOITATION, BY STATE

4.1 INTRODUCTION

One of the best ways to determine the abundance and durability of a marine organism is to analyze the commercial landings of that species. The American oyster was probably one of the earliest marine species to be utilized as a food item. It was readily available to the early Indian tribes that scavenged for food along the coastline. In many cases, huge oyster populations were located along the shoreline and could be easily gathered by hand. The production for the gulf coast has fluctuated over the years in response to both environmental and oyster demand pressures.

In 1981, 42 million lb of American oyster meat came from the east and gulf coasts, while 5.6 million lb of the Pacific oyster were harvested on the west coast (Table 11). Although up approximately 2.4 million lb from 1980, these landings are low compared to a record of 150 million lb in 1908 and production of 70 million lb in the late 1940's. Conversely, imports of oysters, largely from Japan and Korea, increased from 111,000 lb of meat in 1947 to 23.5 million lb in 1978. Total U.S. consumption of oysters has remained between 70 and 80 million lb for the past 30 years. Increases in imports counterbalanced decreases in U.S. production.

Reasons for the decline in domestic production of oysters include over-fishing, natural disasters, loss of habitat, diseases, economic factors, and pollution. Overfishing contributed to major declines after the turn of the century; disease and pollution (over 30% of the beds are closed) caused major declines since the 1940's.

The oyster fishery on the gulf coast during the early 1980's ranked sixth in volume and fourth in value among all the fishery products. Prior to the 1960's the peak year for oyster production in the gulf was 1939. This was later than the peak years for the Atlantic coast, which occurred in 1911 and the big year 1880 for the Chesapeake Bay system. In 1939, 24 million lb of oysters were harvested from the gulf. Similar high yields were recorded in the late 1960's, particularly 1968. The gulf oyster fisheries has shown a decline since 1968, with significant declines in Mississippi and Alabama since 1970 (Table 12). The gulf coast oyster landings averaged approximately 17 million lb for the period 1977-81. In 1981, the Gulf States accounted for 34% of the oyster production in the United States.

Most of the oysters landed in the Gulf States, with the exception of Louisiana, are harvested from public (State controlled) reefs. Louisiana has set aside zones within which waterbottoms can be leased. Virtually all of the Gulf Coast States have some form of waterbottom leasing, but none compare to

Louisiana in acreage leased (which is 234,000 acres to date). Oysters harvested from leased beds may have been transplanted from seed beds that have been closed to harvesting because of pollution. Harvesting methods along the gulf coast are fairly standard. Although hand tonging (Figure 20) is still practiced in some areas, the primary method of harvesting is by dredging (Figure 21).

Table 11. Annual landings of oysters, by area and type, 1965-81 (thousands of pounds, meat weight). Sources: Fisheries of the United States, 1981; U.S. Department of Commerce; National Oceanographic and Atmospheric Administration, National Marine Fisheries Service.

	Eastern oysters						
Year	Chesapeake	South Atlantic	Gulf	Other	Total Eastern oysters	Pacific[a] oysters	Total Eastern & Pacific oysters
1965	21,188	4,082	19,156	1,105	45,531	9,157	54,688
1966	21,232	3,657	17,182	1,338	43,409	7,814	51,223
1967	25,798	3,160	21,747	1,526	52,231	7,726	59,957
1968	22,679	2,965	26,739	1,749	54,132	7,754	61,886
1969	22,157	1,830	19,765	1,491	45,243	6,956	52,199
1970	24,668	1,626	17,714	1,620	45,628	7,974	53,602
1971	25,557	1,846	20,266	2,169	49,838	8,100	57,938
1972	24,066	1,868	18,260	3,473	47,667	8,391	56,058
1973	25,400	1,656	14,914	3,363	45,333	6,598	51,931
1974	25,021	1,841	14,878	3,385	45,125	5,051	50,176
1975	22,640	1,585	19,295	3,878	47,398	5,829	53,227
1976	20,964	1,704	21,569	3,773	48,010	6,384	54,394
1977	17,929	1,847	18,081	2,579	40,436	5,590	46,026
1978	21,531	2,138	18,212	3,302	45,183	5,800	50,983
1979	20,428	2,441	15,289	4,167	42,325	5,756	48,081
1980	20,777	2,279	16,548	2,835	42,439	6,642	49,081
1981	22,153	2,786	17,079	2,406	44,424	5,612	50,036
1982		2,331	23,224		48,489	5,839	54,328
1983		2,620	29,165		44,729	5,431	50,160
1984		2,499	27,597		41,808	6,479	48,287
1985		1,871	26,509		36,578	7,595	44,173
1986		1,776	22,350		35,013	5,531	40,544
1987		1,849	17,928		29,957	9,850	39,807

[a]Landings of Pacific oyster includes _Crassostrea gigas_ and _Ostrea lurida_ landings.

Table 12. Gulf coast oyster landings by States for various years, 1880-1981 (in thousands of pounds, meat weight). Historical catch statistics--U.S. Fish and Wildlife Service Bureau of Commercial Fisheries and National Oceanic and Atmospheric Administration, National Marine Fisheries Service.

Years	Florida, west	Alabama	Mississippi	Louisiana	Texas	Gulf Total
1880	270	327	62	1,189	325	2,173
1890	1,611	1,506	2,008	3,392	2,133	10,650
1902	3,057	1,088	5,989	4,830	1,661	16,625
1911	1,140	1,162	1,621	12,410	1,766	18,099
1923	1,053	730	4,224	4,119	1,742	11,868
1930	1,501	287	4,896	4,846	1,157	12,687
1931	1,406	769	3,438	3,590	982	10,185
1932	1,109	859	5,222	2,978	981	11,149
1934	1,357	392	4,904	5,592	1,312	13,557
1936	917	992	5,771	5,743	823	14,246
1937	817	1,235	12,894	8,048	1,190	24,184
1938	858	1,359	2,241	10,222	1,356	16,036
1939	742	1,358	7,706	13,586	987	24,379
1940	669	936	2,270	12,412	1,297	17,584
1945	1,496	1,606	265	9,884	719	13,970
1950	873	2,070	508	8,715	125	12,291
1951	681	2,191	28	8,164	456	11,520
1952	542	1,842	23	11,402	828	14,637
1953	564	1,450	318	9,435	1,068	12,835
1954	668	739	976	8,361	699	11,443
1955	630	1,581	1,731	9,396	543	13,881
1956	856	770	846	10,056	986	13,514
1957	710	1,291	862	10,489	953	14,306
1958	795	458	579	8,265	311	10,408
1959	1,415	895	333	9,667	1,411	13,721
1960	1,931	1,169	2,391	8,311	3,396	17,198
1961	3,255	509	3,241	10,139	1,096	18,240
1962	4,592	443	3,073	10,160	1,210	19,478
1963	4,282	995	4,679	11,563	2,618	24,137
1964	2,793	1,005	4,829	11,401	3,357	23,385
1965	3,789	492	2,695	8,343	4,836	20,155
1966	4,157	1,304	2,232	4,764	4,725	17,182
1967	4,578	2,087	3,786	7,742	3,553	21,746
1968	5,317	1,212	3,786	13,121	3,302	26,738
1969	4,912	481	1,430	9,178	3,764	19,765
1970	3,573	279	548	8,639	4,675	17,714
1971	3,529	250	1,215	10,528	4,744	20,266
1972	3,231	106	1,220	8,805	3,935	17,297
1973	2,409	591	612	8,953	2,349	14,914

(Continued)

Table 12. (Concluded)

Years	Florida, west	Alabama	Mississippi	Louisiana	Texas	Gulf Total
1974	2,653	733	276	9,972	1,244	14,878
1975	2,134	638	1,080	13,687	1,756	19,295
1976	2,602	1,236	1,516	12,334	3,881	21,569
1977	4,072	1,549	1,386	10,065	2,601	19,673
1978	5,880	760	682	9,662	1,907	18,891
1979	6,125	460	272	7,714	887	15,458
1980	6,756	55	21	6,947	1,739	15,518
1981	7,179	1,330	467	9,093	1,307	19,376
1982	4,817	1,497	2,576	12,621	1,713	23,224
1983	4,326	336	3,333	13,229	7,941	29,165
1984	6,622	477	1,378	13,952	5,168	27,597
1985	4,393	1,442	1,193	14,347	5,134	26,509
1986	1,899	946	1,202	12,654	5,649	22,350
1987	3,283	88	132	12,027	2,398	17,928

Louisiana has been the largest producer of commercial oysters (Table 12), with the 1981 production of 9,093,000 lb valued at approximately $16 million dockside. Louisiana generally accounts for about 45% of the Gulf States' landings, but production has ranged as high as 71% of the total (during 1975). Average annual production figures for various time intervals as presented in Table 13 reveal some rather interesting trends in production. The average catch for Louisiana peaked slightly in the early 1970's probably as a result of flooding in those years. Flooding reduces predators and increases nutrient levels.

Table 13. Average annual oyster meat production (in pounds) on the gulf coast for various time periods (from Gunter 1971).

Time period	Florida	Alabama	Mississippi	Louisiana	Texas
1887 - 1940	1,394,000	939,000	4,108,000	6,252,000	1,514,000
1941 - 1959	859,000	1,385,000	698,300	9,426,000	691,000
1960 - 1965	3,334,000	769,000	2,887,378	9,917,000	2,569,000
1966 - 1970	4,507,000	1,072,000	2,356,000	8,689,200	4,003,800
1971 - 1975	2,791,200	463,600	880,000	10,389,000	2,805,600
1976 - 1980	5,087,000	812,000	775,400	9,344,400	2,203,000

Figure 20. Tonging for oysters.

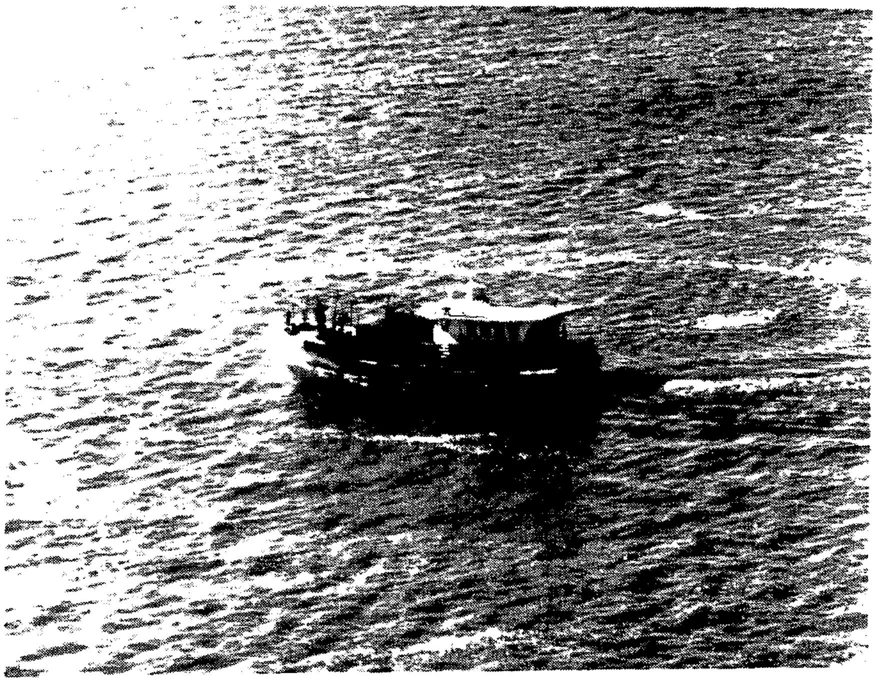


Figure 21. Dredging for oysters.

4.2 MAJOR REEF AREAS

It is virtually impossible to accurately pinpoint the exact locations or dimensions of all oyster reefs along the gulf coast because of several factors, the most important of which is that we are dealing with a benthic community which usually lies several meters under water. Due to environmental and cultural factors, dimensions of certain reefs have changed considerably over a period of years. The following discussion is a summary of information gathered over several years, and should be considered as merely "the best available" information.

Texas

Oyster landings in Texas declined from the mid to late 1960's (4 million lb or 1,800 t/yr) to the past 5 years (about 1 million lb or 450 t/yr). In 1972, there were about 673 vessels licensed by the State and about 91% of those were dredging (Hofstetter 1977). A large number of out-of-state oyster boats, primarily from Louisiana but including vessels from other Gulf States, were also fishing there from time to time. Hofstetter (1977) noted a reduction in production and indicated unfavorable salinities as well as pollution problems as the causes. An additional factor might be the reduction in out-of-state oyster vessels because of increased operations cost, particularly due to the distance away from home port and stringent regulations.

The total acreage of natural and private oyster leases as calculated by Diener (1975) was estimated to be about 7,278 acres (Table 14) and 5,219 acres, respectively. The majority of the oyster fishery as well as the oyster reefs is located in the Galveston Bay area. There are some additional areas in the Corpus Christi-Aransas Bay area. The Galveston Bay reefs and fishery accounted for 80% to 90% of the total State harvest in the early 1970's when about 3.2 million lb were reported. This oyster production in Galveston Bay is from about 5,880 acres of natural reef and 2,768 acres of leased acreage. This represents about 81% of the reported reef acreage in Texas and about 53% of the leased acreage in 1975. The Galveston Bay oyster reefs were characterized by Hoffstetter (1977) as long and narrow, with their long axis perpendicular to the prevailing water current.

The other significant concentration of oyster reefs in Corpus Christi Bay and the adjoining Aransas-Copano Bay area, contains about 1,400 acres. There are oyster reefs of varying sizes in virtually all of the estuarine systems in Texas.

Louisiana

In most aspects the Louisiana oyster fishery has developed into a culture-type industry. Cultivation in this instance means wise utilization of the environment to produce a quality product. During the 1840's and 50's, it became apparent to Louisiana fishermen that oysters obtained from certain waters had a nicer configuration, were better tasting, were larger, and consequently were in greater demand than oysters apparently of the same age but from other locations. These particular oysters became a delicacy, and the

Table 14. Natural (public) reefs on the Texas coast (Diener 1975).

Areas	Acres
Galveston Bay:	
Barrel 1	22.00
Bart's Pass	265.90
Bayview	40.00
Beasley's	91.30
Deep	15.00
De George	2.00
Dollar	292.50
Dow	162.10
Fisher	151.80
Hanna	1,429.20
Humble Camp	5.00
Lewis	1.00
Little Tin Can	2.00
Lost	15.20
Moody	500.00
Red Bluff	20.00
Redfish (N)	406.90
Redfish (S)	1,632.00
San Leon	20.00
Scott's	50.00
Shelton	80.00
Switchover	118.00
Tin Can	9.00
Todd's Dump	90.70
Unnamed	80.00
Unnamed	1.00
Unnamed	3.00
Unnamed	3.00
Unnamed	2.00
Unnamed	4.00
Vingteune	67.30
Total	5,581.90
Copano-Aransas Bays:	
Long	256.19
Pauls	24.79
Daggar	30.70
Jay Bird	167.63
Half Moon	85.94

(Continued)

Table 14. (Concluded)

Areas	Acres
Copano-Aransas Bays:	
Copano	41.52
Shellbank	35.09
Lone Tree	26.14
Lap Reef Bank	21.67
Spaulding	104.45
Proverty	46.24
Total	840.36
Corpus Christi Bay	
Midway	1.00
Hawkins	3.00
Mitchill	1.00
Tucker	8.00
Mason	9.00
Alta Vista	70.00
Mathew	15.00
Edison	11.00
Little Oso	2.00
0s0	3.00
Bulkhead	4.00
Shamrock	83.00
Long	174.00
La Quinta	8.00
Portland	32.00
Indian Point	93.00
Causeway	17.00
Ingleside	11.00
Donnel	10.00
Total	565.00
Total measured acreage Texas Coast	6,987.26

demand soon outstripped the supply. To compensate for this, fishermen began moving small oysters into the choicer growing areas. The early fishermen had enough foresight to recommend legislation which would incorporate certain grounds into private ownership (leased from the State). The remaining natural reefs were placed under State control at that time.

Oysters are harvested from both public and private grounds. The public oyster grounds contain an estimated 22,000 acres of reefs east of the Mississippi River; however, only about half of this area is in production at any one time. In addition, about 500 acres are located in the Hackberry Oyster Seed Reservation in the Barataria Bay complex which are set aside as public grounds. Terrebonne Parish contains about 450 acres of reefs in Sister Lake and 100 acres in the Bay Junop Oyster Seed Reservation. There have been some rather extensive shell planting activities in the Sister Lake area. There are also about 600 acres of reef within the Vermilion Bay area, and about 1,700 acres of reef within the Calcasieu Lake public tonging area.

There is presently no inventory nor any way of determining the amount of productive or non-productive reef acreage within the 234,000 acres leased to private individuals. It is common practice among fishermen to lease non-productive areas surrounding their productive reefs in order to protect them from oyster poachers.

Mississippi

Oyster production in Mississippi depends upon State-managed public reefs. As of 1977, a few small areas of oyster bottom were leased for private farming and were being used primarily for deputation (cleansing) purposes. Some effort is being made around the Biloxi area to use the water column in association with containerized deputation in an attempt to make Biloxi Bay productive again. The Mississippi landings account for some of the lowest productions along the gulf coast, since Mississippi has one of the shortest shorelines and thus less acreage available for production. The maximum landing, 12,694,000 lb in 1937 accounted for 53% of the gulf total and the minimum, 21,000 lb in 1980, accounted for less than 1% of the gulf total. The 5.7 t in 1937 is truly significant when compared to the available estuarine acreage. Like the Texas fisheries, there appeared to be a peak of production in the mid-1960's. The Mississippi oyster fishery is dependent upon the Bonnet Carre Spillway diverting water into Lake Pontchartrain and upon the Pearl River for freshwater flow. Oysters are often harvested in Louisiana but landed in Mississippi ports, thus landing data may be misleading.

Oyster reefs are located along the entire coast, with the largest reef (Pass Christian) near the State line (Table 15). According to Christmas (1973), during good years there are about 7,500 acres in production, while in poor years the productive reef acreage is no more than 2,500 acres. He indicated that possibly as much as 2,000 additional acres could be brought into production for a maximum potential total of 10,000 acres considerable acreage for a state with such a limited shoreline. All reefs were severely damaged during August 1969 by Hurricane Camille and have not fully recovered.

Alabama

The average oyster harvest from 1948 to 1968 was 1,220,000 lb. From 1970 to the present, however, it has very seldom exceeded 1 million lb, and in 1980 it dropped to 55,000 lb. May (1971) indicated an average of 655 hand tongers in Alabama. The oyster industry is almost entirely based upon production from public reefs where only tonging is allowed. There is a limited amount of

Table 15. Natural (public) reefs along the Mississippi coast (Christmas 1973).

Areas	Acres
Point St. Joe	740
St. Louis Bay	170
Pass Christian	7,180
Biloxi Bay	350
Ocean Springs	180
Deer Island	4
Graveline Bayou	5
West Pascagoula	540
Bangs Lake	20
Point aux Chenes Bay	10
Middle Bay	5
Total	9,204

leased acreage where dredges are allowed. May (1971) has mapped approximately 3,064 acres of reefs (Table 16).

Florida

Oyster production in the State of Florida has recently become significant, with a definite rise in production from the mid-1970's to 7.2 million lb reported for 1981 (see Table 12). Apalachicola Bay and St. George Sound contain 83% of the natural public reefs (6,965 acres) on the coast and are foremost in commercial production (Table 17). Some leasing occurs in Charlotte Harbor, Old Tampa Bay, and Choctawhatchee Bay. Since 1972, about 2,134.7 acres have been leased in the State. The southern most oyster reef in the United States is in Oyster Bay, which is immediately north of Cape Sable between Whitewater Bay and the mouth of the Shark River (McNulty et al. 1972).

Table 16. Natural (public) reefs along the Alabama coast (May 1971).

Areas	Acres
Kings Bayou	68.6
Cedar Point A	190.8
Cedar Point B	229.0
Cedar Point C	305.8
Cedar Point D	146.4
Cedar Point E	123.3
Cedar Point F	110.8
Cedar Point G	154.4
Cedar Point H	128.9
Buoy A	147.5
Buoy B	29.5
Sand A	28.9
Heron Bay C	98.6
Peavy Island	22.2
Shellbank	149.0
Bon Secour A	29.3
Bon Secour B	2.4
Bayou Cour	67.0
Fish River A	69.3
Fish River B	36.3
Klondike	160.7
Point Clear C-G	194.7
Point Clear	9.7
Hollingers Island B	7.9
White House A	41.3
White House C	139.5
White House D	24.4
White House F	62.9
White House G	80.5
White House M	6.9
White House H	67.4
Total	2,933.9

Table 17. Reef acreage on the west coast of Florida (McNulty et al. 1972).

Areas	Acres of natural reefs
Pine Island Sound	200
Charlotte Harbor	200
Lemon Bay	5
Sarasota Bay System	110
Tampa Bay	250
Old Tampa Bay	10
Saddle Key to S. Mangrove Point	30
Waccassa Bay	80
Suwannee Sound	110
Apalachee Bay	68
St. George Sound	3,365
Apalachicola Bay	3.600
East Bay (St. Andrew)	40
West Bay	16
North Bay	4
East Bay (Pensacola)	80
Escambia Bay	200
Total	8,368

CHAPTER 5. NATURAL AND CULTURAL PROBLEMS AFFECTING OYSTER REEF COMMUNITIES

5.1 INTRODUCTION

Because oysters are sessile and live in a dynamic environment, they are subjected to many stresses that can have devastating effects. Some of these stresses are natural and some are caused by human activities. Most disturbances can have serious effects in themselves, and some interact to produce long-term effects. Unstable salinity regimes, pollution, dredging, hurricanes, channelization, watershed projects, activities of the petroleum industry, diseases, and predators can all produce major adverse impacts upon oyster-reef communities.

5.2 PHYSICO-CHEMICAL STRESSES

Salinity

Salinity concentrations <5 or >15 ppt have adverse impacts on oyster-reef communities. Near the inland limit of the oyster's range, the biota of reefs is normally composed of relatively few species (marsh clam, mud crabs, blue crab, barnacles, etc.). Low salinities (<5 ppt) for several days will kill oysters but will also drive off or kill many oyster enemies such as oyster drills, stone crabs, and dermo (a protozoan parasite--see Section 5.3).

Oxygen

Oxygen depletion in the vicinity of oyster reefs can be caused by many factors, including decomposition of naturally occurring organic materials, or increased organic loads caused by sewage pollution. Oysters and other reef organisms may suffer from lack of oxygen as a result of being buried by excessive siltation caused by either natural sedimentation or by human activities. Low oxygen levels interfere with reproduction and spat settlement. Although Sparks et al. (1958) showed that oysters are able to survive for several days in water containing <1 ppm dissolved oxygen, May (1970) reported the loss of entire reefs in Mobile Bay due to almost total depletion of oxygen during summer months. Most oysters survived long periods of exposure to oxygen concentrations below 3 ppm, but high mortalities occurred when oxygen was about 1 ppm for 7 weeks. Oxygen depletion in Mobile Bay is an annual summer event. It is caused by several factors, including decreased mixing of waters by tides and currents, and the effect of higher temperatures causing higher rates of organic decomposition and subsequent oxygen demand.

Siltation

Burial of oysters by silt can be caused by either natural or altered sedimentary processes. Floodwaters carry heavy silt loads and can cover oyster reefs to a depth of several centimeters. Gunter (1969) stated that the ultimate fate of all oyster reefs is to become buried in the mud, due to filling of bays by natural geological processes. The Point au Fer Reef, off the mouth of the Atchafalaya River in Louisiana (probably the largest, at 18 km long, oyster reef on Earth in recent times) is now dead and covered with mud. Dredging and prop-wash (propeller turbulence) from large boats can also increase siltation on the reefs. Silt accumulation by oysters can also increase siltation on the reefs. Silt on oysters can inhibit reproduction, growth, and setting of spat, and causes mortality by smothering. Commensals which rely on oyster shells for attachment are similarly affected. Dunnington (1968) found that oysters covered by 75 mm of mud survived up to 5 weeks at winter temperatures (as low as 5 ‘C), but only 2 days at summer temperatures (25 ‘C), due to anaerobic conditions. Butler and Wilson (1963) exposed oysters to silt loads of 1.0 g/1 and found that this caused 30% to 50% decrease in shell growth. They showed that after 11 weeks of exposure to heavy silt loads, oysters immediately recovered when silty conditions were discontinued. The silty condition interfered with the feeding activities of oysters and resulted in a decrease of 25% in meat solids and a decrease of 30% in the condition factor of oysters. They also determined that the silt concentration tested caused no mortality within the time span studied.

Hurricanes

Hurricane Betsy in 1965 caused severe physical disturbance of reefs, and as a result, the oyster harvest in Louisiana was less than half the average (Schafer 1972). In August 1969, Hurricane Camille struck the Mississippi coast with winds of about 89 m/see. Since tide level was above normal when the hurricane struck, most reefs were not severely damaged, although some reefs were covered with mud. Oyster landings in Mississippi were greatly diminished, however, because of the destruction of oyster boats, factories, and shops (MacKenzie 1977).

5.3 DISEASES AND PARASITES

Various pathogenic organisms and parasites have been blamed for oyster mortalities. Some of these organisms use the oyster only as an intermediate host in their life cycle, causing little or no damage.

Dermo

Perkinsus marinus (previously identified as a fungus, Dermocystidium marinum, and also as Labyrinthomyxa marina) was first described by Mackin et al. (1950). This protozoan parasite has caused extensive mortalities in oysters all along the gulf coast. Although dermo is found year round in a wide range of salinities (6 to 36 ppt), Hofstetter (1977) reported that infection incidence was lowest in winter and increased in mid-spring, dropped in early summer as salinities decreased, then climbed to an annual peak in mid-summer in higher salinities. Quick and Mackin (1971) concluded that high temperatures, rather than high salinities, are more important in causing high rates of parasitism by dermo. Among market-size oysters in Texas, annual mortality rates ranged from 40% to 50% (Hofstetter 1977), which was similar to rates found by Quick and Mackin (1971) in Florida. Joyce (1972b) stated that dermo could wipe out 100% of adult oysters "almost overnight." Ray (1954) reported finding the parasite in *Ostrea frons* from Florida and *O. equestris* from Texas. Hoese (1964) found it in the digestive tracts and feces of fish, oyster drills, and crabs that had fed on dying and dead infected oysters. He thought that the pathogen might be transmitted by these scavengers, and that they helped to release the parasite from host tissues.

Nematopsis

Nematopsis ostrearum, a gregarine sporozoan parasite of oysters, was thought to be the cause of extensive mortalities in Virginia and Louisiana (Prytherch 1938, 1940), but Owen et al. (1952) found no correlation between *Nematopsis* and oyster mortalities in Louisiana. Hofstetter (1977) reported the parasite being found in 99% of some oyster samples in Texas, but did not indicate that *Nematopsis* was a cause for higher mortality rates.

Burrowing Clam

The burrowing clam *Diplothyra smithii* is a common inhabitant of the calcareous shell material of oysters. This organism is often considered a parasite, but studies have shown that it does not necessarily prefer live oyster shells because similar numbers are found in dead shells. Chestnut (1981) found 77% of live oysters and 44% of dead shells in Mississippi Sound infested with this organism, with an average infestation of about 23 clams per shell, ranging up to 109 per shell. The burrowing clam does not kill the oyster outright but weakens the shell, making the oyster more susceptible to diseases and predation. Chestnut (1981) determined that metamorphosis of the clam is induced by seasonal temperature changes, noting an annual cycle during which clams set in the summer or early fall and reached morphological maturity during the following spring and summer.

5.4 PREDATORS

Many arthropods, mollusks, and fishes prey upon oysters of various sizes, often causing extensive damage.

Crabs

May (1974) stated that xanthid mud crabs are important associates in oyster communities as predators, scavengers, and as hosts for oyster parasites and diseases. He found that many reefs have more mud crabs than oysters and spat combined, and that the crabs are most abundant in salinities above 15 ppt. Populations of the mud crab *Eurypanopeus depressus* were as high as 143,000/ha, while the number of stone crabs associated with oyster reefs in

Mobile Bay was as high as 1,586/ha. Menzel and Hopkins (1954) found stone crab densities up to 8,645/ha in Terrebonne Parish, Louisiana. In experiments, they determined that stone crabs could kill oyster spat at the rate of 10 per day, and that all sizes of oysters were killed at the rate of 200 oysters per crab per year. Powell and Gunter (1968) conducted experiments which showed that stone crabs preferred acorn barnacles (Balanus eburneus), small oysters, and spat over larger oysters. Blue crabs and hermit crabs also feed upon spat and small oysters, as well as mussels and other organisms attached to oyster shells.

Oyster Drill or Conch

The oyster drill, Thais haemostoma, is a predator of oysters of all sizes. Chapman (1959) showed that drills destroyed most of the spatfall on depleted reefs and about half of the spat and larger oysters on more densely populated productive reefs in Mississippi Sound. May and Bland (1969) observed that during a 9-month period, drills destroyed over 85% of the oysters in a high salinity area in Mobile Bay. The drill does not feed exclusively on oysters, but feeds readily on other mollusks in the reef community. Breithaupt and Dugas (1979) estimated that a population of 100 drills could destroy 1,400 to 2,700 oysters per year. This is a significant amount, since May (1972b) reported finding over 27,000 drills/ha on some reefs in Mobile Bay. Fortunately, since drills are generally intolerant of salinities <15 ppt, periodic springtime freshets can eliminate them from productive reefs for several months. Because of its longevity and lack of natural enemies, the drill will remain a serious problem on reefs in higher salinity areas. Butler (1961) found a mortality rate of 66% for oyster drills over a 6-year period. Surviving snails participated in six annual breeding seasons, with fecundity undiminished among survivors. He estimated that a single female could have produced over 17 billion reproducing offspring during that time, assuming a survival rate of only 0.01%.

Fishes

Several fishes feed upon oysters and other reef organisms, as shown by direct observations and stomach analyses. In a study of fishes in the Biloxi Marsh complex in Louisiana, Fontenot and Rogillio (1970) determined that 14% of sheepshead (Archosargus probatocephalus) stomachs and 38% of black drum (Pogonias cromis) stomachs examined contained oysters and/or clams. Large populations of black drum can nearly wipe out an oyster reef, especially spat and freshly transplanted seed oysters, in a matter of days. Cave (1978) found that in laboratory tank studies large black drum would consume approximately two oysters per kilogram of fish weight per day. Years ago, Louisiana oyster fishermen would often screen off productive reefs, using chicken wire fencing, in an effort to prevent destruction by black drum. In Mississippi Sound, Overstreet and Heard (1982) studied digestive tracts of fishes and found mussels and mud crabs in black drum and sheepshead, and also found hydroids, slipper shells, burrowing clams, barnacles, and tunicates in sheepshead --all common oyster reef inhabitants. Oysters are also eaten by toadfishes and some rays. Before they settle out of the water column as spat, planktonic oyster larvae are susceptible to substantial predation by many small fishes.

5.5 CULTURAL DISTURBANCES

Man has seriously impacted oyster reef communities all along the gulf coast. Sewage and industrial pollution, channelization projects, petroleum exploration and production, shoreline housing developments, dredging, and other activities have either destroyed or forced the closure to harvesting of thousands of hectares of productive reefs. Throughout the gulf, human alterations of wetlands and subsequent pollution have closed about 320,000 ha of shellfish beds (Anon. 1982).

Pollution

Many viruses and bacteria are known to inhabit oyster tissues. Because oysters are filter feeders, they can concentrate viruses to at least 60 times the numbers found in surrounding waters (Mitchell et al. 1966). In November 1982, over 500 cases of gastrointestinal illness in Louisiana were tentatively linked to the consumption of raw oysters, with a virus thought to have been the causative agent. This led to the closure of harvesting for over half the productive reefs in the State during the peak holiday season, when oysters are normally in great demand. The publicity concerning the outbreak caused considerable public avoidance of oyster consumption, severely damaging the industry. Untreated sewage from some coastal communities was thought to be the source of contamination.

Such events have not been restricted to Louisiana. Periodically, all Alabama reefs are closed to harvest because of pollution, sometimes for over 100 days during the peak of the oyster season (May 1972b). Effects of closures in Mississippi have been documented by MacKenzie (1977). Pollution problems can be corrected by proper sewage treatment and disposal, but it will take a concerted effort by all gulf coastal communities and pollution regulatory agencies.

Hofstetter (1974) reported on closures in Lavaca Bay, Texas, as a result of mercury contamination in oysters and crabs. The mercury came from aluminum plant wastes. Zinc, cadmium, pesticides, hydrocarbons, and PCB were also detected. Calabrese et al. (1973) determined the toxicity of 11 heavy metals to oyster embryos, and found lethal concentrations of 0.0056 ppm for mercury, 0.31 ppm for zinc, and 3.80 ppm for cadmium. These metals have been known to cause nerve and reproductive disorders in humans.

Various agricultural pesticides have been shown to inhibit growth in oysters, in concentrations as low as 10 ppb, after only 24 hours of exposure (Butler et al. 1962), but they are not stored by the oyster. Recovery of normal growth rates takes place when the pollutant is removed from the environment. During the mid-1960's, 18 of 43 oyster samples from Louisiana waters were found to contain one or more chlorinated pesticides at levels of 10 ppb or higher (Hammerstrom et al. 1967).

Channelization, Dam Construction, and Dredging

These activities have had drastic effects on oyster reef communities. During channel construction, siltation rates are greatly increased and oyster reefs have been buried by silt deposits. Sykes and Hall (1970) found an average of 60.5 live mollusks and 3.8 mollusk species in samples from undredged areas of Boca Ciega Bay, Florida, but an average of only 1.1 individuals and 0.6 species in dredged canal samples. Saltwater intrusion generally occurs as a result of channelization in coastal areas, allowing the increased incidence of oyster drill predation and infection by pathogens such as dermo. These effects are reversed only for brief periods when freshets occur, reducing salinities to <15 ppt.

Petroleum Exploration and Production Activities

Several different petroleum-related activities impact oyster reef communities, beginning with seismographic operations by geologists looking for promising drilling sites. The movement of heavy drilling equipment by large tug boats through shallow estuaries can produce extensive damage from siltation caused by prop wash, burial of reefs by direct contact of heavy barges, and the chopping up of organisms by boat propellers as they move the deep draft equipment barges through shallow waters. Gowanloch (1934) observed heavy oyster mortality relative to oil well developments in Louisiana's estuarine areas over 50 years ago. Cabrera (1971) found that drilling fluid (a mixture of clay, diesel, and water), in concentrations above 200 ppm, reduced the survival of oysters to a significant degree. Even when oysters are not killed by oil spills, they can develop oily off-flavors which prevent their sale. Within 1 to 2 months after oil pollution is eliminated from the environment, the oysters depurate and off-flavors disappear. If the pollution occurs during the spring harvest season, a delay in harvest until summer months may allow increased mortalities to occur from oyster drills and dermo, as a result of increasing salinities. Pipeline construction from well heads through estuaries to onshore storage and processing facilities cause additional problems due to siltation and subsequent burial of reef organisms.

CHAPTER 6. MANAGEMENT CONSIDERATIONS

6.1 SUMMARY OF THE PROBLEMS

The coastal estuarine ecosystems and the associated oyster populations of the Gulf Coast States have been impacted and reduced by alterations of several origins. Although some of these changes have been natural, the majority have been human made. Oysters are nonmotile creatures which may form massive reefs and, as such, are highly susceptible to alterations of their environment.. Some of the problems that affect oyster communities and that are of importance to management are addressed below.

Recruitment

A limiting factor for any population is recruitment to that particular community. Recruitment is particularly important in a warm environment where growth is rapid and life expectancies are reduced. This factor is of major concern to the fisheries of both natural and cultivated oyster reefs. The supply of young oysters results not only from a reef's overall abundance but also from the consistency of recruitment to the reef. The problem of supply to the fishery has become more critical in recent years because of the total or partial failure of the recruitment to the oyster population along the gulf coast in the late 1970's. Similar spawning failures have spelled disaster to oyster populations on the east coast. Improved hatchery techniques oriented toward present fishery practices combined with research emphasis on genetic selection for disease resistance and improved growth rates may provide a feasible means of compensating for seed shortages.

Space

Much of the once productive acreage for the propagation and growth of the American oyster on the gulf coast has been severely impacted by salinity encroachment, displacement as a result of channelization, and contamination due to pollution. The surrounding areas, as well as the oyster reefs themselves, have been impacted.

Salinity encroachment, either through lack of freshwater input or hydrologic changes within the estuaries, and the corresponding upstream movement of oyster populations, have been observed and documented along the Louisiana coast (Pollard 1973; Van Sickle et al. 1976). Large thriving oyster populations along the gulf coast are indicative of a steady supply of freshwater.

Dredging problems are, for the most part, associated with access to this fragile environment. There is a substantial amount of dredging associated with locating, producing, and transporting oil and gas along the gulf, particularly in Louisiana. Dredging can be destructive to the oyster community and to surrounding communities supportive of the oyster. In addition to direct removal of oyster habitat, siltation caused by the dredging process can have adverse effects on the beds. Pollutants can not only render some areas unsuitable for oyster survival, but can also affect oyster harvesting. If the waters over oyster beds do not meet acceptable health standards, those areas are closed to harvesting. A sizeable portion of suitable oyster habitat along the gulf coast is closed to oyster harvesting because of pollution.

6.2 MANAGEMENT PRACTICES AND IMPLICATIONS

There have been intensive nationwide attempts to reduce the effect of human alteration of the environment. Within the coastal zone, one method used has been to appoint a control group to oversee coastal activities. The Gulf Coast States have individually enacted legislation establishing a permitting system to reduce and partially control marsh destruction, and to provide valuable information on ways to reduce the inevitable damages which result from heavy multiple use of the area. If wildlife and habitat protection were the only considerations for management, then a program of wetland expansion and restoration could easily be implemented. The importance of the area for many commercial, industrial, and recreational uses, however, makes management more complex. Thus, the goal of management becomes a role of maximum reduction of damages.

Oysters are naturally susceptible to environmental alterations and because different reefs and areas have individual assets, a single overall management plan for the Gulf of Mexico is difficult to construct. There are, however, certain salient points that apply in general.

Because of the length of time necessary to establish an oyster reef, the larger and more substantial reefs should be protected from direct destruction. The surrounding area should also be very closely managed because changes there can affect the nearby oyster communities. Management of spawning areas will require their identification, maintenance, and protection.

Those engaged in activities associated with the search for and production of oil and gas are certain to be among the major applicants for permits within the coastal ecosystems. In addition to the alteration of a proposed exploration site, the routes to and from the site are heavily impacted or destroyed. This impact is the result of dredging to permit the transport of heavy equipment to the site and construction of pipelines away from the site. Thus, formulating a comprehensive plan for permitting entire fields and not just individual locations and corridors should be considered.

A supply of freshwater with its associated nutrients is vital to the oyster reef community. The protection and regulation of the watershed are important for the maintenance of the water supply and for limiting pollution. Restriction and discouragement of development in the coastal area should be based on such considerations.

The Gulf States fisheries managers individually administer to their problems and resource difficulties; Appendix 3 gives a summary of the Gulf State laws. The Gulf of Mexico Fisheries Council was formulated in response to Federal congressional action to manage fisheries to the 200-mi fishing limit. Regulations enacted by the Council have not yet had an effect on the gulf oyster beds. A casual inspection of the laws (Appendix 3) reveals the wide differences in public policies relating to shellfish culture among the Gulf Coast States. There are even wider disparities among the national oyster producing States (Table 18) which may be due, in part, to different environmental as well as social conditions. The capacity of the oyster bushel within the oyster-producing States is also variable (Table 19).

All oyster-producing States are required to certify the quality of their waters for oyster harvesting. States are required to close (prohibit harvesting) oyster areas when bacteria counts exceed allowable limits. These limits are prescribed by the National Shellfish Safety Program and utilize coliform bacteria as the indicator organism. "Coliform group" includes all the aerobic and facultative anaerobic, gram-negative, nonspore-forming bacilli which ferment lactose with gas formation within 48 hours at 35 ‘C. Each State has the option of certifying based on total coliform or fecal coliform.

The standards for each count are as follows:

(1) The total coliform median MPN (Most Probable Number, a statistical estimate of the number of bacteria per unit volume) of the samples shall not exceed 70 per 100 ml, and not more than 10% of the samples shall exceed an MPN of 230 per 100 ml for a 5-tube decimal dilution test or 230 per 100 ml when the 3-tube decimal dilution test is used; and

(2) The fecal coliform median MPN of the samples shall not exceed 14 per 100 ml, and not more than 10% of the samples shall exceed an MPN of 43 for a 5-tube decimal dilution test or 49 for a 3-tube decimal dilution test. The 5-tube decimal dilution test should be used for determining fecal coliform MPN values. All of the Gulf States shellfish-certifying agencies have selected the fecal coliform standard.

In addition to the direct program for water certification, there are a number of congressional acts dealing with water quality and the allowable levels of pollutants. Some of them are the Clean Water Act of 1972 (PL 92-500), amended in 1977 (PL 95-217) and 1987 (PL 100-4); the Resource Conservation and Recovery Act of 1976 (PL 94-580) amended by Solid Waste Disposal Act Amendments of 1980 (PL 96-482) and amended again in 1984 (PL 98-616); and the Toxic Substance Control Act of 1976 (PL 94-469), amended in 1981 (PL 97-129), 1983 (PL 98-80), 1984 (PL 98-620), 1986 (PL 99-519), and 1987 (PL 100-11 and PL 100-202). There is presently an Interstate Shellfish Sanitation Conference held annually at which health officials review common problems and seek solutions.

Table 20 provides an indication of the magnitude of contamination. Verber (1981) examined classification data of the individual states

Table 18. Comparison of leasing practices in Atlantic and Gulf States (information current as of November, 1982).

State	Leasing permitted	Annual fee $/acre	Period of lease	Penalty for non-use	Acreage limit	Dredging permitted	Tax on landings	Bottom use required for maintaining lease
Florida	yes	$5.00	10 years	forfeit	none	yes	none	cultivation
Alabama	yes	$1.00	5 years	forfeit	none	yes	$0.03/bushel	cultivate 25% each year
Mississippi	yes	$1.00	indefinite	forfeit	5-100	yes	$0.065/bushel	demonstrate cultivation
Texas	yes	$2.25	1 year	none	100	yes	$0.10/barrel	cultivate within 5 years
Louisiana	yes	$2.00	15 years	forfeit	1,000	yes	$0.025/barrel	cultivate 10%/year
	moratorium							
Georgia	yes	bid	5-10 years	forfeit	none	yes	$0.050 ton	none
South Carolina	yes	$1.50	5 years	forfeit	1,000	yes	none	plant 65 bushels/acre/year
North Carlina	yes	$5.00	10 years	forfeit	50-200	yes	$0.08/bushel	25 bushel/acre/year
	moratorium							
Maryland	yes	$3.50	20 years	forfeit	30-50	yes	none	demonstrate some cultivation
Virginia	yes	$1.50	10 years	forfeit after expiration	5,000: bay 3,000: other	yes	$0.03/bushel	cultivation after 10 years
Potomac River	no							
Delaware	yes	$0.75	no limit	forfeit	no limit	yes	$0.15/bushel	cultivation within 10 years
New Jersey	yes	$1.50/bay $2.00/ coast	30 years	special bay area only	none: bay 2: coast	yes: bay no: coast	none	none
Connecticut	yes	bid	3-10 years	none	none	private: yes natural: no	none	none

Table 19. Oyster bushel measurements for the individual oyster producing states.

State	Capacity of state bushel (cubic inches)
Maine	2,150.4[a]
Massachusetts	2,150.4[a]
Rhode Island	2,150.4[a]
Connecticut	2,150.4[a]
New York	2,150.4[a]
New Jersey	2,257.3
Delaware	2,257.3
Maryland	2,800.7
Virginia	3,003.9
North Carolina	2,801.9
South Carolina	4,071.5
Georgia	5,343.9
Florida, East Coast	3,214.1
Florida, West Coast	3,214.1
Alabama	2,826.2
Mississippi	2,826.2
Louisiana	2,150.4[a]
Texas	2,700.0

[a]U.S. standard bushel.

Table 20), however, and noted that the approved area acreages nationwide have steadily increased from 1971 through 1980. The approved shellfish harvesting areas increased by nearly 200,000 acres nationally. Nevertheless, as pointed out in the 1980 survey, the Gulf Coast States did not follow the national trends. Florida, Alabama, and Louisiana all experienced substantial losses of approved growing waters. The State of Texas remained virtually stable with only minor amounts of acreages shifted within categories, and Mississippi showed considerable improvement. Table 21 includes information on classification of various estuarine systems.

A positive and innovative approach is being developed by a group of Mississippi fishermen with the assistance of State officials. The oyster harvesters move oysters from nonapproved waters to approved waters for deputation purposes. A system of containerized relaying (Figure 22) was developed and appears to be working. This process became necessary as stocks were reduced in approved areas and vast amounts of oysters remained. This method is still in the experimental stage, but seems to be economically feasible.

Throughout history, humans have attempted to alter the land to suit their needs, often with little regard for future ramifications. In the lower Mississippi River Valley of Louisiana, these changes have included leveeing,

Table 20. Oyster harvesting areas which do not meet the national standard based on fecal coliforms contamination. From Verber (1981).

State	Year	Acreage approved	Acreage prohibited	Conditional	Total acreage affected
Texas	1980	817,819	324,418	0	324,418
	1974	822,447	316,839	0	316,839
Louisiana	1980	1,371,215	389,532	20,650	410,182
	1974	2,000,117	432,490	0	432,490
Mississippi	1980	120,201	98,840	171,213	270,053
	1974	76,232	27,678	0	27,678
Alabama	1980	73,919	103,736	193,468	297,204
	1974	81,937	85,589	187,513	273,102
Florida	1980	512,277	292,484[b]	110,281	402,765
(entire state)	1974	663,126	1,024,966	84,099	1,109,065
Entire	1980	10,684,842	2,891,207	586,807	
United States	1974	10,487,997	3,789,671	335,296	

[a]An average acre of reef within the proper environmental conditions on the gulf coast should produce about 200 to 500 sacks per acre.

[b]According to the National Sanitary Shellfish standards, when an area is not classified or sampled it is considered closed to shellfish harvesting.

draining, and clearing vast areas for agriculture and habitation purposes. Prior to public levee construction on the Mississippi River, which began in response to the flooding of the settlement of New Orleans in 1717, the river annually overflowed its natural banks for many miles on either side. The sedimentation from these yearly floods generally exceeded the total attrition from processes of erosion, compaction, and subsidence, so that the shoreline advanced seaward.

The present sub-delta estuarine marsh zone adjacent to the Mississippi River was developed and maintained for centuries by the massive volumes of sediment-laden freshwater from the river and its distributaries. This zone is currently marked by change. In recent years, river flows of about 450,000 ft^3/sec have carried an average of 300 million tons of suspended sediments per year to be dumped offshore or deposited in deep holes near the river mouth (U.S. Army Corps of Engineers 1970). The sediment therefore has not been involved in the building and maintenance of marshes. In fact, through the combined processes of subsidence, compaction, and erosion, Louisiana is reportedly losing 40-50 mi^2 of vegetated coastal wetlands every

Table 21. Classification of oyster producing waters, by estuary (1985) (Broutman and Leonard 1988).

Estuary	Area (acres) Approved	Approved/ Conditional[a]	Conditional	Prohibited	Administr. Closures[b]
Florida					
Ten Thousand Islands	27,737	0	0	17,123	0
Charlotte Harbor	55,122	0	20,916	36,449	0
Caloosahatchee River*	0	0	0	3,252	0
Tampa Bay	5,509	18,507	0	32,269	0
Suwanee River	6,193	0	7,982	2,209	0
Apalachee Bay	0	11,740	1,765	7,560	0
Apalachicola Bay	490	0	101,624	10,096	0
St. Andrew Bay	0	31,017	6,335	26,409	0
Choctawhatchee Bay	0	52,725	0	9,659	0
Pensacola Bay	0	39,606	0	54,186	0
Alabama					
Perdido Bav	0	0	0	0	17,452
Mobile Bay"	0	0	175,487	84,680	0
Mississippi					
Mississippi Sound	76,888	120,083	189,958	96,749	0
Louisiana					
Lake Borgne	187,726	0	55,089	7,289	0
Lake Pontchartrain	0	0	0	454,400	0
Chandeleur/Breton Sounds	982,021	0	27,544	9,154	0
Mississippi Delta	13,984	0	5,086	186,963	0
Barataria Bay	101,279	0	23,137	2,712	0
Terrebonne/Timbalier	240,272	0	20,256	2,882	0
Caillou Bay	57,631	0	31,358	20,849	0
Atchafalaya/Vermilion	12,543	0	120,772	326,295	0
Calcasieu Lake	25,002	0	0	31,613	0
Sabine Lake	0	0	0	0	69, 183
Texas					
Galveston Bay	0	170,840	0	179,524	0
Brazes River	0	0	0	1,479	0
Matagorda Bay	0	212,353	0	27,565	0
San Antonio Bay	0	136,849	0	15,521	0
Aransas Bay	63,448	50,003	0	22,134	0
Corpus Christi Bay	109,213	0	0	35,084	0
Laguna Madre	508,159	0	0	34,524	0
Baffin Bay*	47,121	0	0	12,699	0
Gulf of Mexico Total	2,473,218	843,723	787,309	1,735,377	86,635
Percent of Total	42	14	13	29	1

* Estuaries with asterisks are subsystems of larger estuarine systems.
a/ Areas classified as approved but subject to temporary closure, usually after rainfall.
b/ Not classified on the basis of a sanitary survey.

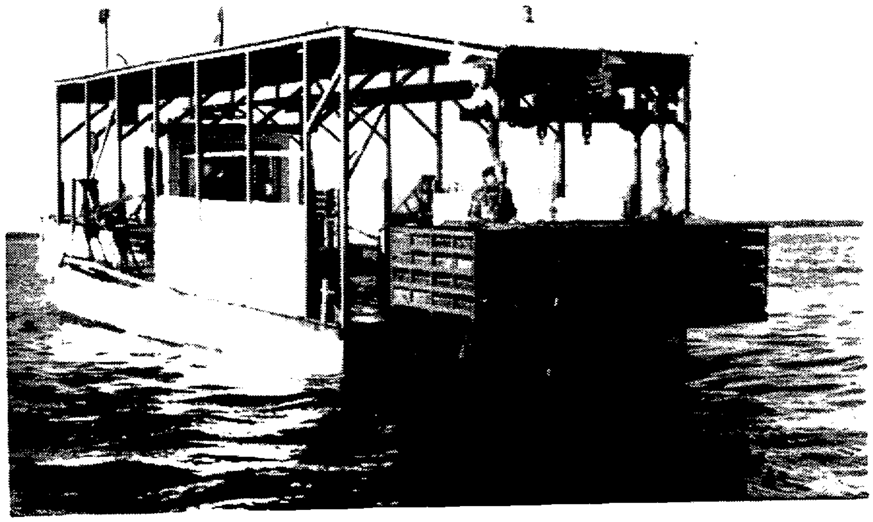


Figure 22. Containerized relaying as practiced in Mississippi.

year. Furthermore nutrient flow to the marshes and coastal waters is impeded by reduced freshwater input through flood control and navigation improvements, and water chemistry in the coastal areas is altered as average salinities rise.

The levee, lock, and flood-dam systems were designed to keep water in the river channels, but in recent years there has been a concerted effort in Louisiana to use these structures to divert freshwater from the Mississippi River into some marsh areas. Other structures specifically designed for controlled freshwater diversion are in various stages of planning and construction. Proper manipulation of the sediment and nutrient supplies to the marshes may help slow the rate of marsh loss and increase associated oyster production.

The shunting of freshwater to marshes and coastal waters lowers the salinity in these areas by varying degrees. Since the establishment of an oyster reef depends on having a low-to-moderate salinity regime, a flow-management program should be designed to maintain optimum salinity in areas well-suited for oyster habitat. There is, of course, the possibility that diverting freshwater to one area may result in increased salinities in other areas, in turn, making them unfit as oyster or other resource habitats. Fishery managers must recognize that what is beneficial to one area may be deleterious to another.

One extensively used method to increase reef acreage, and thus the space available within the optimum environmental zone, is to plant cultch material. Several types of cultch materials are used along the gulf coast. Commonly used *Rangia* clam shells are good cultch material and are desirable for several reasons including abundance, availability, relatively low cost, ease of planting (Figure 23) and a characteristic single or double oyster set per shell. Shell plantings in Louisiana have generated seed (about 3 cm oysters) oyster densities in excess of $900/m^2$ (Kilgen and Dugas, pers. ohs.). Florida has, on numerous occasions, utilized limestone because of its availability in that State. Louisiana is presently exploring the acceptability of limestone (Chatry et al. 1986) and preliminary results indicate sets averaging twice the density of those on *Rangia* shells. If cultch planting is properly timed to catch the maximum spatfall, the supply of seed oysters will be increased. The cultch planting program has been very successful along the gulf coast and has been carried out on a large scale in Louisiana since the early 1920's. The site for a shell plant is ideally selected after careful and extensive evaluation of the bottom conditions and other environmental conditions. The actual deposition of cultch should be timed very closely with the presence of oyster larvae in the water column.

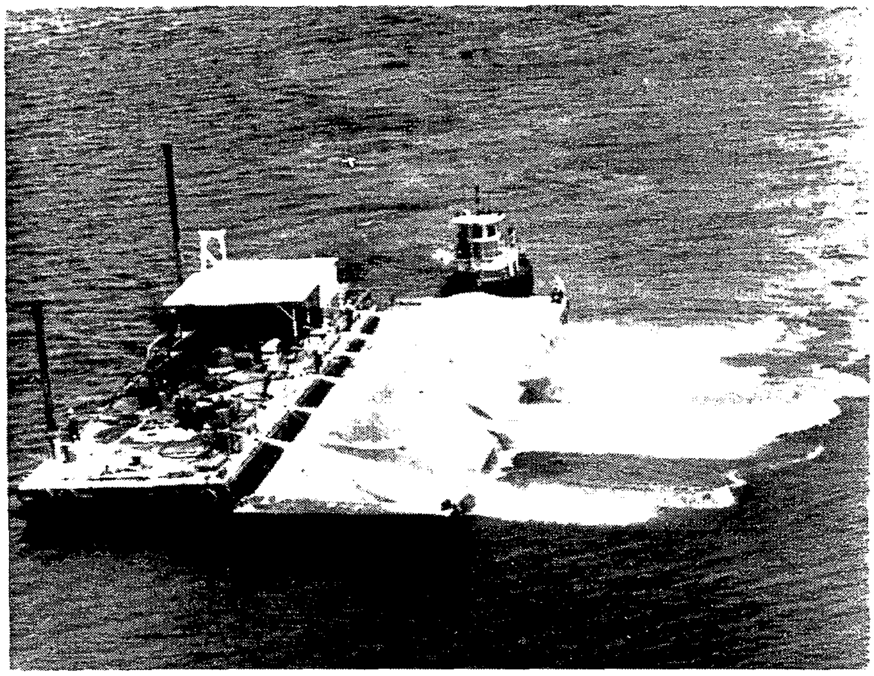


Figure 23. Shell planting operation in Louisiana.

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APPENDIX I

TAXONOMY OF OYSTERS

This appendix gives the taxonomy of oyster species present in the Gulf of Mexico, classified according to Abbott (1974].

Phylum Mollusca

Class Bivalvia (Pelecypoda)

This class includes clams, mussels, scallops, and oysters dwelling in either fresh, brackish, or marine waters. They are generally composed of a shell divided into two valves which are connected or hinged by a horny ligament and are moved by the contractions of one to three adductor muscles attached to the inner side of the valves. They are bilaterally symmetrical animals having a rudimentary head without eyes or tentacles and bodies compressed laterally. Feeding is usually done with the aid of a ciliated gill. There is also a mantle extending to the margins of the shell, which secretes the shell and forms a large mantle cavity.

Order Pterioida (Filibranchia)

The order Pterioida is one of four orders of bivalves, each distinguished by the structure of its gills, and includes pearly and winged oysters, scallops, and the true oysters. This order is characterized by paired gills that are generally long and folded back on themselves to form four demibranches interconnected by tufts of cilia. The mantles in these mollusks have taken over the sensory functions of the molluscan head, including some visual or light-sensing capacity.

Family Ostreidae

This family includes a large number of edible and nonedible oysters. They are generally restricted to shallow coastal waters. The oysters in this family have unequal valves with no hinge teeth except in the prodissoconch (larval shell). In all but their larval stages, oysters have completely lost their byssus and foot and have retained only the posterior adductor muscle.

Genus Ostrea

At one time this genus included all oysters, but today several genera are recognized. All of these oysters are relatively small. The eggs are fertilized and developed within the mantle chamber and gills. Usually about a million eggs are produced at one spawning. The prodissoconch hinge is long; the valves are symmetrical. In the adults, the adductor muscle scar is near the center of the shell and is not pigmented

Ostrea equestris

This small noncommercial oyster of the gulf is often mistaken for young C. virginica. The shell is small, with transverse wrinkles and more or less deep and angularly folded "longitudinal lateral margins near the hinge with from 6 to 12 denticulations of the superior valve. The oyster is hinged very narrowly and curved laterally and abruptly.

Ostrea frons

The shell is small (l-2 inches in height) with radial plicated sculpture and sharply folded margins and is white on the interior and purple-red on the exterior. The valves are closely set with minute denticles almost around the entire circumference. The adductor muscle scar is near the hinge. The beak is slightly curved. This oyster frequently attaches to branches or roots of mangrove trees by a variety of hooked projections. It is common in Florida, Louisiana, and the West Indies.

Ostrea edulis

This European oyster is the type species of the genus Ostrea. Individuals are either round or oval. The left valve is larger and deeper and bulges slightly, with 20 to 30 ribs and irregular concentric lamellae. Upper valve smaller, flat, without ribs, with numerous concentric lamellae. The beak is poorly developed. The ligament consists of three parts; the middle part is flat on the left valve and forms a projection on the right valve. The adductor muscle scar is concentrically located, and is unpigmented. The promyal chamber is absent. This is a hermaphroditic and incubator mollusk and discharges eggs into the gill cavity. The ostia and eggs are relatively large. Small numbers of these European flat oysters were successfully introduced several years ago into the coastal waters of the east coast.

Genus Crassostrea

In this genus, the left or attached valve is larger than the right, and the inner margin is smooth. Females produce a large number of small eggs at one spawning; the eggs are fertilized and develop in the open water outside of the parents. The muscle scar is usually colored. The prodissoconch hinge is short, and the valves asymmetrical. They also possess a distinctive asymmetrical space between the right mantle and gill places, known as the promyal chamber.

Crassostrea virginica

The American or eastern oyster is the principal edible *oyster* of the Atlantic and gulf coasts of the United States and is the main topic of this treatise. It occurs from the Gulf of St. Lawrence to the coastal areas of Central America. The right valve (upper) is generally smaller than the left. The beak is elongated and strongly curved. The valve margins are straight or only slightly undulating. The adductor muscle scar is usually deeply pigmented and is located asymmetrically, well toward the posterodistal border. The oyster's large promyal chamber is on the right side. When reproducing, it is nonincubatory, discharging eggs and sperm directly into the water. Adults vary from 2 to 14 inches in height (dorsoventral direction) depending on age and environment. Shape, sculpture, and pigmenta-ion of inner side of the shell and along the edges of the mantle and tentacles vary greatly.

Crassostrea rhizophorae

This oyster has a light, thin, foliaceous, and deeply cupped shell with a smaller flat upper valve fitting into the lower valve. The inner margins of the shell are straight and smooth with considerable purple coloration especially around the left valve. The beak is twisted dorsally, and its adductor muscle scar is near the dorsal margin. A promyal chamber is present. The oyster is nonincubatory, discharging eggs and sperm directly into the water column. *Crassostrea rhizophorae* differs from *C. virginica* in the following ways: the lower left valve is less plicated than in *C. virginica* and the adductor muscle scar is more' rounded and often unpigmented. Adults may reach 4 inches in height. The oyster frequently attaches itself to the aerial roots of the mangrove, *Rhizophora mangle*, It has been reported in the high salinity areas of Florida and the Laguna Madre areas of Texas.

Crassostrea gigas

This species is commonly referred to as the Japanese or Pacific oyster. Cuplike shells of large size with coarse and widely spaced concentric lamellae and coarse ridges on the outside; shells usually much thinner than those of *C. virginica*. Upper (right) valve flat and smaller than lower (left) valve. Interior surface white. often with faint purplish stain over the adductor muscle scar or near the edges. The large promyal chamber is on the right side. Edges of the mantle are deeply pigmented. As with other oysters of this genus, this oyster is nonincubatory, discharging a very large number of eggs and sperm directly into the water. It was introduced from Japan into the waters of the U.S. Pacific and Atlantic coasts as well as the gulf coast.

APPENDIX 11

GENERAL METHODS OF OYSTER HARVEST AND MARKETING

Oyster harvesting in the Gulf of Mexico is carried out by either tonging or dredging. Oyster tongs are two rakelike heads with sharp teeth attached to two long wooden shafts (Figure A-l). The shafts are placed in a scissor-like fashion opposite each other so that the heads form a small basket when closed. The handles used on the gulf coast are generally 9 to 12 feet long, although some can be as long as 32 feet. The oyster harvester stands upright in the boat, which generally has a free-board of 2 to 4 feet, and works the handles open and shut gathering in the oysters from the reefs. The oysters are brought up, deposited on a washboard, culled, and sacked.

The other means of fishing oysters employed on the gulf coast is the use of the oyster dredge (Figure A-2). Like the tongs, this is an ancient means of fishing which has been improved upon very little over the years. The dredge is the primary method of harvesting and is certainly the more efficient of the two . Like the tongs, dredges employ a rake design. A rakelike set teeth along a bar forms the leading surface on a heavy iron cage. The dredge bag is made of iron rings on the lower side and nylon netting on the top. The entire mechanism is dragged along the bottom with the use of rope, or in the case of large dredges, with the use of a chain. For dredge retrieval, the vessel's engine power drives a drum located in the middle of the deck which, in turn, respools the chain and dredge. Generally, an oyster boat is equipped with two dredges, both about 6 ft wide. From the middle of the deck, the winch assembly is capable of handling both dredges. There are problems associated with the use of a dredge, the majority of which result from improper use. Dredging disturbs the oysters to the point that they stop feeding; it also suspends sediments which impairs feeding and causes chips or breaks of the oyster shell.

Oyster harvesting on the gulf coast is accomplished with the use of an assortment of vessels ranging from rowboats and converted shrimp vessels to large 80 foot oyster luggers. In Louisiana, boats are specifically designed for oyster harvesting and are used almost exclusively by the full-time harvester. These boats are flat decked and are about 50 to 80 ft in length. They are usually equipped with moveable, stacking side boards for holding large piles of seed oysters and sack oysters in a confined, foredeck space.

As mentioned above, tongs and dredges are used to harvest most of the oysters landed in the Gulf States. Most Louisiana and Texas fishermen use dredges, whereas most oyster harvests in Florida and Alabama are hand tonged. Both methods are used in Mississippi. For 1972, National Marine Fisheries

Figure A-1. Oyster tongs.

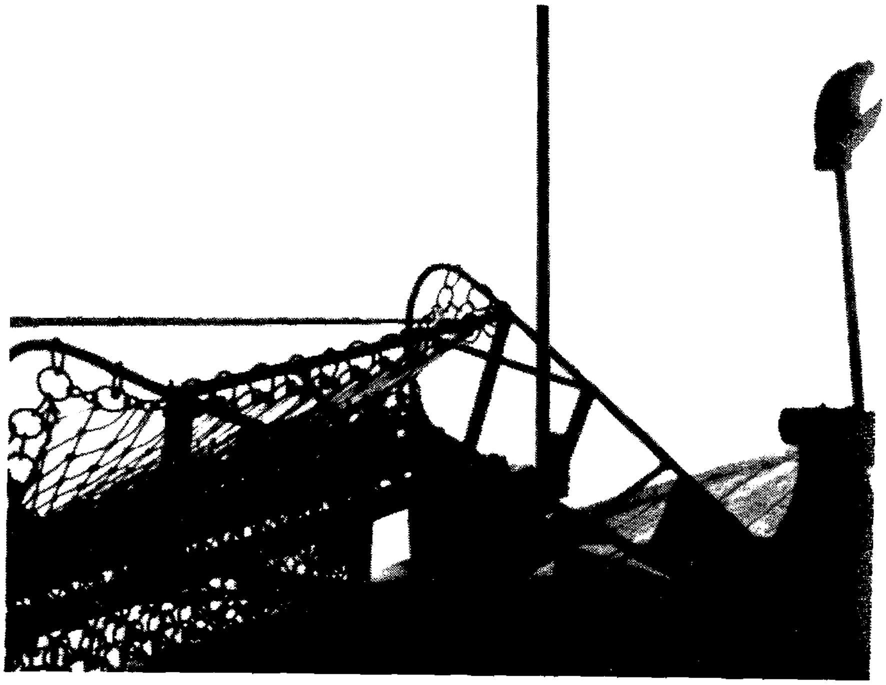

Figure A-2. Gulf coast oyster dredge.

statistics showed that 1,374 dredges and 1,769 tongs were used to harvest 72% and 27% of the Gulf States production, respectively. In recent years, the trend in percentage of production might be expected to have shifted slightly to tonging with the increase in Florida's production, but tonging is a more labor-intensive harvest method than dredging. We therefore assume that the 1972 production figures for each method are accurate for today's fisheries.

Employment in the oyster fishery ranges from full time to part time. Most Louisiana oyster farmers work oysters on a full-time, year-round basis and are considered to be efficient and productive at their trade. In Texas and Mississippi, most of the oyster harvesting is done by fishermen who are primarily shrimpers. In Florida's largest oyster producing area, Apalachicola Bay, many people are engaged principally in oystering.

Oysters are marketed in the shell as a fresh product or in various product forms after the meat has been shucked. These forms include fresh meats, frozen meats (plain or breaded), and meats canned in a variety of ways.

Oysters are landed in loose bulk or in sacks. The loose oysters are landed at canneries where they are steamed open. After steam opening they are mechanically tumbled to remove the meats from the shells and are then separated by water flotation. The meats are sorted by size for canning.

Sacked oysters are landed and delivered to dealers, restaurants, or processing plants. Dealers sort out the counter oysters, oysters of 2.5 to 3.0 inches in size, to be eaten on the half shell. Some offer a quantified product and actually pack them in boxes of 100 oysters each. The larger oysters are shucked and placed in containers, primarily gallon cans. Both these products are sold to restaurants and oyster bars. Restaurants also buy sacked oysters as they are landed and sort the oysters themselves for half shell consumption or shucking, by passing the dealer in the distribution system.

Processing plants receive sacked oysters directly or through dealers. The oysters are shucked by hand. The usual method of opening is to force a sharp knife between the valves and cut the adductor muscle close to the shell. The shell is then easily opened and the oyster removed. After shucking, the oysters are then packaged for sale or further processing. Oysters may also be shucked at processing plants by steaming open the shell. Shucked shells are variously used as road and construction materials, as sources of calcium, lime, and other minerals, as a source of poultry shell for laying hens, and as cultch materials for oyster-reef maintenance and improvement. Emphasis on the latter use may be required in order to improve oyster resources on many depleted gulf-coast reefs.

APPENDIX III

STATE LAWS, REGULATIONS AND POLICIES

A. Alabama

1. License Requirements

All licenses expire September 30 of each year.

Persons are allowed to take up to 100 oysters for personal consumption without a license.

Commercial oyster catcher - $26.00 - Required by all persons (must be in possession) taking oysters for commercial purposes.

Seafood dealer - $126.00 - Required by any person, firm or corporation opening oysters for resale, after acquiring a Health Department permit. Oysters may be opened for resale only on premises certified by the Alabama Department of Public Health.

-- Required by any person, firm or corporation wholesaling oysters, whether shucked or in the shell, to either jobbers or retail dealers.

-- Required by any person, firm, corporation or association before engaging in the retail sale of oysters in or out of the shell (except canned processed oysters), or bartering or exchanging oysters or delivering by vehicle.

Oyster dredge - $25.00 - Required before an oyster dredge can be used along with evidence that a $1,000 bond has been secured.

2. Seasons

The Department of Conservation and Natural Resources and the Department of Public Health are authorized to open and close areas during all or parts of the year. Taking oysters from a closed area for any reason is a misdemeanor. Taking oysters from open areas before sunrise or after 4:00 P.M. is prohibited. Transporting oysters at night through closed areas is prohibited. Reefs are closed on Saturday and Sunday.

3. Gear

Oysters may be taken from public reefs and waterbottoms by hand or oyster tongs. Oyster dredges may be used only by owners or lessees of private oyster reefs only after purchasing an oyster dredge license, posting a $1,000 bond and receiving written authorization from the Department of Conservation and Natural Resources.

4. Size Limits

Oysters taken for either commercial or personal consumption must be at least 3" in length.

5. Limits

Oysters must be culled on the reef where they are taken. Unlawful to take or have in possession more than 8 sacks of oysters per boat per day. Unlawful to land any oysters for commercial purposes which have not been sacked in this manner. [2 bushel baskets = 1/2 barrel; 1 tub = 1 sack; 4 sacks = 1 barrel; 8 sacks = 2 barrels]

6 Leases

Persons, firms or corporations desiring to lease oyster bottoms shall make application in writing to the Commissioner of Conservation and Natural Resources accompanied by such fee as may be prescribed. It is the duty of each lessee to have established an accurate survey by a registered surveyor of the bottoms, beds or reefs under his control, and each corner shall be clearly marked and defined with the lessee's name clearly attached. Intermediate markers shall be placed and plat of the area filed with the division of marine resources together with a list of any persons using said lease area.

7. Restrictions

It is unlawful to drag any seines over the public reefs or private oyster grounds. Oysters taken commercially must be sacked and each sack tagged before landing. Tags may be purchased for $0.25 each at Marine Resources Division offices.

B. Florida

1. License Requirements

Oysters and clams can only be harvested from approved shellfish harvesting areas.

Oyster harvesting license-West of Aucilla River only.

Resident - $5.00
Non-resident and alien - $100.00

Oyster Harvesting Permit (non-resident) - $100.00

Commercial Permit to Transport Oysters Over Land - No Charge - West of Aucilla River only.

Oyster Relaying Permit - No Charge

Oyster leases - $5.00/acre

2. Seasons

Season is closed between June 1 and September 1 of each year except in Apalachicola Bay.

3. Gear

Dredges may be used for harvesting oysters or clams on private leases after posting a $3,000 bond and securing a Special Activity License.

4. Size Limits

Minimum size for oysters is 3". Minimum size for clams is 1" thick.

5. Limits

Bag limits are established in certain areas of the State for oysters.

6. Leases

Information available from FDNR.

7. Restrictions

Oysters and clams can only be harvested from an approved shellfish harvesting area.

c. Louisiana

1. License Requirements

All commercial oyster fishermen must purchase the following licenses:

Commercial Fisherman
  Resident - $55.00
  Non-resident -- $105.00

Vessel
  Resident - $15.00
  Non-resident - $60.00

Gear
  Resident Oyster Tongs - $30.00/tong
  Non-resident Oyster Tongs - $120.00/tong
  Resident Oyster Dredge - $25.00/dredge
  Non-resident Oyster Dredge - $100.00/dredge

2. Seasons

Designated when open by commission action, natural reefs may be fished from the first Wednesday after Labor Day through April 1 of each year.

3. Gear

Oysters may be taken from public oyster beds by dredges, scrapers and tongs. Dredges and scrapers used shall be no smaller than 3′ in width and no longer than 6′ in width measured along the tooth bar. The dredge teeth shall be no longer than 5″ in length and there shall be no more than seven dredges in use on one vessel. Oysters may be taken from privately owned reefs with dredges smaller than 3′ after obtaining a special permit from the secretary.

4. Size Limits

All oysters taken from natural reefs must be over 3″ in length from hinge to mouth. A lessee of private oyster grounds may be permitted to take undersize oysters for bedding purposes only.

5. Limits

No more than 10 1/2 bushel sacks per boat per day may be taken from Calcasieu and Sabine Lakes only; unlimited elsewhere for commercial. Recreational--two sacks per boat per day may be taken without a license if oysters are taken for personal consumption and taken by hand. You may purchase a recreational tong license for $5.00 but are limited to two sacks per boat per day, for your own consumption.

6. Leases

Any person who qualifies and who desires to lease a part of the bottom or bed of any of the waters shall present to the secretary (of LDWF) a written application and cash deposit of such amount as is determined by the Department. Lessees, under supervision of the LDWF, shall stake off and mark the leased waterbottoms in order to locate accurately and fix the limits of the waterbottoms embraced in each lease. Areas shall also be prominently marked with signs which state the lease number and name or initials of the lessee.

7. Restrictions

No person shall trawl or seine over any privately leased bedding ground or oyster propagating place which is staked off, marked, or posted as required by law or regulation.

D. Mississippi

1. License Requirements

Tonging
  Resident- $50.00
  Non-resident - $100.00

Dredging
  Resident - $100.00
  Non-resident - $200.00

Recreational
  Resident - $10.00
  Non-resident - $10.00

2. Seasons

Season is regulated by Legal Notice of the Commission on Wildlife Conservation, and notice thereof will be duly published in local newspapers and released to both the radio and television media. During open season, oysters may be taken only during daylight hours.

3. Gear

Oysters may be taken by any of the traditional methods of oystering in the State of Mississippi, that is, by hand (cooning), with tongs, or by using a hand dredge. Dredges for oystering may not exceed 115 pounds in weight nor may they have in excess of 16 teeth. Restrictions on the maximum number of dredges carried will be established seasonally by the Commission on Wildlife Conservation. Oysters for personal consumption may be taken by hand (cooning) or with tongs.

4. Size Limits

Oysters taken in State waters must be at least 3" long (at the greatest length of the shell). At times, however, the Bureau may decrease this limit upon public notice to that effect.

5. Limits

Commercial dredging limits are to be set and tonging limits are set seasonally. Recreational catch limit is three sacks/day.

6. Leases

The Mississippi Commission on Wildlife Conservation, Bureau of Marine Resources conducts a program of oyster leasing. Any resident of the State may lease state waterbottoms for the purpose of oyster culture. Oysters taken from private lease areas must be so designated by tags indicating the official leased number issued by the BMR.

7. Restrictions

Oysters may be taken only from those waters approved for shellfish harvest by the State Health Department. The harvesting, shucking, processing, and sale of oysters must also conform to all regulations specified by the State Health Department. Following heavy rains, natural reefs and leased areas may be temporarily closed. Such closures are published in local newspapers and released to local television and radio media. Oysters taken from State waters must be tagged. Oysters taken from other than State waters must be accompanied by a Bill of Lading indicating the point of origin. Oysters taken for personal consumption must also be inspected; and a tag will be issued for each sack. Such tags will identify that the contents are not to be sold.

E. Texas

1. License Requirements

Commercial Oyster Dredge - $50.00 - Required for each dredge used. License may be purchased during the month of August only.
Non-resident Commercial Oyster Dredge - $200.00.

2. Seasons

Season is open from November 1 through April 30 except in that part of the Laguna Madre south of the Port Mansfield Channel and all private leases with permits from the Texas Parks and Wildlife Department where there is no closed season. During open season oysters may be taken only from sunrise to sunset.

3. Gear

One oyster dredge not more than 48" in width across the mouth and of not more than two-barrel capacity may be used or possessed on board any boat in public waters.

Commercial vessels may not have more than two dredges on board. Oyster dredge licenses may be purchased only during the month of August.

4. Size Limits

Minimum size for oysters is 3". Oysters 3/4" *to* 3" are to be culled and returned to reef from which taken, provided, however, that each cargo may contain not more than 5% of oysters of this size.

5. Limits

Commercial boats are limited to not more than 50 barrels of legal size oysters. Not more than two barrels of unculled oysters are permitted on board while fishing on a reef.

6. Leases

Leases are granted to individuals upon approval of Coastal Fisheries Division.

7. Restrictions

Oysters may be taken only from waters approved by the State Commissioner of Health.

TAKE PRIDE
in America

U.S. DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.